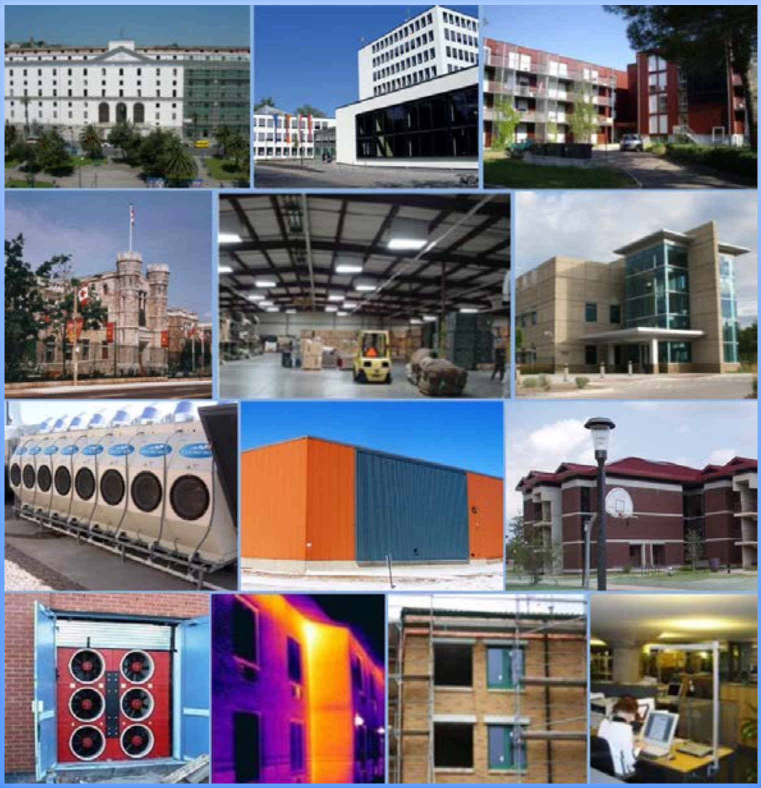
International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

IEA ECBS Annex 46

Subtask B

ENERGY

EFFICIENT TECHNOLOGIES & MEASURES FOR BUILDING RENOVATION: SOURCEBOOK



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Preface

International Energy Agency (IEA)

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an international energy program. A basic aim of the IEA is to foster cooperation among the 24 IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources, and energy research, development, and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems (ECBCS)

The IEA coordinates research and development in a number of areas related to energy. The mission of one of those areas, the IEA ECBCS Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities through innovation and research.

The research and development strategies of the ECBCS Programme are derived from research drivers, national programs within IEA countries, and the IEA Future Building Forum Think Tank Workshop, held in March 2007. The research and development (R&D) strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the building sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, public and government buildings, and community systems, and will impact the building industry in three focus areas of R&D activities:

- Dissemination.
- Decision-making.
- Building products and systems.

The Executive Committee

Overall control of the program is maintained by an executive committee, which not only monitors existing projects, but also identifies new areas where collaborative effort may be beneficial. To date, the following projects have been initiated by the ECBCS executive committee (www.ecbcs.org/annexes/index.htm).

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1 Introduction

The energy efficiency of government and public buildings must be improved to successfully cope with increasing energy costs and mitigate climate change. Such non-residential buildings (i.e., office buildings, production and maintenance facilities) individually consume significantly more energy than typical residential buildings. Thus they pose some specific challenges to those seeking improved energy management and building energy performance. Particular issues for this sector are that:

1. Lighting and ventilation/air-conditioning are more important energy uses in these buildings than in residential buildings.

2. Most non-residential buildings are typically large and require sophisticated building automation systems.

3. Building automation systems frequently include energy management, but concentrate on satisfactory operation rather than on energy efficiency.

4. Total building energy use is heavily influenced by the ventilation requirements and building-specific processes and applications, especially in production and maintenance facilities, restaurants and data centers, hospitals and clinics, etc.

5. The processes usually function satisfactorily, but tolerate waste and inefficiency. A common issue in such buildings is that concerns about energy use generally take second place to, and are seen as incompatible with, goals of maintaining occupant comfort or building functionality. This tendency is most pronounced in the existing building stock. Decisions to retrofit a building are often made in response to dissatisfaction concerning comfort level, or changes in building usage or processes; the primary goal being to improve these conditions. Before decision makers will consider energy conservation in buildings as a primary goal, they must overcome their reservations about the compatibility of energy conservation with occupants' comfort and productivity, and building functionality. They need to see convincing, real world examples of how measures that reduce energy use can also improve comfort and functionality. Good technologies that meet these requirements are already available. The main obstacle to their implementation is a simple lack of knowledge of their intelligent application. Adoption of energy efficiency measures needs to be integrated into facilities management with long-term planning for common retrofit measures when updating the building fabric, services, and processes. This needs to become part of normal operations, maintenance, and building use.

There is a wide variety of possible retrofit options for any given type of building. ('Retrofit measure' means here the full range of possibilities for energy-related refurbishment, renovation, or retrofit.) For every possible retrofit measure, there is an installation cost and a payback time that can vary greatly depending on the building type and the climatic zone in which the building is located. Additionally, the combined effect of different retrofit measures can be lower or greater than each applied in isolation. A decision to implement a retrofit measure often implies a long-term commitment as part of facilities maintenance and management. It is very important to select optimal retrofits for each application.

Public models (of which government buildings are an example) can influence a society's values. Government buildings can exemplify the intelligent application of energy efficient technologies. Private sector individuals are more likely to adopt energy-saving technologies when they can see how Government authorities have constructively addressed energy problems. It is particularly important for Government buildings to demonstrate exemplary solutions and showcase them to the public. In other words, it is not only important to do something positive, but also to take the necessary steps to promote it. Government buildings can potentially change public opinion, and thereby help increase the market penetration of energy-saving technologies.

The IEA ECBCS Programme Annex 46 “Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings” is meant to influence the decision-making process in the retrofit of public and governmental buildings, which determines the use of energy-saving measures in building retrofits

This sourcebook on Energy Efficient Technologies for Building Retrofits is a product of Subtask B of the Annex 46. This sourcebook includes a list of more than 400 promising Energy Conservation Measures and energy-saving technologies – current, proven, well known, or under-used – that can be categorized as:

- building envelope.
- internal load reduction.
- lighting.
- heating, ventilating, and air-conditioning (HVAC) systems.
- energy consuming processes in the building.
- supplemental energy systems (e.g., compressed air, steam system), etc.

For each energy conservation measure, there is either a short description or a more detailed screening analysis. The detailed screening report includes a technology description, qualitative and quantitative (simulation based) analysis of energy savings, and simple payback by climate and building/system type. Analyzed technologies include:

- wall, roof and attic insulation.
- improved building airtightness.
- advanced windows.
- cool roofs.
- insulation for supply/return ducts and hot/cold water pipes.
- exhaust air heat recovery and heat recovery from condensing units.
- grey water heat recovery from showers.
- direct and indirect evaporative cooling.
- hydronic radiant heating/cooling panels.
- dedicated outdoor air systems with radiant cooling and with fan-coil units.
- ground source heat pumps.
- replacement of incandescent lamps with compact fluorescents.
- intelligent lighting controls with daylight, exterior lighting control, spectrally enhanced lighting, etc.

This sourcebook includes case studies that demonstrate the application of different energy conservation technologies in retrofit projects. All 46 case studies contain information on the building site, the retrofit concept, the retrofit cost, energy savings, lessons learned, and general information on retrofitted buildings.

2 Energy Efficiency Technologies and Process Related Measures for Building Retrofits

This chapter provides categorized listings of energy efficiency technologies and process improvement measures (will be referred to as “Energy Efficiency Measures,” or “EEMs”) that can be applied to enable buildings energy use and cost reduction. It identifies some commonly applied elements that can improve building performance, but does not include all of available options. Some EEMs have low or no investment cost (e.g., control strategies, lighting systems improvements, occupant behavior change, etc.). Other, require higher investment costs (e.g., building envelope related measures), but have significantly greater impact on energy use reduction. When selecting specific EEM, it is important that each EEM has a payback during its life before its replacement. When selecting EEMs consider synergistic effect of energy efficient bundles of load reduction technologies (e.g., related to building envelope) and energy generating or converting technologies (e.g., HVAC systems and energy plants), which may significantly reduce overall investment costs. Some measures such as demand response/control may also save energy as an incidental side benefit. Other measures may result in extension of the capacity of given infrastructure systems and/or the ability for energy efficiency to defer or eliminate the need for plant expansions. Such results can be factored into the resulting return on investment (ROI) or life cycle cost (LCC) analysis.

The list has been compiled through extensive literature review, including results of previously completed IEA ECBCS Annexes, materials presented during annual and national workshops and conferences organized throughout duration of the Annex 46, as well as during the ASHRAE Technical Committee 7.6 working group meetings.

2.1 Building Envelope

2.1.1 Walls

- Insulate walls. Retrofit insulation can be external and internal.
- External post insulation makes large savings possible, as this type of insulation contributes not only to a reduction of the heat loss through large wall surfaces, but also eliminates the traditional thermal bridges where floor and internal wall are anchored in the exterior wall.
- Internal insulation is typically done when external insulation is not allowed (e.g., for historical buildings).
- Insulate cavity walls using spray-in insulation.
- Consider converting internal courtyard into an atrium to reduce external wall surface.

2.1.2 Roofs

- Use “cool roof” (high-reflectance roofing material) with reroofing projects.
- Determine roof insulation values and recommend roof insulation as appropriate.
- Insulate ceilings and roofs using spray-on insulation.
- Where appropriate, exhaust hot air from attics.

2.1.3 Floors

- Insulate floors.
- Insulate floors using spray-on insulation.
- Insulate basement wall with a slab over unheated basement.

2.1.4 Windows

- Replace single-pane and leaky windows with thermal/ operable windows to minimize cooling and heating loss.
- Install exterior shading such as blinds or awnings to cut down on heat loss and to reduce heat gain.
- Install storm windows and multiple glazed windows.
- Use tinted or reflective glazing or energy control/solar window films.
- Replace existing fenestration (toplighting and/or sidelighting) with dual-glazed “low-e” glass wherever possible to reduce thermal gain.
- Adopt weatherization/fenestration improvements.
- Consider replacing exterior windows with insulated glass block when visibility is not required but light is required.
- Landscape/plant trees to create shade and reduce air-conditioning loads.

2.1.5 Doors

- Prevent heat loss through doors by draft sealing and thermal insulation.
- Install automatic doors, air curtains, or strip doors at high-traffic passages between conditioned and unconditioned spaces.
- Use self-closing or revolving doors and vestibules if possible.
- Install high-speed doors between heated/cooled building space and unconditioned space in the areas with high-traffic passages.
- Install separate smaller doors for people near the area of large vehicle doors.
- Seal top and bottom of building.
- Seal vertical shafts, stairways, outside walls and openings.
- Compartmentalize garage doors, mechanical and vented internal and special-purpose rooms.

2.1.6 Moisture penetration

- Reduce air leakage.
- Install vapor barriers in walls, ceilings and roofs.

2.2 HVAC Systems

2.2.1 Ventilation

- Reduce HVAC system(s) outdoor air flow rates when possible. Minimum outdoor air flow rates should comply with ASHRAE 62.1 or local code requirements.
- Reduce minimum flow settings in single-duct and dual-duct variable air volume (VAV) terminals as low as practical to meet ventilation requirements.
- Minimize exhaust and makeup (ventilation) rates when possible by complying with the most stringent federal, state, and/or local code requirements.
- Use operable windows for ventilation during mild weather, when available (Natural Ventilation) when outdoor conditions are optimal. Confirm that the facility

has been designed for Natural Ventilation and the control strategies are available to operate the facility in the natural ventilation mode.

- Eliminate outside air ventilation during unoccupied building morning warm-up.
- Convert mixing air supply system into displacement ventilation system to create temperature stratification in spaces with high ceilings and predominant cooling needs.
- Consider replacement of all-air HVAC system with a combination of a dedicated outdoor air system coupled with radiant cooling and heating systems.
- Convert constant volume central exhaust system into a demand-based controlled central exhaust system when possible.
- Convert HVAC systems to provide ventilation in accordance with ASHRAE 62.1 Indoor Air Quality (IAQ) Procedure. Heating and Cooling Systems such as Demand-Controlled Ventilation.

2.2.2 HVAC distribution systems

- Convert a constant air volume system (CAV), including dual-duct, multizone, and constant volume reheat systems) into a VAV system with variable-speed drives (VFDs) on fan motors. A VAV system is designed to deliver only the volume of air needed for conditioning the actual load.
- Control VAV system VFD speed based on the static pressure needs in the system. Reset the static pressure set point dynamically, as low as is practical to meet the zone set points.
- Reset VAV system supply-air temperature set point when system is at minimum speed to provide adequate ventilation.
- If conversion to VAV is impractical for CAV systems, reset supply-air temperatures in response to load. Dynamically control heating duct temperatures as low as possible, and cooling duct temperatures as high as possible, while meeting the load.
- Use high-efficiency fans and pumps; replace or trim impellers of existing fans and pumps if they have excessive capacity relative to peak demand.
- Install higher efficiency air filters/cleaners in HVAC system. Size ducts and select filter sizes for low face velocity to reduce pressure drop where available space permits.
- Insulate HVAC ducts and pipes, particularly where they are outside the conditioned space.
- Check for air leaks in HVAC duct systems, and seal ductwork as indicated.
- Rebalance ducting and piping systems.
- Provide cooling effect by creating air movement with fans.
- Select cooling coils with a face velocity of 300–350 fpm (1.5–1.75 m/s) range to reduce the air pressure drop across the cooling coil, and increase the chilled water system temperature differential across the system.
- Replace standard fan belts with fan belts designed for minimum energy losses, such as cog belts.
- Eliminate or downsize existing HVAC equipment in an existing building or group of buildings when improvements in building envelope, reductions in lighting or plug loads, and other EEMs that reduce cooling or heating loads have been implemented.
- Eliminate HVAC usage in vestibules and unoccupied spaces.
- Minimize direct cooling/heating of unoccupied areas by system zone controls, occupancy sensors or by turning off fan-coil units and unit heaters.
- Replace forced-air heaters with low- or medium-temperature radiant heaters.

- Replace inefficient window air-conditioners with high-efficiency (i.e., high seasonal energy efficiency ratio (SEER) rating) modular units or central systems.
- Employ heat recovery from exhaust air and processes for preheating or pre-cooling incoming outdoor air, or supply air.
- Install transpired air heating collector (solar wall) for ventilation air preheating.
- Modify controls and/or systems to implement night pre-cooling to reduce cooling energy consumption the following day.
- Use waste heat (e.g., hot gas, return air heat, return hot water) as an energy source for reheating for humidity control (often air is cooled to dewpoint to remove moisture and then must be reheated to desired temperature and humidity).
- Avoid temperature stratification with heating, either by proper air supply system design or by using temperature destratifiers (e.g., ceiling fans).
- In humid climates, supply air with a temperature above the dew point to prevent condensation on cold surfaces.
- Insulate fan-coil units and avoid their installation in unconditioned spaces.
- Clean heat exchangers (to maintain heat exchange efficiency) in the evaporators and condensers of refrigeration equipment on a seasonal basis.
- Use high-efficiency dehumidification systems based on either dedicated outdoor air systems (DOAS) or VAV.
- Identify if there are any “rogue” zones (i.e., zones that determine the cooling or heating demand on the entire system) in a multiple-zone air-handling system, and modify them to eliminate their negative impact.
- Modify supply duct systems to eliminate duct configurations that impose high friction losses on the system.
- Convert 3-pipe heating/cooling distribution systems to 4-pipe or 2-pipe systems. Eliminate simultaneous heating and cooling through mixed returns.
- Convert steam or compressed air humidifiers to ultrasonic or high-pressure humidifiers.
- Replace mechanical dehumidification with desiccant systems using heat-recovery regeneration.
- Consider small unitary systems for small zones with long or continuous occupancy. Avoid running large distribution systems to meet needs of small, continuously-occupied spaces.
- Install thermostatic control valves on uncontrolled or manually-controlled radiators.
- Replace unitary systems with newer units with high efficiency and high SEER ratings.
- Install evaporative pre-cooling for DX systems.
- Install or air-side heat recovery for systems using 100% makeup air (e.g., run-around piping or energy exchange wheels).
- In reheat systems, making adjustments as necessary to minimize reheat energy consumption while maintaining indoor environmental quality.
- In multiple-zone systems, identify any “rogue” zones that consistently cause the reset of system level set points to satisfy that one zone’s heating or cooling demands.

2.2.3 Building automation and control systems

- Create building/air-conditioned space zones with separate controls to suit solar exposure and occupancy.
- Use night setback, or turn off HVAC equipment when building is unoccupied.

- Install occupancy sensors with VAV system: setback temperatures and shut off boxes.
- Install system controls to reduce cooling/heating of unoccupied space.
- Lower heating and raise cooling temperature setpoints to match ASHRAE Standard 55 Comfort Range.
- Install an air-side and/or water side economizer cycle with enthalpy switchover when compatible with the existing equipment, space occupancy and distribution system.
- Schedule off-hour meetings in a location that does not require HVAC in the entire facility.
- Retrofit multiple-zone VAV systems with direct digital controls (DDC) controllers at the zone level, and implement supply-air duct pressure reset to reduce supply-air duct pressure until at least one zone damper is nearly wide open.
- Eliminate duplicative zone controls (e.g., multiple thermostats serving a single zone with independent controls).
- Adjust hot water and chilled water temperature to develop peak-shaving strategies based on an outside air temperature reset schedule.
- Adjust housekeeping schedule to minimize HVAC use.
- Install programmable zone thermostats with appropriate deadbands.
- Use variable-speed drives and DDC on water circulation pump and fan motors and controls.
- Reduce operating hours of complementing heating and cooling systems Ensure proper location of thermostat to provide balanced space conditioning.
- Implement an energy management system (EMS) designed to optimize and adjust HVAC operations based on environmental conditions, changing uses, and timing.

2.3 Refrigeration

2.3.1 Reduce loads

- Install strip curtains or automatic fast open & close doors on refrigerated space doorways.
- Replace open refrigerated cases with reach-in refrigerated cases.
- Replace old refrigerated cases with new high-efficiency models (improved glazing, insulation, higher efficiency motors, reduced anti-sweat requirements).
- Replace worn door gaskets.
- Replace broken or missing auto-door closers.
- Check defrost schedules and avoid excessive defrost.
- Repair/install refrigeration piping insulation on suction lines.
- Install humidity responsive Anti-Sweat Heating (ASH) controls on refrigerated case doors.
- Install refrigerated case, walk-in or storage space lighting controls (scheduled and/or occupancy sensors).
- Install night covers to reduce infiltration in open cases.
- Install low/no ASH refrigerated case doors.
- Replace lights with light emitting diode (LED) strip lights with motion sensors in refrigerated cases and spaces.
- Increase insulation on walk-in boxes and storage spaces that have visible moisture or ice on walls, corners, etc.

2.3.2 Improve system operating efficiency

- Clean condenser coils.
- Check the refrigerant charge and add when needed.
- Reclaim heat from hot gas line for domestic water heating or space heating.
- Install floating head pressure controls, adjustable head pressure control valve and balanced port expansion valves for DX systems.
- Install floating suction pressure controls on DX systems.
- Install evaporator fan motor variable-speed drives and controllers in walk-ins and refrigerated storage spaces.
- Replace single-phase, less than 1 HP evaporator fan motors with electrically commutated motors.
- Replace 3-phase evaporator and condenser motors with premium efficiency motors.
- Replace single compressor systems with multiplex systems and control system.
- Install mechanical sub-cooling.
- Install mechanical unloaders on appropriate multiplex reciprocating semi-hermetic compressors.
- Install VFD on ammonia screw compressor.
- Install high specific efficiency (Btu/watt) condenser.
- Install hybrid air-cooled/evaporative-cooled condenser.

2.4 Water Systems

2.4.1 Domestic hot water systems

- Lower domestic water setpoint temperatures to 120 °F.
- Install point of use gas or electric water heaters.
- Install water heater blankets on water heaters.
- Install automatic flue dampers on fuel-fired water heaters.
- Insulate hot water pipes.
- Reclaim heat from waste water, refrigeration system, cogeneration, or chillers.
- Install solar heating where applicable.
- Dishwashers, replacement: Install low-temperature dishwashers that sanitize primarily through chemical agents rather than high water temperatures.
- Dishwashers, retrofit: Install electric eye or sensor systems in conveyor-type machines so that the presence of dishes moving along the conveyor activates the water flow.
- Reduce operating hours for water heating systems.
- Install grey water heat recovery from showers, dishwashers, washing machines.
- Install low-flow dishwashing pre-wash spray nozzles.
- Replace outdated laundry equipment with newer models.

2.4.2 Water conservation

- Replace faucet (with units that have infrared sensors or automatic shutoff).
- Install water flow restrictors on shower heads and faucets.
- Install covers on swimming pools and tanks.
- Install devices to save hot water by pumping water in the distribution lines back to the water heater so hot water is not wasted. Install industrial waste/sewage metering.
- Install water metering.

- Landscape irrigation: Install irrigation timers to schedule sprinkler use to off-peak, night, or early morning hours, when water rates are cheaper and water used is less likely to evaporate.
- Landscape irrigation: Use low-flow sprinkler heads instead of turf sprinklers in areas with plants, trees, and shrubs.
- Landscape irrigation: Use sprinkler controls employing soil tensiometers or electric moisture sensors to help determine when soil is dry and to gauge the amount of water needed.
- Landscape irrigation: Use trickle or subsurface drip irrigation systems that provide water directly to turf roots, preventing water loss by evaporation and runoff.
- Install low-flow toilets and waterless urinals.
- Use water reclamation techniques.

2.5 Energy Generation and Distribution

2.5.1 Boiler system

- Install air-atomizing and low NOx burners for oil-fired boiler systems.
- Install automatic boiler blowdown control.
- Install flue gas analyzers for boilers.
- Install an automatic flue damper to close the flue when not firing.
- Install turbulators to improve heat transfer efficiency in older fire tube boilers.
- Install low–excess air burners.
- Install condensing economizers.
- Install electric ignitions instead of pilot lights.
- Install an automatic combustion control system to monitor the combustion of exit gases and adjust the fuel-air ratio to reduce excess combustion air.
- Install isolation valves to isolate offline boilers.
- Maintain insulation on heat distribution system. Replace insulation after the system repair and repair damaged insulation.
- Provide proper water treatment to reduce fouling.
- Replace central plant with distributed satellite systems.
- Downsize boilers with optimum burner size and forced draft (FD) fans.
- Operate boilers at their peak efficiency; shut down large boilers during summer and use smaller boilers.
- Install expansion tank on hot water systems that are properly sized for the system.
- Heat recovery through de-superheating.
- Preheat combustion air, feed water, or fuel oil with reclaimed waste heat from boiler blowdown and/or flue gases.
- Boilers: Install automatic controls to treat boiler makeup water.
- Adjust boilers and air-conditioner controls so that boilers do not fire and compressors do not start at the same time, but satisfy demand.
- Clean boiler surfaces regularly to reduce scale and deposit, which will improve heat transfer.
- Replace non-condensing boilers with condensing boilers (15–20% compared to new standard).
- Prevent dumping steam condensate to drain.
- Survey and fix steam/hot water/condensate leaks and failed steam traps.

- Convert steam system to low-temperature sliding temperature hot water system. Install complementing steam boilers where needed.
- Improve boiler insulation. It is possible to use new materials that insulate better and have lower heat capacity.
- Check steam trap sizes to verify they are adequately sized to provide proper condensate removal.
- Consider opportunities for flash steam use in low-temperature processes.
- Consider pressuring atmospheric condensate return systems to minimize flash losses.
- Consider relocation or conversion of remote equipment such as steam-heated storage.
- Evaluate potential for cogeneration in multi-pressure steam systems presently using large pressure-reducing valves.
- Install steam metering and monitoring systems.
- Investigate economics of adding insulation on presently insulated or uninsulated lines.
- Review mechanical standby turbines presently left in the idling mode.
- Review operation of steam systems used only for occasional services, such as winter-only tracing lines.
- Review pressure-level requirements of steam-driven mechanical equipment to consider using lower exhaust pressure levels.
- Survey condensate presently being discharged to waste drains for feasibility of reclaim or heat recovery.
- Reduce boiler operating pressure to minimize heat losses through leakage.

2.5.2 Chiller system

- Chiller retrofits with equipment that has high efficiency at full and part load.
- Cooling tower retrofits including high-efficiency fill, variable speed drive (VSD) fans, fiberglass fans, hyperbolic stack extensions, fan controls, VSD pump drives, and improved distribution nozzles.
- Install economizer cooling systems (Heat Exchanger [HX] between cooling tower loop and chilled water loop before the chiller.
- Install evaporative-cooled evaporative pre-cooled or water-cooled condensers in place of air-cooled condensers.
- Isolate offline chillers and cooling towers.
- Reduce over-pumping on chilled water systems.
- Replace single compressor with multiple different-size staged compressors.
- Install two-speed, mechanical unloading or VFD on compressor motors.
- Use of absorption chiller when there is cogen system, waste heat or solar thermal available.
- Install double-bundle chillers for heat recovery.
- Free cooling cycle by piping chilled water to condenser during cold weather.
- Prevent chilled water or condenser water flowing through the offline chiller. Chillers can be isolated by turning off pumps and closing valves.
- Equipment cooling: Control makeup water and reduce blowdown by adding temperature control valves to cooling water discharge lines in equipment such as air compressors and refrigeration systems.
- Evaporative cooling systems: Install drift eliminators or repair existing equipment.

- Evaporative cooling systems: Install softeners for makeup water, side-stream filtration (including nano-filtration, a form of low-pressure reverse osmosis), and side-stream injection of ozone.
- Evaporative cooling systems: Install sub-meters for makeup water and bleed-off water for equipment such as cooling towers that use large volumes of water.
- Evaporative cooling systems control cooling tower bleed-off based on conductivity by allowing bleed-off within a high and narrow conductivity range. This will achieve high cycles of concentration in the cooling system and reduce water use in cooling tower.
- Clean evaporator and condenser surfaces of fouling.
- Optimize plant controls to raise evaporator temperature as high as possible while meeting loads of the system. Also optimize condenser water temperature control to achieve best combination of chiller and tower efficiency.
- Optimize multiple chiller sequencing.
- Control crankcase heaters off when not needed.
- Raise evaporator or lower condenser water temperature.
- Optimize multiple chiller sequencing.
- Use two-speed or variable-speed fan instead of water bypass to modulate the cooling tower capacity.
- Balance water flow in the chilled water system.
- Use variable-frequency drives (VFDs) for the primary chilled water pumps above 5 HP (3.7 kW). Consult chiller and tower manufacturers' specifications to set appropriate minimum flow limits.
- Apply cooling load–based optimization strategies.
- Install water source heat pumps (WSHPs) to augment the capacity of the hot water boiler and to reduce the cooling load on the existing chiller systems when heat is required.
- Trim impellers on all condenser water and chilled water pumps that are oversized.
- Replace all pump and fan motors with premium efficiency motors.

2.5.3 Thermal storage and heat pumps

- Install cool storage to reduce peak demand and lower electric bills.
- Install hot water storage to shave peaks of hot water usage or to store reclaimed energy from combined heat and power systems or waste heat from chillers for later use.
- Install add-on heat pumps.
- Install secondary pumping systems.
- Install VFDs on secondary pumps and replace most 3-way valves with 2-way valves.
- With cool storage and VFDs on fans and pumps, consider use of low-temperature chilled water to reduce fan and pump energy.
- Replace electrically powered air-conditioning and heating units with heat pumps. Consider geothermal heat pumps.
- Replace electric water heaters with electric heat pump water heaters.

2.6 Non-residential Lighting

- In implementing any of these EEMs, care should be taken to not compromise the photometric distribution or any required light levels.

- General: Check the current Illuminating Engineering Society (IES) recommended light levels for the tasks in the facility. They may be lower than when the original lighting system was designed. Use these current recommended light levels to help shape all future lighting decisions including those enumerated here.

2.6.1 Daylighting

- In areas illuminated by daylight, evaluate opportunities for daylight harvesting. Measure light levels on a day with a clear sky both with the electric lighting turn on and turned off. If daylighting provides sufficient light level then install daylight switching or daylight dimming controls (and appropriate ballasts if the lighting system is fluorescent or High Intensity Discharge [HID]) to reduce the use of electric lighting.
- Install interior and/or exterior shading as appropriate to reduce solar heat gain and cut down on heat loss and control the amount of light entering the space from the exterior.
- Install a skylight, tubular daylighting device, or sunlight delivery system to reduce the use of electric lighting and provide natural daylight to the internal spaces of the building.

2.6.2 Luminaire upgrades

- Upgrade incandescent lamps in existing luminaires with more efficacious sources such as halogen, integrally ballasted compact fluorescent, solid state (LED), or metal halide retrofit lamps. Alternatively, replace incandescent luminaires with luminaires using these sources.
- Upgrade T12 fluorescent luminaires with more efficacious sources such as high-performance T8 or T5 systems by: (1) replacing lamps and ballasts, (2) using luminaire up-grade kits, or (3) installing new luminaires.
- If the lighting system is already a high-performance fluorescent system, consider replacing the lamps with reduced wattage lamps (where appropriate).
- For fluorescent lighting, install high-performance electronic ballasts that are multi-level or continuously dimmable with the appropriate controls.
- Replace mercury vapor or probe-start metal halide HID luminaires with pulse start metal halide or high-performance T8 or T5 fluorescent luminaires.
- Upgrade task and display lighting, including lighting in refrigeration and freezer cases, to more efficacious sources such as LED.

2.6.3 Signage

- Evaluate upgrading standard fluorescent or neon signage with more efficacious sources such as high-performance T8 or T5 fluorescent systems or solid state (LED) systems.
- Upgrade all exit signs to solid state (LED) exit signs. Supplemental lighting may need to be added if the existing exit sign also provided general lighting.

2.6.4 Lighting controls

- Reduced lighting usage through management and controlled systems – in general, consider bringing the lighting control protocols for the building up to 90.1-2010 (Section 9.4.1) standards; this includes the following.
- Reduce operating hours for lighting systems through the use of controls and building management systems. This includes the use of shut off controls such as time switches.

- Use reduced lighting levels, including off, when spaces are unoccupied, during nighttime hours, for restocking, cleaning and security. Whenever possible move restocking and cleaning operations to normal operating hours.
- Use occupancy, vacancy, or motion sensors. Wherever applicable, these sensors should either be manual-on or turn lighting on to no more than 50% of lighting power.
- Use controls to provide multiple light levels or dimming where appropriate.
- Re-circuit or re-zone lighting to allow personnel to only turn on zones based on use rather than operating the entire lighting system.
- Install personal lighting controls so individual occupants can vary the light levels within their spaces.
- Consider installation of lighting systems that facilitate load shed requests from the electric utility or energy aggregator.
- Evaluate turning emergency lighting off or to a lower level when a building or portion of a building is completely unoccupied without sacrificing safety requirements.

2.6.5 Exterior lighting

- Use automatic controls that can reduce outdoor lighting levels or turn them off when either sufficient daylight is available or when not needed. All facade and landscape lighting should be off from an hour after closing until an hour before opening. All other lighting should be reduced by at least 30% during that same time frame or when a motion sensor detects no activity for 15 minutes.
    - Exception: Lighting for covered vehicle entrances or exits from buildings or parking structures where required for safety, security or eye adaptation.
- Reduce power levels or turn exterior signage off when appropriate.
- Signs that are meant to be on for some part of daylight hours should be reduced in power by at least 65% during nighttime hours.
    - Exception: Sign lighting using metal halide, high-pressure sodium, induction, cold cathode or neon lamps that are automatically reduced by at least 30% during nighttime hours.
- All other sign lighting should be off automatically turn off during daylight hours and reduced in power by at least 30% from an hour after closing until an hour before opening.
- When selecting new outdoor luminaires, consider the amount of backlight, uplight and glare delivered by each luminaire type to improve functionality and minimize environmental impact. See section 5.3.3 of ASHRAE 189.1-2011.

2.6.6 Luminaire layout

- Consider using lower levels of general illumination overall and then supplement with task lighting where needed.
- Consider new layouts that may maximize efficiency and reduce the total connected lighting load. Consider plug and play systems to provide flexibility as space use changes.

2.6.7 Other

- Implement a plan to recycle lamps, ballasts and luminaires removed from the building.
- Consider updating lighting system to provide for demand response capability so that lighting load is reduced during periods of peak electricity demand. These

types of systems can provide day-to-day energy savings in addition to demand response capability.

2.7 Residential Lighting

2.7.1 General

- Replace incandescent lamps with halogen, integrally ballasted compact fluorescent or solid state (LED) retrofit lamps in existing luminaires.
- Select lamps that deliver the appropriate color temperature of light. Color temperature indicates the color appearance of the light produced by the lamp. Halogen lamps are a more energy efficient form of incandescent technology and will deliver light similar to incandescent lamps. Linear fluorescent, compact fluorescent and solid state (LED) lamps are available in a variety of color temperatures. Lamps with color temperatures of 2700K and 3000K will deliver the most incandescent-like light. Lamps with a color temperature of 3500K deliver a neutral, white light. Lamps with color temperatures of 4000K and higher will deliver cooler, white light; the higher the color temperature number, the cooler the light.
- Select lamps appropriate for use in enclosed luminaires, outdoor applications, cold temperature applications and with dimming controls. Check the packaging or manufacturer's website for guidance.
- Use energy efficient technologies such as fluorescent, compact fluorescent or solid state (LED) in applications with the longest operating times.
- Use a whole-home lighting control system that provides energy-saving features such as dimming, occupancy sensing, daylight harvesting, and allows occupants to turn all the lights off from a single location or remotely.

2.7.2 Interior

- Replace "on/off" switches with dimming controls, vacancy sensors or count-down timers. Use dimming controls, vacancy sensors, or count-down timers for lights or fans in bathrooms; use vacancy sensors in garages, laundry rooms, closets, and utility rooms.
- Upgrade T12 fluorescent luminaires to high-efficiency T8 or T5 systems by replacing lamps and ballasts or installing new luminaires. Ballasts should be Federal Communications Commission (FCC) rated for residential use.
- Evaluate replacing incandescent and halogen luminaires with dedicated compact fluorescent or solid state (LED) luminaires.
- When replacing fluorescent ballasts or installing new fluorescent luminaires, evaluate using electronic, dimming ballasts with the appropriate dimming controls.
- Evaluate adding daylight sensing controls for general illumination lighting in rooms with windows or skylights. Use in combination with dimming systems so the electric light level can be adjusted based on the amount of daylight available.
- Install vacancy sensors to automatically turn off lighting in closets, storage, work rooms, garages and exterior buildings when the space has been vacated for 15 minutes.
- Add task lighting that uses energy efficient technologies such as fluorescent and solid state (LED) and reduce or eliminate overhead lighting.

2.7.3 Exterior

- Install time switches and/or motion sensors to control outdoor lighting.

2.8 Electric Systems, Motors

- Install energy efficient transformers. Use infrared camera to identify high-heat-loss transformers.
- Install electrical meters for sub-metering lighting, elevators, plug loads and HVAC equipment.
- Reduce demand charges through load shedding, operational changes, and procedural changes.
- Replace oversized electric motors with right-sized or slightly oversized motors.
- Replace existing 3-phase, 1 HP and greater electric motors with premium efficiency motors (often a better choice than rewinding motors).
- Replace existing 1-phase, 1 HP (and less) motors with electrically commutated motors.
- Correct power factors depending on tariff considerations.
- Use emergency generators for peak electric load shaving.
- Use timer switches to turn off process equipment.
- Use blower/fans instead of compressed air for cooling, drying, or blow-off operations.
- Use energy efficient air blow-off nozzles.
- Use energy efficient v-belts for air compressors.
- Check belt tension on electric motors.

2.9 Appliances

- Install appliances (clothes washers, dehumidifiers, dishwashers, freezers, refrigerators, room air cleaners and purifiers, office equipment, and televisions) that are certified as Energy Star compliant.
- Reduce plug loads, using devices to shut off equipment not being used (use occupancy sensors or timers).
- Install vending machine controllers.

2.10 Process Systems

2.10.1 General process improvement

- Reduce operating cost by optimizing the process.
- Reduce cost of product or service by eliminating waste.
- Optimize maintenance costs to increase capacity utilization.
- Increase process throughput by reducing cycle times.
- Optimize yields by reducing off-specification product.
- Reduce scrap/wastage/breakage by modifying the process causes.
- Reduce rework by not taking short cuts that make rework.
- Reduce downtime by optimizing planning and scheduling.
- Improve product quality by improved process control.
- Improve repeatability/consistency by using Statistical Process Control (SPC).
- Improve safety by thinking about the safest way before starting.
- Reduce pollution/hazardous waste by modifying the processes that cause it.

- Reduce labor cost by optimizing labor use.
- Optimize overtime by analyzing the causes and correcting them.
- Simplify processes by eliminating unnecessary, non-value added steps.
- Reduce number of process steps by questioning and challenging their value.
- Improve tooling/fixtures/jigs to increase capacity use.
- Improve working conditions to improve productivity by increasing building ventilation.
- Reduce work hours/day or days/week by working on the important things.
- Improve process specifications/documentation to treat continuous improvement.
- Reduce inspections without reducing quality by eliminating unnecessary inspections.
- Optimize inventory by optimizing procurement/logistics.
- Improve tools to increase productivity and product quality.
- Simplify inspections by eliminating unnecessary requirements.
- Encapsulate process to reduce indoor air contaminating emission.
- Change the process by replacing materials with lower contaminant emission materials when possible.
- Increase accuracy, timeliness, applicability, and usefulness of the inspection by optimizing the inspection processes.

2.10.2 Painting

- Recycle water used to collect overspray paint by treating water with dissolved air flotation and filter dewatering system to separate toxic solids.
- Install heat recovery from paint process. 40 to 60% of heat input is vented through the exhaust from painting process, while additional heat is lost as waste heat through the walls Heat recovery in paint process, therefore can be significant. However, some of this heat recovered from the stack is low grade heat. If the problem of tar contamination can be overcome, heat can be recovered from the stack. Heat can be recovered using heat wheels or other technologies.
- Maintain optimal air temperature and relative humidity for faster drying and to eliminate rework due to defects in the coating. These parameters depend upon the paint process and type of paint used.
- Install VFDs on exhaust and supply fans connected to the sensor installed on the compressed air line to the paint gun. VFDs allow reduction of exhaust and supply air into the paint booth when there is no paint spraying. Reducing the volume of air put through paint booth also limits the amount of energy to treat the supply and exhaust air.
- Use infrared paint curing. Infrared ovens replace gas-fired low-bake ovens to speed up the stoving process. Infrared process reduces energy consumption by reducing paint booth size and increases productivity by reducing stoving time.
- Use ultrafiltration/reverse osmosis (UF/RO) for wastewater cleaning. When the water-based paint is used, processing equipment must be regularly cleaned with water. A typical painting operation requires significant amount of water to clean, all of it must be disposed of as hazardous waste. Reducing this hazardous waste therefore reduces transportation and incineration energy associated with its removal. A combined UF/RO process cleans wastewater to the point where it is again suitable for cleaning purpose. The UF/RO can recover 95% of the waste water.

- Insulate the drying booth or tunnel. Insulation of the drying booth or tunnel can reduce the heat losses through irradiation, which can be about 5% of the total energy input.
- Fix badly functioning entry and exit doors of drying booths, which can cause additional heat losses.
- Enclose painting operation when possible, e.g., in a booth.

2.10.3 Plating and metal finishing

- Install emission “elimination” cover on Cr tank and reduce exhaust air flow rate when the tank is covered.
- Control exhaust airflows and steam heating on plating tanks.
- Insulate plating tanks with the surface temperature above 49 °C (120 °F).
- Treat rinse water to recover valuable metals or chemicals to return to plating bath, with clean water returned to rinse system.
- Rinsing and cleaning – install timers and tamper-proof conductivity controllers to control quality of water in rinses.
- Rinsing and cleaning – install ultrasonic cleaning equipment.
- Rinsing and cleaning – install water-saving technologies or modification that are specifically geared toward each facility. Examples are counter-current rinsing, drag-out tanks or first stage static rinses, spray systems, flow reduction devices.
- Use no-mask anode tooling technology to reduce labor cost, plating time and the amount of time needed to grind the surface after plating. Reduction in plating time results in increased throughput and reduced energy consumption (for tank heating and cooling and exhaust air transportation and scrubbing).

2.10.4 Machining

- Use process enclosures connected to exhaust systems or having built-in fans and filter for turning (lathe), drilling, milling and grinding machines. For older machines use partial enclosures or local capture hoods.
- Use area lighting system to deliver in a combination with a task (supplemental) lighting for workstations.

2.10.5 Welding

- Select welding process that produces the least volume of fume consistent with other application considerations. Gas tungsten arc welding (GTAW), plasma arc welding (PAW), and submerged arc welding (SAW) processes generally produce the lowest fume levels. Gas metal arc welding (GMAW) is normally the process with the next lowest fume generation rate.
- Use high-efficiency welding power sources, which have better electrical efficiency and an improved power factor. In high-efficiency welding, power to the transformer is shut off during system idling and cooling fans only run when needed. These power sources provide 10 to 40% energy savings over older units.
- Use modern inverter welding power sources, which can reduce the fume generation for pulsed gas metal arc welding (GMAW-P) compared to conventional GMAW procedures.
- Selecting optimum welding voltage to reduce fume generation.
- Select welding electrodes with reduced fume generation. Electrodes and electrode coatings containing higher percentages of more volatile ingredients produce higher levels of fume.

- Select shielding gas with reduced fume generation for the GMAW and Flux Cored Arc Welding (FCAW) processes. Argon-based shielding gases with the lowest percentages of oxygen or carbon dioxide will minimize fume for both GMAW and FCAW. The fume generation rate can be cut almost in half by changing from 100% CO_2 shielding gas to a mixture of Argon with 25% CO_2 shielding gas. A further reduction in fume generation rate can be achieved by use of a shielding gas containing Argon with only 5% CO_2 along with the appropriate electrode.
- Avoid, remove, or reduce oil film, paint, primer, rust, galvanizing or other coatings on the welded surfaces since these coatings increase fume.
- Reduce expulsion during spot welding.
- Avoid short-time conditions with spot welding, changing over to medium-time conditions.
- Place containers with welded small parts in the totally enclosed cabinets connected to exhaust system to avoid residual welding smoke release into the building.
- Exhaust from the total welding process enclosure when automatic welding machines are used.
- Exhaust from the welding area enclosure separating welding process from operator's environment, when robotic welding and material handling are used,.
- Install local exhaust, which captures the contaminants at or near their source, with manual and semiautomatic welding operations.
- Use built-in fixture exhaust system for repetitive arc and resistance manual and robotic welding operations. An engineered design to reduce exhaust air volume, increase capture effectiveness of fumes generated during and after welding operations. Requires cooperation of process and ventilation engineers.
- Install demand-based exhaust system for weld fumes control in shops with variable work load and welding processes with duty cycle below 70%.
- Storage.
- Use automatic "speed" doors operating via motion sensor.
- Use dock seals for truck docks.
- Use natural daylighting whenever possible and turn lights on only when needed.

2.10.6 Catering facilities

- Food storage. Locate refrigerators and freezers away from heat sources, Minimize frequency of opening refrigerators and freezers. Never put hot food in refrigerators. Adopt a planned defrosting program. Check door/lid seals and replace as necessary. Replace old equipment with new efficient models. Install motor controls to improve compressor efficiency at low loads.
- Food cooking and serving. Minimize preheating time for ovens, fryers and other equipment. Switch off ovens before the end of the cooking time. Minimize hot storage of cooked food. Keep hot plates and gas burners clean. Introduce regular servicing of cooking appliances, including thermostats and automatic timers. Install energy efficient and effective cooking appliances. Select induction hobs. Select equipment sizes appropriate to task. Consider batch cooking to optimize use of cooking appliances. Install microwave ovens to cook and reheat meals.
- Air extraction equipment. Install energy efficient ventilation hoods. Locate hoods directly over ovens, fryers, and grills, which need air extraction. Coordinate layout of kitchen hoods and ductwork with cooking equipment layout and process. Switch on extract systems only when required and switch off as soon as

possible. Clean filters, grills and fan blades regularly to prevent grease build-up. Close external doors when operating extract fans.
- Dishwashers (replacement) – install low-temperature dishwashers that sanitize primarily through the use of chemical agents rather than high water temperatures.
- Dishwashers (retrofit) – install electric eye or sensor systems in conveyor-type machines so that the presence of dishes moving along the conveyor activates the water flow.
- Eliminate all single pass water use.
- Dishwashers (operational modifications) – limit water temperature and flow rate settings to manufacturer's recommendations. To avoid compromising the sanitation process, do not set water temperature below 180 °F.
- Use water conserving dishwashers.
- Install grey water heat recovery.
- Low-flow pre-rinse spray nozzle (≤ 1.6 gpm).
- Install end panels on kitchen hoods to lower exhaust rates,.
- Use compact fluorescent lamps (CFLs) in exhaust hoods, walk-in coolers and dining room fixtures.
- Install plastic strip curtains and auto-door closers for a walk-in cooler or freezer.
- Install electronically commutated motor for walk-in cooler and freezer evaporator fan.
- Use Energy Star rated deep fat fryer.
- Use Energy Star boilerless steamers.
- Use high-efficiency ovens.
- To extend it is feasible, change location and co-location of kitchen equipment to increase local exhaust capture efficiency: position cooking appliances close to the walls and avoid island installations when possible or back to back.
- Use supply-air diffusers that direct air parallel to the hood's face or downward.
- Eliminate a gap between kitchen equipment and the back wall.
- Calibrate the hot water heater temperature set point in accordance with the requirements of the dish machine – typically 140 °F for a high temperature machines and 125 °F for low-temperature machines.
- Install an automated flue damper atop the water heater flue.
- Install a time clock to shut recirculation pump on the water line during hours of close.

2.10.7 Virtual training facilities

- Maintain room air temperature within requirements to current generation of equipment and electronics components.
- Direct heat stream from the simulator's condenser unit outside the air-conditioned space via a duct of a central system or move condenser units outside air-conditioned space.
- Place power conditioners outside the air-conditioned space and use waste heat for heating spaces with heating needs.
- Vent heated air away from the manned module exhaust grilles using a central exhaust system. In the summer, the heat stream from the simulator can be directed outside. In the winter, warm air can be directed to spaces with heating needs.
- Vent heated air away from the computer server exhaust grille using a central exhaust system connected to exhaust grilles. In the summer, the heat stream

from the simulator can be directed outside. In the winter, warm air can be directed to spaces with heating needs.

2.10.8 Swimming pool

- Cover swimming pool when pool is not in use, e.g., lunch time, after hours to save both water and energy (heating, cooling and electrical energy saving.) On external pools can save 80% of energy costs.
- Check the water temperature (shall not be above 27 °C (81 °F).

2.10.9 Photo and x-ray processing

- Install temperature control valve to reduce flow when not developing.
- Reduce flow to manufacturer's specifications for actual operating conditions.
- Install solenoid valve to shut off rinse and cooling flows when product is not being developed.

2.10.10 Process control

- Energy Management Control System (EMCS) installation, replacement, and alteration.
- Install demand limiting control system.
- Install duty cycling control system.
- Install economizer cooling control system.
- Install hot/chilled water supply temperature reset control systems.
- Install supply-air temperature reset control system.
- Install temperature setup/setback control system.
- Install time-of-day control system.
- Install ventilation purging control system.
- Install single building controllers (DDC).
- On/off controls (electronic time clocks).
- Install temperature control valve to reduce flow when not developing.
- Reduce flow to manufacturer's specifications for actual operating conditions.
- Install solenoid valve to shut off rinse and cooling flows when product is not being developed.
- Regular maintenance plan.
- General.
- Inspect to ensure dampers are sealed tightly.
- Clean coil surfaces.
- Ensure doors and windows have tight seals.
- Check fans for lint, dirt or other causes of reduced flow.
- Schedule HVAC tune-ups (the typical energy savings generated by tune-up is 10%).
- Check and calibrate thermostat regularly.
- Replace air filters regularly.
- Adjust fan speed and belt drives.
- Check valves, dampers, linkages and motors.
- Check/maintain steam traps, vacuum systems and vents in one-pipe steam systems.
- Repair, calibrate or replace controls.
- Cooling system maintenance.

- Clean the surfaces on the coiling coils, heat exchangers, evaporators and condensing units regularly so that they are clear of obstructions.
- Adjust the temperature of the cold air supply from air-conditioner or heat pump or the cold water supplied by the chiller (a 2° to 3 °F adjustment can bring a 3 to 5% energy savings).
- Test and repair leaks in equipment and refrigerant lines.
- Upgrade inefficient chillers.
- Fuel-fired heating system maintenance.
- Clean and adjust the boiler or furnace.
- Check the combustion efficiency by measuring carbon dioxide and oxygen concentrations and the temperature of stack gases; make any necessary adjustments.
- Remove accumulated soot from boiler tubes and heat transfer surfaces.
- Install a fuel-efficient burner.
- Upgrade fuel-burning equipment.
- Install a more efficient burner.
- Install an automatic flue damper to close the flue when not firing.
- Install turbulators to improve heat transfer efficiency in older fire tube boilers.
- Install an automatic combustion control system to monitor the combustion of exit gases and adjust the intake air for large boilers.
- Insulate hot boiler surfaces.

3 Energy Modeling

Upgrading or retrofitting existing buildings for improved energy efficiency requires an understanding of where energy is used in the building and where improvements can be implemented. Sorting through the range of options and selecting the most effective and cost-efficient measures to implement is difficult. The energy-saving potential of energy conservation measures (ECMs) are often strongly dependent on some combination of climate, building use, envelope design, HVAC system design and plant design and their specific application. Some technologies (e.g., speed control using VFD, or replacement of lighting fixtures with more efficient ones) can be evaluated using a simple spreadsheet-type calculation. Other, require more sophisticated tools to account for multiple effects on the building envelop, thermal comfort and different building systems. Due to the difficulty of evaluating these new technologies through simple traditional methods, energy simulation software has emerged as the most efficient and effective method of evaluating the potential of a specific energy conservation technology applied to a specific building. Modern simulation tools such as *EnergyPlus* (Strand 2000) and *ESP-r* (Hand 2006, Clarke 2001) are well tailored to analyze different ECMs. In these modern simulation tools, models for many ECMs already exist or can be composed from elements within the tools. Expert users of these tools can readily assemble the building, system and plant data required to construct a building model. Typically this information, along with climate data, building use data, and typical system control strategies, is gleaned from onsite inspections, architectural drawings, and published equipment performance data. Once the basic model of the building has been constructed the expert simulation user can modify the simulation input to create model variants to evaluate each energy conservation measure of interest. ECMs can be evaluated one at a time or in combination with other measures.

This chapter provides results of modeling analysis to evaluate the energy performance of several ECMs applied to existing administrative, barracks/dormitories and industrial buildings. Simulation of of administrative and barracks buildigns was conducted by the National Renewable Energy Laboratory (NREL) to complete this work. At the same time, parallel work for these types of buildings was conducted at Oklahoma State University (OSU). OSU also conducted analysis of ECMs for an industrial facility that could represent a large maintenance facility or light manufacturing facility.

The premise of the IEA ECBCS Annex 46 Subtask B was to create baseline models for each of the three building types that are somewhat representative of existing buildings and evaluate the performance ECMs in locations representing US, Canadian and European climates in countries participating the the Annex 46. The baseline models are not intended to represent any one particular building, but are meant to be rough representations of most of the buildings. Several assumptions had to be made to build the models and usually with very little knowledge of the buildings represented with this study. The results presented in this book should be viewed as a first screening to help understand relative performance of the ECMs within the limits of the assumptions applied in the modeling. When retrofitting a building, these results will help guide the building manager in selecting the most promising measures to consider. It is anticipated that additional analyses will be completed to understand the performance of the selected ECMs as applied to each building and economic situation.

The evaluations were conducted using detailed whole building energy simulations using EnergyPlus (USDOE 2009). The simulations were completed for 15 representative US and Canadian locations (for all three types of buildings) and 16 European locations for administartive and barracks/dormitory buildings. The relative energy and energy cost performance compared to the baseline building are presented for each ECM, and in some cases where a good cost data was available, a simple payback of the ECM is presented.

3.1 Industrial Buildings

Specification of the baseline building model has a significant impact on the ranking of the ECMs. In general, a unique baseline model must be specified for buildings that differ significantly in envelope construction, ceiling height and use:

- *Building Envelope Construction:* The airtightness, thermal mass and thermal resistance of the envelope may have an impact on the screening process. The relative significance of these parameters, however, is largely determined by the building use. Often the heating and cooling load profile of industrial buildings is dominated by the internal gains rather than the envelope.
- *Building Ceiling Height:* The ceiling height has a significant impact on the degree of thermal stratification in the space. As a result, both system performance and the relative ranking of system ECMs are impacted by this parameter.
- *Building Use:* Building use largely determines internal heat gains, infiltration rates, and required ventilation rates. The magnitude of the internal gains effectively shifts the relative importance of ECMs from heating to cooling. By reducing the heating load and increasing the cooling load, large internal gains associated with industrial processes minimize the impact of technologies that improve the performance of the heating system and maximize the performance of technologies that improve the performance of the cooling system. For industrial buildings, infiltration rates are often dominated by the frequent use of large overhead doors, and outside air requirements are often determined by the rate at which contaminants and toxins are released into the air.

The industrial facility, shown in the Figure 3.1, was modeled as a 50,000 sq ft metal building with three work areas, a loading dock and an office.

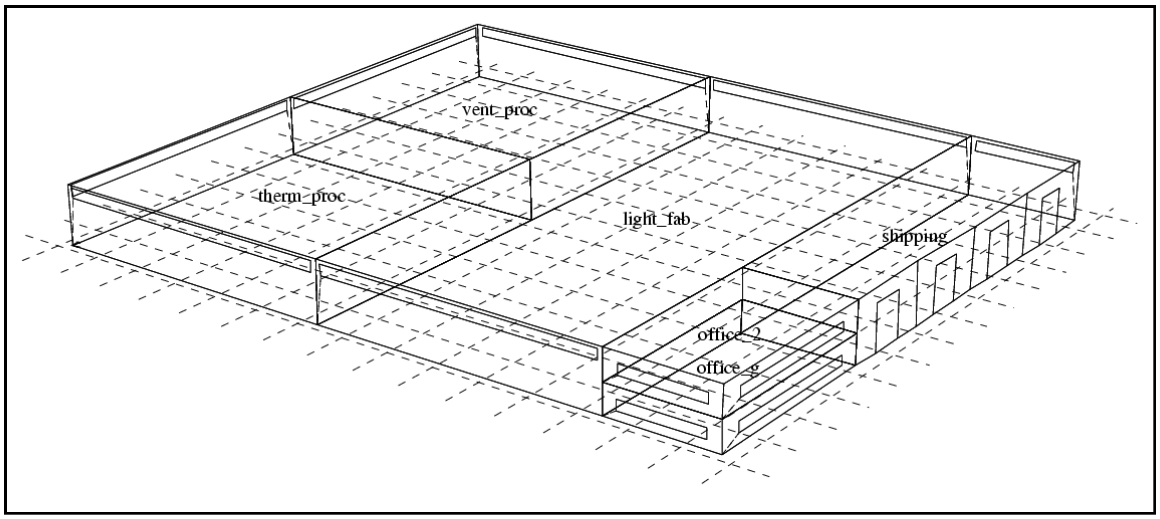

Figure 3.1. Zoning of the industrial building.

The three industrial work areas were designed to model a range of industrial processes and include:

1. A thermally intensive processing area (e.g., a heat treat shop)

2. A ventilation intensive processing area (e.g., a plating shop)

3. A light fabrication area (e.g., a welding shop).In addition, the model includes a shipping and receiving area with four large overhead doors and a typical office area. The zones are differentiated from one another primarily on the basis of their internal heat gains (Table 3.1). Internal gains are scheduled on the basis of a two-shift operation.

Industrial buildings often have significant cracks in the façade, low quality fenestration and large doors that are opened with some frequency. The base case model explicitly represents such leakage paths and the opening of doors and the assessments, at 1-minute intervals solves the air movement within the zones accounting for current weather conditions and possible imbalances in the mechanical ventilation system. To ensure both *EnergyPlus* and *ESP-r* were working with compatible assumptions about flow, the *ESP-r* predictions were exported to *EnergyPlus* as averaged hourly values of infiltration for each building zone and for each climatic zone.

Table 3.1. Zone area and internal heat gains.

Zone	Area	Light Heat Gain W/sq ft	Equipment Heat Gain W/sq ft	People (total number)	Infiltration ACH (m^3/s)
Office	5000	1	0.5	10	0.5 (0.393289 m^3/s)
Shipping & Receiving	5000	1	0.001	2	3 (2.359737 m^3/s)
High Thermal Loads	10000	1.5	30	20	2 (3.146316 m^3/s)
High Ventilation Loads	10000	1.5	15	20	2 (3.146316 m^3/s)
Light Fabrication Loads	20000	1.5	8	20	2 (6.292633 m^3/s)

Typical light industrial wall and roof constructions were used in modeling the building. The walls are insulated metal construction (R-4). Single-pane windows were used in the work areas and double pane windows were used in the office areas. An 8-in. lightweight concrete block wall separated the office area from the work areas. The roof was a standard built up bitumen roof and the main floor consisted of an 8-` concrete slab.

The HVAC system configuration can have a significant impact on the relative effectiveness of an industrial building ECM. The rank order of a set of ECMs is highly dependent on the system type and its interaction with the space. Three space/system configurations are of particular importance:

Ventilation vs. Air-Conditioning: Many industrial facilities in moderate climates have “heating only” systems and rely on mechanical ventilation to provide tolerable working conditions during the cooling season. For these systems, ECMs that would otherwise reduce the cooling load or improve system efficiency have no effect on the building’s energy use since the ventilation fan operates on a set schedule without regard for the cooling load.

Radiant vs. Convective Heating: Because these two system types interact with the space and maintain thermal comfort differently, the relative effectiveness of a given ECM can change significantly depending on the dominant heat transfer mechanism of the system. For convective systems, the degree of thermal stratification in the space is dependent on a number of parameters including diffuser location, characteristics of the diffuser jet and the configuration of the space—especially the ceiling height. Together, these parameters can affect the relative impact of system ECMs.

Outside Air vs. Recirculation: The outside air load can significantly alter the rank order of industrial building ECMs. For industrial facilities that require 100% outside air to flush toxins and contaminants from the process areas, ECMs that focus on outside air reduction rank very high. For facilities that already operate with minimal outside air, the same ECMs rank much lower.

The HVAC system specifications for the industrial baseline model used in this study are listed in Table 3.2. The table shows thermostat settings, the HVAC system type, ventilation schedules and the plant type. The data in Table 3.2 show that only the office is air-conditioned. The office cooling setpoint is 82 °F with a 6 °F deadband, and the heating setpoint is 62 °F with a 10 °F deadband. All of the other zones are heating only with setpoints of 60 °F and 10 °F deadbands.

Each zone is served by a dedicated forced-air system. Ventilation air is scheduled for all zones based on occupancy and work schedules as shown in the table. The ventilation system uses 100% outside air in zones with high ventilation and thermal load. In zones with light fabrication and in shipping and receiving the outdoor airflow rate is varies between 30% during the heating season and 100% during the warm season Recirculation and heat-recovery strategies are evaluated as ECMs for this building. Gas-fired coils provide heat for the space.

Table 3.2. HVAC system specifications.

Zone	Thermostat Settings	System Operation	Ventilation Schedule
Office	Cooling 76 - 82 (24.44 - 27.778); Heating 72 - 62 (22.22 - 16.667)	6am - 1am; M-F	200 CFM occupied 0 CFM unoccupied
Shipping & Receiving	Heating 70 - 60 (21.11 - 15.556)	6am - 1am; M-F	3 ACH
High Thermal Loads	Heating 70 - 60 (21.11 - 15.556)	6am - 1am; M-F	3 ACH
High Ventilation Loads	Heating 70 - 60 (21.11 - 15.556)	6am - 1am; M-F	9 ACH
Light Fabrication Loads	Heating 70 - 60 (21.11 - 15.556)	6am - 1am; M-F	4 ACH

3.1.1 Representative climate zones and cities

The US Department of Energy (USDOE Climate Zone Map 2003) has determined that the US climate can be adequately represented by eight climatic zones (with a humid and a dry sub-zone in each) (Figure 3.3).The energy models were simulated in 15 US cities representative of the 15 US climate zones Cities representative cities to these climate Zones (Table 3.3). The table also include the table number from ASHRAE Standard 90.1-1989 used for climate related envelope characteristics and the heating degree days (HDD) and cooling degree days (CDD). The EnergyPlus version of all weather files were taken from the EnergyPlus weather data website (USDOE 2010). The US weather files were based on Typical Meteorological Year-2 (TMY2) data.

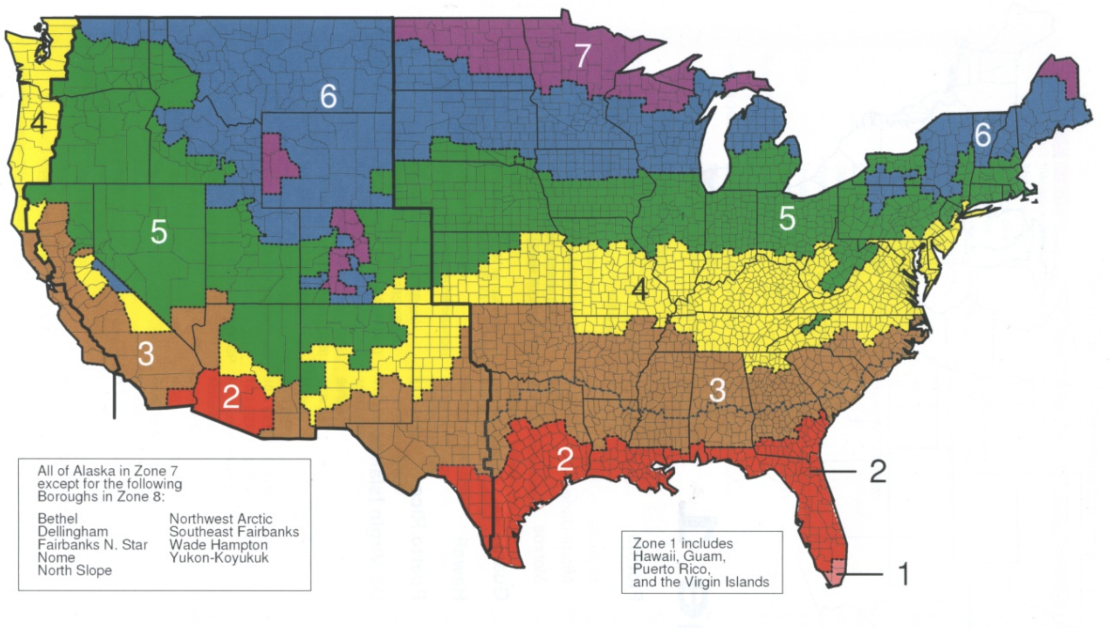

Figure 3.2. US climate zones (USDOE Climate Zone Map 2003).

Table 3.3. US cities and climate zones used for simulations.

City	Climate Zone	90.1-1989 Table 8A-	HDD (Base 65ºF)	HDD (Base 18ºC)	CDD (Base 50ºF)	CDD (Base 10ºC)
Miami, FL	1A	15	200	111	9,474	5,263
Houston, TX	2A	10	1,599	888	6,876	3,820
Phoenix, AZ	2B	18	1,350	750	8,425	4,681
Memphis, TN	3A	24	3,082	1,712	5,467	3,037
El Paso, TX	3B	12	2,708	1,504	5,488	3,049
San Francisco, CA	3C	5	3,016	1,676	2,883	1,602
Baltimore, MD	4A	25	4,707	2,615	3,709	2,061
Albuquerque, NM	4B	23	4,425	2,458	3,908	2,171
Seattle, WA	4C	19	4,908	2,727	1,823	1,013
Chicago, IL	5A	26	6,536	3,631	2,941	1,634
Colorado Springs, CO	5B	28	6,415	3,564	2,312	1,284
Burlington, VT	6A	33	7,771	4,317	2,228	1,238
Helena, MT	6B	32	7,699	4,277	1,841	1,023
Duluth, MN	7A	36	9,818	5,454	1,536	853
Fairbanks, AK	8A	38	13,940	7,744	1,040	578

The annual expected gas and electric energy savings reported by the simulation results were converted to dollars based on maximum, minimum, and average energy rates reported on the US Department of Energy (USDOE) website (Table 3.4).

Table 3.4. Regional energy rates, 2004 EIA Data.

	City, State	Electricity Cost ($/kWh)			Natural Gas Cost ($/MMBtu)		
		Minimum	Average	Maximum	Minimum	Average	Maximum
AK	Fairbanks,	0.080	0.113	0.120	2.03	4.42	4.68
AZ	Phoenix, A	0.054	0.073	0.082	7.14	8.11	11.24
FL	Miami, FL	0.058	0.081	0.090	8.46	11.24	16.77
ID	Boise, ID	0.038	0.049	0.059	6.62	7.98	8.57
IL	Chicago, IL	0.045	0.067	0.083	7.70	8.29	8.67
MD	Baltimore,	0.040	0.064	0.075	8.96	10.11	11.35
MN	Duluth, MN	0.045	0.061	0.077	6.36	8.05	8.83
NM	Albuquerqu	0.050	0.071	0.086	7.41	7.44	8.54
TN	Memphis, T	0.045	0.061	0.069	6.14	8.77	9.64
TX1	El Paso, TX	0.055	0.075	0.092	5.56	7.74	9.21
TX2	Houston, T	0.055	0.075	0.092	5.56	7.74	9.21
VT	Burlington,	0.080	0.110	0.129	5.73	8.52	10.70

Industrial ECMs Screening Metrics

Energy Conservation Metrics: Although annual energy savings may be presented in raw form (Btu/hr or Watts), some type of normalization is required to accommodate comparisons between building types. For purposes of the screening tool, energy savings are appropriately normalized by building or system parameters, but are not appropriately normalized by parameters related to the technology being screened. Normalization on the basis of technology parameters is only useful in comparing similar technologies. Since the screening tool compares a wide range of technologies, this type of normalization is not appropriate. For example, a comparison of competing transpired solar wall technologies is best served by estimating energy savings per unit area of installed solar wall (a technology design parameter), but the screening tool is best served by estimating energy savings per unit of system volumetric flow rate (a system parameter) or on the basis of zone floor area (a building parameter).

The two energy conservation metrics are selected for screening tool comparison are:

$$\text{Energy Savings} = \frac{\text{Annual Energy Savings}}{\text{Building Area}}$$

and:

$$\text{Energy Savings} = \frac{\text{Annual Energy Savings}}{\text{Sum of the System Volumetric Flow Rates}}$$

By using the *total* building area and the *total* system volumetric flow rate as a basis for comparison, these metrics penalize technologies that can only be applied selectively to specific zone or system types. Technologies that are more generally applicable are favored by the broader basis of comparison.

Life Cycle and Simple Payback Calculations: From a pragmatic point of view, a metric based on economics is arguably more useful than one based on energy savings alone. As with the energy metric, one could just present the total yearly monetary savings due to implementation of an ECM, but since this raw data would be specific to one building irrespective of its size, a more sophisticated economic metric must be used to generalize the results. Two commonly used metrics were tested and compared: a simple payback metric and a more complex LCC metric.

The simple payback (SPB) metric was very easy to calculate as shown in the following equations. First the initial cost (IC) and change in maintenance cost (MC) of a technology were estimated based on current equipment and construction costs. To estimate the electricity savings (ES) and gas savings (GS), average utility rates for each location were determined (World Energy Overview 2006). If productivity is included in the analysis, the increase in productive hours (ΔPH) due to the ECM is multiplied by an average labor rate to estimate the annual savings due to increased productivity.

$$SPB = \frac{\mathrm{IC}}{\mathrm{ES} + \mathrm{GS} - \Delta\mathrm{MC}} \quad \text{and} \quad SPB = \frac{\mathrm{IC}}{\mathrm{ES} + \mathrm{GS} + \Delta\mathrm{PH} * \mathrm{Rate} - \Delta\mathrm{MC}}$$

Although the simple payback metric is very easy to implement it may not provide an accurate representation of the results, due to the fact it does not take into account the time value of money nor does it consider increasing utility prices. To assess the impact of the simple payback assumption, an LCC metric was also developed for the screening tool. As shown in the equations below, the LCC calculation returns the present worth of the savings over the life of an ECM. A positive result means that it makes sense to invest money into that technology; a negative result indicates that money is better invested elsewhere. This metric also accounts for increases in the cost of utilities, maintenance and labor. It was assumed that these prices would increase at a constant rate. Escalation of electricity [ER] and gas [GR] rates were determined from Energy Information Administration (EIA) projections (World Energy Overview 2006). It was further assumed that maintenance costs and labor rates would increase at the historical inflation rate (Inf). Finally, all these costs are brought back to present worth by using a discount rate (DR), which is generally specific to each company.

$$LCC = PW(ES, GS, \Delta MC) - IC$$

$$PW = \sum_{n=0}^{period-1} \frac{1}{(1+DR)^n} \left(ES(1+ER)^n + GS(1+GR)^n - \Delta MC(1+Inf)^n \right)$$

and:

$$LCC = PW(ES, GS, \Delta MC, WBGT) - IC$$

To calculate the Present Worth (PW) the future worth is first calculated. Future energy prices are based on an EIA report, an average escalation rate was calculated from this data for gas and electricity. The rate for gas was found to be 3.4% per year. The rate for electricity was found to be 3.5% per year. It was assumed that maintenance and productivity rates would increase at a rate equal to infiltration or 4.1% per year. A period of 20 years and a discount rate of 7.5% were used for the analysis.

<u>Productivity and Thermal Comfort Metrics</u>: Many industrial buildings are cooled by natural or forced ventilation without the assistance of chillers, air-conditioners, roof top units, etc. For these buildings, ECMs that are designed to reduce the cooling load or improve the performance of the air-conditioning equipment will show no effect. Even if the ECM completely eliminates the cooling load, the ventilation fans will run to provide fresh air to the space.

For ventilated industrial buildings, evaluation of ECMs that reduce the building cooling load or improve the performance of air-conditioning equipment requires some sort of thermal comfort analysis. The International Standards Organization (ISO) standard on thermal comfort (ISO 1989) specifies the “wet bulb globe temperature,” WBGT, as the standard metric for determining the suitability of hot work environments. Table 3.5 lists the allowable work demand for light and moderate work for both acclimatized and unacclimatized workers as a function of WBGT.

Table 3.5. Productivity as a function of wet bulb globe temperature (ACGIH 2003).

	Acclimatized Employee		Unacclimatized Employee	
Productivity	**Light Work (WBGT ºF)**	**Moderate Work (WBGT ºF)**	**Light Work (WBGT ºF)**	**Moderate Work (WBGT ºF)**
100% Work	85.1	81.5	81.5	77
75% Work	86.9	83.3	84.2	79.7
50% Work	88.7	85.1	86	82.4
25% Work	90.5	87.8	87.8	84.2

To apply this metric to the evaluation of cooling ECMs, a subroutine calculating WBGT was written for *EnergyPlus*. The algorithm is based on the following equation, which calculates WBGT as a function of globe temperature, T_g, and natural wet bulb temperature, T_{nwb}, as follows:

$$WBGT = 0.3 * T_g + 0.7 * T_{nwb}$$

The globe temperature, Tg, was solved using the following correlation as given by Sullivan and Corton (Sullivan 1976):

$$T_g = T_{DB} + \frac{1.73 \times 10^{-7} \left(T_{MRT}^4 - T_g^4\right)}{V_a^{0.6}}$$

In this implicit formulation, the globe temperature is a function of the mean radiant temperature, T_{MRT}, the air temperature, T_{DB} and the air velocity, V_a. The fourth power temperature difference renders the equation both sensitive to the initial guess of the globe temperature and prone to non-convergence. Since the globe temperature is by definition bounded by the mean radiant temperature, T_{MRT}, and the air temperature, T_{DB}, it is easily bounded. With a relaxation parameter of 0.1, convergence was always achieved.

The natural wet bulb temperature, T_{nwb}, was solved using Romero's "still air" correlation (**Malchaire 1976**).

$$T_{nwb} = T_{WB} + \frac{0.16\left(T_g - T_a\right) + 0.8}{200}\left(560 - 2RH - 5Ta\right) - 0.8$$

The table, which was also included in *EnergyPlus* and the next release of *ESP-r*, was then used to determine the allowable work demand for moderate work by an acclimatized employee. This fraction was then multiplied by the maximum number of man-hours available in the zone based as determined by the occupancy schedule. Lost revenue was calculated at a fully burdened labor rate of $40/hr.

3.1.2 Analyzed energy conservation measures

Table 3.6 lists ECMs simulated for industrial buildings. And detailed technology analysis for them are presented in Section 3.6.6.

Table 3.6. Energy conservation measure overview.

Energy Conservation Measure	Description
Vehicle Vestibule	Decrease the amount of infiltration into the building
High-Speed Roller Door	Decrease the amount of infiltration into the building
Envelope Sealing	Decrease the amount of infiltration into the building
Dock Seals	Decrease the amount of infiltration into the building
Cool Roofs	Increase the albedo of the roof surfaces, reduces cooling load and improves thermal comfort and worker's productivity
Destratification Fans	Reduces temperature stratification with heating
Displacement Ventilation	Increases ventilation effectiveness and creates temperature stratification with cooling
High Temperature Radiant Heating	Provides working space heating by radiation, reduces heating inefficiency
Solar Wall	Preheats ventilation air using solar energy
Daylighting	Provides high bay illumination without using electrical power, reduces electrical energy cost
Demand-based Local Exhaust System for Welding Shops	Captures welding fumes at source; operates only during the welding process
Close Capture Exhaust Systems for Moving/Stationary Vehicles	Stationary and moving vehicle exhaust capture system traps and removes by-products of the engine combustion process
Energy Recovery in Paint Booths	Recovers heat from exhaust air to preheat supply air
VFD Drives to Balance Airflow with Production Rates	Controls fan operation in accordance with production rate schedule
Turn off Idling Equipment	Turns-off production equipment during non-operating time intervals
Recirculation with Filtration	Removes contaminants from recirculating air to reduce energy for heating ventilation air
Setback thermostats	Reduces the heating or cooling load on the HVAC system during unoccupied hours

3.2 Barracks

The prototypical barracks facility described here is a three-story building totaling 28,965 sq ft. The building includes 40 2-bedroom apartment units, a lobby, and laundry rooms on each floor. A rendering of the building's exterior is shown in Figure 3.3, and the zoning plan used in the thermal model is shown in Figure 3.4 through Figure 3.6. The apartment units were grouped into large zones to simplify the model development and shorten the run time of the simulations. It is not expected that this simplification will have a large effect on the relative performance of the efficiency measures. Table 3.8 lists an overview of the building specifications and the data in Table 3.8 summarize the zone geometry.

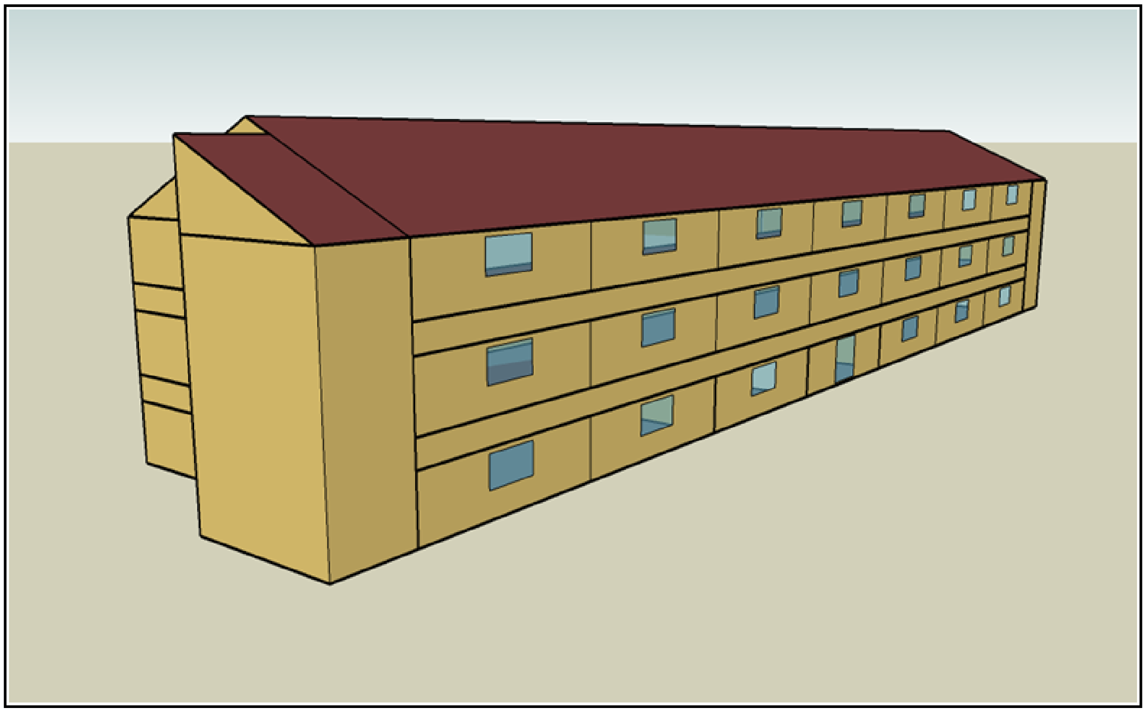

Figure 3.3. Rendering of the energy simulation model for the Army barracks.

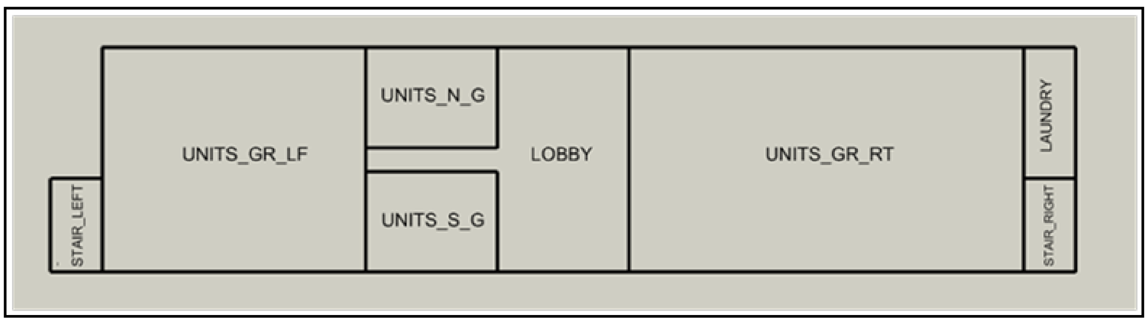

Figure 3.4. Ground level floor plan.

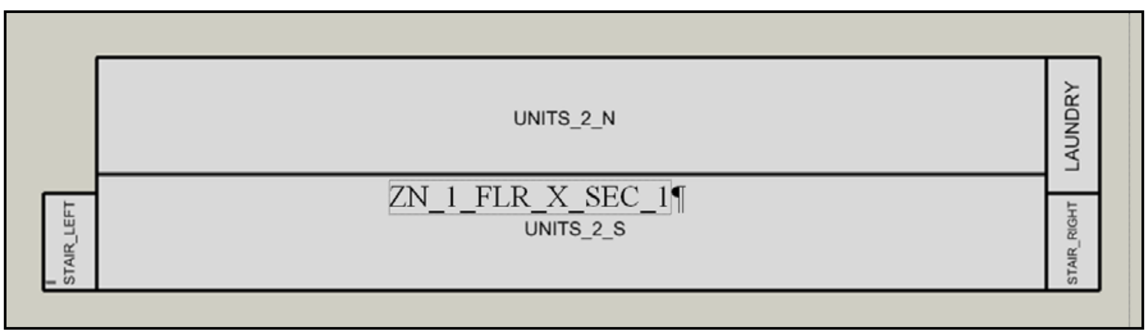

Figure 3.5. Second level floor plan.

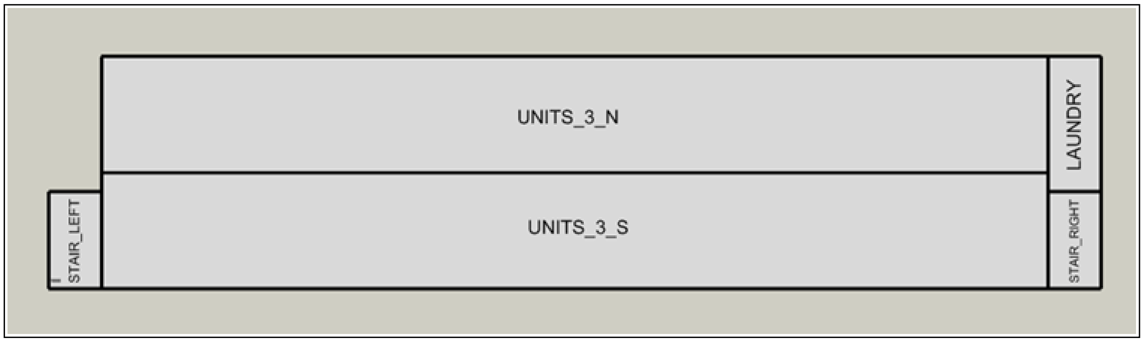

Figure 3.6. Third level floor plan.

Table 3.7. Building model parameters.

Building Component	Component Description
Area	28,965 sq ft (2,691 m^2)
Floors	3
Foot print shape	Rectangle
Fenestration type	Standard 90.1-1989
Wall construction	Wood frame with brick exterior
Wall insulation	Standard 90.1-1989, mass wall
Roof construction	Sloped metal roof with Insulation at roof Level
Roof insulation	Standard 90.1-1989, with attic
Infiltration	1 cfm/sq ft of shell area @ 0.3 in w.c.
Window-to-wall ratio	Total – 6.88%; North – 8.91%; East – 0.00%; South – 9.38%; West – 0.00%
Temperature set points	75 ˚F (23.9 ˚C) cooling and 70˚F (21.1 ˚C) heating
HVAC	PSZ with DX-AC (2.6 COP) and gas furnace (0.8 E_t)
Domestic Hot Water (DHW)	Natural gas boiler

Table 3.8. Summary of thermal zones.

Zone	Area (sq ft)	Volume (ft^3)	Conditioned
UNITS_GR_LF	2,688	21,499	Yes
UNITS_GR_RT	4,032	32,248	Yes
UNIT_S_G	602	4,816	Yes
UNIT_N_G	602	4,816	Yes
LOBBY	1,484	11,867	Yes
UNITS_2_S	4,704	37,623	Yes
UNITS_2_N	4,704	37,623	Yes
UNITS_3_S	4,704	37,623	Yes
UNITS_3_N	4,704	37,623	Yes
CEILING_1	9,407	31,356	No
CEILING_2	9,407	31,356	No
ROOF_SPACE	10,155	33,847	No
STAIR_LEFT	220	6,746	Yes
STAIR_RIGHT	220	6,746	Yes
LAUNDRY	308	5,348	Yes

The roof height (calculated as volume/area) of the laundry zone and the left and right stair zones is much greater than that of the other occupied spaces. This is because the laundry and stair zones were modeled as single, three-story tall zones, instead of as individual zones at each floor. Since values listed in this report are as-modeled zone values, items such as lower lighting power density (LPD) and outside air (OA) flow rates are three times larger than they would be had each of the zones been modeled on a floor-by-floor basis.

3.3 Locations

The energy models were simulated in 15 US cities representative of the 15 US climate zones and in 16 Canadian and European cities (termed “international cities” in this book selected by the IEA Annex 46 members as representative cities for their countries. The cities and climate zones are shown in Tables 3.9 and 3.10. The tables also include the table number from ASHRAE Standard 90.1-1989 used for climate related envelope characteristics and the HDD and CDD. The EnergyPlus version of all weather files were taken from the EnergyPlus weather data website (USDOE 2010). The US weather files were based on Typical Meteorological Year-2 (TMY2) data, the Canadian weather files were based on Weather Year for Energy Calculations-2 (WYEC2) data, and the European weather files were based on International Weather for Energy Calculations (IWEC) data.

Table 3.9. US cities and climate zones used for simulations.

City	Climate Zone	90.1-1989 Table 8A-	HDD (Base 65ºF)	HDD (Base 18ºC)	CDD (Base 50ºF)	CDD (Base 10ºC)
Miami, FL	1A	15	200	111	9,474	5,263
Houston, TX	2A	10	1,599	888	6,876	3,820
Phoenix, AZ	2B	18	1,350	750	8,425	4,681
Memphis, TN	3A	24	3,082	1,712	5,467	3,037
El Paso, TX	3B	12	2,708	1,504	5,488	3,049
San Francisco, CA	3C	5	3,016	1,676	2,883	1,602
Baltimore, MD	4A	25	4,707	2,615	3,709	2,061
Albuquerque, NM	4B	23	4,425	2,458	3,908	2,171
Seattle, WA	4C	19	4,908	2,727	1,823	1,013
Chicago, IL	5A	26	6,536	3,631	2,941	1,634
Colorado Springs, CO	5B	28	6,415	3,564	2,312	1,284
Burlington, VT	6A	33	7,771	4,317	2,228	1,238
Helena, MT	6B	32	7,699	4,277	1,841	1,023
Duluth, MN	7A	36	9,818	5,454	1,536	853
Fairbanks, AK	8A	38	13,940	7,744	1,040	578

Table 3.10. International cities and climate zones used for simulations.

City	Climate Zone	90.1-1989 Table 8A-	HDD (Base 18ºC)	CDD (Base 10ºC)
Edmonton, CAN	7	36	5583	579
Ottawa, CAN	6	33	4664	1119
Vancouver, CAN	5	19	3020	806
Copenhagen, DNK	5	28	3563	713

City	Climate Zone	90.1-1989 Table 8A-	HDD (Base 18ºC)	CDD (Base 10ºC)
Helsinki, FIN	7	33	4712	577
Tampere, FIN	7	33	5020	528
Lyon, FRA	4	20	2539	1483
Marseille, FRA	4	3	1735	2105
Nantes, FRA	4	4	2254	1311
Paris, FRA	4	19	2644	1209
Stuttgart, DEU	5	28	3338	1300
Milan, ITA	4	25	2639	1637
Naples, ITA	4	9	1364	2485
Palermo, ITA	2	9	724	3225
Rome, ITA	4	24	1444	2333
London, UK	4	19	2866	864

Table 3.11 lists utility rates for US locations, based on the average state costs from the Energy Information Administration for 2007 (EIA 2008). Table 3.12 lists utility costs for the Canadian and European locations.

Table 3.11. Utility rates for US locations.

City	Electricity Cost ($/kWh)	Natural Gas Cost ($/therm)
Miami, FL	$0.097	$1.131
Houston, TX	$0.097	$1.319
Phoenix, AZ	$0.100	$0.987
Memphis, TN	$0.083	$1.284
El Paso, TX	$0.080	$1.258
San Francisco, CA	$0.100	$0.987
Baltimore, MD	$0.128	$1.020
Albuquerque, NM	$0.115	$1.328
Seattle, WA	$0.076	$0.991
Chicago, IL	$0.066	$1.237
Boise, ID	$0.091	$1.043
Burlington, VT	$0.051	$1.079
Helena, MT	$0.123	$1.279
Duluth, MN	$0.080	$0.981
Fairbanks, AK	$0.074	$1.014

Table 3.12. Utility rates for Canadian and European locations.

City	Electricity Cost (cost/kWh)	Natural Gas Cost (cost/therm)
Edmonton, CAN	$0.093	$1.067
Ottawa, CAN	$0.093	$1.067
Vancouver, CAN	$0.093	$1.067
Copenhagen, DNK	€ 0.075	€ 2.834
Helsinki, FIN	€ 0.114	€ 2.408
Tampere, FIN	€ 0.074	€ 2.665
Lyon, FRA	€ 0.063	€ 2.327
Marseille, FRA	€ 0.116	€ 2.402
Nantes, FRA	€ 0.079	€ 2.323
Paris, FRA	€ 0.075	€ 2.544
Stuttgart, DEU	€ 0.062	€ 2.611
Milan, ITA	€ 0.054	€ 2.364
Naples, ITA	€ 0.071	€ 2.711
Palermo, ITA	€ 0.079	€ 2.333
Rome, ITA	€ 0.076	€ 3.155
London, UK	€ 0.072	€ 2.394

3.3.1 Modeling assumptions used in baseline energy model

The energy simulations were completed over a span of 3 years using the latest available version of EnergyPlus (v2.0 – v5.0 depending on the simulation date).

3.3.2 Envelope

The building has a slab-on-grade floor, insulated steel stud walls with a brick exterior façade, and an attic with a standing seam metal roof. Table 3.13 lists details of the main envelope construction. The insulation levels and the properties of the fenestration for the US locations are designed to comply with ASHRAE Standard 90.1-1989 (ASHRAE 1989) for each climate zone. Table 3.14 lists the 90.1-1989 opaque construction properties by location. For some ECMs, additional baseline insulation values were created to represent different construction practices. Table 3.15 lists a set of insulation values that represent construction practices around 1960, developed from a review of construction practices of office buildings by Briggs et al. (1987). Another practice that was common for pre-1970 construction was to construct walls with no insulation, which was used as a baseline for the wall insulation ECM. Table 3.16 lists window thermal properties for the US locations from Standard 90.1-1989. The opaque construction and window thermal properties for the international locations (Tables 3.17 and 3.18).were defined by the Annex 46 members from these countries.

Table 3.13. Envelope construction layers.

Construction	Outer Layer	Layer 2	Inner Layer
Roof	Steel Cladding	¾ in (2 cm) Plywood	Insulation per Location
Exterior Wall	4 in (10 cm) Brick	Insulation per Location	½ in (1.3 cm) Gypsum Board
Slab	4 in (10 cm) Concrete	Not Applicable (NA)	Carpet

Table 3.14. US opaque construction thermal properties – Standard 90.1-1989.

City	Wall U-Value (Btu/hr°sq ft)	Roof U-Value (Btu/hr·°F·sq ft)	Wall U-value (W/m^2·K)	Roof U-value (W/m^2·K)
Miami, FL	1.000	0.074	5.68	0.42
Houston, TX	0.340	0.066	1.93	0.37
Phoenix, AZ	0.410	0.046	2.33	0.26
Memphis, TN	0.190	0.057	1.08	0.32
El Paso, TX	0.300	0.058	1.70	0.33
San Francisco, CA	0.490	0.088	2.78	0.50
Baltimore, MD	0.120	0.058	0.68	0.33
Albuquerque, NM	0.190	0.059	1.08	0.34
Seattle, WA	0.100	0.064	0.57	0.36
Chicago, IL	0.100	0.053	0.57	0.30
Boise, ID	0.140	0.051	0.79	0.29
Burlington, VT	0.071	0.045	0.40	0.26
Helena, MT	0.079	0.049	0.45	0.28
Duluth, MN	0.061	0.040	0.35	0.23
Fairbanks, AK	0.047	0.031	0.27	0.18

Table 3.15. US opaque construction thermal properties, 1960 construction.

City	Wall U-Value (Btu/hr·°F·sq ft)	Roof U-Value (Btu/hr·°F·sq ft)	Wall U-value (W/m^2·K)	Roof U-value (W/m^2·K)
Miami, FL	0.230	0.200	1.31	1.14
Houston, TX	0.230	0.200	1.31	1.14
Phoenix, AZ	0.230	0.200	1.31	1.14
Memphis, TN	0.224	0.115	1.27	0.65
El Paso, TX	0.230	0.200	1.31	1.14
San Francisco, CA	0.226	0.116	1.28	0.66
Baltimore, MD	0.196	0.102	1.27	0.58
Albuquerque, NM	0.199	0.105	1.13	0.59
Seattle, WA	0.193	0.101	1.10	0.57
Chicago, IL	0.180	0.088	1.02	0.50
Boise, ID	0.185	0.093	1.05	0.53
Burlington, VT	0.174	0.078	0.99	0.44
Helena, MT	0.175	0.078	0.99	0.45
Duluth, MN	0.167	0.076	0.95	0.43
Fairbanks, AK	0.160	0.076	0.91	0.43

Table 3.16. US window thermal properties.

City	Window U-Value (Btu/hr·°F·sq ft)	Window U-Value ($W/m^2 \cdot K$)	Window SHGC*	Window-to-Wall Ratio (%)
Miami, FL	1.08	6.14	0.61	7.3
Houston, TX	1.08	6.14	0.61	7.3
Phoenix, AZ	1.08	6.14	0.61	7.3
Memphis, TN	0.56	3.19	0.63	7.3
El Paso, TX	1.08	6.14	0.61	7.3
San Francisco, CA	0.56	3.19	0.63	7.3
Baltimore, MD	0.56	3.19	0.63	7.3
Albuquerque, NM	0.56	3.19	0.63	7.3
Seattle, WA	0.56	3.19	0.63	7.3
Chicago, IL	0.56	3.19	0.63	7.3
Boise, ID	0.56	3.19	0.63	7.3
Burlington, VT	0.49	2.77	0.61	7.3
Helena, MT	0.49	2.77	0.61	7.3
Duluth, MN	0.49	2.77	0.61	7.3
Fairbanks, AK	0.49	2.77	0.61	7.3
*Solar Heat Gain Coefficient (SHGC)				

Table 3.17. International opaque construction thermal properties.

City	Wall U-Value (Btu/hr·°F·sq ft)	Roof U-Value (Btu/hr·°F·sq ft)	Wall U-value ($W/m^2 \cdot K$)	Roof U-value ($W/m^2 \cdot K$)
Edmonton, CAN	0.109	0.069	0.62	0.39
Ottawa, CAN	0.049	0.032	0.28	0.18
Vancouver, CAN	0.065	0.042	0.37	0.24
Copenhagen, DNK	0.072	0.039	0.41	0.22
Helsinki, FIN	0.083	0.594	0.47	3.37
Tampere, FIN	0.083	0.594	0.47	3.37
Lyon, FRA	0.081	0.085	0.46	0.48
Marseille, FRA	0.081	0.085	0.46	0.48
Nantes, FRA	0.081	0.085	0.46	0.48
Paris, FRA	0.081	0.085	0.46	0.48
Stuttgart, DEU	0.321	0.704	1.82	4.00
Milan, ITA	0.085	0.092	0.48	0.52
Naples, ITA	0.085	0.092	0.48	0.52
Palermo, ITA	0.085	0.092	0.48	0.52
Rome, ITA	0.085	0.092	0.48	0.52
London, UK	0.321	0.704	1.82	4.00

Table 3.18. International window thermal properties.

City	Window U-Value (Btu/hr·˚F·sq ft)	Window U-Value ($W/m^2 \cdot K$)	Window SHGC	Window-to-Wall Ratio (%)
Edmonton, CAN	0.56	3.19	0.627	7.3
Ottawa, CAN	0.49	2.77	0.610	7.3
Vancouver, CAN	0.49	2.77	0.610	7.3
Copenhagen, DNK	0.51	2.90	0.281	16.7
Helsinki, FIN	0.36	2.02	0.226	33.7
Tampere, FIN	0.36	2.02	0.226	33.7
Lyon, FRA	0.49	2.78	0.763	25.4
Marseille, FRA	0.49	2.78	0.763	25.4
Nantes, FRA	0.49	2.78	0.763	25.4
Paris, FRA	0.49	2.78	0.763	25.4
Stuttgart, DEU	0.51	2.90	0.281	33.7
Milan, ITA	0.49	2.78	0.763	16.2
Naples, ITA	0.49	2.78	0.763	16.2
Palermo, ITA	0.49	2.78	0.763	16.2
Rome, ITA	0.49	2.78	0.763	16.2
London, UK	0.51	2.90	0.281	33.7

3.3.3 Airtightness and infiltration

Infiltration is an especially difficult parameter to obtain good data on because the governing physics are complicated by many factors, including the operation of the building and outdoor environmental conditions. Instead of attempting to model the governing physics of infiltration, a simplified model was used. However, even in the simple model, many assumptions about the level of infiltration and how it was affected by the operation of the mechanical ventilation systems were made.

For the barracks building, it was assumed that the building leakage rate was equal to 1.0 cfm/sq ft (5.1 $L/s/m^2$) of envelope (exterior walls and roof) at 0.3 in w.g. (75 Pa) pressure difference across the building envelope. However, several assumptions and calculations were required in order to go from a leakage rate to the simple infiltration model used in the building energy simulation. First, a lower pressure of 0.016 in w.g. (4 Pa) was assumed to be the average pressure difference across the building envelope without the pressurization or depressurization of the building from the HVAC and exhaust fans. The infiltration leakage rate was calculated, assuming a flow exponent (n) of 0.65 according to Equation 3-1 and the total building infiltration was found by multiplying this flow rate by the total shell area (Equation 3-2).

$$Flow\ Rate_2 = Flow\ Rate_1 \times \left(\frac{Pressure_2}{Pressure_1}\right)^n \qquad 3\text{-}1$$

where:

Flow Rate2 = OA infiltration flow rate per shell area at Pressure2
Flow Rate1 = OA infiltration flow rate per shell area at Pressure1
Pressure2 = pressure at which the updated flow rate is desired
Pressure1 = reference pressure
n = flow exponent

$$Infiltration_{Building} = Flow\ Rate \times Shell\ Area_{Building} \tag{3-2}$$

where:

InfiltrationBuilding	=	total building infiltration
Flow Rate	=	OA infiltration flow rate per shell area
Shell AreaBuilding	=	area of the building shell (exterior walls and roof)

Individual zone infiltration rates are assumed to be proportional to the floor area of that zone compared to the total conditioned floor area and were calculated using Equation 3-3. Table 3.19 lists the resulting zone level infiltration rates in terms of air changes per hour (ACH).

$$Infiltration_{Zone} = Infiltration_{Building} \times \frac{Floor\ Area_{Zone}}{Floor\ Area_{Building}} \tag{3-3}$$

where:

InfiltrationZone	=	zone infiltration rate
InfiltrationBuilding	=	building infiltration rate
Floor AreaZone	=	zone floor area
Floor AreaBuilding	=	building floor area

Infiltration is often assumed to go to zero when buildings are pressurized in energy models. This assumption is made because there is a lack of evidence about what really happens and lack of knowledge of how to model it in an energy simulation. As such, it is assumed that the uncontrolled infiltration is reduced to zero when the building ventilation system is running. When the ventilation system is off (no outside air), the infiltration is modeled at the full leakage rate calculated at 0.016 in w.g. (4 Pa). Infiltration is modeled at constant ACH and is assumed to reasonably model the average effect of infiltration over the course of the year. This is a gross assumption, but one that is necessary without moving to more complicated flow network simulations.

Table 3.19. Zone infiltration.

Zone	Air Change Rate (ACH)
UNITS_GR_LF	0.97
UNITS_GR_RT	0.97
UNIT_S_G	0.97
UNIT_N_G	0.97
LOBBY	0.97
UNITS_2_S	0.97
UNITS_2_N	0.97
UNITS_3_S	0.97
UNITS_3_N	0.97
STAIR_LEFT	0.76
STAIR_RIGHT	0.76
LAUNDRY	0.76

3.3.4 Occupancy

The general occupancy rate is 2 people per two-bedroom unit. Table 3.20 lists the maximum occupancy for each thermal zone. These maximum rates are modified by the occupancy schedules included in Appendix A. It was assumed that the maximum occupancy rate of the building is 80% at night and 20% occupancy during the day.

Table 3.20. Summary of zone internal loads.

Zone	Max Occupants Per Zone	Electric Equipment Power Density		Lighting Power Density	
		(W/ft^2)	(W/m^2)	(W/ft^2)	(W/m^2)
UNITS_GR_LF	8	1.6	17.2	1.1	11.8
UNITS_GR_RT	12	1.6	17.2	1.1	11.8
UNIT_S_G	2	1.6	18.3	1.1	11.8
UNIT_N_G	2	1.6	18.3	1.1	11.8
LOBBY	2	0.25	2.7	1	10.8
UNITS_2_S	14	1.6	17.2	1.1	11.8
UNITS_2_N	14	1.6	17.2	1.1	11.8
UNITS_3_S	14	1.6	17.2	1.1	11.8
UNITS_3_N	14	1.6	17.2	1.1	11.8
STAIR_LEFT	0	0	0	1.8	19.4
STAIR_RIGHT	0	0	0	1.8	19.4
LAUNDRY	1	41	441.3	2.7	29.1

3.3.5 Plug loads

Unfortunately there is no measured data available for the barracks facility plug loads. The plug loads used in the baseline model are based on engineering judgment. It was assumed that each occupant has their own television, computer, stereo and other electronics, and it was assumed that the kitchen has a refrigerator, microwave and electric cook top. Table 3.20 lists the peak loads for each zone, and Appendix B includes the operating schedules for the plug loads.

3.3.6 Washer and dryer loads

It was assumed that there are two washing machines and dryers per floor. Assuming a 90% occupancy rate for the building, there are 72 occupants. It was assumed that each occupant does three loads of laundry per week, which gives 216 loads per week or approximately 31 loads per day. ENERGY STAR commercial washing machines use approximately 20 gallons of water per load and 0.60 kWh of electricity per load. Assume dryers use 1.5 kWh of electricity per load.

3.3.7 Lighting

Table 3.20 lists the lighting power densities for each zone of the baseline model, which follow Standard 90.1-1989 and are listed in Appendices B and D as lighting control schedules.

3.3.8 HVAC

The baseline HVAC system consists of a packaged single zone air-conditioning (PSZ-AC) unit in each zone of the building. Each system contains a DX cooling coil with a Coefficient of Performance (COP) of 2.6 and a gas furnace with an efficiency of 0.8. The system fans are constant volume fans with total efficiencies of 0.5. The pressure rise across each fan is 500 Pa. The maximum flow rate for each fan varies with calculated load. This value is allowed to autosize within the simulation as the flow rate required to meet the load on the system is location dependent. A schematic of the HVAC system is shown in Figure 3.7. The stairways have 80% efficient gas-fired unit heaters and no cooling equipment. The temperature setpoints are summarized in Table 3.2 and the hourly schedules are listed in Appendix B.

The models for the Canadian locations used the same systems as the US models. The European models contained no cooling systems and hydronic baseboard heating with an 80% efficient gas-fired boiler.

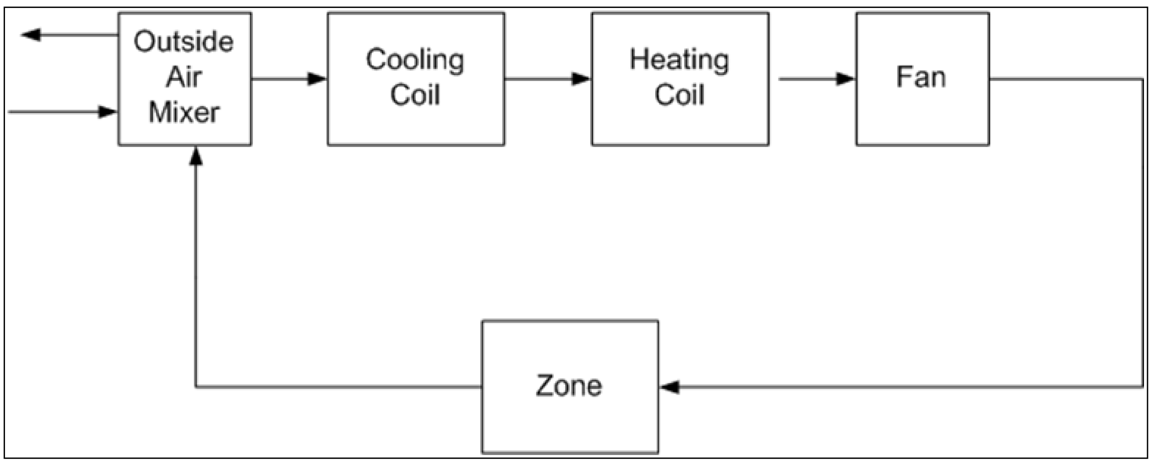

Figure 3.7. Baseline HVAC system diagram for US and Canadian locations.

3.3.9 Ventilation and outside air

Required minimum outdoor air flow rates were 450 cfm/sq ft for the laundry zone, 13 cfm/sq ft for most apartment spaces, and 30 cfm/person for the lobby

3.3.10 Analyzed energy conservation measures

Table 3.21 lists 17 ECMs simulated for barracks building. There are nine enveloape related measures, seven HVAC measures, and one domestic hot water measure. Chapter 4 includes simulation results and Chapter 5 gives a detailed analysis of some of the technologies.

Table 3.21. Energy conservation measure overview.

Energy Conservation Measure	**Description**
Increased Wall Insulation	Increase the amount of insulation in the exterior walls
Increased Roof Insulation	Increase the amount of insulation in the roof
Attic Insulation	Add insulation to the attic (ceiling) surface and remove it from the roof surface
Cool Roofs	Increase the albedo of the roof surfaces

Energy Conservation Measure	Description
Building Airtightness	Decrease the assumed amount of infiltration into the building
Advanced Windows	Replace baseline windows with more efficient models
External Roller Shades	Add roller shades to the outside of windows to prevent solar heat gains to the space during cooling and heat loss from the space during heating
Overhangs	Installation of horizontal shading devices over the south-facing windows to block direct solar gains
Exterior Vertical Fins	Installation of vertical fins on the outside of the building near windows to prevent direct sunlight penetration during the early morning and/or late evening
Energy Recovery Ventilators	Use heat exchangers to sensibly temper outdoor air with exhaust air (no mixing of air streams)
Indirect Evaporative Cooling	Use direct evaporation to cool an air stream. That air stream is then used to sensibly cool, via a heat exchanger, the supply-air stream (no mixing of air streams)
Hybrid Evaporative Cooling	Cool the supply-air stream by using an indirectly evaporatively cooled air stream as the inlet to a direct evaporation process
DOAS with Fan-Coil Units	Uses two separate systems: one to supply and condition outdoor air (this system handles the latent loads as well) and one to meet the thermal loads (sensible only) of the space
DOAS with Radiant Heating and Cooling	Circulates warm or cool liquid through pipes embedded in the floor and/or ceiling to radiantly condition a space. Paired with a DOAS that delivers the required volume of outdoor air
Ground Source Heat Pumps	Use of the ground as the heat source/sink in a direct expansion loop. The fluid from this loop is passed through the HVAC system heating and cooling coils as needed
Reheat Using Condenser Waste Heat	Condenser waste heat from the chiller is used to heat the water that is passed through the heating coil
Grey Water Heat Recovery	Extract heat from grey water to preheat incoming mains water to be used for DHW

3.3.11 Office/administrative building

The administrative facility (baseline) used in the Annex 46 study in is a four story building totaling 23,250 sq ft. The building model represents an existing building that is at least 20 years old. ANSI/ASHRAE IESNA 90.1-1989 was used as the basis for the energy systems and thermal envelope parameters (ASHRAE 1989). Figure 3.8 shows an artist’s rendering of the building’s exterior, and Figure 3.9 shows the floor plan of the zoning used in the thermal model. The data in Table 3.22 give an overview of the building specifications, and the data in Table 3.23 summarize the zone geometry. Section 3.4 includes a more detailed discussion of the parameters and the assumptions that went into choosing them. Section 3.4.3 discusses internal loads. (See Table 3.31 for a summary of zone internal loads.)

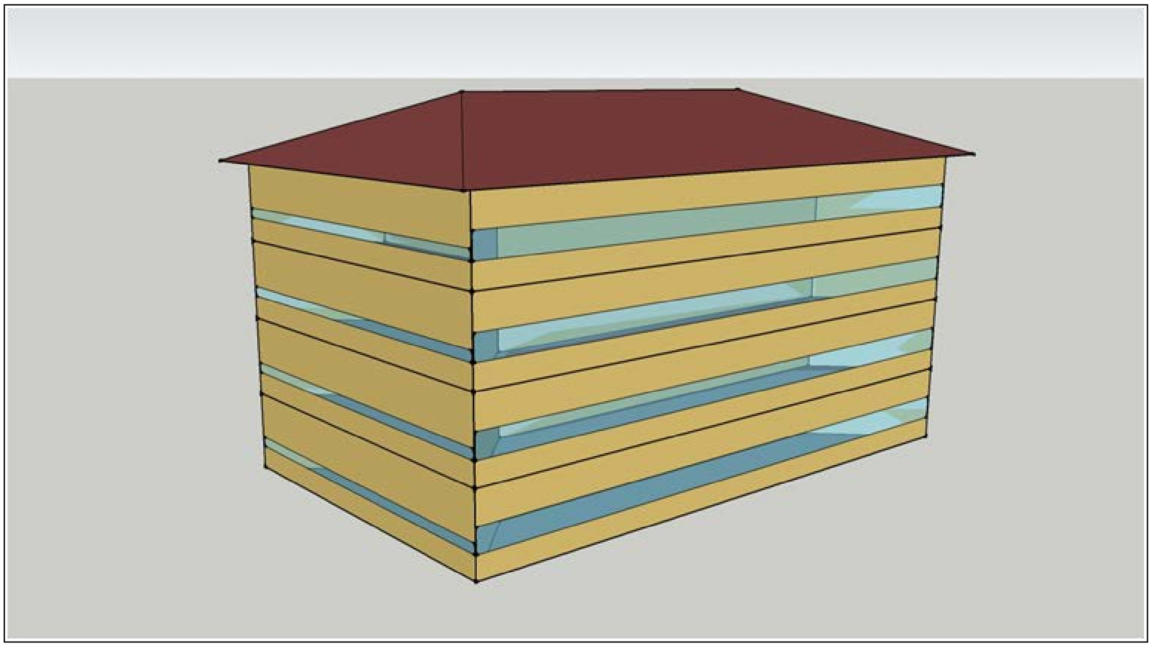

Figure 3.8. Rendering of the energy simulation model for the Army administrative facility.

Figure 3.9. Thermal zoning repeated for each floor.

Table 3.22. Building model parameters.

Building Component	Component Description
Area	23,250 sq ft (2,160 m^2)
Floors	4
Foot print shape	Rectangle
Fenestration type	Standard 90.1-1989
Wall construction	Steel frame with brick exterior

Building Component	Component Description
Wall insulation	Standard 90.1-1989, mass wall
Roof construction	Sloped metal roof with insulation at roof level
Roof insulation	Standard 90.1-1989, with attic
Infiltration	1 cfm/sq ft of shell area
Window-to-wall ratio	Total – 23.44%; North – 30.00%; East – 12.51%; South – 30.00%; West – 12.51%
Temperature set points	75 ˚F (23.9 °C) cooling and 70 °F (21.1 °C) heating with night setback to 86 °F (30 °C) cooling and 60 °F (15.6°C) heating
HVAC	VAV system with central chiller (4.5 COP) and natural gas boiler (0.8 Et)
DHW	Natural gas boiler

Table 3.23. Summary of zone dimensions.

Zone	Area (sq ft)	Volume (ft3)	Conditioned?
ROOF	5,813	31,081	No
FLR_1_SEC_1	1,251	15,594	Yes
FLR_2_SEC_1	1,251	15,594	Yes
FLR_3_SEC_1	1,251	15,594	Yes
FLR_1_SEC_2	660	8,235	Yes
FLR_2_SEC_2	660	8,235	Yes
FLR_3_SEC_2	660	8,235	Yes
FLR_1_SEC_3	1,251	15,594	Yes
FLR_2_SEC_3	1,251	15,594	Yes
FLR_3_SEC_3	1,251	15,594	Yes
FLR_1_SEC_4	660	8,235	Yes
FLR_2_SEC_4	660	8,235	Yes
FLR_3_SEC_4	660	8,235	Yes
FLR_1_SEC_5	1,989	24,799	Yes
FLR_2_SEC_5	1,989	24,799	Yes
FLR_3_SEC_5	1,989	24,799	Yes

The energy models were simulated in 15 US cities representative of the 15 US climate zones and in 16 Canadian and European cities (termed “international cities” in this book selected by the IEA Annex 46 members as representative cities for their countries. Table 3.9 and Table 3.10 (p 3-12) list the city and climate zones. The tables also include the table number from ASHRAE Standard 90.1-1989 used for climate related envelope characteristics and the HDD and CDD. The EnergyPlus version of all weather files were taken from the EnergyPlus weather data website (USDOE 2010). The US weather files were based on Typical Meteorological Year-2 (TMY2) data, the Canadian weather files were based on Weather Year for Energy Calculations-2 (WYEC2) data, and the European weather files were based on IWEC data.

Table 3.11 (p 3-13) lists utility rates for US locations based on the average state costs from the Energy Information Administration for 2007 (EIA 2008). Table 3.12 (p 3-14) lists utility costs for the Canadian and European.

3.4 Modeling Assumptions Used in Baseline Energy Model

This section describes the modeling assumptions used in the baseline energy model. The energy simulations were completed over a span of 2 years using the latest available version of EnergyPlus, v2.0 – v5.0 depending on the simulation date. All simulations were carried out using the NREL analysis platform that manages EnergyPlus simulations.

3.4.1 Envelope

The building has a slab-on-grade floor, insulated steel stud walls with a brick exterior façade, and an attic with a standing seam metal roof. The data in Table 3.24 detail the main envelope constructions. The insulation levels and the properties of the fenestration for the US locations are designed to comply with ASHRAE Standard 90.1-1989 for each climate zone. Table 3.25 lists the 90.1-1989 opaque construction properties by location. For some ECMs, additional baseline insulation values were created to represent different construction practices. Table 3.26 lists a set of insulation values that represent construction practices around 1960, developed from a review of construction practices of office buildings by Briggs et al. (1987). Another practice that was common for pre-1970 construction was to construct walls with no insulation, which was used as a baseline for the wall insulation ECM. Table 3.27 lists window thermal properties for the US locations from Standard 90.1-1989. Tables 3.28 and 3.29 list the opaque construction and window thermal properties for the international locations, as defined by the Annex 46 members from these countries.

Table 3.24. Envelope construction layers.

Construction	Outer Layer	Layer 2	Inner Layer
Roof	Steel Cladding	¾ in (2 cm) Plywood	Insulation per Location
Exterior Wall	4 in (10 cm) Brick	Insulation per Location	½ in (1.3 cm) Gypsum Board
Slab	4 in (10 cm) Concrete	NA	Carpet

Table 3.25. US opaque construction thermal properties – Standard 90.1-1989.

City	Wall U-Value (Btu/hr·˚F·sq ft)	Roof U-Value (Btu/hr·˚F·sq ft)	Wall U-value ($W/m^2\cdot K$)	Roof U-value ($W/m^2\cdot K$)
Miami, FL	1.000	0.074	5.68	0.42
Houston, TX	0.340	0.066	1.93	0.37
Phoenix, AZ	0.410	0.046	2.33	0.26
Memphis, TN	0.190	0.057	1.08	0.32
El Paso, TX	0.300	0.058	1.70	0.33
San Francisco, CA	0.490	0.088	2.78	0.50
Baltimore, MD	0.120	0.058	0.68	0.33
Albuquerque, NM	0.190	0.059	1.08	0.34
Seattle, WA	0.100	0.064	0.57	0.36
Chicago, IL	0.100	0.053	0.57	0.30
Boise, ID	0.140	0.051	0.79	0.29
Burlington, VT	0.071	0.045	0.40	0.26
Helena, MT	0.079	0.049	0.45	0.28

City	Wall U-Value (Btu/hr·˚F·sq ft)	Roof U-Value (Btu/hr·˚F·sq ft)	Wall U-value ($W/m^2·K$)	Roof U-value ($W/m^2·K$)
Duluth, MN	0.061	0.040	0.35	0.23
Fairbanks, AK	0.047	0.031	0.27	0.18

Table 3.26. US Opaque construction thermal properties, 1960 construction.

City	Wall U-Value (Btu/hr·˚F·sq ft)	Roof U-Value (Btu/hr·˚F·sq ft)	Wall U-value ($W/m^2·K$)	Roof U-value ($W/m^2·K$)
Miami, FL	0.230	0.200	1.31	1.14
Houston, TX	0.230	0.200	1.31	1.14
Phoenix, AZ	0.230	0.200	1.31	1.14
Memphis, TN	0.224	0.115	1.27	0.65
El Paso, TX	0.230	0.200	1.31	1.14
San Francisco, CA	0.226	0.116	1.28	0.66
Baltimore, MD	0.196	0.102	1.27	0.58
Albuquerque, NM	0.199	0.105	1.13	0.59
Seattle, WA	0.193	0.101	1.10	0.57
Chicago, IL	0.180	0.088	1.02	0.50
Boise, ID	0.185	0.093	1.05	0.53
Burlington, VT	0.174	0.078	0.99	0.44
Helena, MT	0.175	0.078	0.99	0.45
Duluth, MN	0.167	0.076	0.95	0.43
Fairbanks, AK	0.160	0.076	0.91	0.43

Table 3.27. US window thermal properties.

City	Window U-Value (Btu/hr·˚F·sq ft)	Window U-Value ($W/m^2·K$)	Window SHGC
Miami, FL	1.08	6.14	0.61
Houston, TX	1.08	6.14	0.61
Phoenix, AZ	1.08	6.14	0.61
Memphis, TN	0.56	3.19	0.63
El Paso, TX	1.08	6.14	0.61
San Francisco, CA	0.56	3.19	0.63
Baltimore, MD	0.56	3.19	0.63
Albuquerque, NM	0.56	3.19	0.63
Seattle, WA	0.56	3.19	0.63
Chicago, IL	0.56	3.19	0.63
Boise, ID	0.56	3.19	0.63
Burlington, VT	0.49	2.77	0.61
Helena, MT	0.49	2.77	0.61
Duluth, MN	0.49	2.77	0.61
Fairbanks, AK	0.49	2.77	0.61

Table 3.28. International opaque construction thermal properties.

City	Wall U-Value (Btu/hr·°F·sq ft)	Roof U-Value (Btu/hr·°F·sq ft)	Wall U-value ($W/m^2·K$)	Roof U-value ($W/m^2·K$)
Edmonton, CAN	0.109	0.069	0.62	0.39
Ottawa, CAN	0.049	0.032	0.28	0.18
Vancouver, CAN	0.065	0.042	0.37	0.24
Copenhagen, DNK	0.072	0.039	0.41	0.22
Helsinki, FIN	0.083	0.594	0.47	3.37
Tampere, FIN	0.083	0.594	0.47	3.37
Lyon, FRA	0.081	0.085	0.46	0.48
Marseille, FRA	0.081	0.085	0.46	0.48
Nantes, FRA	0.081	0.085	0.46	0.48
Paris, FRA	0.081	0.085	0.46	0.48
Stuttgart, DEU	0.321	0.704	1.82	4.00
Milan, ITA	0.085	0.092	0.48	0.52
Naples, ITA	0.085	0.092	0.48	0.52
Palermo, ITA	0.085	0.092	0.48	0.52
Rome, ITA	0.085	0.092	0.48	0.52
London, UK	0.321	0.704	1.82	4.00

Table 3.29. International window thermal properties.

City	Window U-Value (Btu/hr·°F·sq ft)	Window U-Value ($W/m^2·K$)	Window SHGC
Edmonton, CAN	0.56	3.19	0.627
Ottawa, CAN	0.49	2.77	0.610
Vancouver, CAN	0.49	2.77	0.610
Copenhagen, DNK	0.51	2.90	0.281
Helsinki, FIN	0.36	2.02	0.226
Tampere, FIN	0.36	2.02	0.226
Lyon, FRA	0.49	2.78	0.763
Marseille, FRA	0.49	2.78	0.763
Nantes, FRA	0.49	2.78	0.763
Paris, FRA	0.49	2.78	0.763
Stuttgart, DEU	0.51	2.90	0.281
Milan, ITA	0.49	2.78	0.763
Naples, ITA	0.49	2.78	0.763
Palermo, ITA	0.49	2.78	0.763
Rome, ITA	0.49	2.78	0.763
London, UK	0.51	2.90	0.281

3.4.2 Airtightness and infiltration

Infiltration is an especially difficult parameter to obtain good data on because the governing physics are complicated by many factors, including the operation of the building and outdoor environmental conditions. Instead of attempting to model the governing physics of infiltration, a simplified model was used. However, even in the simple model, many assumptions about the level of infiltration and how it was affected by the operation of the mechanical ventilation systems were made.

For the administrative building, it was assumed that the building leakage rate was equal to 1.0 cfm/sq ft of envelope (exterior walls and roof) at 75 Pa pressure difference across the building envelope. However, several assumptions and calculations were required in order to go from a leakage rate to the simple infiltration model used in the building energy simulation. First, a lower pressure of 0.016 in w.g. (4 Pa) was assumed to be the average pressure difference across the building envelope without the pressurization or depressurization of the building from the HVAC and exhaust fans. The infiltration leakage rate was recalculated, assuming a flow exponent (n) of 0.65 according to Equation 4-1 and the total building infiltration was found by multiplying this flow rate by the total shell area (Equation 4-2).

$$Flow\ Rate_2 = Flow\ Rate_1 \times \left(\frac{Pressure_2}{Pressure_1}\right)^n \qquad 3\text{-}4$$

where:

Flow Rate2	=	OA infiltration flow rate per shell area at Pressure2
Flow Rate1	=	OA infiltration flow rate per shell area at Pressure1
Pressure2	=	pressure at which the updated flow rate is desired
Pressure1	=	reference pressure
n	=	flow exponent

$$Infiltration_{Building} = Flow\ Rate \times Shell\ Area_{Building} \qquad 3\text{-}5$$

where:

InfiltrationBuilding	=	total building infiltration
Flow Rate	=	OA infiltration flow rate per shell area
Shell AreaBuilding	=	area of the building shell (exterior walls and roof)

Individual zone infiltration rates are assumed to be proportional to the floor area of that zone compared to the total conditioned floor area and were calculated using Equation 4-3. Table 3.30 lists the resulting zone level infiltration rates in terms of ACH.

$$Infiltration_{Zone} = Infiltration_{Building} \times \frac{Floor\ Area_{Zone}}{Floor\ Area_{Building}} \qquad 3\text{-}6$$

where:

InfiltrationZone	=	zone infiltration rate
InfiltrationBuilding	=	building infiltration rate
Floor AreaZone	=	zone floor area
Floor AreaBuilding	=	building floor area

Infiltration is often assumed to go to zero when buildings are pressurized in energy models. This assumption is made because there is a lack of evidence about what really happens and lack of knowledge of how to model it in an energy simulation. As such, it is assumed that the uncontrolled infiltration is reduced to zero when the building ventilation system is running. When the ventilation system is off (no outside air), the infiltration is modeled at the full leakage rate calculated at 4 Pa. Infiltration is modeled at constant ACH and is assumed to reasonably model the average effect of infiltration over the course of the year. This is a gross assumption, but one that is necessary without moving to more complicated flow network simulations.

Table 3.30. Zone infiltration.

Zone	Air Change Rate (ACH)
FLR_1_SEC_1	0.63
FLR_2_SEC_1	0.63
FLR_3_SEC_1	0.63
FLR_1_SEC_2	0.63
FLR_2_SEC_2	0.63
FLR_3_SEC_2	0.63
FLR_1_SEC_3	0.63
FLR_2_SEC_3	0.63
FLR_3_SEC_3	0.63
FLR_1_SEC_4	0.63
FLR_2_SEC_4	0.63
FLR_3_SEC_4	0.63
FLR_1_SEC_5	0.63
FLR_2_SEC_5	0.63
FLR_3_SEC_5	0.63

3.4.3 Internal loads

Table 3.31 lists the peak zone internal loads, which are controlled by schedules found in Appendix D. This occupancy density was assumed to represent typical office operations. The lighting power density was taken from Standard 90.1-1989 and the electric equipment power density was set from Standard 90.1-1989 for typical office loads.

Table 3.31. Summary of zone internal loads.

Zone	Max Occupants		Lighting Power Density		Electric Equipment Power Density	
	(ft^2/Person)	(m^2/Person)	(W/ft^2)	(W/m^2)	(W/ft^2)	(W/m^2)
FLR_1_SEC_1	229	21	1.8	19.4	0.75	8.1
FLR_2_SEC_1	229	21	1.8	19.4	0.75	8.1
FLR_3_SEC_1	229	21	1.8	19.4	0.75	8.1
FLR_1_SEC_2	229	21	1.8	19.4	0.75	8.1
FLR_2_SEC_2	229	21	1.8	19.4	0.75	8.1
FLR_3_SEC_2	229	21	1.8	19.4	0.75	8.1
FLR_1_SEC_3	229	21	1.8	19.4	0.75	8.1
FLR_2_SEC_3	229	21	1.8	19.4	0.75	8.1
FLR_3_SEC_3	229	21	1.8	19.4	0.75	8.1
FLR_1_SEC_4	229	21	1.8	19.4	0.75	8.1
FLR_2_SEC_4	229	21	1.8	19.4	0.75	8.1
FLR_3_SEC_4	229	21	1.8	19.4	0.75	8.1
FLR_1_SEC_5	229	21	1.8	19.4	0.75	8.1
FLR_2_SEC_5	229	21	1.8	19.4	0.75	8.1
FLR_3_SEC_5	229	21	1.8	19.4	0.75	8.1

3.4.4 HVAC

The baseline HVAC system consists of four VAV systems with electric reheat, one serving each floor of the building. Terminal units with reheat control the supply air to each zone. A central chiller (4.5 COP) and natural gas boiler (0.8 Et) provide chilled and hot water to the air systems. The system fans are VAV fans with total efficiencies of 0.5. The pressure rise across each fan is 750 Pa. The maximum flow rate for each fan varies. This value is allowed to autosize within the simulation as the flow rate required to meet the load on the system is location dependent. The international buildings were modeled with packaged single zone systems with gas heating and DX cooling.

3.4.5 Ventilation and outside air

Required minimum outdoor flow rates of 0.06 cfm/sq ft plus 20.0 cfm/person were specified for each zone. All HVAC systems were equipped with differential dry bulb controlled economizers with a maximum dry bulb temperature limit of 82°F (28°C) and no lockout.

3.4.6 Analyzed energy conservation measures

Table 3.32 lists ECMs simulated for office/administrative building. Chapter 4 includes simulation results and Chapter 5 gives a detailed analysis of some of the technologies.

Table 3.32. Energy conservation measure overview.

Energy Conservation Measure	Description
Increased Wall Insulation	Increase the amount of insulation in the exterior walls
Increased Roof Insulation	Increase the amount of insulation in the roof
Attic Insulation	Add insulation to the attic (ceiling) surface and remove it from the roof surface
Cool Roofs	Increase the albedo of the roof surfaces
Building Airtightness	Decrease the assumed amount of infiltration into the building
Advanced Windows	Replace baseline windows with more efficient models
Overhangs	Installation of horizontal shading devices over the south-facing windows to block direct solar gains
Exterior Vertical Fins	Installation of vertical fins on the outside of the building near windows to prevent direct sunlight penetration during the early morning and/or late evening
Energy Recovery Ventilators	Use heat exchangers to sensibly temper outdoor air with exhaust air (no mixing of air streams)
Indirect Evaporative Cooling	Use direct evaporation to cool an air stream. That air stream is then used to sensibly cool, via a heat exchanger, the supply-air stream (no mixing of air streams)
Hybrid Evaporative Cooling	Cool the supply-air stream by using an indirectly evaporatively cooled air stream as the inlet to a direct evaporation process
DOAS with Fan-Coil Units	Uses two separate systems: one to supply and condition outdoor air (this system handles the latent loads as well) and one to meet the thermal loads (sensible only) of the space

Energy Conservation Measure	Description
DOAS with Radiant Heating and Cooling	Circulates warm or cool liquid through pipes embedded in the floor and/or ceiling to radiantly condition a space. Paired with a DOAS that delivers the required volume of outdoor air
Ground Source Heat Pumps	Use of the ground as the heat source/sink in a direct expansion loop. The fluid from this loop is passed through the HVAC system heating and cooling coils as needed
Reheat Using Condenser Waste Heat	Condenser waste heat from the chiller is used to heat the water that is passed through the VAV reheat terminal boxes

4 Energy Conservation Measures

4.1 Introduction

This chapter provides results of an initial screening of 17 technologies for an energy retrofit of a barracks (section 4.1) and 15 technologies for an energy retrofit of a administrative/office buildings (section 4.2) in 15 US, 3 Canadian, and 13 European climate zones. The results for barracks buildign could also apply to similar buildings such as dormitories, apartment buildings, or highway lodging. The energy savings were determined relative to an assumed baseline building, which may or may not be representative of a particular building under consideration for retrofits. Therefore, the results should not be taken as absolute answers, but rather as relative performance and indications of trends that can be used to help a facility manager or engineer determine which technologies to focus on for their project. Additional analyses should be completed to determine the best ECMs and expected performance for particular projects.

The energy and energy cost savings for each of the 17 ECMs in this report were calculated with annual hourly whole building energy simulations. Ideally, a payback analysis or ROI would be determined for each ECM and used to rank the best use of energy efficiency investment funds. However, retrofit ECM costs are very specific to individual projects and difficult to determine for several ECMs and locations as presented in this report. The energy cost savings for each ECM are reported and can be used with estimated ECM costs to determine simple payback times. Simple payback analyses were performed for advanced windows because we were able to determine the incremental costs of advanced windows over a standard window retrofit as an example of how this might be completed.

Modeling results presented in thic chapter show that there is wide range in energy savings for ECMs. Some of the results are very dependent on location and others are not. Some of the savings for the barracks are much higher than for other building types like offices because of the 24 hour occupancy and the need for continuous ventilation air and space conditioning.

For heating climates, the highest energy savings were achieved by ECMs that reduced the heating loads through reducing the envelope thermal conduction, reducing outside air into the building, and energy recovery. Reducing infiltration had a significant impact and combining insulation with improved airtightness provided very strong energy savings in cold climates. Energy recovery on the HVAC system was also a significant energy-saving ECM in the cold climates.

For cooling dominated climates, reductions in solar gains and outside air had the largest energy savings. Improvements in the efficiency of the delivery of the cooling to building also showed significant energy savings. Adding wall and roof insulation also provided significant energy savings in the warm climates because the older energy codes required zero or very little insulation in these locations.

Other ECMs that are known to have significant energy savings such as lighting retrofits and plug load control were not part of the scope of this project are not included in this Chapter and are adressed in Chapter 5.

Many ECMs have very long payback periods when evaluated solely based on the installation costs and energy savings; however, they may have other benefits that should also be considered when designing a retrofit program. For example, advanced windows can improve indoor comfort and productivity by reducing hot and cold radiant effects, reducing infiltration, and reducing glare. In addition, many retrofits are conducted for other reasons than energy savings, such as replacement of non-operating equipment. In these cases, energy efficiency should be considered and evaluated based on the incremental costs and performance improvements over the baseline or standard retrofit case. Finally, combinations of ECMs should be considered for the highest savings. Many ECMs can produce higher savings when considered together with other ECMs. For example, the best performing HVAC system in this report combined a DOAS with an Energy recovery ventilator (ERV) and radiant heating and cooling. These three HVAC technologies work very well together for barracks buildings in all climates. Further improvements could be achieved with a whole building integrated retrofit. Improving the envelope performance with increased insulation, improved airtightness, and improved windows can lead to downsizing and possibly a complete redesign of the HVAC system for multiplied energy savings.

4.2 ECMs

A list of the ECMs that were investigated can be found in Table 4.1 below. For a more detailed description of what was modeled for each ECM and specific parameter values, see Appendix A. Graphical results from the simulations showing the percent energy use reduction and cost savings per area over the baseline model are presented in the following sections.

Table 4.1. Energy conservation measure overview.

Energy Conservation Measure	Description
Increased Wall Insulation	Increase the amount of insulation in the exterior walls
Increased Roof Insulation	Increase the amount of insulation in the roof
Attic Insulation	Add insulation to the attic (ceiling) surface and remove it from the roof surface
Cool Roofs	Increase the albedo of the roof surfaces
Building Airtightness	Decrease the assumed amount of infiltration into the building
Advanced Windows	Replace baseline windows with more efficient models
External Roller Shades	Add roller shades to the outside of windows to prevent solar heat gains to the space during cooling and heat loss from the space during heating
Overhangs	Installation of horizontal shading devices over the south-facing windows to block direct solar gains
Exterior Vertical Fins	Installation of vertical fins on the outside of the building near windows to prevent direct sunlight penetration during the early morning and/or late evening
ERVs	Use heat exchangers to sensibly temper outdoor air with exhaust air (no mixing of air streams)
Indirect Evaporative Cooling	Use direct evaporation to cool an air stream. That air stream is then used to sensibly cool, via a heat exchanger, the supply-air stream (no mixing of air streams)
Hybrid Evaporative Cooling	Cool the supply-air stream by using an indirectly evaporatively cooled air stream as the inlet to a direct evaporation process

Energy Conservation Measure	Description
DOAS with Fan-Coil Units	Uses two separate systems: one to supply and condition outdoor air (this system handles the latent loads as well) and one to meet the thermal loads (sensible only) of the space
DOAS with Radiant Heating and Cooling	Circulates warm or cool liquid through pipes embedded in the floor and/or ceiling to radiantly condition a space. Paired with a DOAS that delivers the required volume of outdoor air
Ground Source Heat Pumps	Use of the ground as the heat source/sink in a direct expansion loop. The fluid from this loop is passed through the HVAC system heating and cooling coils as needed
Reheat Using Condenser Waste Heat	Condenser waste heat from the chiller is used to heat the water that is passed through the heating coil
Grey Water Heat Recovery	Extract heat from grey water to preheat incoming mains water to be used for DHW

4.3 Barracks

4.3.1 Increased wall insulation

This section presents the effects of retrofitting the exterior walls with additional insulation. Insulation with an R-value of 3.85 sq ft·h·°F/Btu per inch (0.347 m^2·K/W per cm) was added in increments of 1, 2, 4, 6, and 8 in (2.5, 5, 10, 15, and 20 cm). For this study an additional baseline building was created with zero insulation in the walls. In addition, it was assumed that adding wall insulation would improve the airtightness from the baseline by 15%. One set of cases were run with the added insulation over the 901.1989 baseline and no change in the infiltration.

Table 4.2. Insulation ECM overview.

Wall Construction	Additional Insulation (sq ft·hr·°F/Btu)	Air Leakage	
		(cfm/sq ft @ 0.3 in w.g.)	(L/s/m^2 @ 75 Pa)
Baseline (90.1-1989 insulation)	—	1.00	5.1
No insulation	—	1.00	5.1
1989 Baseline with 1 in (2.5 cm) insulation	R-3.85	1.00	5.1
1989 Baseline with 2 in (5 cm) insulation	R-7.7	1.00	5.1
1989 Baseline with 4 in (10 cm) insulation	R-15.4	1.00	5.1
1989 Baseline with 6 in (15 cm) insulation	R-23.1	1.00	5.1
1989 Baseline with 8 in (20 cm) insulation	R-30.8	1.00	5.1
1989 Baseline with 1 in (2.5 cm) insulation	R-3.85	0.85	4.3
1989 Baseline with 2 in (5 cm) insulation	R-7.7	0.85	4.3
1989 Baseline with 4 in (10 cm) insulation	R-15.4	0.85	4.3
1989 Baseline with 6 in (15 cm) insulation	R-23.1	0.85	4.3
1989 Baseline with 8 in (20 cm) insulation	R-30.8	0.85	4.3
Zero Baseline with 1 in (2.5 cm) insulation	R-3.85	0.85	4.3
Zero Baseline with 2 in (5 cm) insulation	R-7.7	0.85	4.3
Zero Baseline with 4 in (10 cm) insulation	R-15.4	0.85	4.3
Zero Baseline with 6 in (15 cm) insulation	R-23.1	0.85	4.3
Zero Baseline with 8 in (20 cm) insulation	R-30.8	0.85	4.3

The results of the simulations are shown in Figures 4.1 through 4.14. The percent energy savings and the area normalized energy and energy cost savings are shown for all locations and compared to the standard baseline insulation case and the no-insulation case. Most of the energy savings is achieved with the first one inch (2.5 cm) of insulation; however, significant savings are achieved with additional insulation. The overall energy savings for the US locations above the 90.1-1989 baseline ranges from 7% to 20%, and the overall energy savings above the no-insulation baseline varies from 10% to 30%. For the international locations, the overall energy savings compared to the no-insulation baseline varies between 1% and 25%. Insulation in the Italy locations showed very little energy savings.

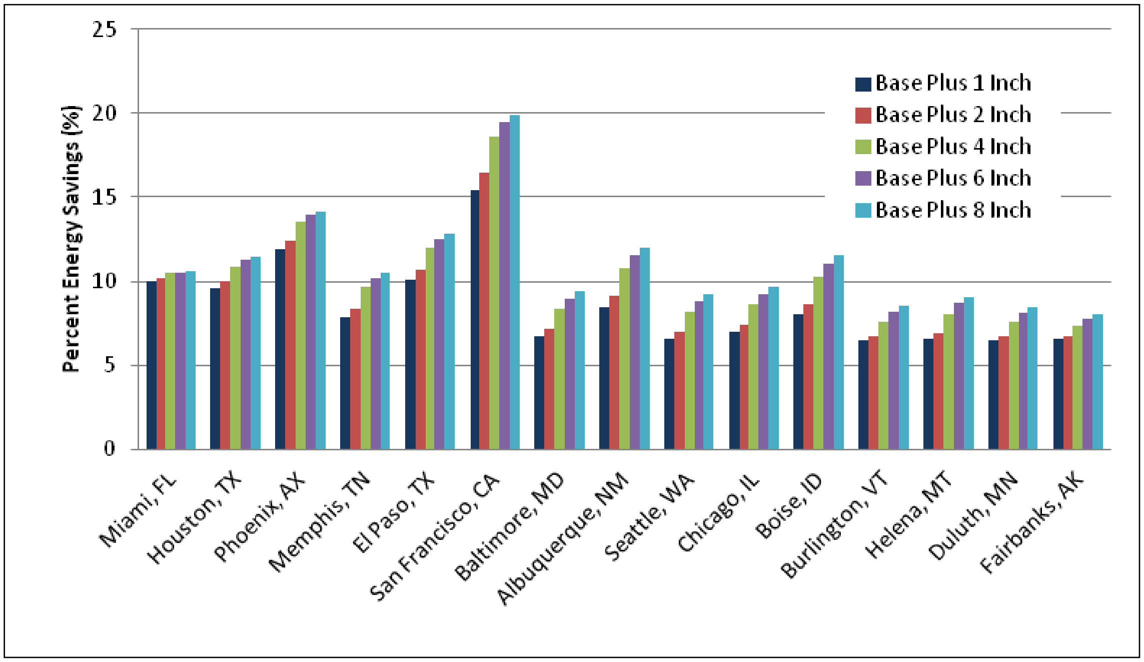

Figure 4.1. Percent energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

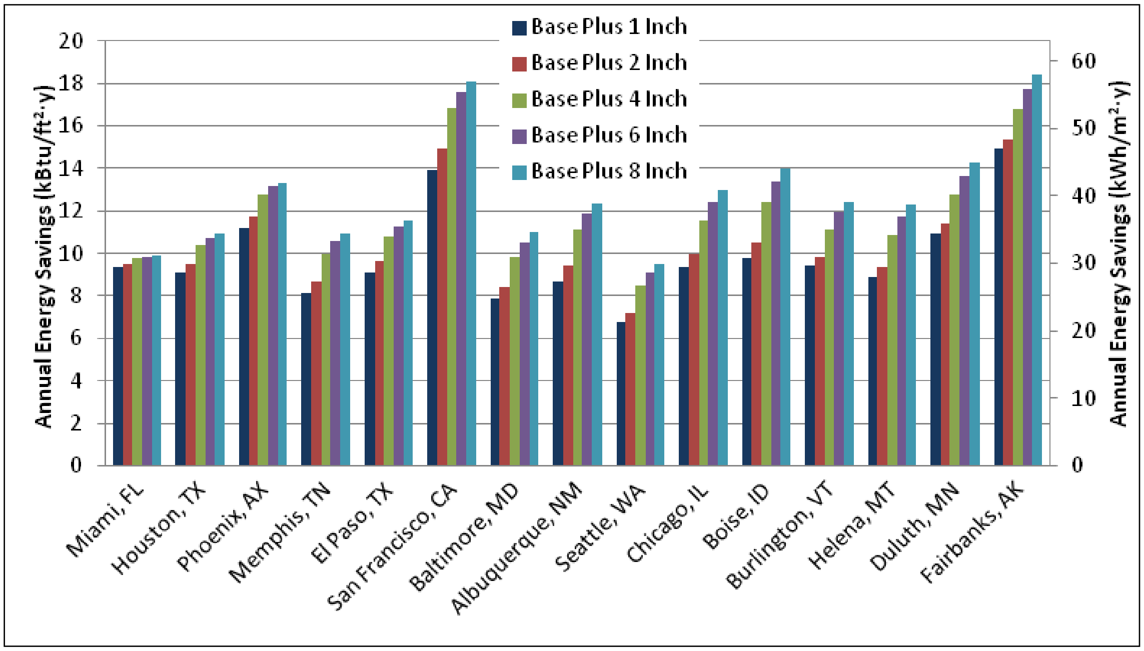

Figure 4.2. Energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

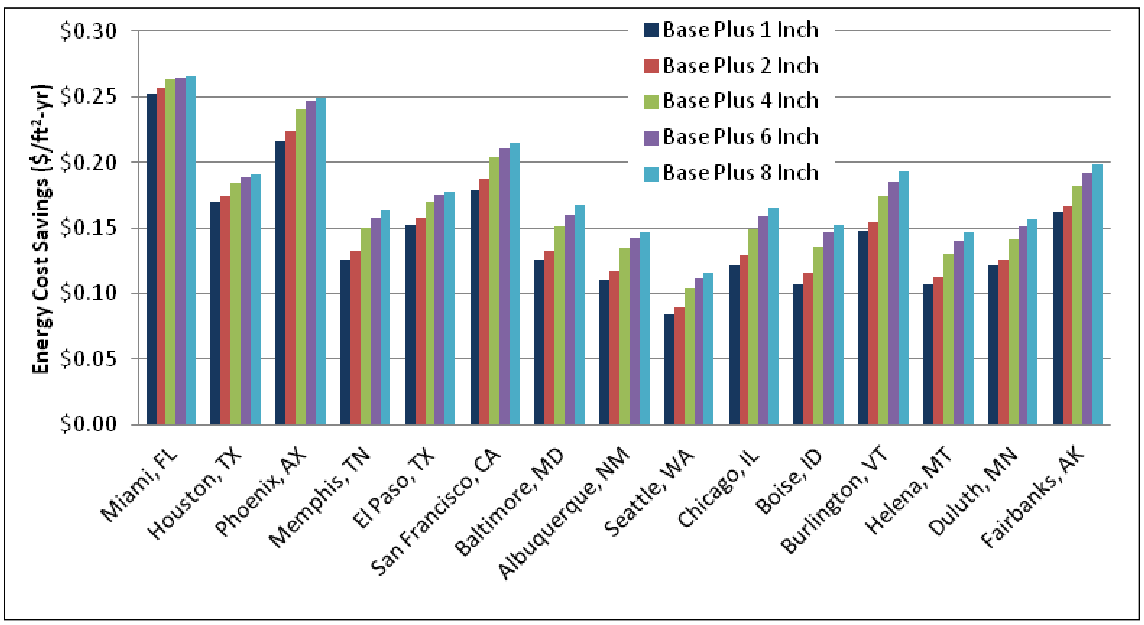

Figure 4.3. Energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

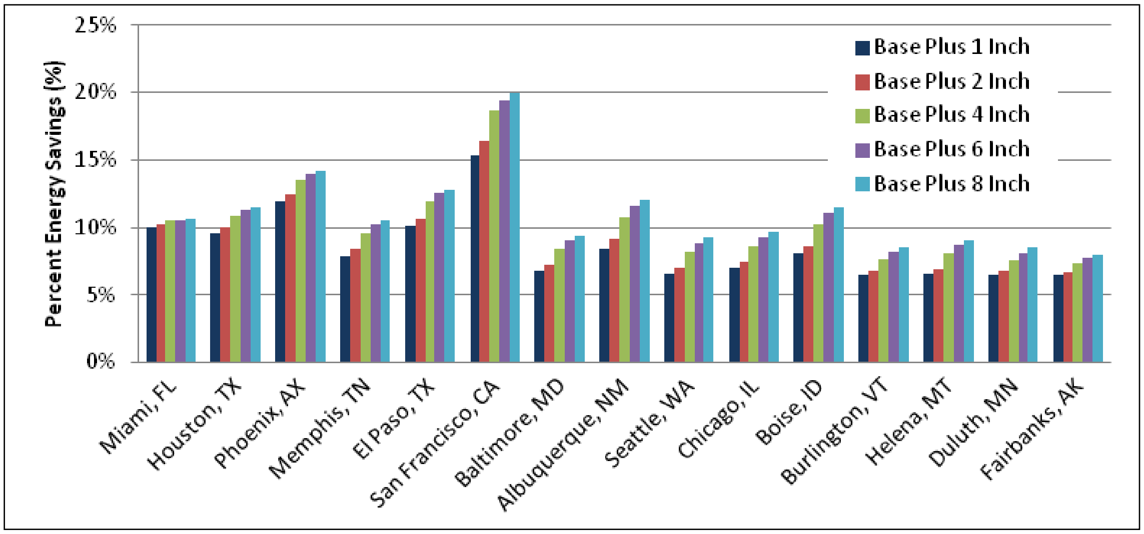

Figure 4.4. Percent energy savings for wall insulation and reduced infiltration over the no-insulation baseline.

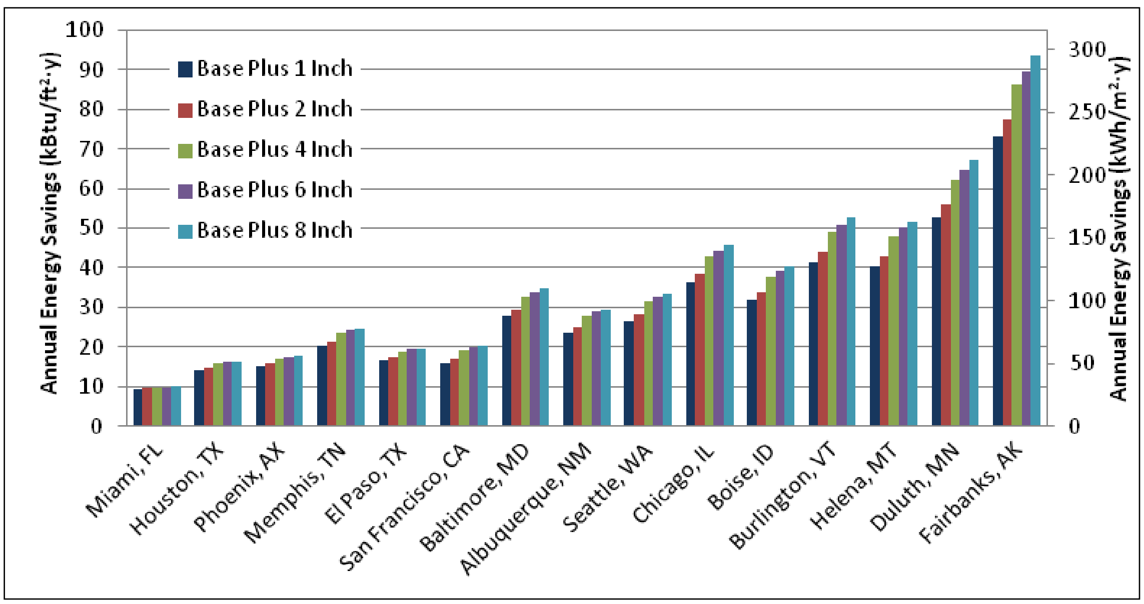

Figure 4.5. Energy savings for wall insulation and reduced infiltration over the no-insulation baseline.

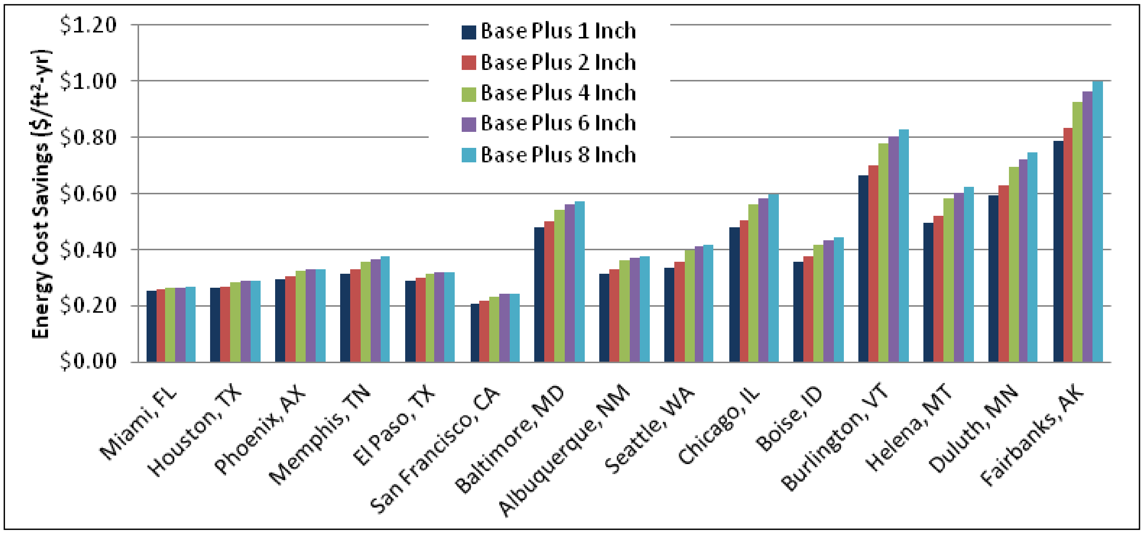

Figure 4.6. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline.

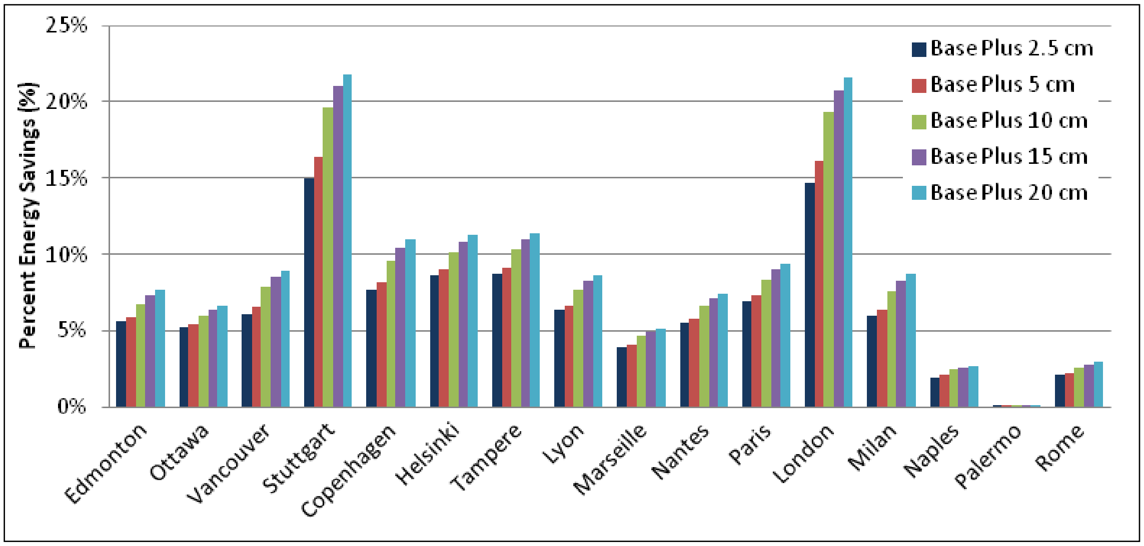

Figure 4.7. Percent energy savings for wall insulation and reduced infiltration over the Standard 90.1-1989 baseline - international locations.

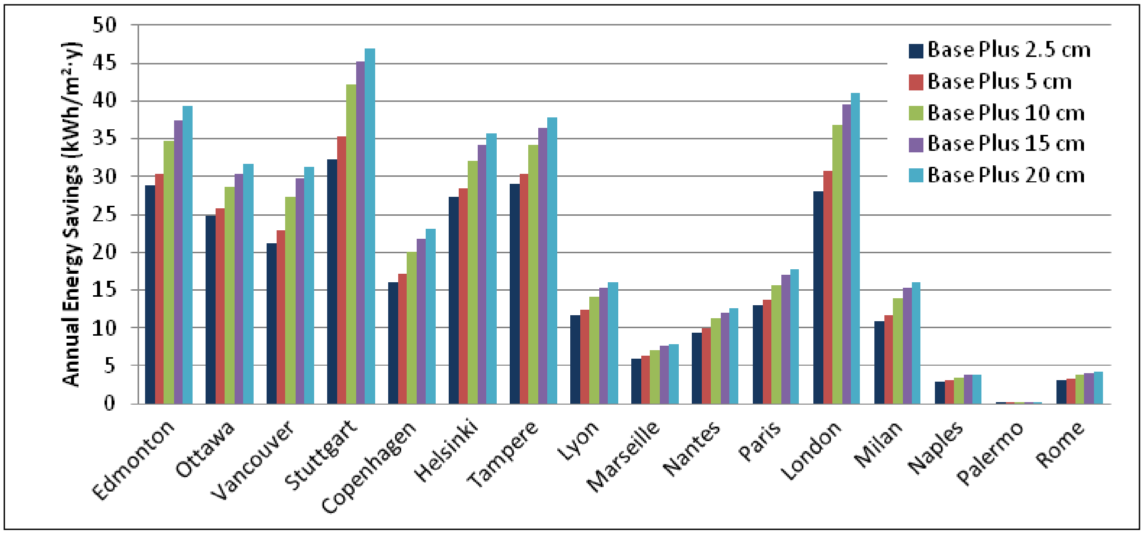

Figure 4.8. Energy savings for wall insulation and reduced infiltration over the Standard 90.1-1989 baseline - international locations.

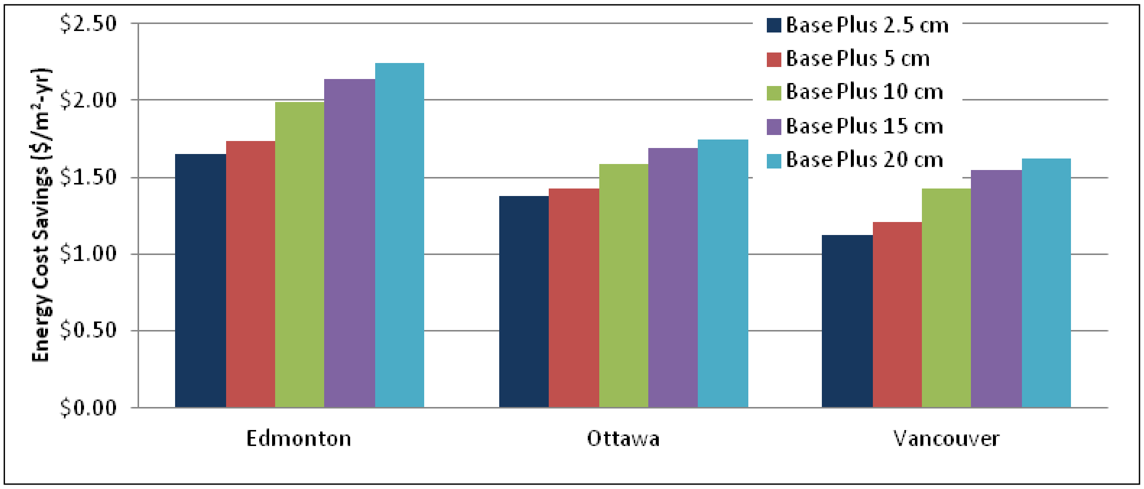

Figure 4.9. Energy cost savings for wall insulation and reduced infiltration over the Standard 90.1-1989 baseline - Canadian locations.

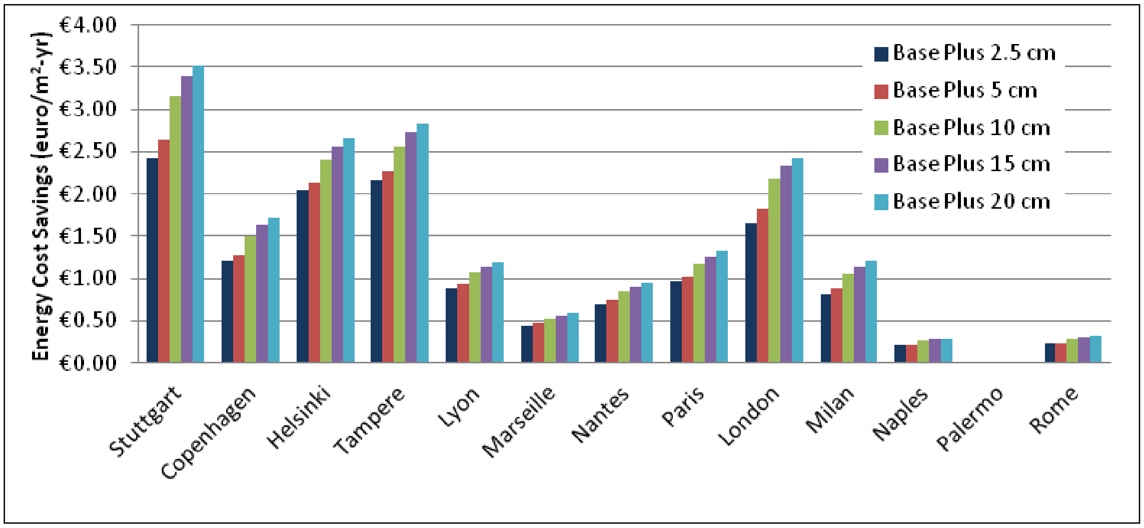

Figure 4.10. Energy cost savings for wall insulation and reduced infiltration over the Standard 90.1-1989 baseline - European locations.

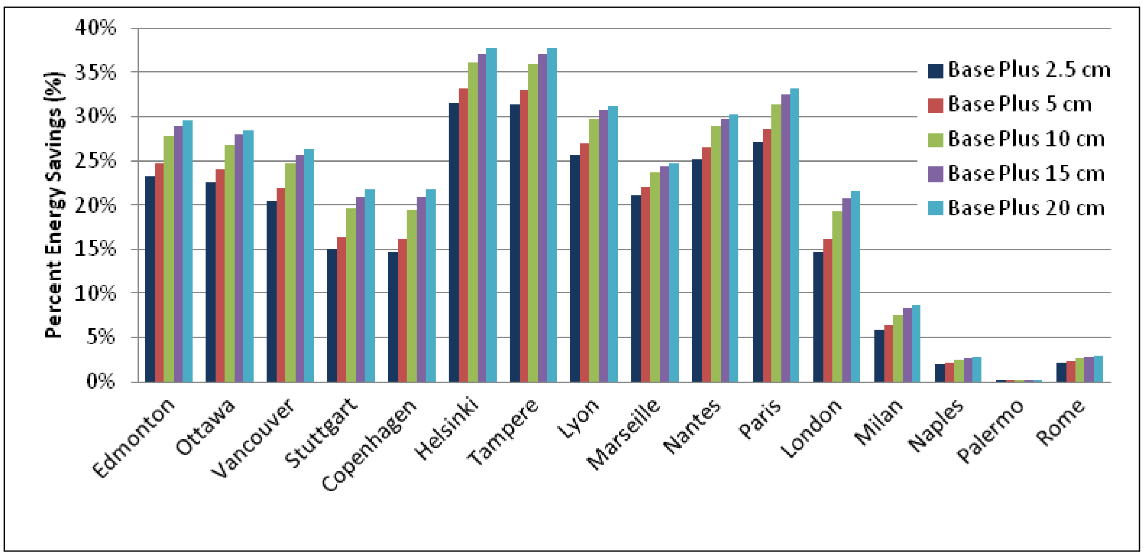

Figure 4.11. Percent energy savings for wall insulation and reduced infiltration over the no-insulation baseline- international locations.

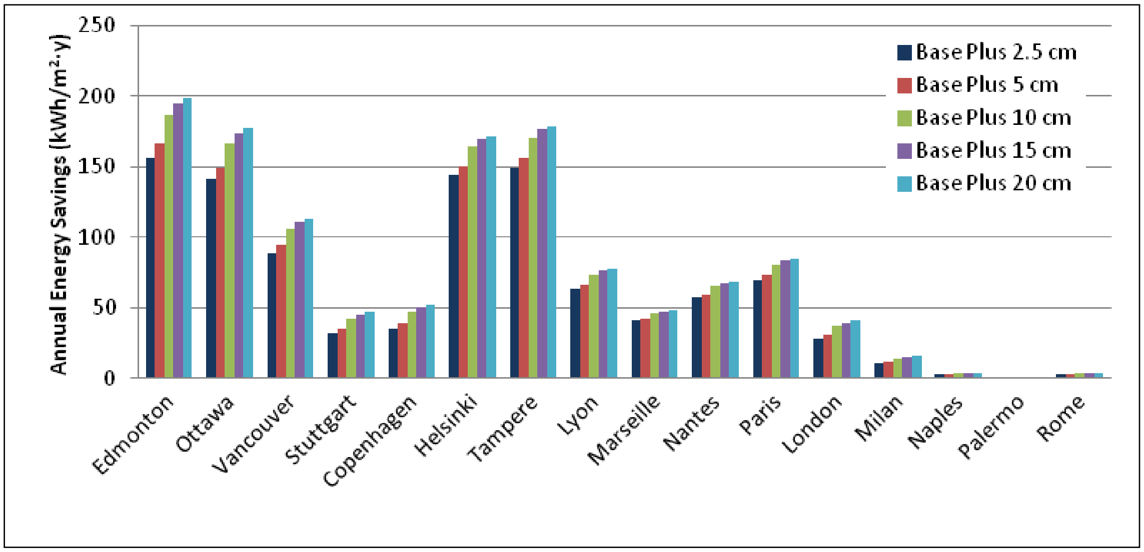

Figure 4.12. Energy savings for wall insulation and reduced infiltration over the no-insulation baseline- international locations.

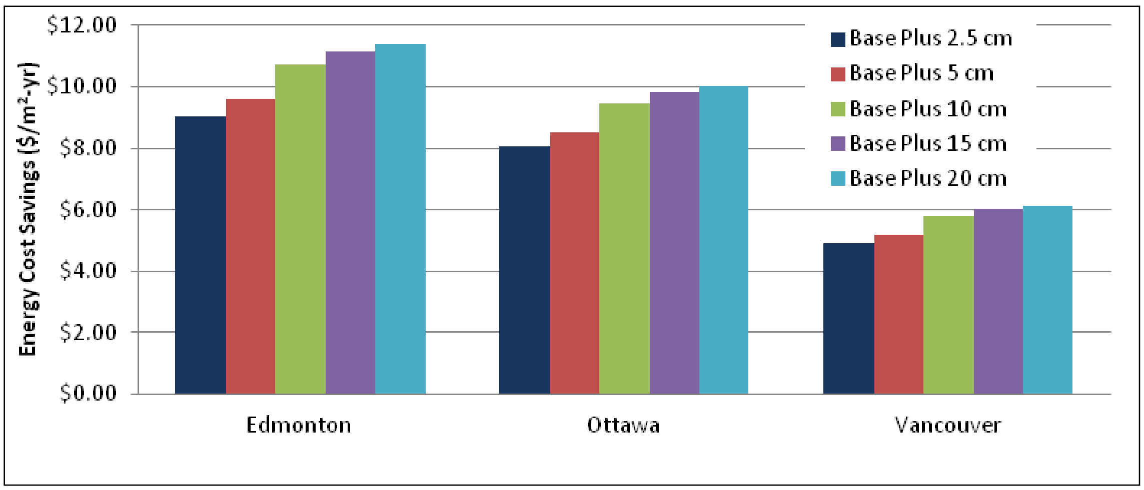

Figure 4.13. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline- Canadian locations.

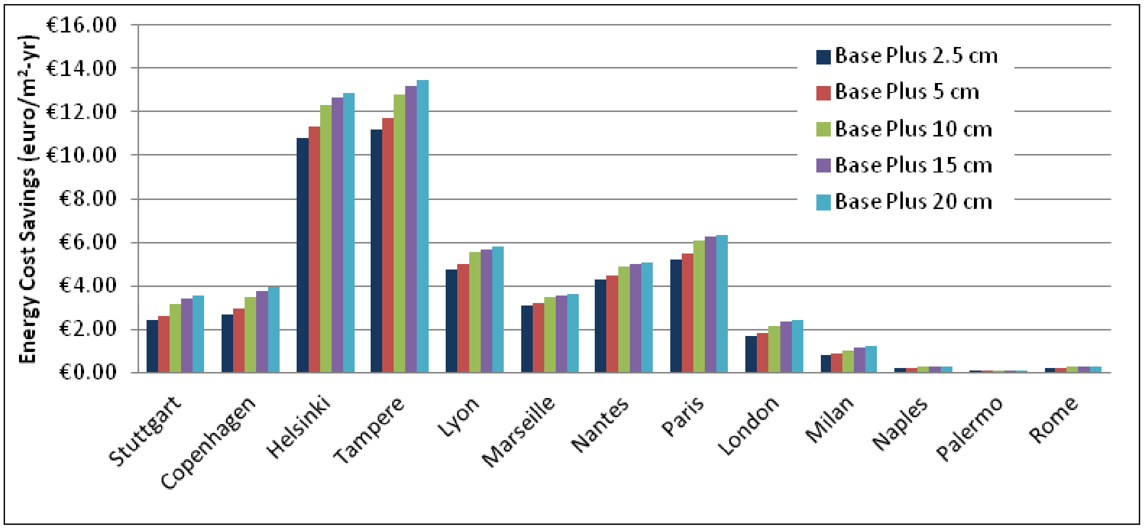

Figure 4.14. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline- European locations.

4.3.2 Increased roof insulation

The baseline building has insulation at the attic floor level. This section presents the results of replacing this insulation with insulation at the roof level. A second baseline building was created with attic insulation representative of buildings built around 1960. The 1960 insulation values were estimated from a report by Briggs et al. (1987), who estimated envelope thermal properties by construction year for office buildings.

Table 4.3. Insulation ECM overview.

Case	Baseline	Added Roof Insulation (R-value)	Building Air Leakage cfm/sq ft @ 0.3 in w.g. (L/s·m^2 @ 75 Pa)	Attic Infiltration Rate (ACH)
Baseline 000	1989	-	1.00 (5.08)	1.0
Baseline 100	1960	-	1.00 (5.08)	1.0
Roof 001	000	10	1.00 (5.08)	0.25
Roof 002	000	20	1.00 (5.08)	0.25
Roof 002	000	30	1.00 (5.08)	0.25
Roof 004	000	40	1.00 (5.08)	0.25
Roof 004	000	50	1.00 (5.08)	0.25
Roof 001.2	000	10	0.85 (4.32)	0.25
Roof 002.2	000	20	0.85 (4.32)	0.25
Roof 003.2	000	30	0.85 (4.32)	0.25
Roof 004.2	000	40	0.85 (4.32)	0.25
Roof 005.2	000	50	0.85 (4.32)	0.25

The results for the roof insulation cases are shown in Figure 4.15 through Figure 4.21. The savings for the US locations vary from near zero in Miami to over 6% in Duluth; however, there is almost no change in saving with increasing insulation levels. The results for the international locations show less than 1% savings in all locations except Stuttgart, Helsinki, Tampere, and London. These locations show energy savings between 4% and 7%. Some of the locations show negative savings due to increased cooling energy.

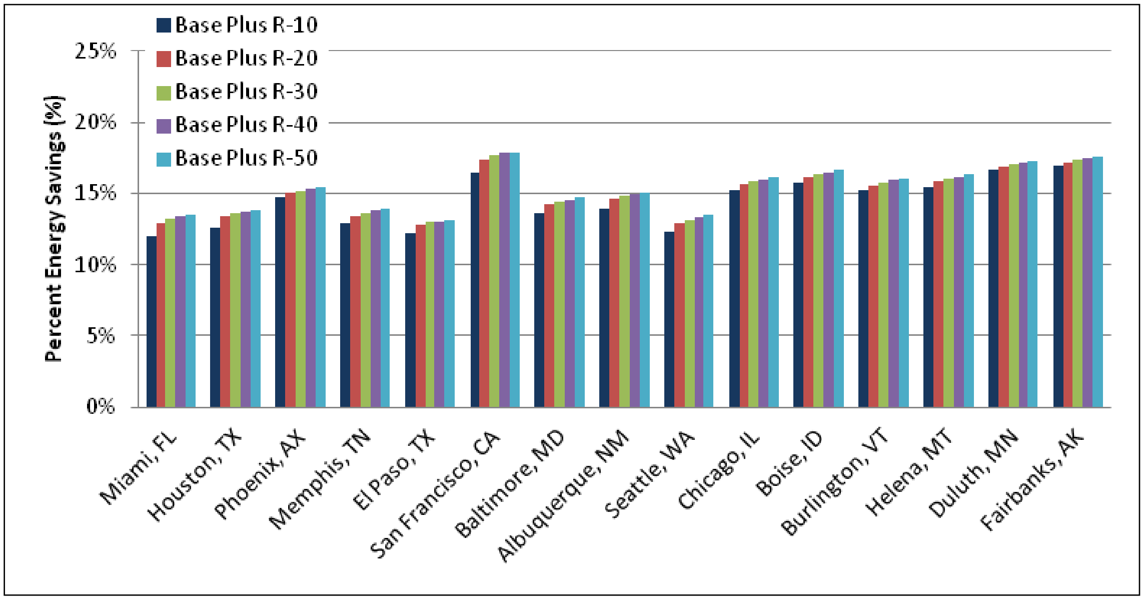

Figure 4.15. Percent energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline.

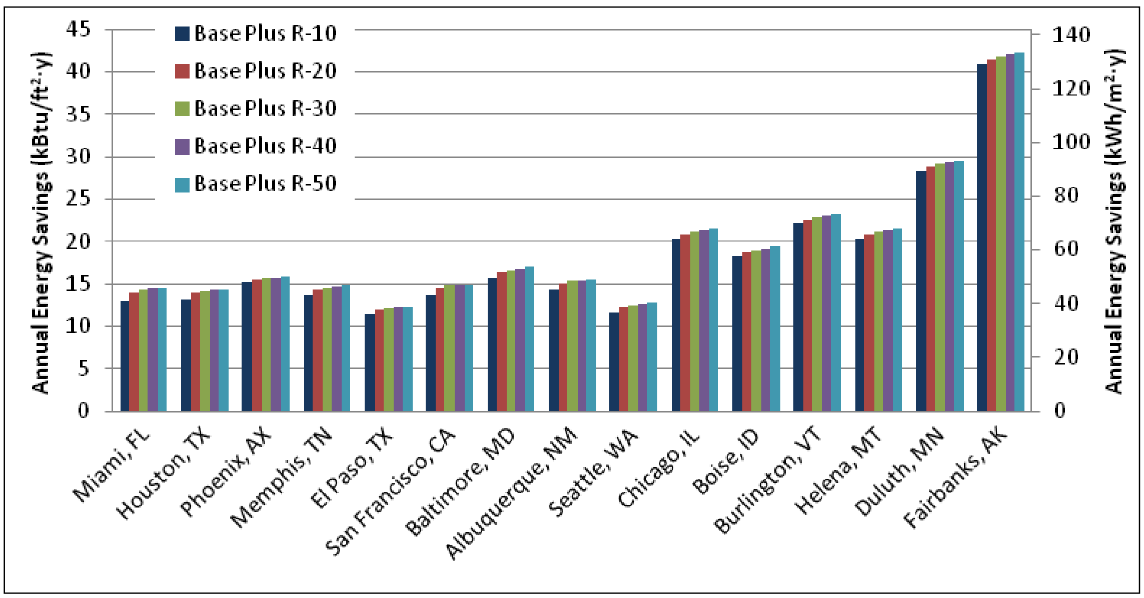

Figure 4.16. Energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline.

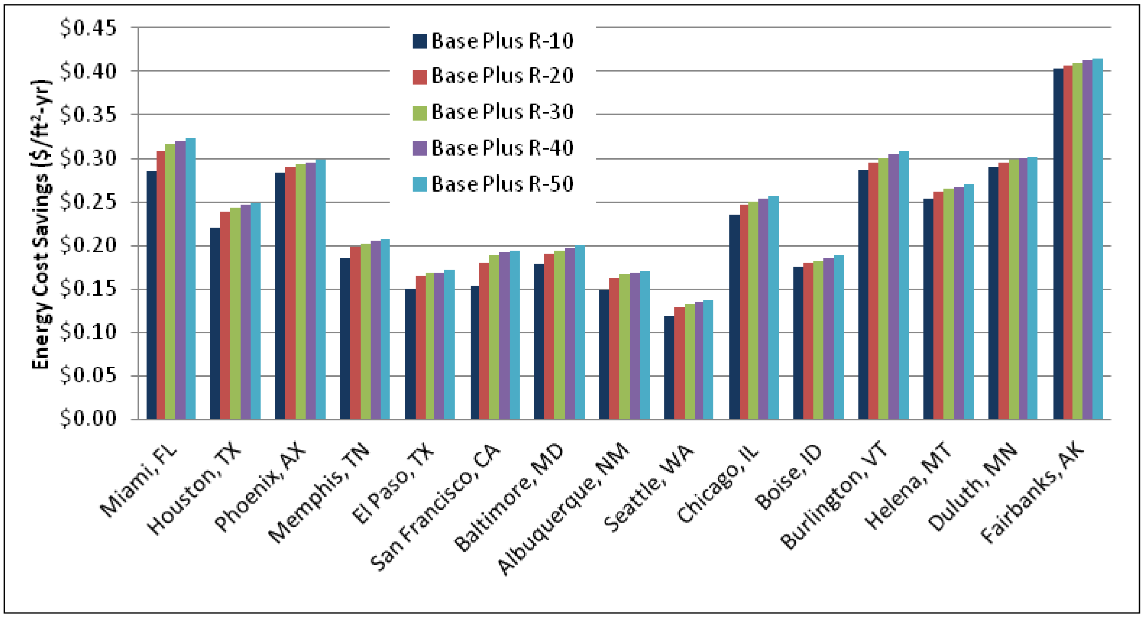

Figure 4.17. Energy cost savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline.

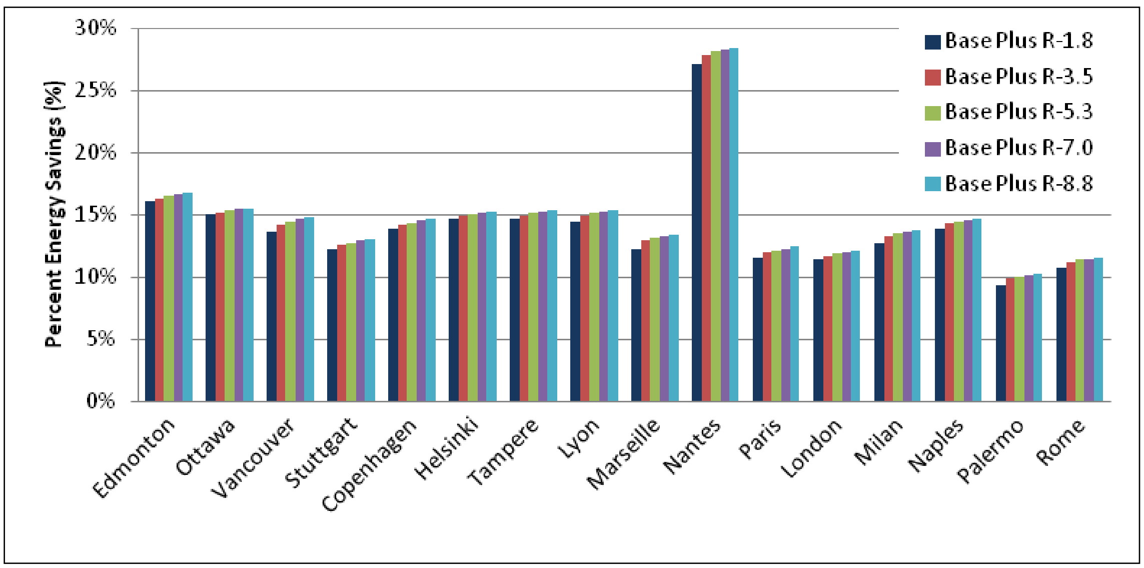

Figure 4.18. Percent energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline – international locations.

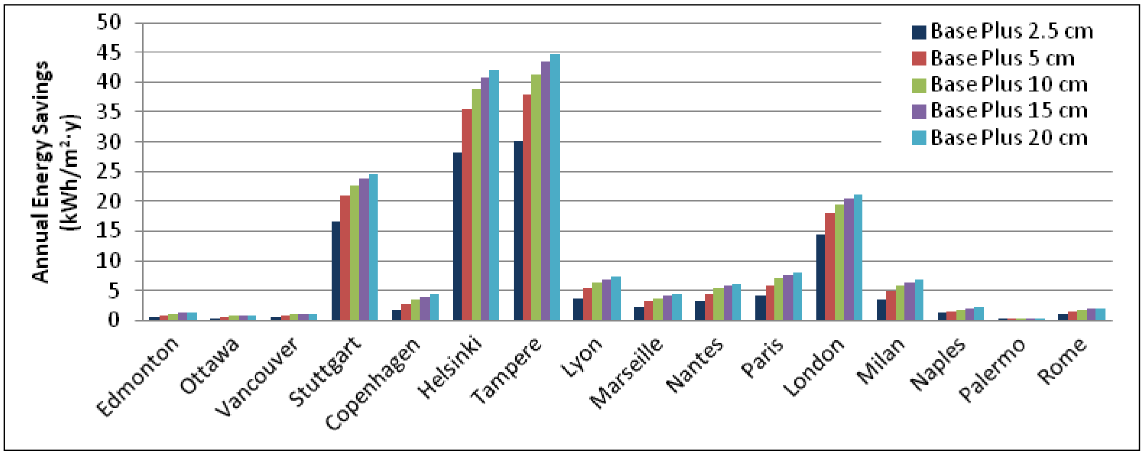

Figure 4.19. Energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline – international locations.

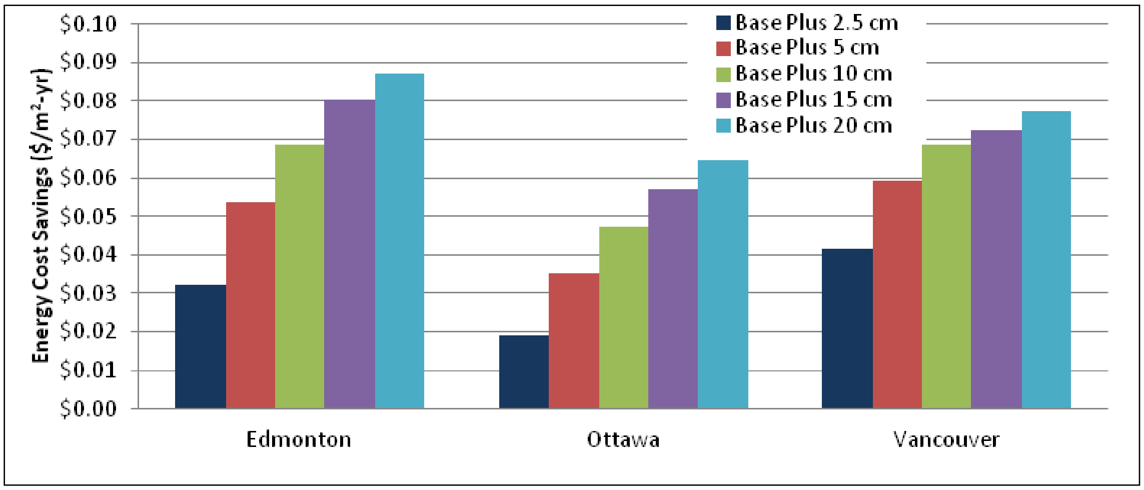

Figure 4.20. Energy cost savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline – Canadian locations.

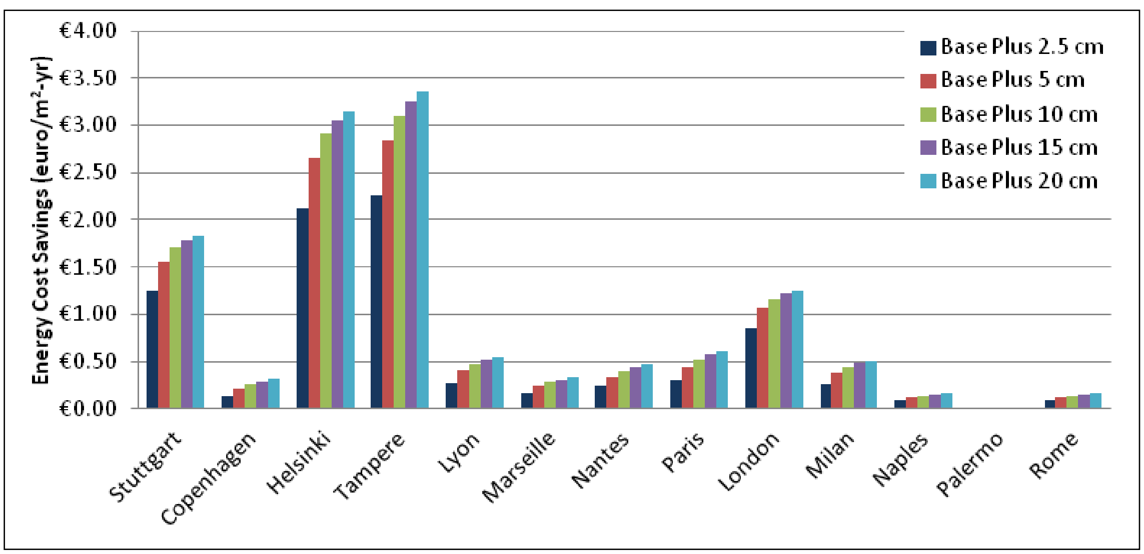

Figure 4.21. Energy cost savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline – European locations.

4.3.3 Attic insulation

The attic insulation retrofit scenarios considered are described in Table 4.4. There are two baselines: one for 1989 construction (000) and one for 1960 construction (100). All six retrofit scenarios are repeated with each baseline.

Table 4.4. overview.

Case	Baseline	Added Ceiling Insulation (R-value)	Building Air Leakage cfm/sq ft @ 0.3 in w.g. (L/s·m^2 @ 75 Pa)	Attic Infiltration Rate (ACH)
Baseline 000	1989	—	1.00 (5.08)	1.0
Baseline 100	1960	—	1.00 (5.08)	1.0
Roof 021	000	10	1.00 (5.08)	1.0
Roof 022	000	20	1.00 (5.08)	1.0
Roof 023	000	30	1.00 (5.08)	1.0
Roof 024	000	40	1.00 (5.08)	1.0
Roof 025	000	50	1.00 (5.08)	1.0
Roof 021.2	000	10	0.85 (4.32)	1.0
Roof 022.2	000	20	0.85 (4.32)	1.0
Roof 023.2	000	30	0.85 (4.32)	1.0
Roof 024.2	000	40	0.85 (4.32)	1.0
Roof 025.2	000	50	0.85 (4.32)	1.0

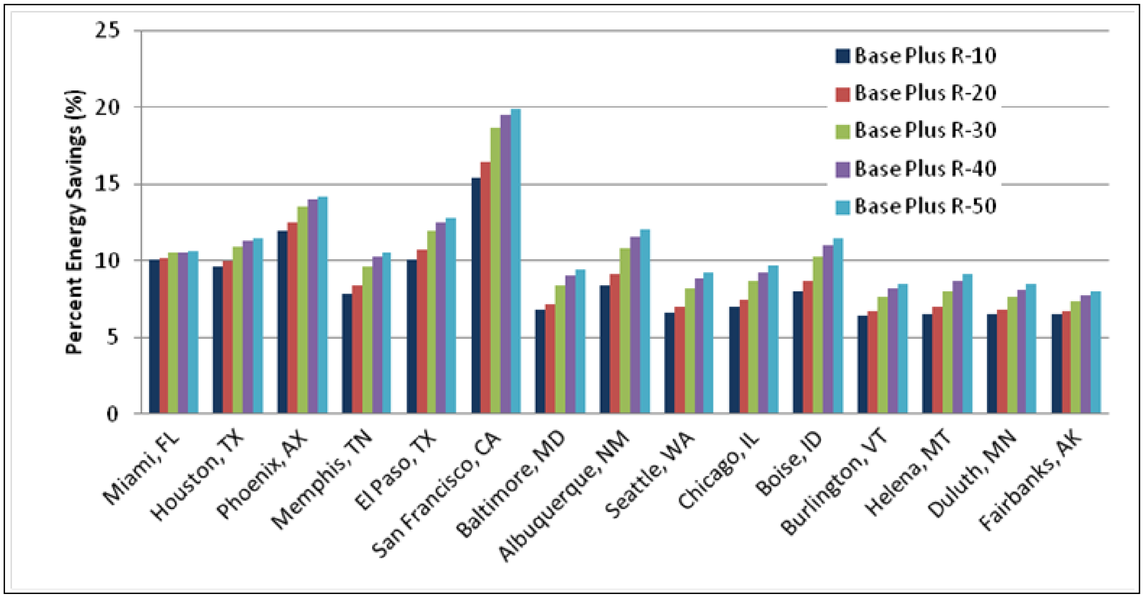

Figure 4.22. Percent energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline.

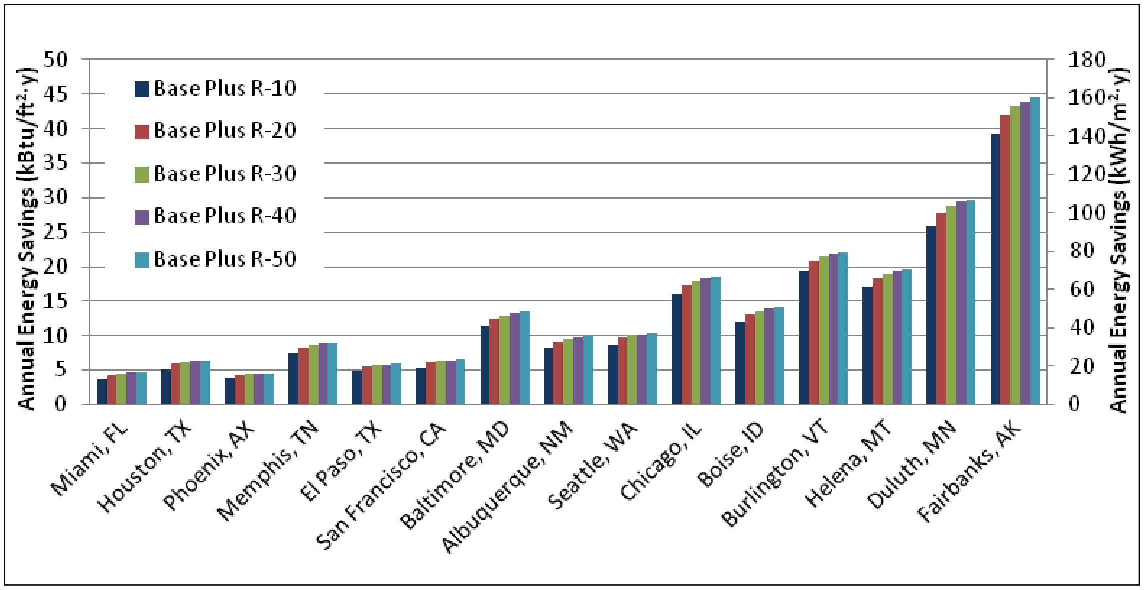

Figure 4.23. Energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline.

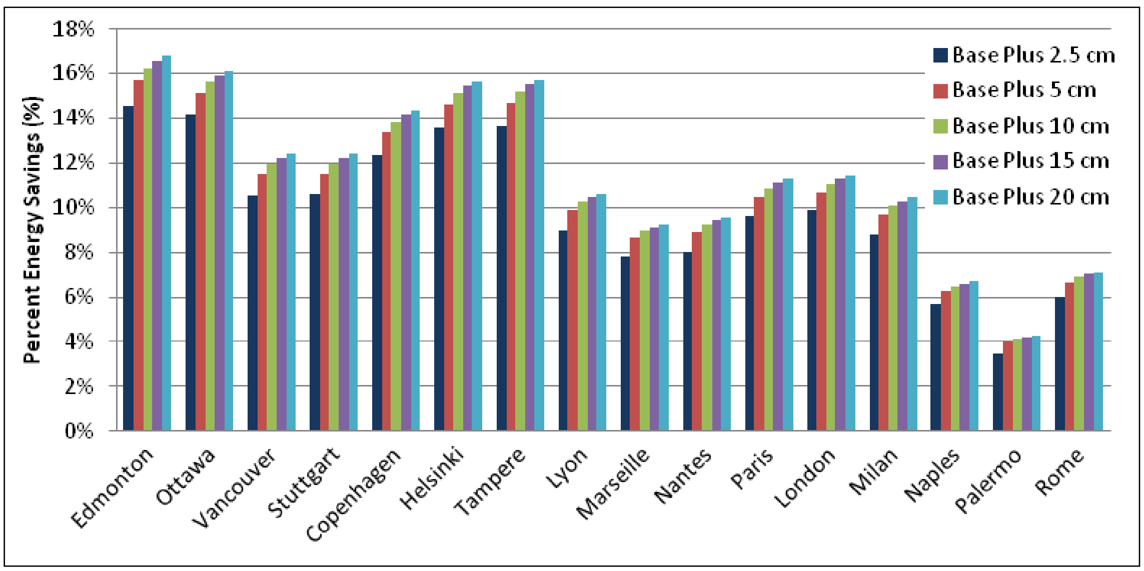

Figure 4.24. Percent energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline – International locations.

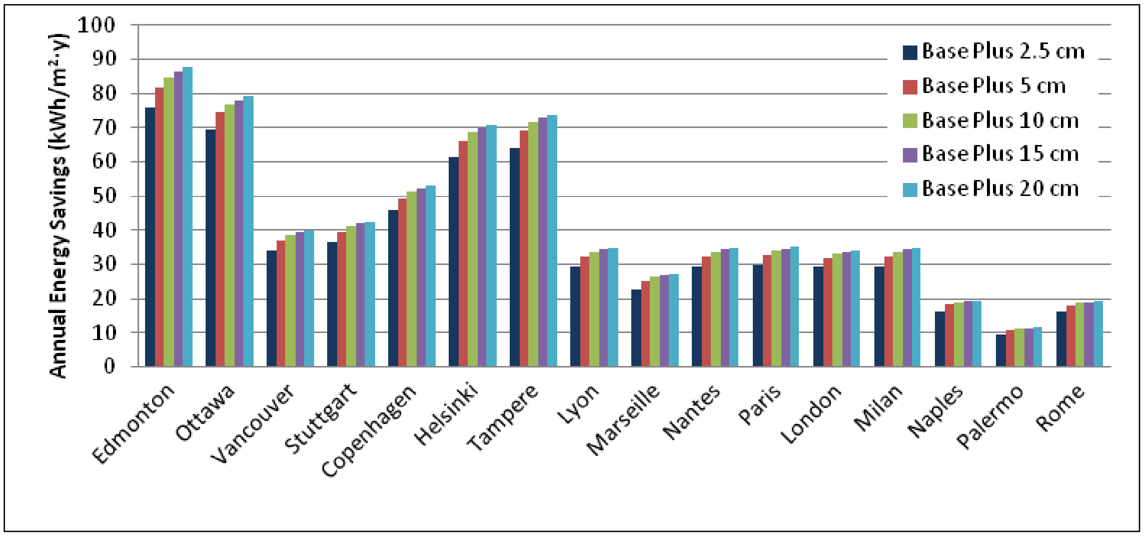

Figure 4.25. Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline – International locations.

4.3.4 Cool roofs

It was assumed that the baseline building has a pitched roof with brown roofing material with a reflectance of ρ = 0.08. A thermal reflective brown roof with a solar reflectance of ρ = 0.27 was modeled as a medium reflectance case, and a white roof with a solar reflectance value of ρ = 0.65 was modeled to represent a highly reflective roof. These cases are shown in Table 4.5. Cool roof technologies primarily impact the cooling energy and potentially the comfort in spaces that are directly below the roof. The results for the European models are not included here because they do not have cooling systems and there is very little impact on the heating energy for this building type.

Table 4.5. Overview.

Case	Description	Roof Solar Reflectance	Mechanical Venting
Baseline	Standard brown	0.08	No
Case 1	Cool brown	0.27	No
Case 2	Cool white	0.65	No

The results of the cool roof simulations are shown in Figures 4.26 through 4.28. The cool roof technology had a relatively small impact compared to some of the other EEMs. Across the climate zones, cool roofs had a largest impact on the overall energy use in the warm climate zones 1 through 3B and very little impact in the other climate zones. The cool roofs tend to decrease cooling and increase heating energy and therefore decrease electricity use and increase gas use for this building. Because of the this tradeoff between electricity and gas, the energy cost savings was higher than the energy savings and changed from slightly negative to slightly positive in most of the colder climates. San Francisco has a slightly negative energy savings, but a significant positive energy cost savings.

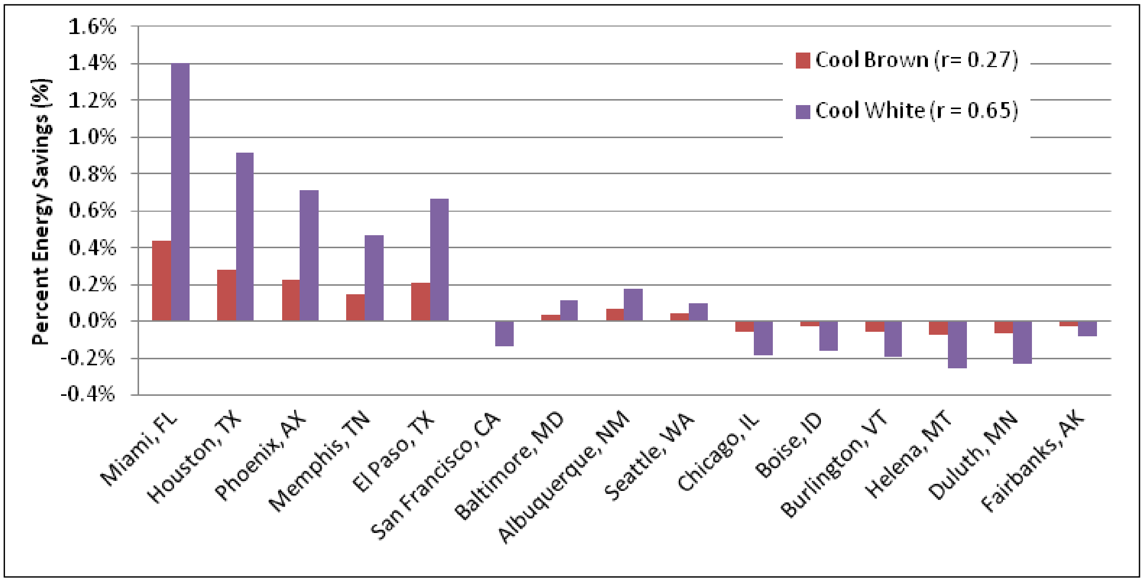

Figure 4.26. Percent energy savings for cool roof.

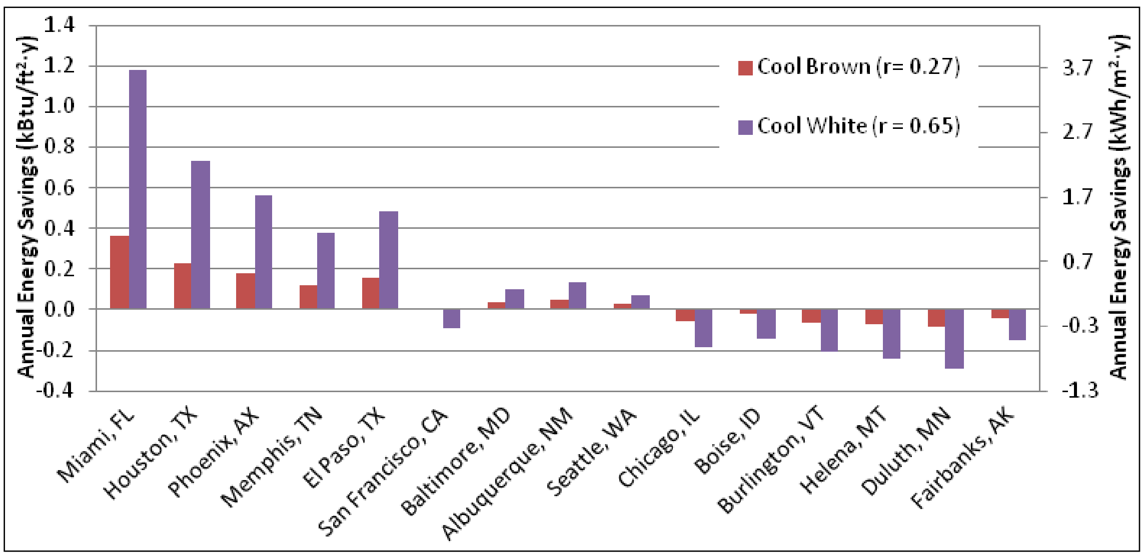

Figure 4.27. Annual energy savings for cool roof.

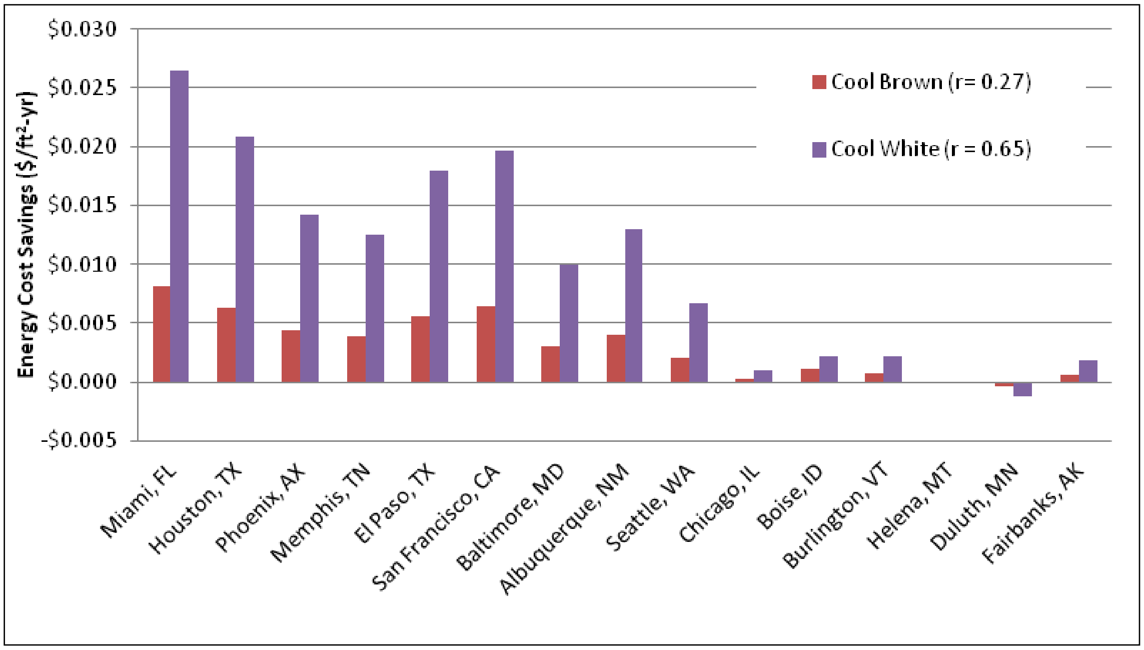

Figure 4.28. Annual energy cost savings for cool roof.

4.3.5 Building airtightness

The effects of retrofitting the barracks facility with a tighter envelope were evaluated with three levels of air leakage for the US locations and two for the non-US locations. The baseline leakage rate was assumed to be 1.0 cfm/sq ft (5.07 L/s/m^2) at a pressure difference across the envelope of 0.3 in. w.g. (75 Pa). The three levels of improved airtightness and the associated average air changes per hour in the building are shown in Table 4.6. The method used to derive air change rates from envelope leakage rates is described in Section 4 pertaining to the baseline airtightness.

Table 4.6. Airtightness ECM overview.

Case	Leakage Rate at 0.3 in w.g. (75 Pa) cfm/sq ft (L/s/m^2)	Leakage Rate at 0.016 in w.g. (4 Pa) cfm/sq ft (L/s/m^2)	ACH at 0.016 in w.g. (4 Pa)
Baseline	1.0 (5.07)	0.15 (0.65)	0.97
Typical practice for air sealing retrofit	0.50 (2.54)	0.074 (0.33)	0.48
Good practice for air sealing retrofit	0.25 (1.27)	0.037 (0.16)	0.24
Best practice for air sealing retrofit	0.15 (0.76)	0.022 (0.11)	0.15

The results for improved envelope airtightness are shown in Figure 3.34 through Figure 3.40. The baseline building model is fairly leaky, but is realistic based on data measured by the US Army Corps of Engineers. The first level of improvement cuts the leakage rate in half and provides most of the savings. The energy savings for all levels of improved airtightness is above 6% for all US locations and above 10% for all Canadian and most European locations. It is only the very mild locations that did not show significant energy savings. The cost of this efficiency measure can vary widely depending on the condition of the building, but it is generally not very expensive and a simple payback of one to 4 years can be expected. Improved airtightness is also very important for controlling humidity in hot, humid climates.

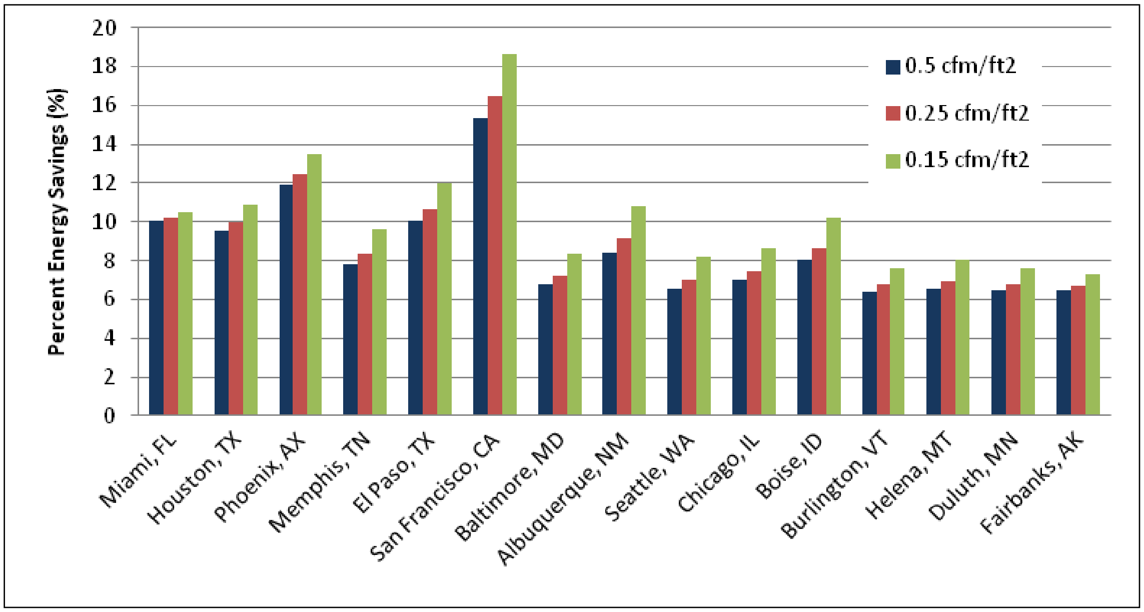

Figure 4.29. Percent energy savings for improved airtightness.

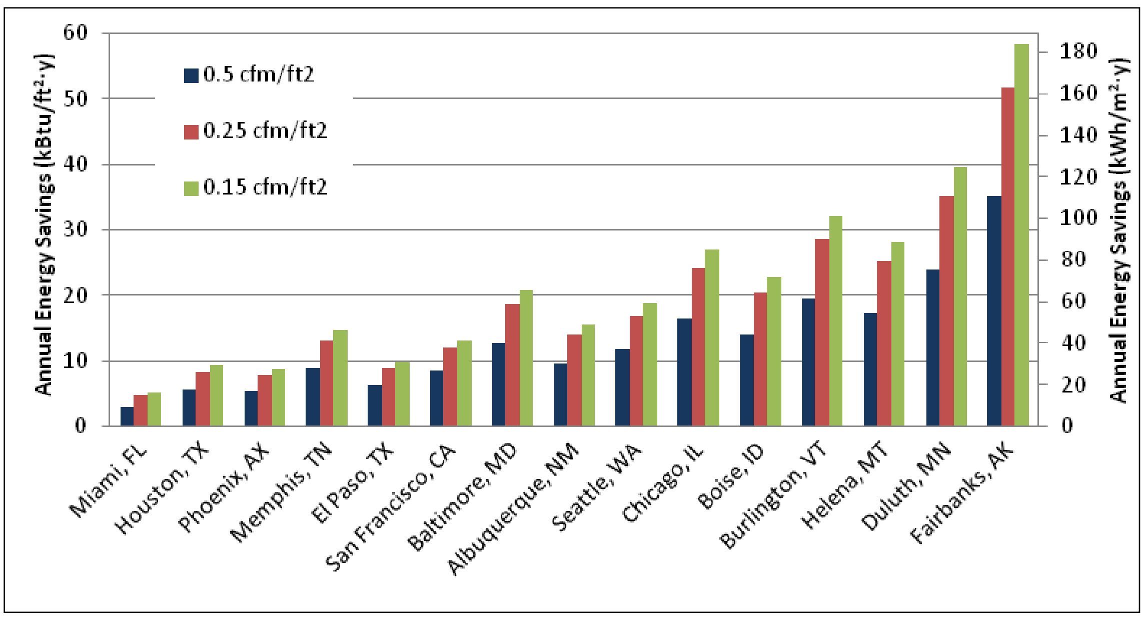

Figure 4.30. Annual energy savings for improved airtightness.

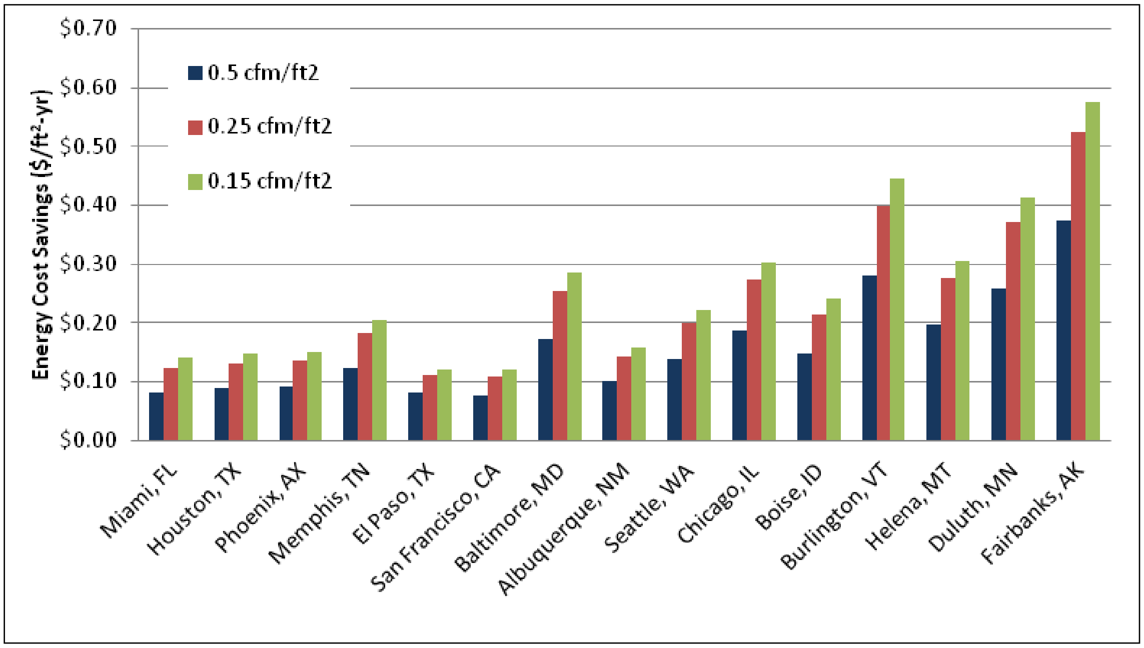

Figure 4.31. Annual energy cost savings for improved airtightness.

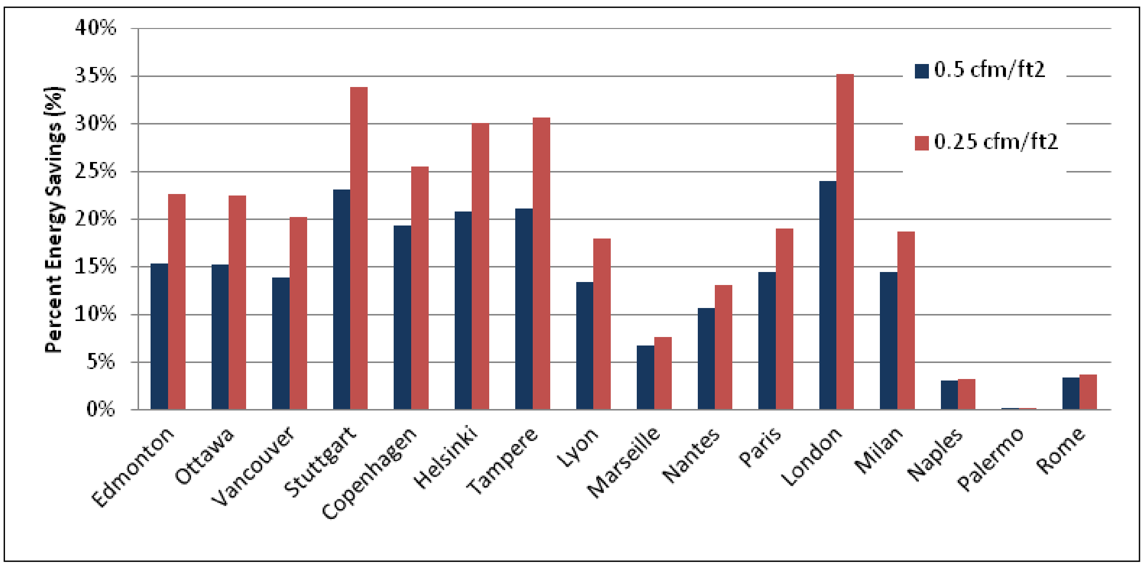

Figure 4.32. Percent energy savings for improved airtightness – international locations.

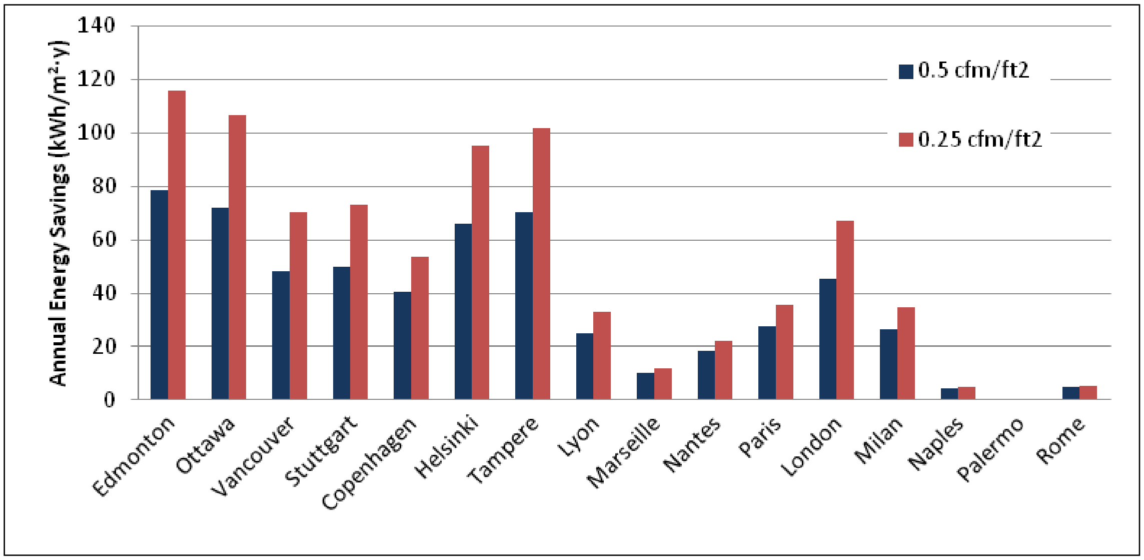

Figure 4.33. Annual energy savings for improved airtightness – international locations.

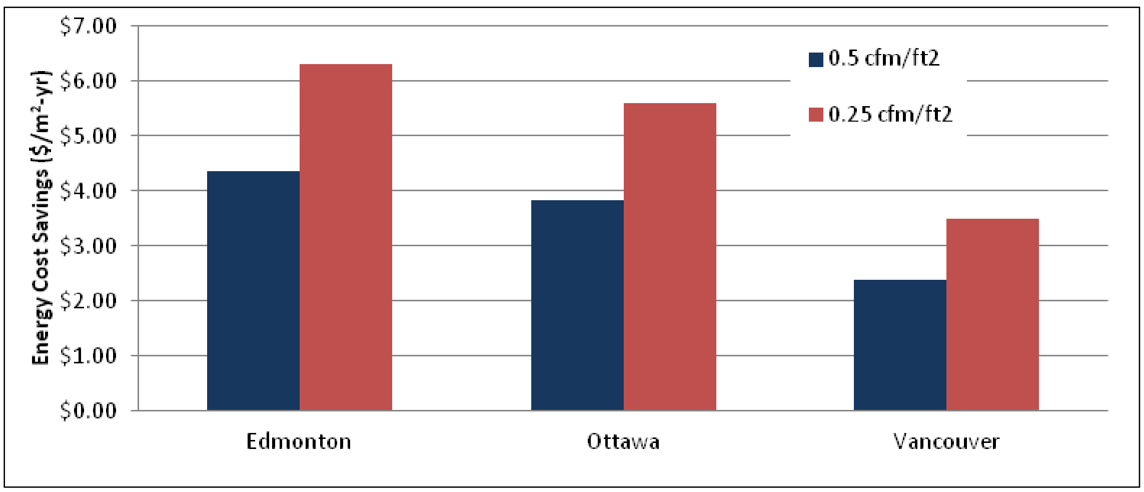

Figure 4.34. Annual energy cost savings for improved airtightness – Canadian locations.

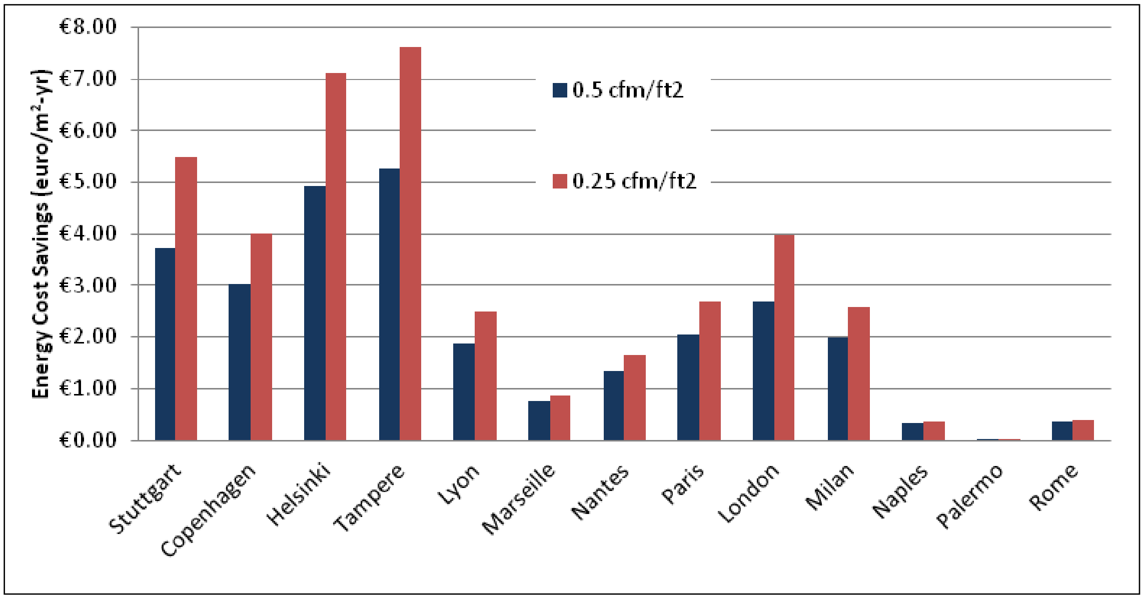

Figure 4.35. Annual energy cost savings for improved airtightness – European locations.

4.3.6 Advanced windows

The set of advanced window options evaluated are shown in Table 4.7. Exact models of the recommended windows are not readily available in the NREL database; therefore, a set of suitable alternative models were used. The properties of the eight replacement windows as they were modeled are given in Table 4.8. Included in the table is the estimated cost per square foot of glazing and the air leakage (AL) for each retrofit, which was assumed to improve from the baseline of 1.00 cfm/sq ft at 75 Pa to 0.85 cfm/sq ft at 75 Pa.

Table 4.7. Retrofit windows.

Window Options With Default Performance Values							Cost per Window (12 sq ft)	
#	Glazing Type	Frame Type	U-Factor Btu/hr·ft·˚F (W/m·K)	SHGC	VT	AL cfm/sq ft (L/s/m^2)	Installed Cost	Cost Premium
I	2-pane, tinted	Aluminum	0.76 (4.3)	0.56	0.51	0.2 (1.0)	$300	baseline
II	2-pane, uncoated	Non-metal	0.49 (2.8)	0.56	0.59	0.2 (1.0)	$350	baseline
A	2-pane, low-solar-gain low-E	Aluminum, thermal break	0.47 (2.7)	0.33	0.55	0.2 (1.0)	$325	$25
B	2-pane, low-solar-gain low-E	Non-metal	0.34 (1.9)	0.30	0.51	0.2 (1.0)	$375	$25
C	2-pane, high-solar-gain low-E	Non-metal	0.36 (2.0)	0.49	0.54	0.2 (1.0)	$375	$25
D	3-pane, low-solar-gain low-E	Non-metal	0.26 (1.4)	0.25	0.40	0.1 (0.5)	$450	$100
E	3-pane, high-solar-gain low-E	Non-metal	0.27 (1.5)	0.38	0.47	0.1 (0.5)	$450	$100
F	3-pane, high-solar-gain low-E	Non-metal, insulated	0.18 (1.0)	0.40	0.50	0.1 (0.5)	$500	$150

Table 4.8. Modeled windows.

Window	Cost $/sq ft ($/m^2)	Fenestration, Overall U-value Btu/h·°F·sq ft (W/m^2·K)	SHGC	Building AL cfm/sq ft at 0.3 in w.g. (L/s·m^2 at 75 Pa)
I	25.00 (269.08)	0.69 (3.92)	0.43	0.85 (4.32)
II	29.17 (313.96)	0.48 (2.73)	0.50	0.85 (4.32)
A	27.08 (291.46)	0.48 (2.73)	0.36	0.85 (4.32)
B	31.25 (336.34)	0.35 (1.99)	0.32	0.85 (4.32)
C	31.25 (336.34)	0.36 (2.04)	0.44	0.85 (4.32)
D	37.5 (403.61)	0.29 (1.65)	0.29	0.85 (4.32)
E	37.5 (403.61)	0.26 (1.48)	0.37	0.85 (4.32)
F	41.67 (448.49)	0.17 (0.97)	0.47	0.85 (4.32)

The results from the advanced window simulations are shown in Figure 3.41 through Figure 3.48. Window F has the lowest thermal conductance and performed the best in US climate zones 3A to 8. Window D has the lowest SHGC and performed the best in the warmer climates. The payback for all windows in all US locations varies between 10 and 50 years. However, if a window replacement is already planned, then we can look at the relative performance of each of the windows compared to the replacement window (Window I). Figure 3.44 shows the simple payback in years for each window compared to Window I. Window A has the lowest payback for every climate because of the low cost. There are several other windows with paybacks of less than 5 years and should be considered for improved energy performance.

The results for the Canadian and European locations are mixed and depend on the climate and the baseline window. The set of windows used for the analysis were selected based on US conditions. Ideally, a unique set of windows would be selected for each country based on the conditions of the baseline building.

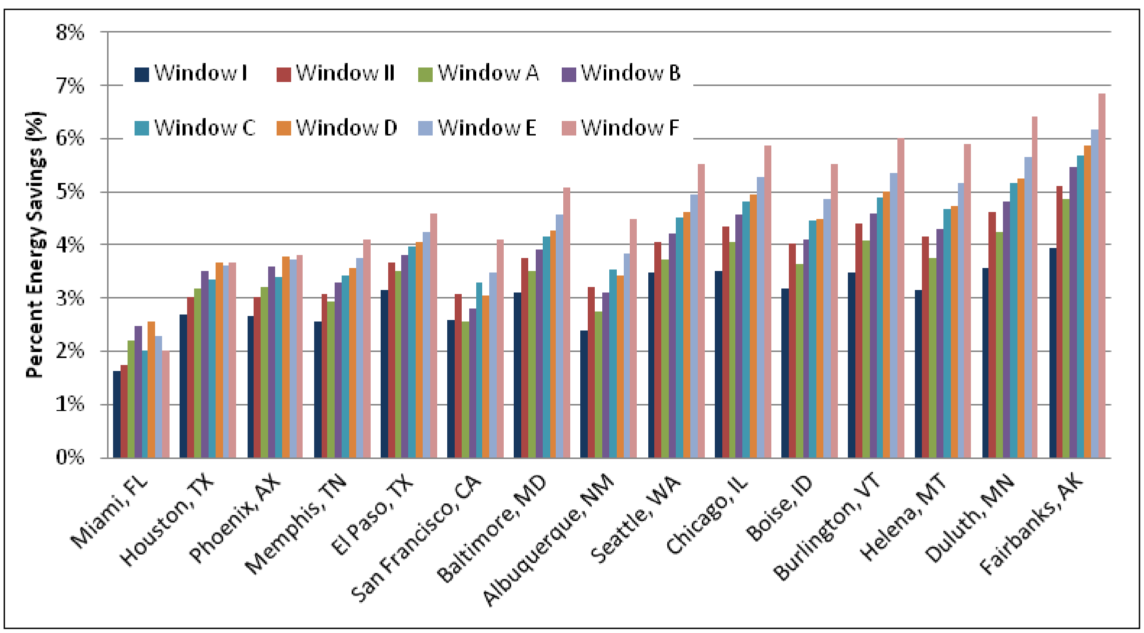

Figure 4.36. Percent energy savings for advanced windows.

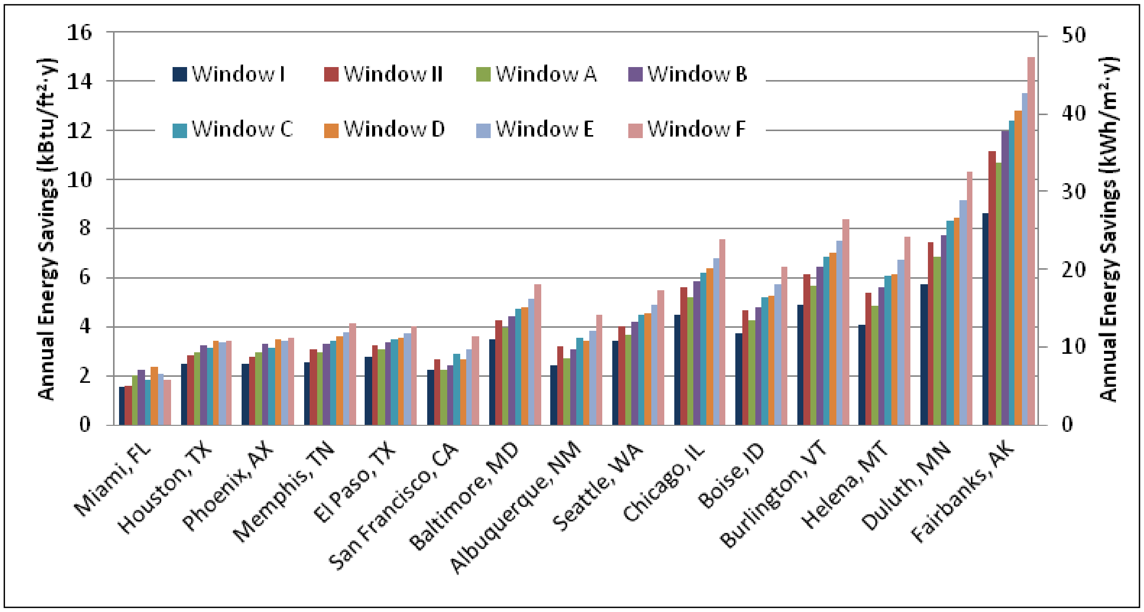

Figure 4.37. Annual energy savings for advanced windows.

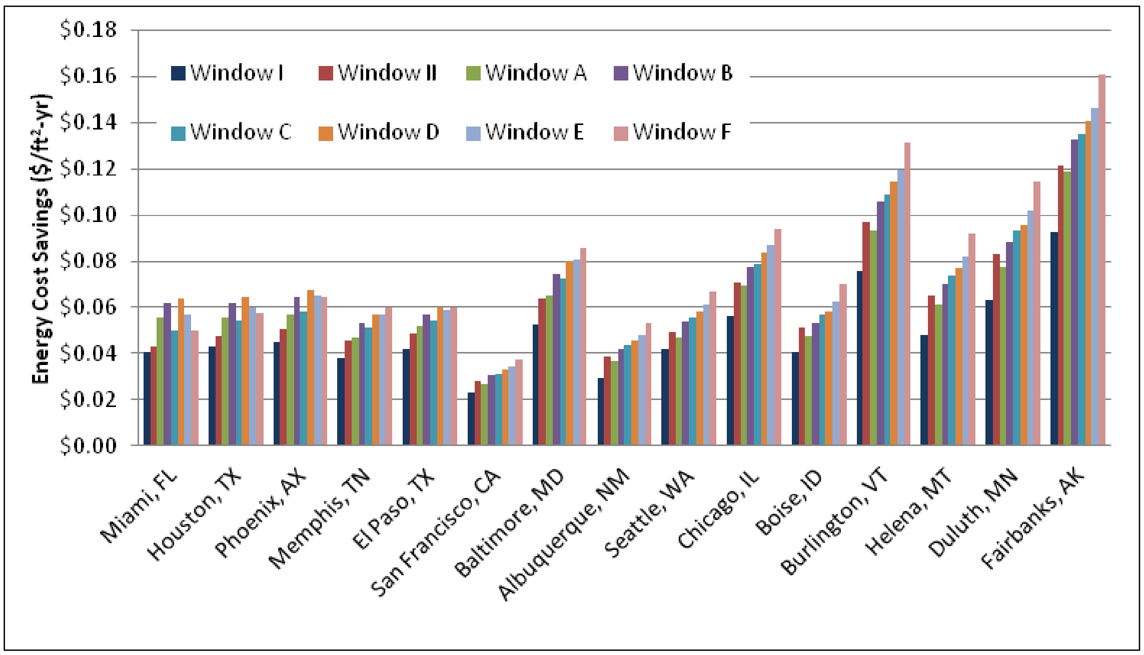

Figure 4.38. Annual energy cost savings for advanced windows.

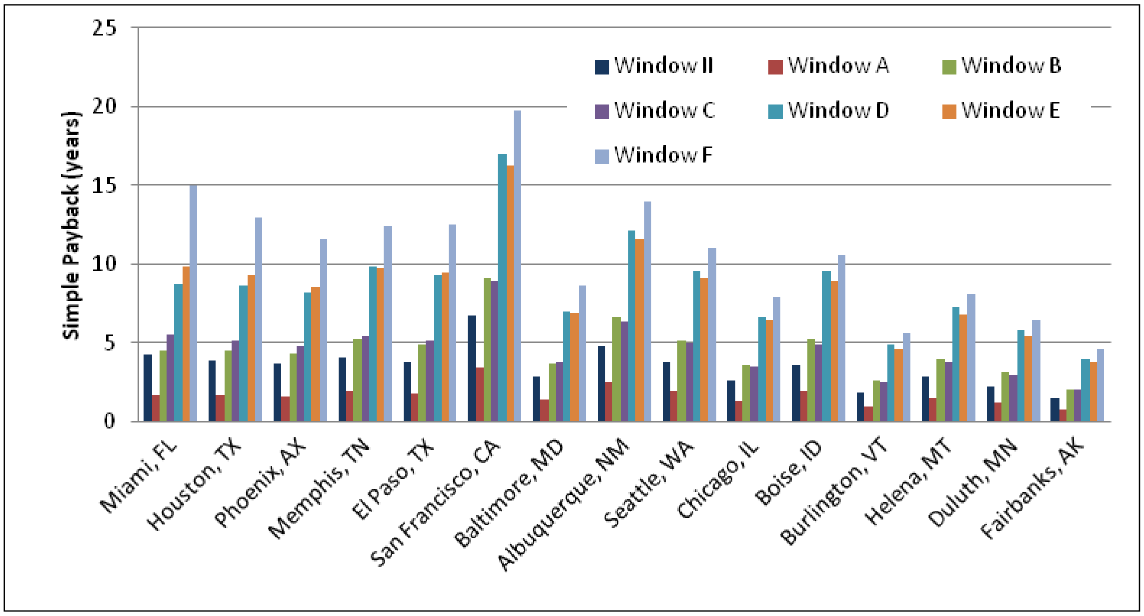

Figure 4.39. Simple payback relative to window I.

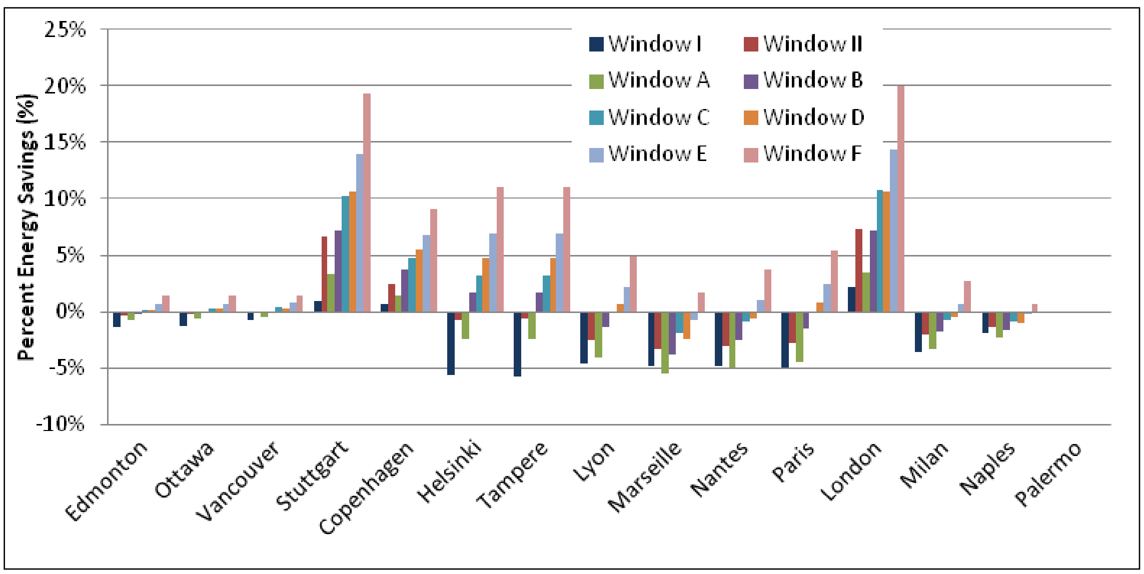

Figure 4.40. Percent energy savings for advanced windows – international locations.

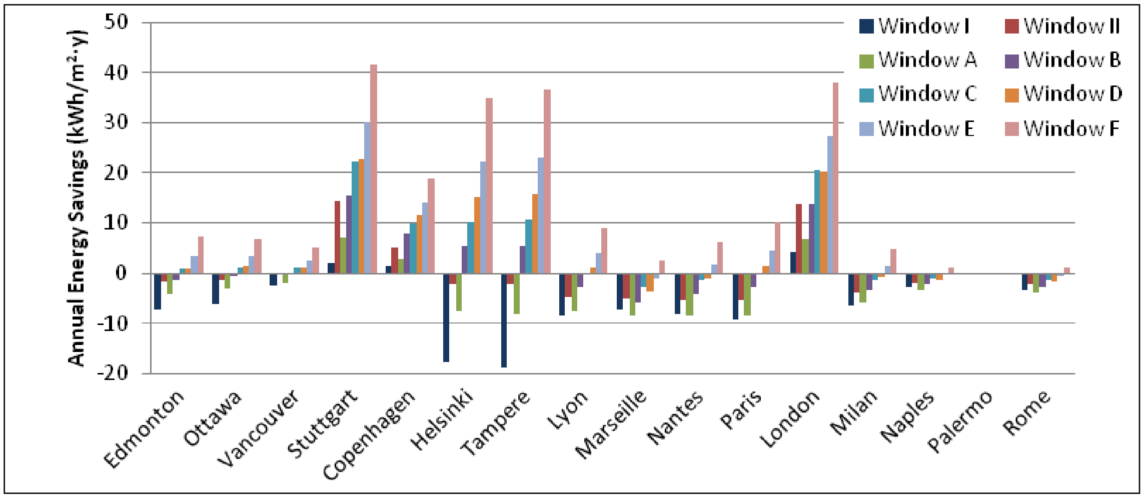

Figure 4.41. Annual energy savings for advanced windows – international locations.

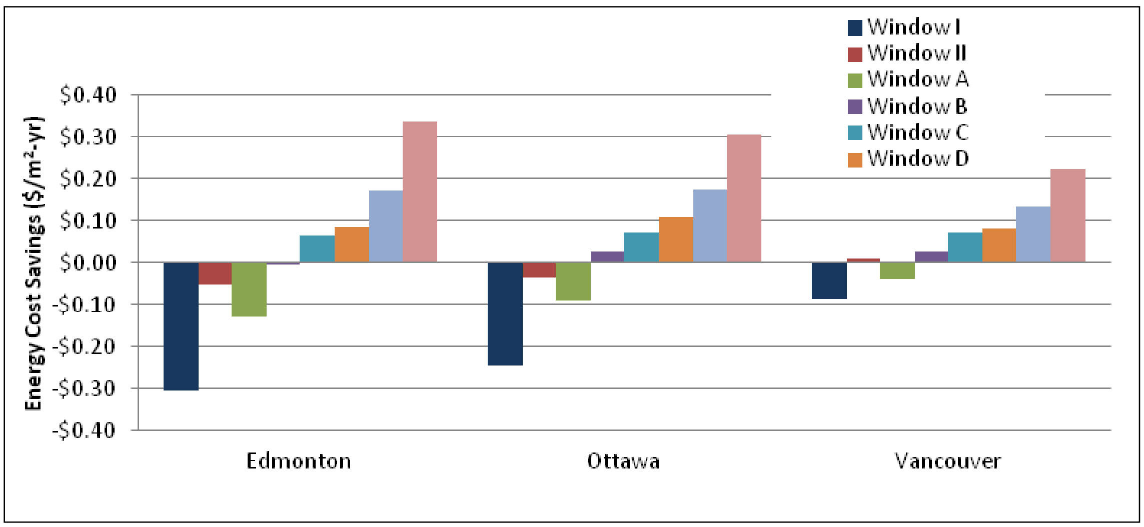

Figure 4.42. Annual energy cost savings for advanced windows – Canadian locations.

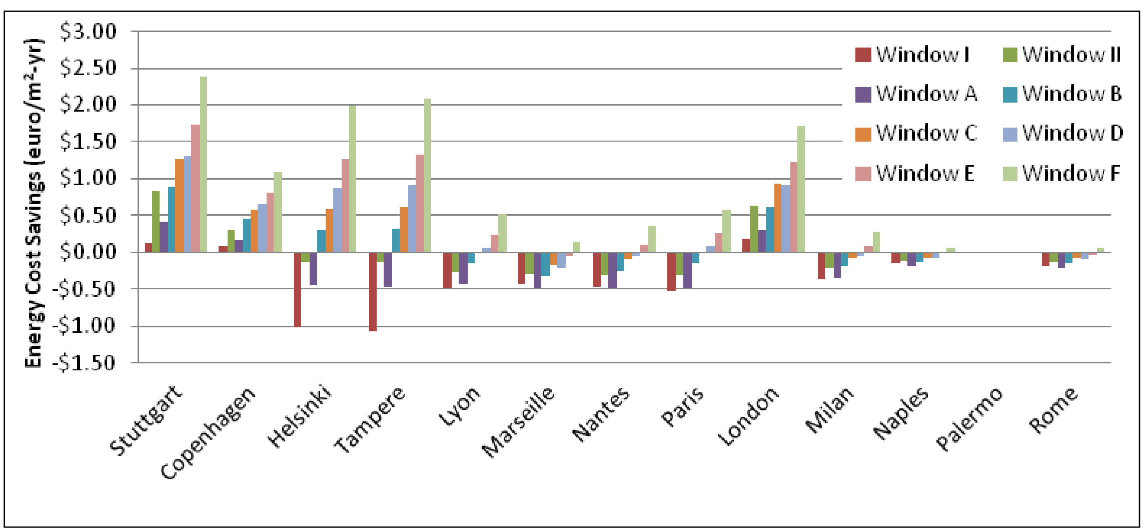

Figure 4.43. Annual energy cost savings for advanced windows – European locations.

4.3.7 External roller shades

The modeled rolling shutter consists of aluminum slats that are filled with a regular-density polyurethane foam core. The technical details are shown in Table 4.9.

Table 4.9. Roller shade description.

	IP Units	SI Units
U–Value (without air gap between slat and window glass)	5.43 (Btu/hr·ºF·sq ft)	30.9 ($W/m^2 \cdot K$)
Solar transmittance	0.0	0.0
Solar reflectance	0.5	0.5
Visible transmittance	0.0	0.0
Visible reflectance	0.5	0.5
Thermal emissivity	0.9	0.9
Thermal transmittance	0.0	0.0
Air gap (distance between slat and window glass)	1.5 in	0.038 m

Several control strategies were considered for opening and closing the shades. These control mechanisms were chosen based on a subset of the capabilities provided by EnergyPlus. For the purpose of this report, only the two most energy efficient options are presented – Active Control and Schedule Control. Active control proved to be the most efficient strategy and was based on closing the shades during the day when the zone load required cooling and at night when the outdoor temperature was below the heating set point. The schedule control also proved to be effective and was based on the schedule outlined in Table 4.10.

Table 4.10. Roller shade schedule.

Day of Year	Hours	Shutter Position
Jan 1 – May 1	12:00 am – 6:00 am	Closed
	6:00 am – 10:00 pm	Open
	10:00 pm – 12:00 am	Closed
May 1 – October 31	12:00 am – 8:00 am	Open
	8:00 am – 5:00 pm	Closed
	5:00 pm – 12:00 am	Open
October 31 – December 31	12:00 am – 6:00 am	Closed
	6:00 am – 10:00 pm	Open
	10:00 pm – 12:00 am	Closed

In addition to these shade control options, two building orientations were considered. One orientation positions the building such that the windows face north and south, while the other orientation rotates the building 90 degrees so that the windows face to the east and west. The shutters were modeled on the south-facing windows in the first orientation and on both the east and west facing windows in the second orientation.

The results for the roller shade simulations are shown in Figures 4.44 through 4.49. The roller shades had the best performance in the warmer climates and had very little impact in climate zones 3C – 8. The savings for the east-west orientation windows is about twice that for the north-south orientation. This is because the east-west orientation results in higher cooling energy and more opportunity for energy savings. The roller shades resulted in increased energy in most of the international locations because there is no cooling energy in the barracks. However, the roller shades are very useful for these buildings because they help keep the spaces from overheating. A more optimal control strategy could be implemented that would not increase the heating energy and still keep the spaces from overheating.

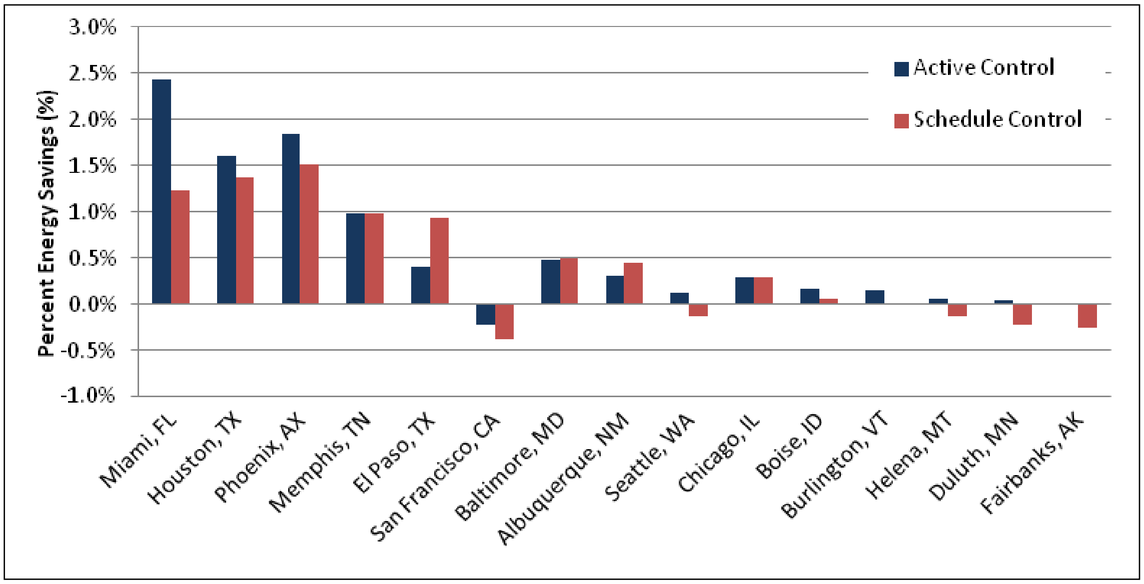

Figure 4.44. Percent energy savings for external roller shades for a north-south orientation.

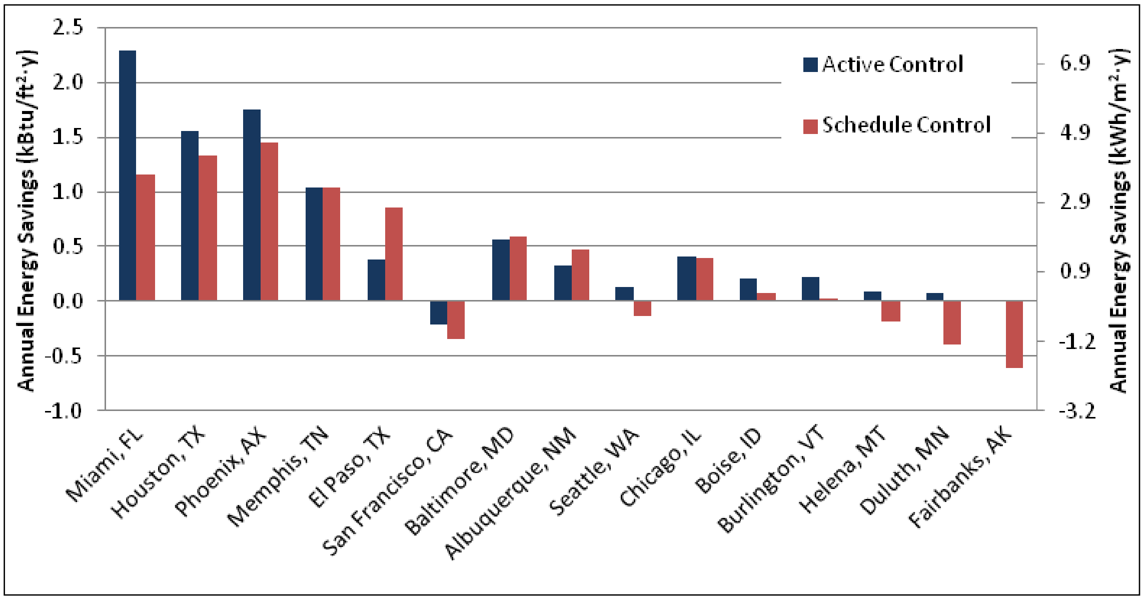

Figure 4.45. Annual energy savings for external roller shades for a north-south orientation.

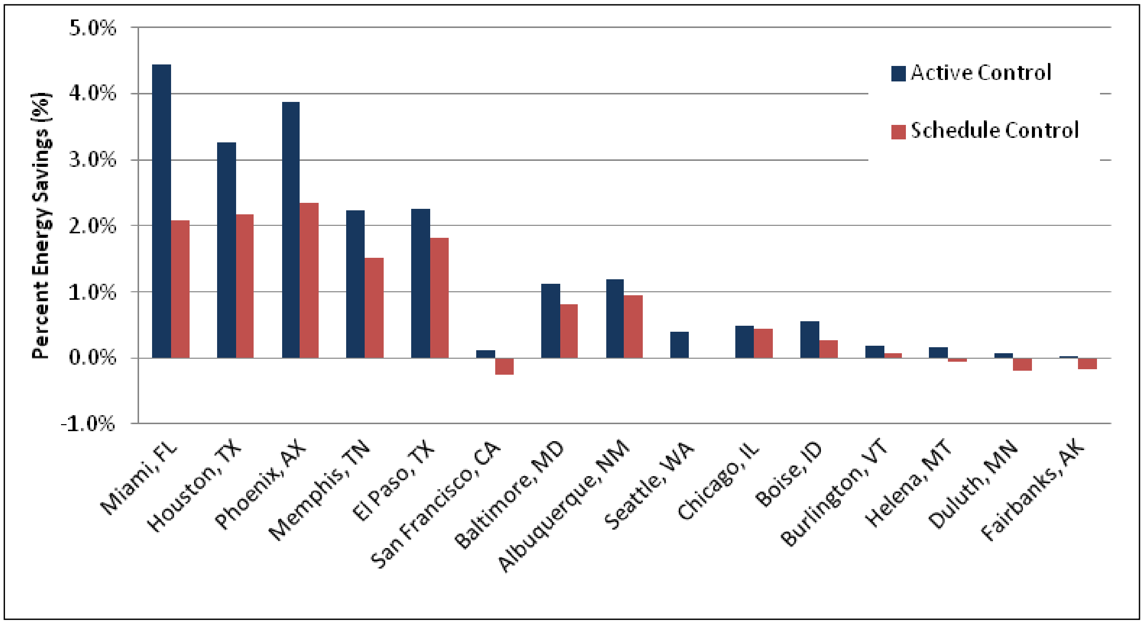

Figure 4.46. Percent energy savings for external roller shades for an east-west orientation.

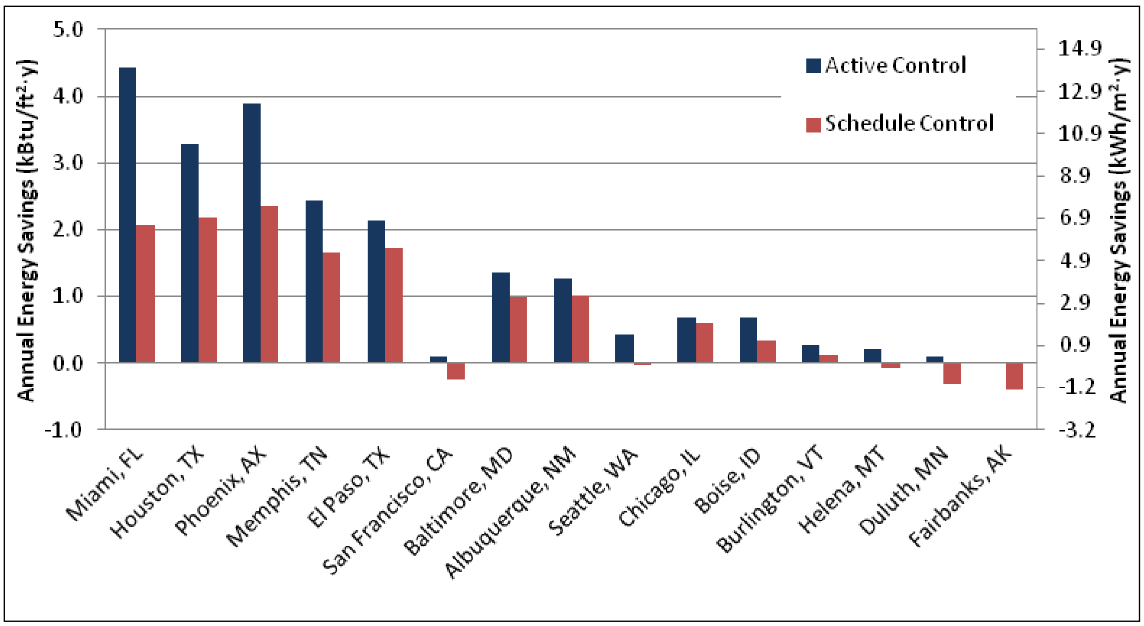

Figure 4.47. Annual energy savings for external roller shades for an east-west orientation.

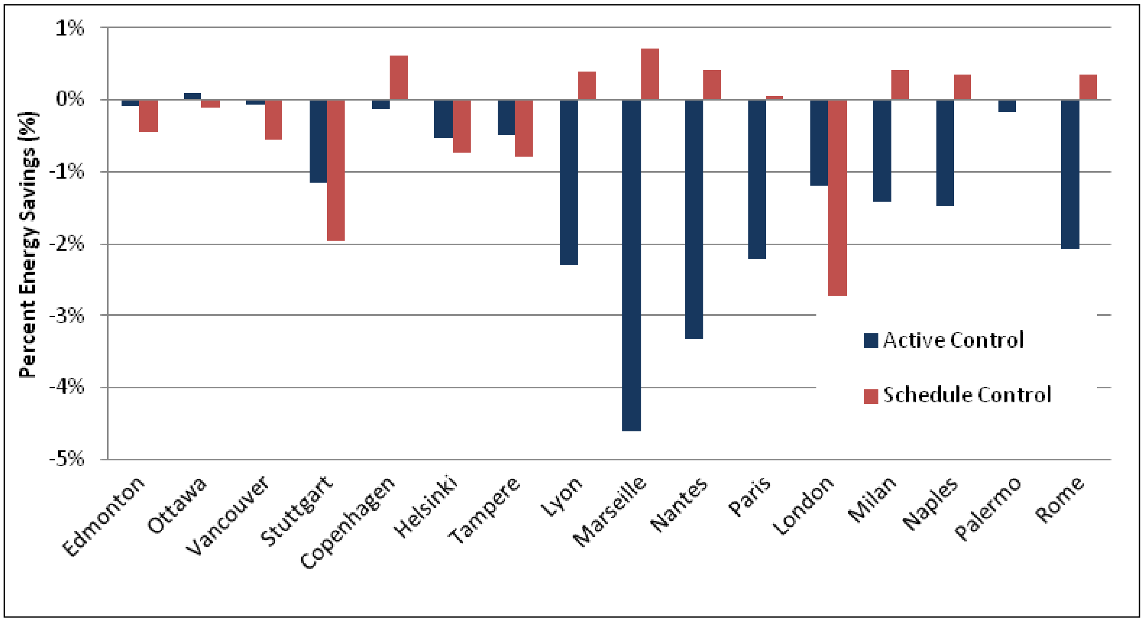

Figure 4.48. Percent energy savings for external roller shades for a north-south orientation – international locations.

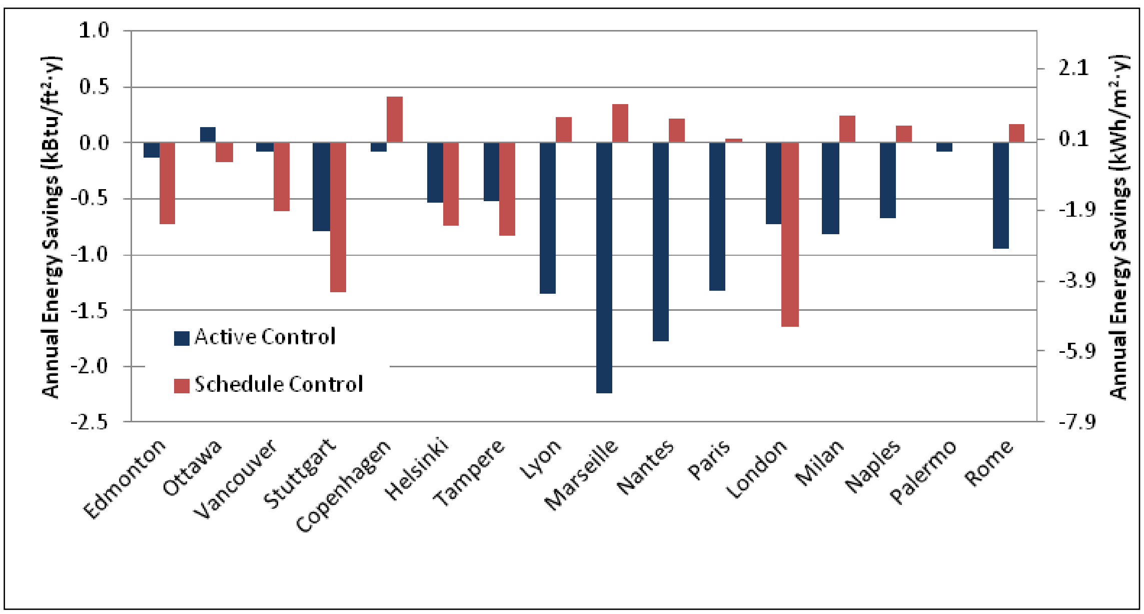

Figure 4.49. Annual energy savings for external roller shades for a north-south orientation – international locations.

4.3.8 Overhangs

The effect on whole building energy performance from retrofitting the building with exterior overhangs above the south-facing windows was modeled in EnergyPlus using simple shading devices which protrude orthogonally from the building façade by 1.6 ft (0.5 m).

The results of the US locations are presented in Figures 4.50 through 4.52. There are small energy savings in the hot climate zones 1, 2A, and 2B and small energy increases in the remaining climate zones because of the increase in heating energy was greater than the cooling energy savings. European locations showed negative energy savings with this retrofit, because of a general increase in heating energy and no cooling savings, because the European locations are not air-conditioned. The decision to install overhangs is often driven by the desire to control glare, which may override the impact on energy performance. The performance of overhangs will depend on the glass properties, most specifically the SHGC. The performance of each project should be evaluated to understand the tradeoffs.

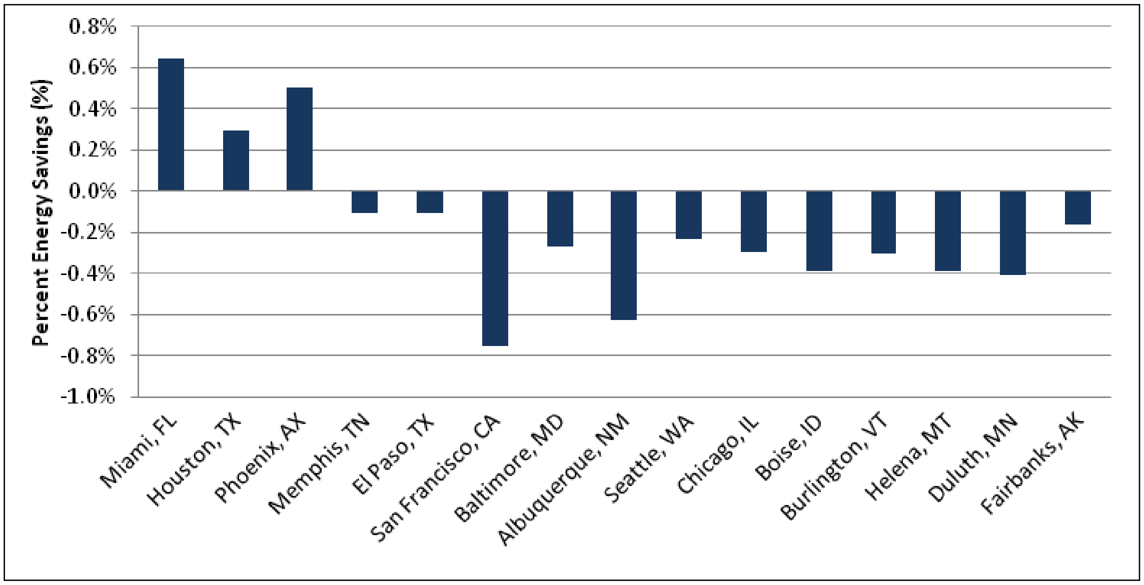

Figure 4.50. Percent energy savings for overhangs.

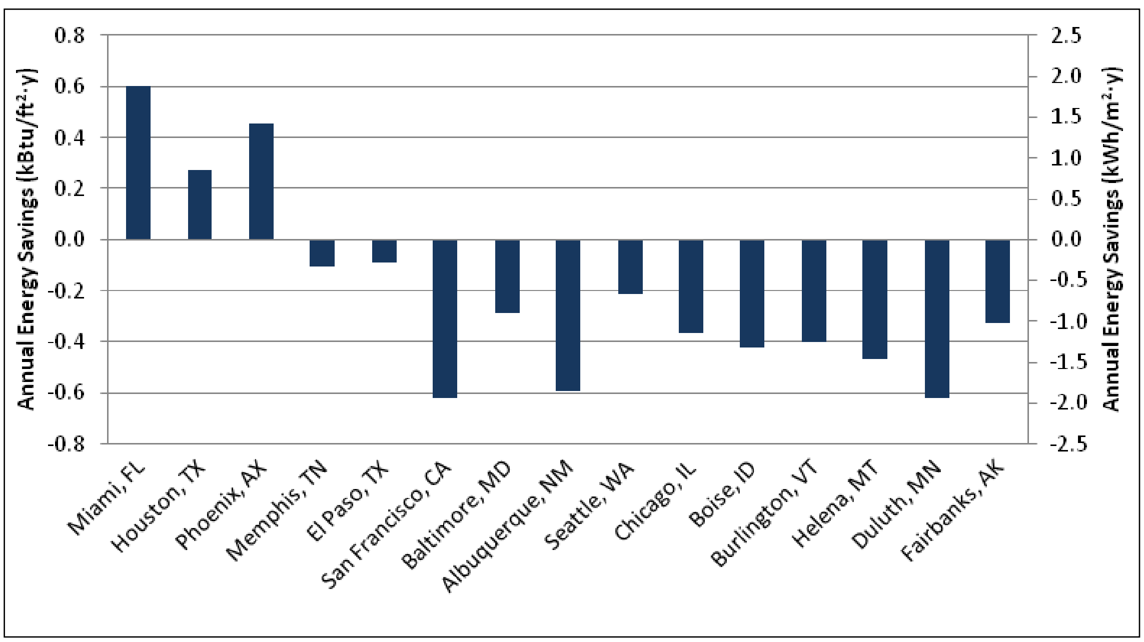

Figure 4.51. Annual energy savings for overhangs.

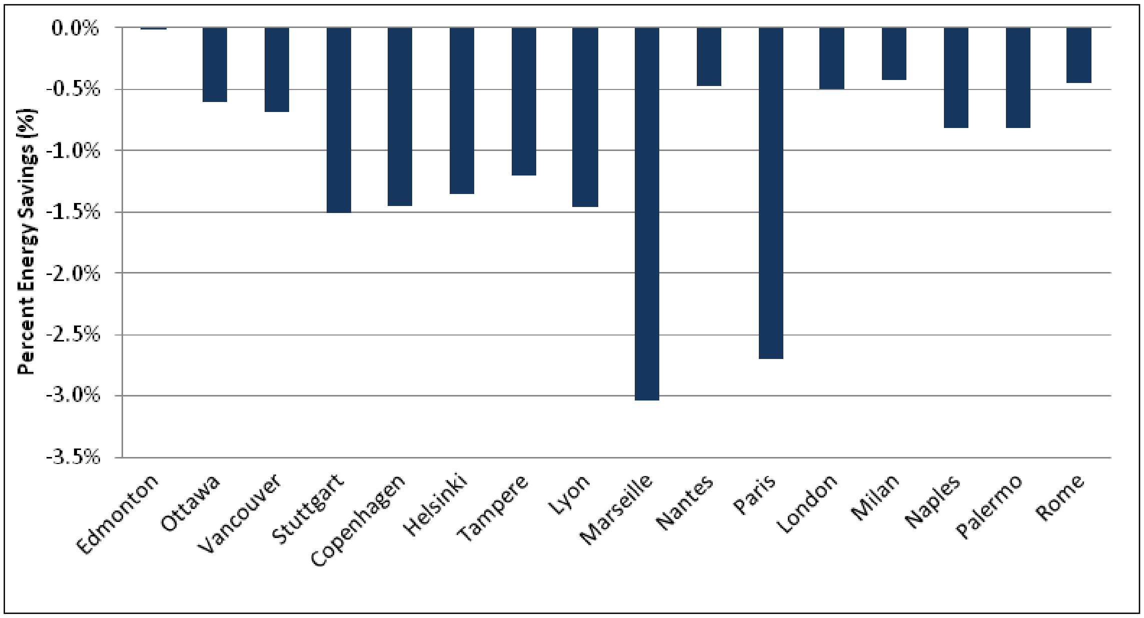

Figure 4.52. Percent energy savings for overhangs – international locations.

4.3.9 Exterior vertical fins

The effect of retrofitting the building with exterior vertical fins around the windows was modeled in a similar way as window overhangs. Shading devices protruding out 1.6 ft (0.5 m) orthogonally around the left, right, and top sides of the east-, west-, and south-facing windows were modeled using EnergyPlus.

The effects of exterior vertical fins are similar to exterior light shelves. The results of the simulations are presented in Figures 4.53 through 4.55. There are small energy savings in the hot climate zones 1, 2A, and 2B and small energy increases in the remaining climate zones because of the increase in heating energy was greater than the cooling energy savings. European locations showed negative energy savings with this retrofit, because of a general increase in heating energy and no cooling savings, because the European locations are not air-conditioned. The decision to install exterior fins and overhangs is often driven by the desire to control glare, which override the impact on energy performance. The performance of fins and overhangs will depend on the glass properties, most specifically the SHGC. The performance on each project should be evaluated to understand the performance.

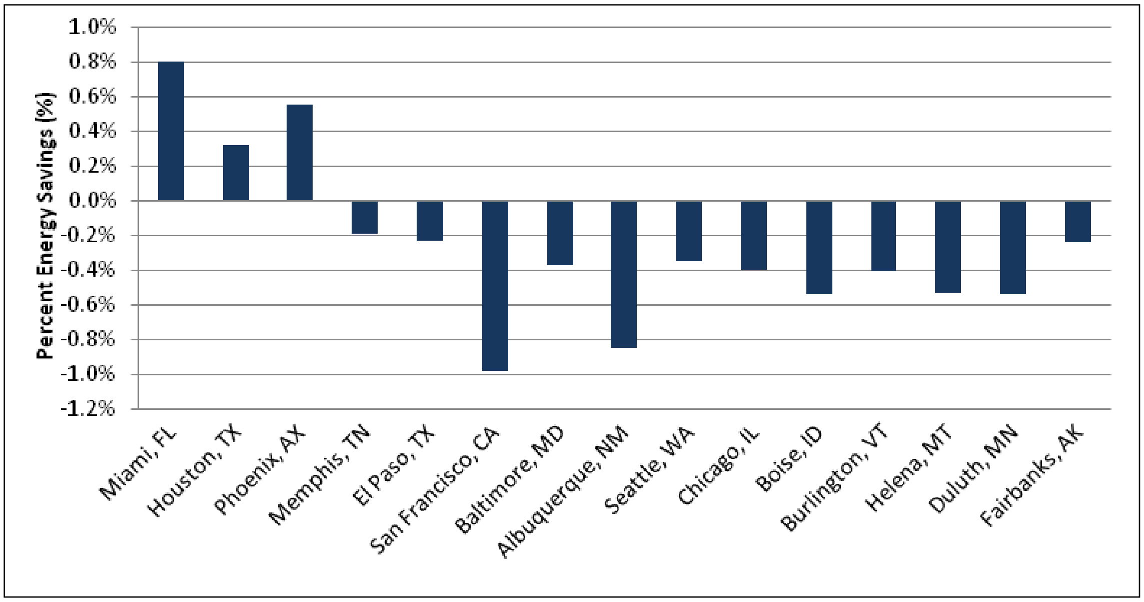

Figure 4.53. Percent energy savings for exterior vertical fins.

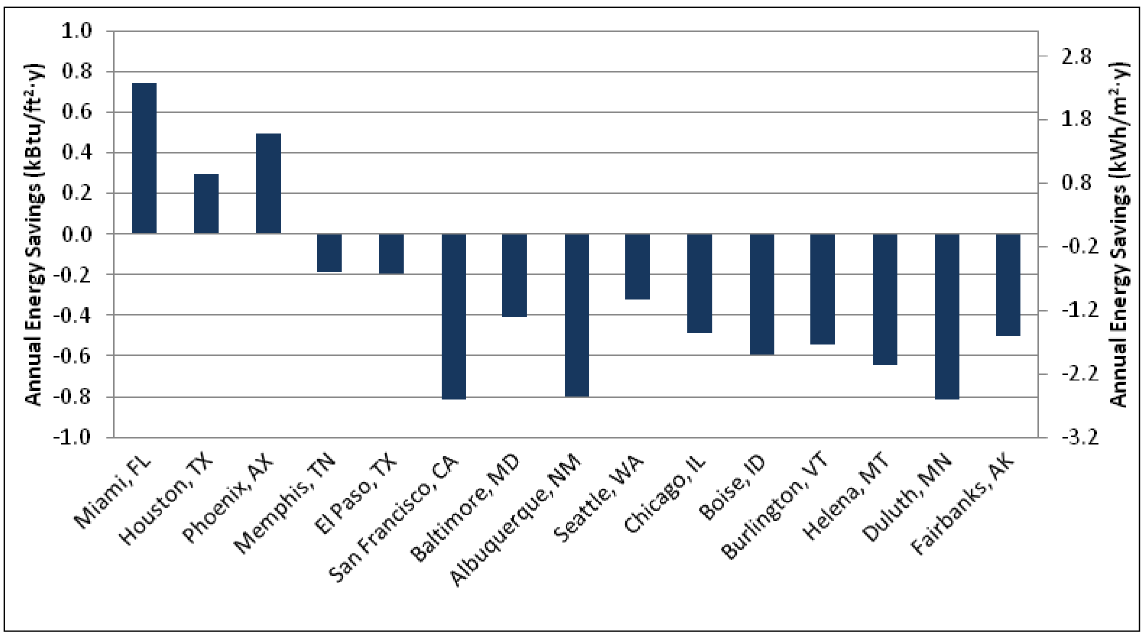

Figure 4.54. Annual energy for exterior vertical fins.

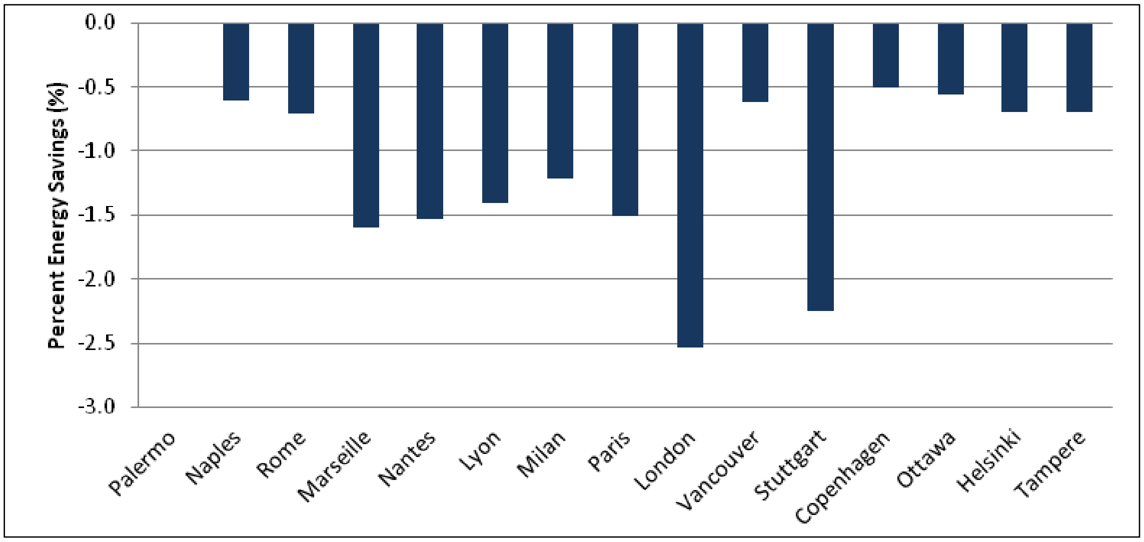

Figure 4.55. Percent energy savings for exterior vertical fins – international locations.

4.3.10 Energy recovery ventilators

ERVs are used to transfer useful energy from the exhaust air stream to the incoming outdoor air stream. A retrofit application of ERVs was modeled using three levels of performance. The specifications of the ERV are selected to represent a desiccant wheel type ERV, which has the capability to transfer moisture between the two air streams and is sometimes called a total energy recovery system. The specific properties of each device are shown in Table 4.11.

Table 4.11. ERV retrofit model parameters.

ERV Name	Sensible Effectiveness	Latent Effectiveness	Pressure Drop (in water)
ERV 60	0.6	0.5	0.70
ERV 70	0.7	0.6	0.86
ERV 80	0.8	0.7	1.00

A schematic of the retrofit system is shown in Figure 4.56. Each individual air handler in the baseline building was retrofitted with an ERV across the outdoor air and relief air streams of the outdoor air systems.

International locations were not simulated, because with the exception of Canada, they lack an air system that this technology would apply to. Results for the Canadian locations would be similar to US locations located in similar climate zones.

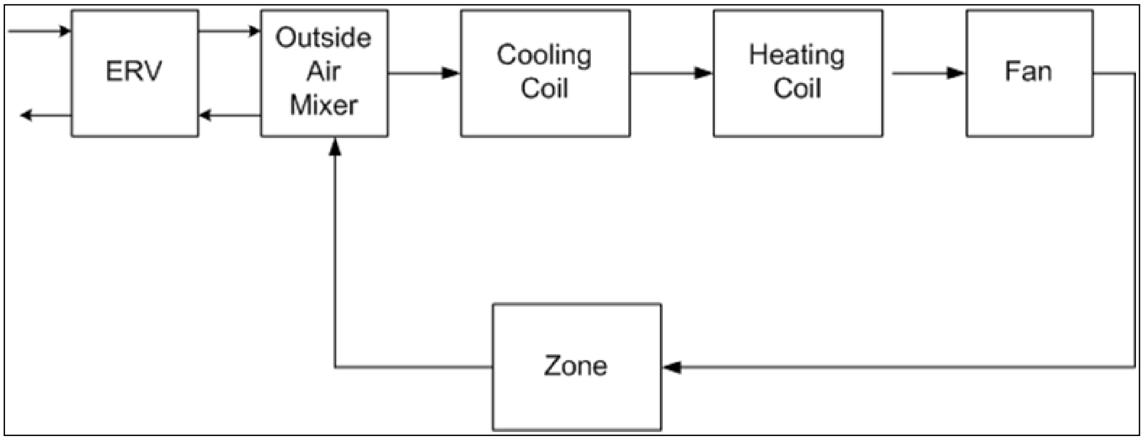

Figure 4.56. Schematic of the energy recovery ventilator model (credit: Kyle Benne).

The results for the ERV simulations are shown in Figures 4.57 through 4.59. Energy recovery devices are generally most effective in cold climates. The results below show over 10% energy savings for most climates and over 20% energy savings in the cold-humid climates. ERVs are especially effective for barracks because of the 24 hour heating load. An ERV bypass was not modeled in this study, but would improve performance in some climates by avoiding the fan energy penalty of the ERV when the system is in economizer mode.

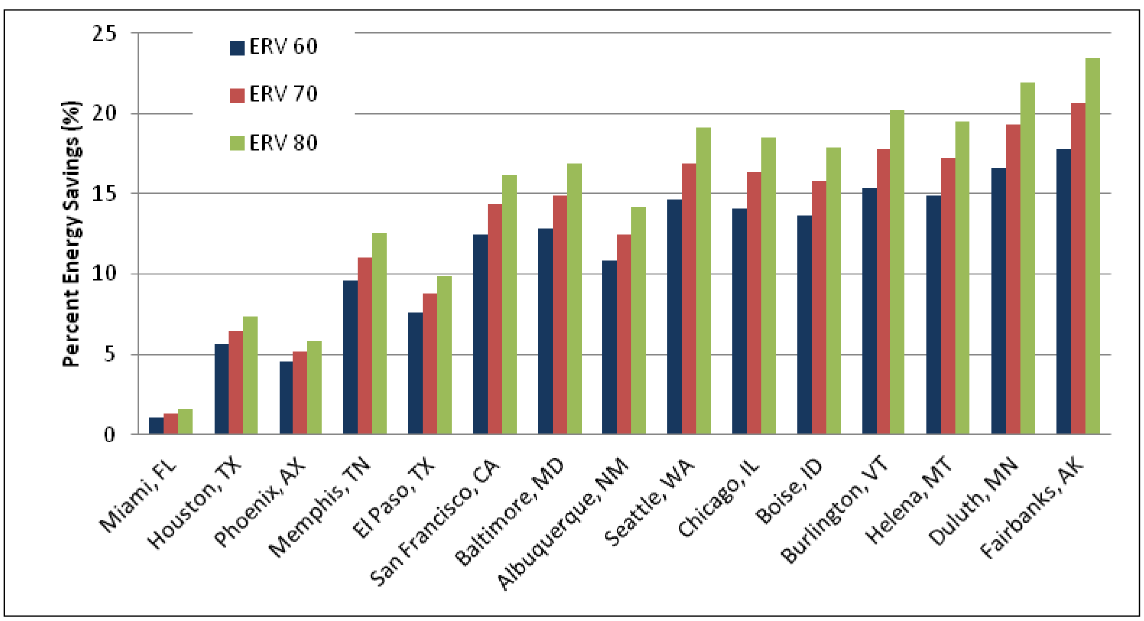

Figure 4.57. Percent energy savings for ERVs.

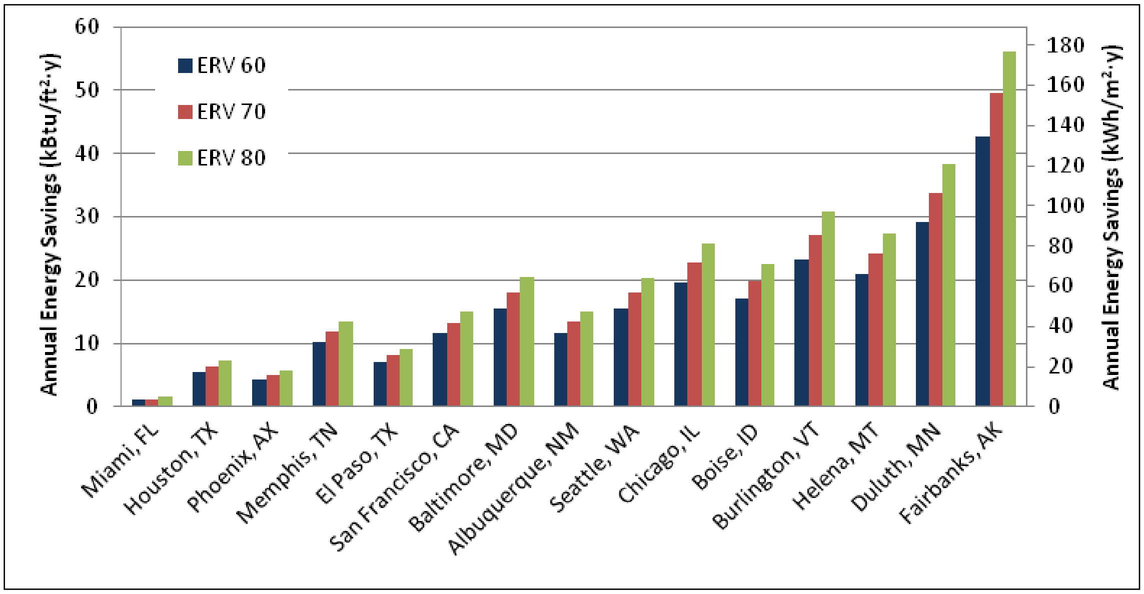

Figure 4.58. Annual energy savings for ERVs.

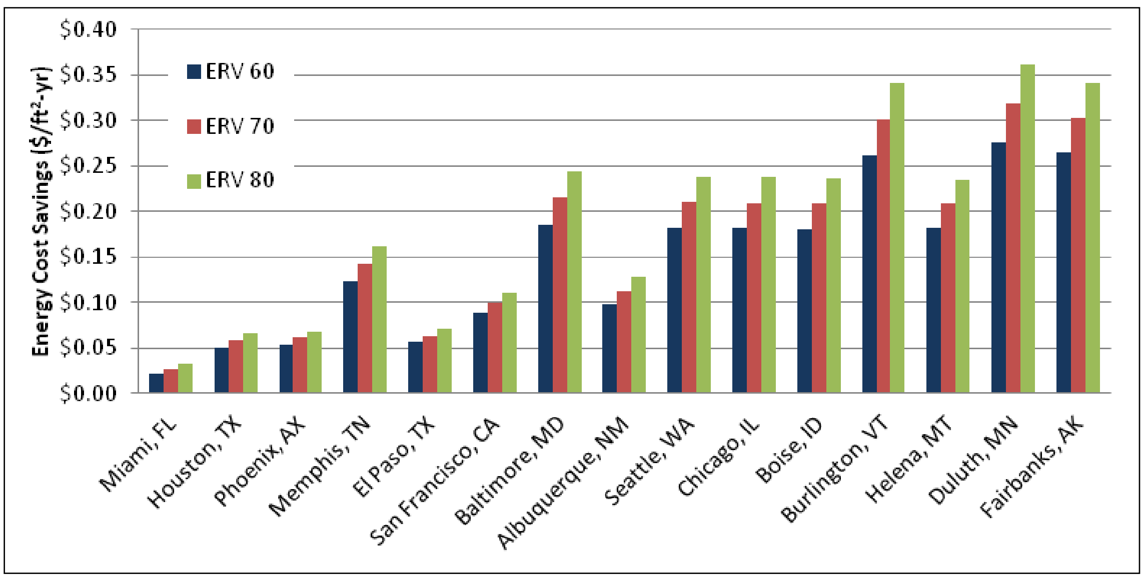

Figure 4.59. Annual energy cost savings for ERVs.

4.3.11 Indirect evaporative cooling

A retrofit with the addition of an indirect evaporative cooling (IDEC) system was simulated as a preconditioner of the outdoor air before mixing at the outdoor air mixing device. In this study, each packaged system had its own evaporative cooler. This arrangement of adding an IDEC to each packaged DX system is probably not viable, but the impact on the energy performance is similar to having a central system with and the same IDEC arrangement.

The systems were modeled using the outside air and the return air as the secondary air stream for the IDEC. The return-air strategy provided the best results, and these are the only results included in this report. The IDEC was bypassed when in heating mode to reduce the pressure drop on the fan. In order to maximize the benefit of the evaporative cooler, economizer controls where used to increase the outdoor air fraction under favorable conditions; however, the economizer control strategy was not optimized and it is believed that there are missed opportunities for economizing in some climates. Better economizing logic is expected to further improve the benefit of this technology in favorable locations. The model parameters are shown in Table 4.12 and a schematic of the main HVAC components of the evaporative cooling retrofit is shown in Figure 4.60.

It is possible to use the IDEC as a heat exchanger for heat recovery when in heating mode if return air is used as the secondary air stream. The energy savings for this arrangement was approximated by estimating the gas energy savings from the ERV simulations. It was assumed that the gas energy savings would be half of the gas energy savings from the ERV 60 (60% effective) simulations.

Table 4.12. IDEC model parameters.

Wet Bulb Effectiveness	Primary Air Pressure Drop in w.g. (Pa)	Secondary Air Pressure Drop in w.g. (Pa)	Fan Efficiency
0.75	0.75 (187)	0.5 (125)	0.5

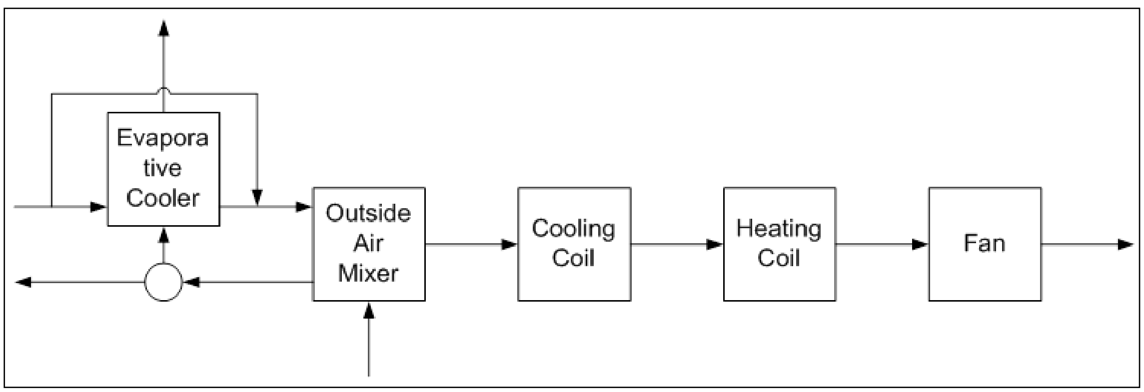

Figure 4.60. Schematic of the indirect evaporative cooling model (credit: Kyle Benne).

The results for the US locations for the IDEC and the IDEC + ERV are shown in Figures 4.61 through 4.63. The best climates for evaporative cooling are the hot and dry locations. In particular, Phoenix, El Paso, and Albuquerque are good climates for evaporative. International locations were not simulated, because with the exception of Canada, they do not have air-conditioning in the barracks facility.

The estimated performance of the IDEC with energy recovery in heating mode is also shown in the figures. The performance showed significant additional savings in the cold climates; however, it only makes sense to combine the IDEC with an ERV in climates that show good savings in cooling and heating energy.

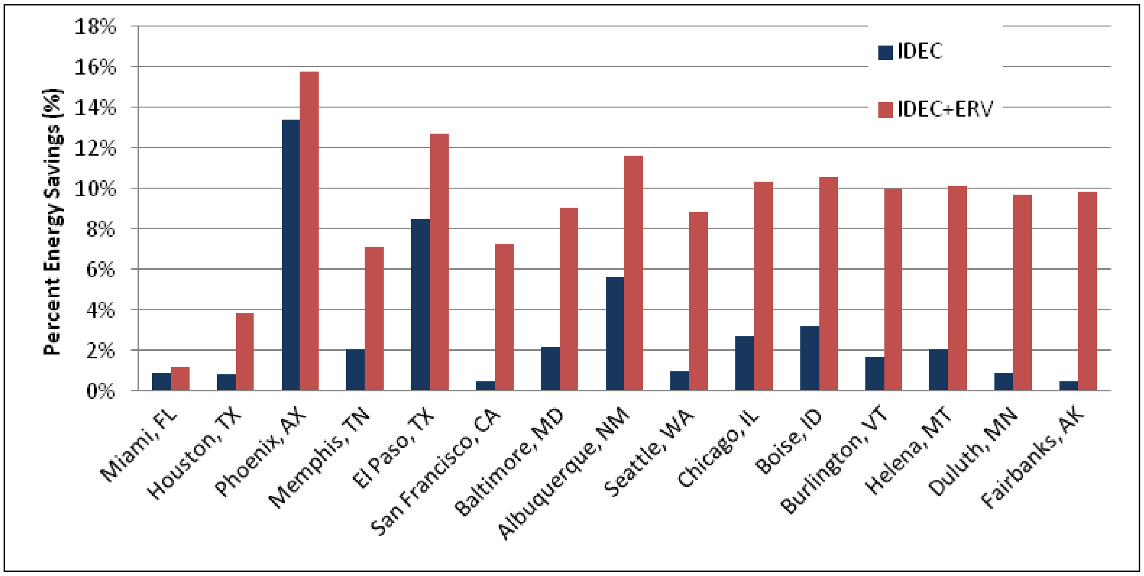

Figure 4.61. Percent energy savings for indirect evaporative cooling and indirect evaporative cooling with energy recovery.

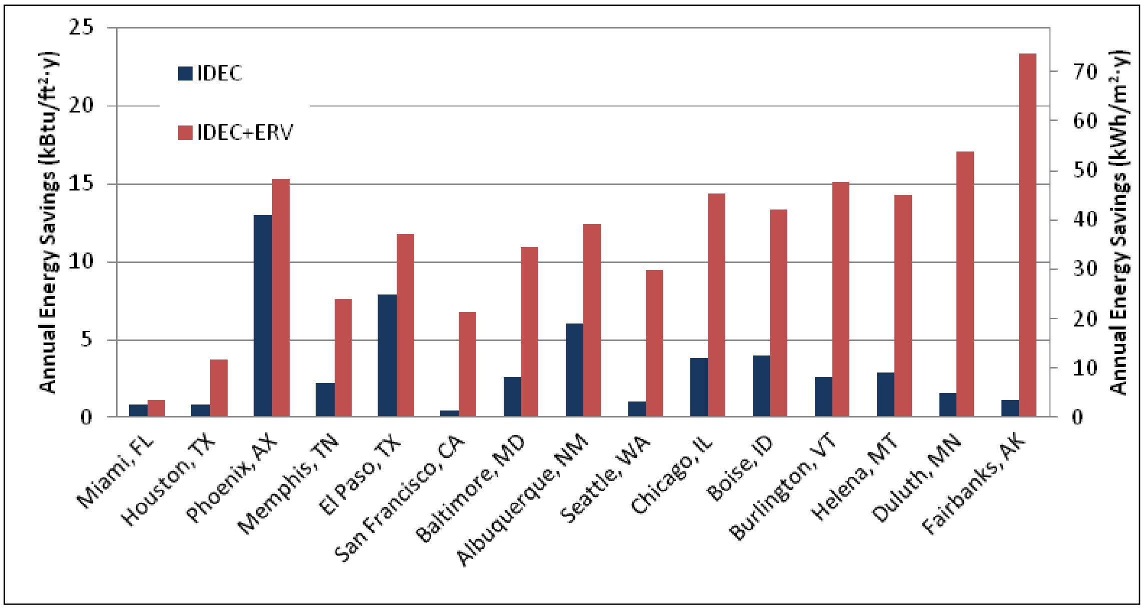

Figure 4.62. Annual energy savings for indirect evaporative cooling and indirect evaporative cooling with energy recovery.

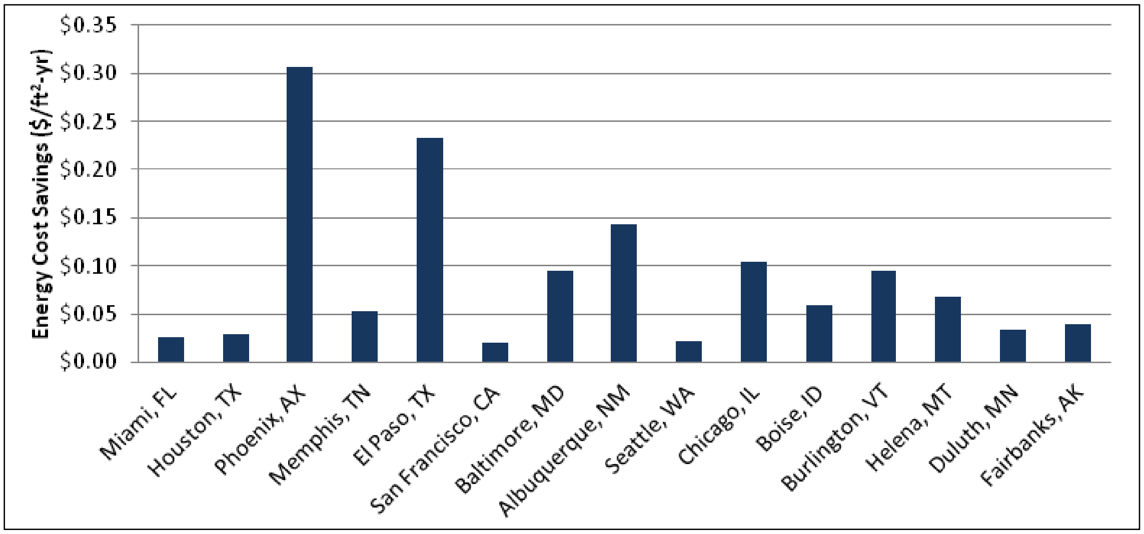

Figure 4.63. Annual energy cost savings for indirect evaporative cooling.

4.3.12 Hybrid evaporative cooling

A retrofit of a hybrid evaporative cooling system was simulated to improve on the strategy of indirect evaporative cooling. The hybrid system consists of an indirect evaporative cooling component followed immediately by a direct evaporative cooling component. Aside from the additional component, this hybrid system was configured and controlled identically to the previous indirect evaporative cooling system. The direct component was modeled using a wet bulb effectiveness of 0.90.

The same hot dry locations favorable for indirect evaporative cooling show potential with the hybrid system, but adding the direct component boosts the overall performance of the system significantly. High humidity is however, even more of a concern with a direct evaporative cooling component, and it is not recommended in humid locations. The European locations were not simulated because they do not have air-conditioning in the barracks facility.

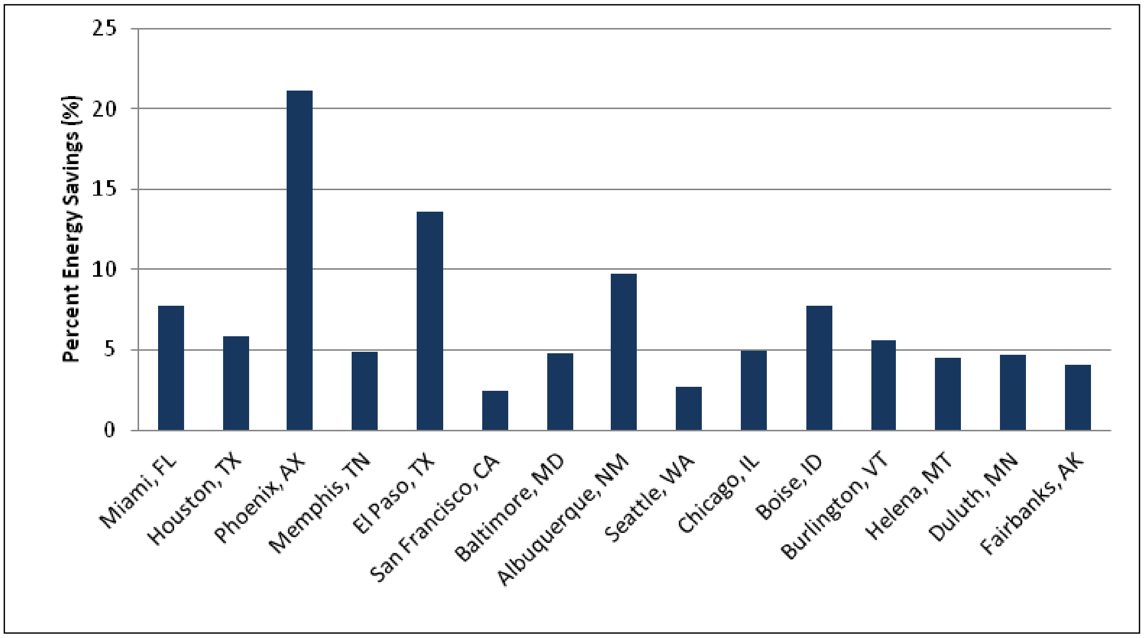

Figure 4.64. Percent energy savings for hybrid evaporative cooling.

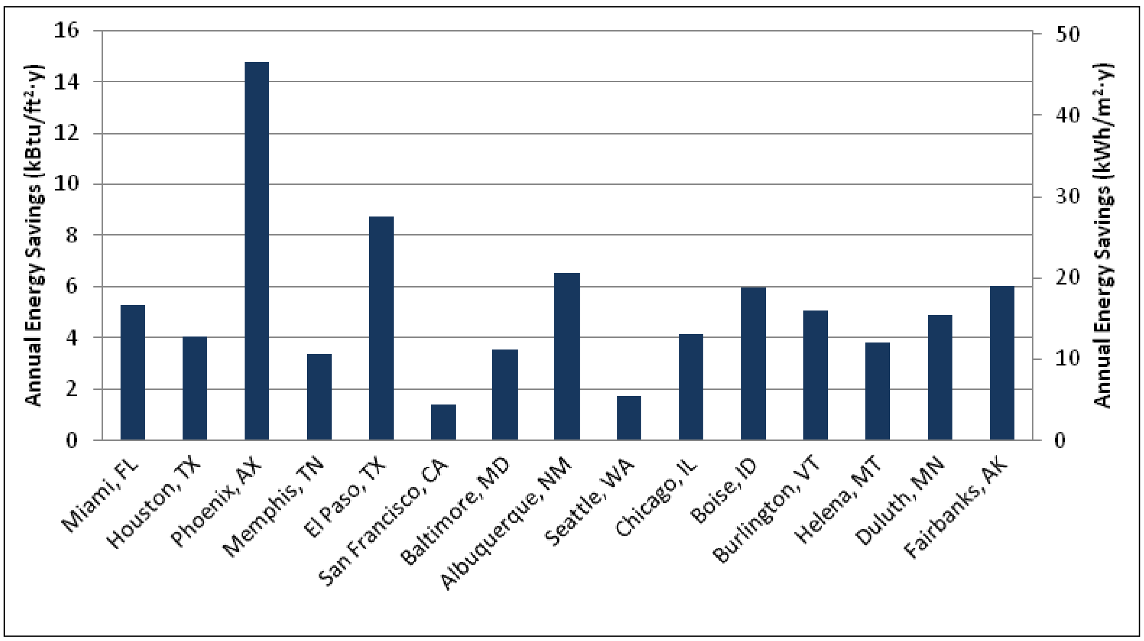

Figure 4.65. Annual energy savings for hybrid evaporative cooling.

4.3.13 DOAS with fan-coil unit (FCU)

A DOAS in combination with a four-pipe FCU was simulated as a potential retrofit to the barracks building. Only the US locations were simulated with this technology. The DOAS consisted of central heating and cooling coils served by a gas-fired boiler and an air-cooled chiller. The DOAS is a constant volume system that provides the minimum ventilation air only during the office hours of operation. The supply-air temperature of the DOAS is governed by an outside air reset. The DOAS provides minimal heating through water coils supplied by a gas boiler and a small amount of cooling through a chilled water coil supplied by an air-cooled chiller. A key component of the DOAS is an energy recovery device between the outdoor air and relief air streams. The water loops feeding the DOAS are separate from the FCU system.

The results for this system are shown in Figures 4.66 through 4.68. Energy savings were achieved in all climates with the most significant energy savings in cold climates reflecting the benefit of the heat recovery. Energy savings in warm climates were modest and attributed to slightly better cooling efficiency of the chiller relative to the DX cooling system in the baseline. In all locations, there was an increase in electricity consumption from increased fan energy because of the increased pressure drop and a decrease in gas consumption because of the energy recovery component. The trade off of gas savings and electricity increase results in moderate energy cost savings in most locations and an energy cost increase in San Francisco. Improved performance could be achieved with alternative system configurations and control strategies that minimizes the fan energy and optimizes the delivery of the space conditioning supply air. Systems design and operation for specific climates and applications are important for the best performance.

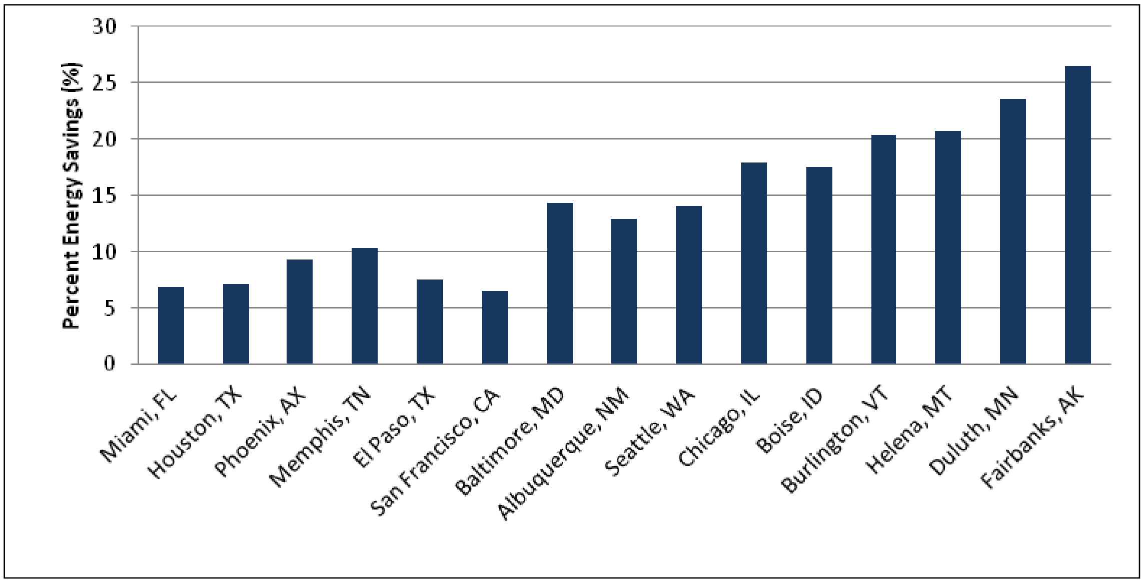

Figure 4.66. Percent energy savings for DOAS with FCU.

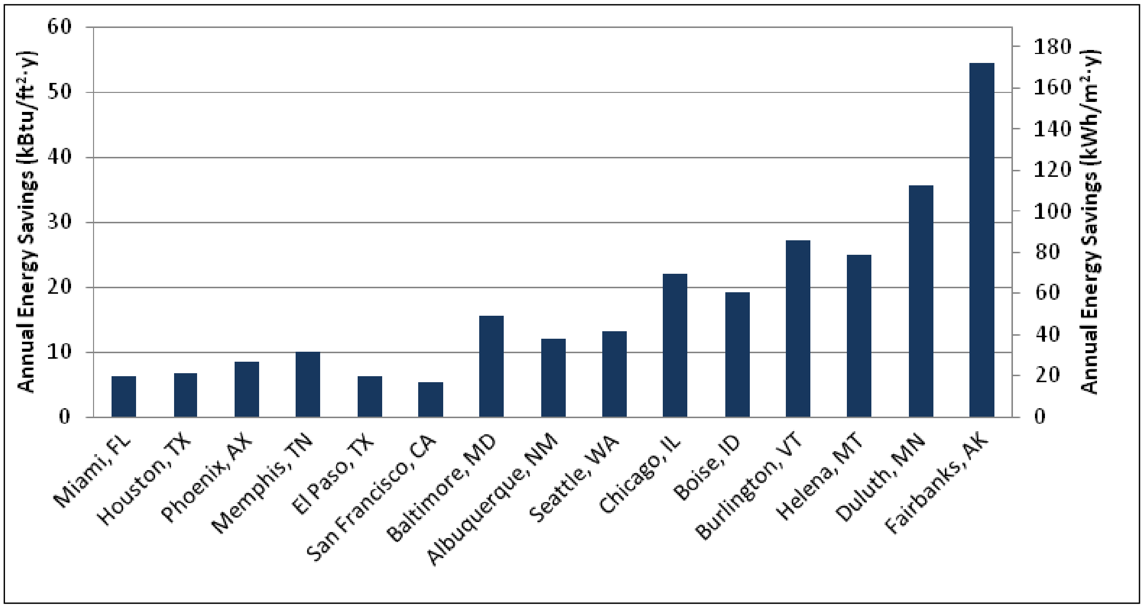

Figure 4.67. Annual energy savings for DOAS with FCU.

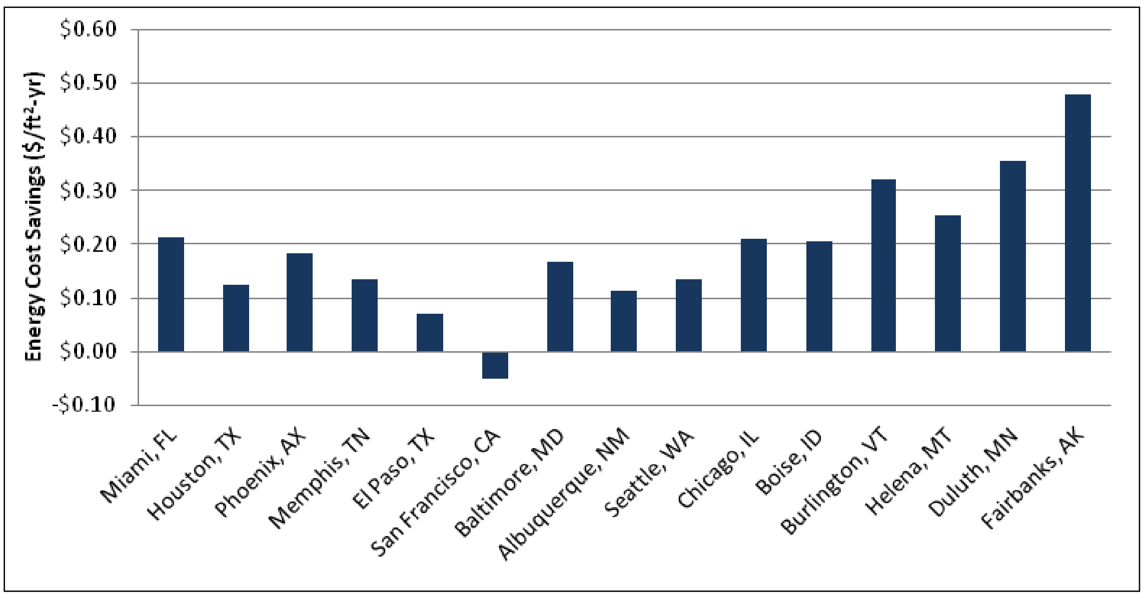

Figure 4.68. Annual energy cost savings for DOAS with FCU.

4.3.14 DOAS with radiant heating and cooling

A DOAS in combination with radiant heating and cooling was evaluated. The DOAS of this retrofit was identical to the system model for the DOAS with FCU case. The radiant system consisted of actively heated and cooled panels embedded into the ceiling. The radiant panels are served by chilled water from a water-cooled chiller, and hot water from a gas boiler. The radiant system is controlled by mean radiant temperature instead of average space temperature as in the baseline system, which translates to a looser space temperature requirement while maintaining similar or perhaps even better comfort. The radiant system was controlled to turn off during cooling mode if the surface temperature reached the space dew point temperature to avoid condensation.

The results for this system are shown in Figures 4.69 through 4.75. Simulations show significant energy savings in all US locations and mixed results for the non-US locations. There are three driving factors for the observed energy savings of the radiant system retrofit. One is that there is reduced fan energy for the DOAS system with radiant heating and cooling as compared to the baseline system. Second, the ERV reduces some of the load on the system especially in the colder climates. Finally, the mean radiant temperature control of the radiant system allowed a wider variation in the dry bulb temperature.

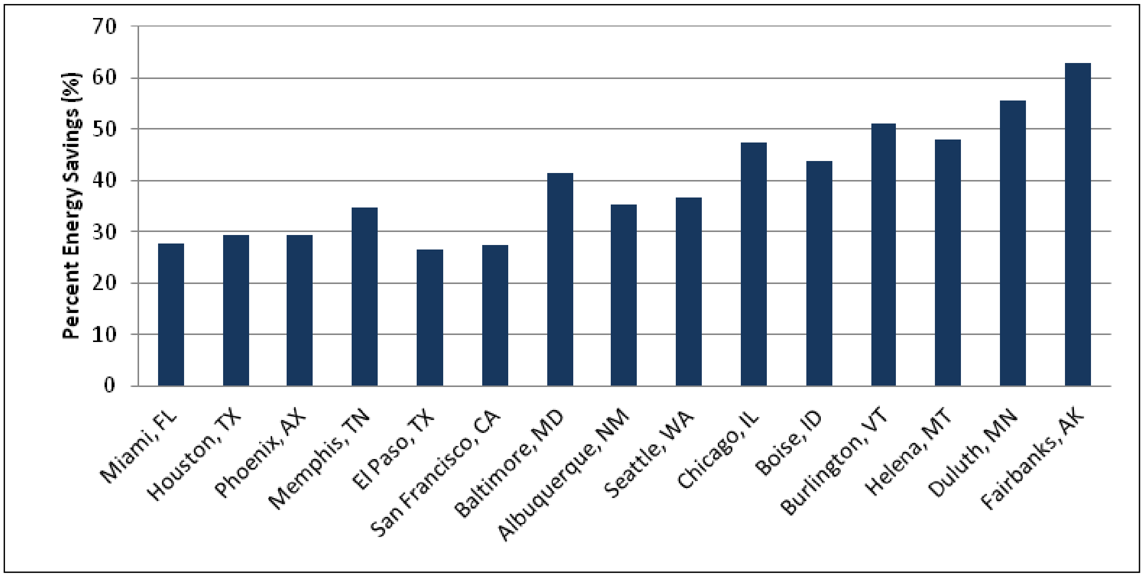

Figure 4.69. Percent energy savings for DOAS with radiant heating and cooling.

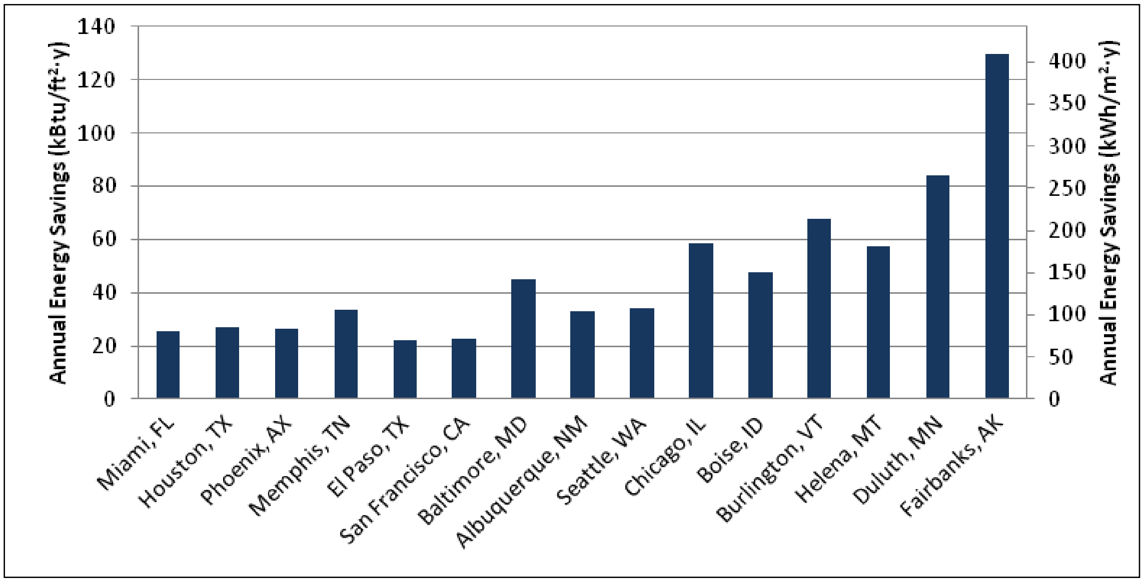

Figure 4.70. Annual energy savings for DOAS with radiant heating and cooling.

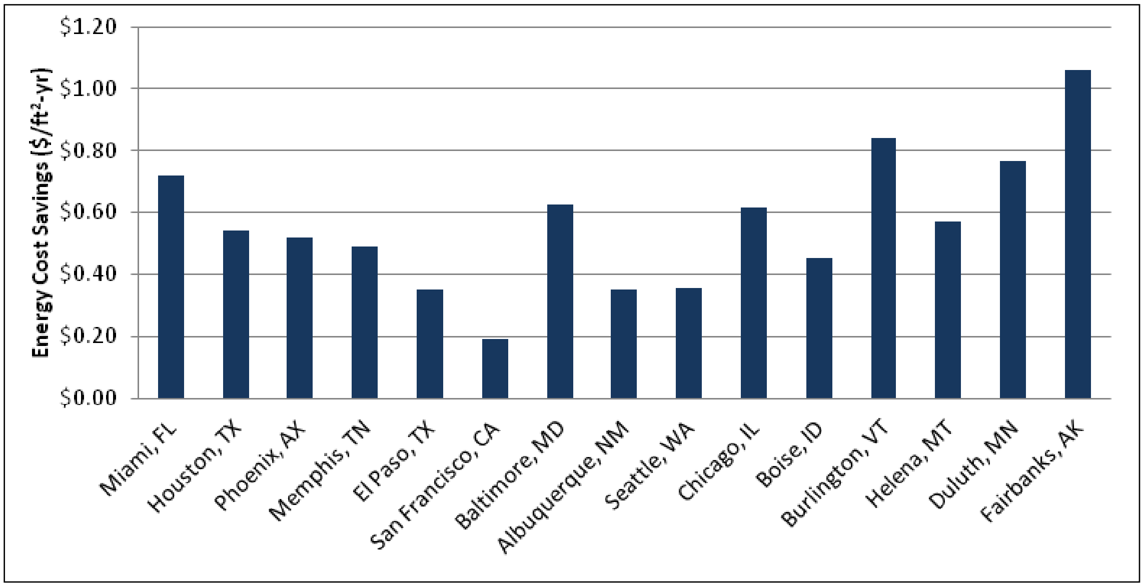

Figure 4.71. Annual energy cost savings for DOAS with radiant heating and cooling.

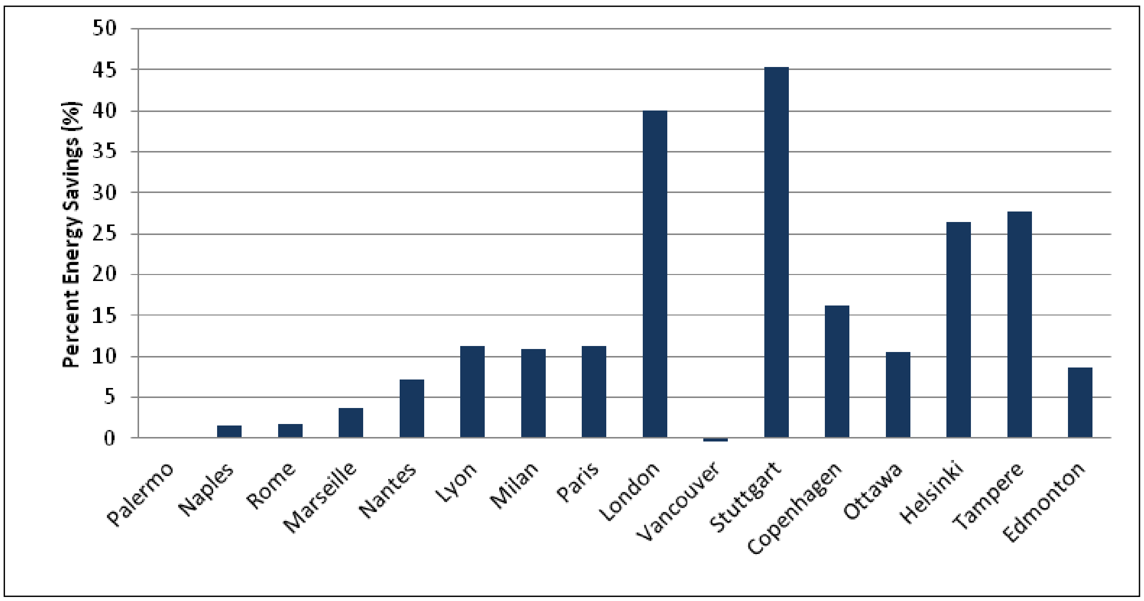

Figure 4.72. Percent energy savings for DOAS with radiant heating and cooling – international locations.

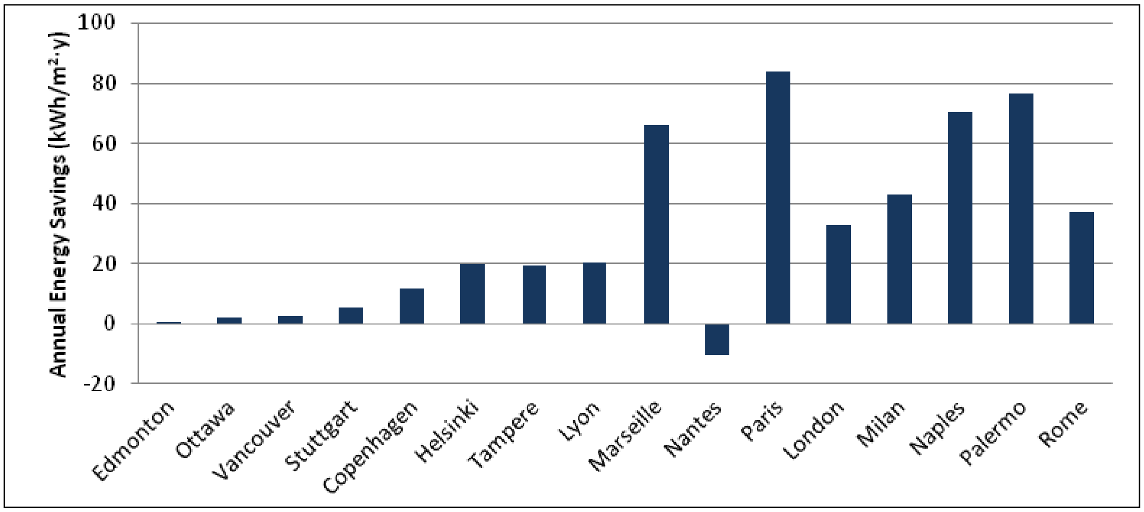

Figure 4.73. Annual energy savings for DOAS with radiant heating and cooling – international locations.

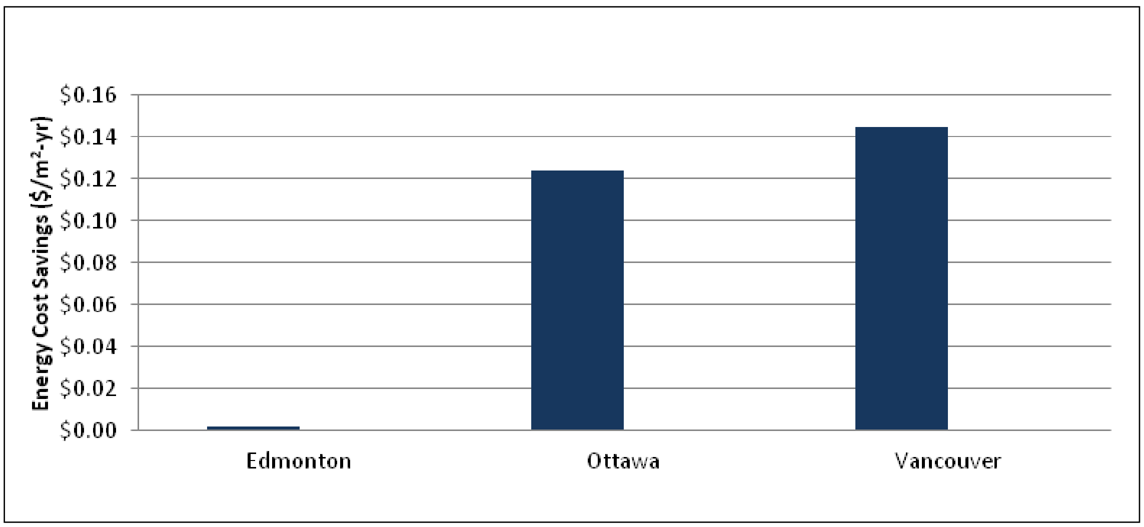

Figure 4.74. Annual energy cost savings for DOAS with radiant heating and cooling – Canadian locations.

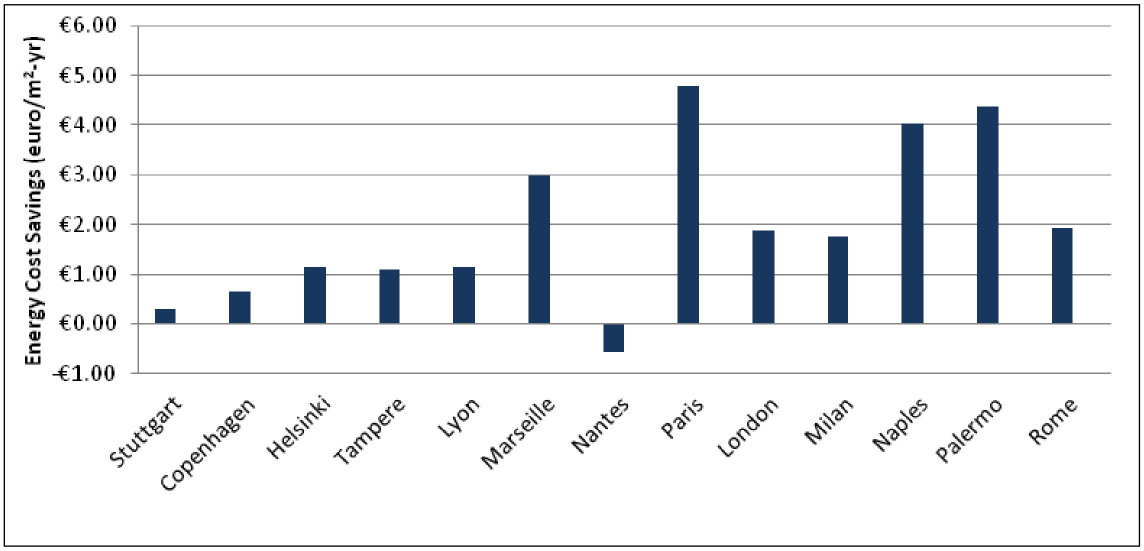

Figure 4.75. Annual energy cost savings for DOAS with radiant heating and cooling – European locations.

4.3.15 Ground source heat pumps

Ground source heat pumps (GSHPs) were modeled as packaged single zone systems served by a common ground water loop with an auxiliary fluid cooler and boiler in case loop temperatures exceed allowed limits. In some regards, the packaged single zone systems could be viewed as a step backwards from the multizone, central plant setup of the US baseline. Certainly, a multizone GSHP system is realistic in practice and in EnergyPlus; however, the NREL software tools that were used for this project are not equipped to generate such models. The single zone GSHP used in this work is considered adequate to gauge the potential value of a GSHP system, regardless of the air-handling technology. The results presented in this section should be considered preliminary estimates because the energy models for the ground loops and the connection to EnergyPlus are the least understood and tested of all the energy models in this report.

GSHPs combine efficient vapor compression refrigeration systems with a relatively constant heat source and heat sink temperature, which can provide superior performance to the typical HVAC system of air-cooled DX and natural gas furnace. However, pumping energy can be significant and should be considered carefully in the design and operation of these systems. Vertical U-tube heat exchangers were considered for this study with six bore-field sizes ranging from 25 bores (5 by 5) up to 130 bores (10 by 13). All bores were simulated to reach a depth of 250 feet. In addition, a standard ground material composition was simulated for all locations. In reality, ground composition can vary substantially depending on the location. The performance of the bore fields were modeled with GLHEPRO 4.0 (OSU 2009) with the results supplied to EnergyPlus for the building modeling.

The results are shown in Figures 4.76 and 4.77. The system produced significant energy savings in all climates, especially the colder climates. The results are somewhat surprising and should be taken as preliminary estimates. The bore-field size seemed to have little impact on the savings relative to the change in size. Some of this is due to the tradeoff between heating and cooling efficiency gains and the increased pumping energy. However, it may be that the energy models are not fully capturing the heat transfer with the ground loops.

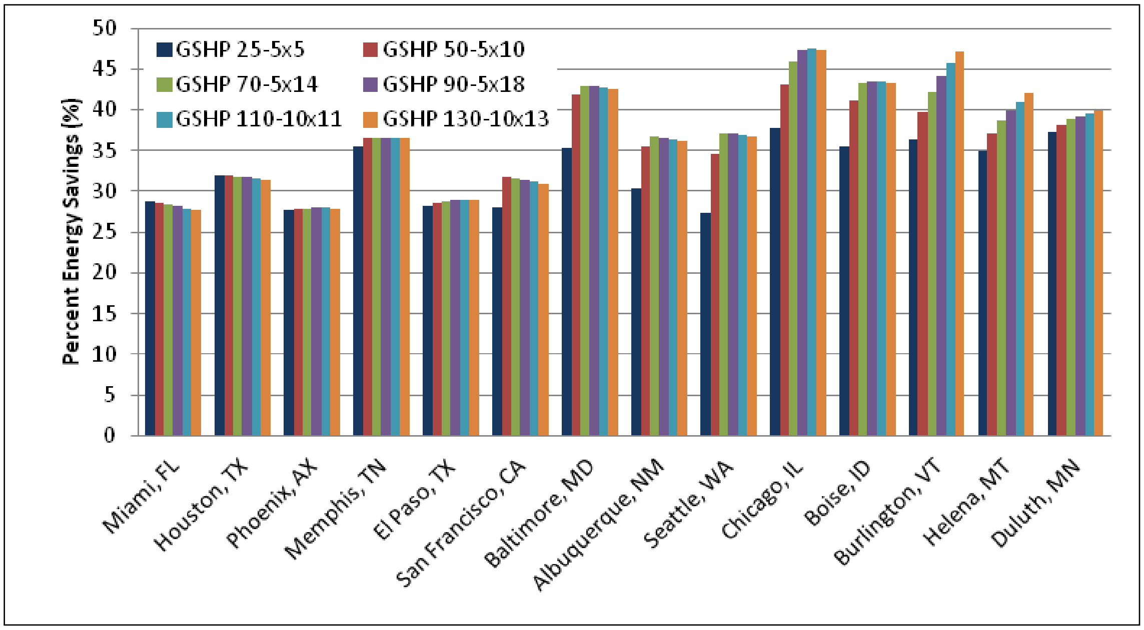

Figure 4.76. Percent energy savings for GSHPs.

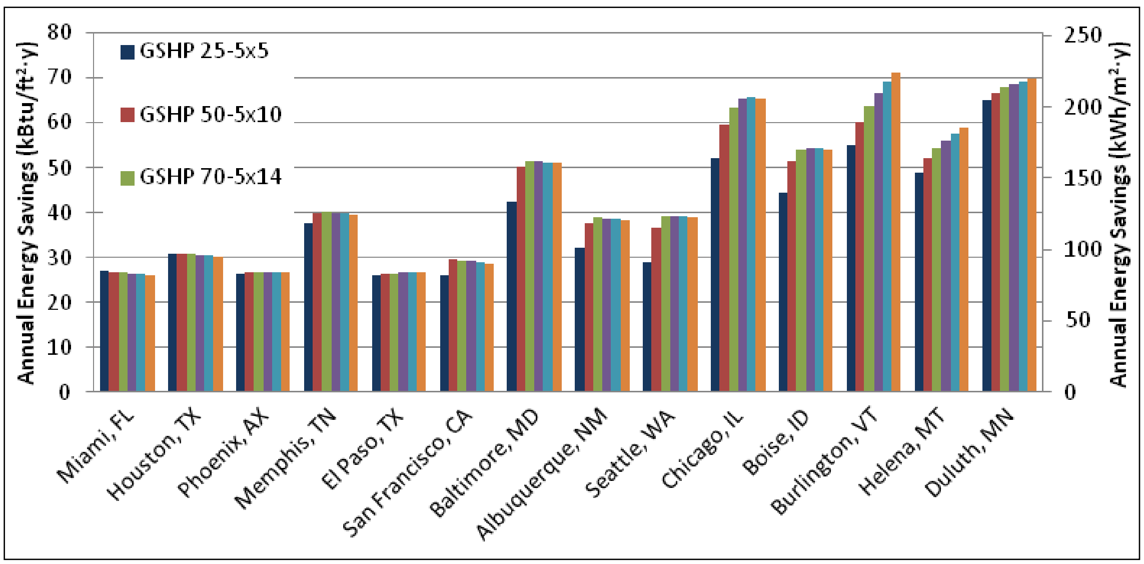

Figure 4.77. Annual energy savings for GSHPs.

4.3.16 Reheat using condenser waste heat

The baseline barracks facility used in this study consists of packaged single zone systems that do not actively control humidity, which results in high humidity levels and potential comfort problems. The benefit of retrofitting the barracks facility with DX systems with humidity control using condenser waste heat-recovery system was evaluated by first creating a new baseline with a system that used humidistats and electric reheat. This revised baseline system uses more energy due to increased cooling and reheat; however, buildings in humid climates were also much drier. International locations were not simulated, because with the exception of Canada, they do not have air-conditioning in the barracks facility.

The results are shown in Figure 4.78 and 4.79. There are significant savings in the warm-humid climate zones and almost no effect in the dry climate zones. There are other technologies for humidity control such as desiccants, which should be evaluated to determine the best solution for specific applications.

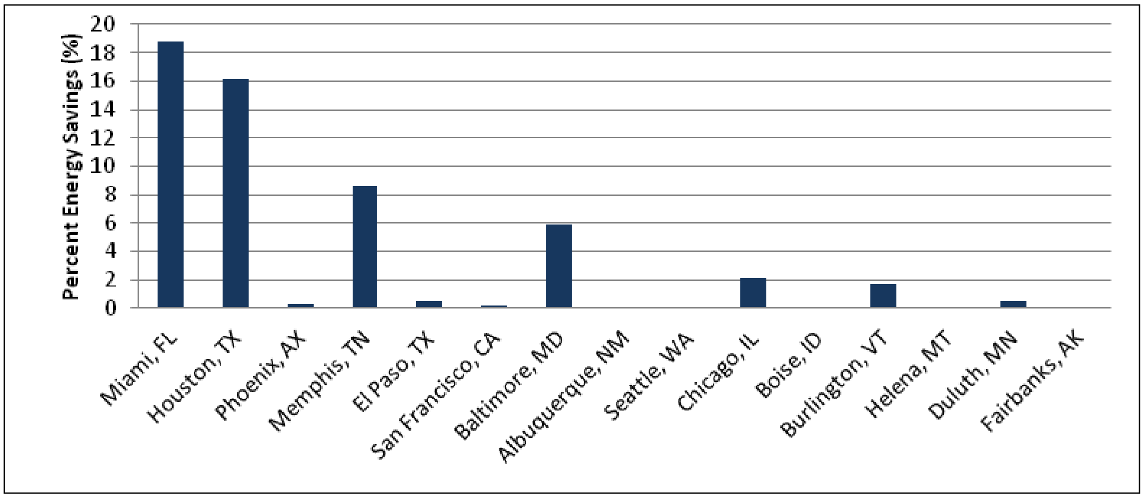

Figure 4.78. Percent energy savings for reheat using condenser waste heat.

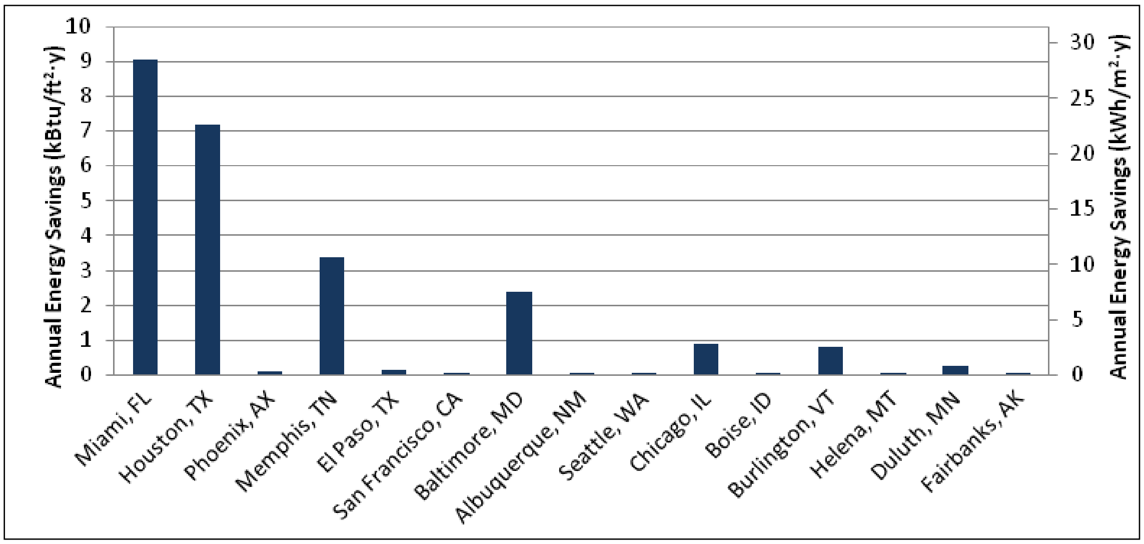

Figure 4.79. Annual energy savings for reheat using condenser waste heat.

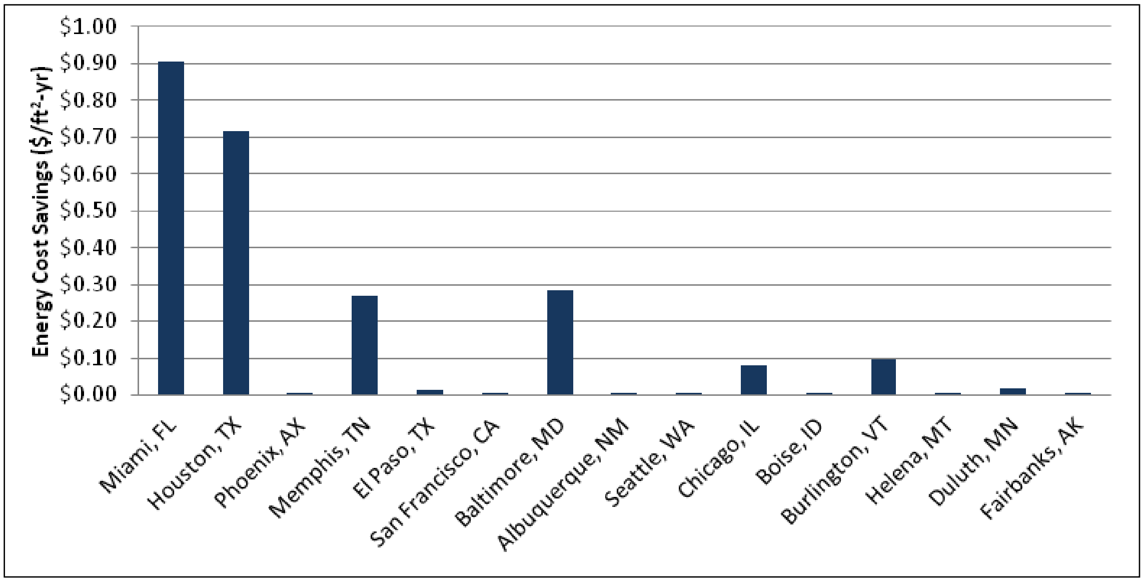

Figure 4.80. Annual energy cost savings for reheat using condenser waste heat.

4.3.17 Grey Water Heat Recovery

4.4 Office Buildings

4.4.1 Increased Wall Insulation

This section presents the effects of retrofitting the exterior walls with additional insulation. Insulation with an R-value of 3.85 ft^2·h·°F/Btu per inch (0.347 m^2·K/W per cm) was added in increments of 1, 2, 4, 6, and 8 in (2.5, 5, 10, 15, and 20 cm). For this study an additional baseline building was created with zero insulation in the walls. In addition, it was assumed that adding wall insulation would improve the airtightness from the baseline by 15%. One set of cases were run with the added insulation over the 901.1989 baseline and no change in the infiltration.

Table 4.13. Wall insulation ECM overview.

Wall Construction	Additional Insulation (ft²·hr·°F/Btu)	Air Leakage	
		(cfm/ft² @ 0.3 in w.g.)	(L/s/m² @ 75 Pa)
Baseline (90.1-1989 insulation)	-	1.00	5.1
No insulation	-	1.00	5.1
1989 Baseline with 1 in (2.5 cm) insulation	R-3.85	1.00	5.1
1989 Baseline with 2 in (5 cm) insulation	R-7.7	1.00	5.1
1989 Baseline with 4 in (10 cm) insulation	R-15.4	1.00	5.1
1989 Baseline with 6 in (15 cm) insulation	R-23.1	1.00	5.1
1989 Baseline with 8 in (20 cm) insulation	R-30.8	1.00	5.1
1989 Baseline with 1 in (2.5 cm) insulation	R-3.85	0.85	4.3
1989 Baseline with 2 in (5 cm) insulation	R-7.7	0.85	4.3
1989 Baseline with 4 in (10 cm) insulation	R-15.4	0.85	4.3
1989 Baseline with 6 in (15 cm) insulation	R-23.1	0.85	4.3
1989 Baseline with 8 in (20 cm) insulation	R-30.8	0.85	4.3
Zero Baseline with 1 in (2.5 cm) insulation	R-3.85	0.85	4.3

Zero Baseline with 2 in (5 cm) insulation	R-7.7	0.85	4.3
Zero Baseline with 4 in (10 cm) insulation	R-15.4	0.85	4.3
Zero Baseline with 6 in (15 cm) insulation	R-23.1	0.85	4.3
Zero Baseline with 8 in (20 cm) insulation	R-30.8	0.85	4.3

The results of the simulations are shown in Figures 4.81 through 4.94. The percent energy savings and the area normalized energy and energy cost savings are shown for all locations and compared to the standard baseline insulation case and the no-insulation case. Most of the energy savings is achieved with the first one inch (2.5 cm) of insulation; however, significant savings are achieved with additional insulation. The overall energy savings for the U.S. locations above the 90.1-1989 baseline ranges from 5% to 20%, and the overall energy savings above the no-insulation baseline varies from 10% to 40%. For the international locations, the overall energy savings compared to the no-insulation baseline varies between 1% and 25%. Insulation in the Italy locations showed very little energy savings.

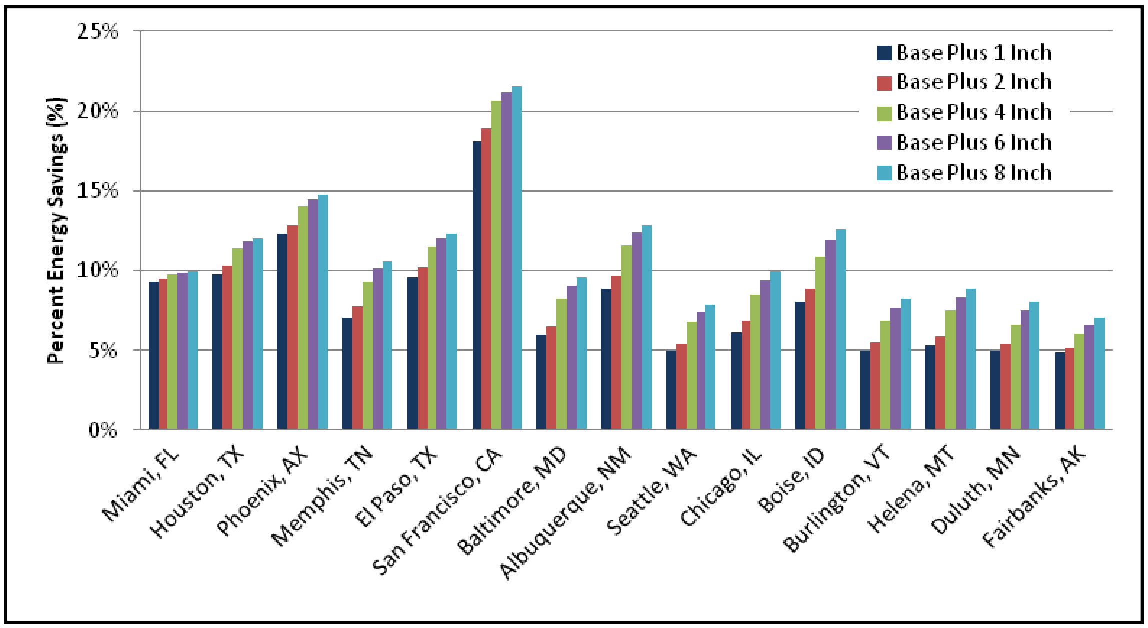

Figure 4.81. Percent energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

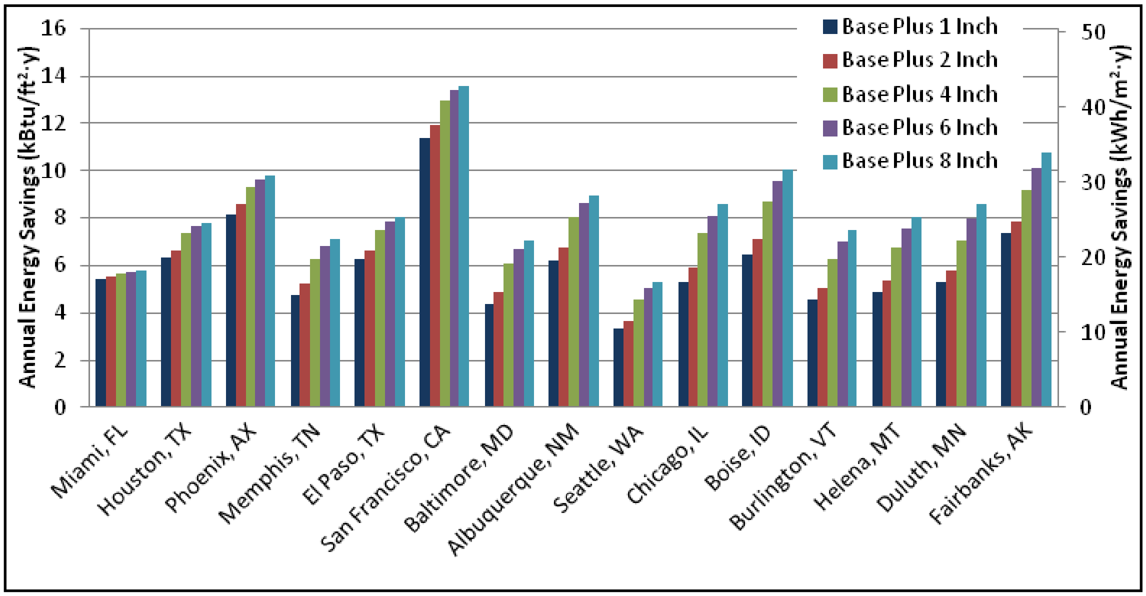

Figure 4.82. Energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

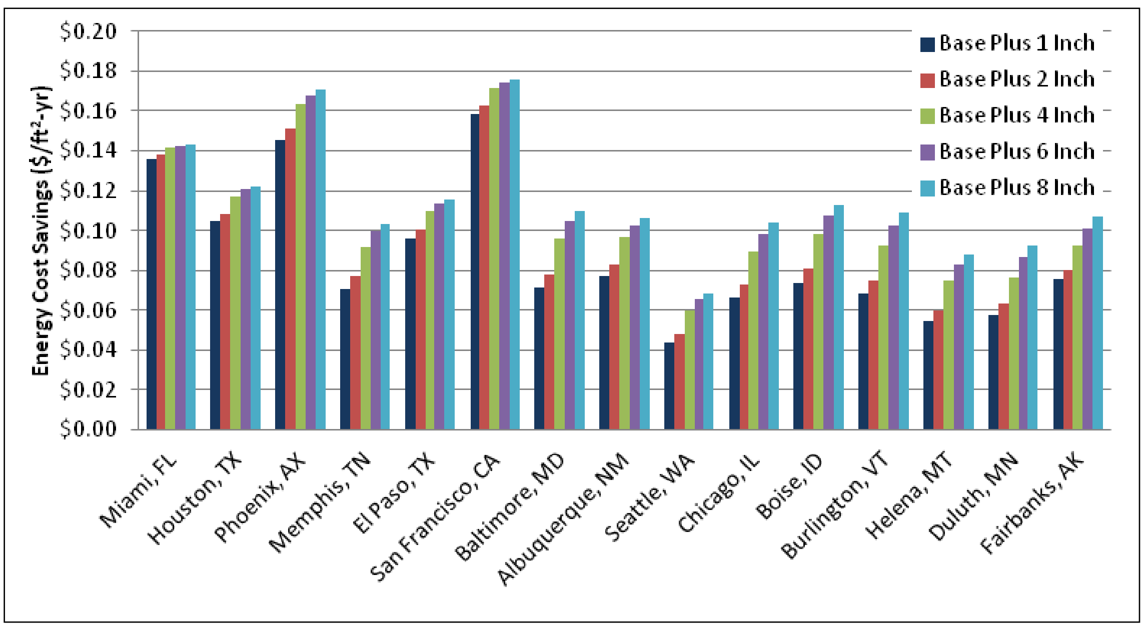

Figure 4.83. Energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

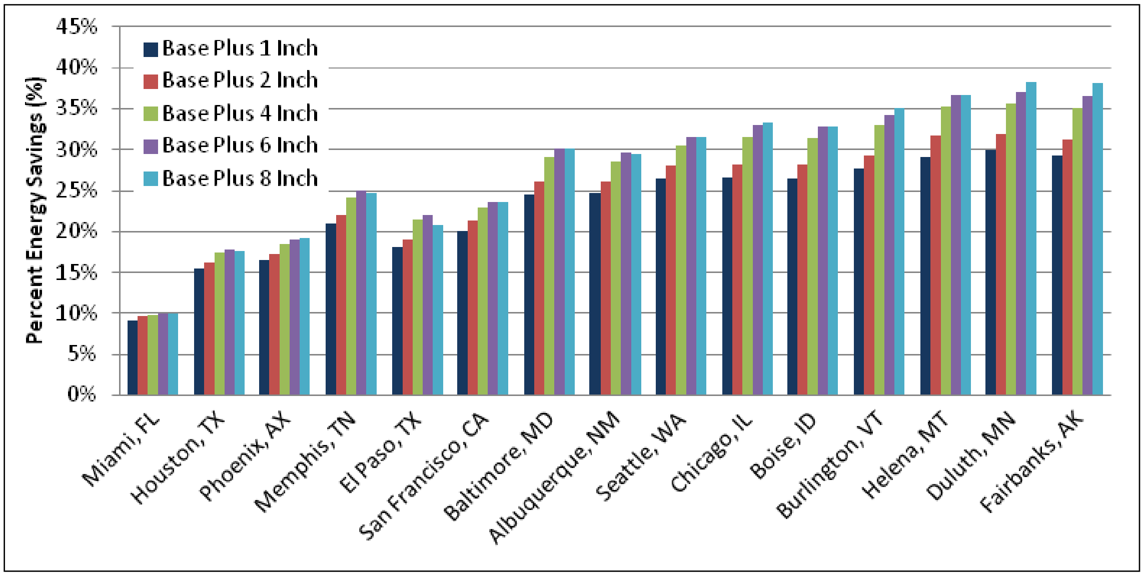

Figure 4.84. Percent energy savings for wall insulation and reduced infiltration over the no-insulation baseline.

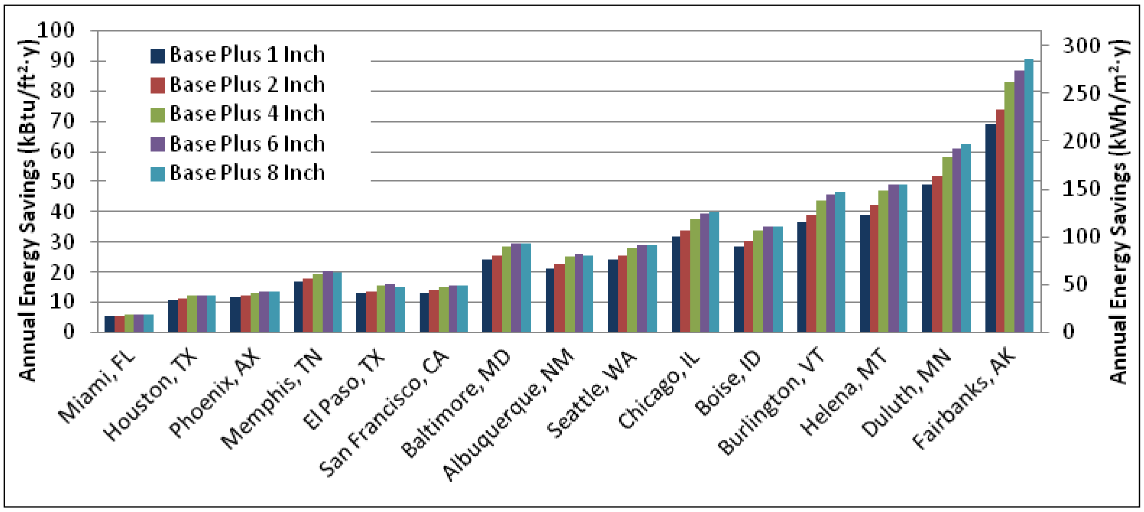

Figure 4.85. Energy savings for wall insulation and reduced infiltration over the no-insulation baseline.

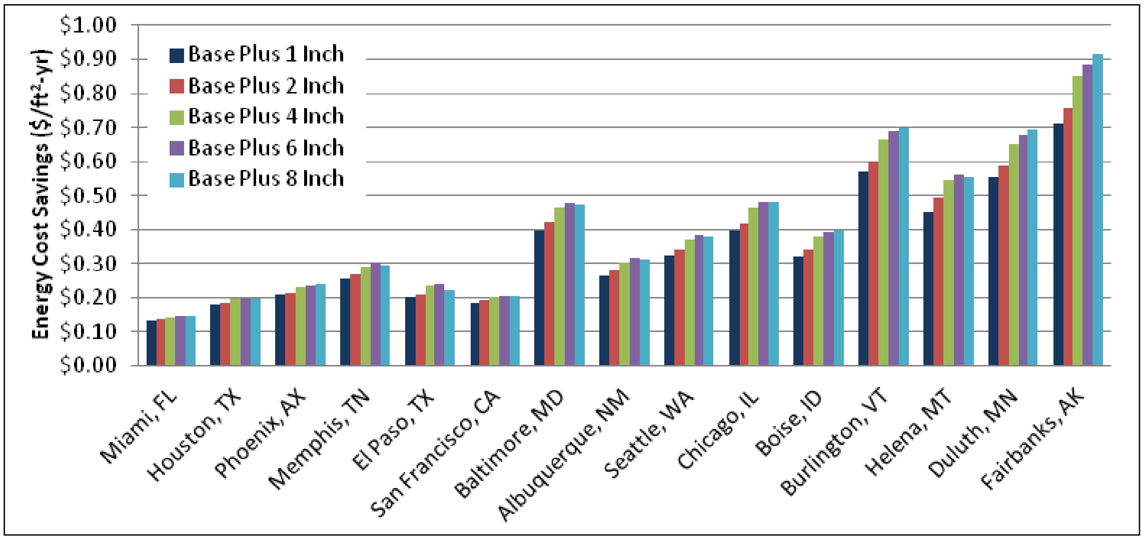

Figure 4.86. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline.

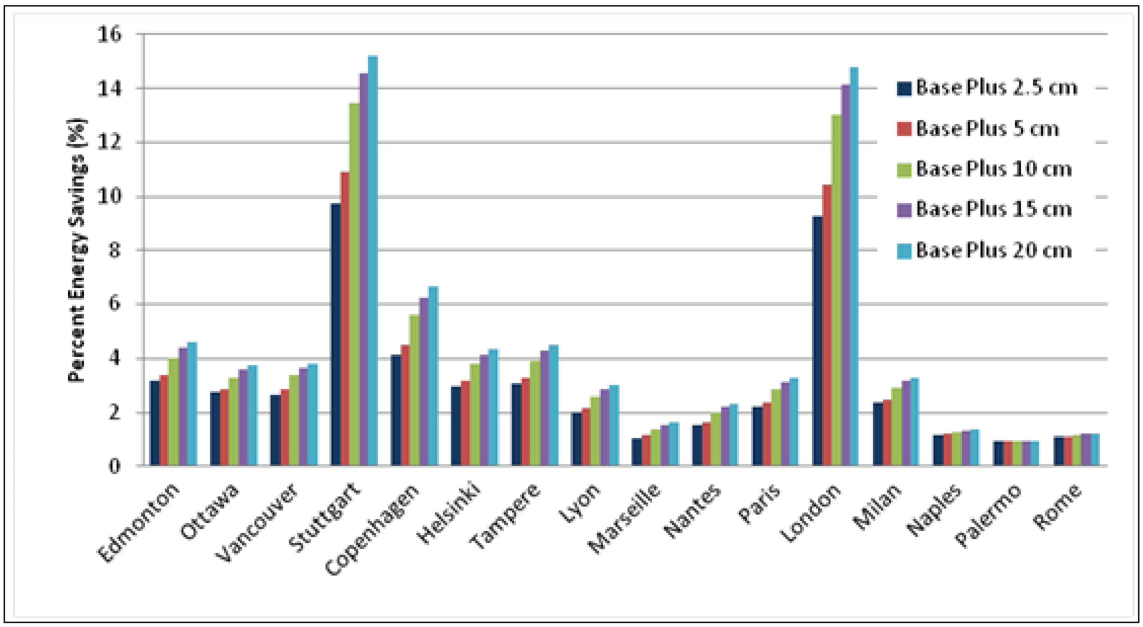

Figure 4.87. Percent energy savings for wall insulation and reduced infiltration over the standard baseline – international locations.

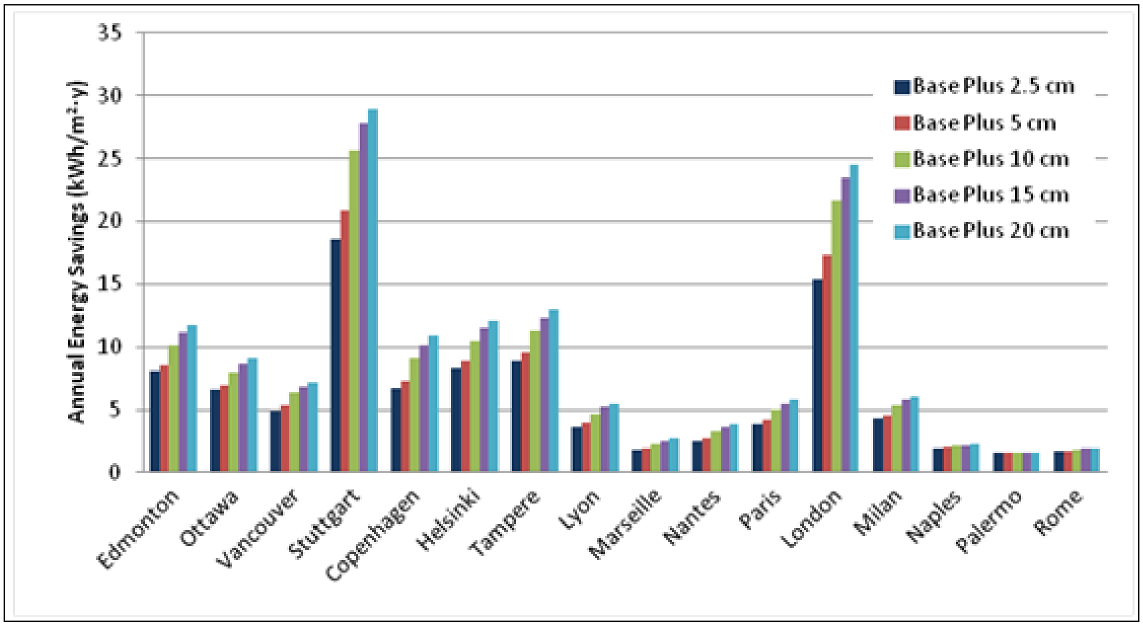

Figure 4.88. Energy savings for wall insulation and reduced infiltration over the standard baseline – international locations.

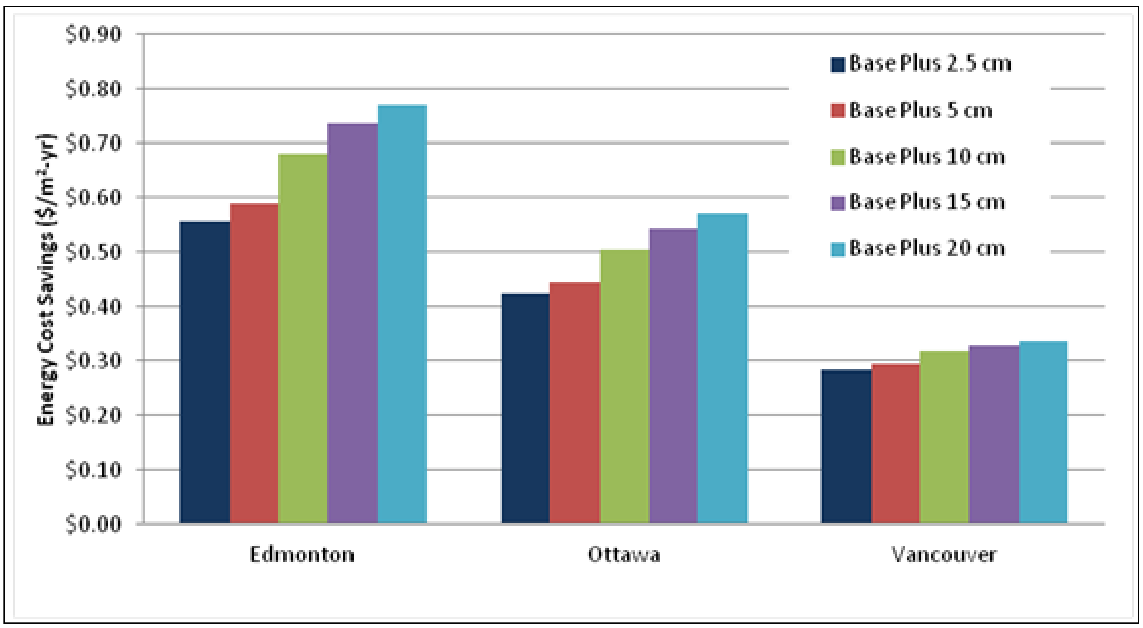

Figure 4.89. Energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline – Canadian locations.

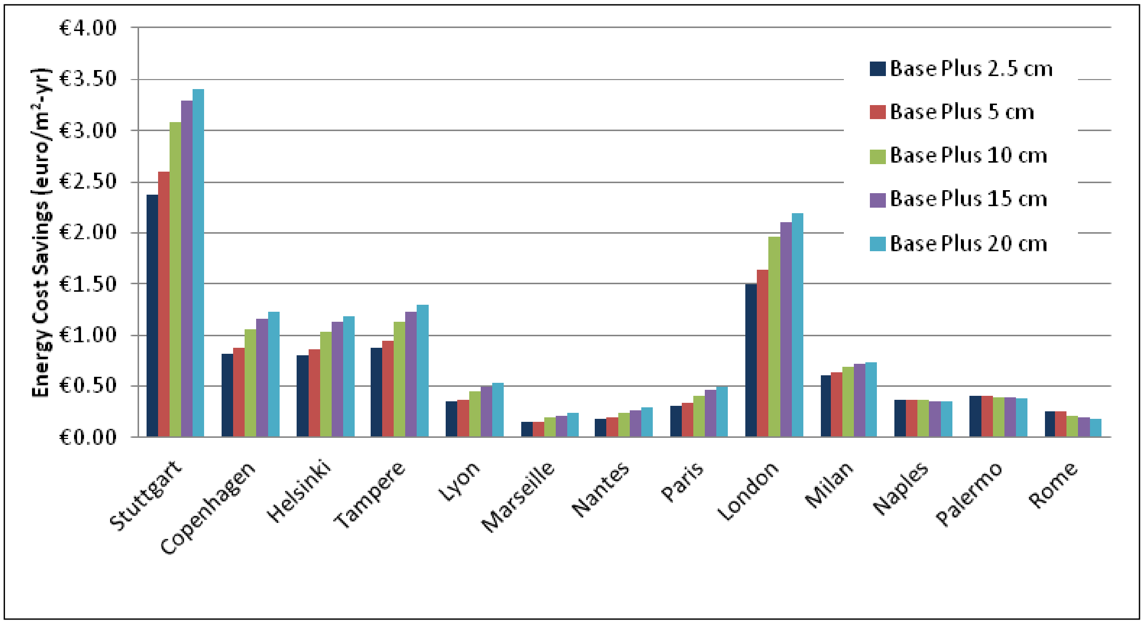

Figure 4.90. Energy cost savings for wall insulation and reduced infiltration over the standard baseline – European locations.

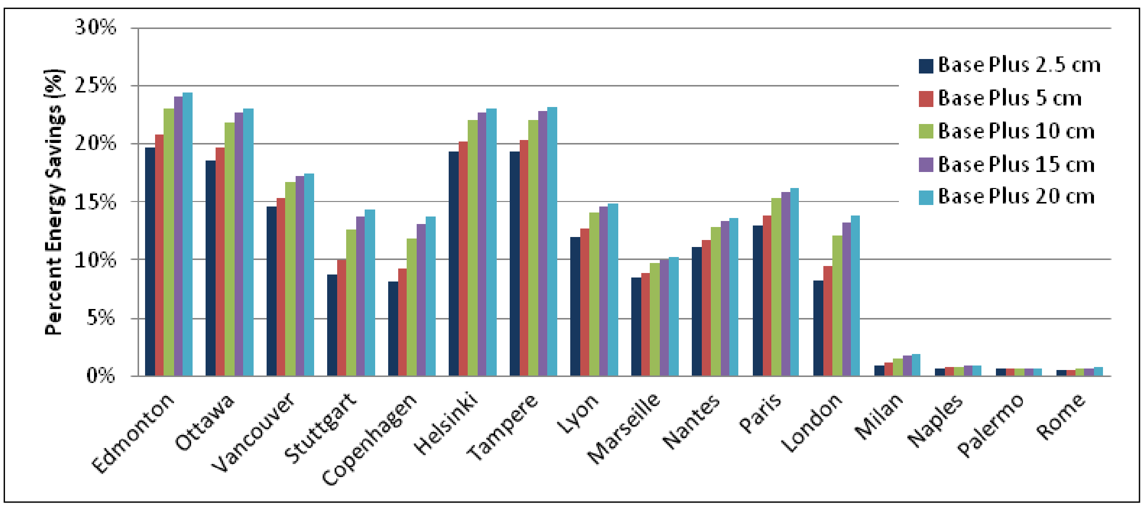

Figure 4.91. Percent energy savings for wall insulation and reduced infiltration over the no-insulation baseline – International locations.

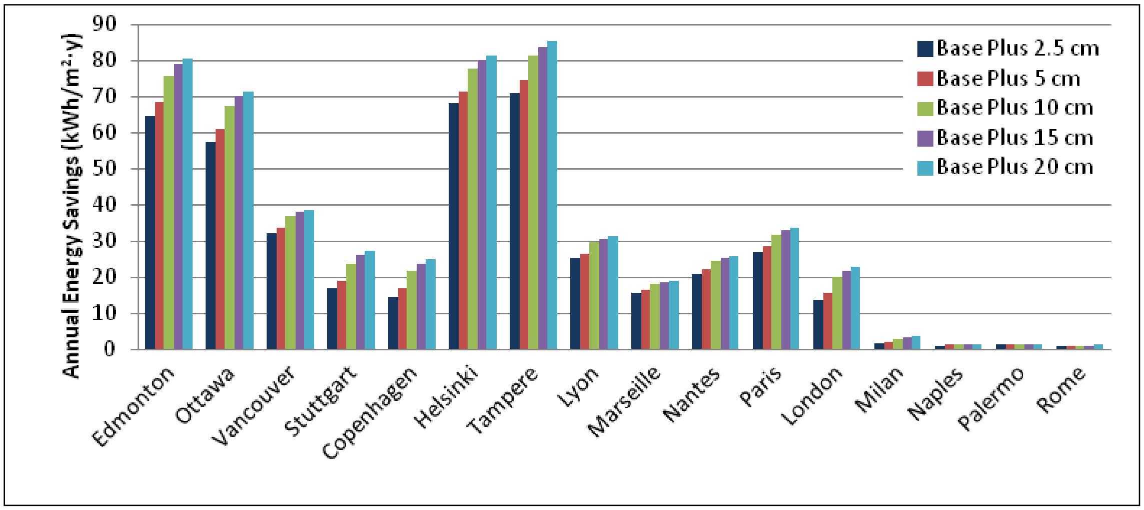

Figure 4.92. Energy savings for wall insulation and reduced infiltration over the no-insulation baseline – international locations.

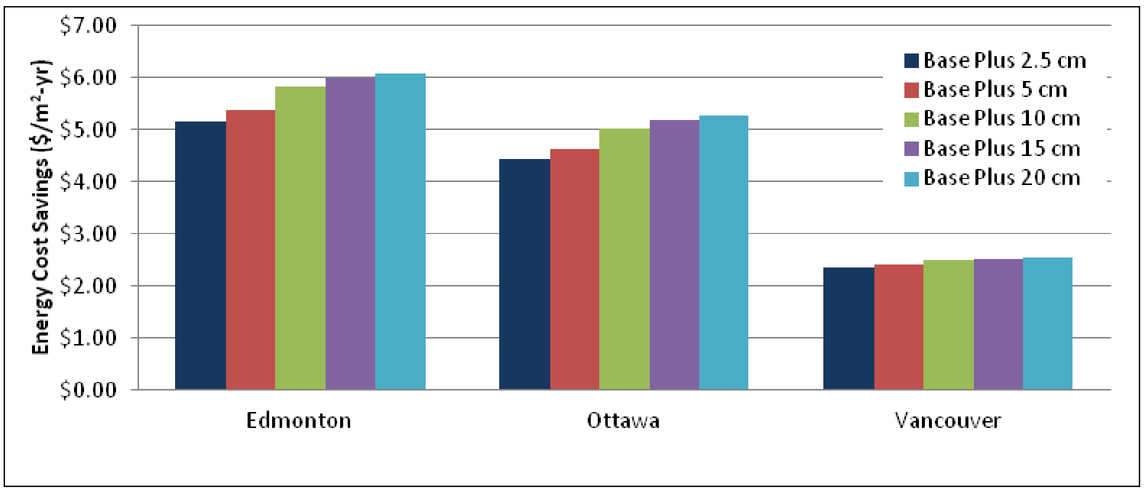

Figure 4.93. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline – Canadian locations.

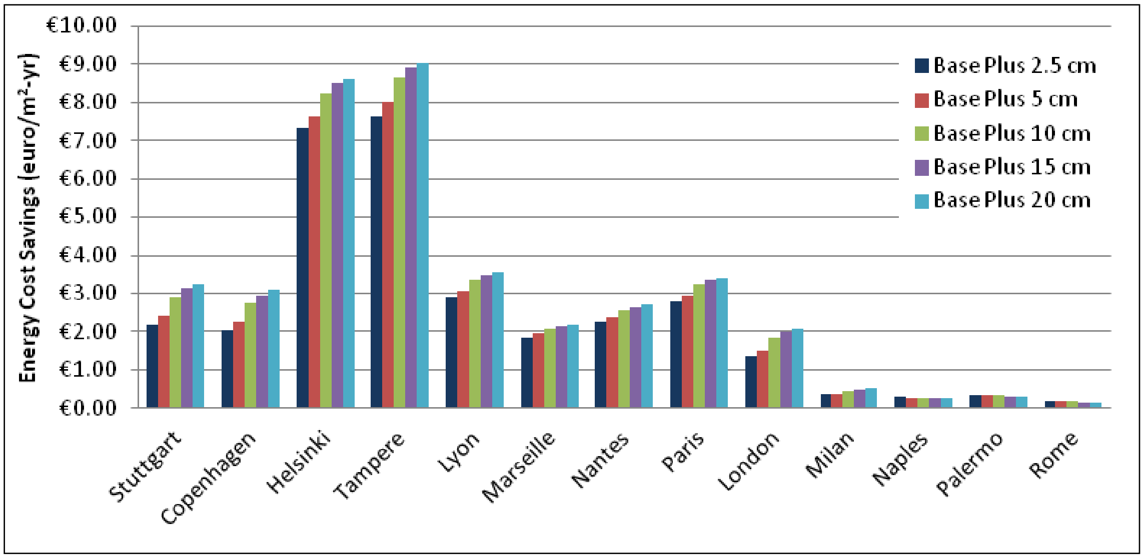

Figure 4.94. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline – European locations.

4.4.2 Increased roof insulation

The baseline building has insulation at the attic floor level. This section presents the results of replacing this insulation with insulation at the roof level. It was assumed that insulating the roof also improved the air leakage in the attic and the building. Table 4.14 summarizes the cases included in this report.

Table 4.14. Roof insulation ECM overview.

Case	Added Roof Insulation (R-value)	Building AL cfm/ft^2 @ 0.3 in w.g. (L/s·m^2 @ 75 Pa)	Attic Infiltration Rate (ACH)
Baseline 000	—	1.00 (5.08)	1.0
Roof 001.2	10	0.85 (4.32)	0.25
Roof 002.2	20	0.85 (4.32)	0.25
Roof 003.2	30	0.85 (4.32)	0.25
Roof 004.2	40	0.85 (4.32)	0.25
Roof 005.2	50	0.85 (4.32)	0.25

The results for the roof insulation cases are shown in Figures 4.95 through 4.101. The savings for the U.S. locations vary from near zero in Miami to over 6% in Duluth; however, there is almost no change in saving with increasing insulation levels. The results for the international locations show less than 1% savings in all locations except Stuttgart, Helsinki, Tampere, and London. These locations show energy savings between 4% and 7%. Some of the locations show negative savings due to increased cooling energy.

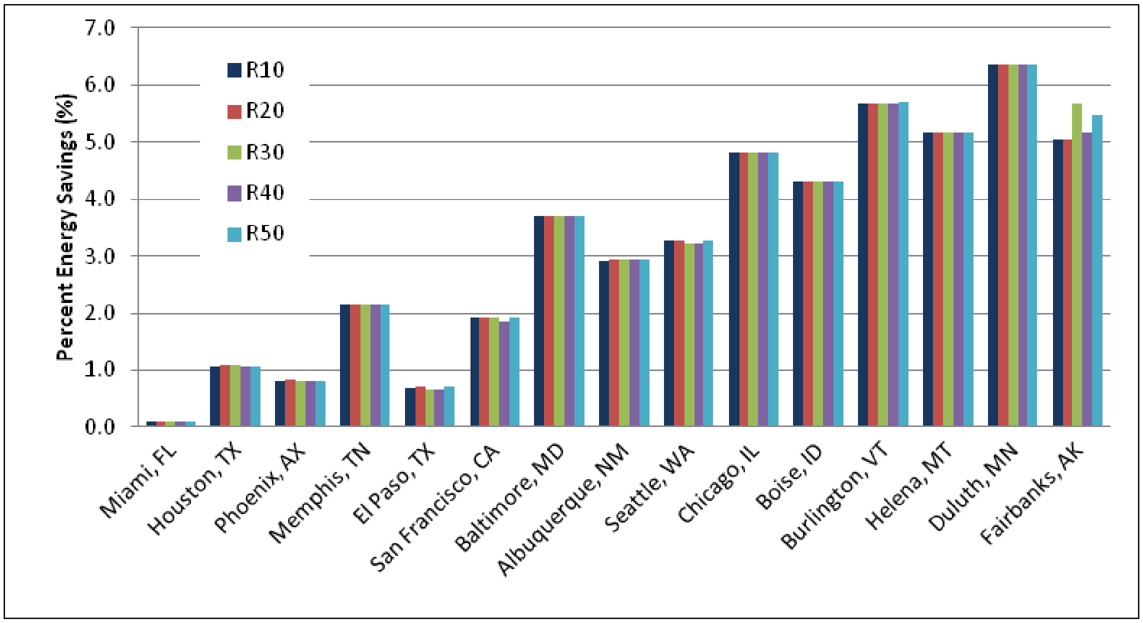

Figure 4.95. Percent energy savings for increased roof insulation.

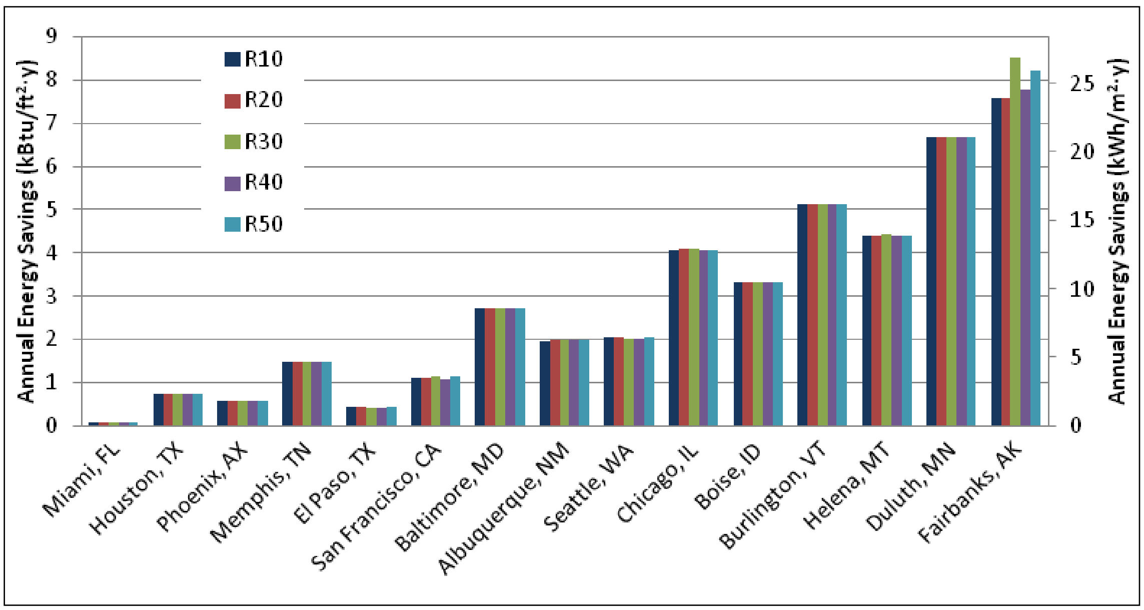

Figure 4.96. Annual energy savings for increased roof insulation.

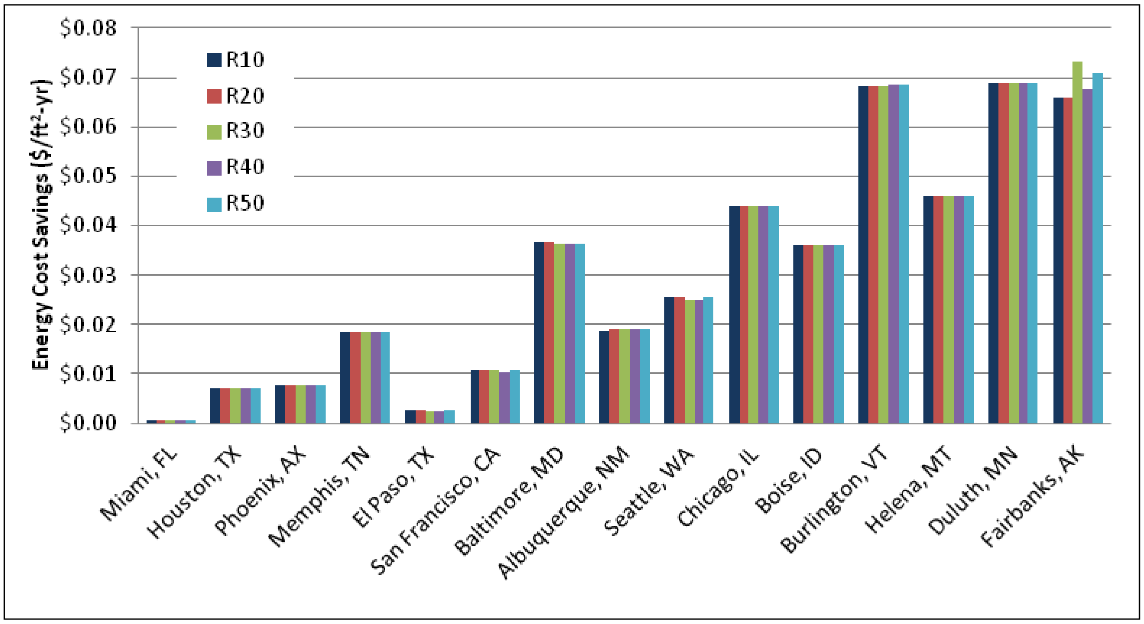

Figure 4.97. Annual energy cost savings for increased roof insulation.

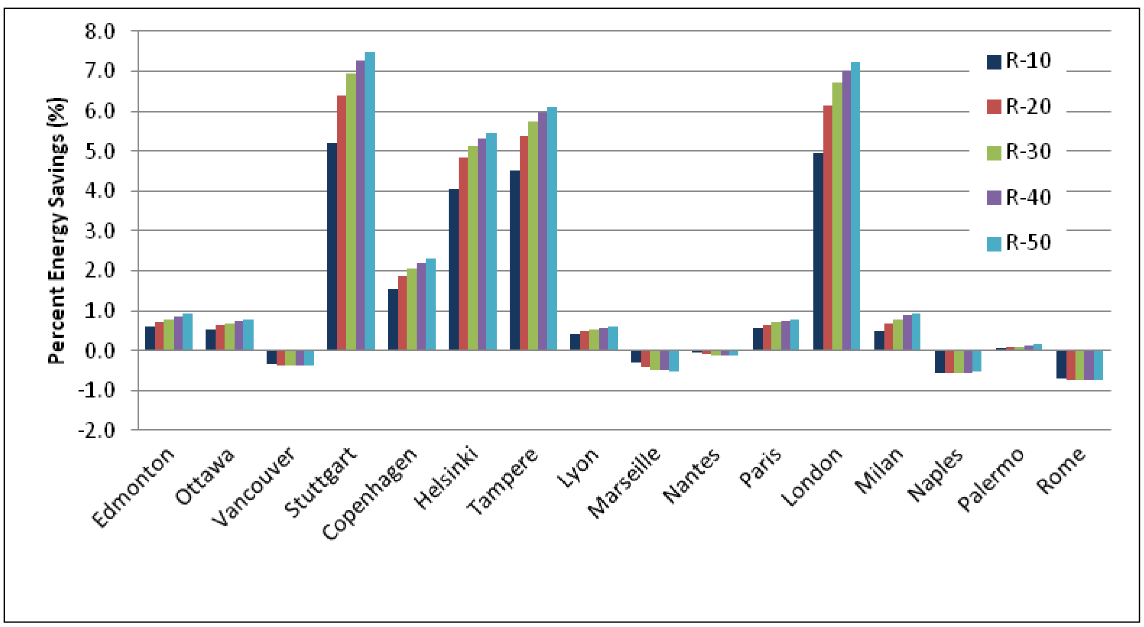

Figure 4.98. Percent energy savings for increased roof insulation – International locations.

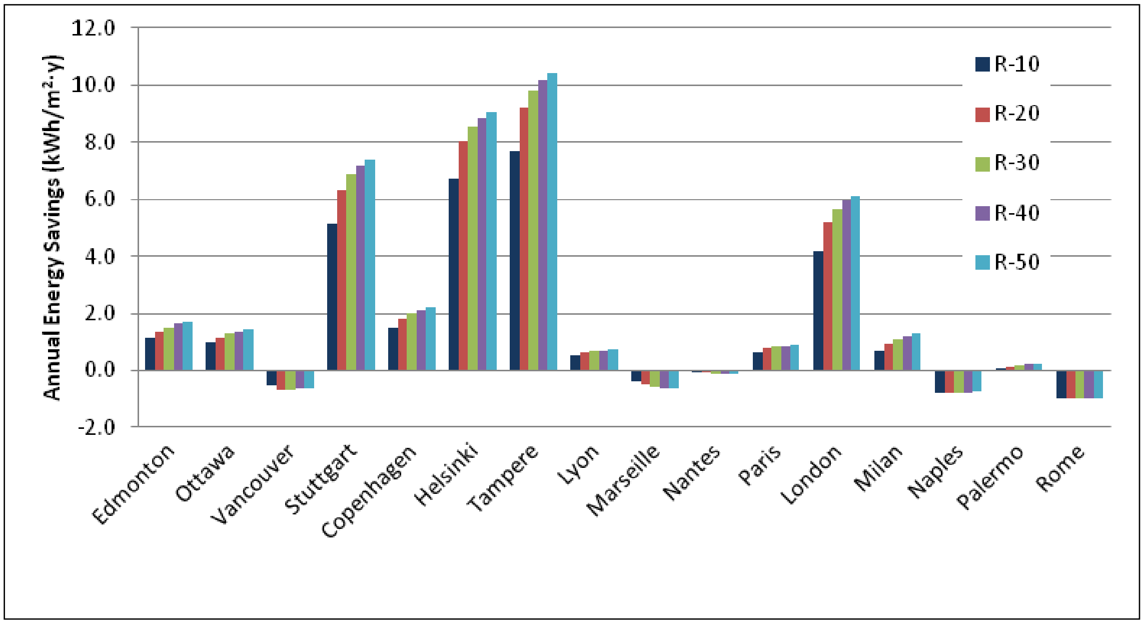

Figure 4.99. Annual energy savings for increased roof insulation – International locations.

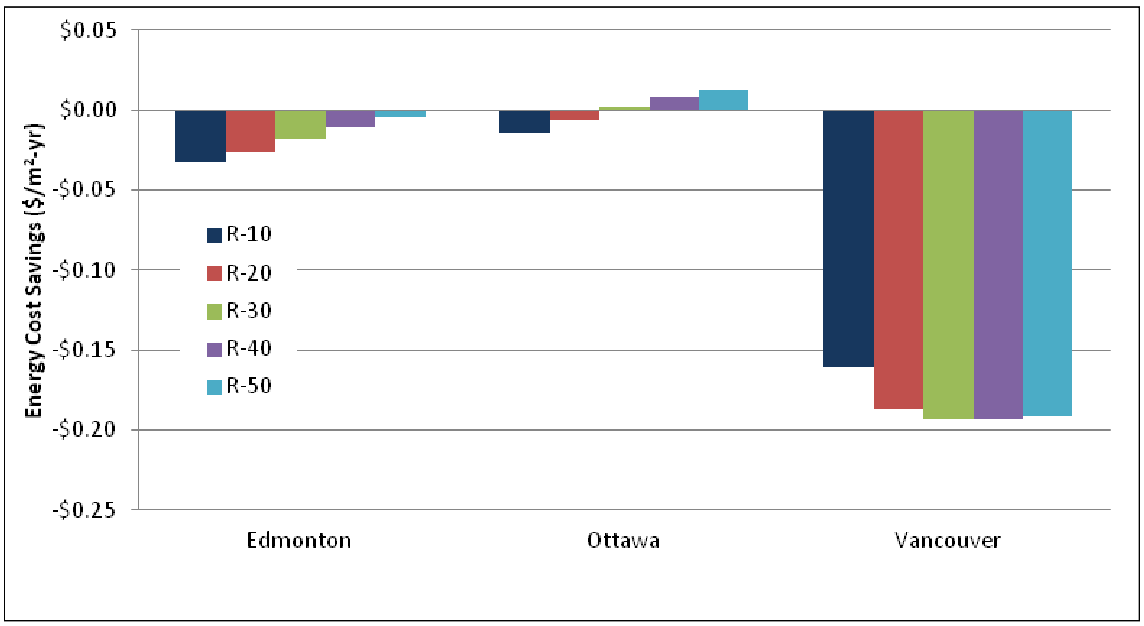

Figure 4.100. Annual energy cost savings for increased roof insulation – Canadian locations.

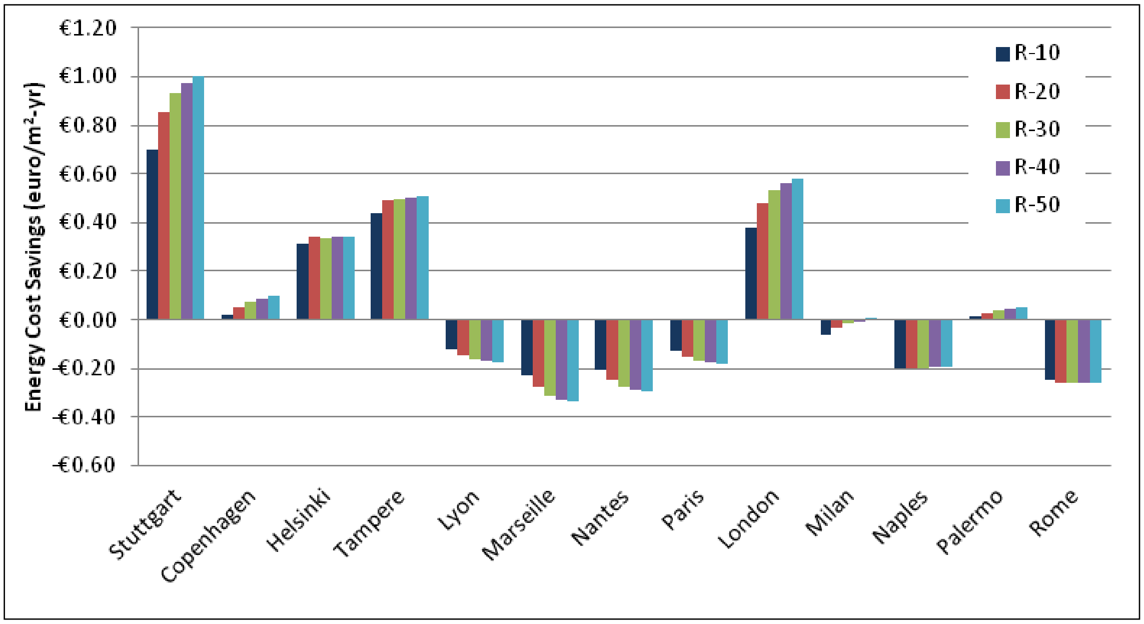

Figure 4.101. Annual energy cost savings for increased roof insulation – European locations.

4.4.3 Attic insulation

The performance of increased insulation at the attic level (i.e. floor of the attic) was simulated for the administration building model. The attic insulation retrofit scenarios considered are described in Table 4.15.

Table 4.15. Attic insulation ECM overview.

Case	Baseline	Added Ceiling Insulation (R-value)	Building AL cfm/ft^2 @ 0.3 in w.g. (L/s·m^2 @ 75 Pa)	Attic Infiltration Rate (ACH)
Baseline 000	1989	-	1.00 (5.08)	1.0
Baseline 100	1960	-	1.00 (5.08)	1.0
Roof 021	000	10	1.00 (5.08)	1.0
Roof 022	000	20	1.00 (5.08)	1.0
Roof 023	000	30	1.00 (5.08)	1.0
Roof 024	000	40	1.00 (5.08)	1.0
Roof 025	000	50	1.00 (5.08)	1.0
Roof 021.2	000	10	0.85 (4.32)	1.0
Roof 022.2	000	20	0.85 (4.32)	1.0
Roof 023.2	000	30	0.85 (4.32)	1.0
Roof 024.2	000	40	0.85 (4.32)	1.0
Roof 025.2	000	50	0.85 (4.32)	1.0

The results for the increased attic insulation are shown in Figures 4.102 through 4.108.

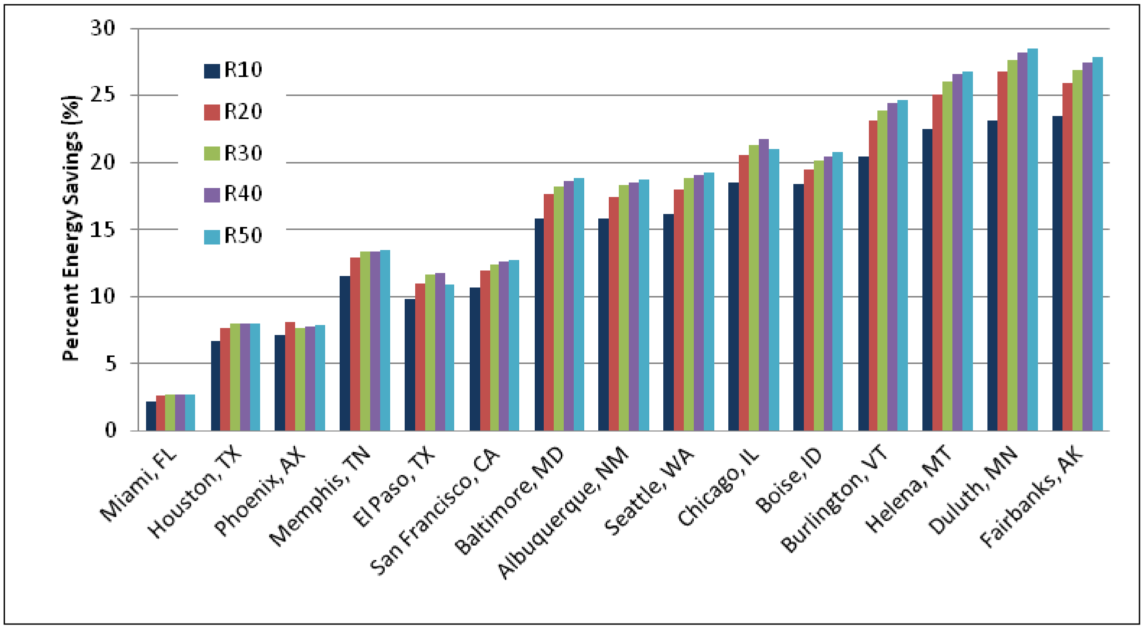

Figure 4.102. Percent energy savings for attic insulation increased above the baseline.

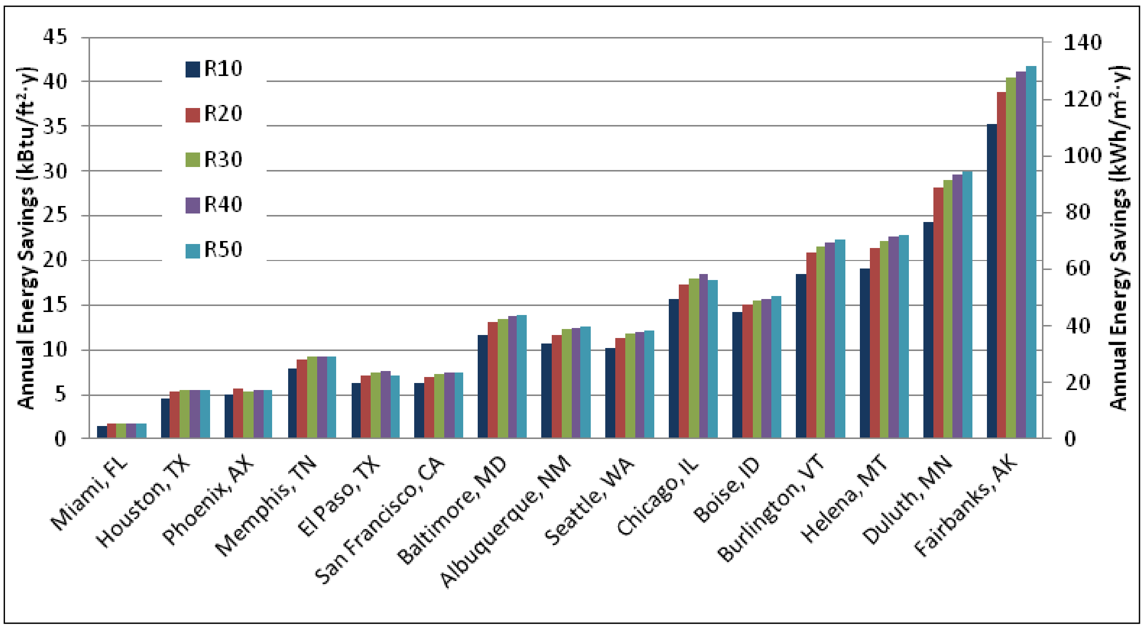

Figure 4.103. Annual energy savings for attic insulation increased above the baseline.

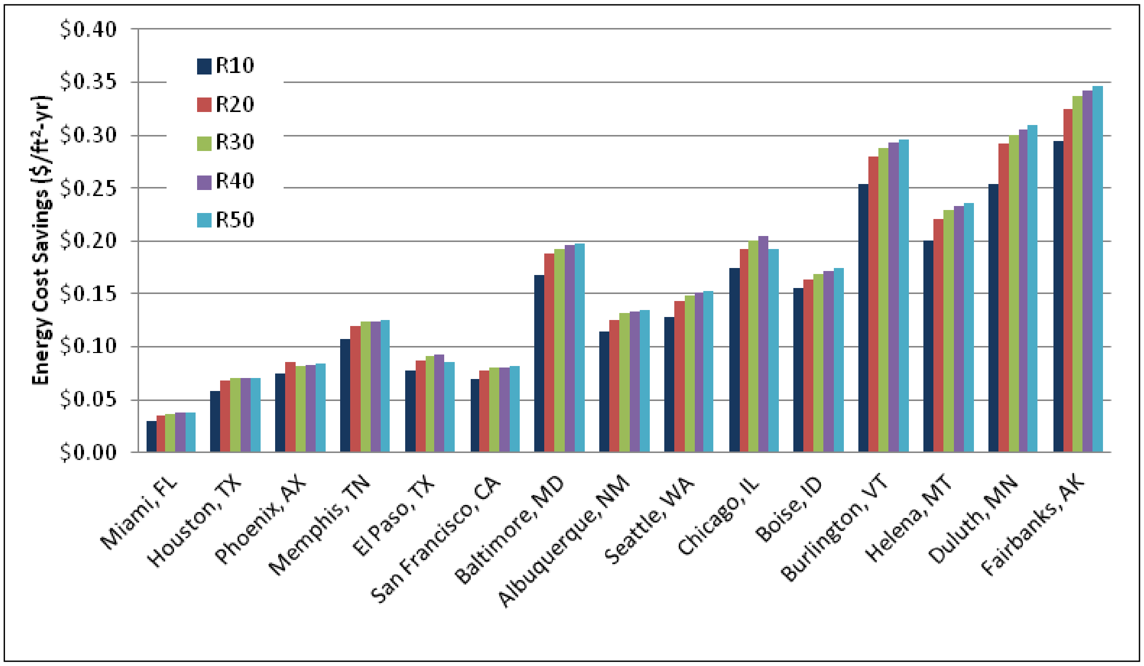

Figure 4.104. Annual energy cost savings for attic insulation increased above the baseline.

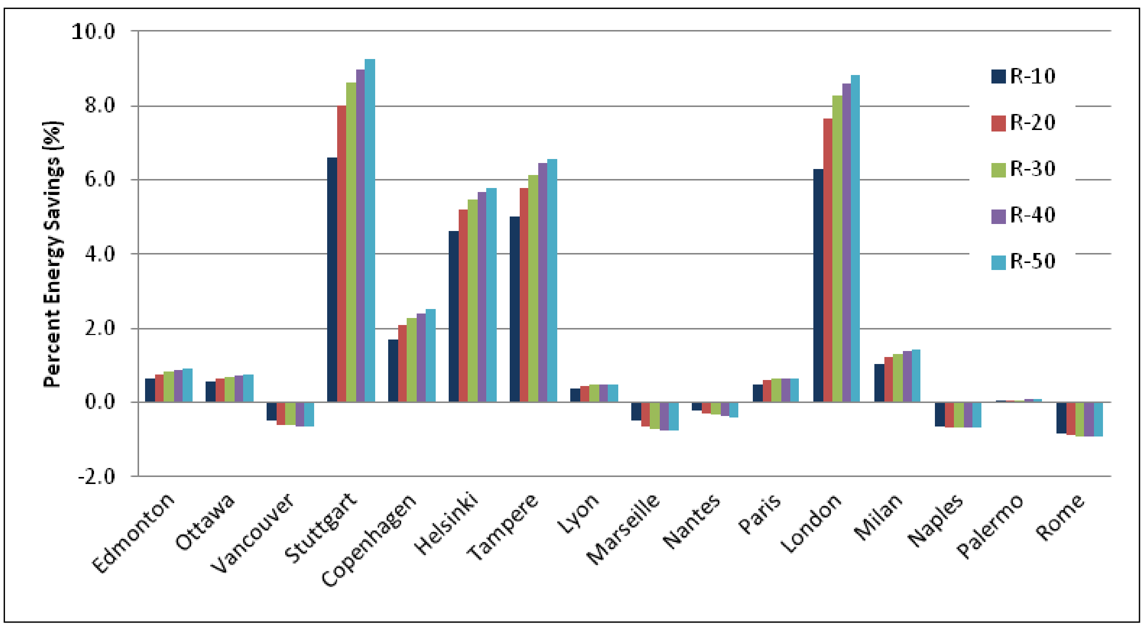

Figure 4.105. Percent energy savings for attic insulation increased above the baseline – International locations.

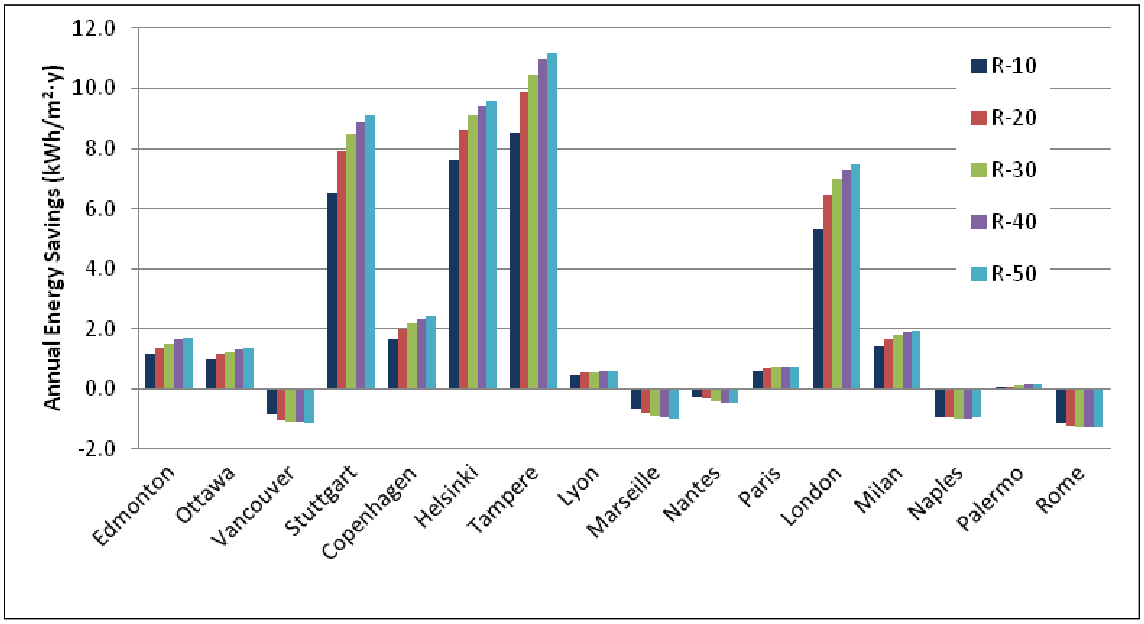

Figure 4.106. Annual energy savings for attic insulation increased above the baseline – International locations.

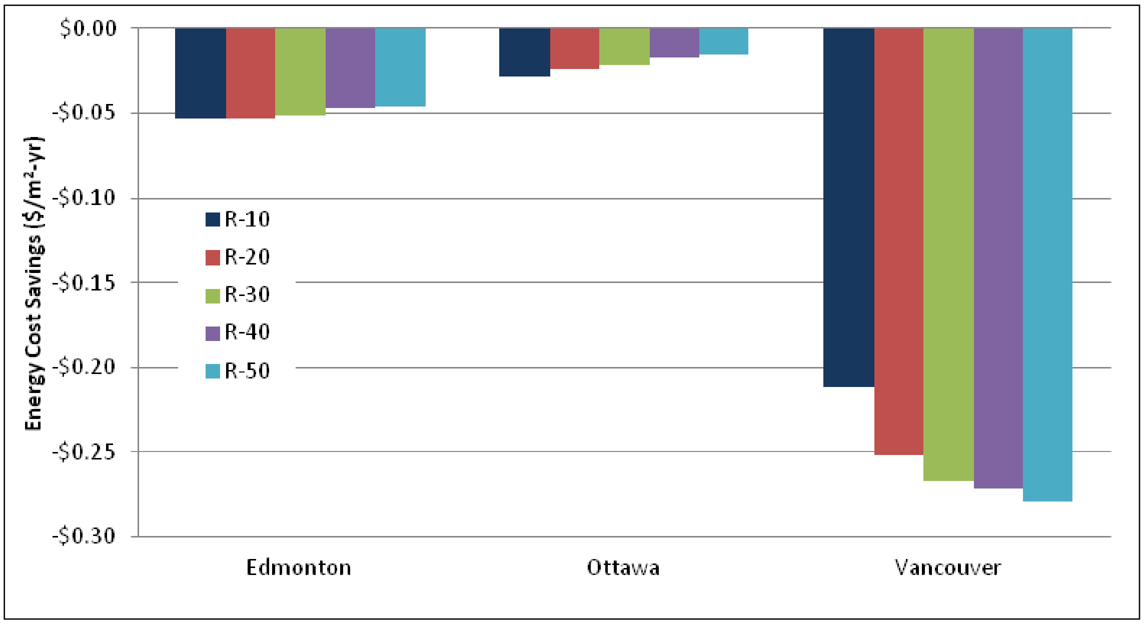

Figure 4.107. Annual energy cost savings for attic insulation increased above the baseline – Canadian locations.

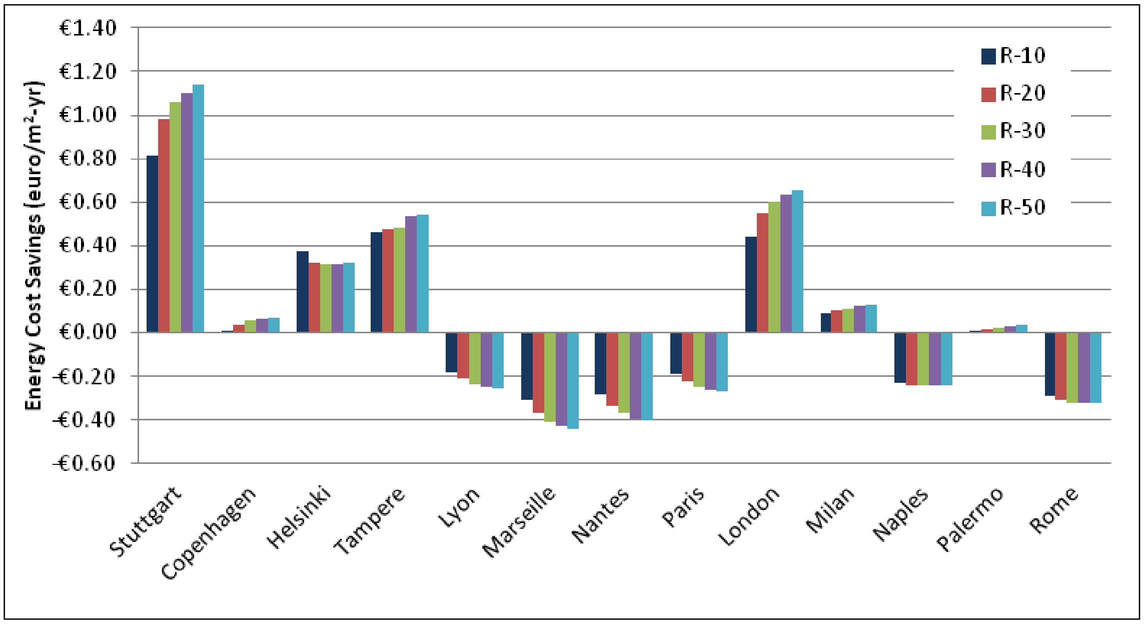

Figure 4.108. Annual energy cost savings for attic insulation increased above the baseline – European locations.

4.4.4 Cool roofs

It was assumed that the baseline building has a brown colored pitched roof with a solar reflectance of $\rho = 0.08$. Two alternative roofing materials with higher solar reflectance values were modeled. A thermal reflective brown roof with a solar reflectance of $\rho = 0.27$ was modeled as a medium reflectance case, and a white roof with a solar reflectance value of $\rho = 0.65$ was modeled to represent a highly reflective roof. These cases are shown in Table 4.16.

The energy simulations did not account for the potential impacts of temperature changes in the attic on the HVAC systems. It was assumed that there were no ducts or system components in the attic.

Thermostatically controlled mechanical venting of the attic was also modeled for the three roof types to see how this would impact the energy use. The mechanical venting was modeled to provide 3 ACH when the attic temperature exceeded 90ºF (32ºC). The ventilated attic had the most impact on the baseline building, but almost no change to the overall energy use in the white roof case. The results from these simulations are not included in this report.

Table 4.16. Cool roof ECM overview.

Case	Description	Roof Solar Reflectance	Mechanical Venting
Baseline	Standard brown	0.08	No
Case 1	Cool brown	0.27	No
Case 2	Cool white	0.65	No

The results for the cool roof simulations are shown in Figures 4.109 through 4.115. For the U.S., the savings are larger for the warmer climates and the two marine climates, and there is a slight increase in energy use in the two coldest climates. The energy cost savings are small, but positive in all locations. The energy savings results for the Canadian and European locations are similar to the U.S. All of the locations show some energy savings except for Edmonton and Ottawa, which show higher energy use with the cool roof. All of the locations except for Stuttgart, Helsinki and Tampere show energy cost savings.

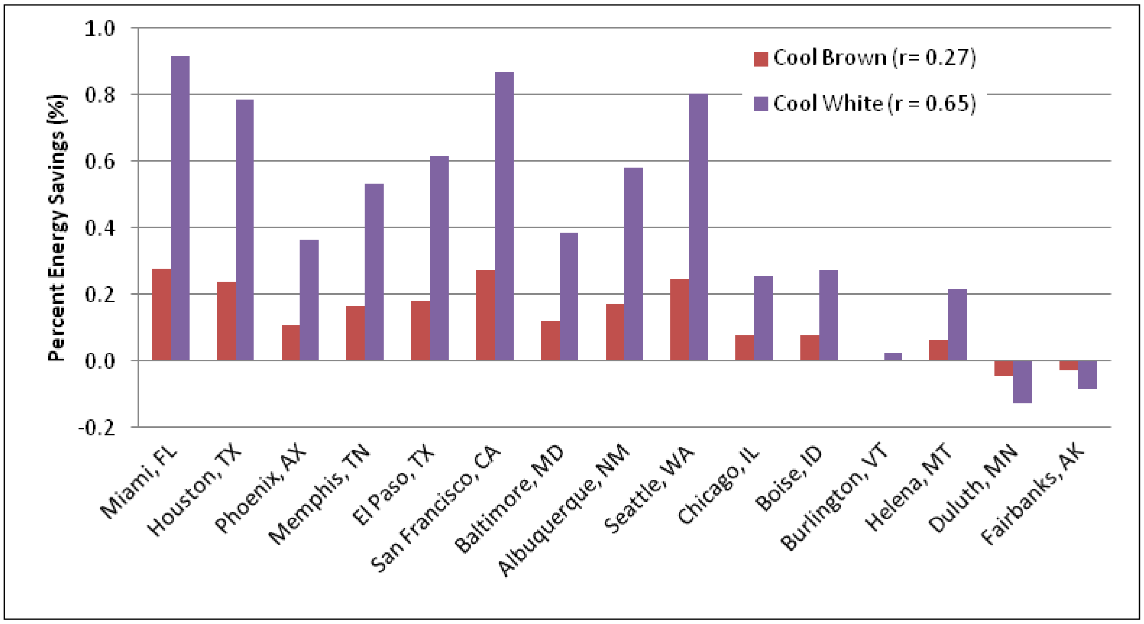

Figure 4.109. Percent energy savings for cool roof.

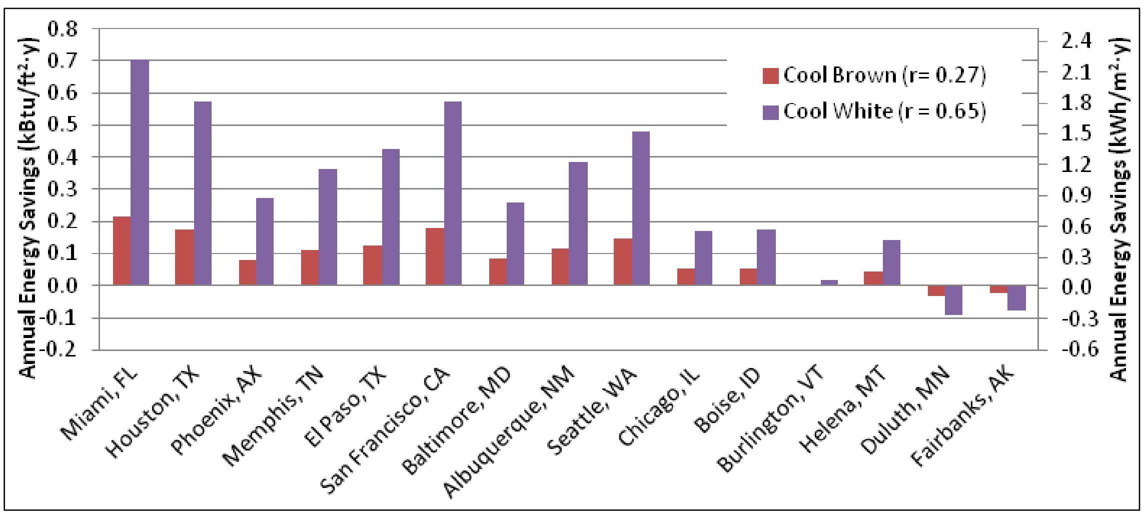

Figure 4.110. Annual energy savings for cool roof.

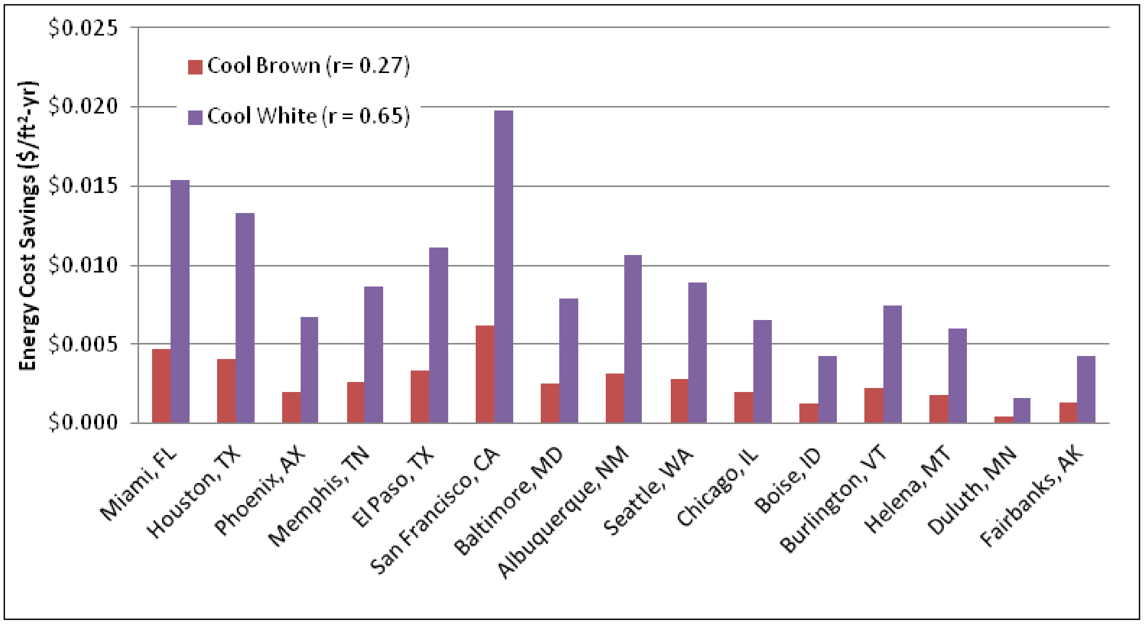

Figure 4.111. Annual energy cost savings for cool roof.

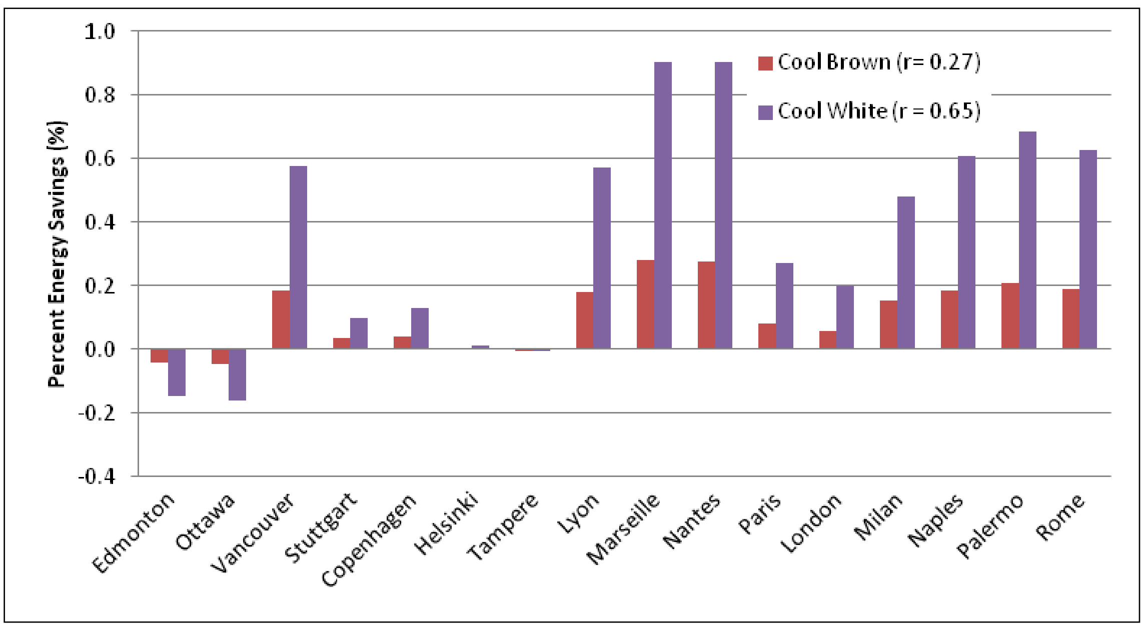

Figure 4.112. Percent energy savings for cool roof – International locations.

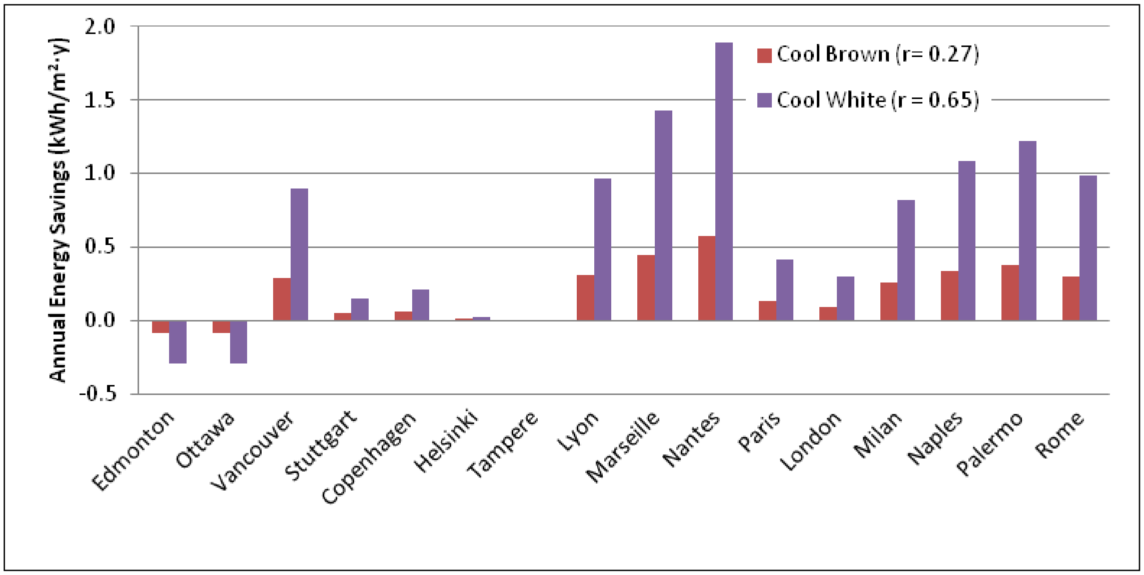

Figure 4.113. Annual energy savings for cool roof – International locations.

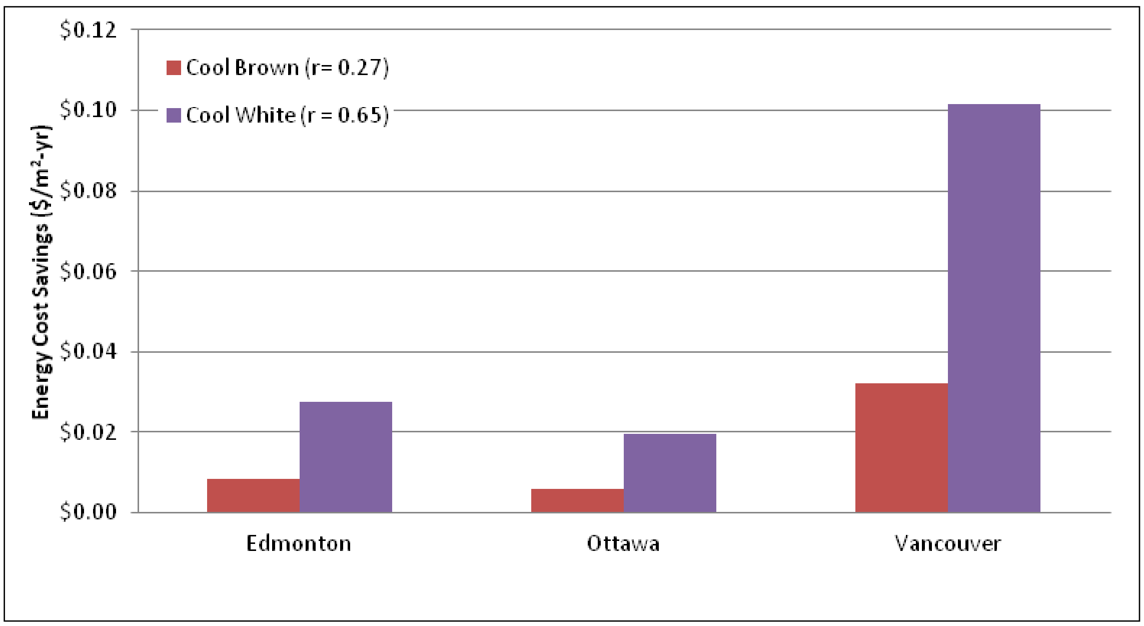

Figure 4.114. Annual energy cost savings for cool roof – Canadian locations.

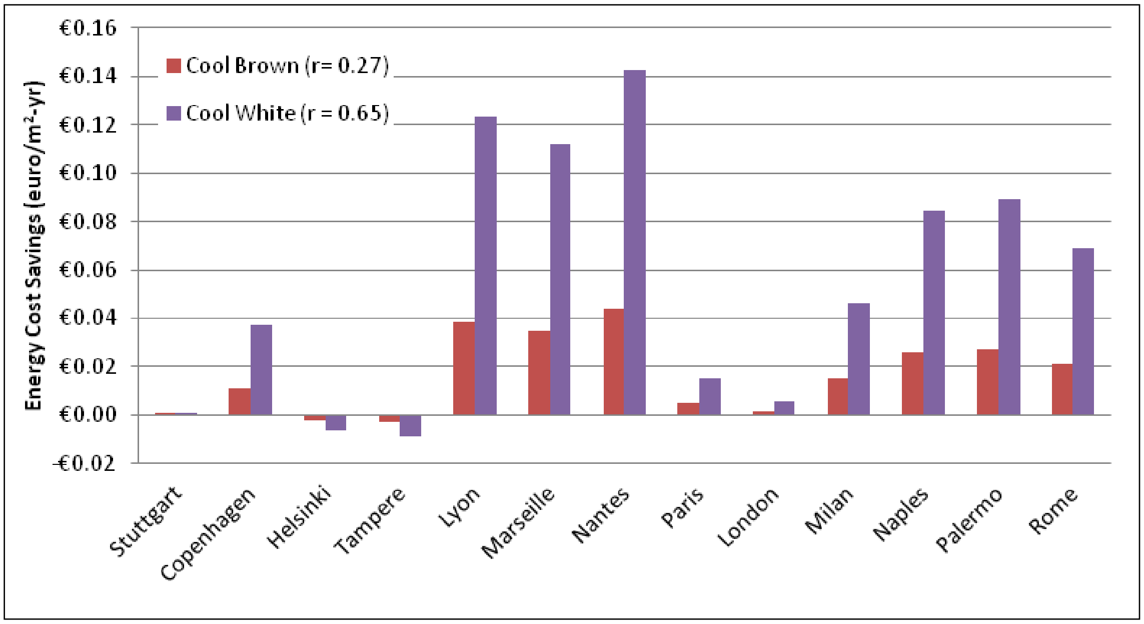

Figure 4.115. Annual energy cost savings for cool roof – European locations.

4.4.5 Building airtightness

The effects of retrofitting the administration facility with a tighter envelope were evaluated with two levels of improvement over the baseline. Envelope leakage rates were assumed for the baseline and the two improved cases loosely based on blower door results from real buildings. The leakage rates and corresponding air changes per hour used for modeling are shown in Table 4.17. The method used to derive air change rates from envelope leakage rates is described in Section 4.

Table 4.17. Building airtightness ECM overview.

Source	Leakage Rate at 0.3 in w.g. (75 Pa) cfm/ft² (L/s/m²)	Leakage Rate at 0.016 in w.g. (4 Pa) cfm/ft² (L/s/m²)	ACH at 0.016 in w.g. (4 Pa)
Baseline	1.0 (5.07)	0.15 (0.65)	0.97
Typical practice for air sealing retrofit	0.50 (2.54)	0.074 (0.33)	0.48
Good practice for air sealing retrofit	0.25 (1.27)	0.037 (0.16)	0.24

The results for the improved airtightness simulations are shown in Figures 4.116 through 4.122. The energy savings can be significant especially in the colder climates. For cold climates this is the highest energy savings ECM for leaky buildings. For the warm-humid climates it is also an important measure to reduce humidity problems, which was not a focus of this modeling effort. There is very little energy savings for the mild climates, and Vancouver is the only climate that had a negative energy cost savings.

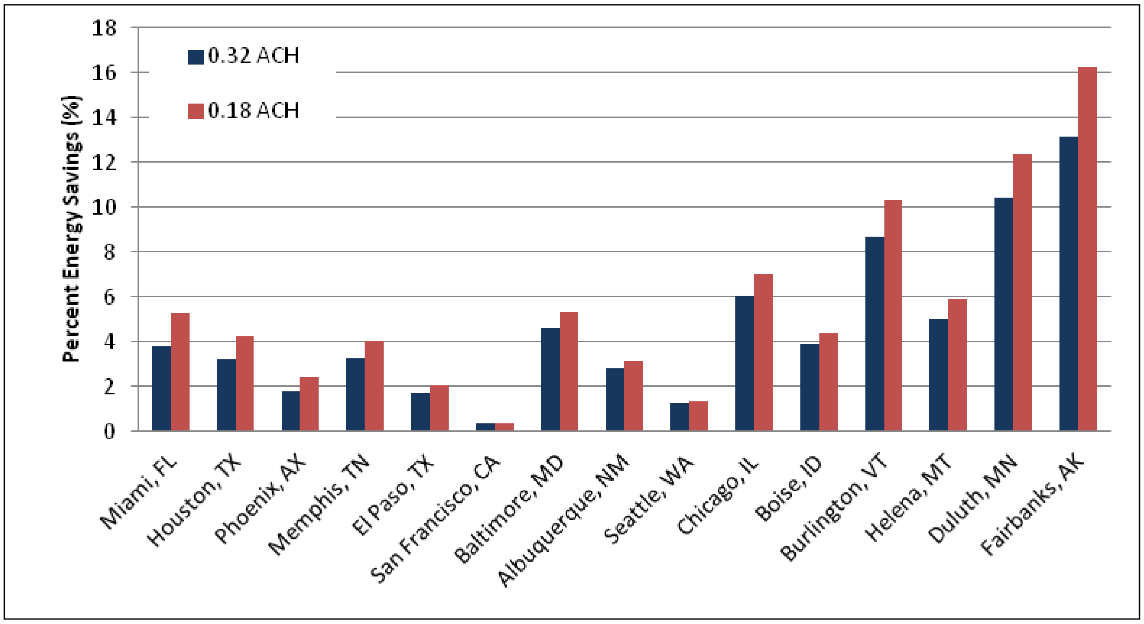

Figure 4.116. Percent energy savings for improved airtightness.

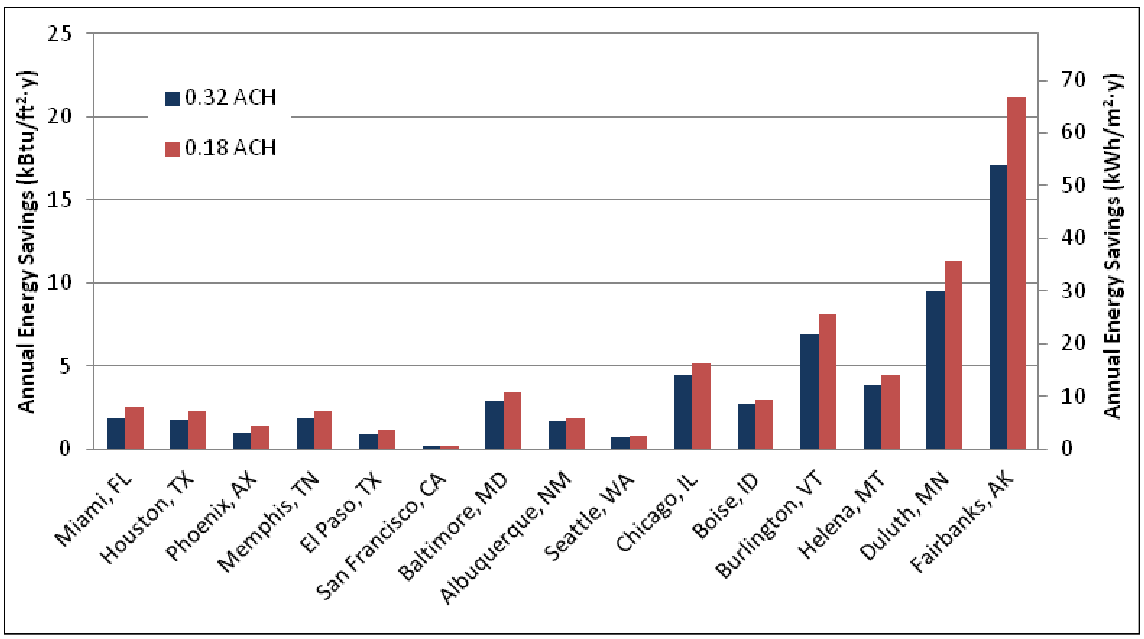

Figure 4.117. Annual energy savings for improved airtightness.

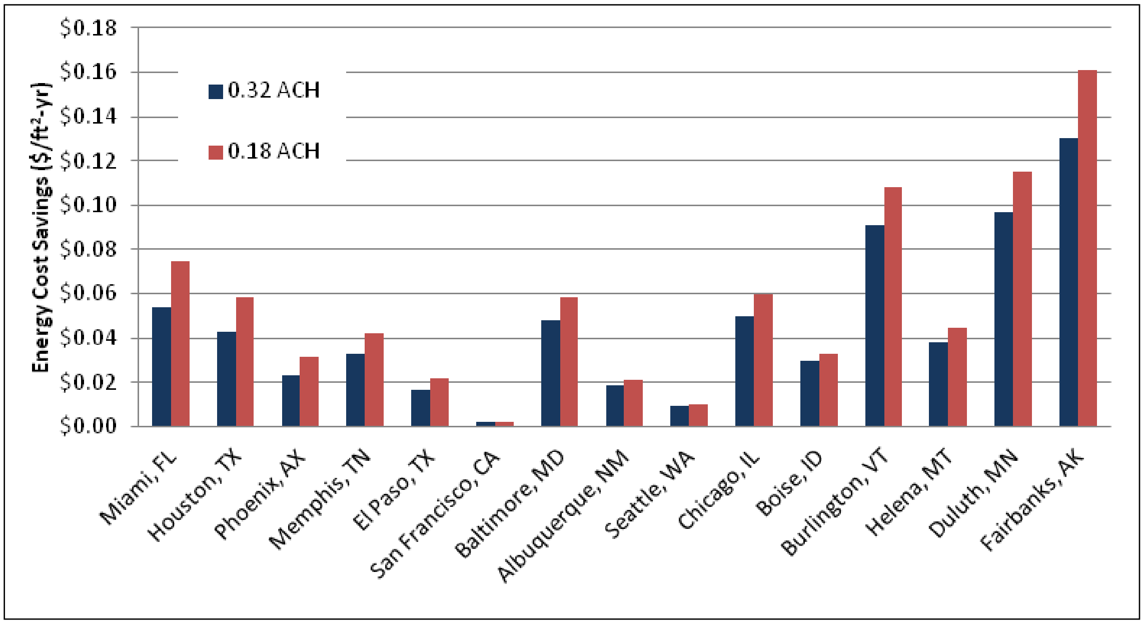

Figure 4.118. Annual energy cost savings for improved airtightness.

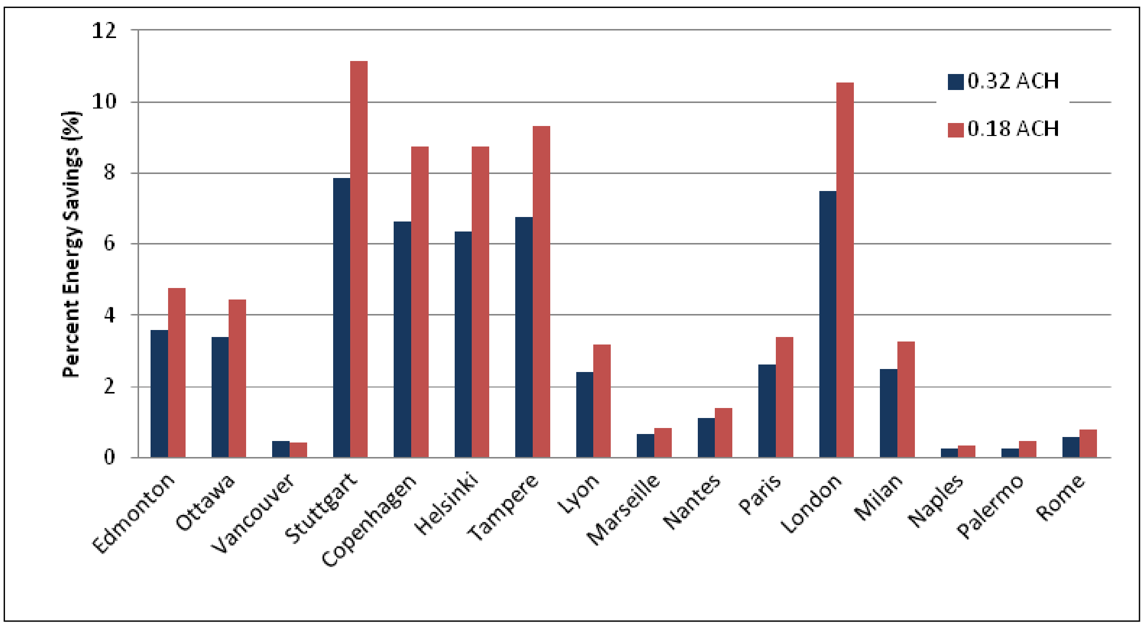

Figure 4.119. Percent energy savings for improved airtightness – International locations.

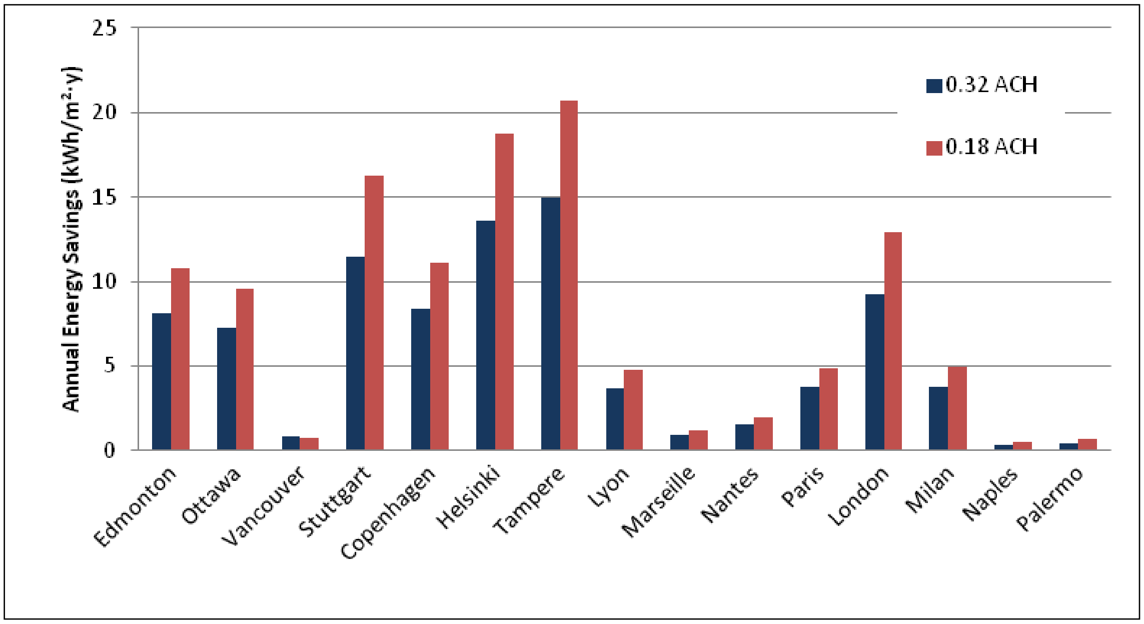

Figure 4.120. Annual energy savings for improved airtightness – International locations.

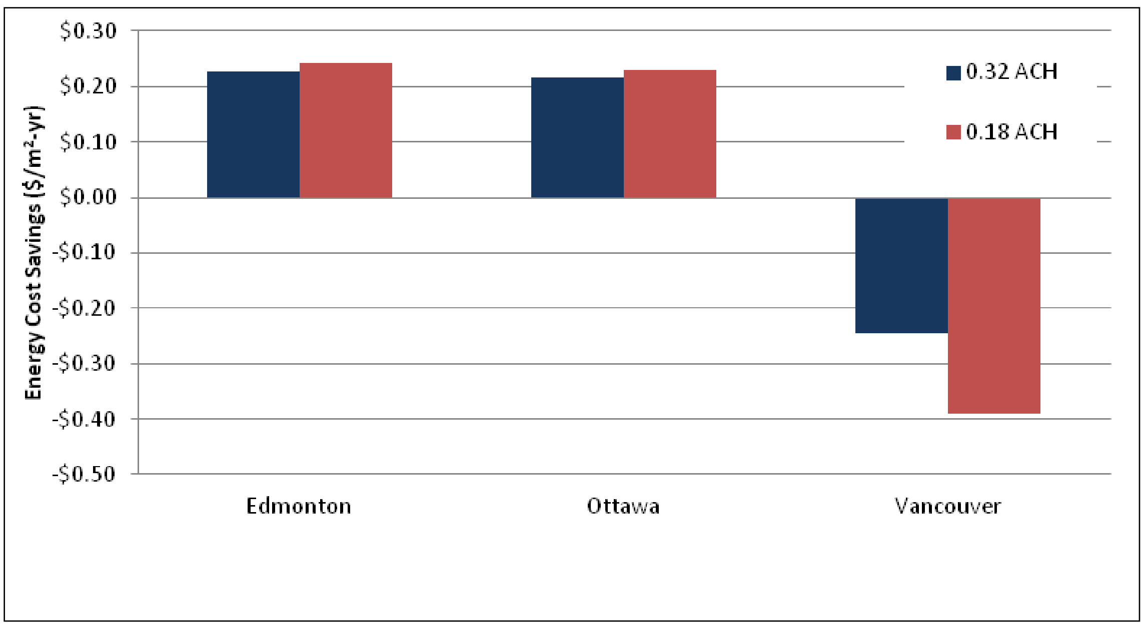

Figure 4.121. Annual energy cost savings for improved airtightness – Canadian locations.

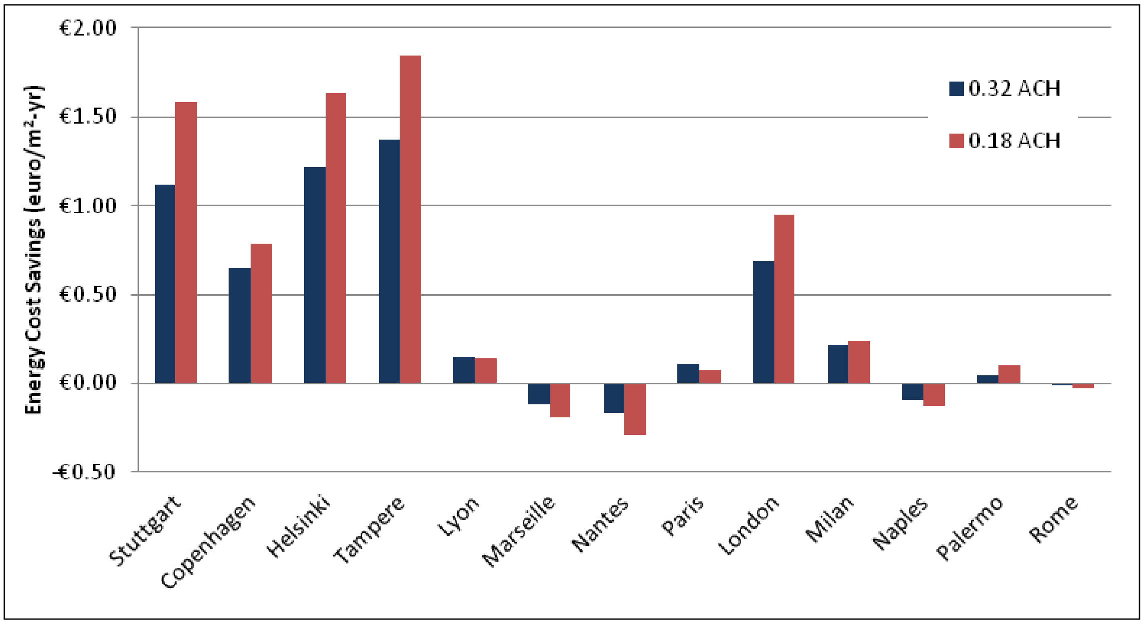

Figure 4.122. Annual energy cost savings for improved airtightness – European locations.

4.4.6 Advanced windows

The set of advanced window options evaluated are shown in Table 4.18. Exact models of the recommended windows are not readily available in the NREL database; therefore, a set of suitable alternative models were used. The properties of the six replacement windows as they are modeled are given by Table 4.19. Included in the tables are the estimated costs per square foot of glazing and the airtightness of the building after the retrofit. In this analysis the airtightness is assumed to be unchanged by the replacement windows.

Table 4.18. Thermal properties of retrofit windows.

Glazing Type	Frame Type	U-Factor Btu/ft^2·hr·°F (W/m^2·K)	SHGC	VT	Incremental Cost (\$/ft^2)
2-pane, uncoated glass	Aluminum, thermal break	0.60 (3.4)	0.60	0.63	Baseline cost
2-pane, tinted	Aluminum, thermal break	0.60 (3.4)	0.42	0.38	$0.50
2-pane, reflective coating	Aluminum, thermal break	0.54 (3.1)	0.17	0.10	$1.25
2-pane, low-E, tinted	Aluminum, thermal break	0.46 (2.6)	0.27	0.43	$1.75
2-pane, low-E	Aluminum, thermal break	0.46 (2.6)	0.34	0.57	$1.50
3-pane, low-E	Insulated	0.20 (1.1)	0.22	0.37	$9.00
3-pane, high-SHGC, low-E	Non-metal	0.27 (1.5)	0.38	0.47	$15.50
-pane, high-SHGC, low-E	Non-metal, insulated	0.18 (1.0)	0.40	0.50	$19.67

Table 4.19. Thermal properties of modeled windows.

Window	Cost $/ft² ($/m²)	Fenestration, Overall U-Value Btu/h·°F·ft² (W/m²·K)	SHGC	Building AL at 0.3 in w.g. cfm/ft² (L/s·m² at 75 Pa)
I	22.00 (236.81)	0.56 (3.19)	0.61	1.00 (5.08)
II	22.50 (242.2)	0.55 (3.12)	0.50	1.00 (5.08)
A	23.25 (250.27)	0.51 (2.88)	0.22	1.00 (5.08)
B	23.75 (255.65)	0.44 (2.48)	0.30	1.00 (5.08)
C	23.50 (252.96)	0.45 (2.53)	0.35	1.00 (5.08)
D	31.00 (333.69)	0.21 (1.20)	0.19	1.00 (5.08)
E	37.5 (403.61)	0.26 (1.48)	0.37	1.00 (5.08)
F	41.67 (448.49)	0.17 (0.97)	0.47	1.00 (5.08)

The results for the window simulations are shown in Figures 4.123 through 4.129. The performance of the windows is a combination of the U-value and the SHGC. Daylighting was not modeled in this building and therefore the visual transmittance is not a factor in the energy performance. All of the windows show energy savings in the warmer climates. In the colder climates, the baseline window is better than the first three windows. Lower U-values provide energy savings in all climates. In the hot climates (climate zones 1-3), the lower SHGC windows perform better, and the opposite is true of the colder climate zones (4-8). The baseline windows for the international locations varied from country to country and had a large impact on the savings. The largest energy savings are in Italy, France, and Finland.

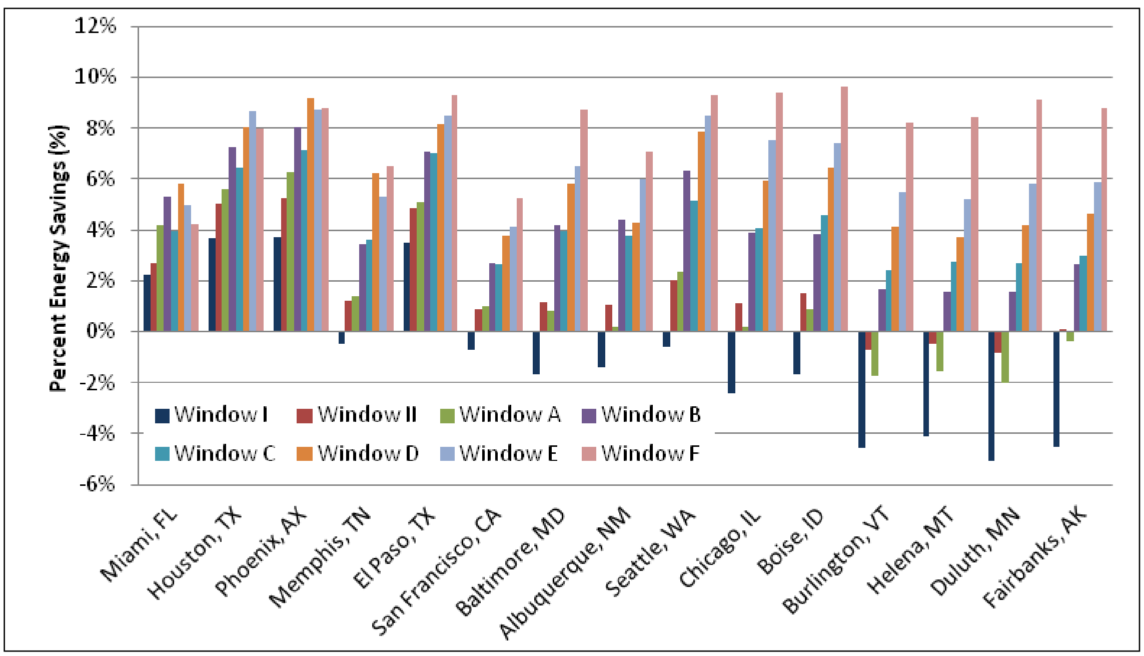

Figure 4.123. Percent energy savings for advanced windows.

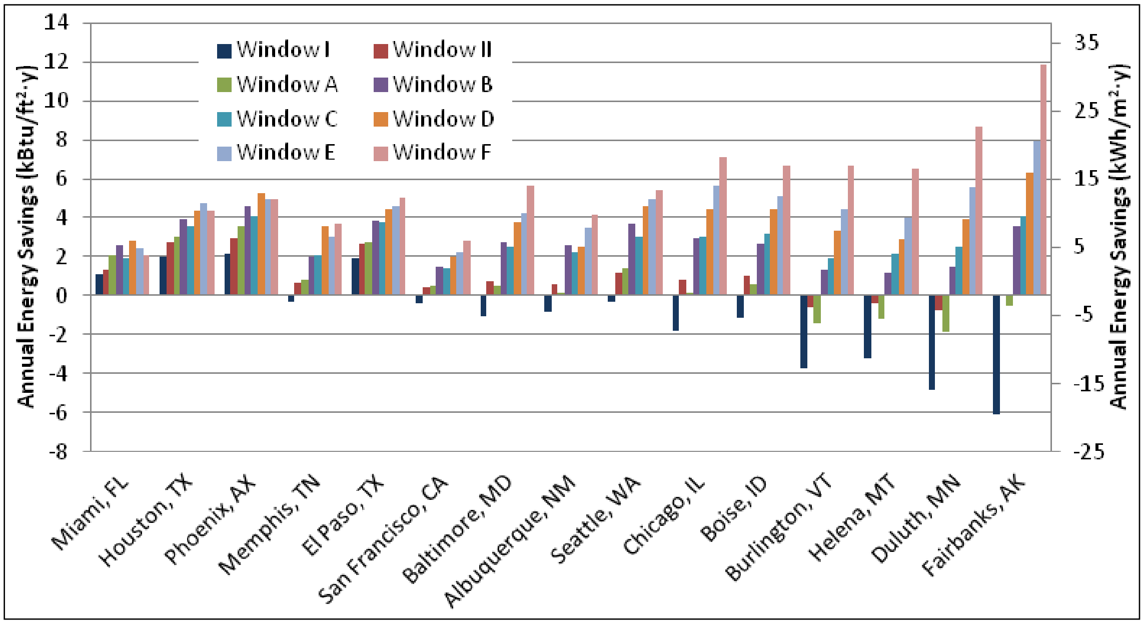

Figure 4.124. Annual energy savings for advanced windows.

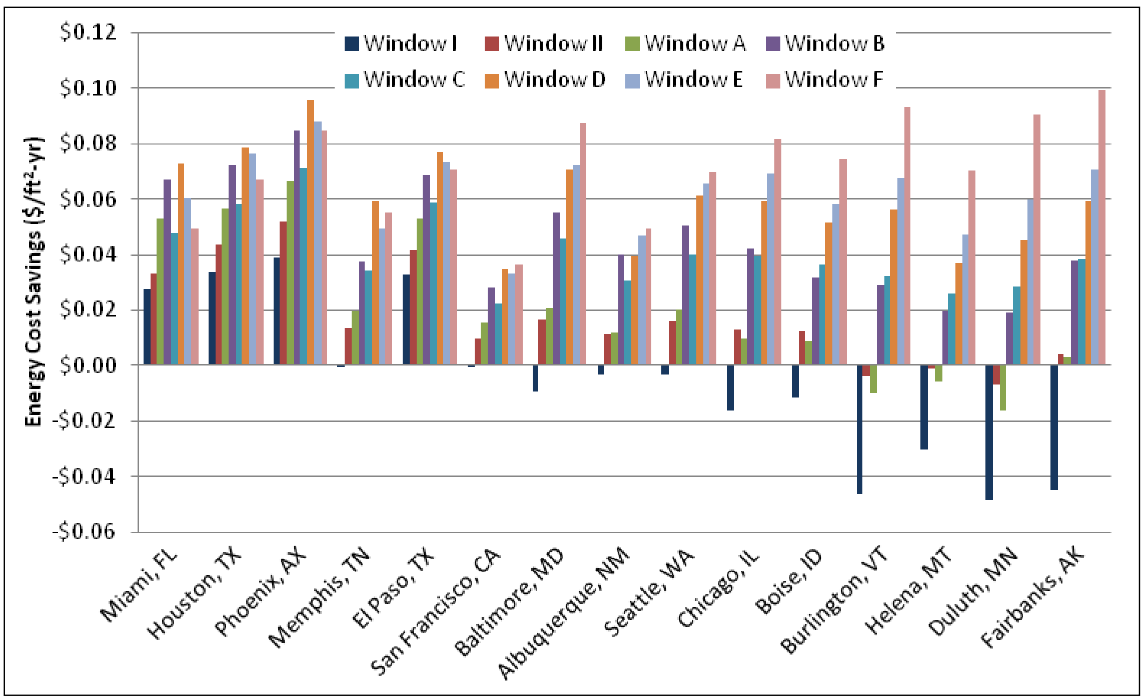

Figure 4.125. Annual energy cost savings for advanced windows.

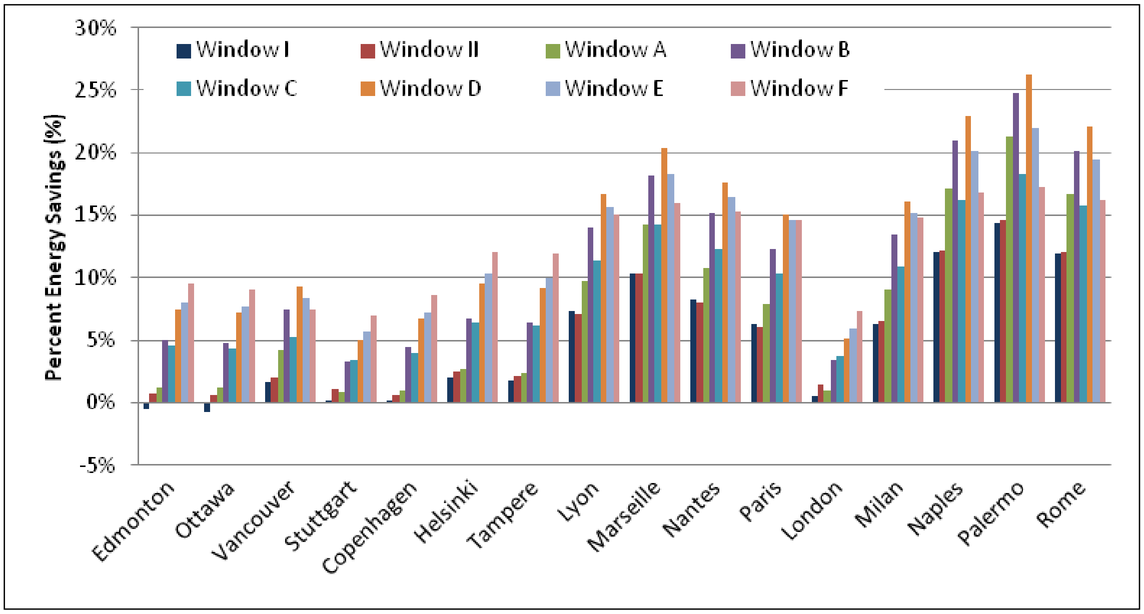

Figure 4.126. Percent energy savings for advanced windows – International locations.

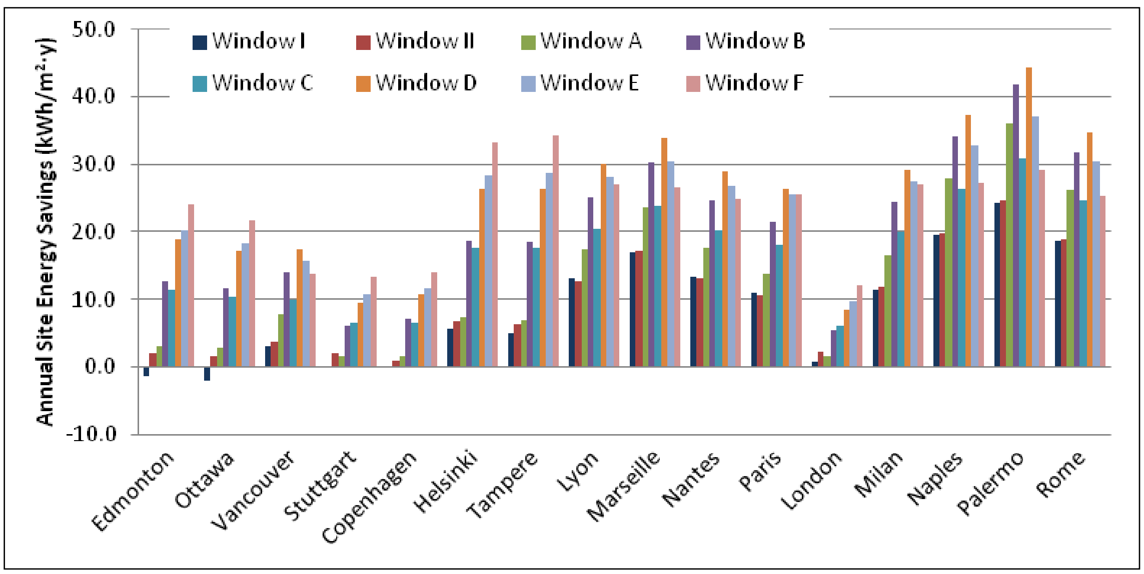

Figure 4.127. Annual energy savings for advanced windows – International locations.

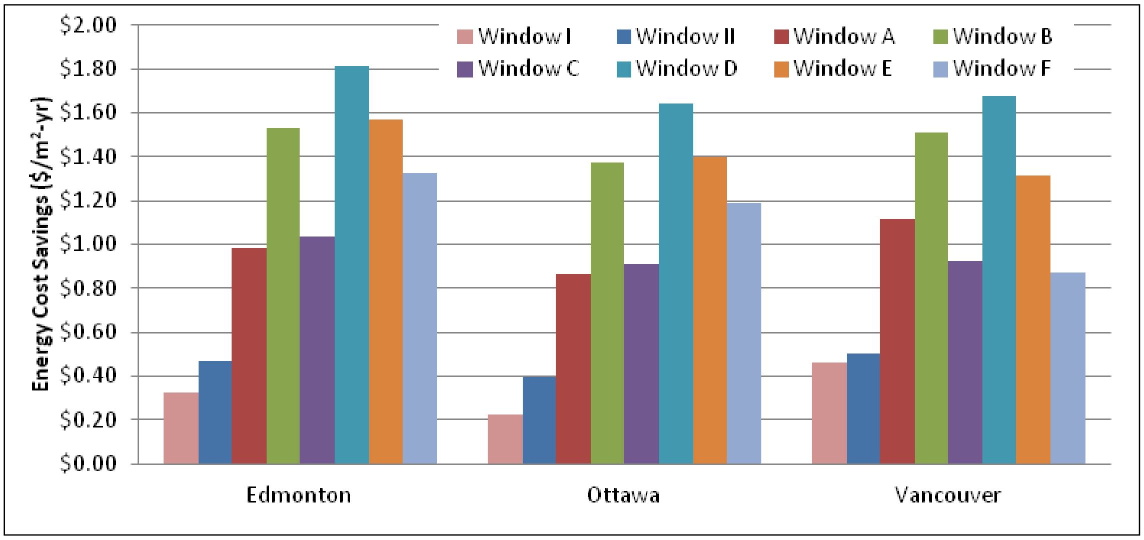

Figure 4.128. Annual energy cost savings for advanced windows – Canadian locations.

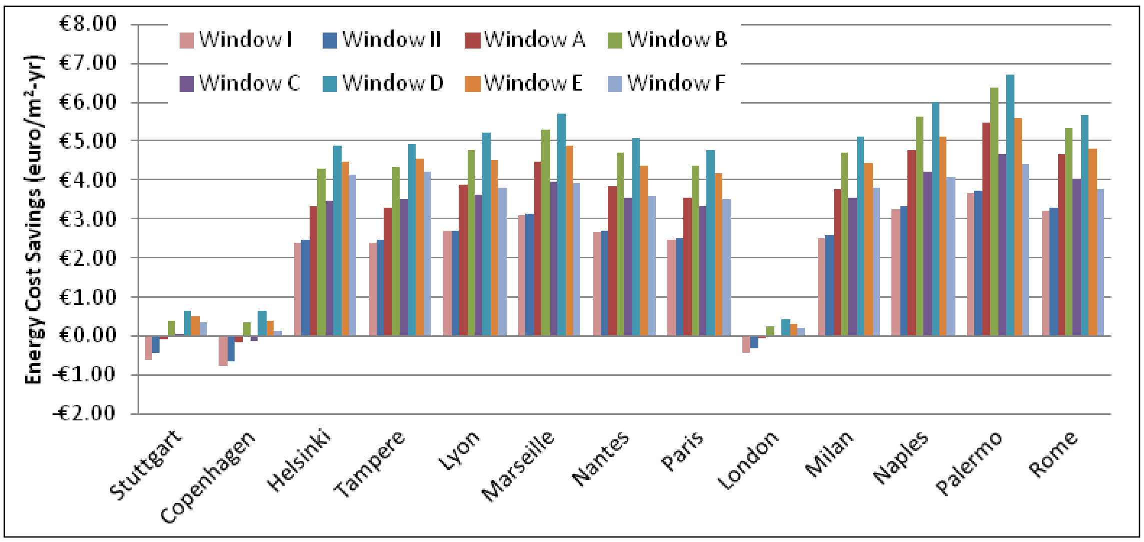

Figure 4.129. Annual energy cost savings for advanced windows – International locations.

4.4.7 Overhangs

The effect on whole building energy performance from retrofitting the building with exterior overhangs above the south-facing windows was modeled in EnergyPlus using simple shading devices which protrude orthogonally from the building façade by 1.6 ft (0.5 m).

In general, overhangs showed small savings for the U.S. locations and slightly higher savings for the international locations. This outcome is attributed to the generally lower SHGC found in the windows in the U.S. buildings, which makes them less vulnerable to solar heat gains. Other benefits to overhangs such as glare control and thermal comfort improvement on south windows were not analyzed in this study.

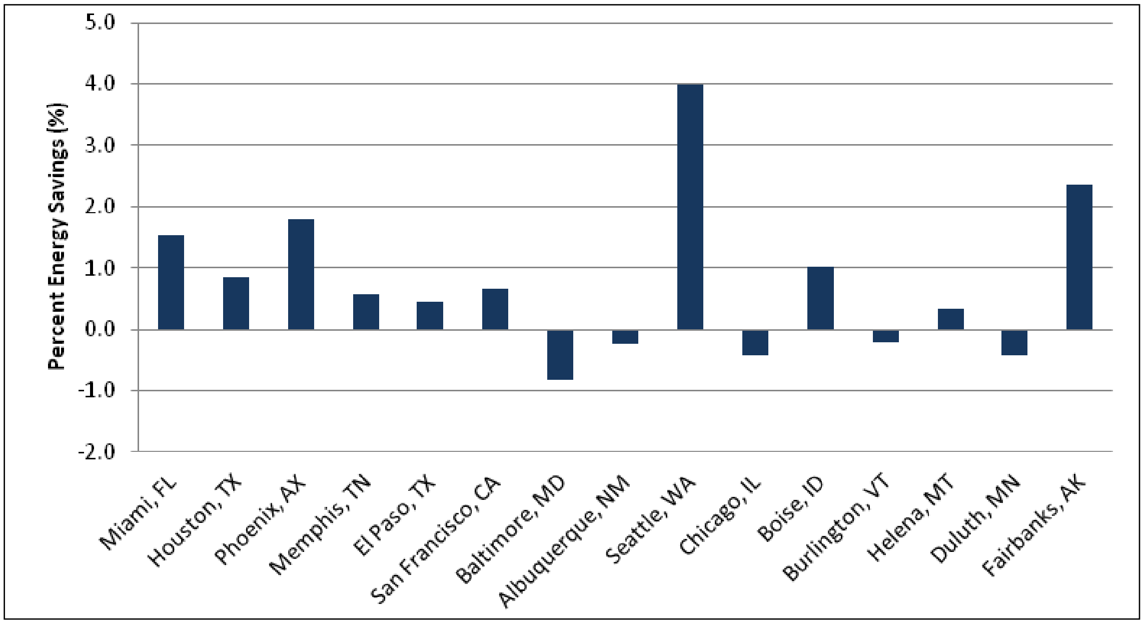

Figure 4.130. Percent energy savings for overhangs.

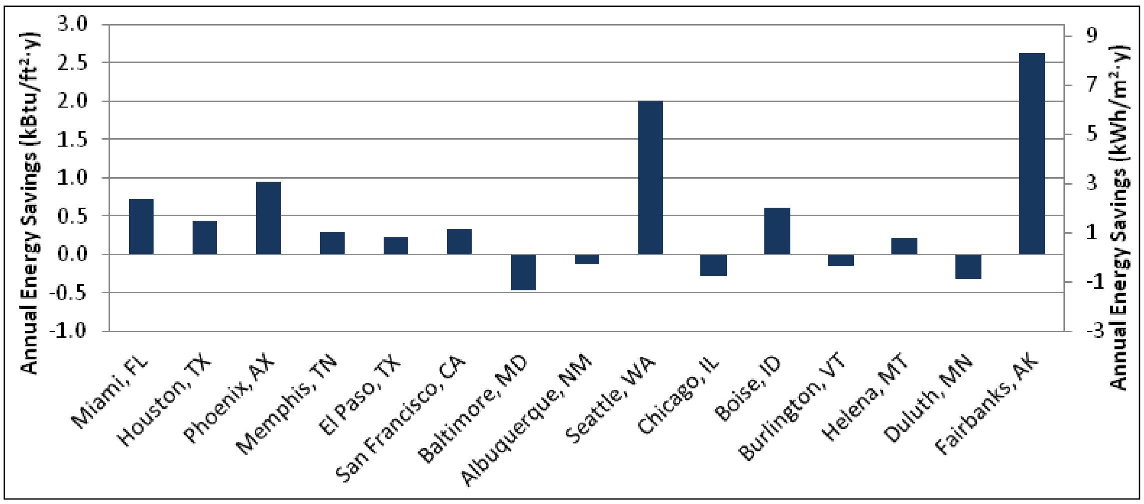

Figure 4.131. Annual energy savings for overhangs.

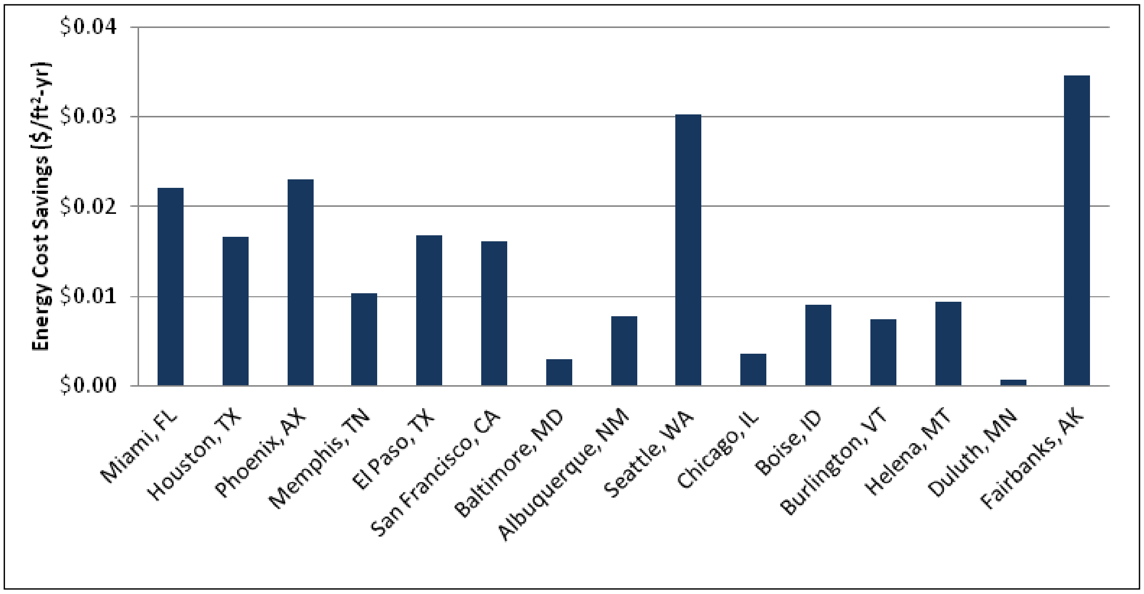

Figure 4.132. Annual energy cost savings for overhangs.

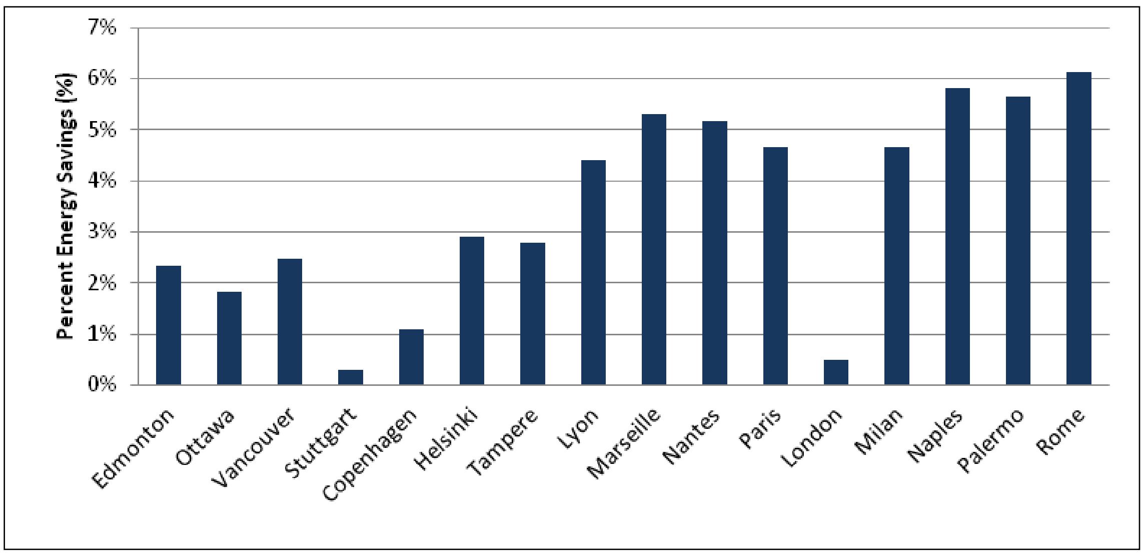

Figure 4.133. Percent energy savings for overhangs – International locations.

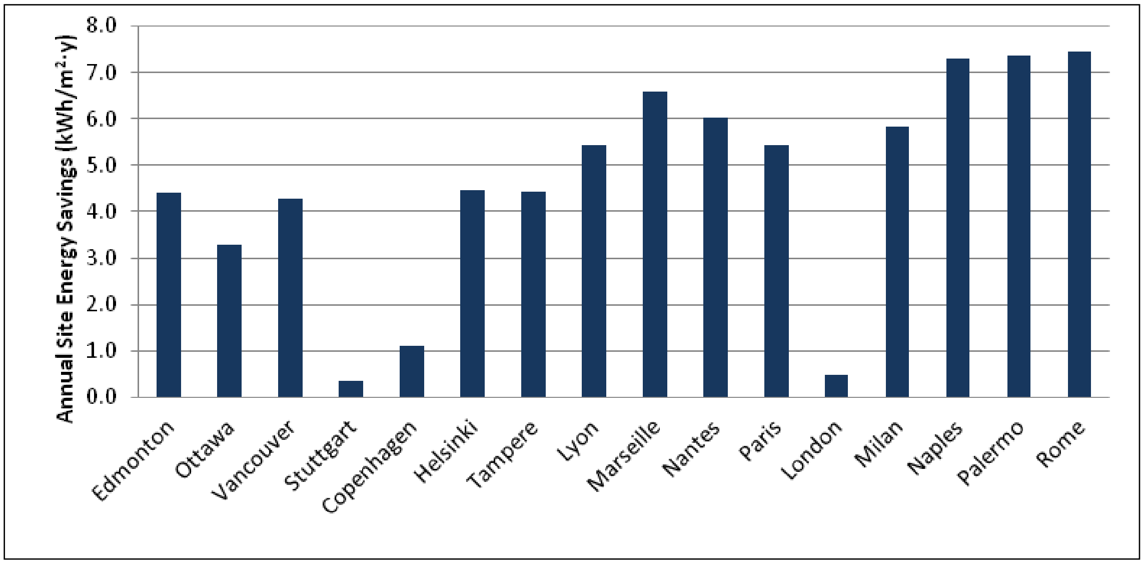

Figure 4.134. Annual energy savings for overhangs – International locations.

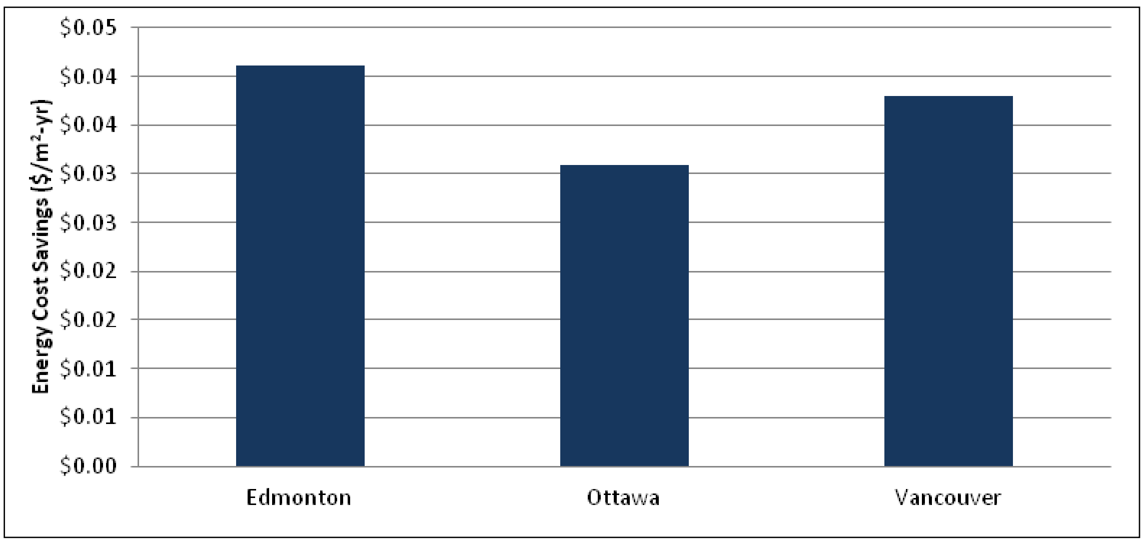

Figure 4.135. Annual energy cost savings for overhangs – Canadian locations.

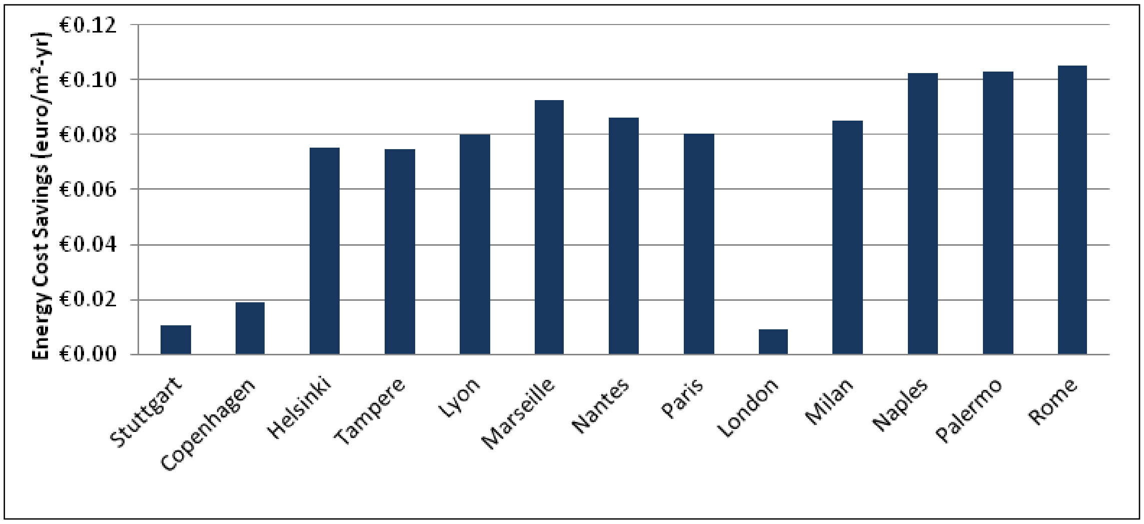

Figure 4.136. Annual energy cost savings for overhangs – European locations.

4.4.8 Exterior vertical fins

The effect of retrofitting the building with exterior vertical fins around the windows was modeled in a similar way as window overhangs. Shading devices protruding out 1.6 ft (0.5 m) orthogonally around the left, right, and top sides of the east-, west-, and south-facing windows were modeled using EnergyPlus.

Similar to the windows overhangs, the vertical fins were found to have only marginal effect on the U.S. locations. Seattle was an outlier, showing about 6% energy savings. In general, vertical fins were found to offer a greater advantage in the international locations. This was attributed to the higher SHGC in the baseline international buildings. Vertical fins are typically added to a building to control direct beam radiation and not for direct energy savings.

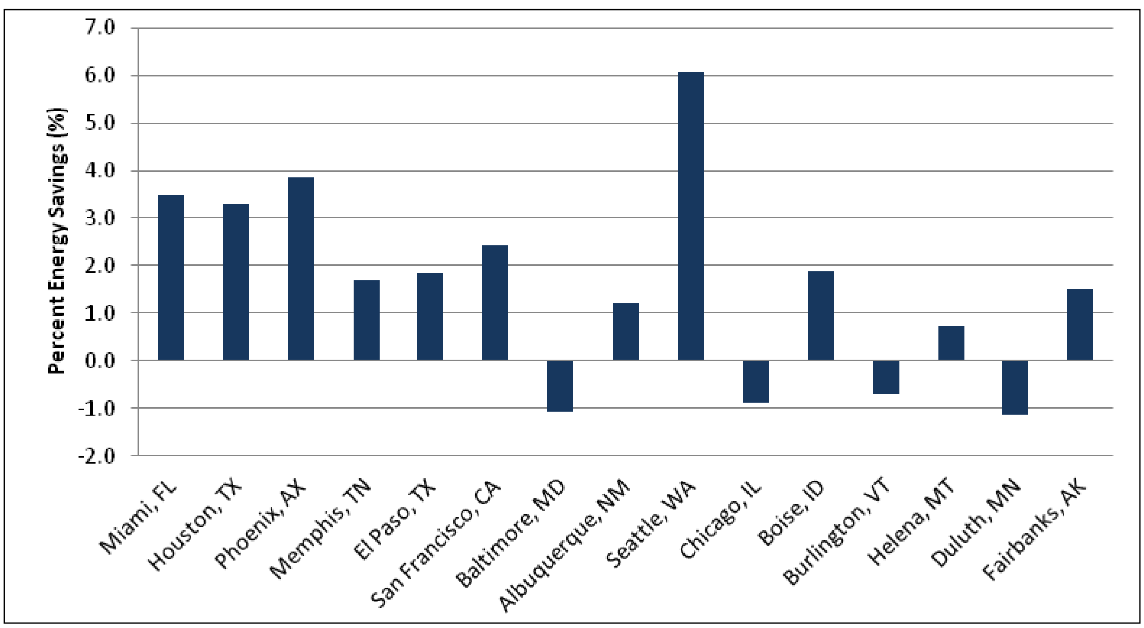

Figure 4.137. Percent energy savings for exterior vertical fins.

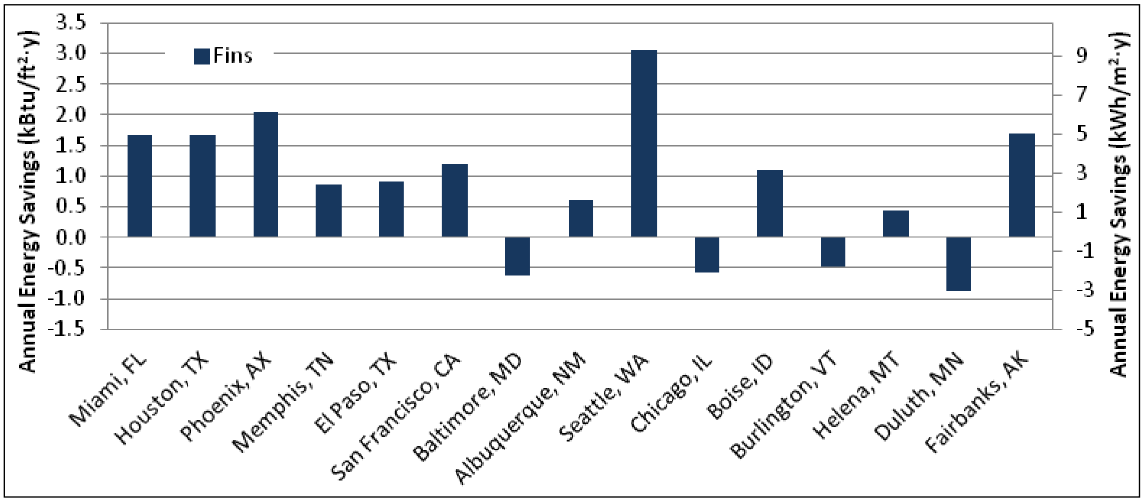

Figure 4.138. Annual energy savings for exterior vertical fins.

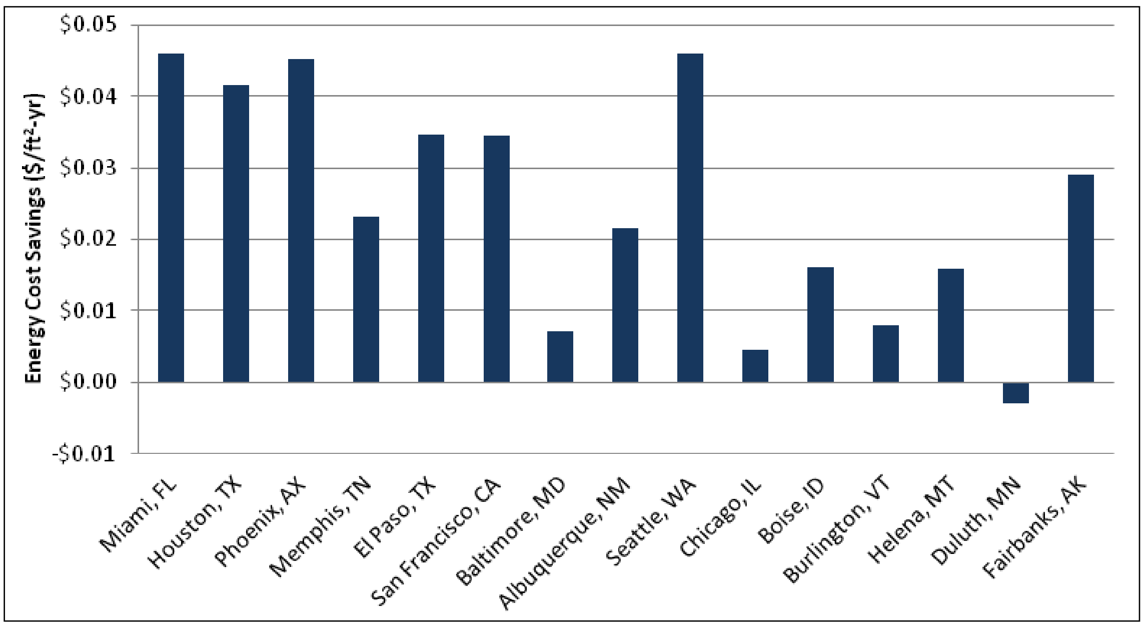

Figure 4.139. Annual energy cost savings for exterior vertical fins.

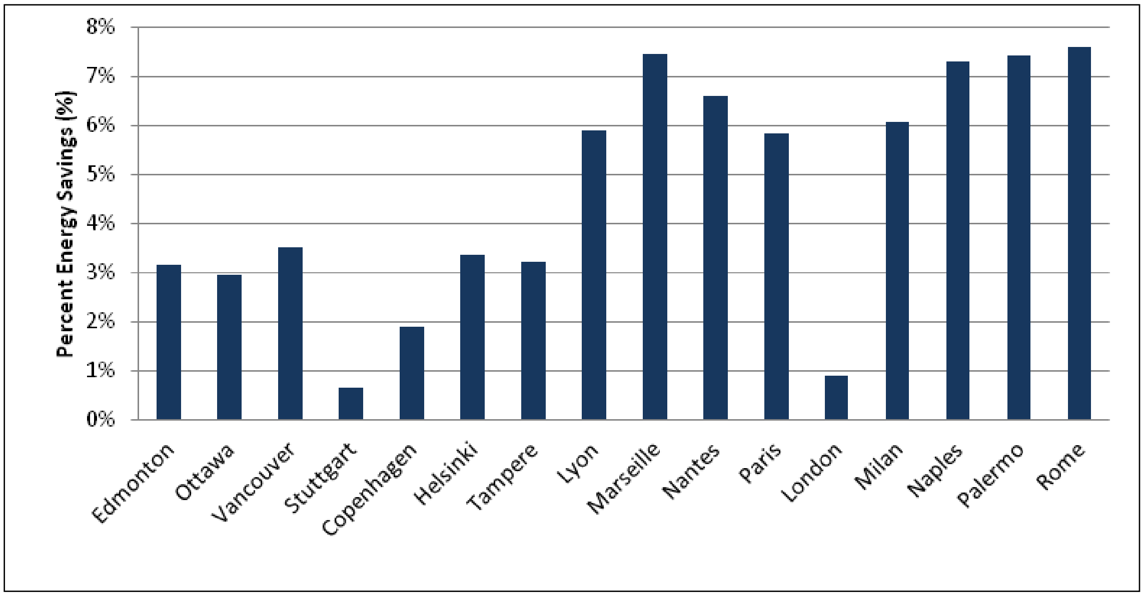

Figure 4.140. Percent energy savings for exterior vertical fins – International locations.

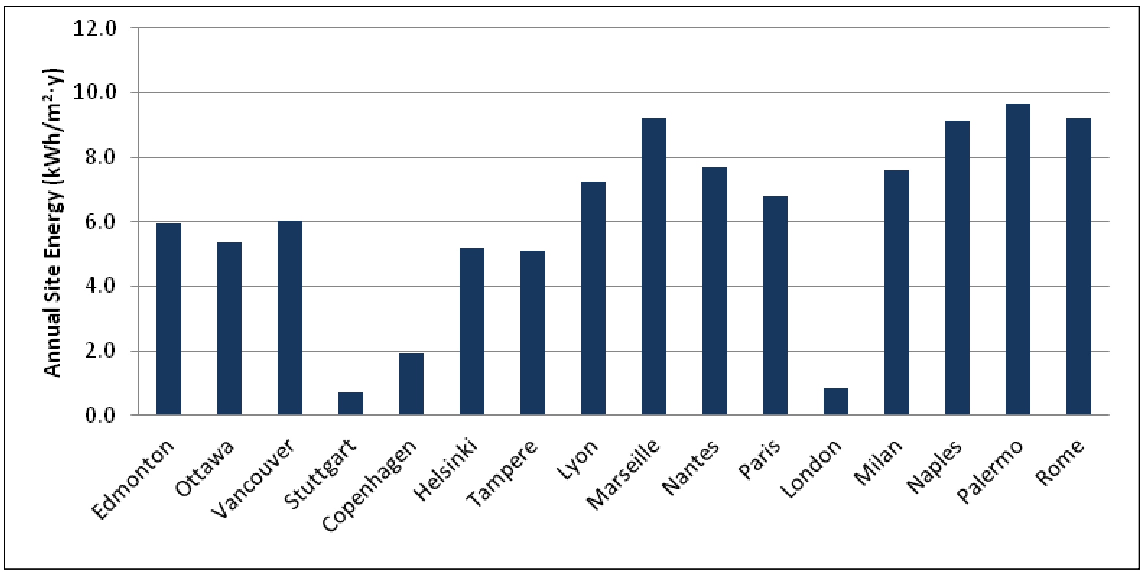

Figure 4.141. Annual energy savings for exterior vertical fins – International locations.

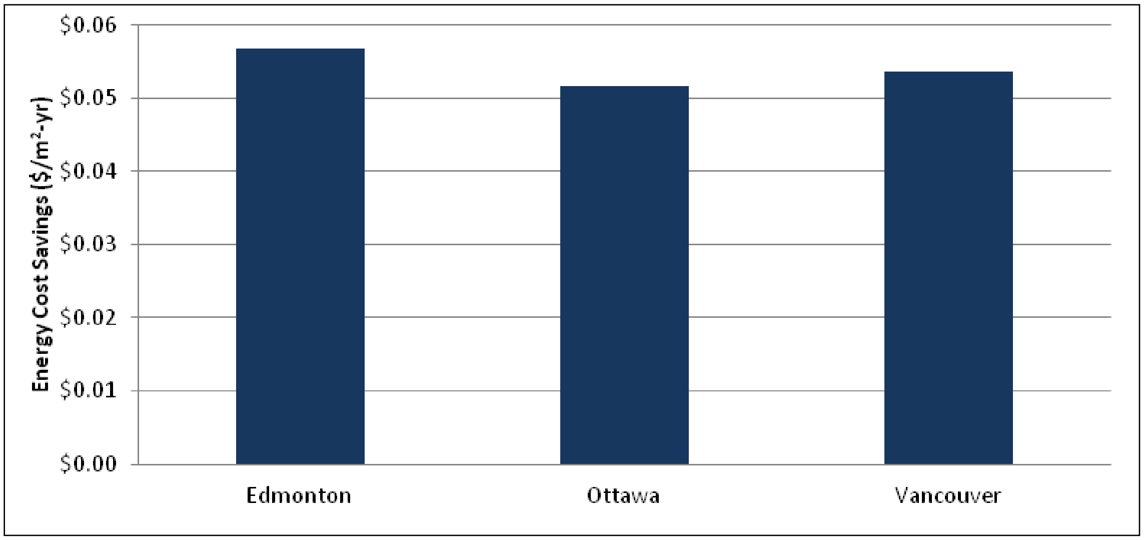

Figure 4.142. Annual energy cost savings for exterior vertical fins – Canadian locations.

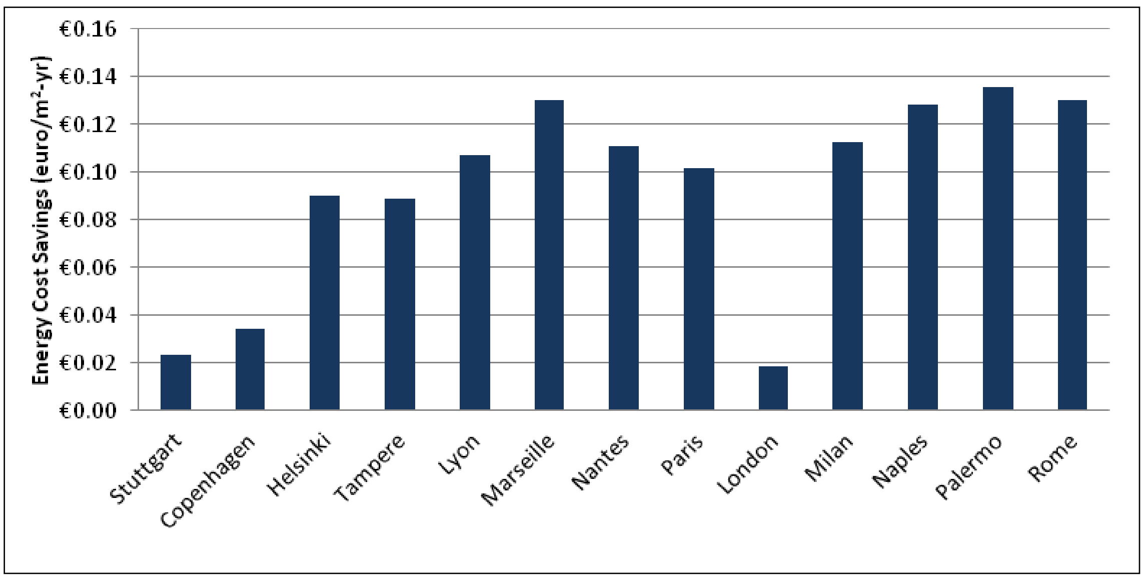

Figure 4.143. Annual energy cost savings for exterior vertical fins – European locations.

4.4.9 Energy recovery ventilators

ERVs are used to transfer useful energy from the exhaust air stream of a building's air handler to the incoming outdoor air stream. A retrofit application of ERVs was modeled using three levels of performance. The specifications of the ERV are selected to represent a desiccant wheel type ERV, which has the capability to transfer moisture between the two air streams and is sometimes called a total energy recovery system. The specific properties of each are shown in Table 4.20.

Table 4.20. ERV retrofit model parameters.

ERV Name	Sensible Effectiveness	Latent Effectiveness	Pressure Drop (in water)
ERV 60	0.6	0.5	0.70
ERV 70	0.7	0.6	0.86
ERV 80	0.8	0.7	1.00

A schematic of the retrofit system is shown in Figure 4.144. Each individual air handler in the baseline building was retrofitted with an ERV across the outdoor air and relief air streams of the outdoor air systems. In the US locations the air handlers serve multiple zones whereas the international buildings contain packaged single zone systems.

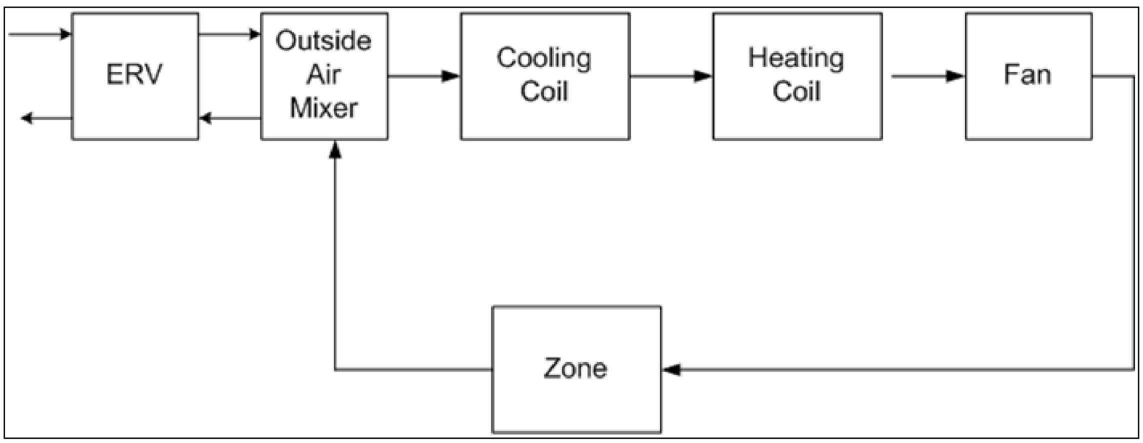

Figure 4.144. Schematic of the energy recovery ventilator model (credit: Kyle Benne).

The results for the ERV simulations are shown in Figure 4.145 through Figure 4.151. Energy recovery devices are generally most effective in cold climates. The results below show over 10% energy savings in the cold-humid climates. Buildings in a few climates can actually be penalized for the use of an ERV. These are climates that have large opportunities for economizing, and any small savings due to energy recovery is offset by an increase in fan energy due to the added pressure drop of the device. An ERV bypass was not modeled in this study, but would improve performance by avoiding the fan energy penalty of the ERV when the system is in economizer mode.

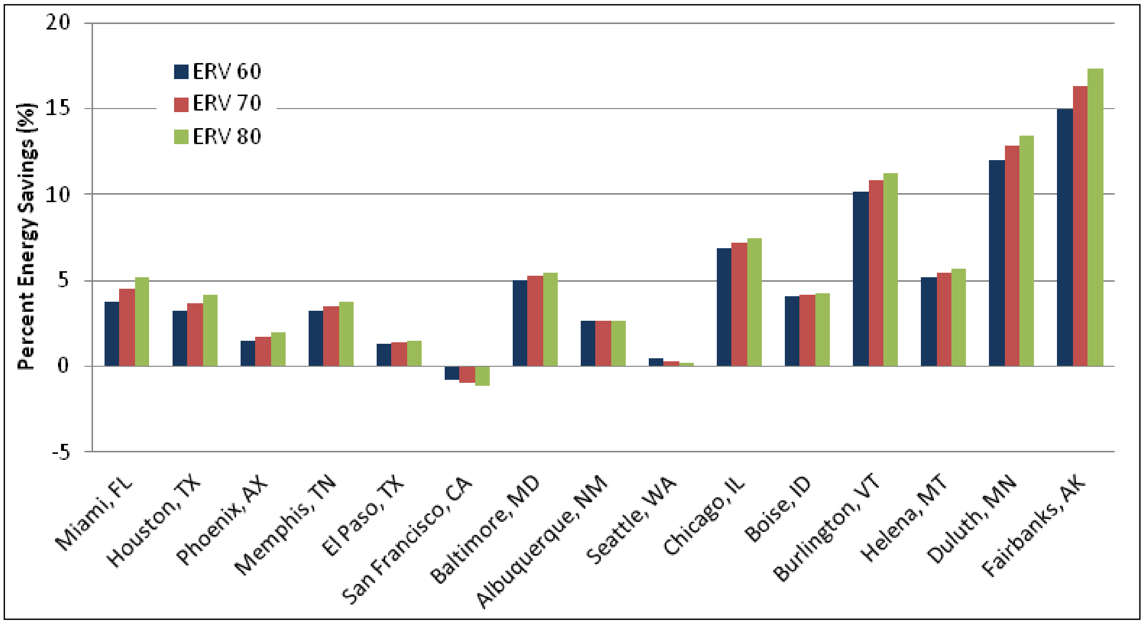

Figure 4.145. Percent energy savings for ERVs.

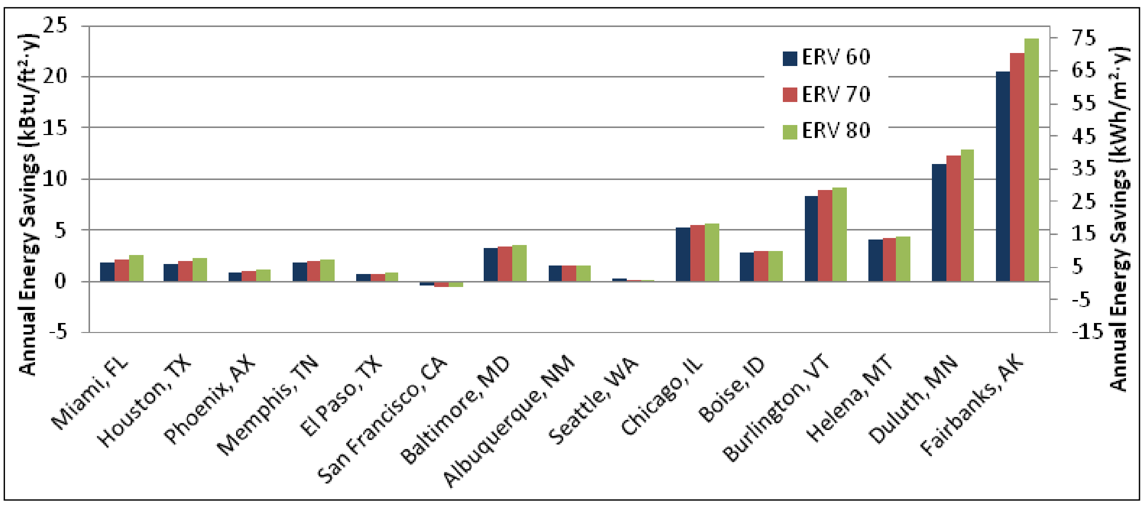

Figure 4.146. Annual energy savings for ERVs.

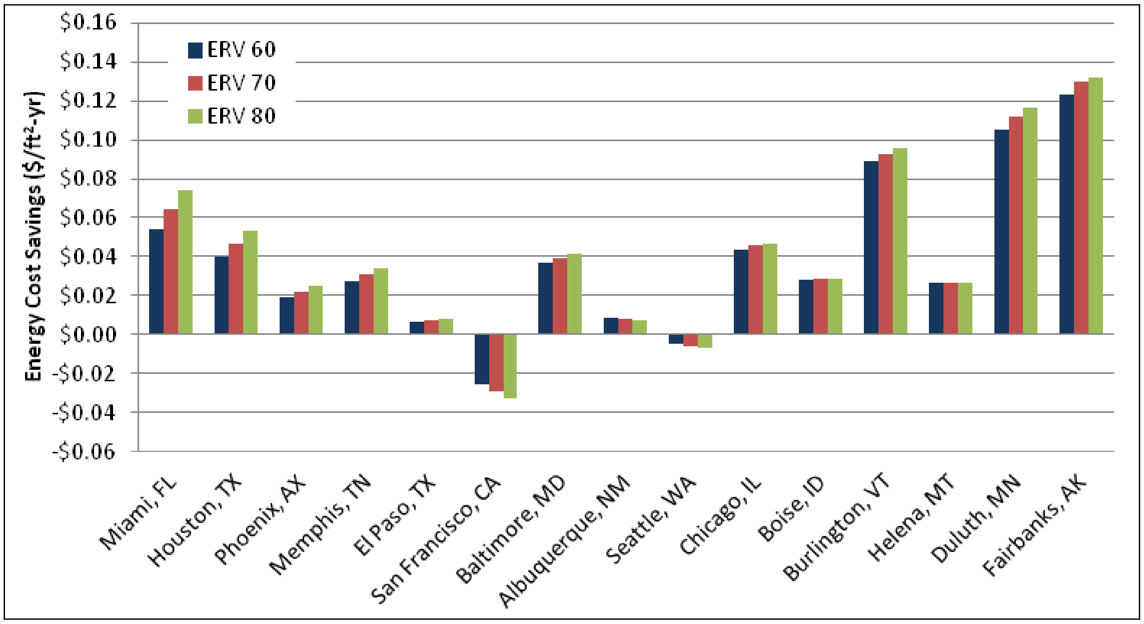

Figure 4.147. Annual energy cost savings for ERVs.

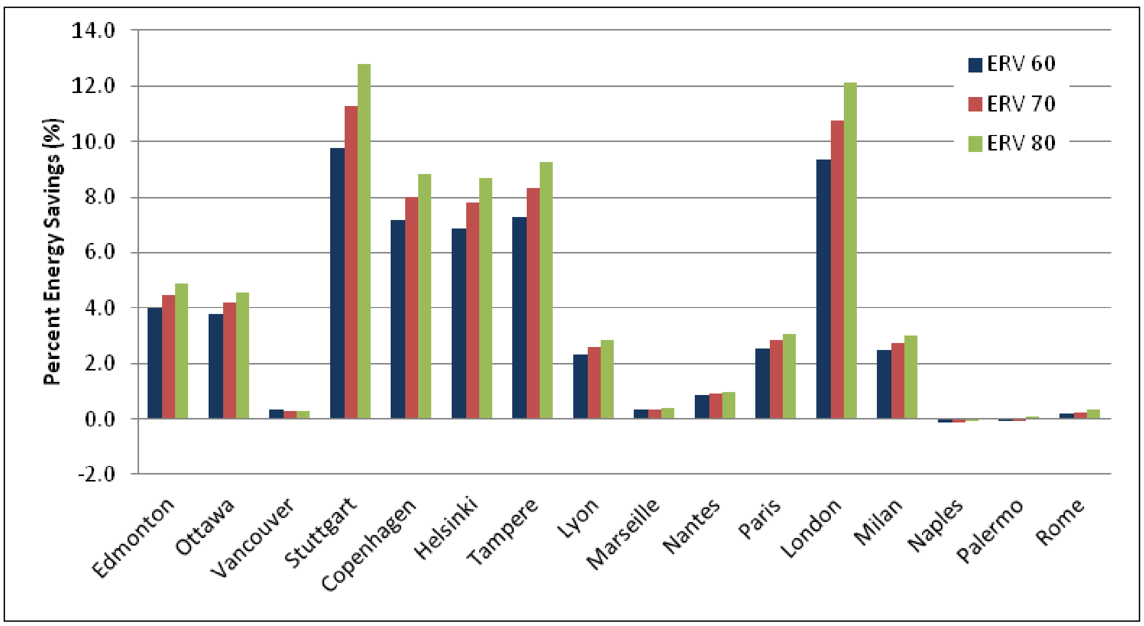

Figure 4.148. Percent energy savings for ERVs – International locations.

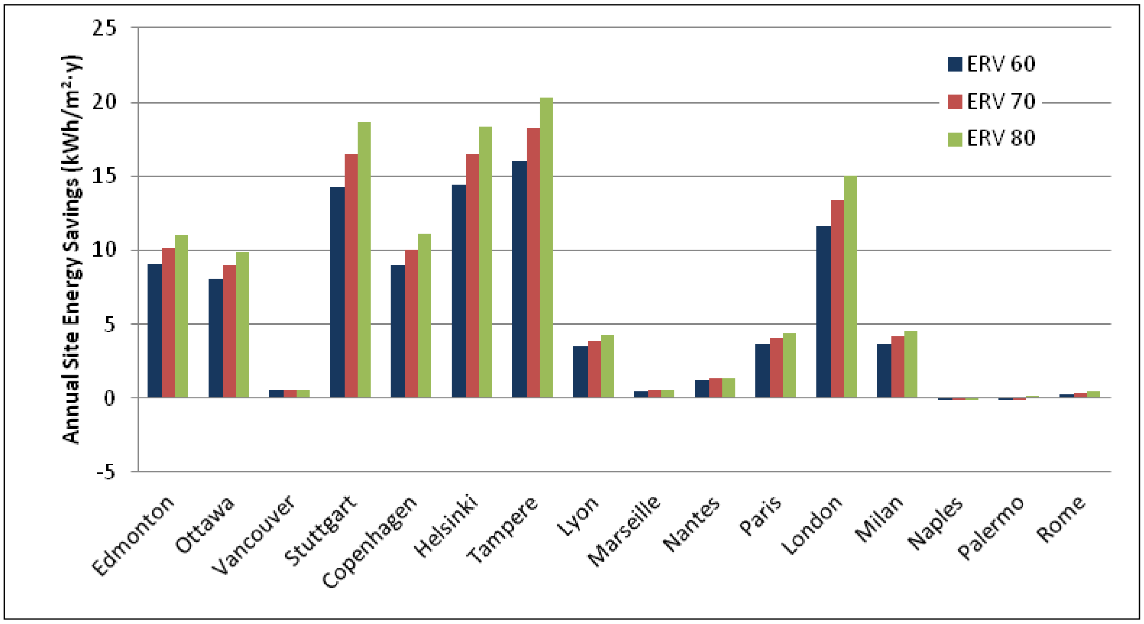

Figure 4.149. Annual energy savings for ERVs – International locations.

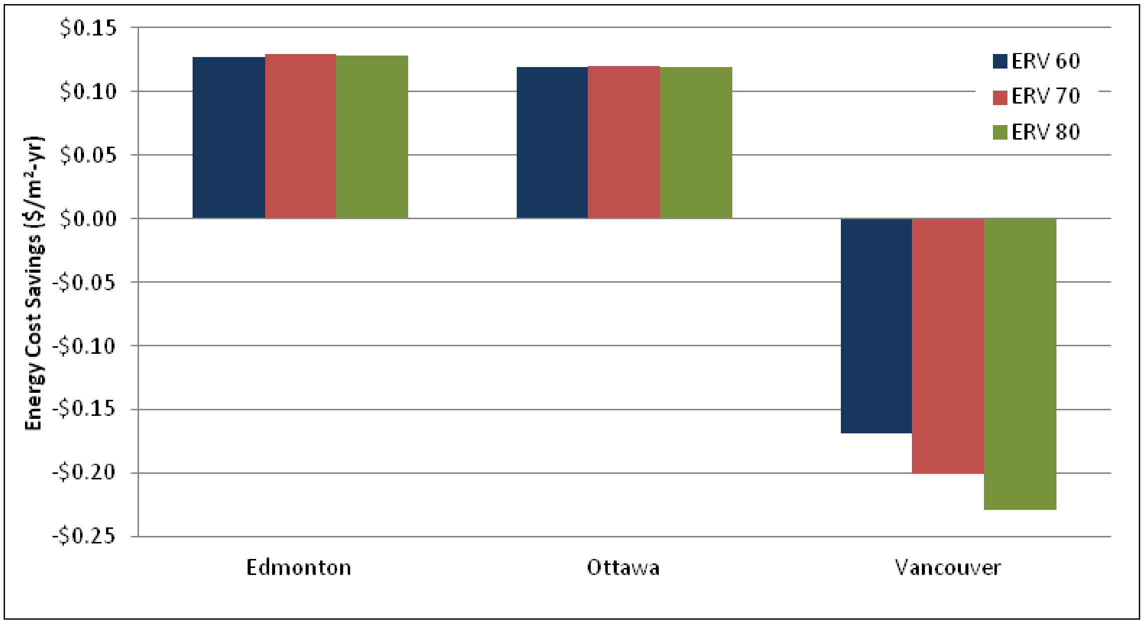

Figure 4.150. Annual energy cost savings for ERVs – Canadian locations.

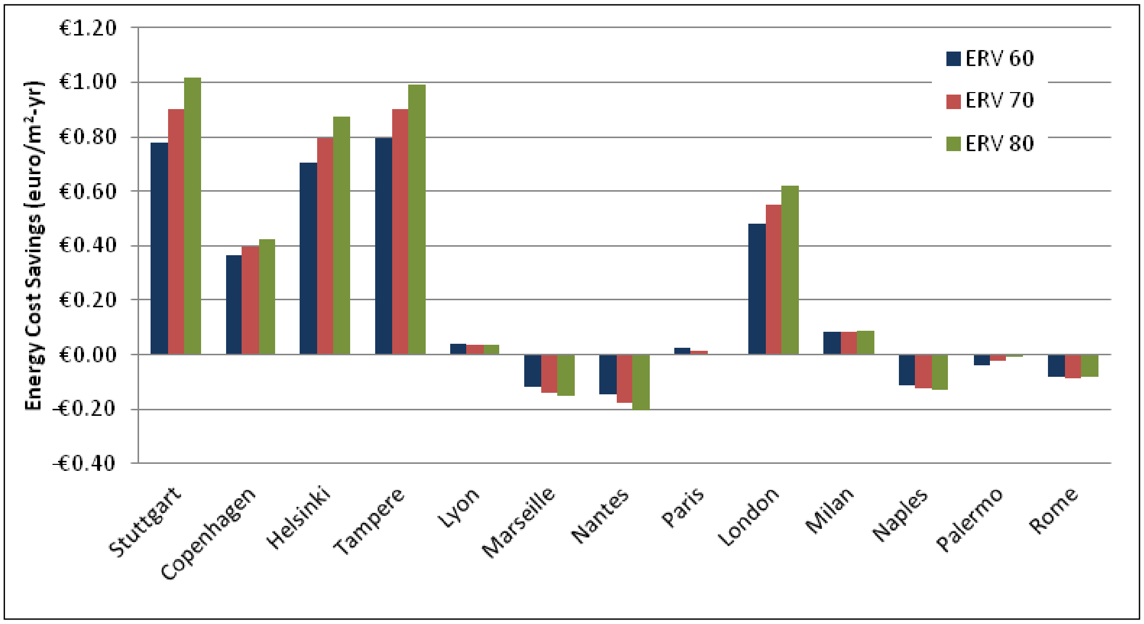

Figure 4.151. Annual energy cost savings for ERVs – European locations.

4.4.10 Indirect evaporative cooling

A retrofit with the addition of an indirect evaporative cooling (IDEC) system was simulated as a preconditioner to the outdoor air before mixing at the outdoor air mixing device. In this study, each air handler had its own evaporative cooler, although other configurations are certainly possible, such as a DOAS serving multiple zones. The systems were modeled using the outside air and the return air as the secondary air stream for the IDEC. The return-air strategy provided the best results, and these are the only results included in this report. The IDEC was bypassed when in heating mode to reduce the pressure drop on the fan. In order to maximize the benefit of the evaporative cooler, economizer controls where used to increase the outdoor air fraction under favorable conditions; however, the economizer control strategy was not optimized and it is believed that there are missed opportunities for economizing in some climates. Better economizing logic is expected to further improve the benefit of this technology in favorable locations. The model parameters are shown in Table 4.21 and a schematic of the main HVAC components of the evaporative cooling retrofit is shown in Figure 4.152.

It is possible to use the IDEC as a heat exchanger for heat recovery when in heating mode if return air is used as the secondary air stream. The energy savings for this arrangement was approximated by estimating the gas energy savings from the ERV simulations. It was assumed that the gas energy savings would be half of the gas energy savings from the ERV 60 (60% effective).

Table 4.21. IDEC model parameters.

Wet Bulb Effectiveness	Primary Air Pressure Drop in w.g. (Pa)	Secondary Air Pressure Drop in w.g. (Pa)	Fan Efficiency
0.75	0.75 (187)	0.5 (125)	0.5

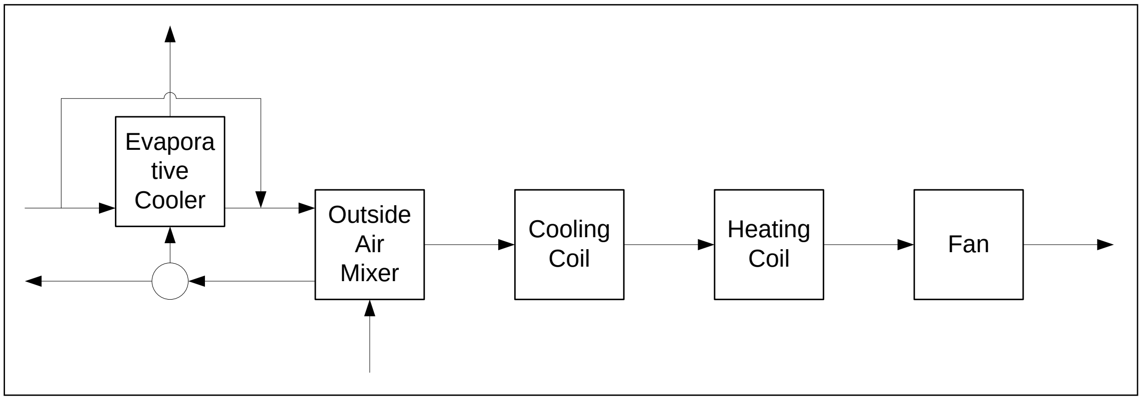

Figure 4.152. Schematic of the indirect evaporative cooling model (credit: Kyle Benne).

The results of the IDEC simulations are shown in Figures 4.153 through 4.159. The IDEC was found to offer energy savings in all climates except for Palermo Italy, and significant energy savings were achieved in the hot dry climates. The estimated performance of IDEC plus heat recovery in heating mode is also shown in these figures. The energy savings are favorable for the cold climates. Additional savings may be achievable with a system design specifically for this application. These results should be viewed as preliminary estimates and actual savings for specific projects may vary considerably depending on the building loads, systems, and application of the technology.

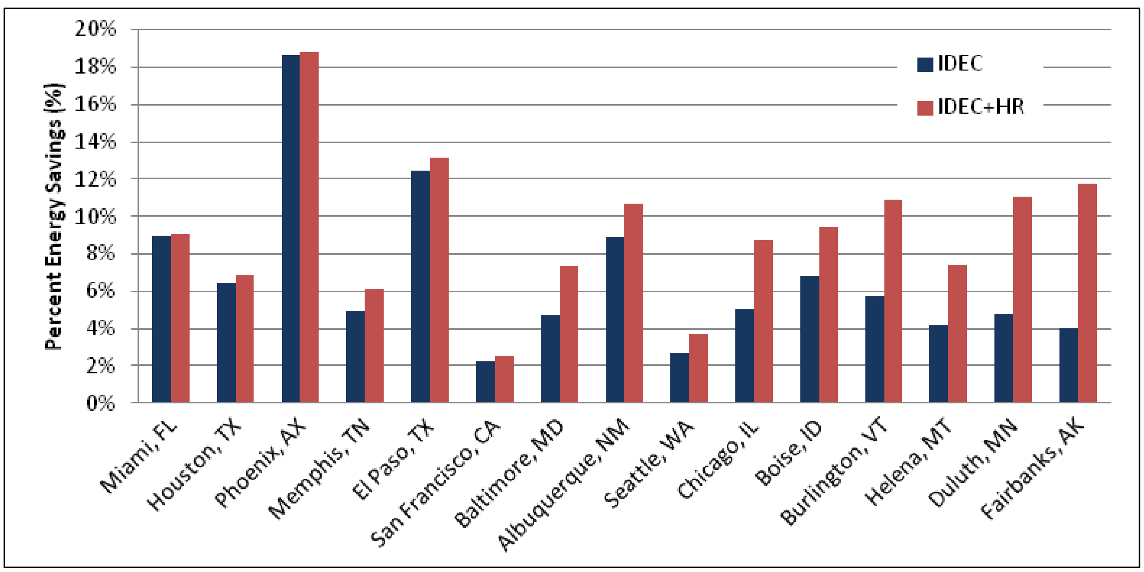

Figure 4.153. Percent energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery.

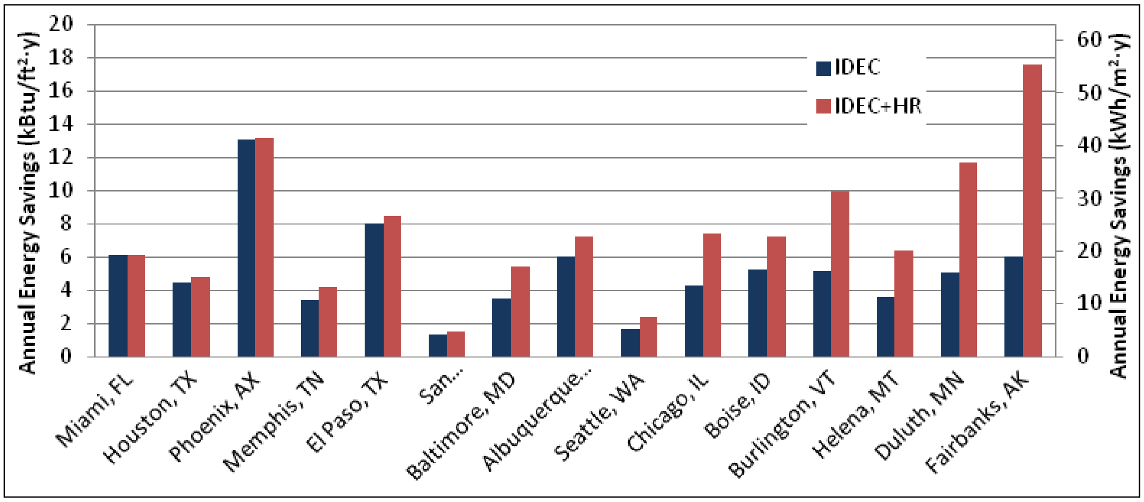

Figure 4.154. Annual energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery.

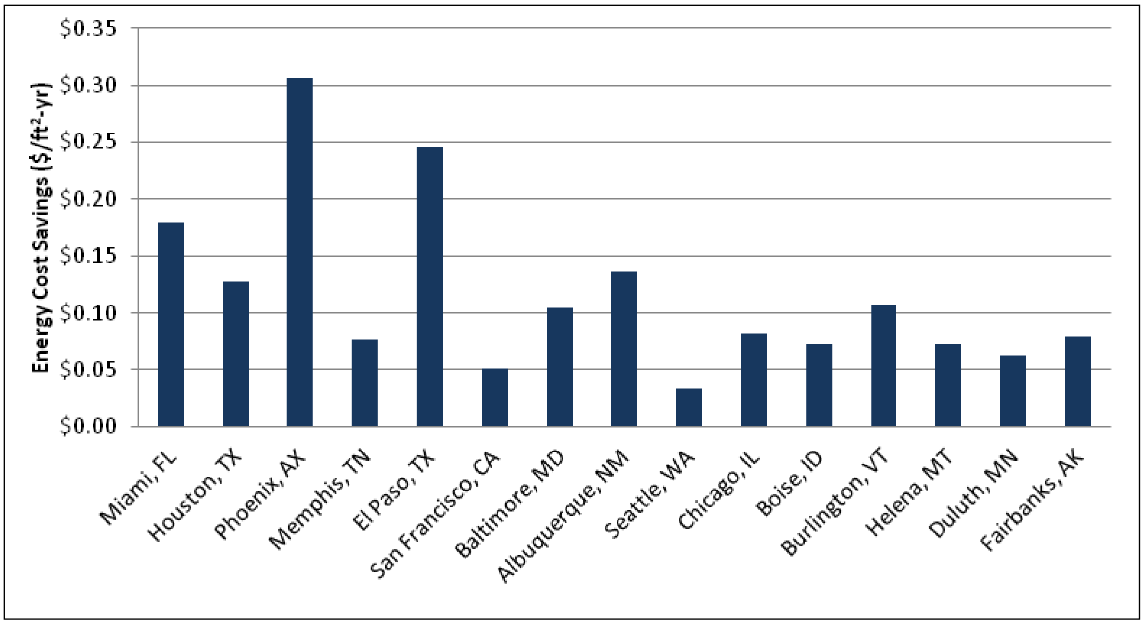

Figure 4.155. Annual energy cost savings for indirect evaporative cooling.

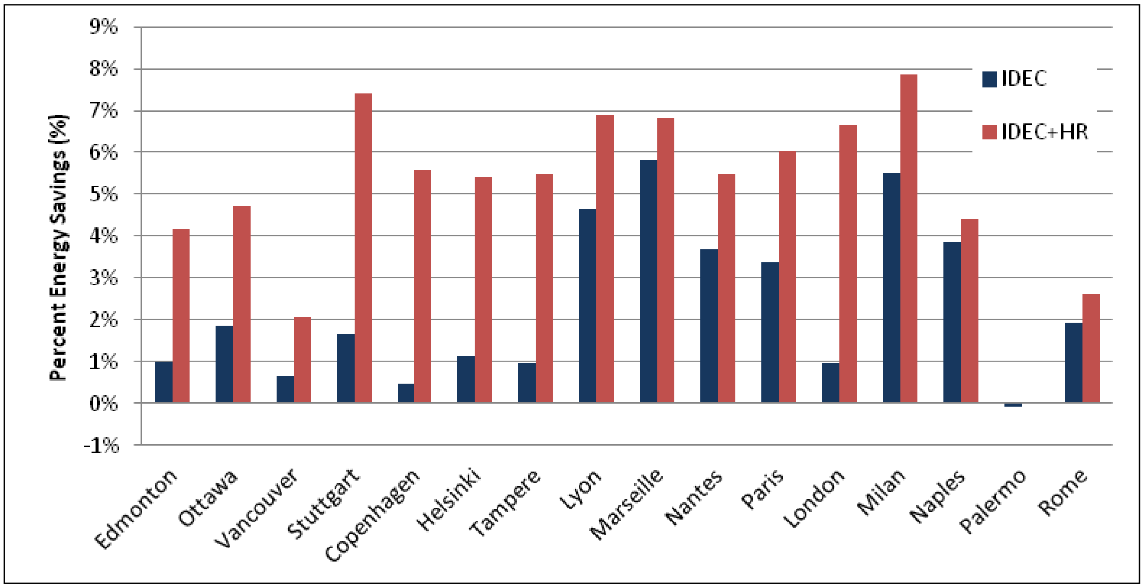

Figure 4.156. Percent energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery – International locations.

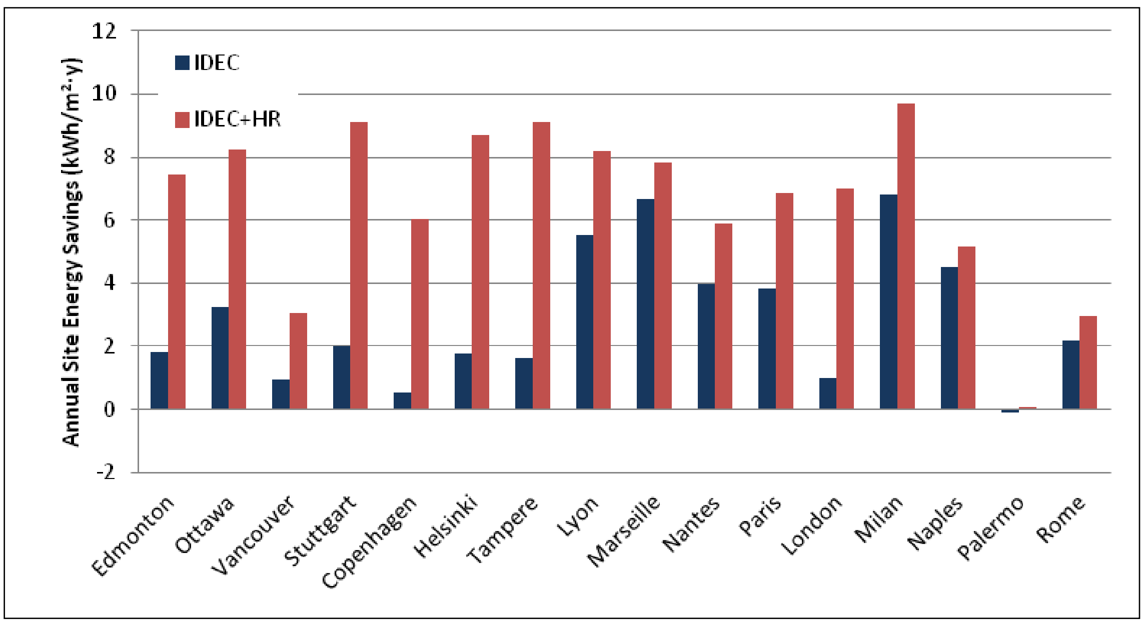

Figure 4.157. Annual energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery – International locations.

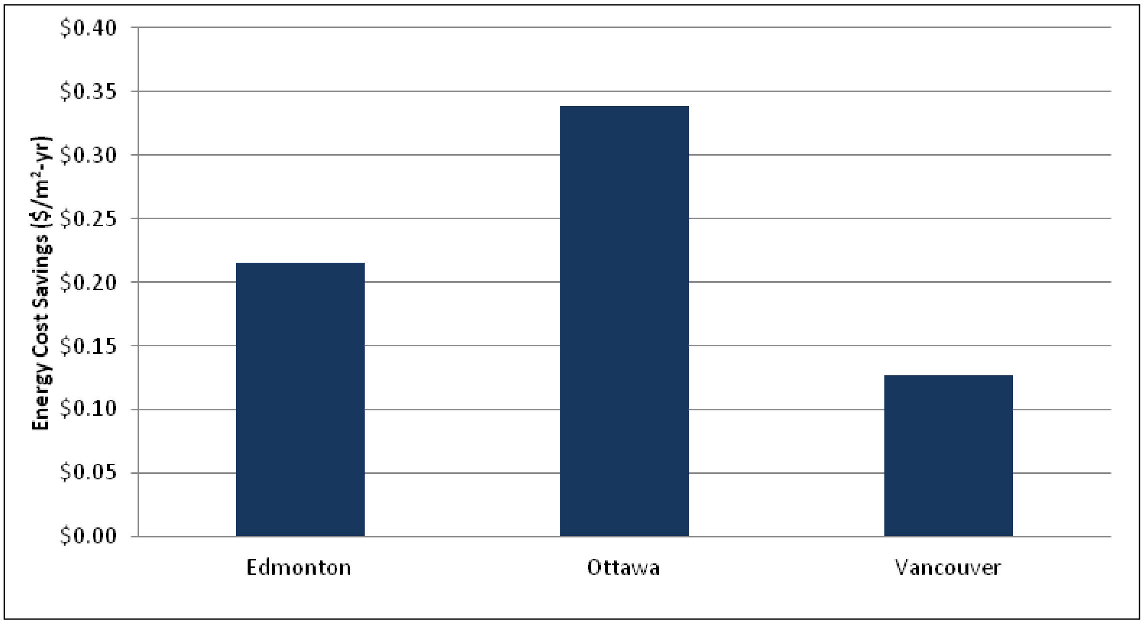

Figure 4.158. Annual energy cost savings for indirect evaporative cooling – Canadian locations.

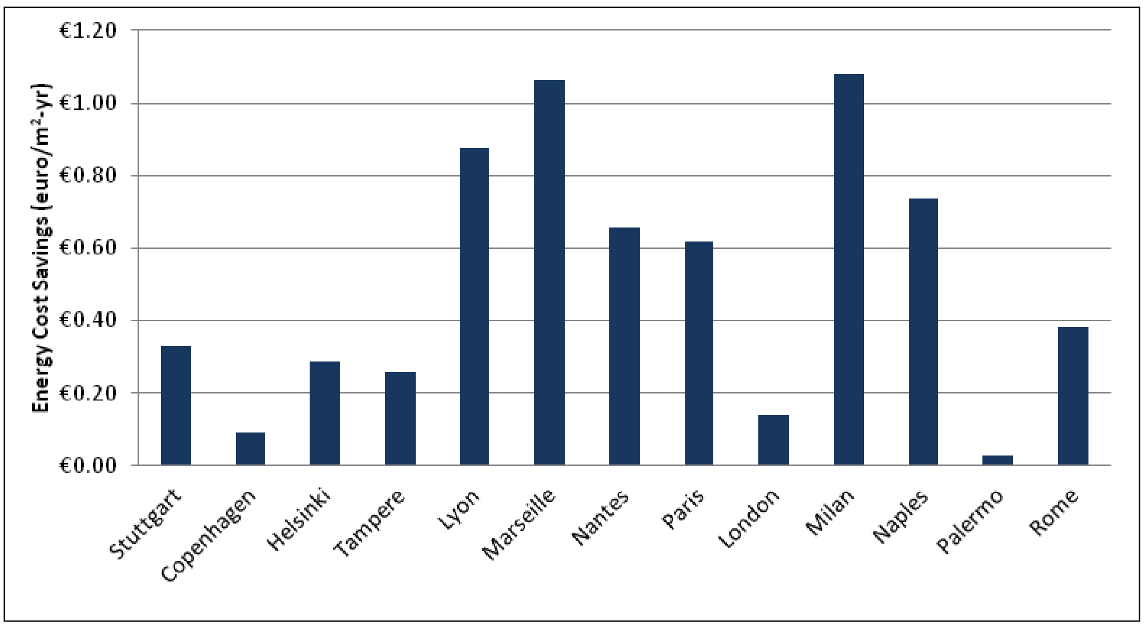

Figure 4.159. Annual energy cost savings for indirect evaporative cooling – International locations.

4.4.11 Hybrid evaporative cooling

A retrofit of a hybrid evaporative cooling system was simulated to understand the performance of a combined indirect and direct evaporative cooling system. The hybrid system consists of an indirect evaporative cooling component followed immediately by a direct evaporative cooling component. Aside from the additional component, this hybrid system was configured and controlled identically to the previous indirect evaporative cooling system. The direct component was modeled using a wet bulb effectiveness of 0.90.

The results for the hybrid evaporative cooling systems are shown in Figures 4.160 through 4.166. The same hot dry locations favorable for indirect evaporative cooling show potential with the hybrid system, but adding the direct component boosts the overall performance of the system by a few percent. However, high humidity is even more of a concern with direct evaporative cooling, and the direct evaporative section should be turned off when high humidity is of concern. The direct evaporative component may not be appropriate in humid locations.

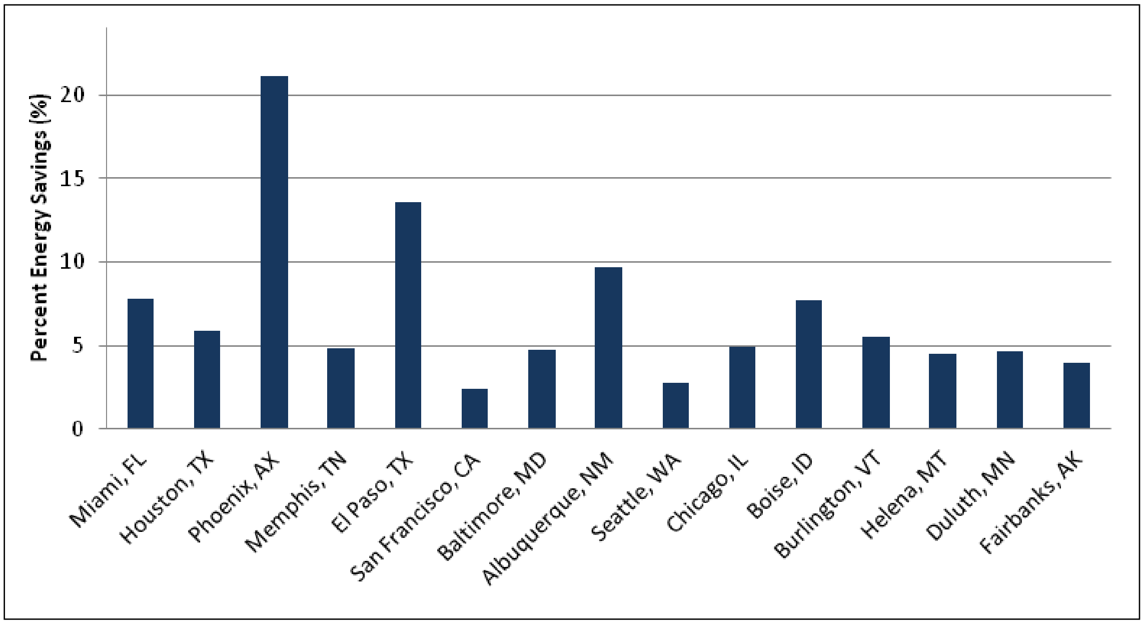

Figure 4.160. Percent energy savings for hybrid evaporative cooling.

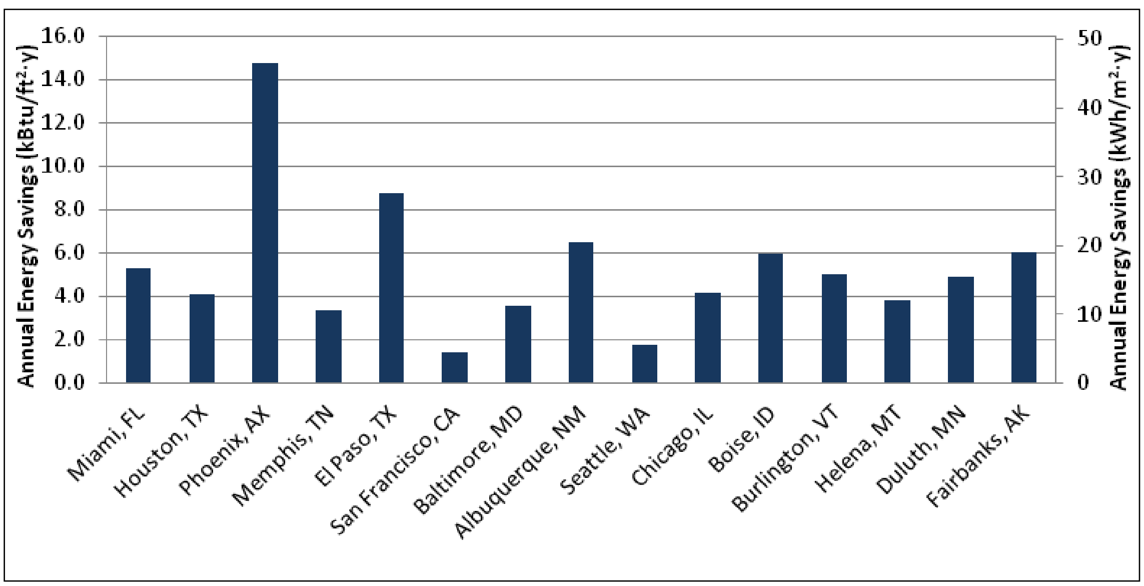

Figure 4.161. Annual energy savings for hybrid evaporative cooling.

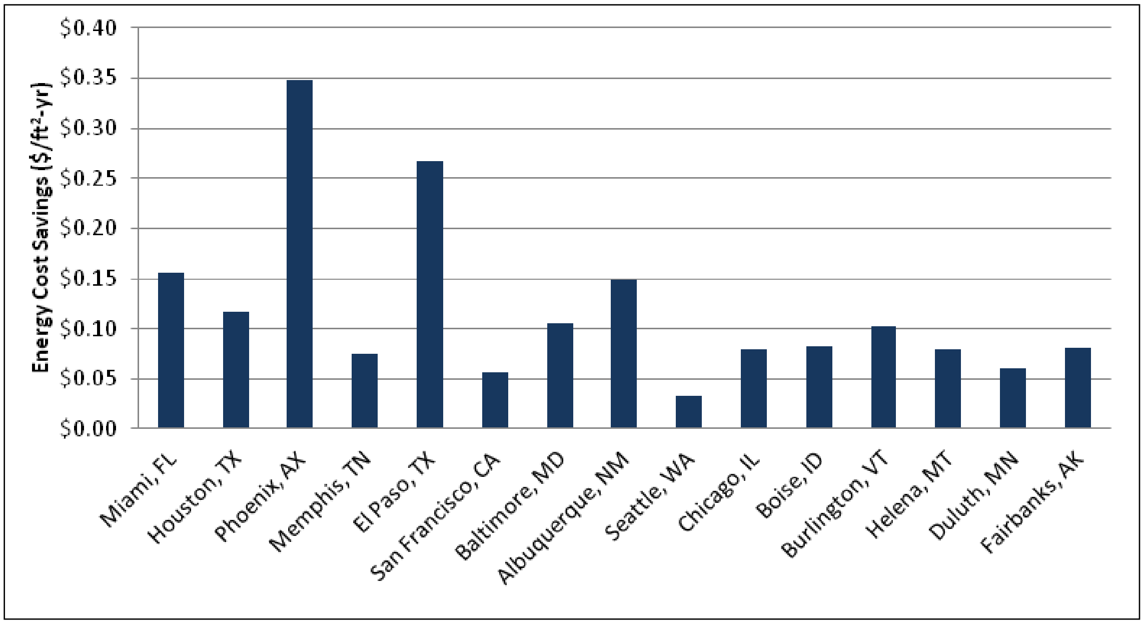

Figure 4.162. Annual energy cost savings for hybrid evaporative cooling.

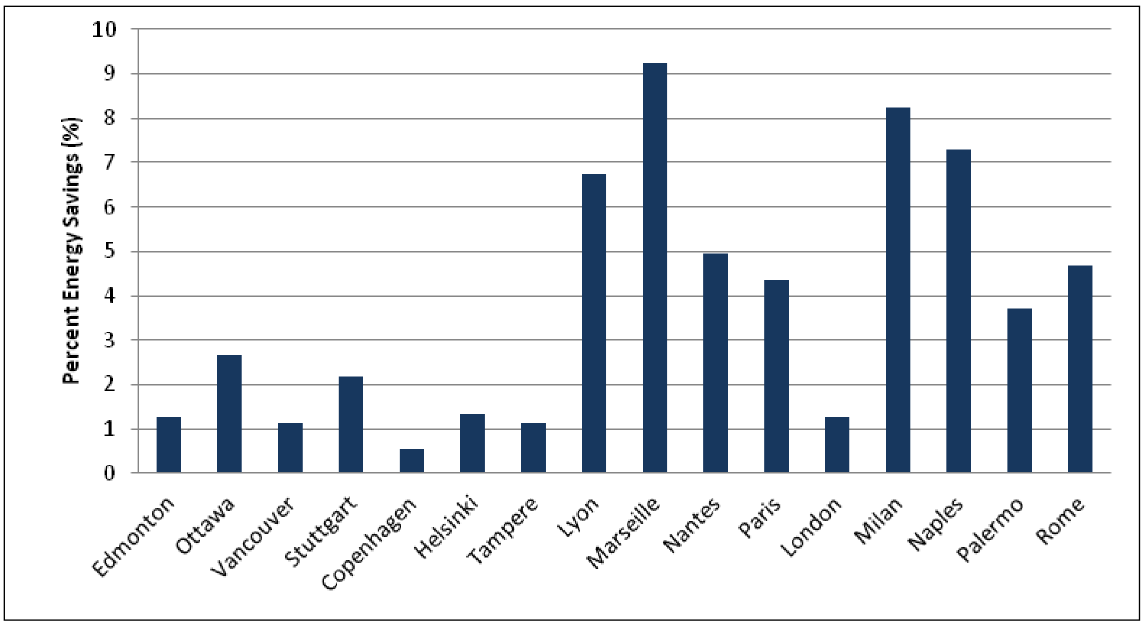

Figure 4.163. Percent energy savings for hybrid evaporative cooling – International locations.

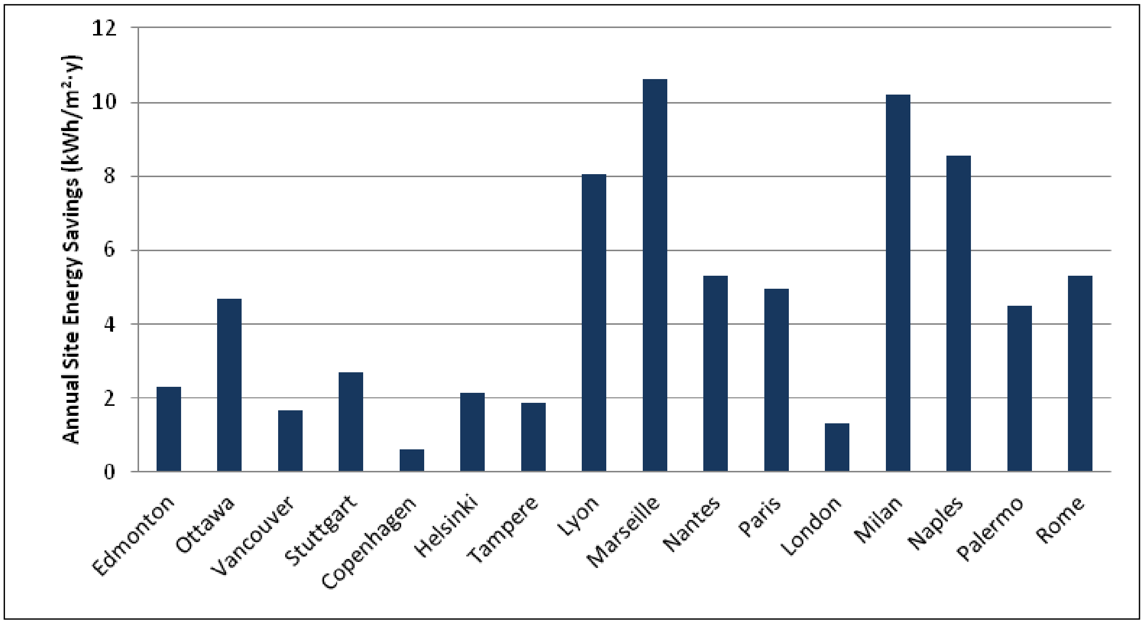

Figure 4.164. Annual energy savings for hybrid evaporative cooling – International locations.

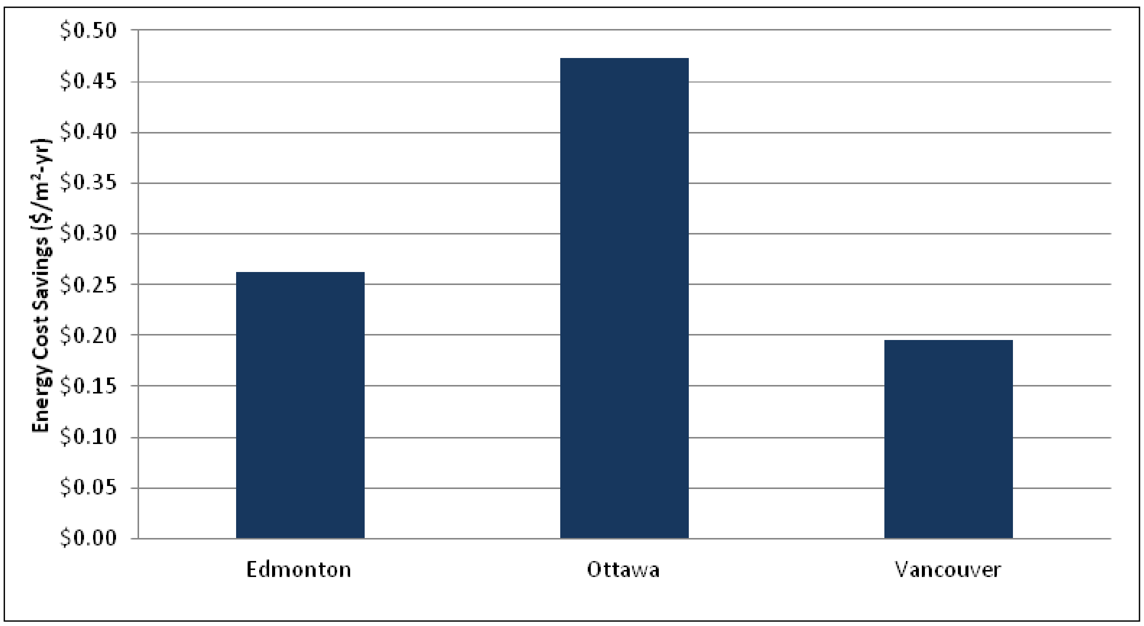

Figure 4.165. Annual energy cost savings for hybrid evaporative cooling – Canadian locations.

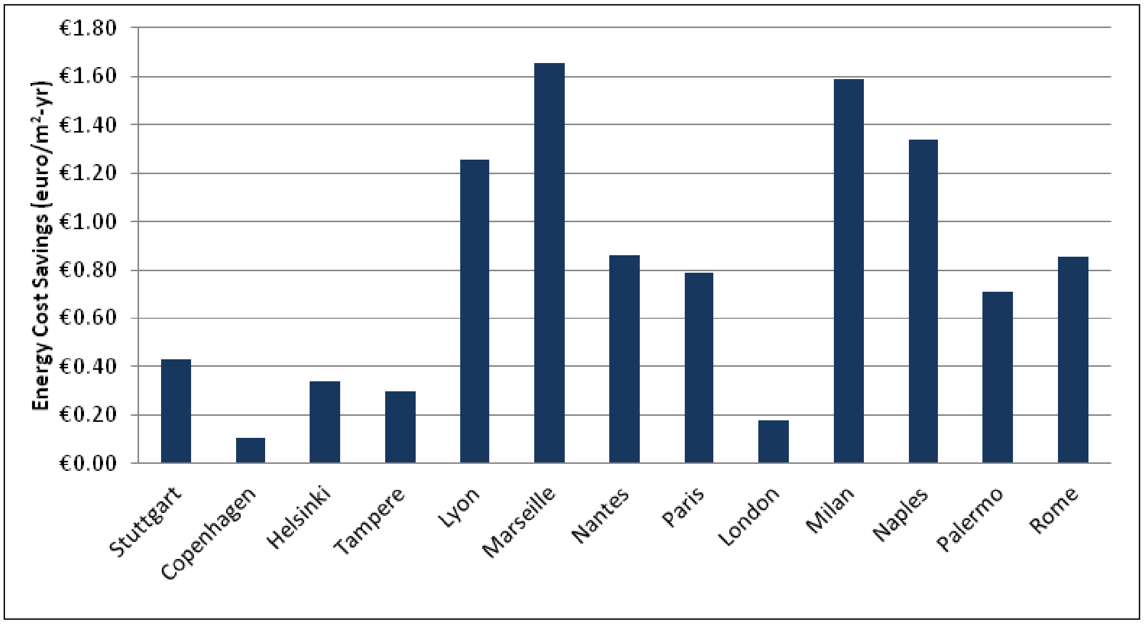

Figure 4.166. Annual energy cost savings for hybrid evaporative cooling – International locations.

4.4.12 DOAS with FCU

A DOAS in combination with a four-pipe FCU was simulated as a potential retrofit to the administration building. Only the U.S. locations were simulated with this technology. The DOAS consisted of central heating and cooling coils served by a gas-fired boiler and an air-cooled chiller. The DOAS is a constant volume system that provides the minimum ventilation air only during the office hours of operation. The DOAS does not provide economizer operation because of the constant speed fan and constant air flow rate. The supply-air temperature of the DOAS is governed by an outside air reset, which varied slightly with climate. The DOAS provides minimal heating through water coils supplied by a gas boiler and a small amount of cooling through a chilled water coil supplied by an air-cooled chiller. A key component of the DOAS is an energy recovery device between the outdoor air and relief air streams. The water loops feeding the DOAS are separate from the FCU system.

The results for this system are shown in Figures 4.167 through 4.169. The most significant energy savings were achieved in cold climates reflecting the benefit of the heat recovery. Energy savings in warm climates were modest and attributed to slightly better cooling efficiency of the chiller relative to the DX cooling system in the baseline. In all locations, there was an increase in electricity consumption from increased fan energy because of the increased pressure drop and a decrease in gas consumption because of the energy recovery component. The trade off of gas savings and electricity increase results in moderate energy cost savings in some locations and energy cost increases in other locations. Improved performance could be achieved with alternative system configurations and control strategies that minimizes the fan energy and optimizes the delivery of the space conditioning supply air. Systems design and operation for specific climates and applications are important for the best performance.

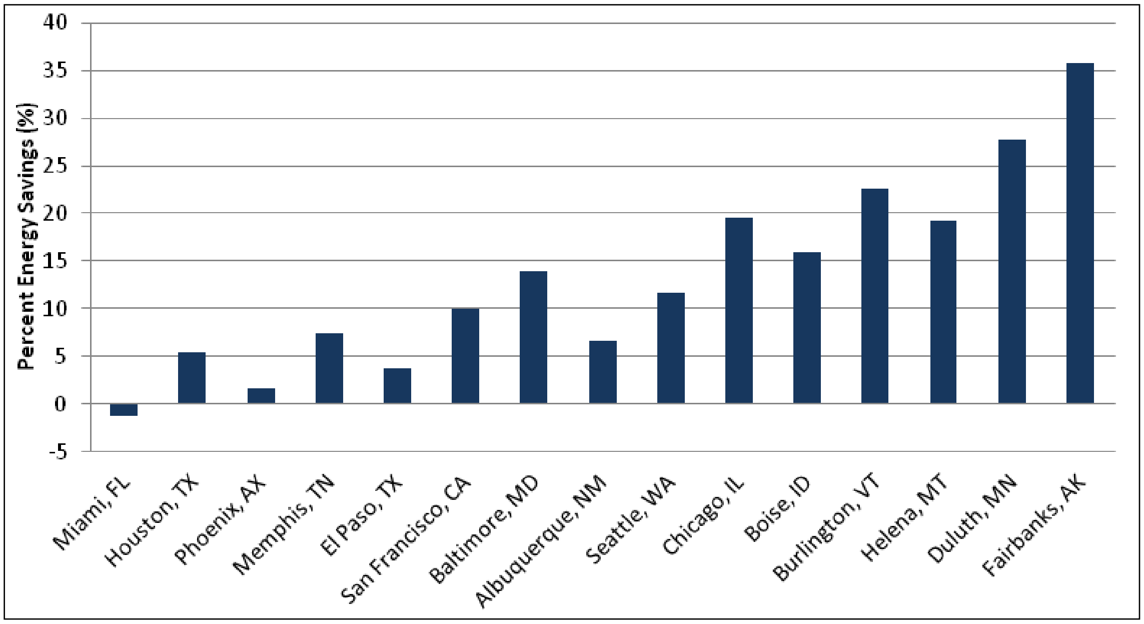

Figure 4.167. Percent energy savings for DOAS with FCU.

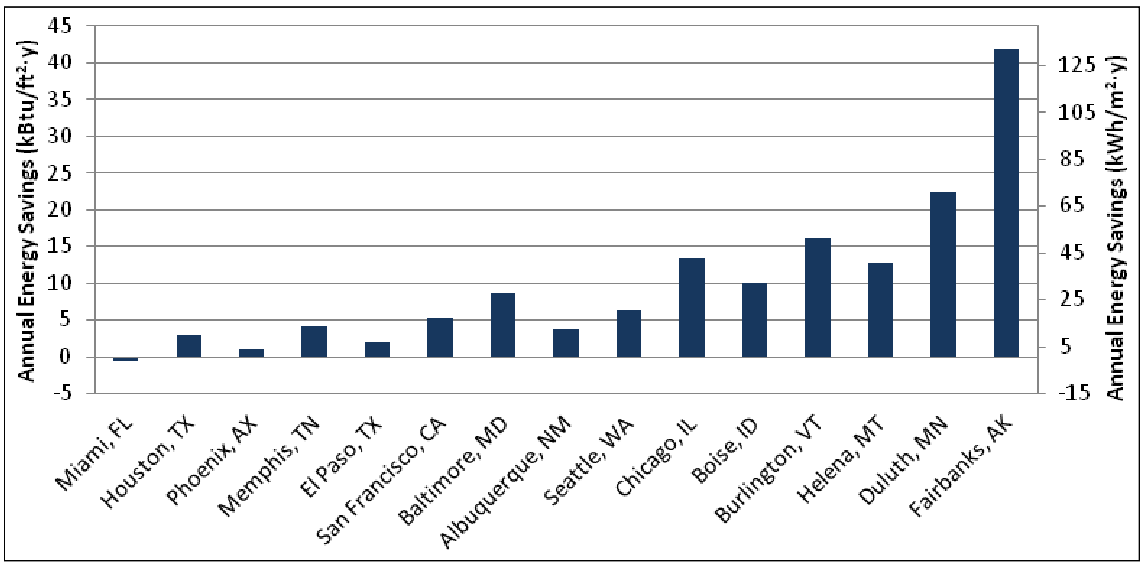

Figure 4.168. Annual energy savings for DOAS with FCU.

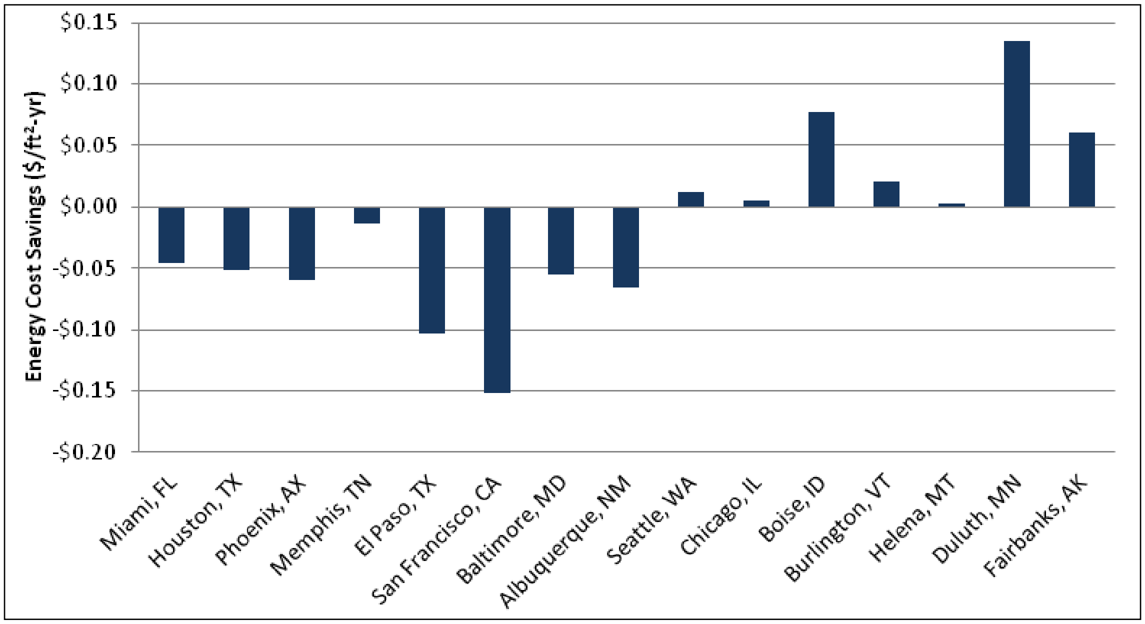

Figure 4.169. Annual energy cost savings for DOAS with FCU.

4.4.13 DOAS with radiant heating and cooling

A DOAS in combination with radiant heating and cooling was evaluated. The DOAS of this retrofit was identical to the system model for the DOAS with FCU case. The radiant system consisted of actively heated and cooled panels embedded into the ceiling. The radiant panels are served by chilled water from a water-cooled chiller, and hot water from a gas boiler. The radiant system is controlled by mean radiant temperature instead of average space temperature as in the baseline system, which translates to a looser space temperature requirement while maintaining similar or perhaps even better comfort. The radiant system was controlled to turn off during cooling mode if the surface temperature reached the space dew point temperature to avoid condensation.

The results for this system are shown in Figures 4.170 through 4.183. Simulations show moderate energy savings in most U.S. climates, significant savings in the very cold climates, and increased energy consumption in three climates. The increased energy consumption is partially due to economizer operation as explained below and probably also due to a non-optimal control strategy for these climates. The results for the non-U.S. locations show significant energy savings in most climates. There are two driving factors for the observed energy savings of the radiant system retrofit. One is that there is reduced fan energy for the DOAS system with radiant heating and cooling as compared to the baseline system. Second, the mean radiant temperature control of the radiant system allowed a wider variation in the dry bulb temperature. Improved performance is possible with optimal system design and control for specific building designs and locations.

One drawback of the DOAS and radiant system as it was modeled is related to economizing. The baseline VAV system has an air-side economizer; however, the retrofit DOAS with a constant speed fan does not economize. The retrofit therefore shows greatly reduced performance in good economizing climates, a drawback that could be at least partly avoided by implementing a water side economizer to take full advantage of the higher chilled water temperature requirements of the radiant system compared to the baseline VAV system. This analysis did not attempt to implement a water side economizer; however, buildings being designed in good economizing climates should consider one, if implementing a radiant system.

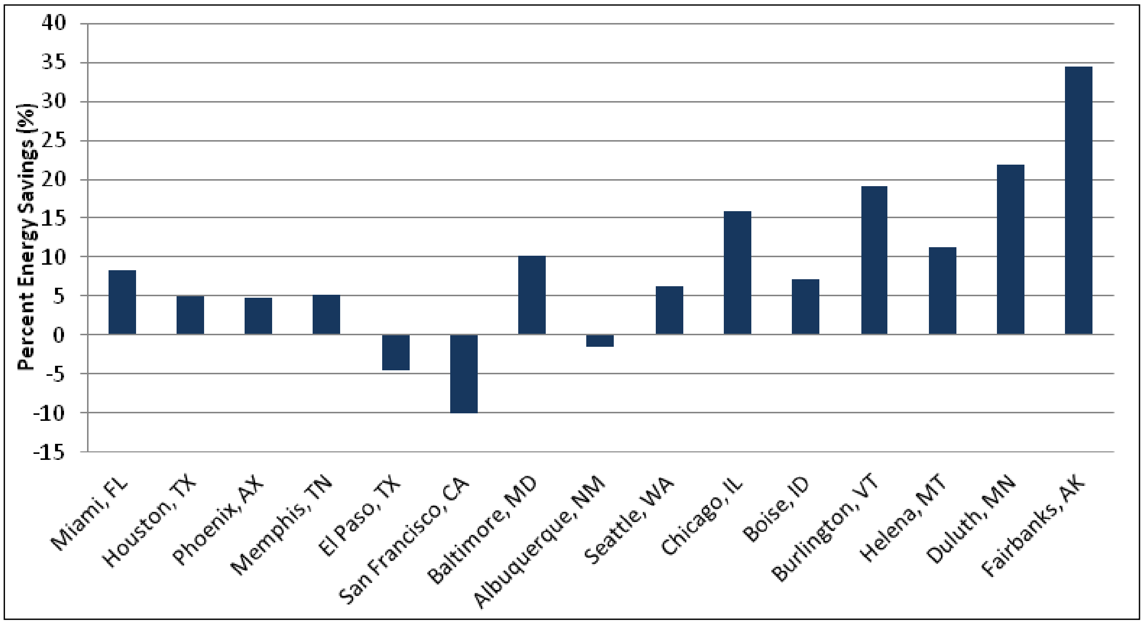

Figure 4.170. Percent energy savings for radiant system.

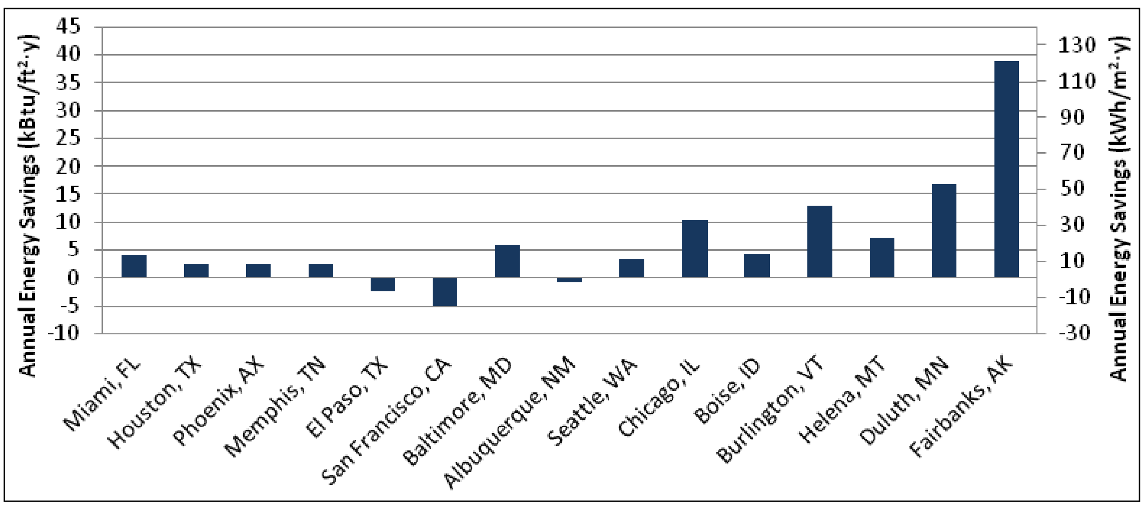

Figure 4.171. Annual energy savings for radiant system.

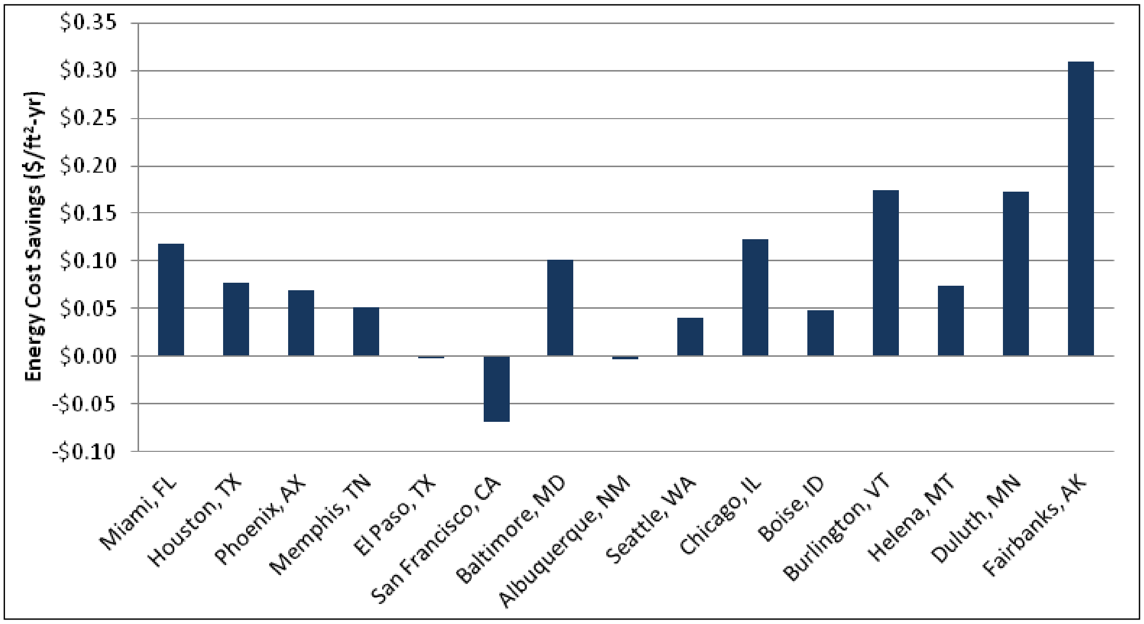

Figure 4.172. Annual energy cost savings for radiant system.

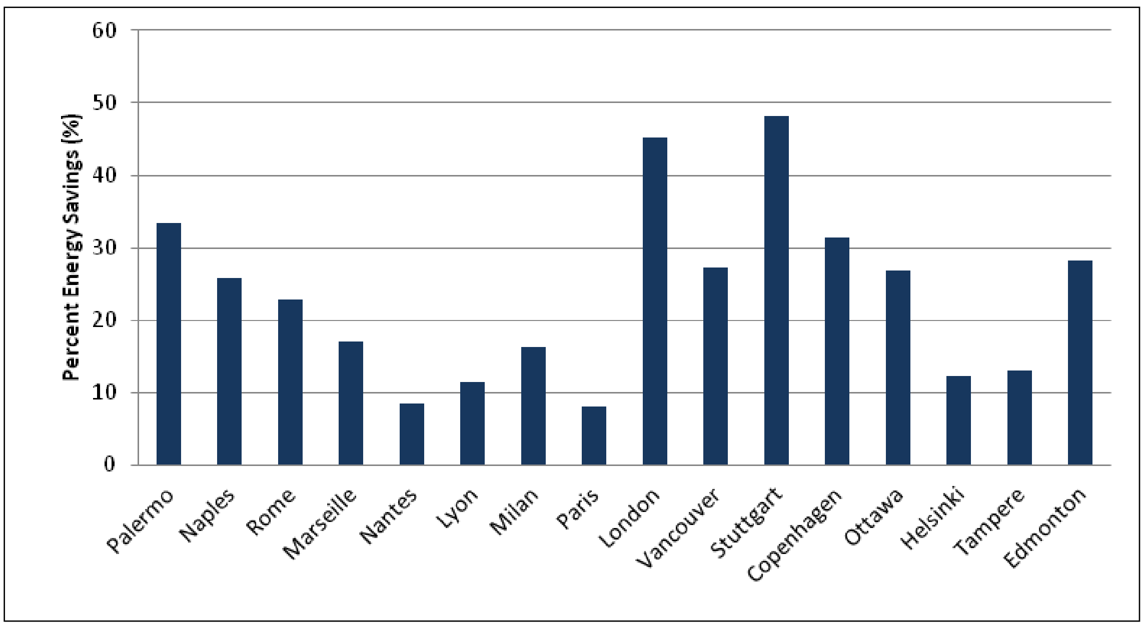

Figure 4.173. Percent energy savings for radiant system – International locations.

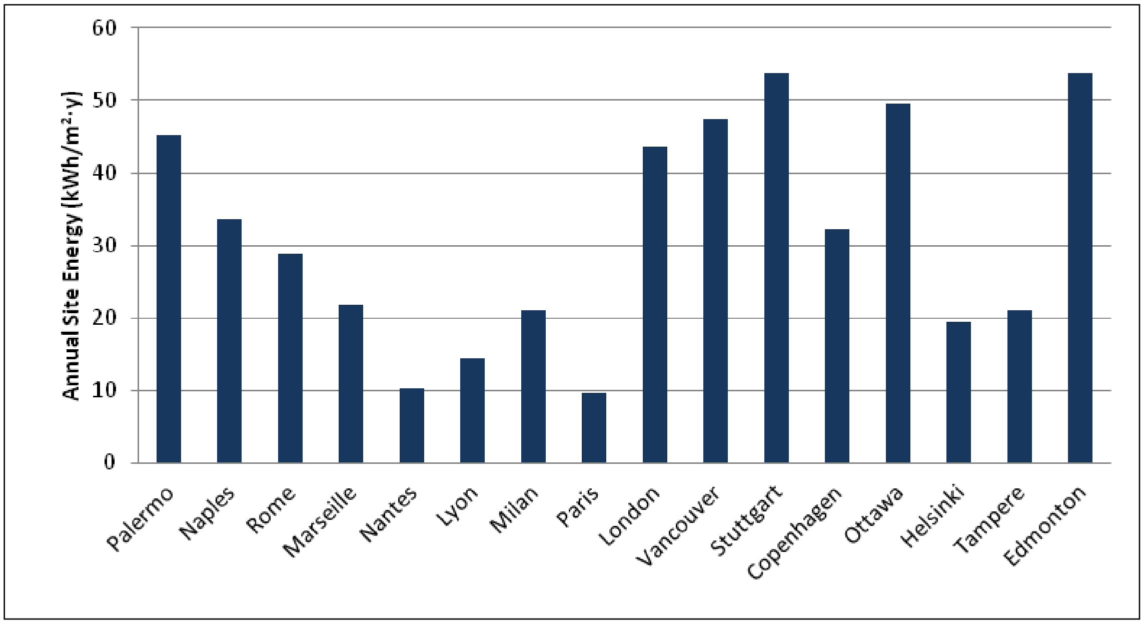

Figure 4.174. Annual energy savings for radiant system – International locations.

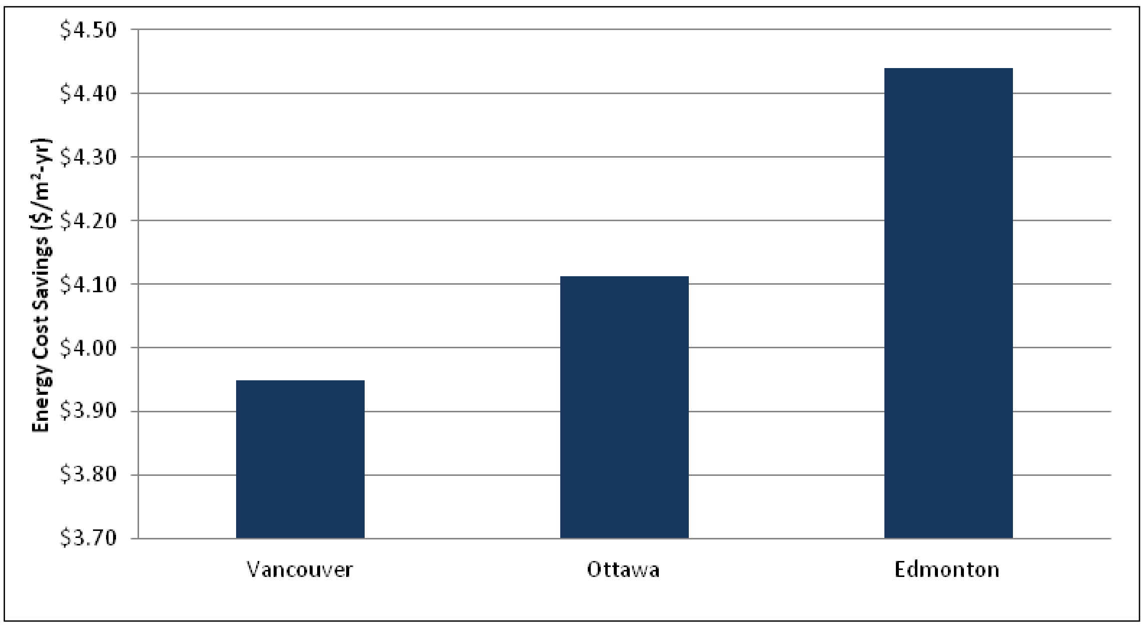

Figure 4.175. Annual energy cost savings for radiant system – Canadian locations.

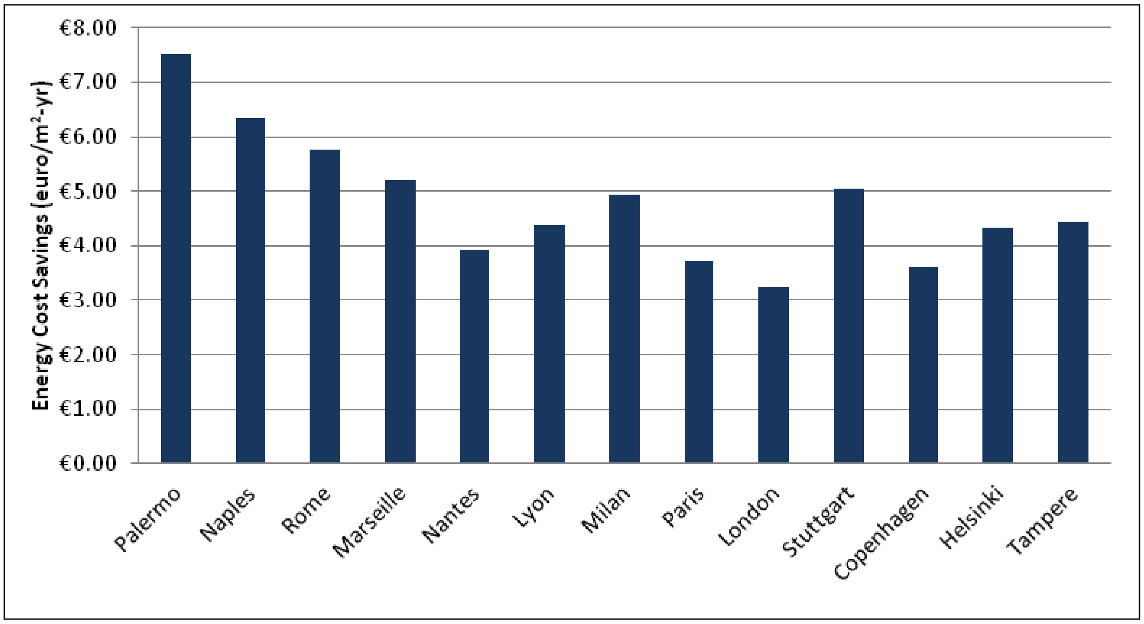

Figure 4.176. Annual energy cost savings for radiant system – International locations.

4.4.14 Ground source heat pumps

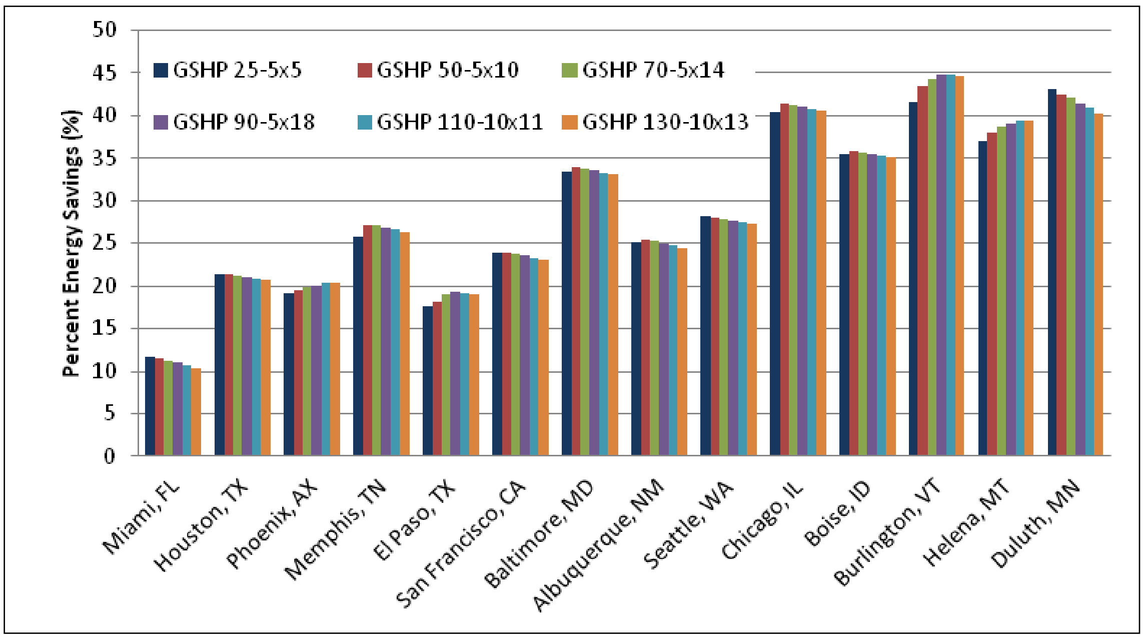

Figure 4.177. Percent energy savings for GSHPs.

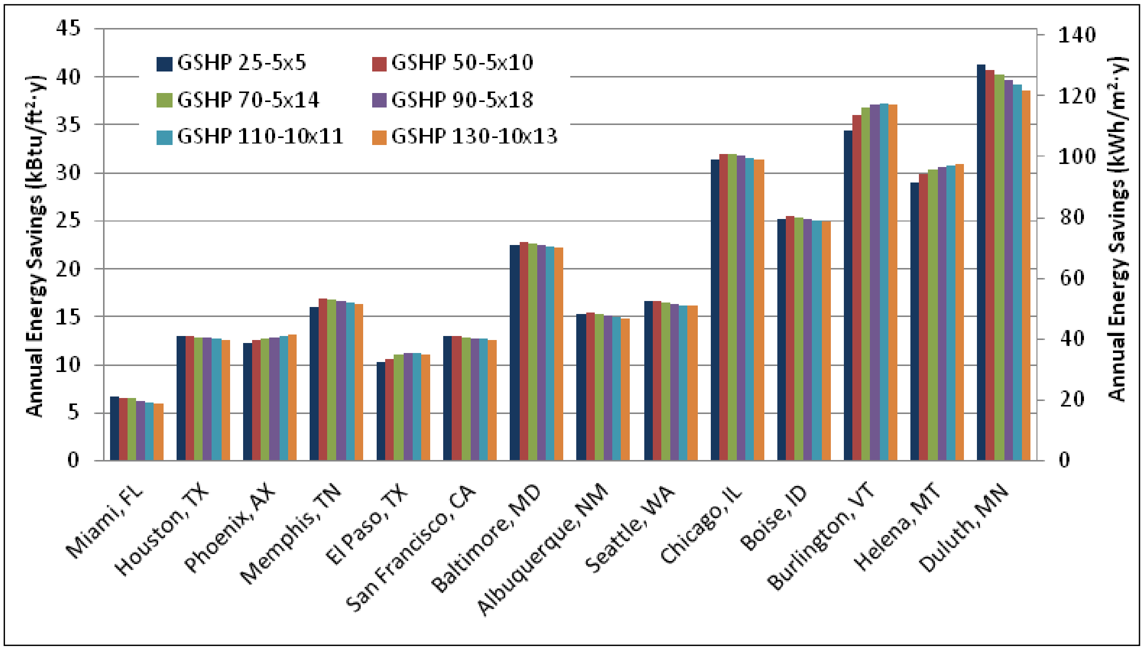

Figure 4.178. Annual energy savings for GSHPs.

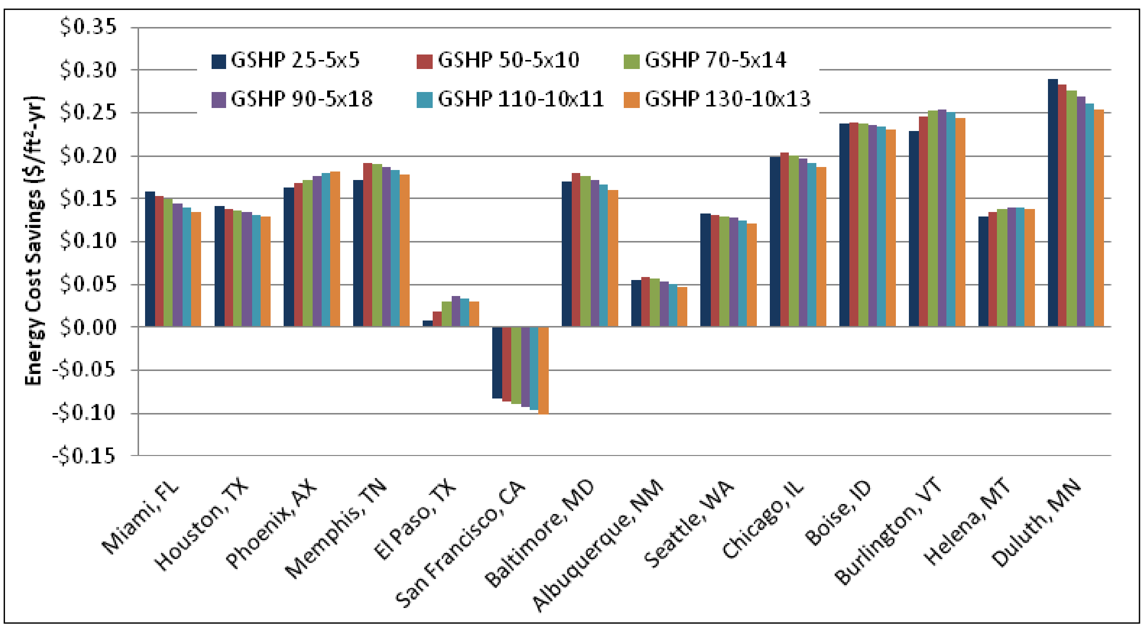

Figure 4.179. Annual energy cost savings for GSHPs.

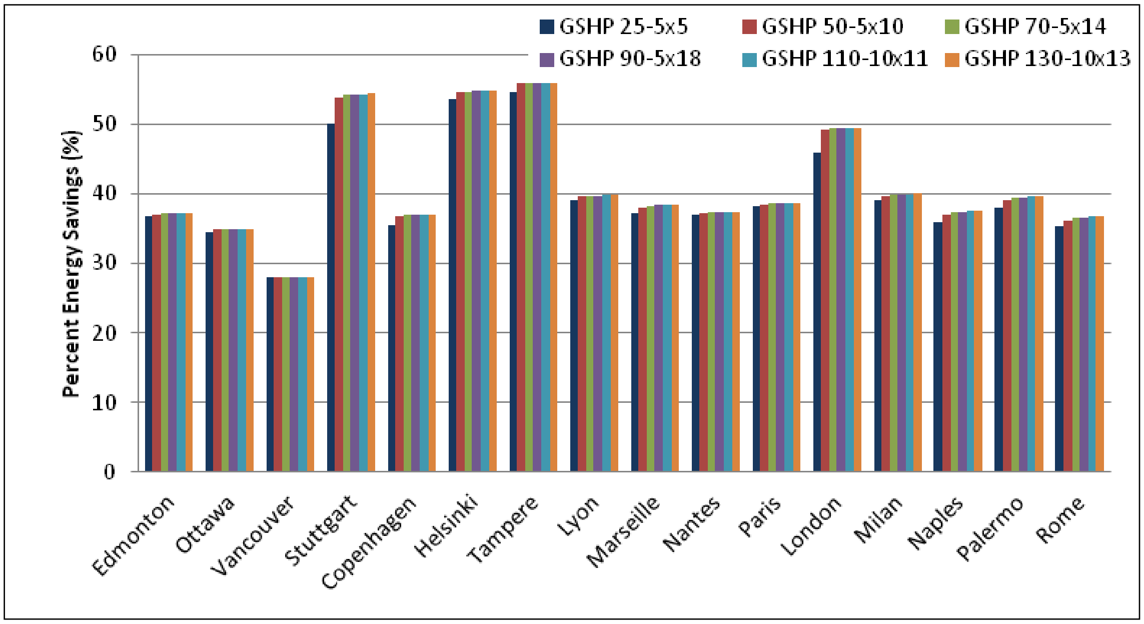

Figure 4.180. Percent energy savings for GSHPs – International locations.

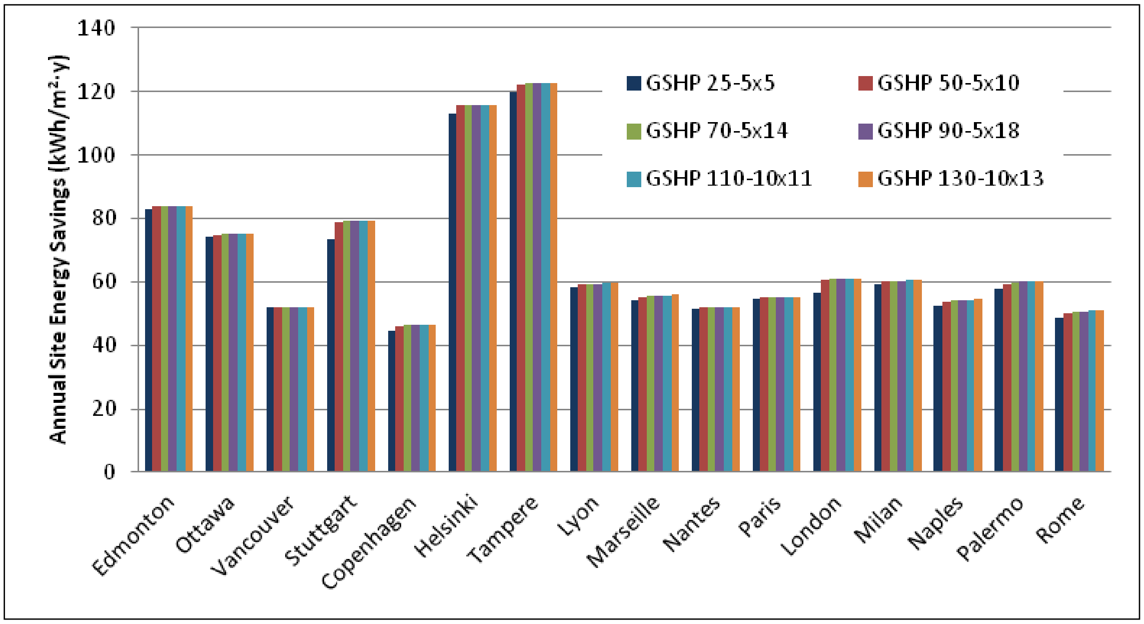

Figure 4.181. Annual energy savings for GSHPs – International locations.

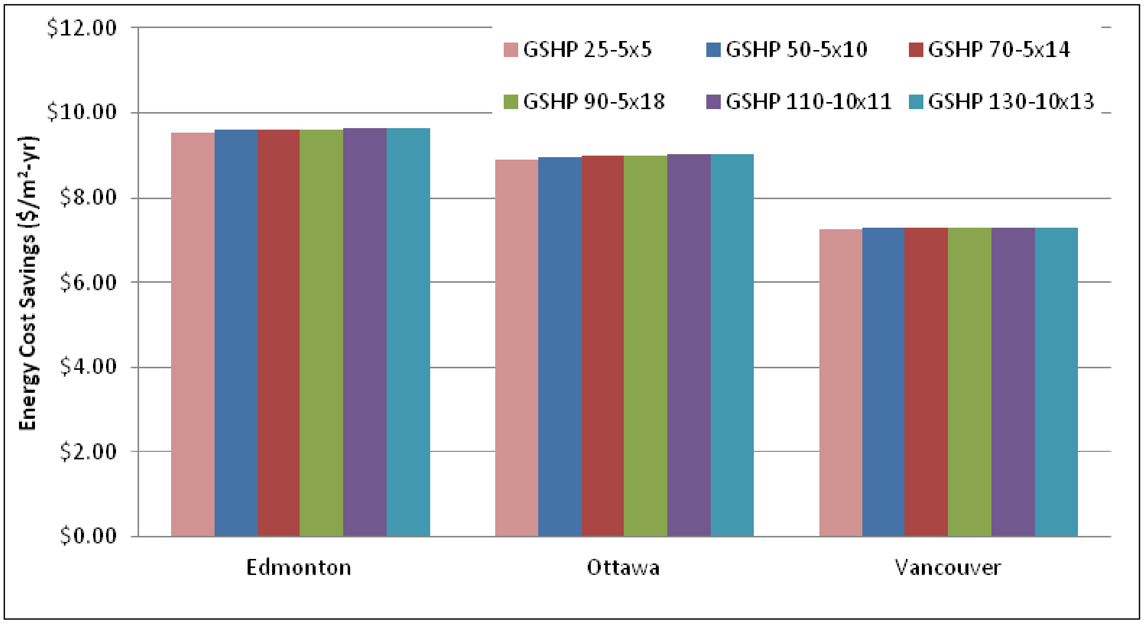

Figure 4.182. Annual energy cost savings for GSHPs – Canadian locations.

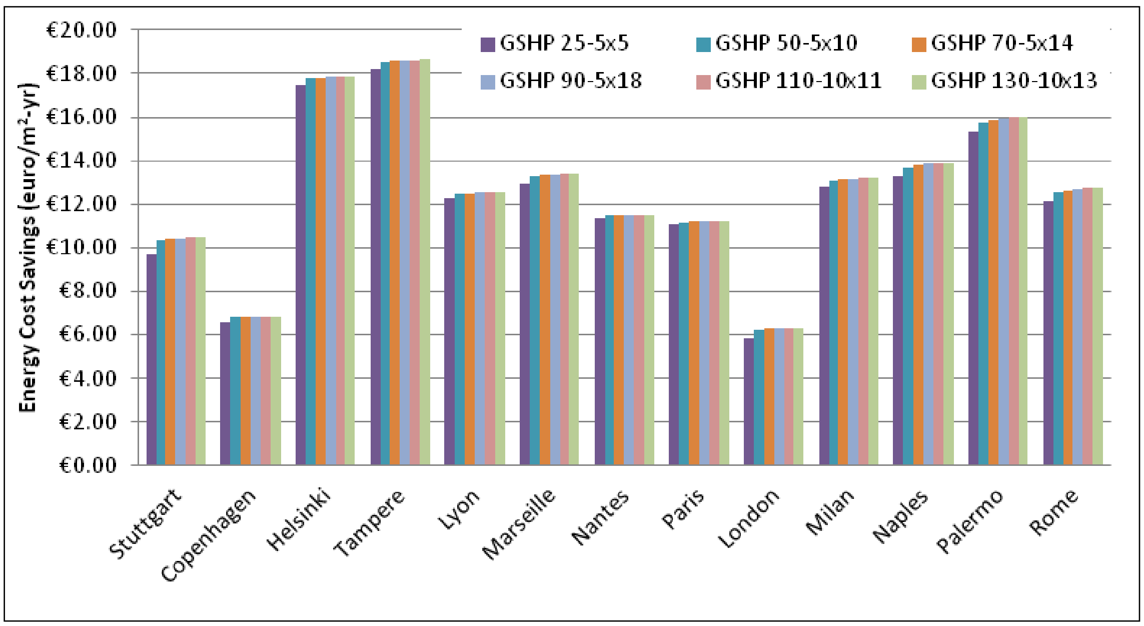

Figure 4.183. Annual energy cost savings for GSHPs – European locations.

4.4.15 Reheat using condenser waste heat

Cooling system condenser waste heat recovery was evaluated for both the U.S. locations and the international locations. Different approaches were taken for the U.S. and international locations because the systems types are different.

The U.S. administrative building has multizone air handlers served by central heating and cooling plants. The central air handlers cool or heat to a seasonal deck temperature and reheat at the zone terminals if necessary to trim to the individual zone loads. This retrofit provides waste heat from the chiller to the hot water plant serving the heating coils as required. Modeling this technology directly in EnergyPlus is possible; however, developing the model and control strategy is particularly cumbersome. To avoid this burden, the effect of the proposed retrofit was analyzed using a post processing technique. Hourly data of the chiller waste heat, and boiler energy consumption were reported by the baseline EnergyPlus simulation. The effect of heat recovery was quantified by subtracting available condenser waste heat from the boiler energy consumption at a single time step, and then integrating over time.

The existing international administrative facility consists of packaged single zone systems that do not actively control humidity and never use reheat. In this study, the benefit of retrofitting the building with a condenser waste heat-recovery system was evaluated by first creating a new baseline point of comparison with a system that used humidistats and conventional reheat. The new systems use more energy due to increased cooling and reheat; however, buildings in humid climates were also much drier. By introducing a new baseline, there is a fair comparison for the condenser waste heat-recovery system.

The results for this system are shown in Figures 4.184 through 4.190. The simulations show small energy savings in all U.S. climates.

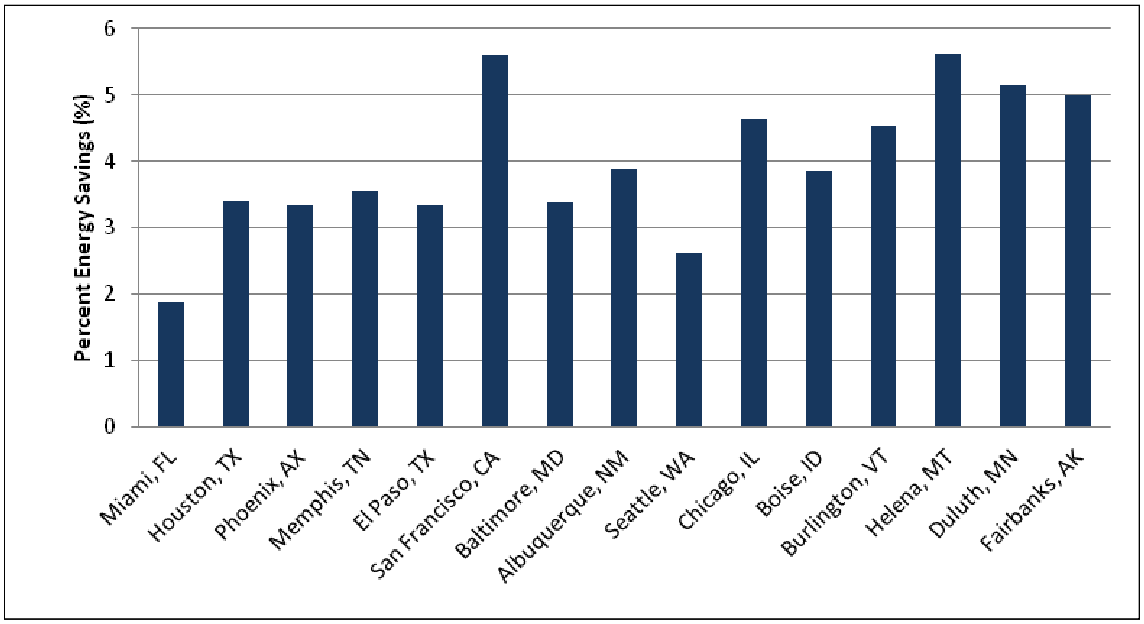

Figure 4.184. Percent energy savings for condenser waste heat recovery.

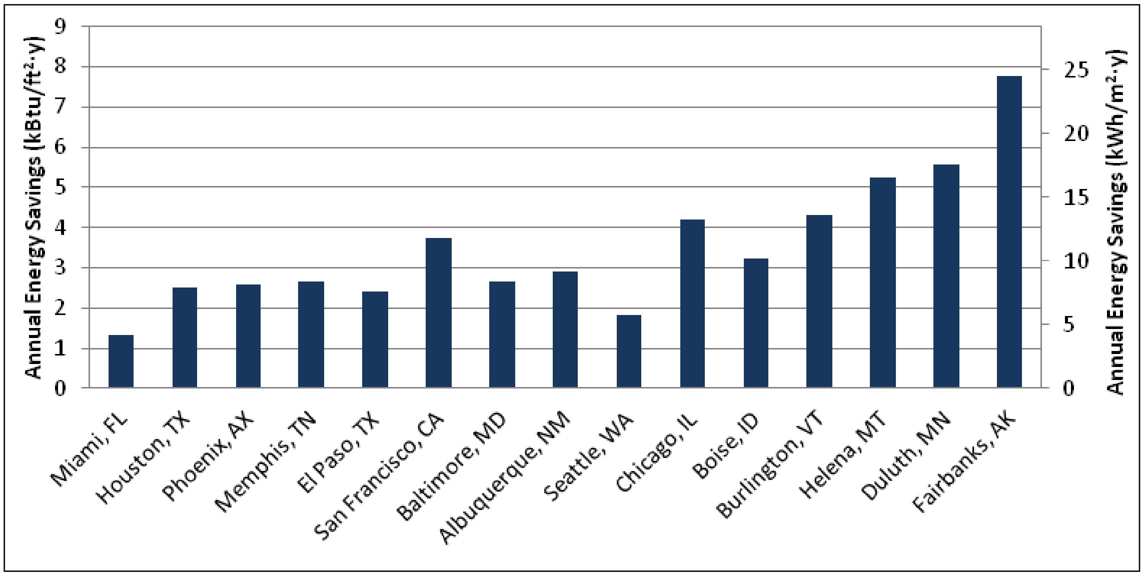

Figure 4.185. Annual energy savings for condenser waste heat recovery.

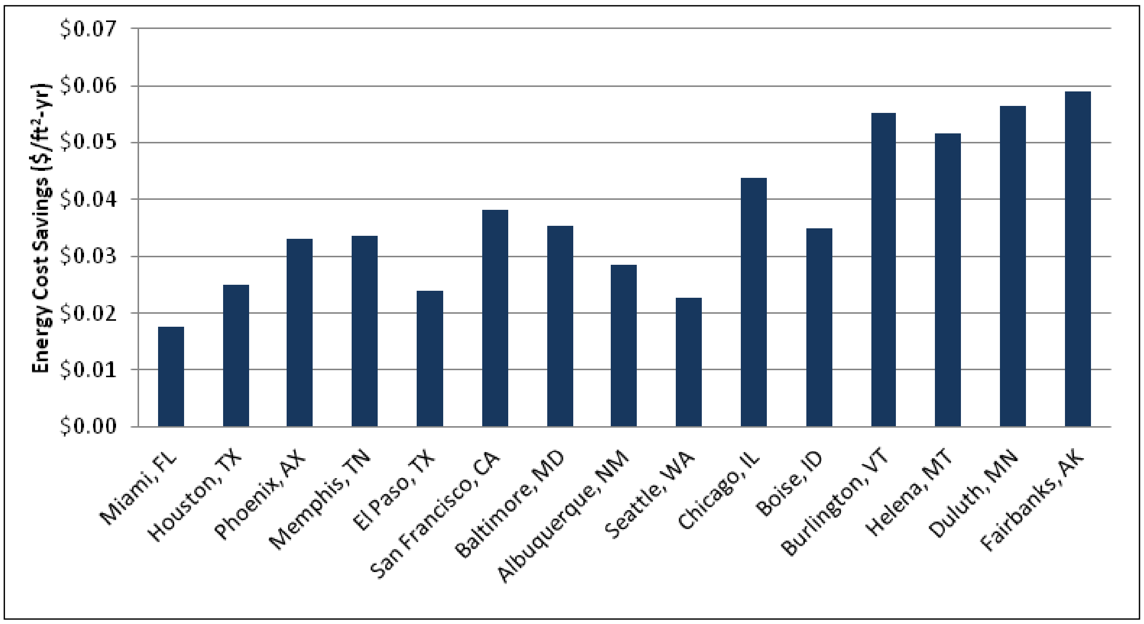

Figure 4.186. Annual energy cost savings for condenser waste heat recovery.

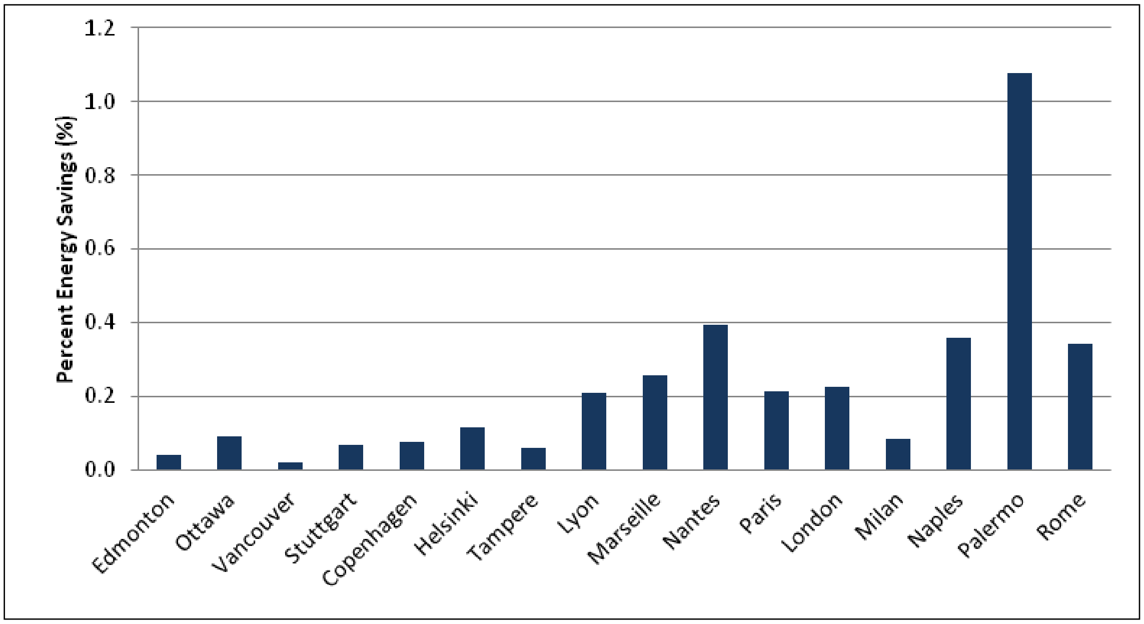

Figure 4.187. Percent energy savings for condenser waste heat recovery – International locations.

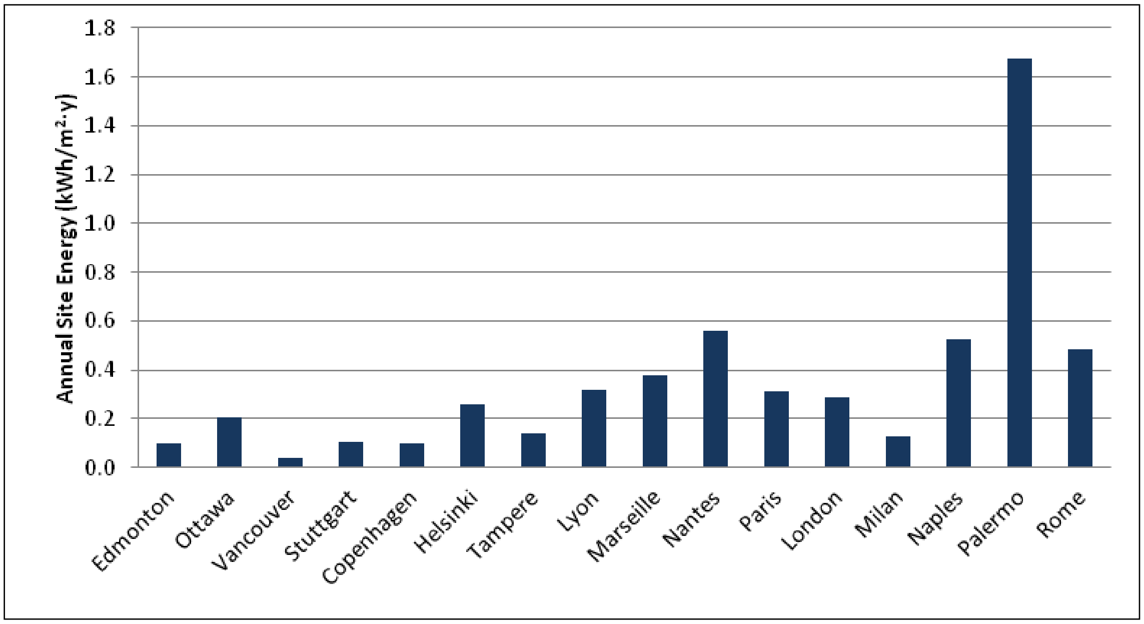

Figure 4.188. Annual energy savings for condenser waste heat recovery – International locations.

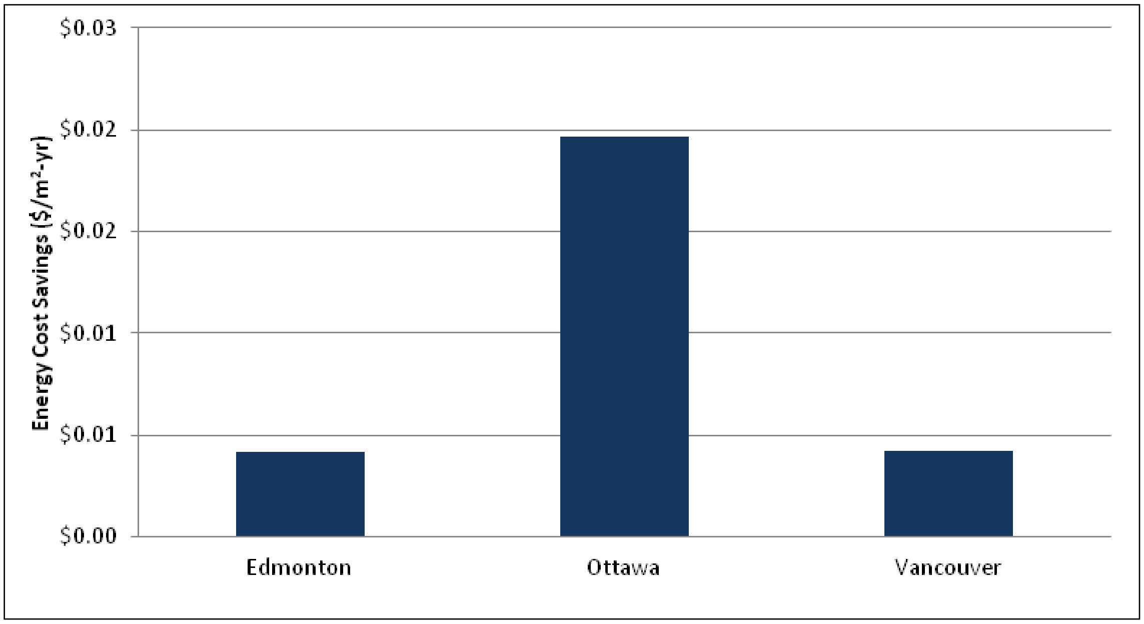

Figure 4.189. Annual energy cost savings for condenser waste heat recovery – Canadian locations.

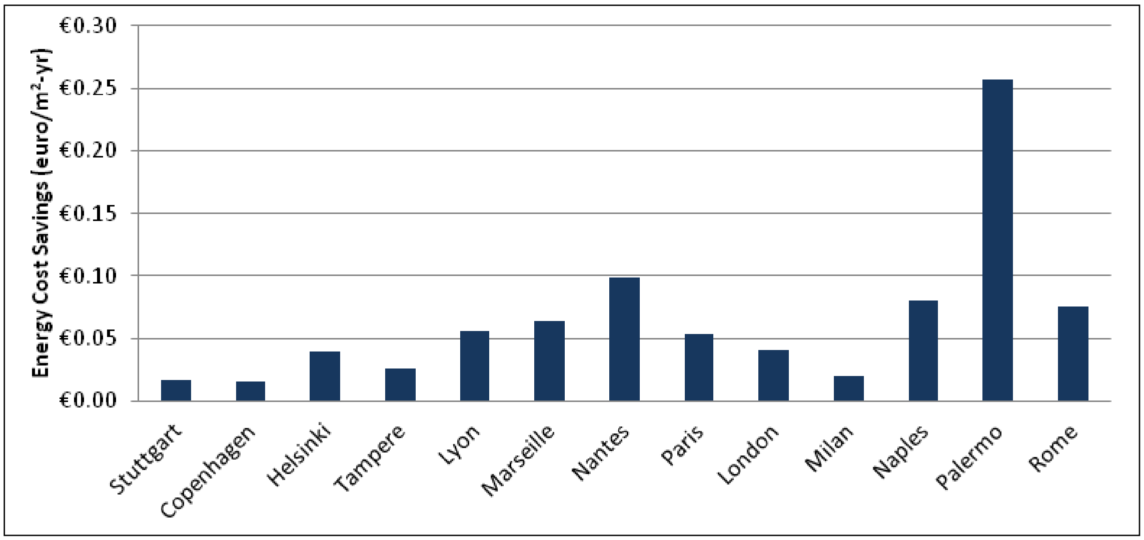

Figure 4.190. Annual energy cost savings for condenser waste heat recovery – European locations.

4.5 Increased Wall Insulation

This section presents the effects of retrofitting the exterior walls with additional insulation. Insulation with an R-value of 3.85 $ft^2 \cdot h \cdot °F/Btu$ per inch (0.347 $m^2 \cdot K/W$ per cm) was added in increments of 1, 2, 4, 6, and 8 in (2.5, 5, 10, 15, and 20 cm). For this study an additional baseline building was created with zero insulation in the walls. In addition, it was assumed that adding wall insulation would improve the airtightness from the baseline by 15%. One set of cases were run with the added insulation over the 901.1989 baseline and no change in the infiltration.

Table 4.22. Wall insulation ECM overview.

Wall Construction	Additional Insulation ($ft^2 \cdot hr \cdot {}^{o}F/Btu$)	Air Leakage	
		(cfm/ft^2 @ 0.3 in w.g.)	(L/s/m^2 @ 75 Pa)
Baseline (90.1-1989 insulation)	-	1.00	5.1
No insulation	-	1.00	5.1
1989 Baseline with 1 in (2.5 cm) insulation	R-3.85	1.00	5.1
1989 Baseline with 2 in (5 cm) insulation	R-7.7	1.00	5.1
1989 Baseline with 4 in (10 cm) insulation	R-15.4	1.00	5.1
1989 Baseline with 6 in (15 cm) insulation	R-23.1	1.00	5.1
1989 Baseline with 8 in (20 cm) insulation	R-30.8	1.00	5.1
1989 Baseline with 1 in (2.5 cm) insulation	R-3.85	0.85	4.3
1989 Baseline with 2 in (5 cm) insulation	R-7.7	0.85	4.3
1989 Baseline with 4 in (10 cm) insulation	R-15.4	0.85	4.3
1989 Baseline with 6 in (15 cm) insulation	R-23.1	0.85	4.3
1989 Baseline with 8 in (20 cm) insulation	R-30.8	0.85	4.3
Zero Baseline with 1 in (2.5 cm) insulation	R-3.85	0.85	4.3
Zero Baseline with 2 in (5 cm) insulation	R-7.7	0.85	4.3
Zero Baseline with 4 in (10 cm) insulation	R-15.4	0.85	4.3
Zero Baseline with 6 in (15 cm) insulation	R-23.1	0.85	4.3
Zero Baseline with 8 in (20 cm) insulation	R-30.8	0.85	4.3

The results of the simulations are shown in Figures 4.191 through 4.204. The percent energy savings and the area normalized energy and energy cost savings are shown for all locations and compared to the standard baseline insulation case and the no-insulation case. Most of the energy savings is achieved with the first one inch (2.5 cm) of insulation; however, significant savings are achieved with additional insulation. The overall energy savings for the U.S. locations above the 90.1-1989 baseline ranges from 5% to 20%, and the overall energy savings above the no-insulation baseline varies from 10% to 40%. For the international locations, the overall energy savings compared to the no-insulation baseline varies between 1% and 25%. Insulation in the Italy locations showed very little energy savings.

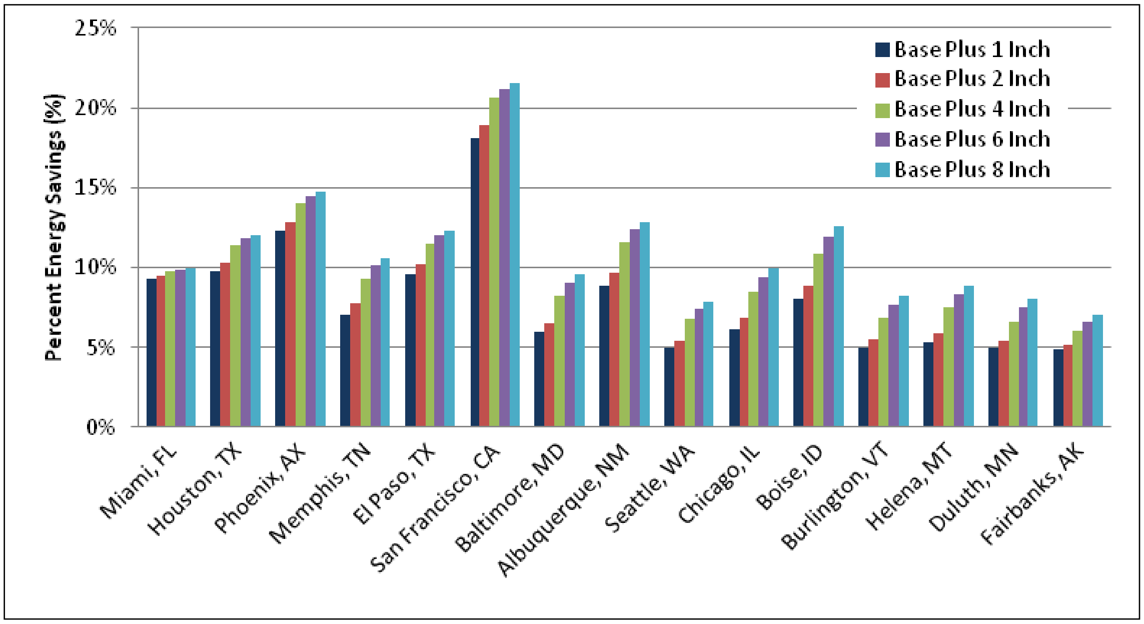

Figure 4.191. Percent energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

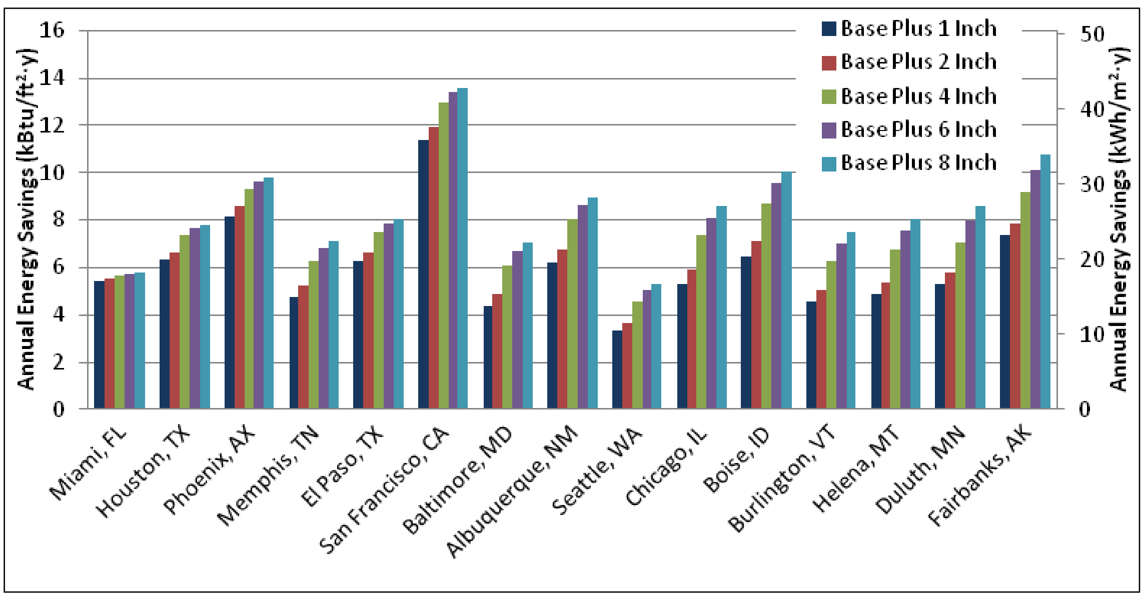

Figure 4.192. Energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

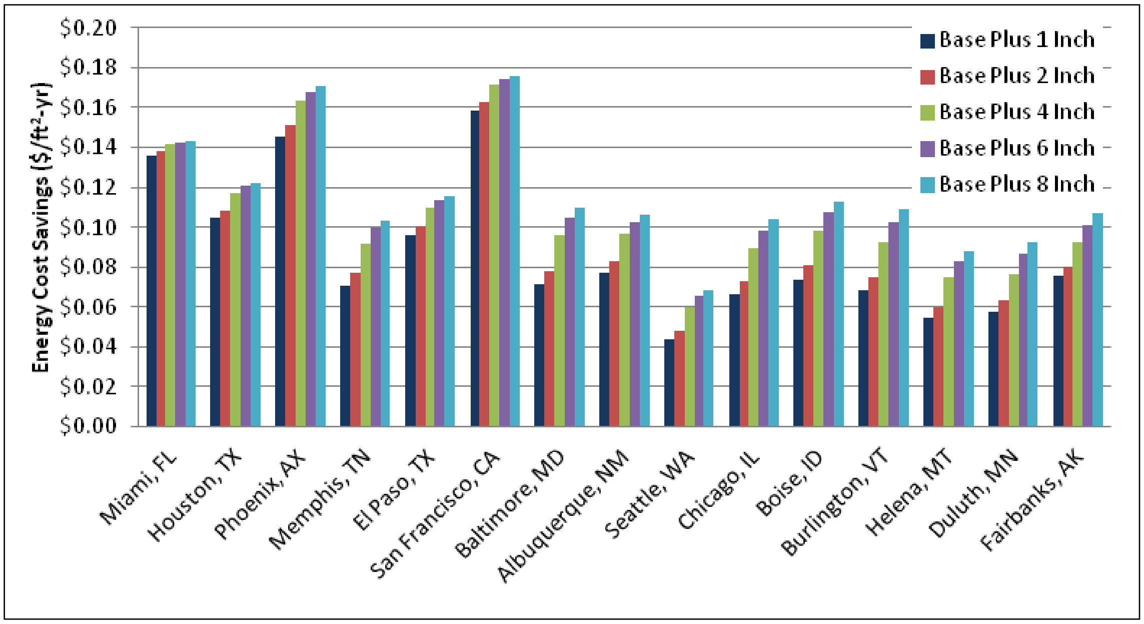

Figure 4.193. Energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline.

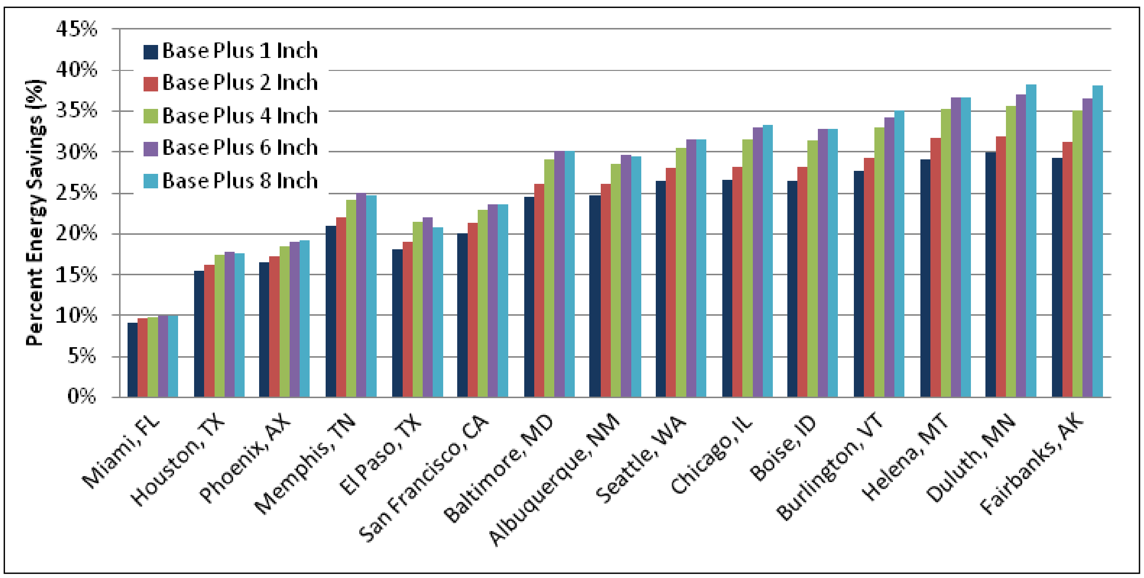

Figure 4.194. Percent energy savings for wall insulation and reduced infiltration over the no-insulation baseline.

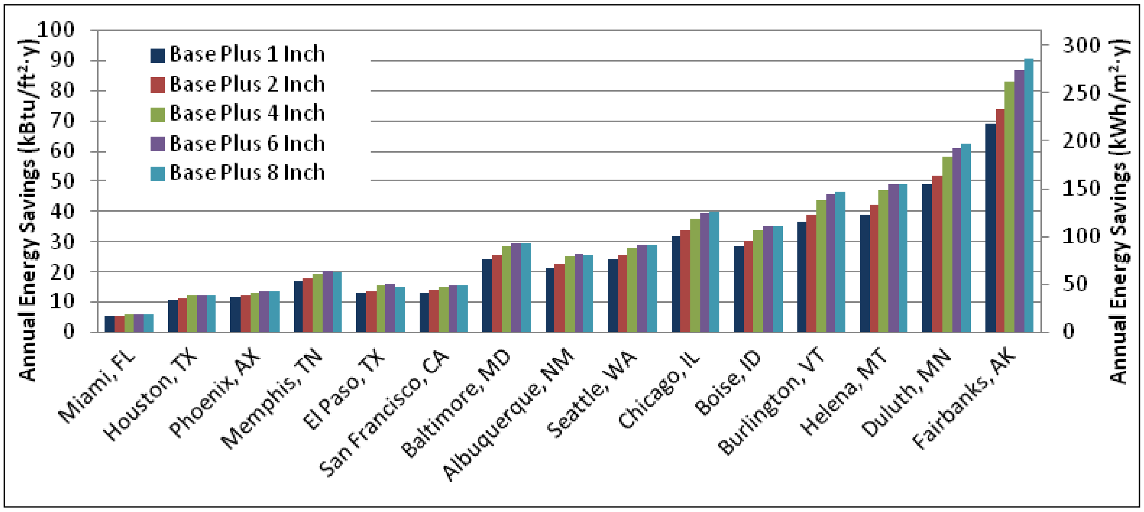

Figure 4.195. Energy savings for wall insulation and reduced infiltration over the no-insulation baseline.

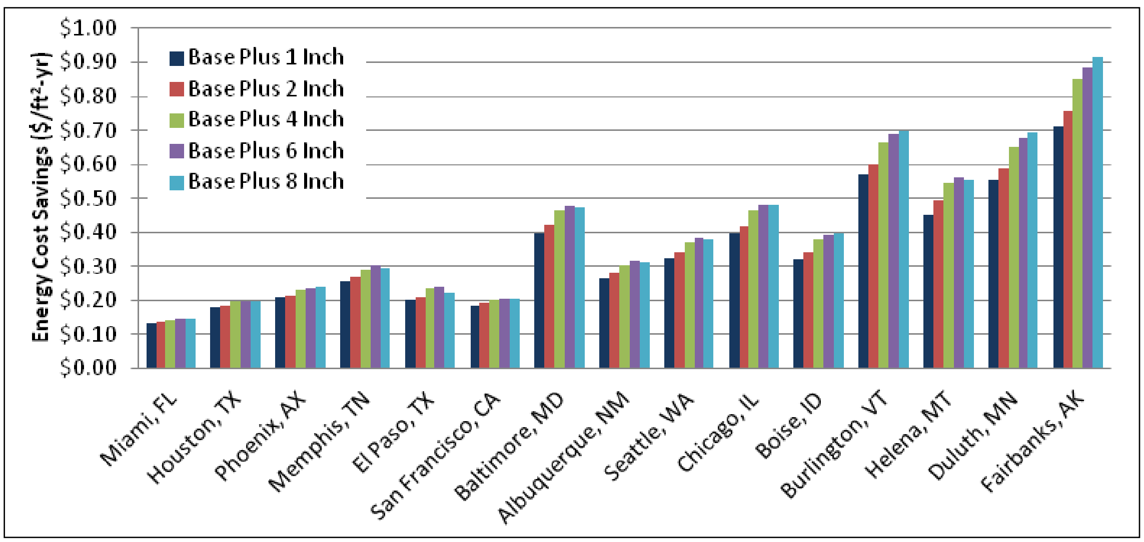

Figure 4.196. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline.

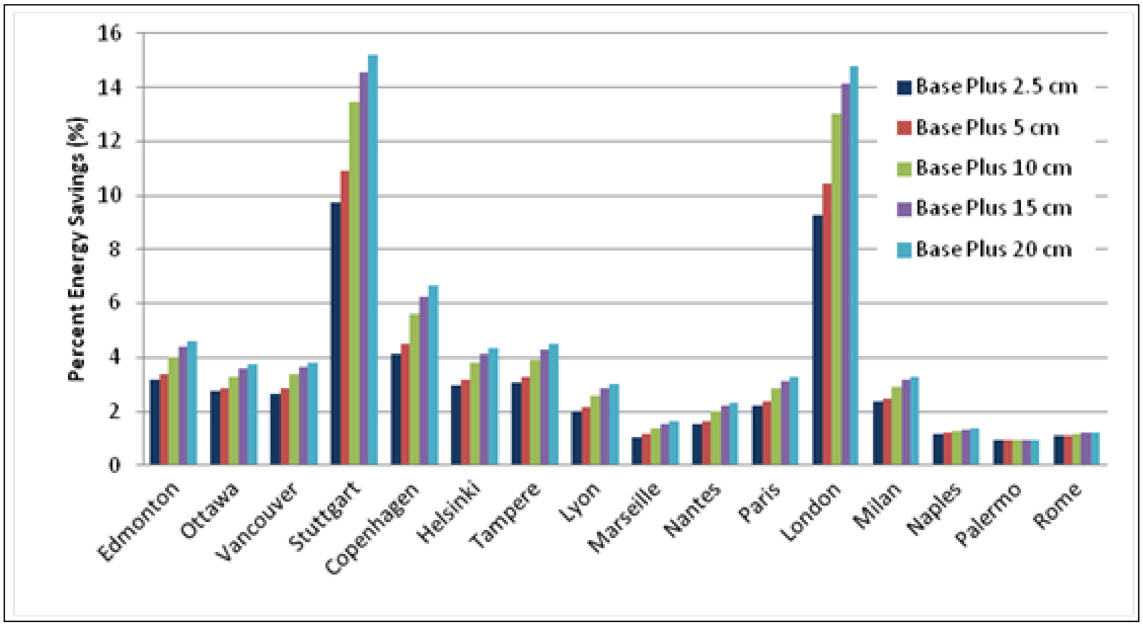

Figure 4.197. Percent energy savings for wall insulation and reduced infiltration over the standard baseline – international locations.

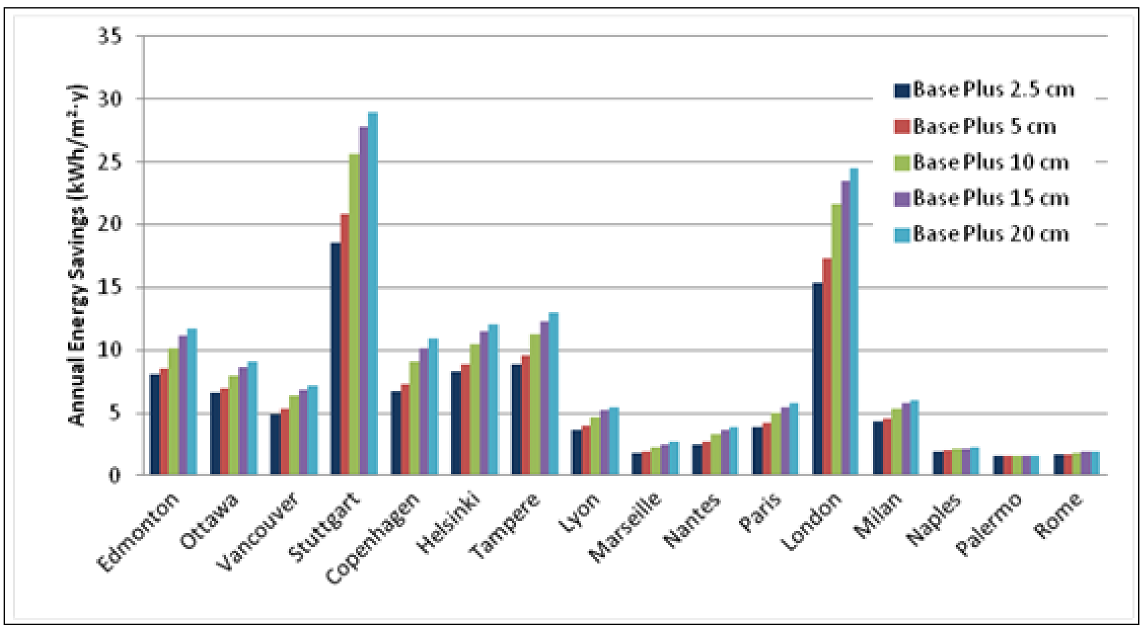

Figure 4.198. Energy savings for wall insulation and reduced infiltration over the standard baseline – international locations.

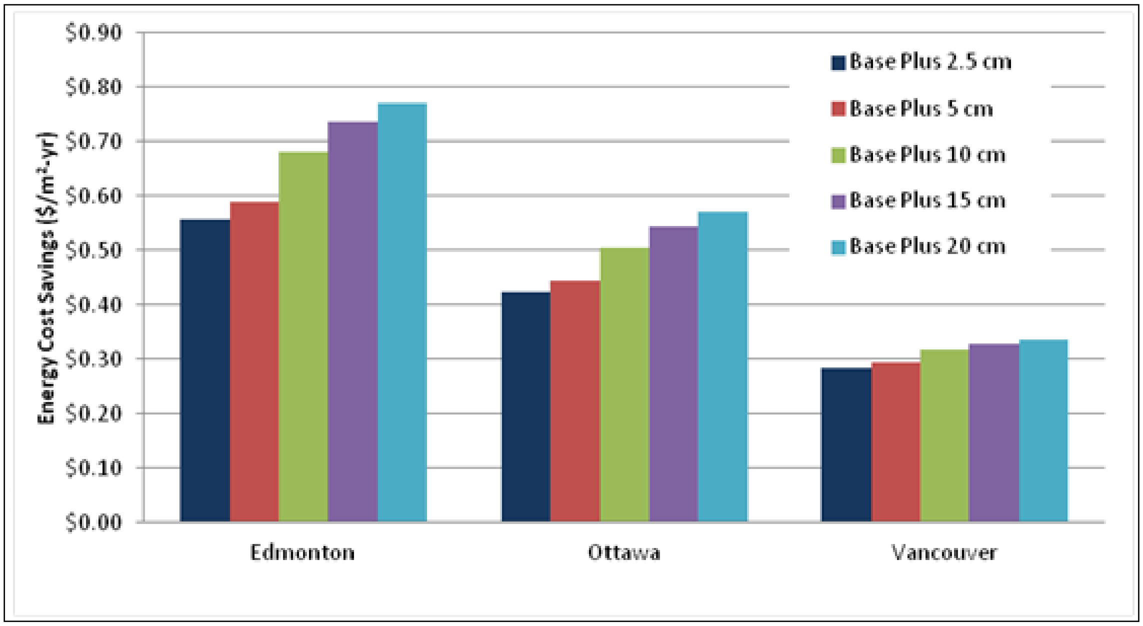

Figure 4.199. Energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline – Canadian locations.

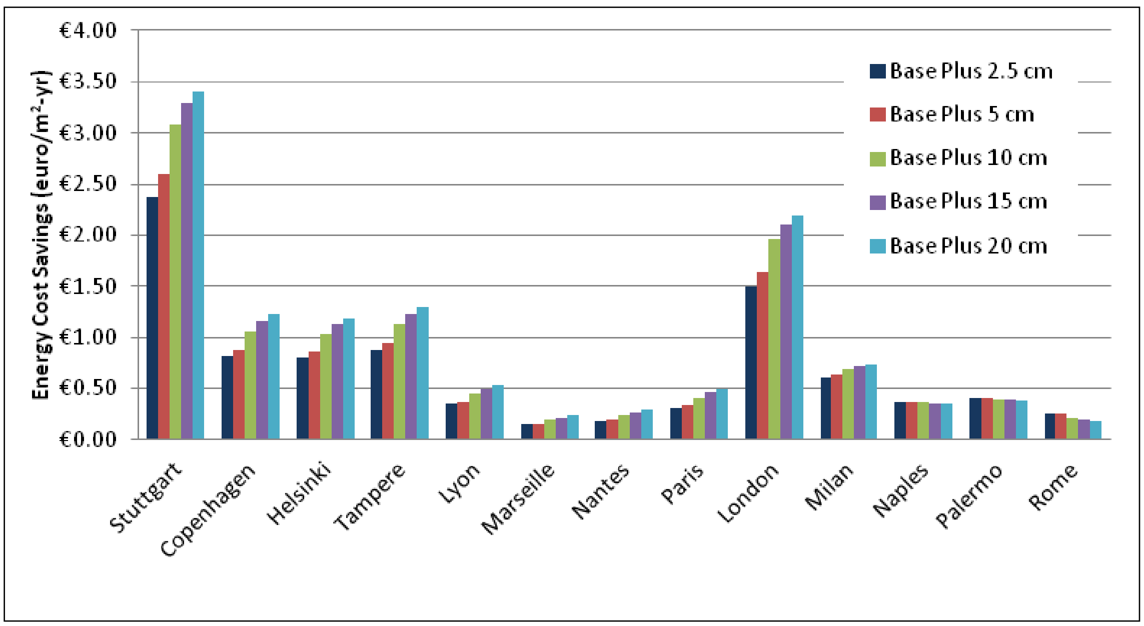

Figure 4.200. Energy cost savings for wall insulation and reduced infiltration over the standard baseline – European locations.

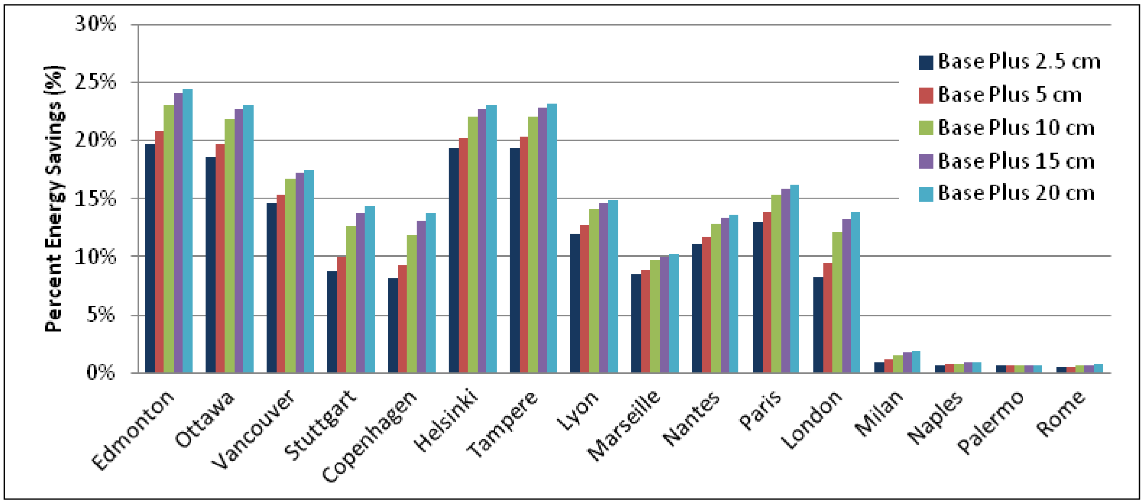

Figure 4.201. Percent energy savings for wall insulation and reduced infiltration over the no-insulation baseline – International locations.

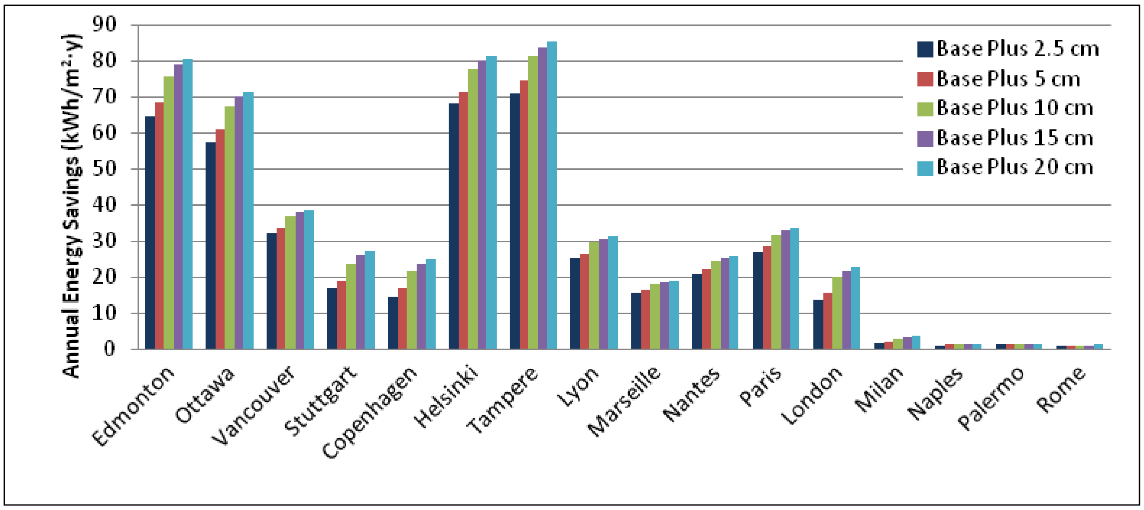

Figure 4.202. Energy savings for wall insulation and reduced infiltration over the no-insulation baseline – international locations.

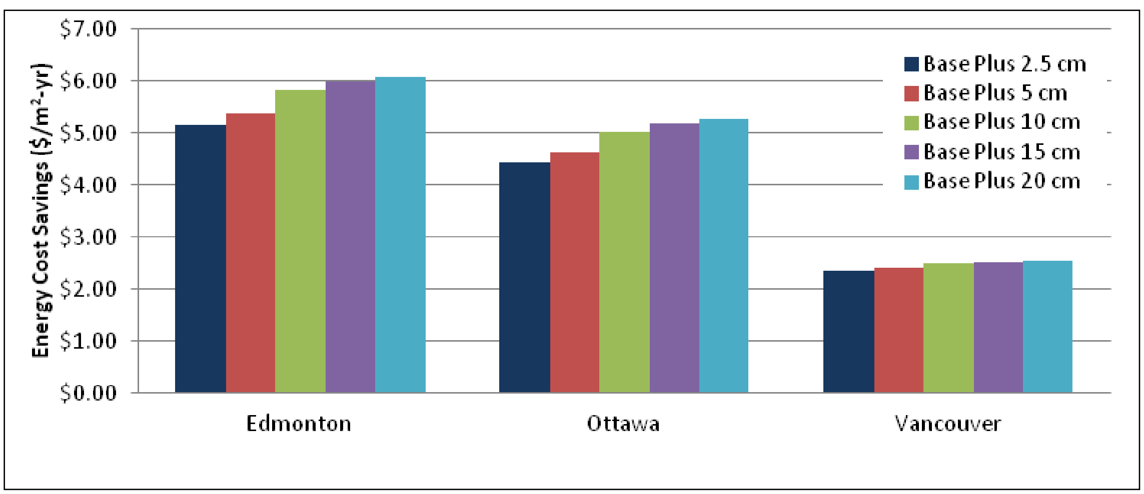

Figure 4.203. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline – Canadian locations.

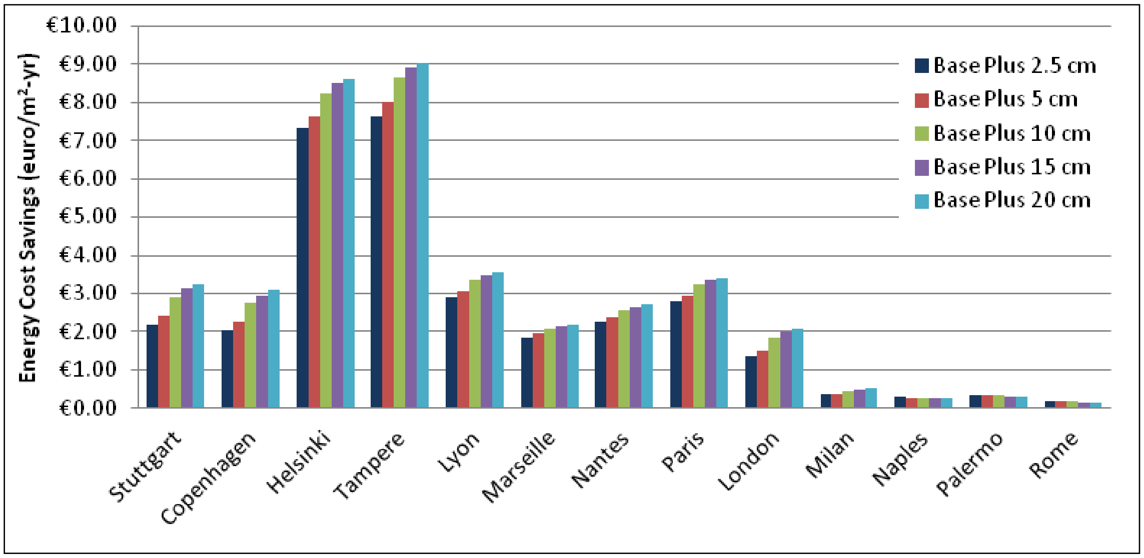

Figure 4.204. Energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline – European locations.

4.6 Increased Roof Insulation

The baseline building has insulation at the attic floor level. This section presents the results of replacing this insulation with insulation at the roof level. It was assumed that insulating the roof also improved the air leakage in the attic and the building. Table 4.23 summarizes the cases included in this report.

Table 4.23. Roof insulation ECM overview.

Case	Added Roof Insulation (R-value)	Building AL cfm/ft^2 @ 0.3 in w.g. (L/s·m^2 @ 75 Pa)	Attic Infiltration Rate (ACH)
Baseline 000	-	1.00 (5.08)	1.0
Roof 001.2	10	0.85 (4.32)	0.25
Roof 002.2	20	0.85 (4.32)	0.25
Roof 003.2	30	0.85 (4.32)	0.25
Roof 004.2	40	0.85 (4.32)	0.25
Roof 005.2	50	0.85 (4.32)	0.25

The results for the roof insulation cases are shown in Figures 4.205 through 4.211. The savings for the U.S. locations vary from near zero in Miami to over 6% in Duluth; however, there is almost no change in saving with increasing insulation levels. The results for the international locations show less than 1% savings in all locations except Stuttgart, Helsinki, Tampere, and London. These locations show energy savings between 4% and 7%. Some of the locations show negative savings due to increased cooling energy.

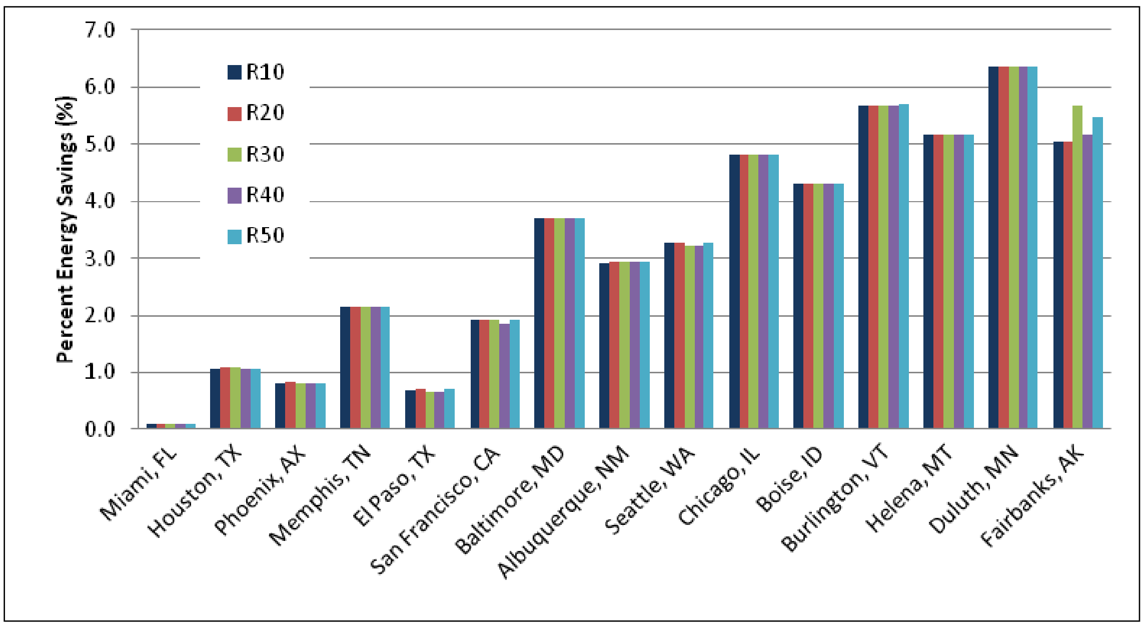

Figure 4.205. Percent energy savings for increased roof insulation.

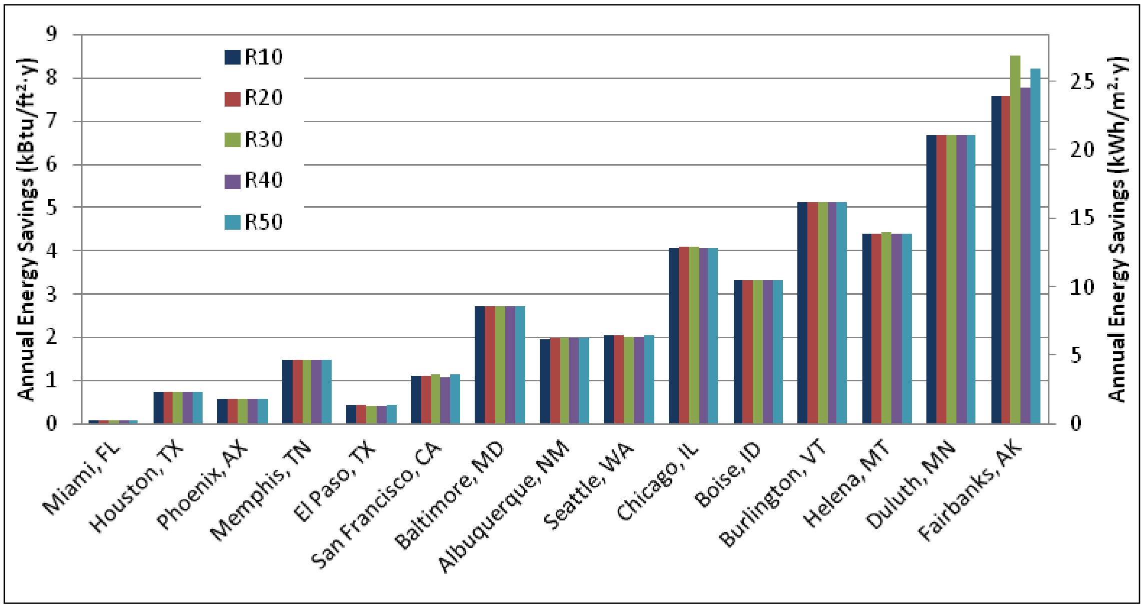

Figure 4.206. Annual energy savings for increased roof insulation.

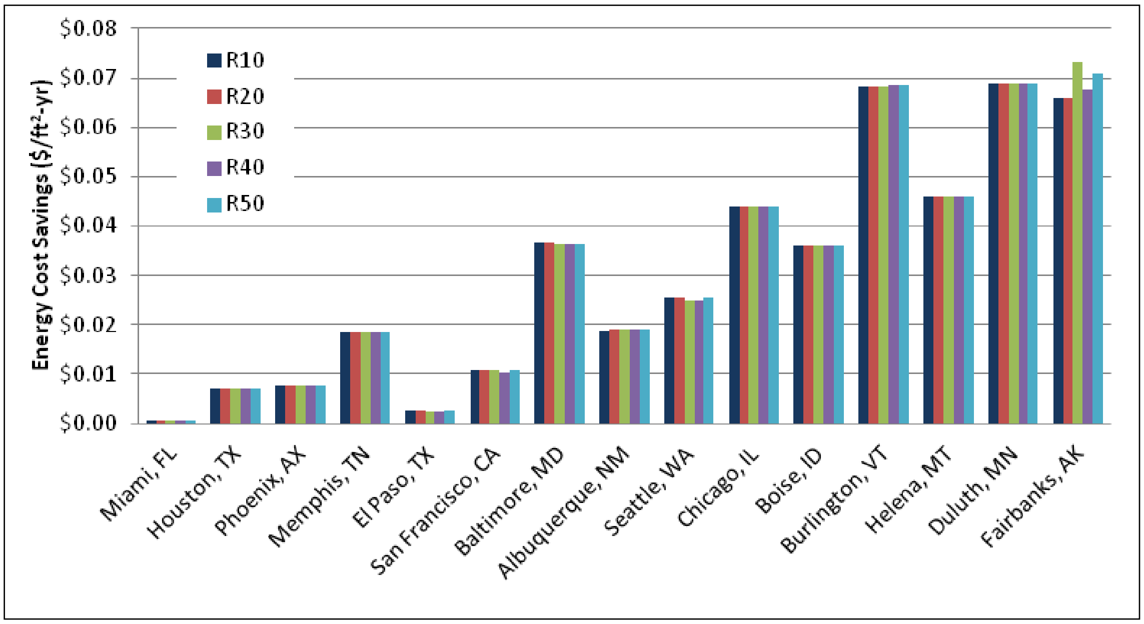

Figure 4.207. Annual energy cost savings for increased roof insulation.

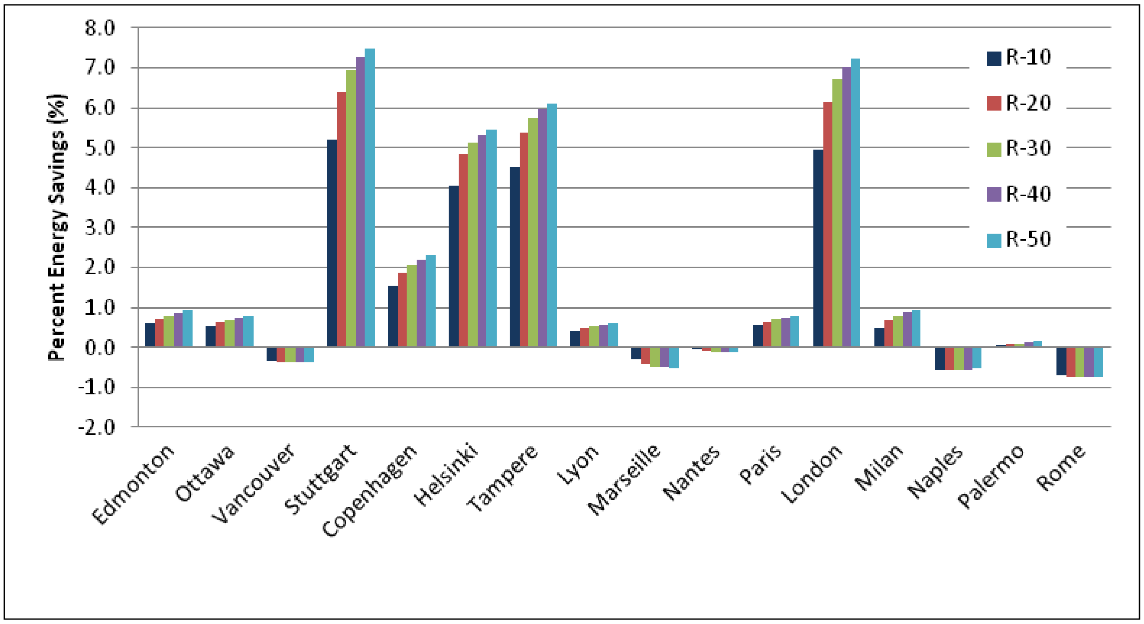

Figure 4.208. Percent energy savings for increased roof insulation – International locations.

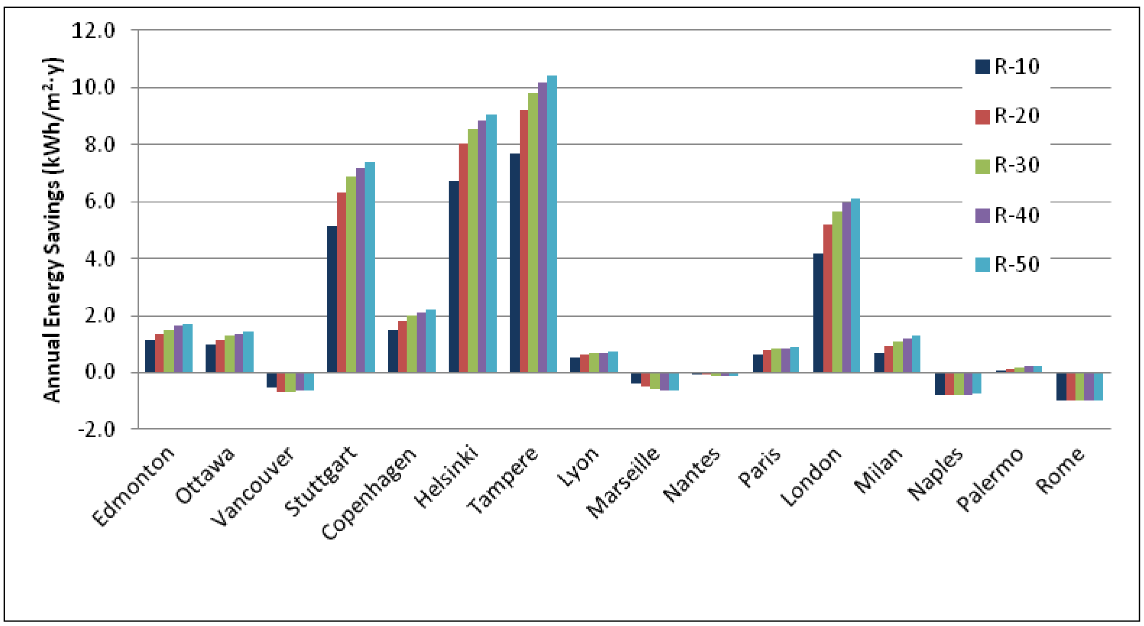

Figure 4.209. Annual energy savings for increased roof insulation – International locations.

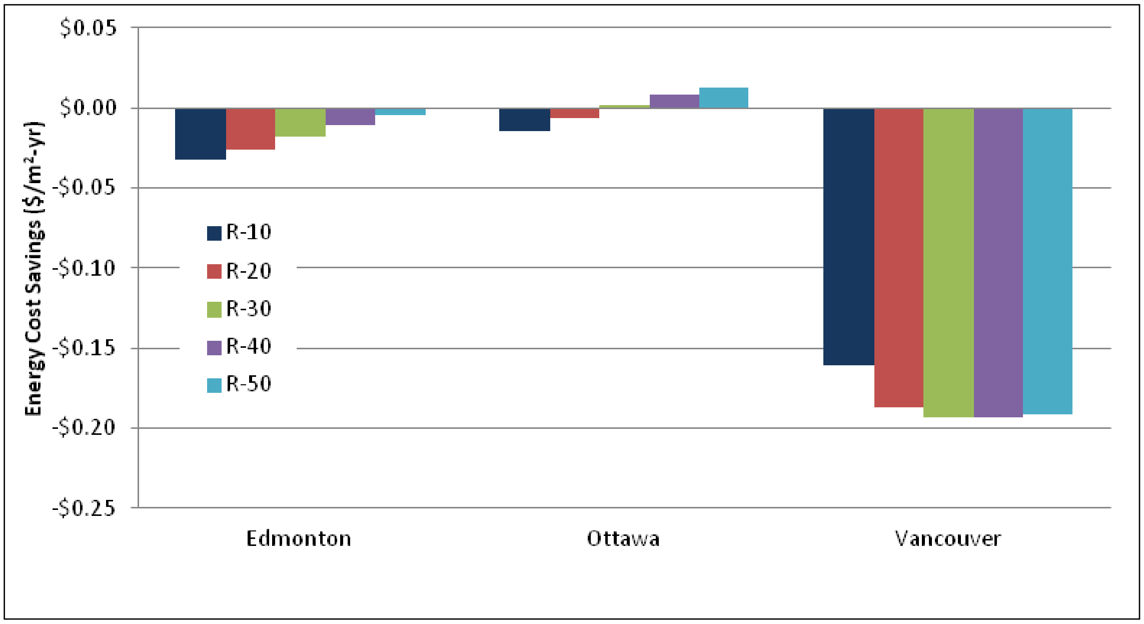

Figure 4.210. Annual energy cost savings for increased roof insulation – Canadian locations.

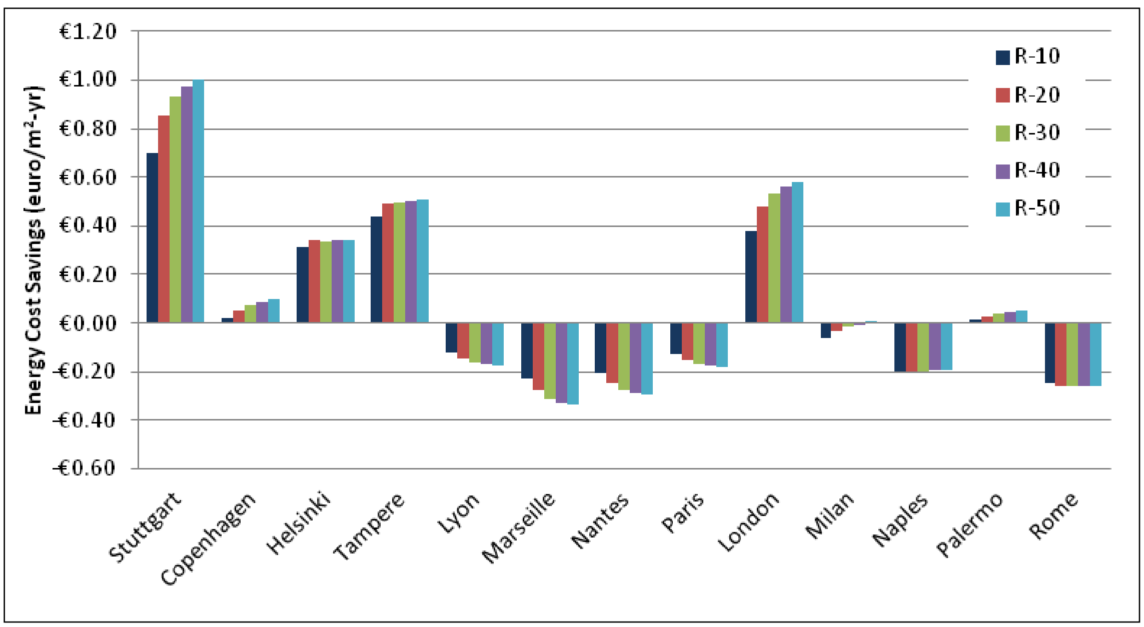

Figure 4.211. Annual energy cost savings for increased roof insulation – European locations.

4.7 Attic Insulation

The performance of increased insulation at the attic level (i.e. floor of the attic) was simulated for the administration building model. The attic insulation retrofit scenarios considered are described in Table 4.24.

Table 4.24. Attic insulation ECM overview.

Case	Baseline	Added Ceiling Insulation (R-value)	Building AL cfm/ft^2 @ 0.3 in w.g. (L/s·m^2 @ 75 Pa)	Attic Infiltration Rate (ACH)
Baseline 000	1989	-	1.00 (5.08)	1.0
Baseline 100	1960	-	1.00 (5.08)	1.0
Roof 021	000	10	1.00 (5.08)	1.0
Roof 022	000	20	1.00 (5.08)	1.0
Roof 023	000	30	1.00 (5.08)	1.0
Roof 024	000	40	1.00 (5.08)	1.0
Roof 025	000	50	1.00 (5.08)	1.0
Roof 021.2	000	10	0.85 (4.32)	1.0
Roof 022.2	000	20	0.85 (4.32)	1.0
Roof 023.2	000	30	0.85 (4.32)	1.0
Roof 024.2	000	40	0.85 (4.32)	1.0
Roof 025.2	000	50	0.85 (4.32)	1.0

The results for the increased attic insulation are shown in Figures 4.212 through 4.218.

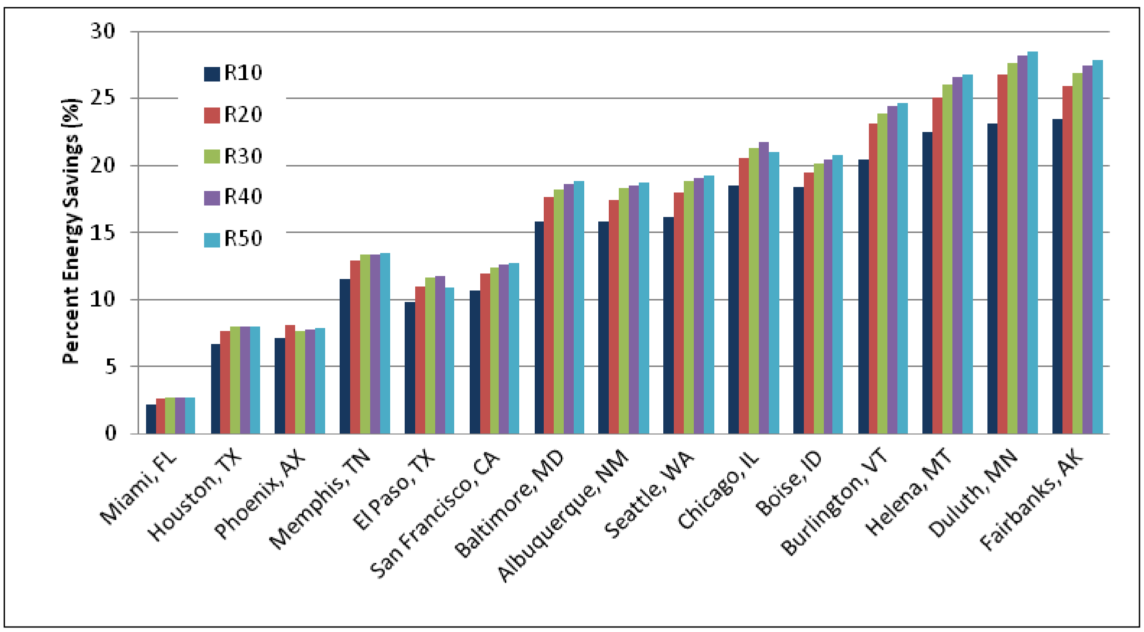

Figure 4.212. Percent energy savings for attic insulation increased above the baseline.

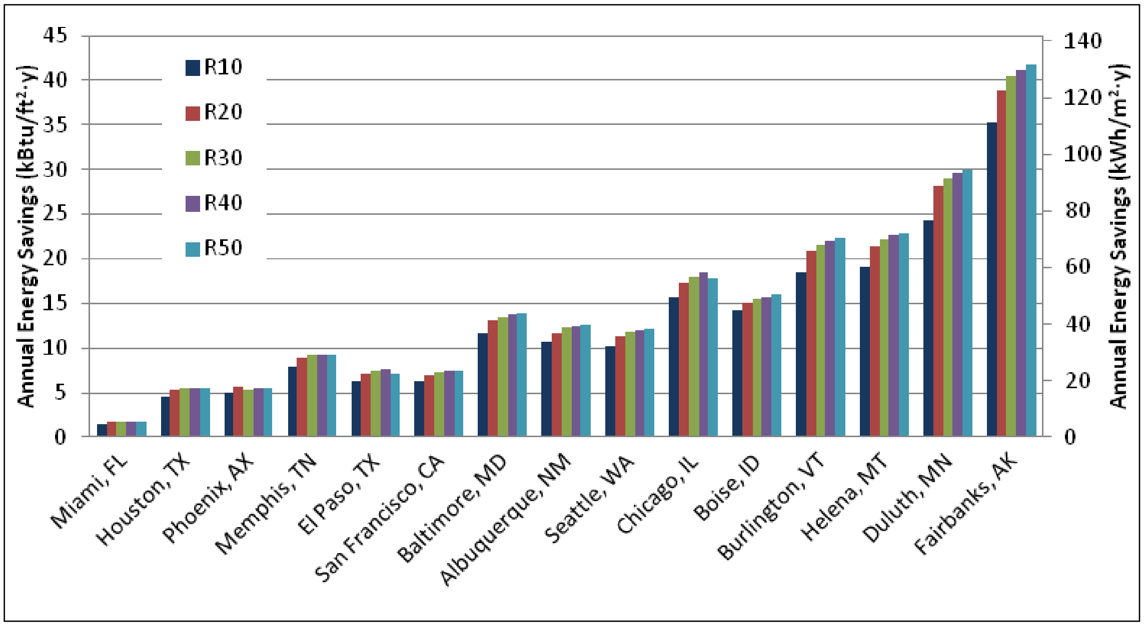

Figure 4.213. Annual energy savings for attic insulation increased above the baseline.

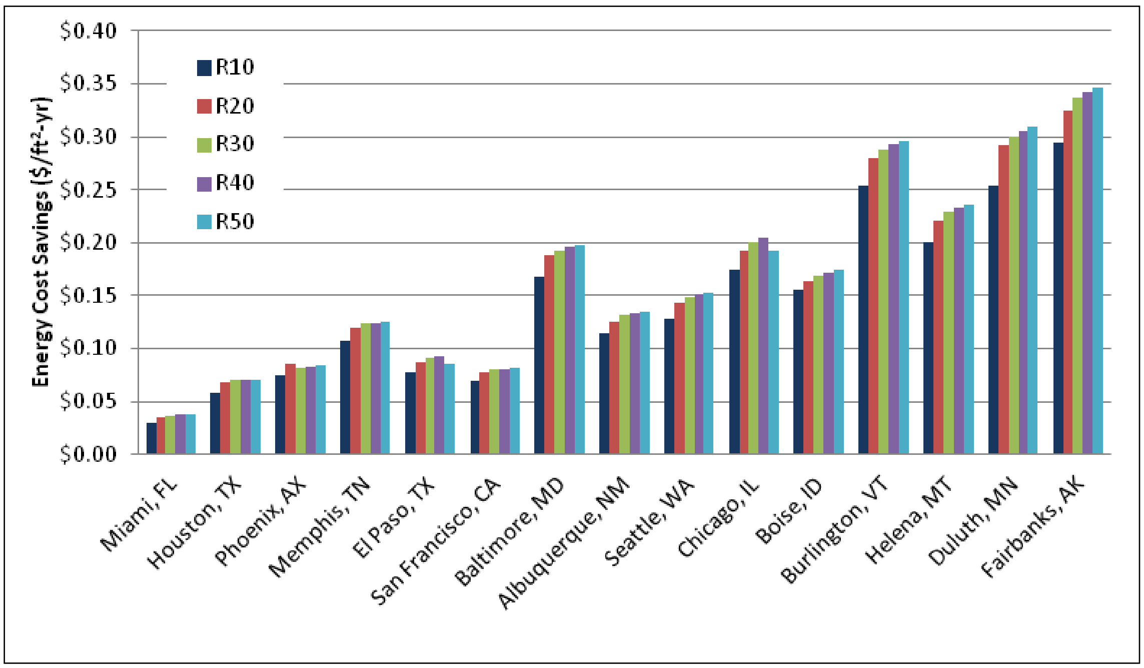

Figure 4.214. Annual energy cost savings for attic insulation increased above the baseline.

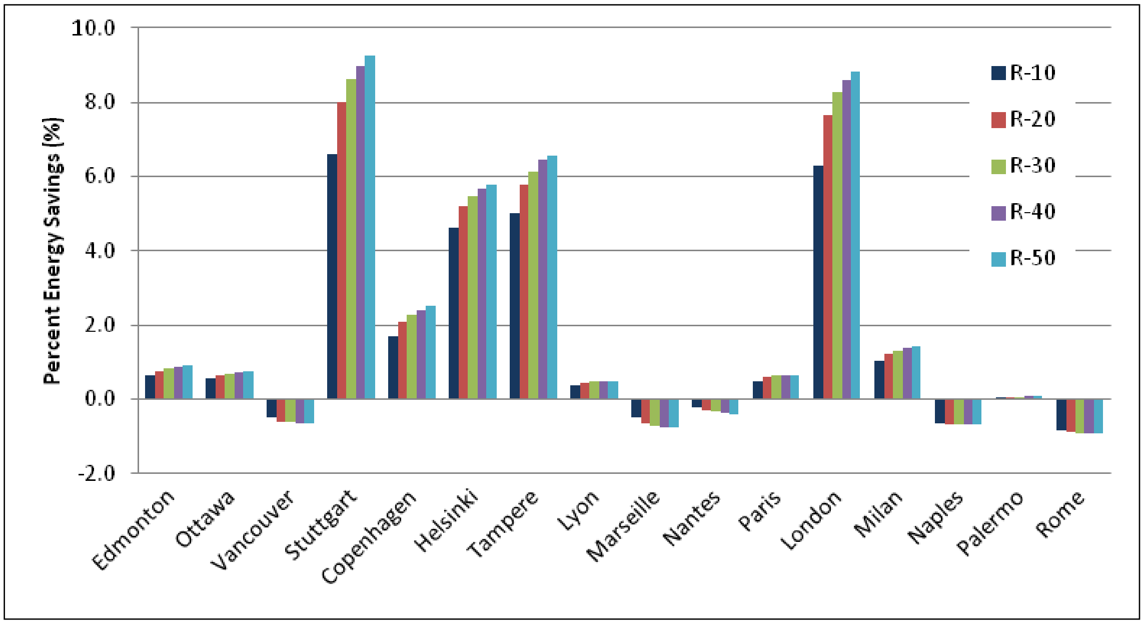

Figure 4.215. Percent energy savings for attic insulation increased above the baseline – International locations.

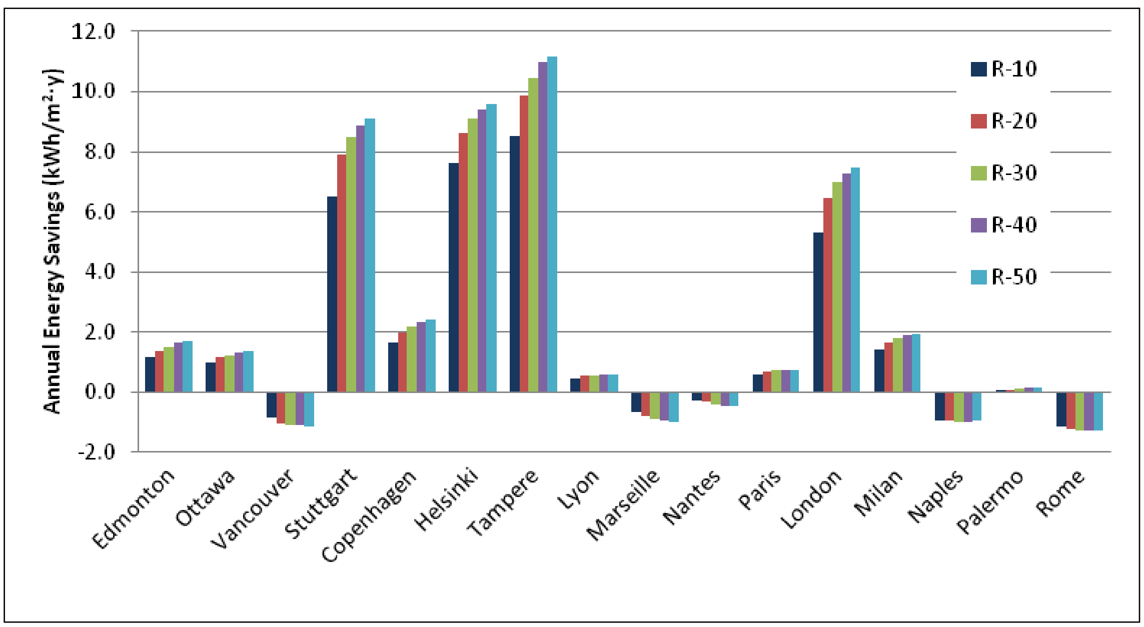

Figure 4.216. Annual energy savings for attic insulation increased above the baseline – International locations.

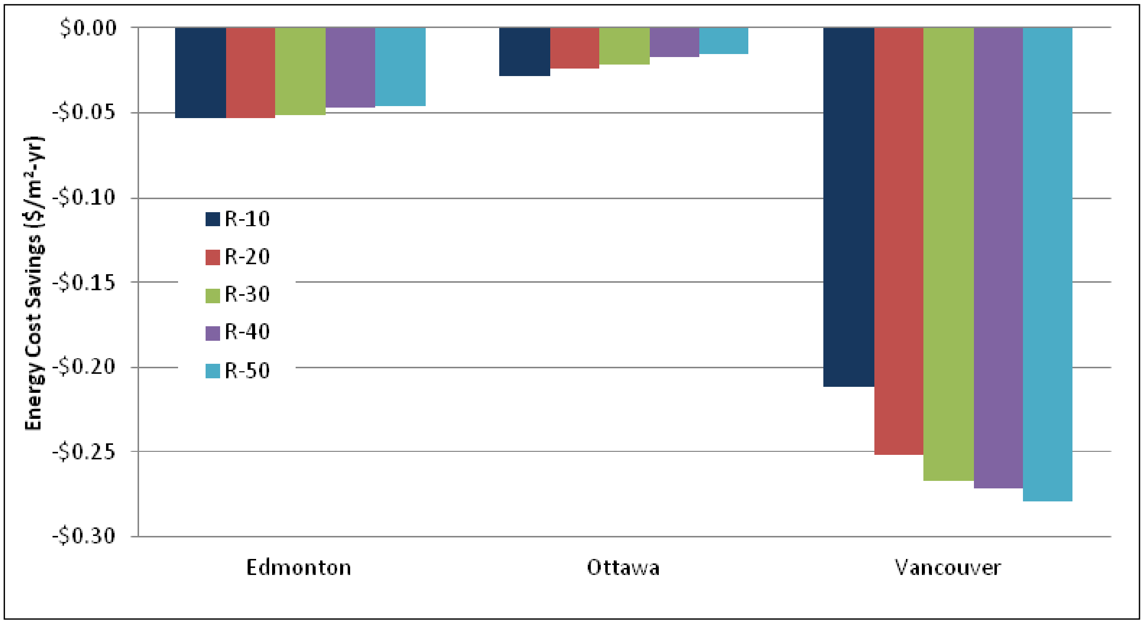

Figure 4.217. Annual energy cost savings for attic insulation increased above the baseline – Canadian locations.

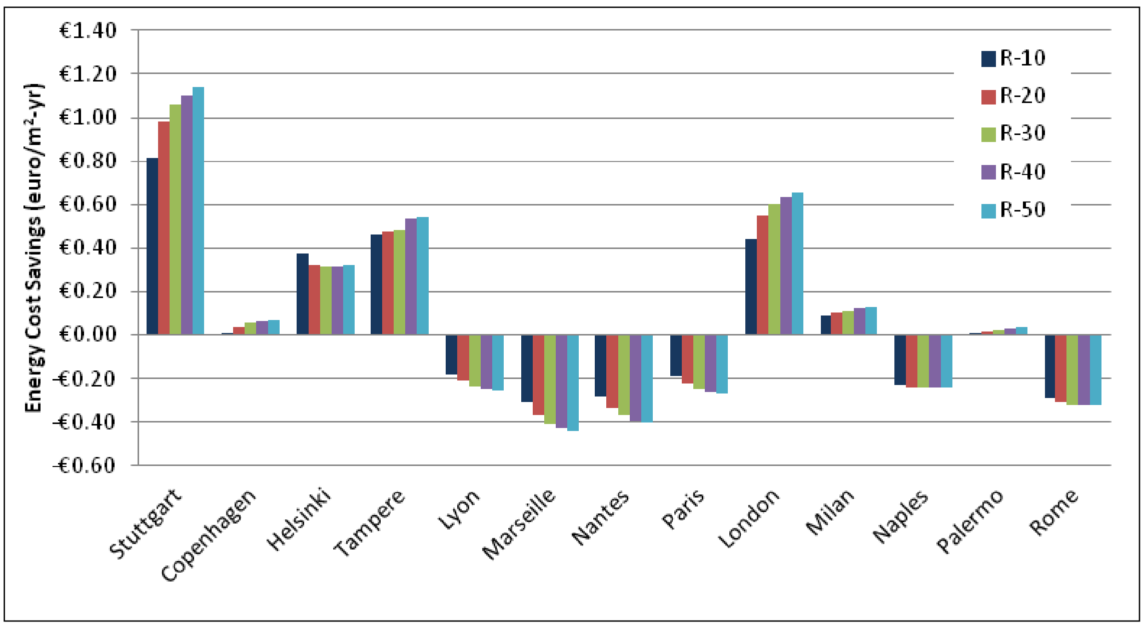

Figure 4.218. Annual energy cost savings for attic insulation increased above the baseline – European locations.

4.8 Cool Roofs

It was assumed that the baseline building has a brown colored pitched roof with a solar reflectance of ρ = 0.08. Two alternative roofing materials with higher solar reflectance values were modeled. A thermal reflective brown roof with a solar reflectance of ρ = 0.27 was modeled as a medium reflectance case, and a white roof with a solar reflectance value of ρ = 0.65 was modeled to represent a highly reflective roof. These cases are shown in Table 4.25.

The energy simulations did not account for the potential impacts of temperature changes in the attic on the HVAC systems. It was assumed that there were no ducts or system components in the attic.

Thermostatically controlled mechanical venting of the attic was also modeled for the three roof types to see how this would impact the energy use. The mechanical venting was modeled to provide 3 ACH when the attic temperature exceeded 90ºF (32ºC). The ventilated attic had the most impact on the baseline building, but almost no change to the overall energy use in the white roof case. The results from these simulations are not included in this report.

Table 4.25. Cool roof ECM overview.

Case	Description	Roof Solar Reflectance	Mechanical Venting
Baseline	Standard brown	0.08	No
Case 1	Cool brown	0.27	No
Case 2	Cool white	0.65	No

The results for the cool roof simulations are shown in Figures 4.219 through 4.225. For the U.S., the savings are larger for the warmer climates and the two marine climates, and there is a slight increase in energy use in the two coldest climates. The energy cost savings are small, but positive in all locations. The energy savings results for the Canadian and European locations are similar to the U.S. All of the locations show some energy savings except for Edmonton and Ottawa, which show higher energy use with the cool roof. All of the locations except for Stuttgart, Helsinki and Tampere show energy cost savings.

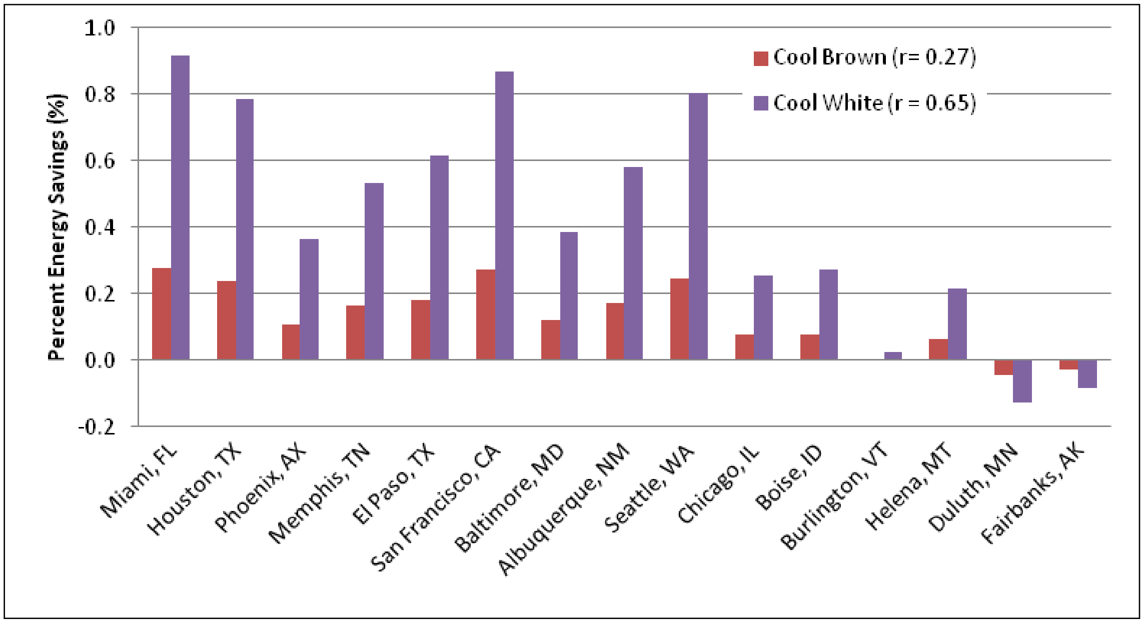

Figure 4.219. Percent energy savings for cool roof.

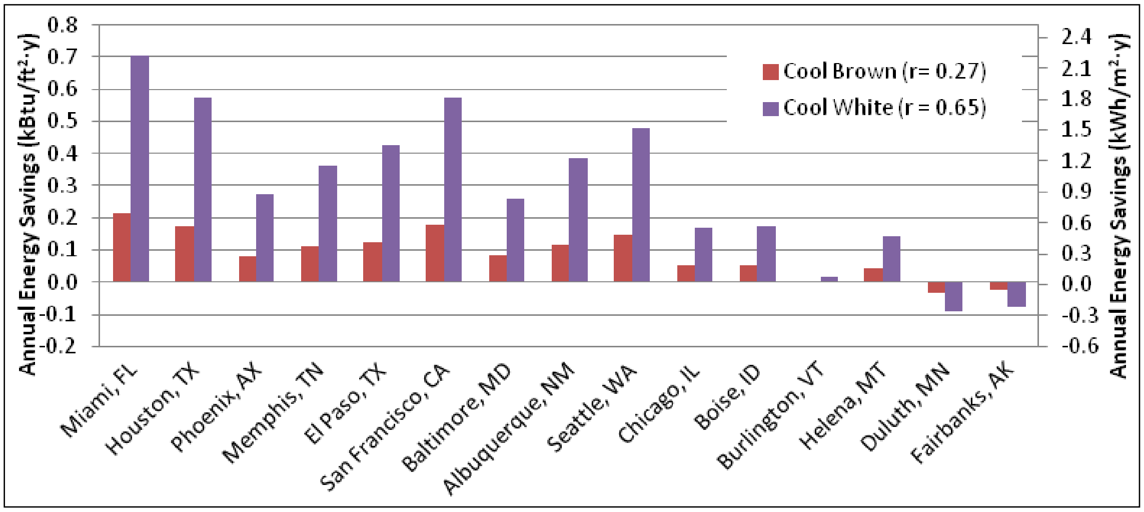

Figure 4.220. Annual energy savings for cool roof.

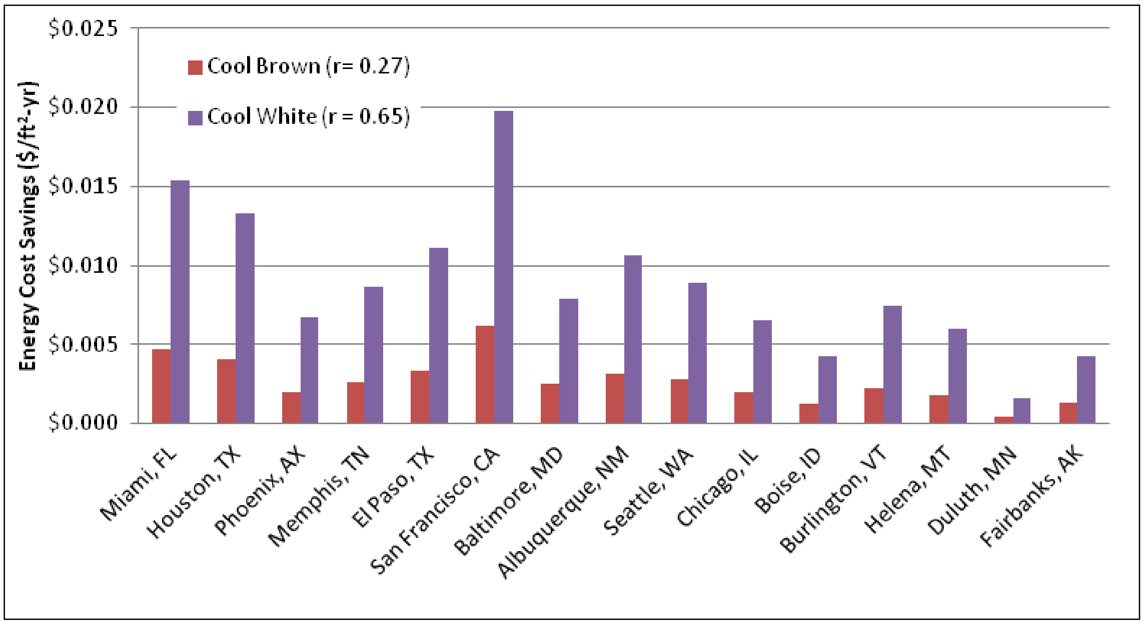

Figure 4.221. Annual energy cost savings for cool roof.

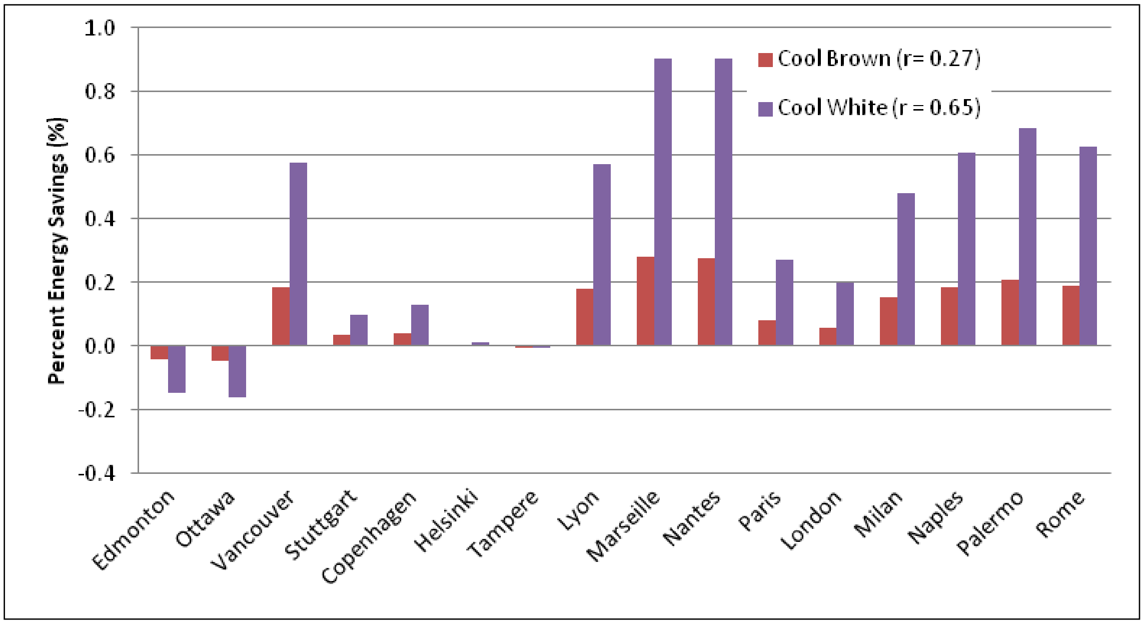

Figure 4.222. Percent energy savings for cool roof – International locations.

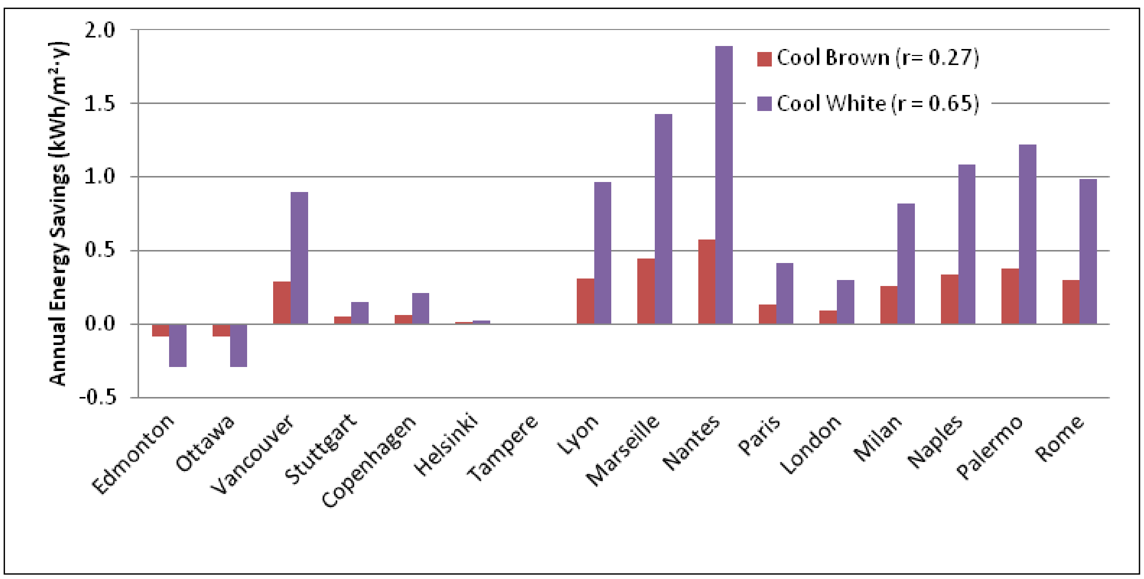

Figure 4.223. Annual energy savings for cool roof – International locations.

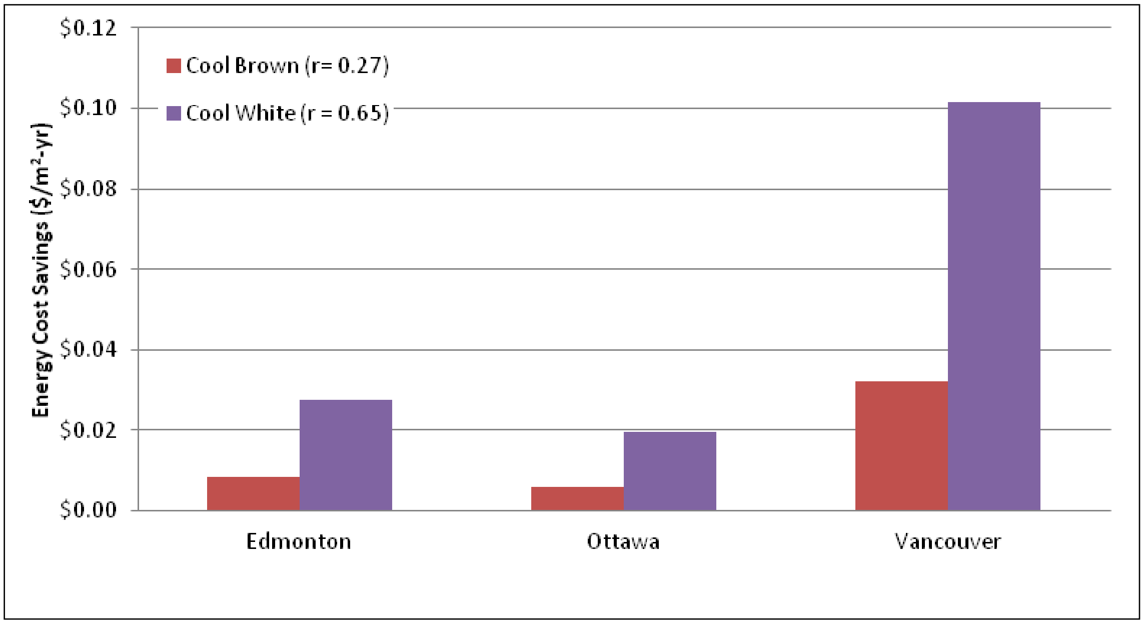

Figure 4.224. Annual energy cost savings for cool roof – Canadian locations.

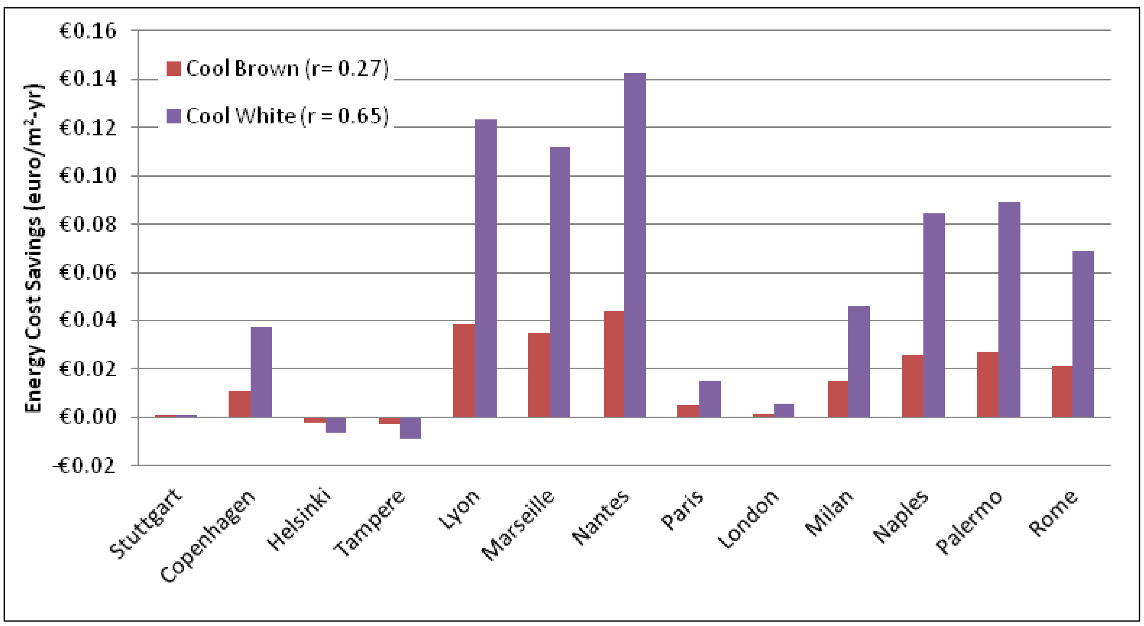

Figure 4.225. Annual energy cost savings for cool roof – European locations.

4.9 Building Airtightness

The effects of retrofitting the administration facility with a tighter envelope were evaluated with two levels of improvement over the baseline. Envelope leakage rates were assumed for the baseline and the two improved cases loosely based on blower door results from real buildings. The leakage rates and corresponding air changes per hour used for modeling are shown in Table 4.26. The method used to derive air change rates from envelope leakage rates is described in Section 4.

Table 4.26. Building airtightness ECM overview.

Source	Leakage Rate at 0.3 in w.g. (75 Pa) cfm/ft^2 (L/s/m^2)	Leakage Rate at 0.016 in w.g. (4 Pa) cfm/ft^2 (L/s/m^2)	ACH at 0.016 in w.g. (4 Pa)
Baseline	1.0 (5.07)	0.15 (0.65)	0.97
Typical practice for air sealing retrofit	0.50 (2.54)	0.074 (0.33)	0.48
Good practice for air sealing retrofit	0.25 (1.27)	0.037 (0.16)	0.24

The results for the improved airtightness simulations are shown in Figures 4.226 through 4.232. The energy savings can be significant especially in the colder climates. For cold climates this is the highest energy savings ECM for leaky buildings. For the warm-humid climates it is also an important measure to reduce humidity problems, which was not a focus of this modeling effort. There is very little energy savings for the mild climates, and Vancouver is the only climate that had a negative energy cost savings.

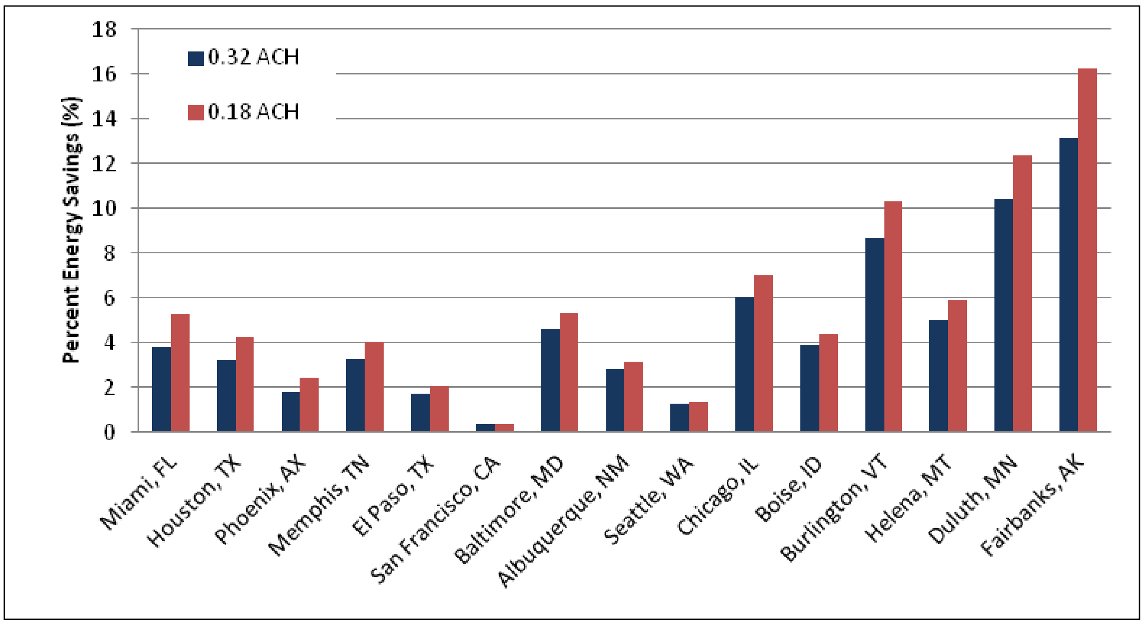

Figure 4.226. Percent energy savings for improved airtightness.

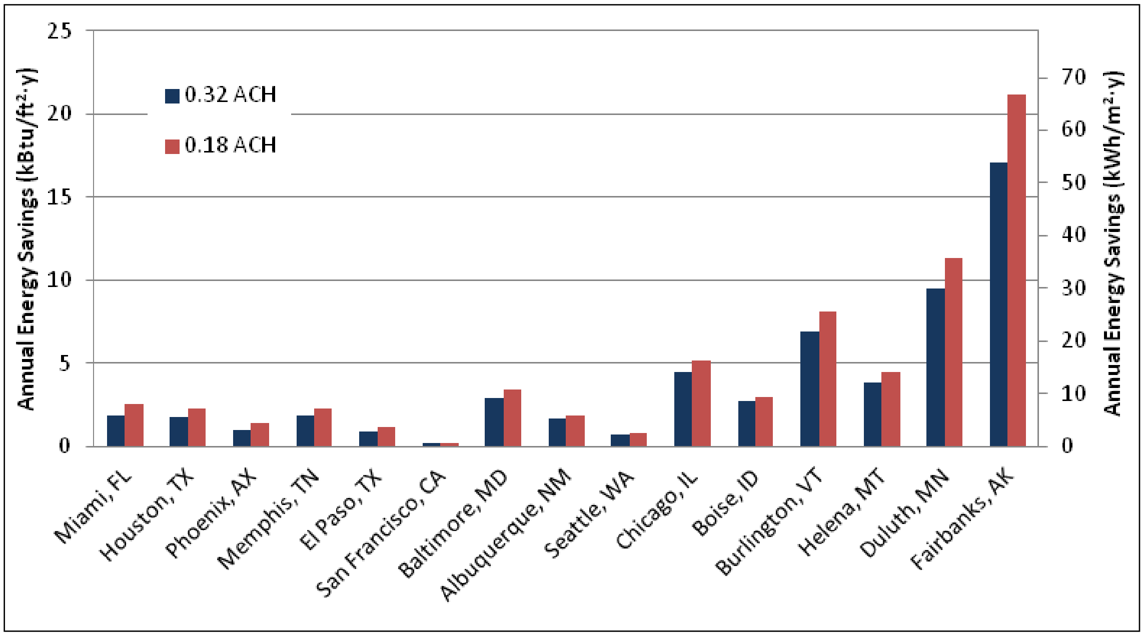

Figure 4.227. Annual energy savings for improved airtightness.

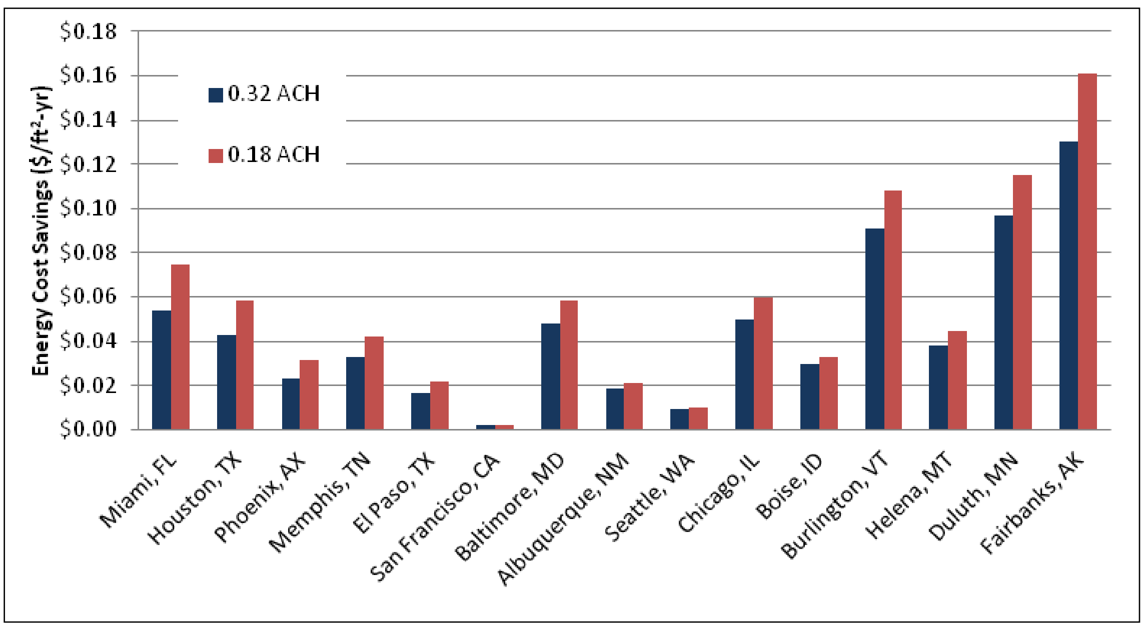

Figure 4.228. Annual energy cost savings for improved airtightness.

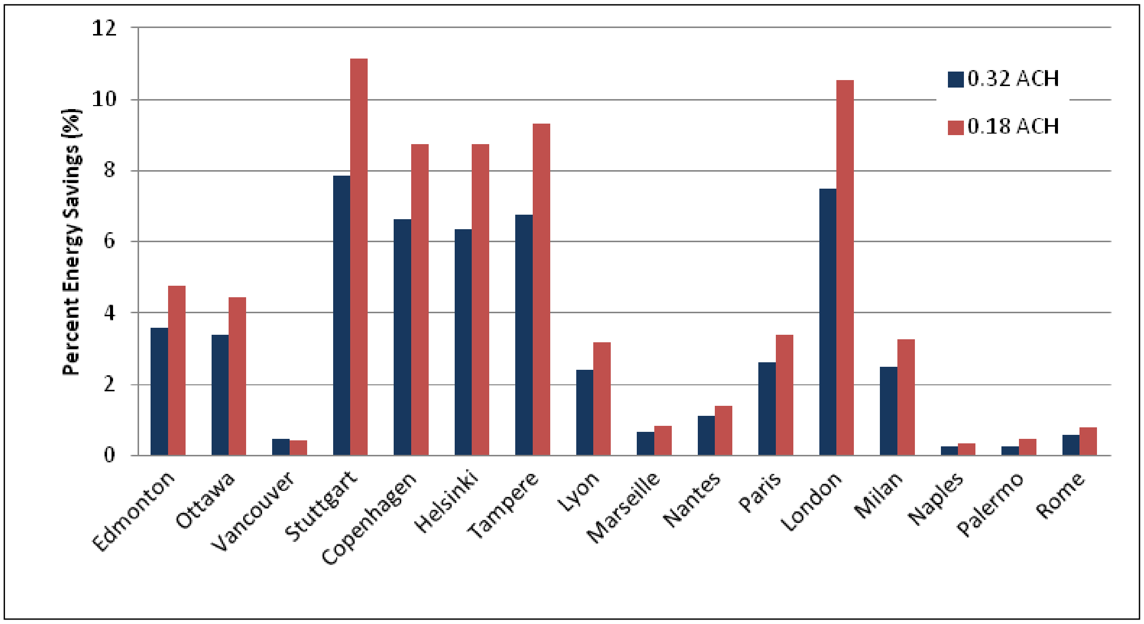

Figure 4.229. Percent energy savings for improved airtightness – International locations.

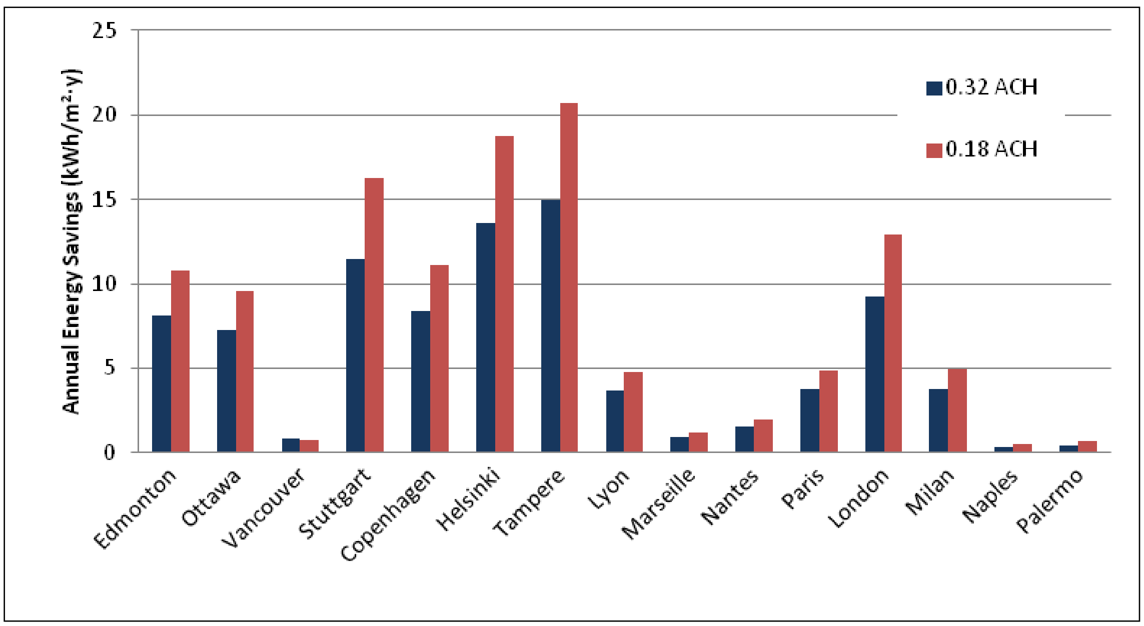

Figure 4.230. Annual energy savings for improved airtightness – International locations.

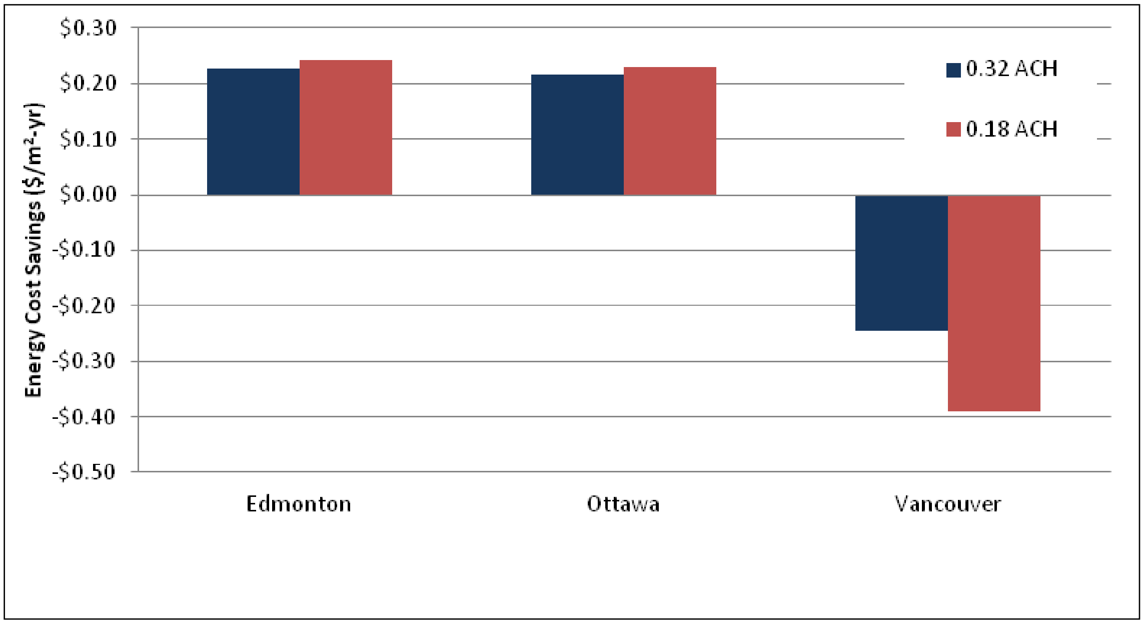

Figure 4.231. Annual energy cost savings for improved airtightness – Canadian locations.

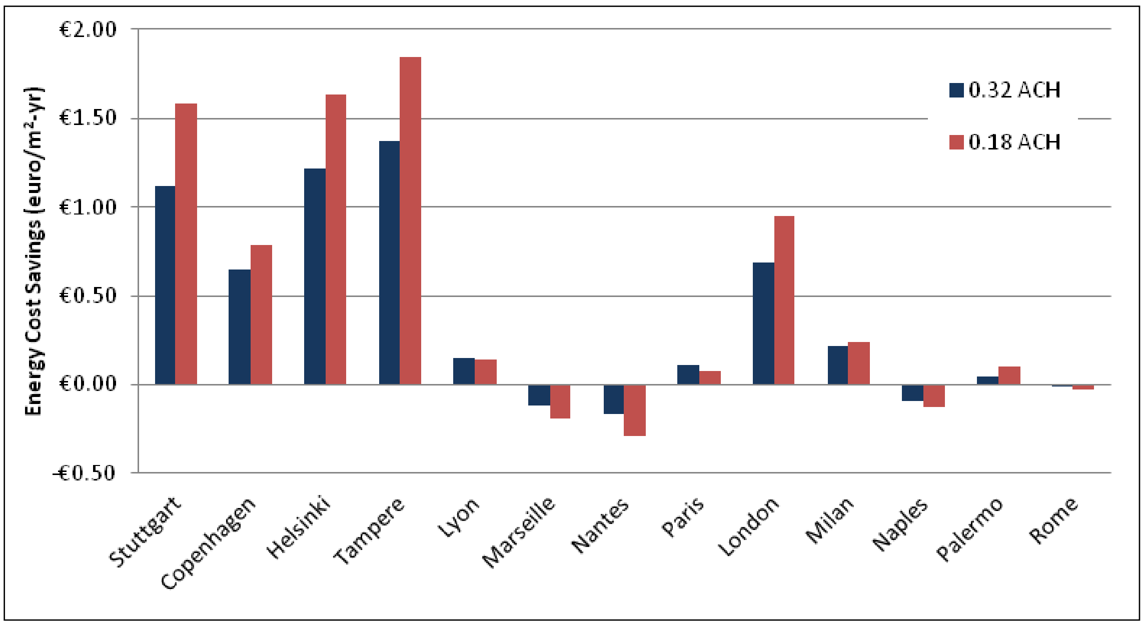

Figure 4.232. Annual energy cost savings for improved airtightness – European locations.

4.10 Advanced Windows

The set of advanced window options evaluated are shown in Table 4.27. Exact models of the recommended windows are not readily available in the NREL database; therefore, a set of suitable alternative models were used. The properties of the six replacement windows as they are modeled are given by Table 4.28. Included in the tables are the estimated costs per square foot of glazing and the airtightness of the building after the retrofit. In this analysis the airtightness is assumed to be unchanged by the replacement windows.

Table 4.27. Thermal properties of retrofit windows.

#	Glazing Type	Frame Type	U-Factor Btu/ft²·hr·°F (W/m²·K)	SHGC	VT	Incremental Cost ($/ft²)
I	2-pane, uncoated glass	Aluminum, thermal break	0.60 (3.4)	0.60	0.63	Baseline cost
II	2-pane, tinted	Aluminum, thermal break	0.60 (3.4)	0.42	0.38	$0.50
A	2-pane, reflective coating	Aluminum, thermal break	0.54 (3.1)	0.17	0.10	$1.25
B	2-pane, low-E, tinted	Aluminum, thermal break	0.46 (2.6)	0.27	0.43	$1.75
C	2-pane, low-E	Aluminum, thermal break	0.46 (2.6)	0.34	0.57	$1.50
D	3-pane, low-E	Insulated	0.20 (1.1)	0.22	0.37	$9.00
E	3-pane, high-SHGC, low-E	Non-metal	0.27 (1.5)	0.38	0.47	$15.50
F	3-pane, high-SHGC, low-E	Non-metal, insulated	0.18 (1.0)	0.40	0.50	$19.67

Table 4.28. Thermal properties of modeled windows.

Window	Cost $/ft² ($/m²)	Fenestration, Overall U-Value Btu/h·°F·ft² (W/m²·K)	SHGC	Building AL at 0.3 in w.g. cfm/ft² (L/s·m² at 75 Pa)
I	22.00 (236.81)	0.56 (3.19)	0.61	1.00 (5.08)
II	22.50 (242.2)	0.55 (3.12)	0.50	1.00 (5.08)
A	23.25 (250.27)	0.51 (2.88)	0.22	1.00 (5.08)
B	23.75 (255.65)	0.44 (2.48)	0.30	1.00 (5.08)
C	23.50 (252.96)	0.45 (2.53)	0.35	1.00 (5.08)
D	31.00 (333.69)	0.21 (1.20)	0.19	1.00 (5.08)
E	37.5 (403.61)	0.26 (1.48)	0.37	1.00 (5.08)
F	41.67 (448.49)	0.17 (0.97)	0.47	1.00 (5.08)

The results for the window simulations are shown in Figures 4.233 through 4.239. The performance of the windows is a combination of the U-value and the SHGC. Daylighting was not modeled in this building and therefore the visual transmittance is not a factor in the energy performance. All of the windows show energy savings in the warmer climates. In the colder climates, the baseline window is better than the first three windows. Lower U-values provide energy savings in all climates. In the hot climates (climate zones 1-3), the lower SHGC windows perform better, and the opposite is true of the colder climate zones (4-8). The baseline windows for the international locations varied from country to country and had a large impact on the savings. The largest energy savings are in Italy, France, and Finland.

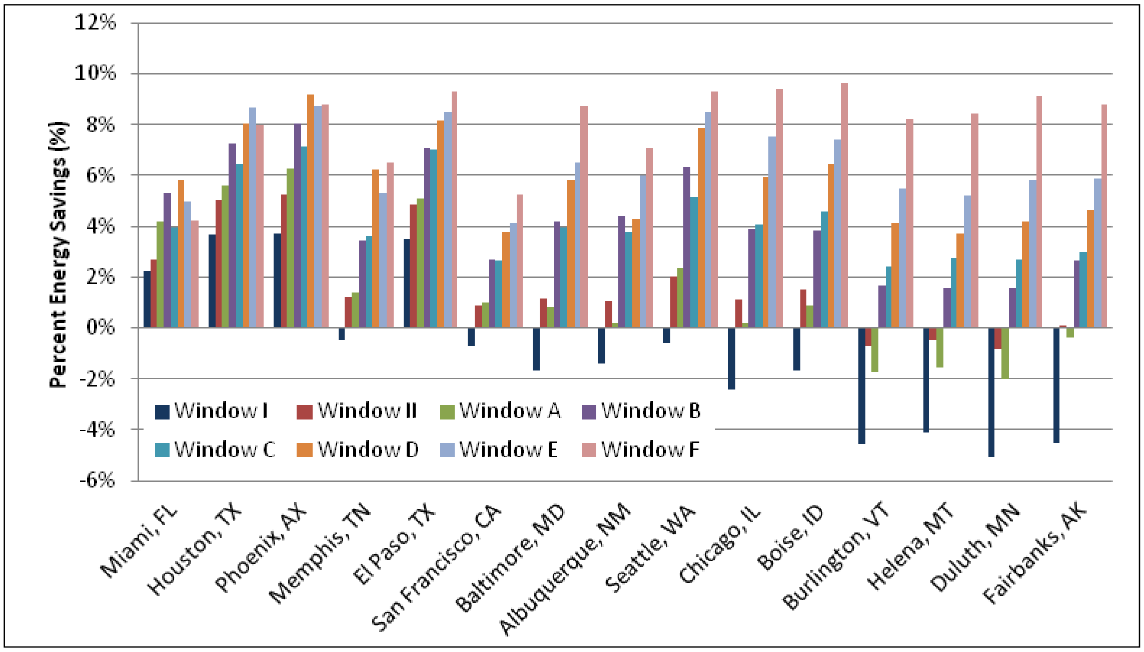

Figure 4.233. Percent energy savings for advanced windows.

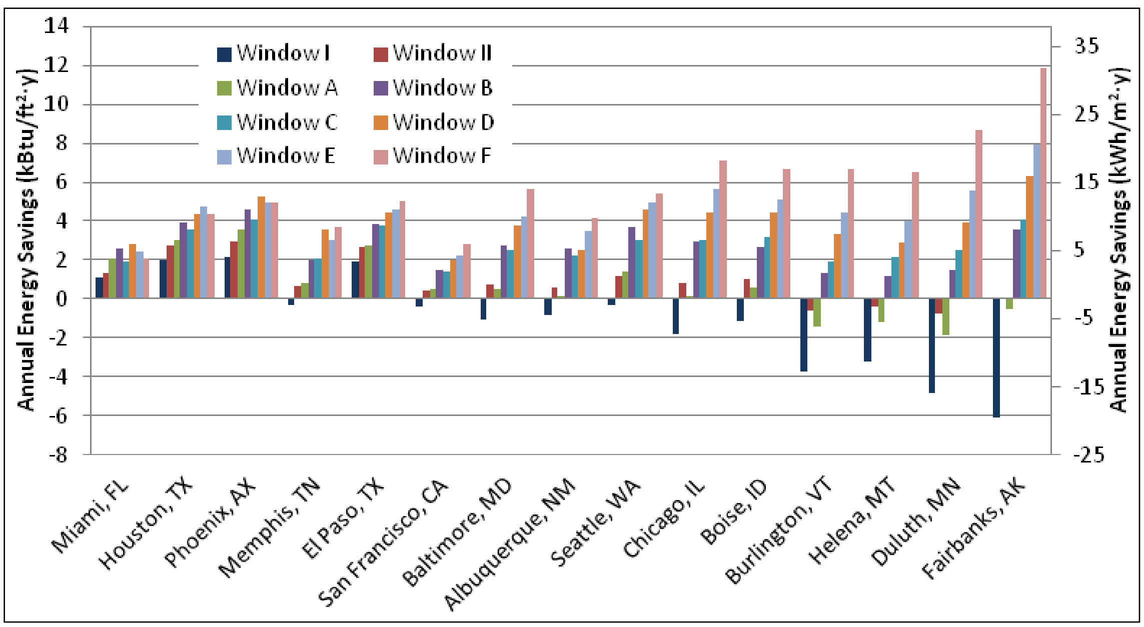

Figure 4.234. Annual energy savings for advanced windows.

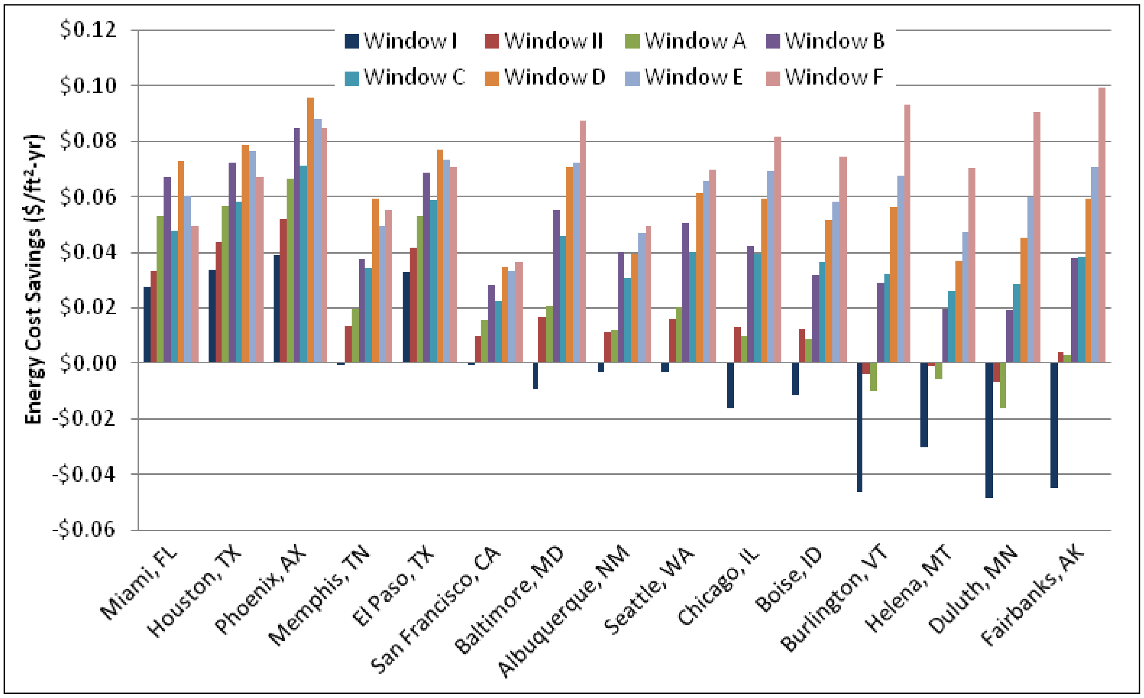

Figure 4.235. Annual energy cost savings for advanced windows.

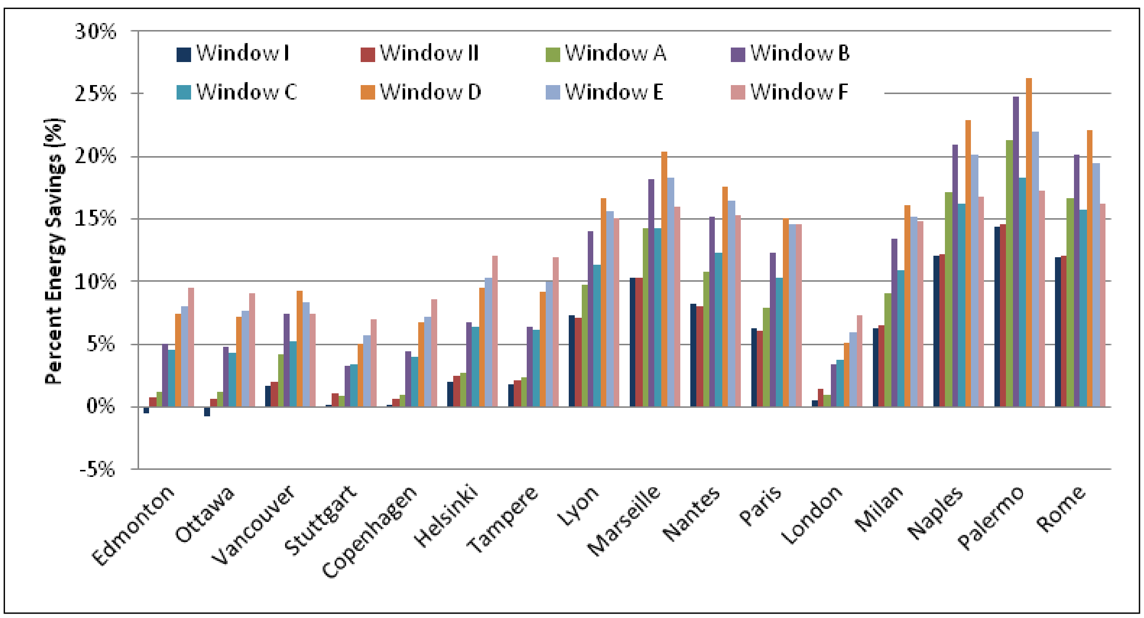

Figure 4.236. Percent energy savings for advanced windows – International locations.

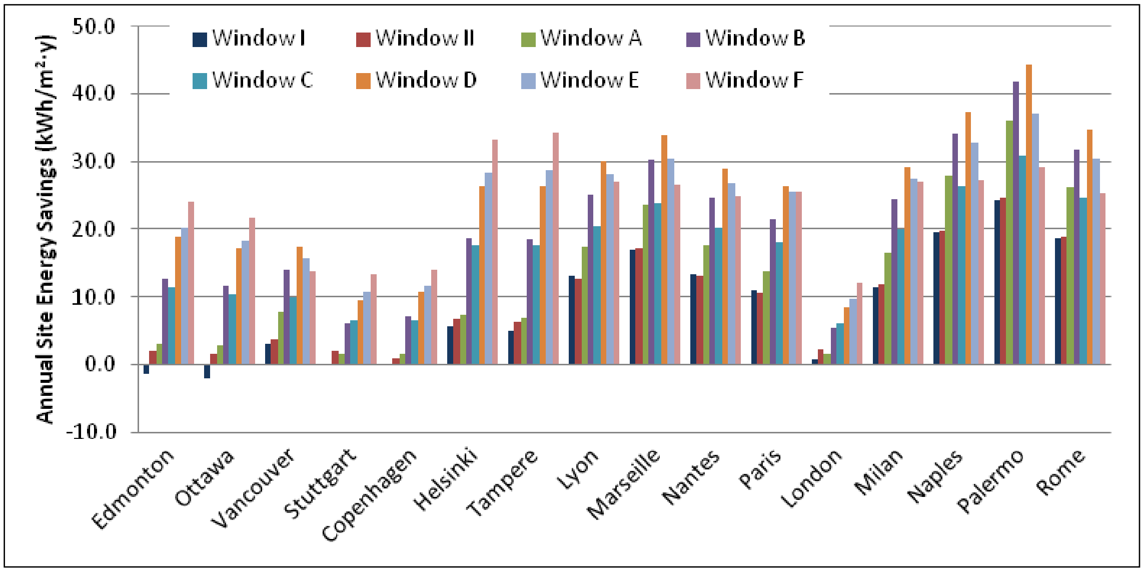

Figure 4.237. Annual energy savings for advanced windows – International locations.

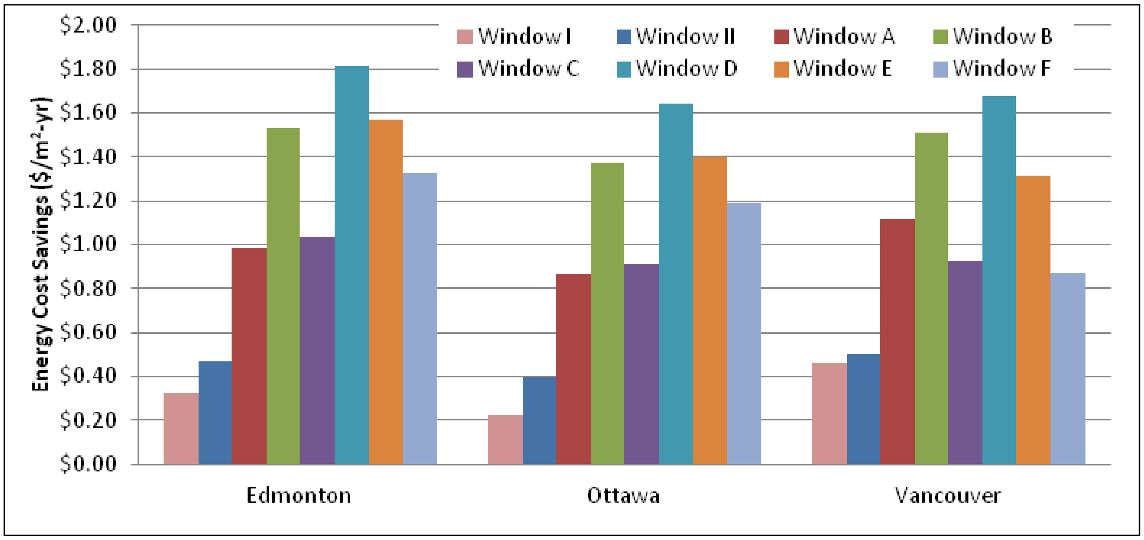

Figure 4.238. Annual energy cost savings for advanced windows – Canadian locations.

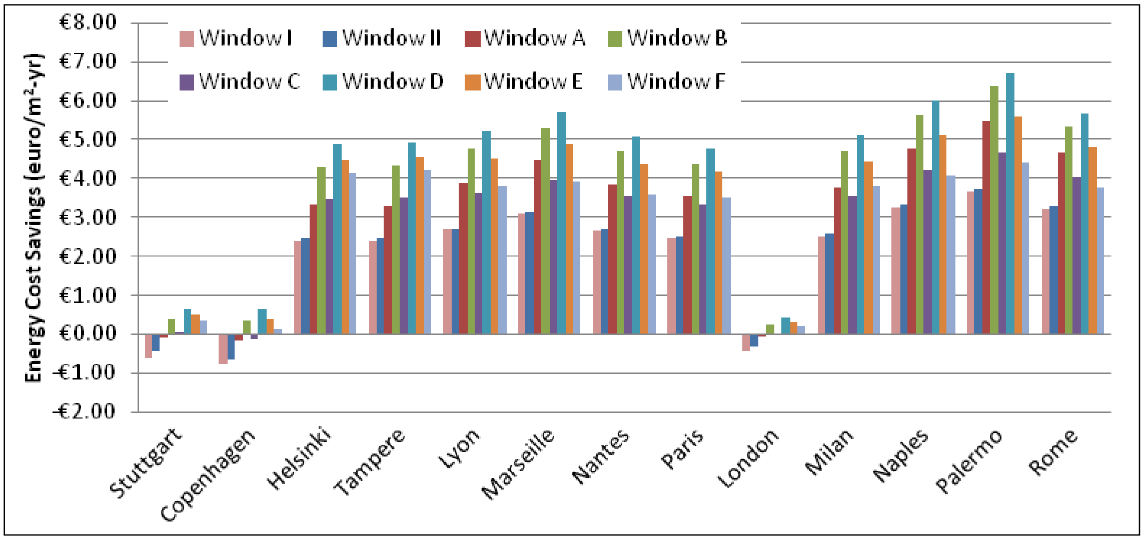

Figure 4.239. Annual energy cost savings for advanced windows – International locations.

4.11 Overhangs

The effect on whole building energy performance from retrofitting the building with exterior overhangs above the south-facing windows was modeled in EnergyPlus using simple shading devices which protrude orthogonally from the building façade by 1.6 ft (0.5 m).

In general, overhangs showed small savings for the U.S. locations and slightly higher savings for the international locations. This outcome is attributed to the generally lower SHGC found in the windows in the U.S. buildings, which makes them less vulnerable to solar heat gains. Other benefits to overhangs such as glare control and thermal comfort improvement on south windows were not analyzed in this study.

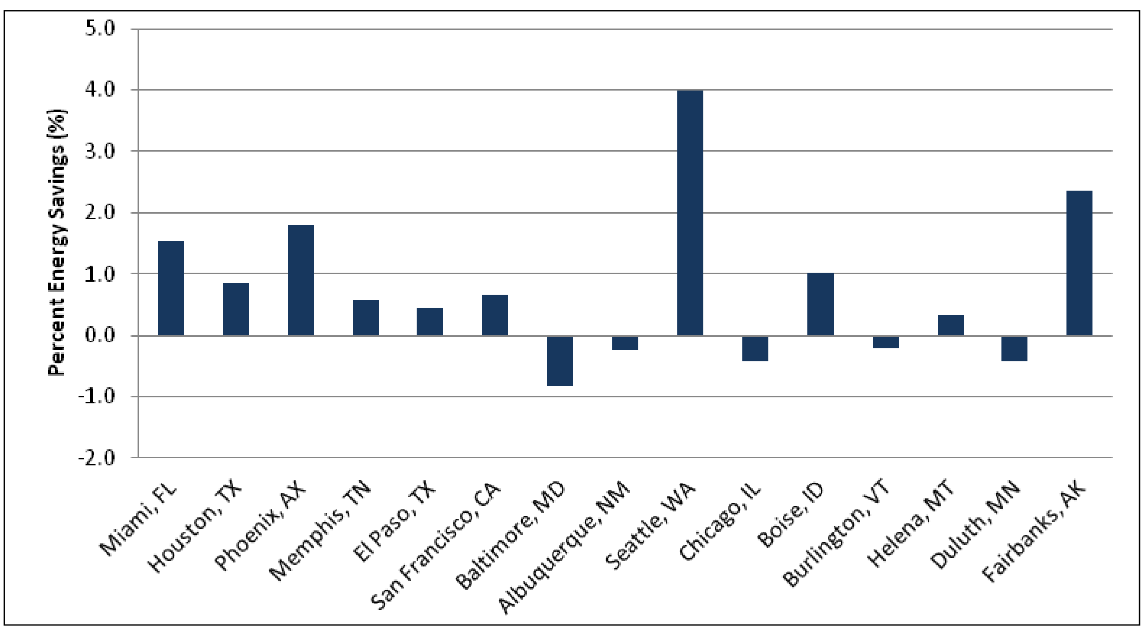

Figure 4.240. Percent energy savings for overhangs.

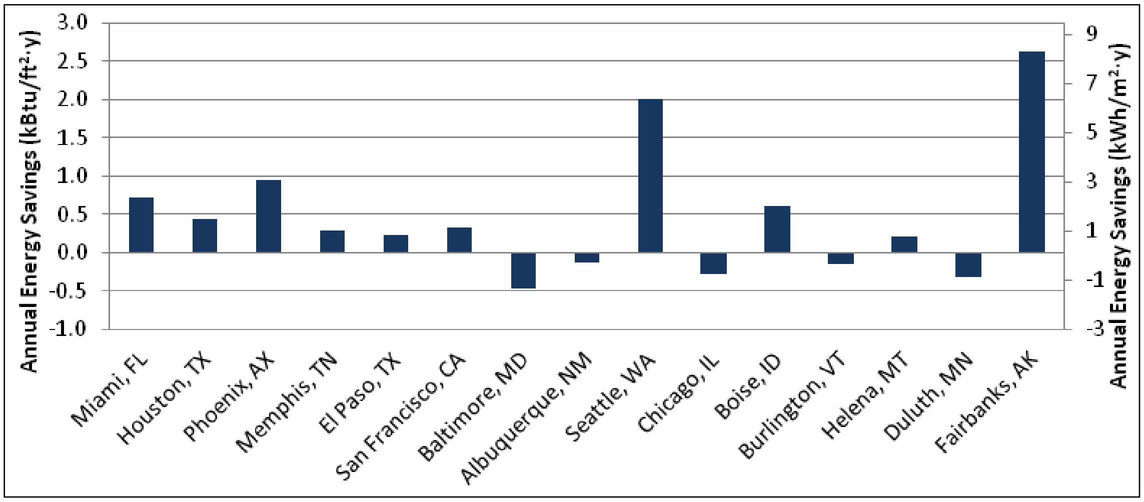

Figure 4.241. Annual energy savings for overhangs.

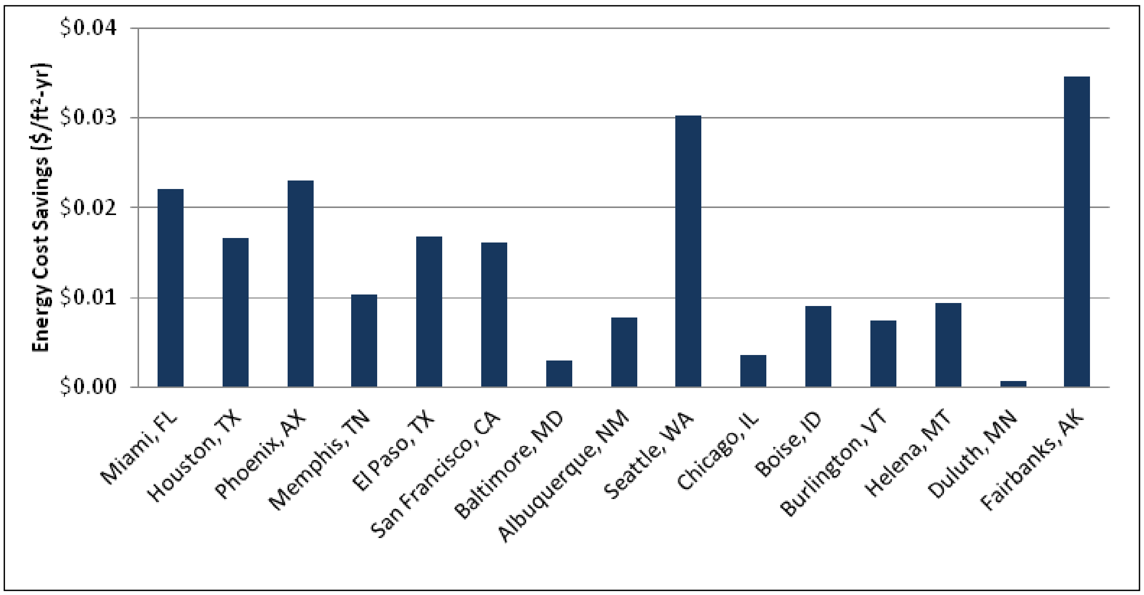

Figure 4.242. Annual energy cost savings for overhangs.

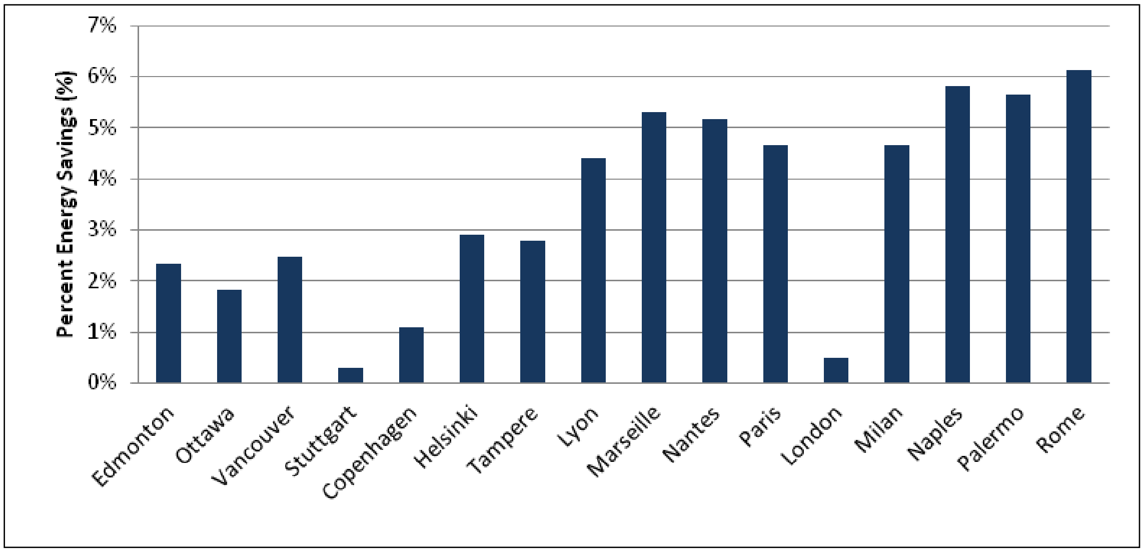

Figure 4.243. Percent energy savings for overhangs – International locations.

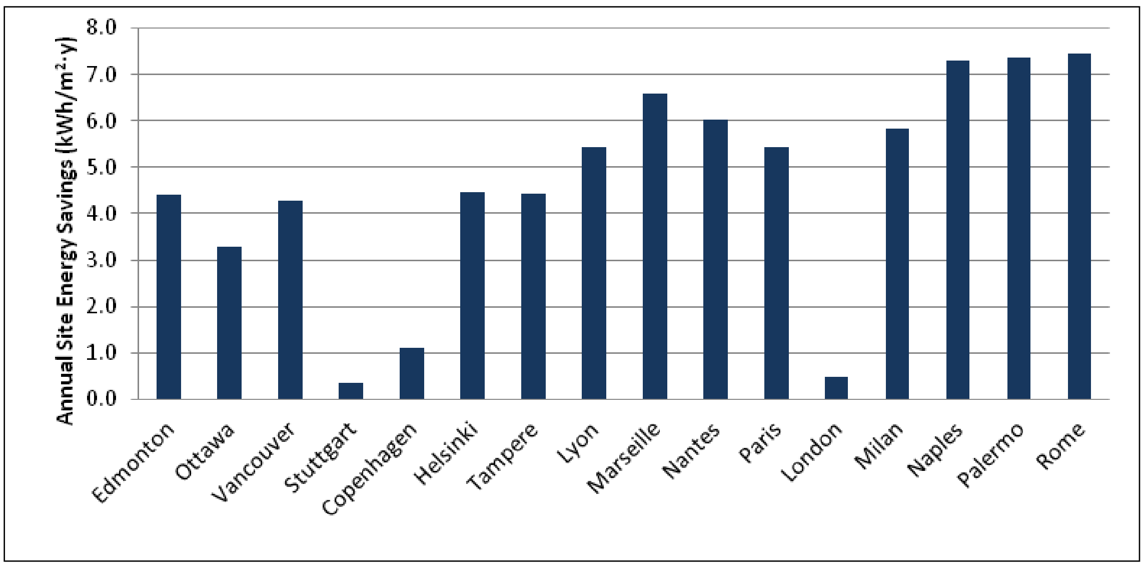

Figure 4.244. Annual energy savings for overhangs – International locations.

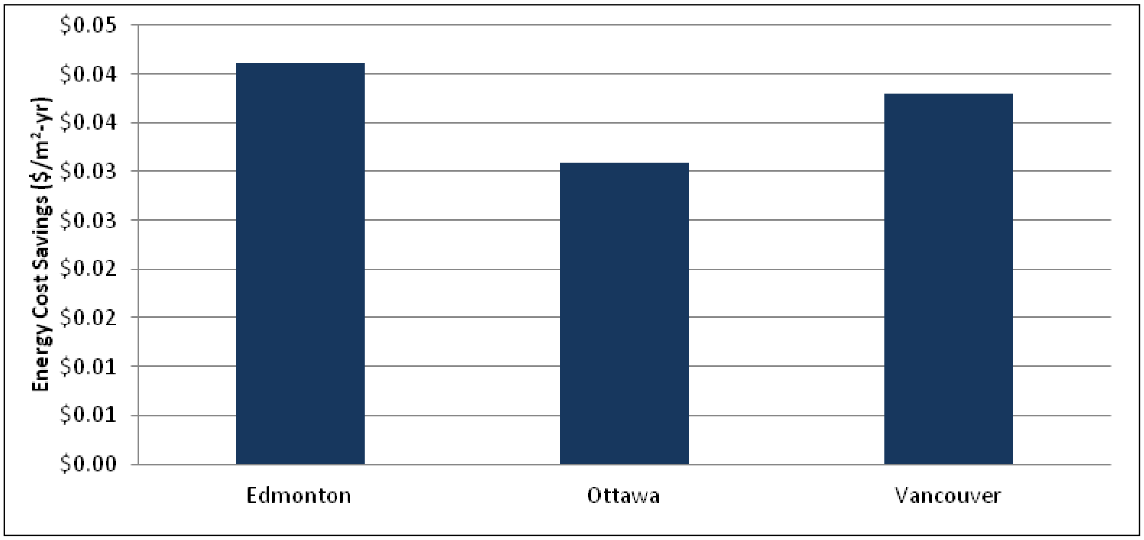

Figure 4.245. Annual energy cost savings for overhangs – Canadian locations.

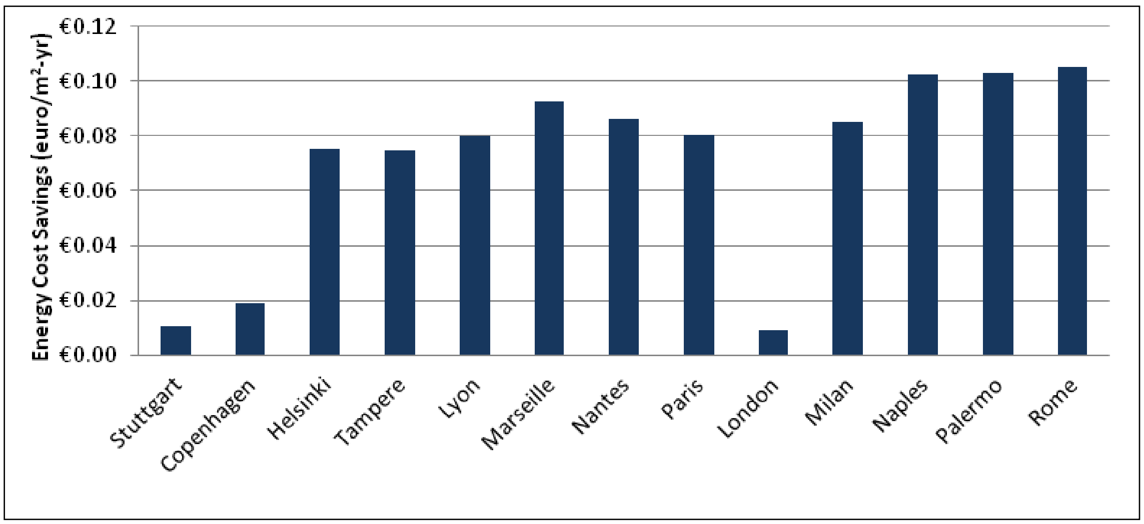

Figure 4.246. Annual energy cost savings for overhangs – European locations.

4.12 Exterior Vertical Fins

The effect of retrofitting the building with exterior vertical fins around the windows was modeled in a similar way as window overhangs. Shading devices protruding out 1.6 ft (0.5 m) orthogonally around the left, right, and top sides of the east-, west-, and south-facing windows were modeled using EnergyPlus.

Similar to the windows overhangs, the vertical fins were found to have only marginal effect on the U.S. locations. Seattle was an outlier, showing about 6% energy savings. In general, vertical fins were found to offer a greater advantage in the international locations. This was attributed to the higher SHGC in the baseline international buildings. Vertical fins are typically added to a building to control direct beam radiation and not for direct energy savings.

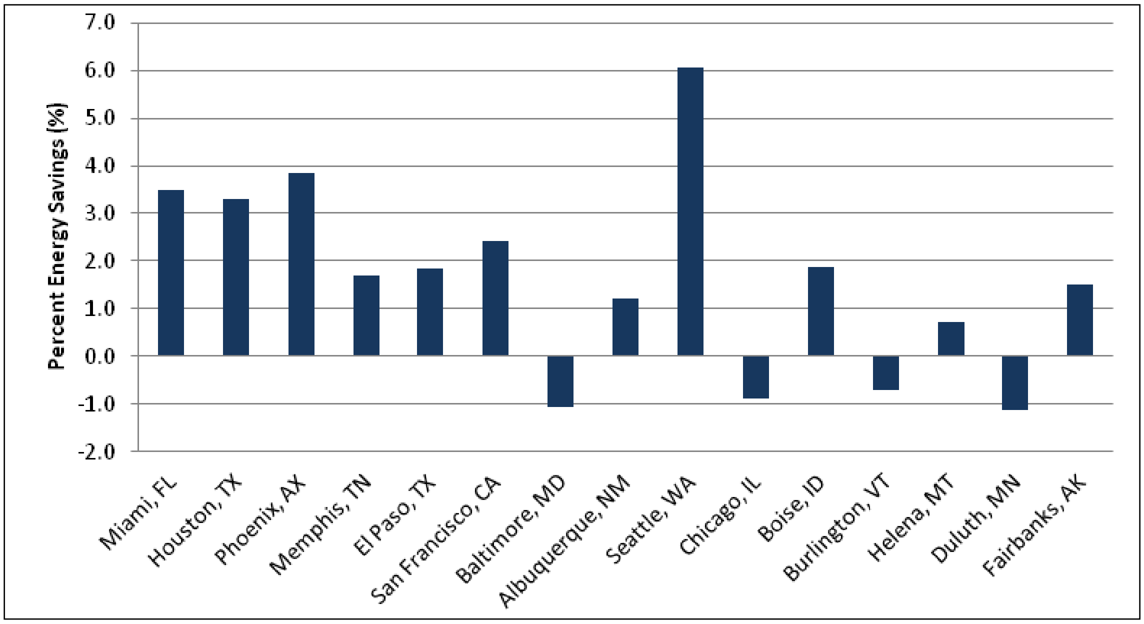

Figure 4.247. Percent energy savings for exterior vertical fins.

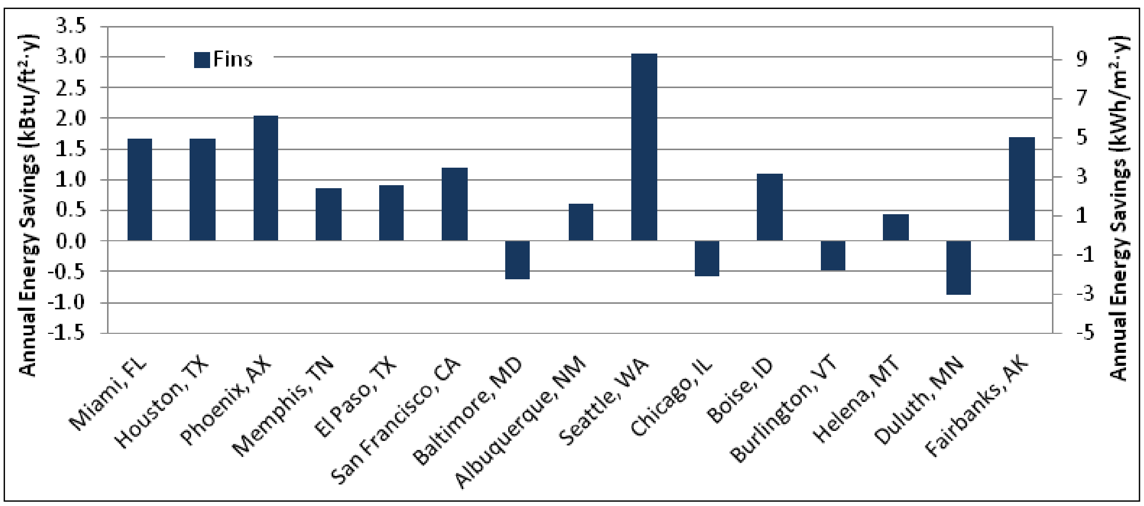

Figure 4.248. Annual energy savings for exterior vertical fins.

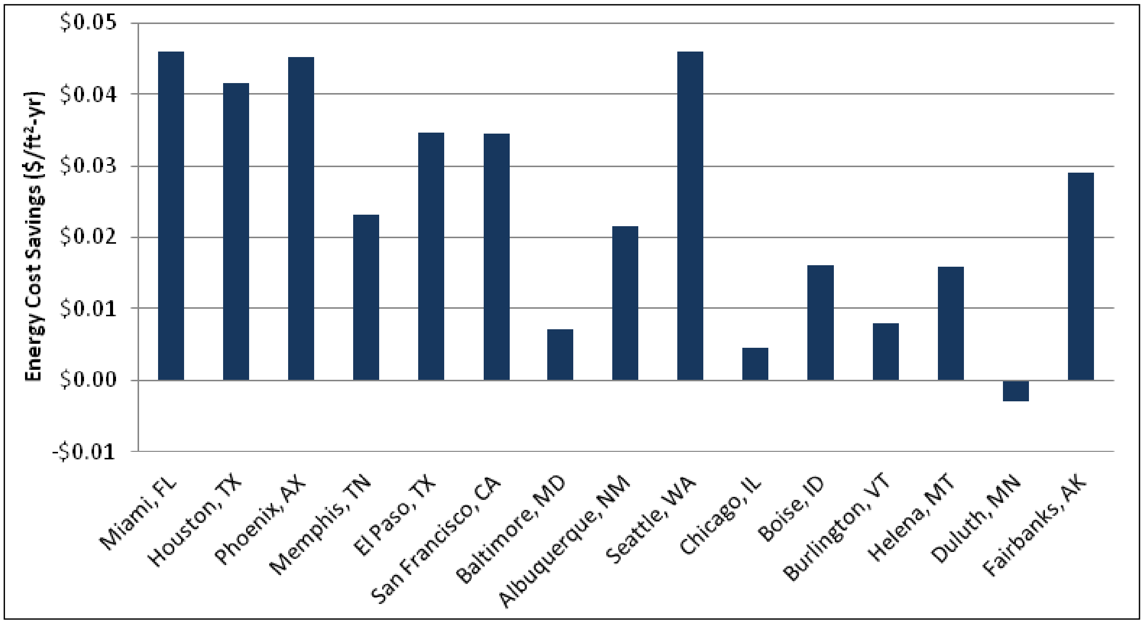

Figure 4.249. Annual energy cost savings for exterior vertical fins.

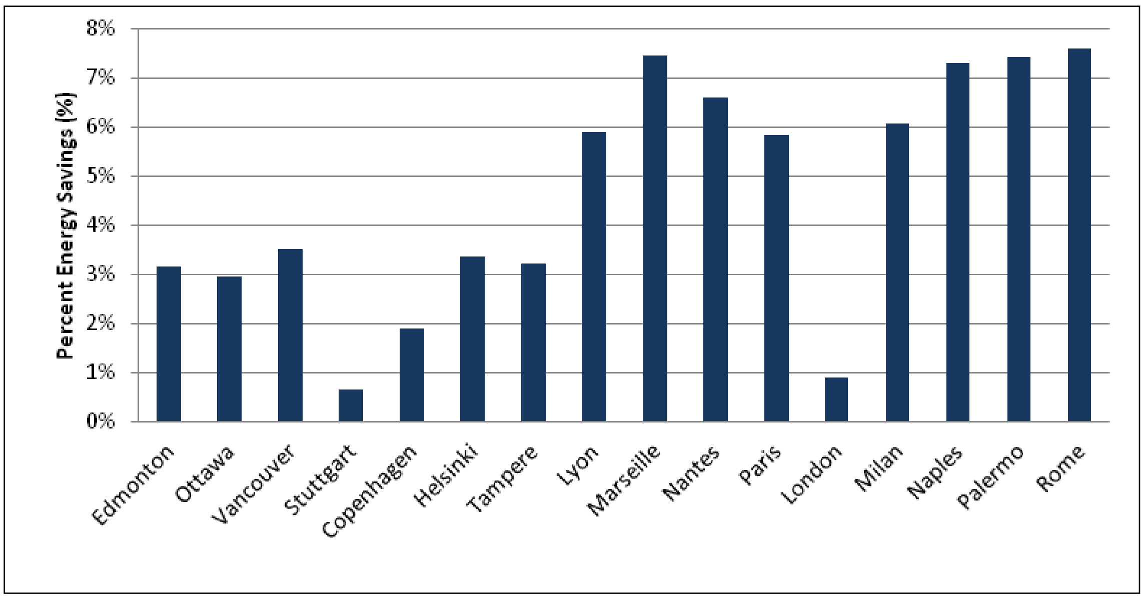

Figure 4.250. Percent energy savings for exterior vertical fins – International locations.

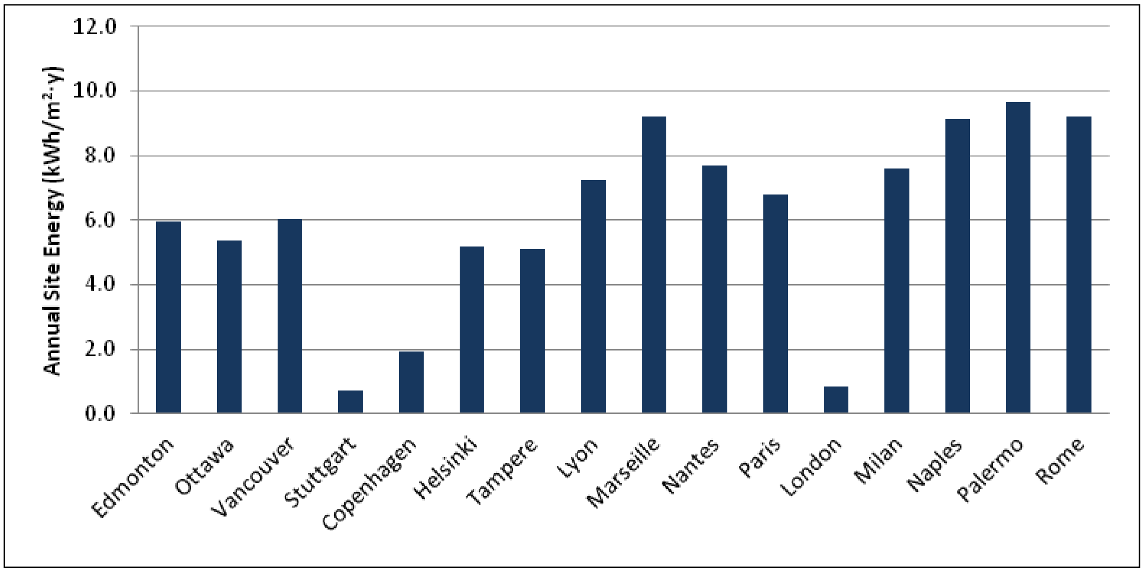

Figure 4.251. Annual energy savings for exterior vertical fins – International locations.

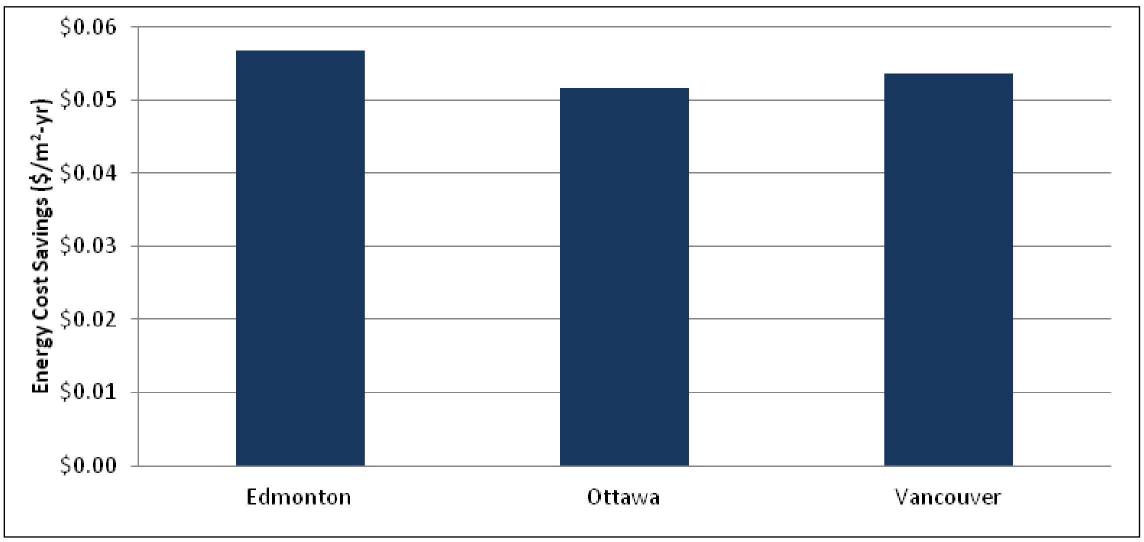

Figure 4.252. Annual energy cost savings for exterior vertical fins – Canadian locations.

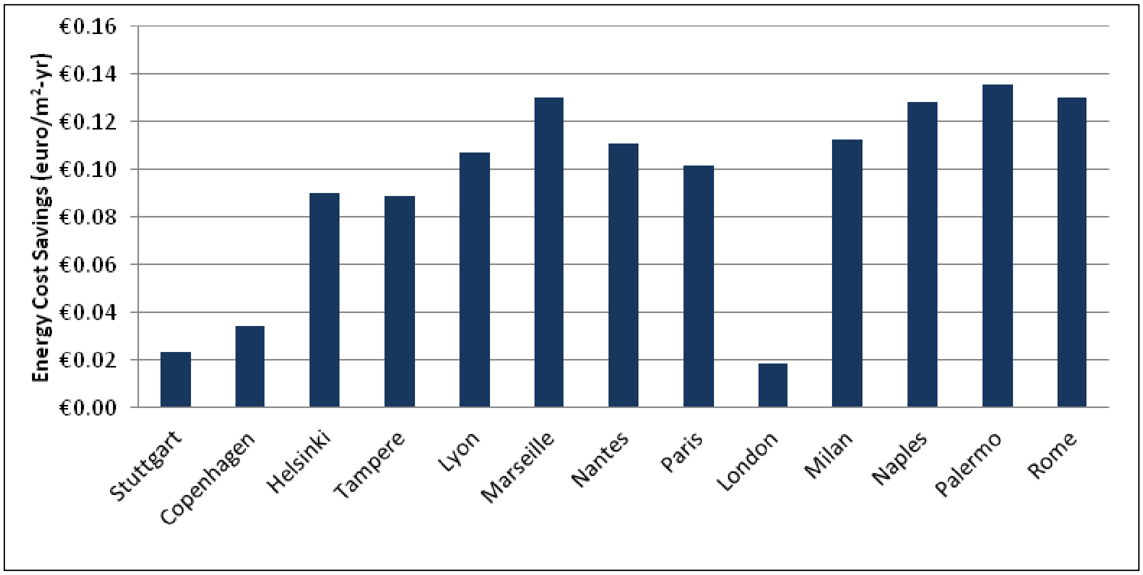

Figure 4.253. Annual energy cost savings for exterior vertical fins – European locations.

4.13 Energy Recovery Ventilators

ERVs are used to transfer useful energy from the exhaust air stream of a building's air handler to the incoming outdoor air stream. A retrofit application of ERVs was modeled using three levels of performance. The specifications of the ERV are selected to represent a desiccant wheel type ERV, which has the capability to transfer moisture between the two air streams and is sometimes called a total energy recovery system. The specific properties of each device are shown in Table 4.29.

Table 4.29. ERV retrofit model parameters.

ERV Name	Sensible Effectiveness	Latent Effectiveness	Pressure Drop (in water)
ERV 60	0.6	0.5	0.70
ERV 70	0.7	0.6	0.86
ERV 80	0.8	0.7	1.00

A schematic of the retrofit system is shown in Figure 4.254. Each individual air handler in the baseline building was retrofitted with an ERV across the outdoor air and relief air streams of the outdoor air systems. In the US locations the air handlers serve multiple zones whereas the international buildings contain packaged single zone systems.

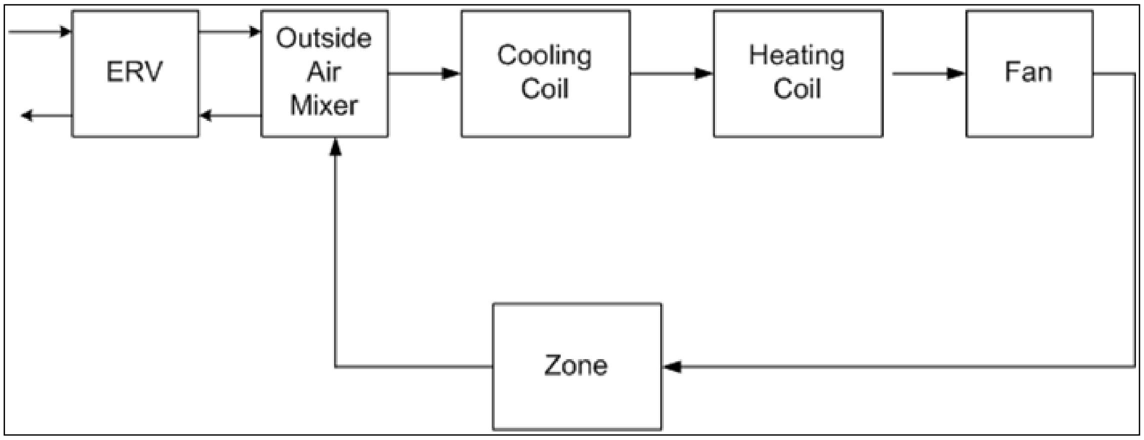

Figure 4.254. Schematic of the energy recovery ventilator model (credit: Kyle Benne).

The results for the ERV simulations are shown in Figures 4.255 through 4.261. Energy recovery devices are generally most effective in cold climates. The results below show over 10% energy savings in the cold-humid climates. Buildings in a few climates can actually be penalized for the use of an ERV. These are climates that have large opportunities for economizing, and any small savings due to energy recovery is offset by an increase in fan energy due to the added pressure drop of the device. An ERV bypass was not modeled in this study, but would improve performance by avoiding the fan energy penalty of the ERV when the system is in economizer mode.

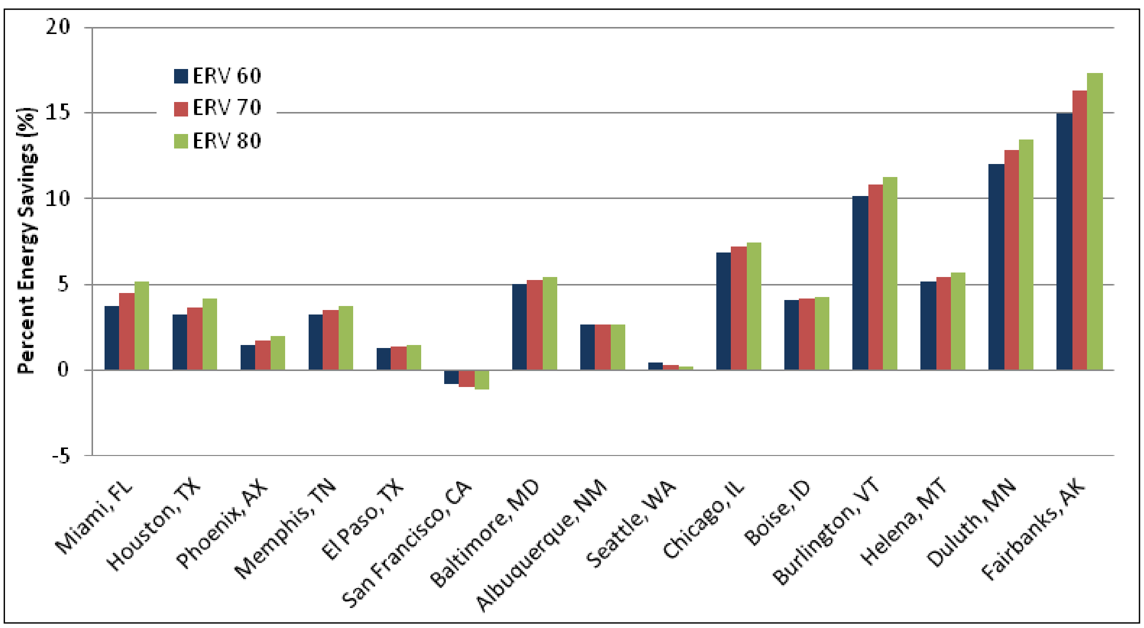

Figure 4.255. Percent energy savings for ERVs.

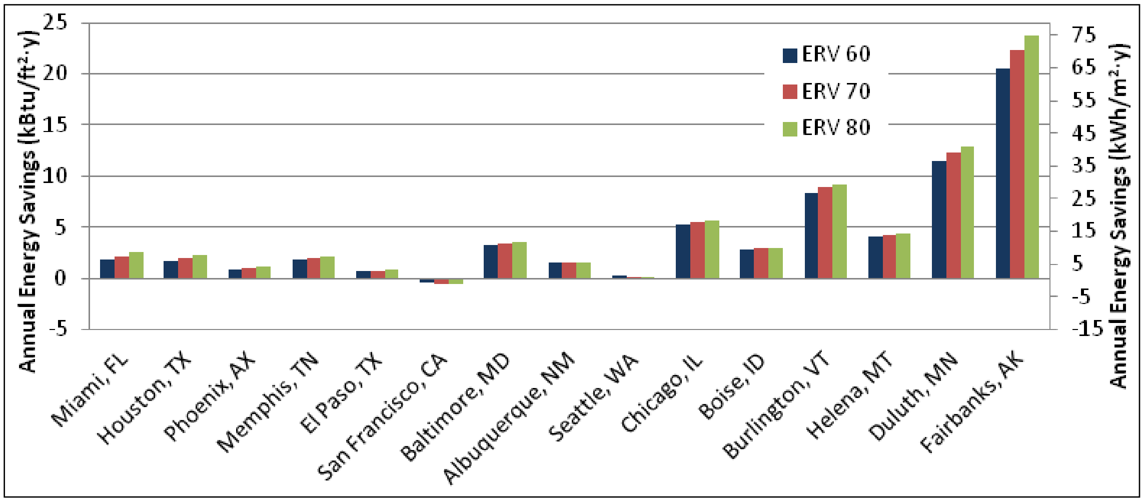

Figure 4.256. Annual energy savings for ERVs.

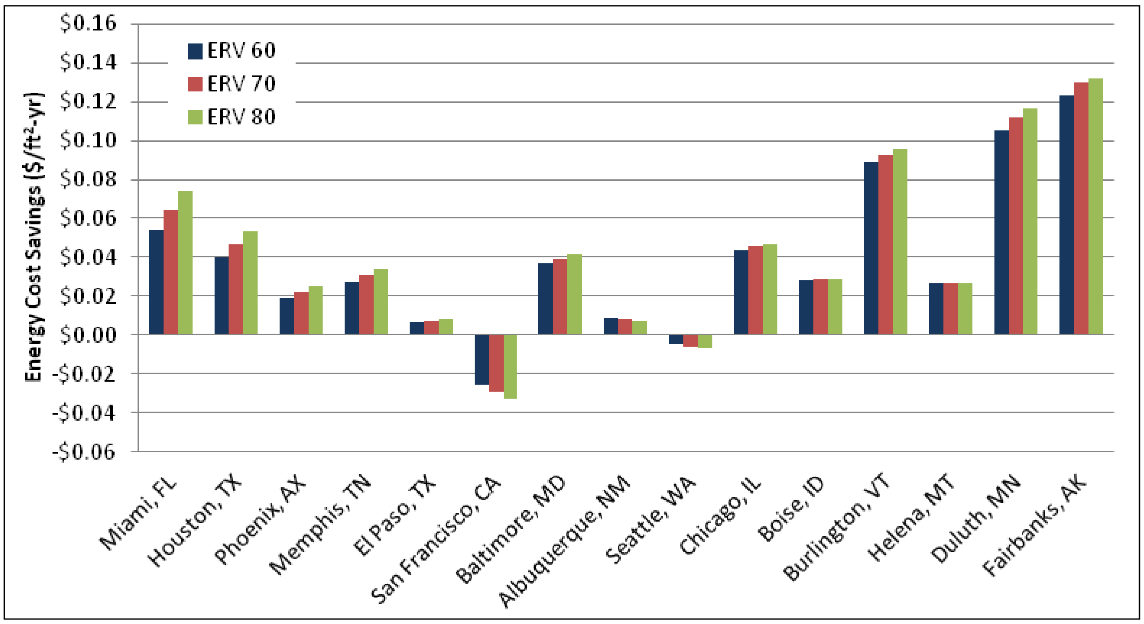

Figure 4.257. Annual energy cost savings for ERVs.

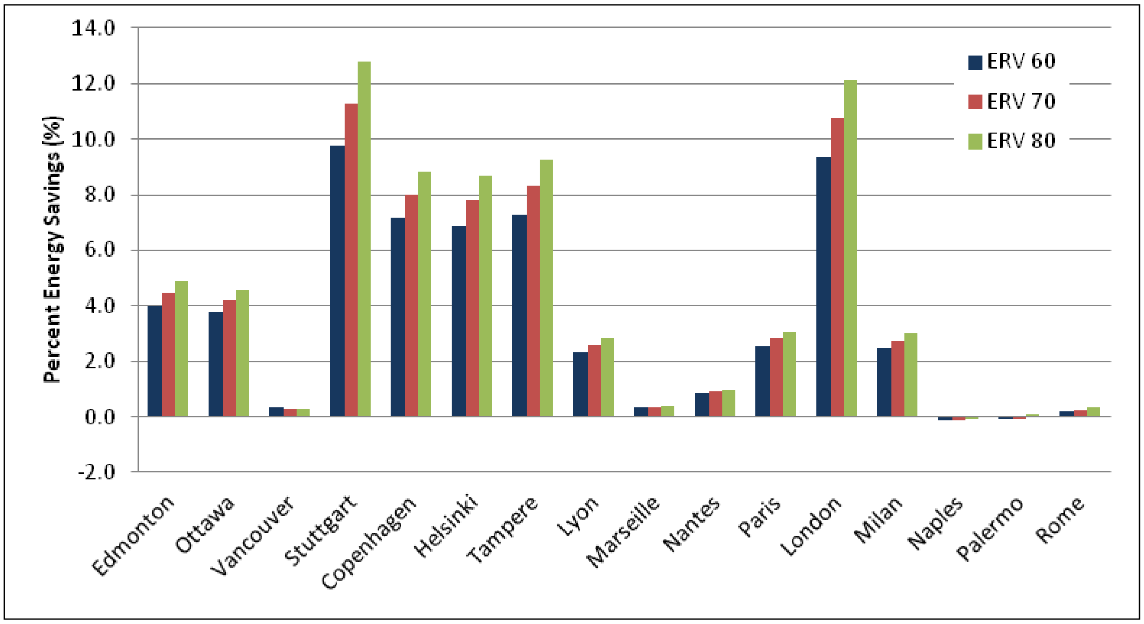

Figure 4.258. Percent energy savings for ERVs – International locations.

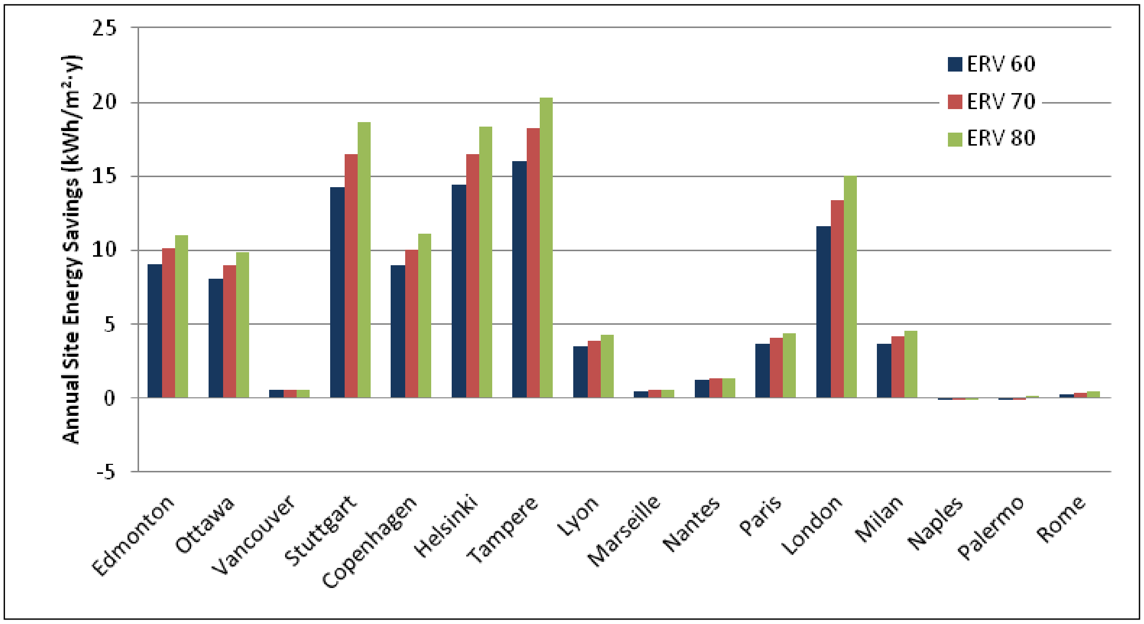

Figure 4.259. Annual energy savings for ERVs – International locations.

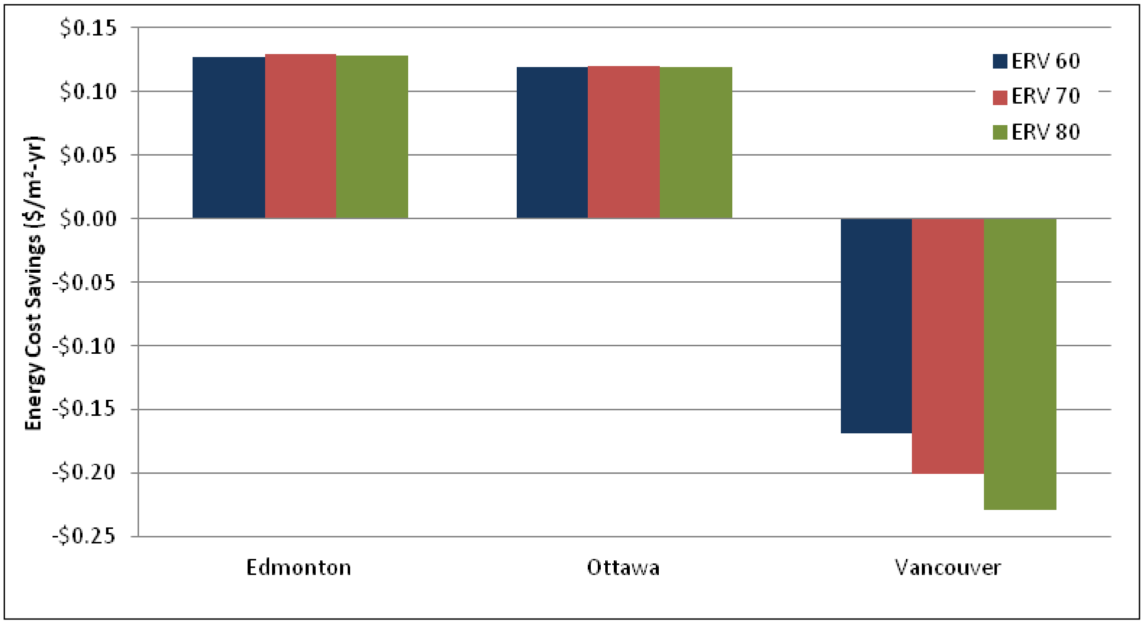

Figure 4.260. Annual energy cost savings for ERVs – Canadian locations.

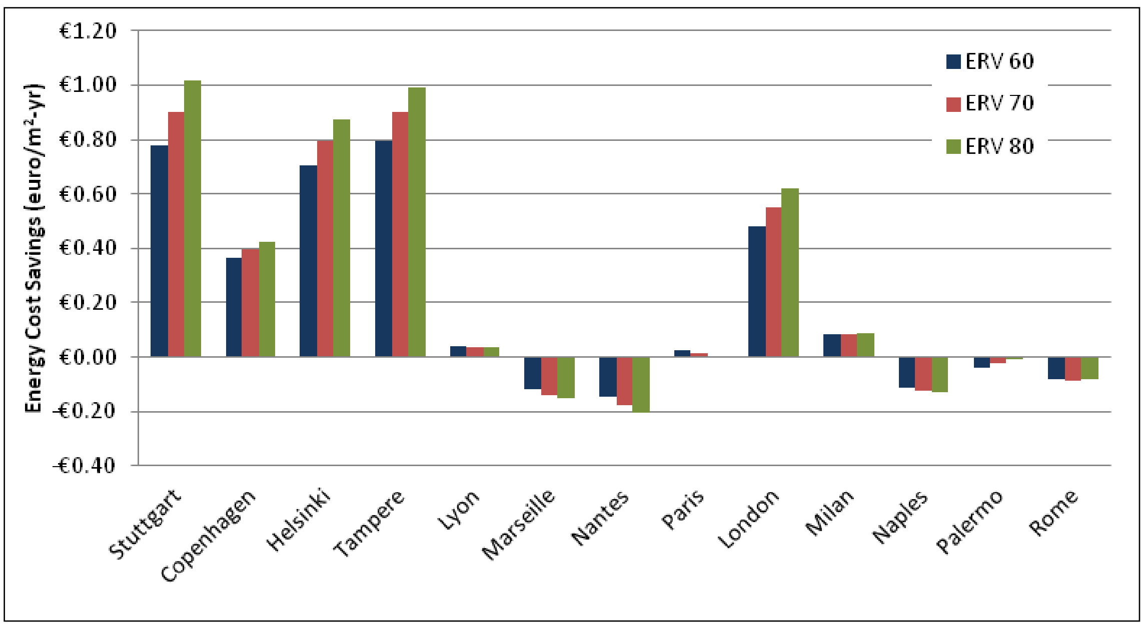

Figure 4.261. Annual energy cost savings for ERVs – European locations.

4.14 Indirect Evaporative Cooling

A retrofit with the addition of an indirect evaporative cooling (IDEC) system was simulated as a preconditioner to the outdoor air before mixing at the outdoor air mixing device. In this study, each air handler had its own evaporative cooler, although other configurations are certainly possible, such as a DOAS serving multiple zones. The systems were modeled using the outside air and the return air as the secondary air stream for the IDEC. The return-air strategy provided the best results, and these are the only results included in this report. The IDEC was bypassed when in heating mode to reduce the pressure drop on the fan. In order to maximize the benefit of the evaporative cooler, economizer controls where used to increase the outdoor air fraction under favorable conditions; however, the economizer control strategy was not optimized and it is believed that there are missed opportunities for economizing in some climates. Better economizing logic is expected to further improve the benefit of this technology in favorable locations. The model parameters are shown in Table 4.30 and a schematic of the main HVAC components of the evaporative cooling retrofit is shown in Figure 4.262.

It is possible to use the IDEC as a heat exchanger for heat recovery when in heating mode if return air is used as the secondary air stream. The energy savings for this arrangement was approximated by estimating the gas energy savings from the ERV simulations. It was assumed that the gas energy savings would be half of the gas energy savings from the ERV 60 (60% effective) simulations.

Table 4.30. IDEC model parameters.

Wet Bulb Effectiveness	Primary Air Pressure Drop in w.g. (Pa)	Secondary Air Pressure Drop in w.g. (Pa)	Fan Efficiency
0.75	0.75 (187)	0.5 (125)	0.5

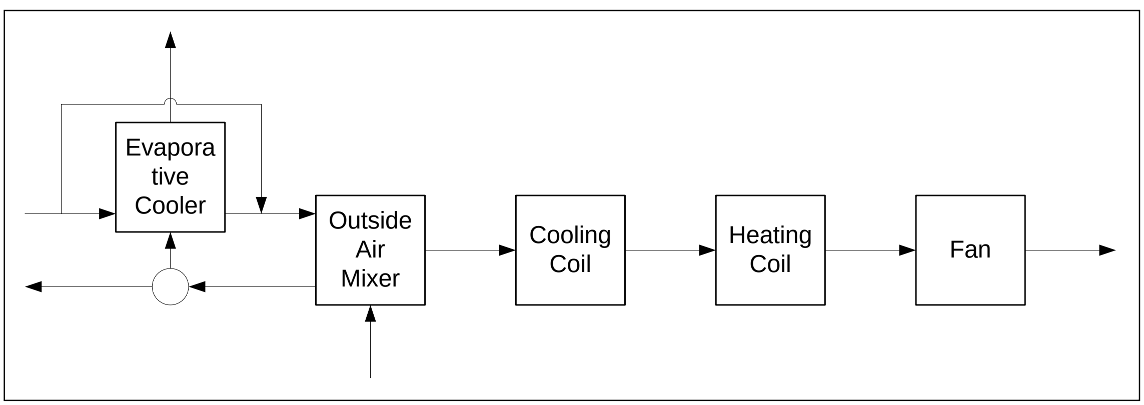

Figure 4.262. Schematic of the indirect evaporative cooling model (credit: Kyle Benne).

The results of the IDEC simulations are shown in Figures 4.263 through 4.269. The IDEC was found to offer energy savings in all climates except for Palermo Italy, and significant energy savings were achieved in the hot dry climates. The estimated performance of IDEC plus heat recovery in heating mode is also shown in these figures. The energy savings are favorable for the cold climates. Additional savings may be achievable with a system design specifically for this application. These results should be viewed as preliminary estimates and actual savings for specific projects may vary considerably depending on the building loads, systems, and application of the technology.

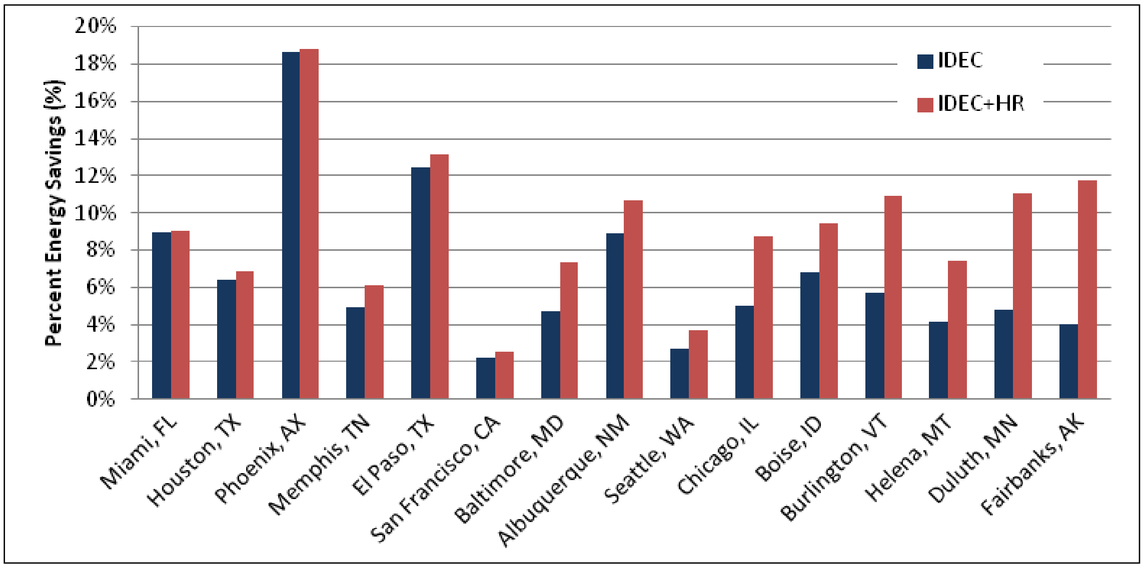

Figure 4.263. Percent energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery.

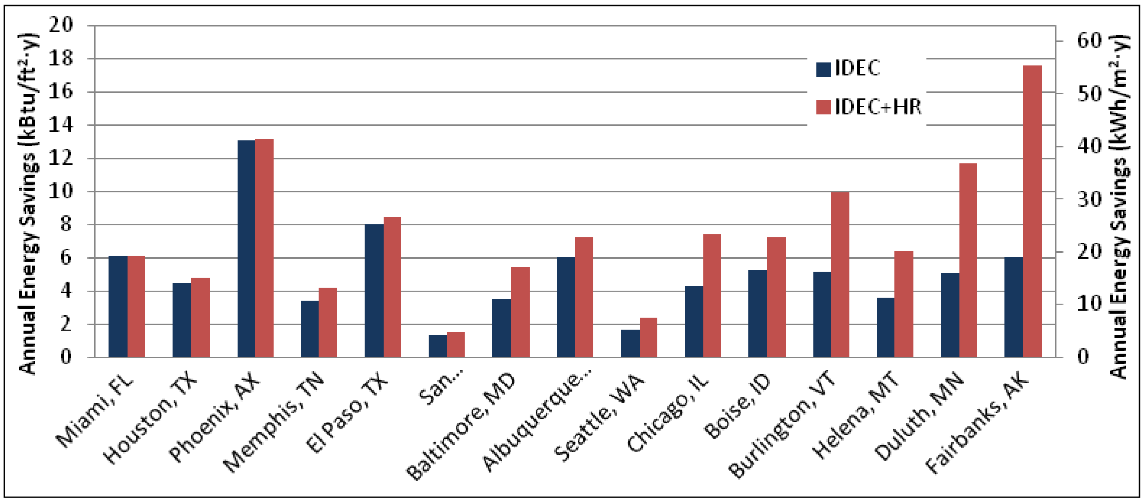

Figure 4.264. Annual energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery.

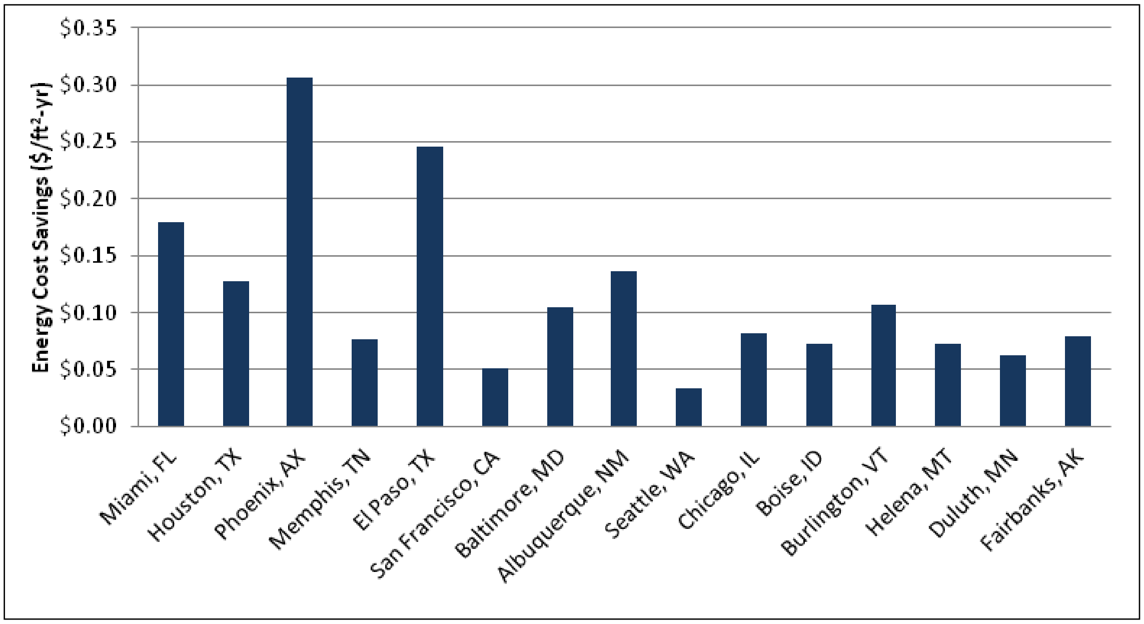

Figure 4.265. Annual energy cost savings for indirect evaporative cooling.

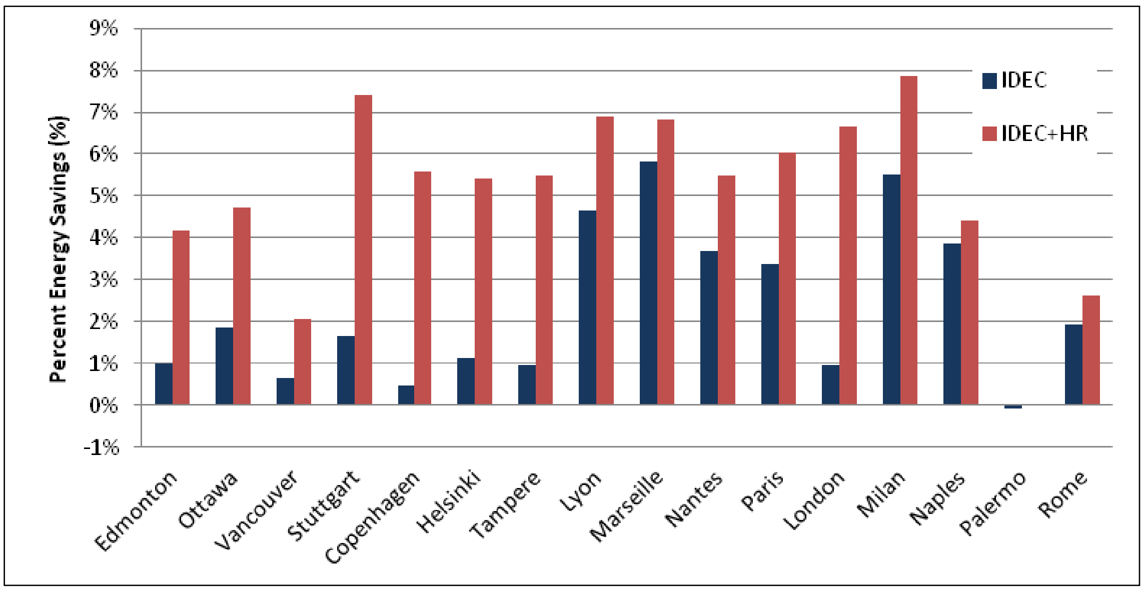

Figure 4.266. Percent energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery – International locations.

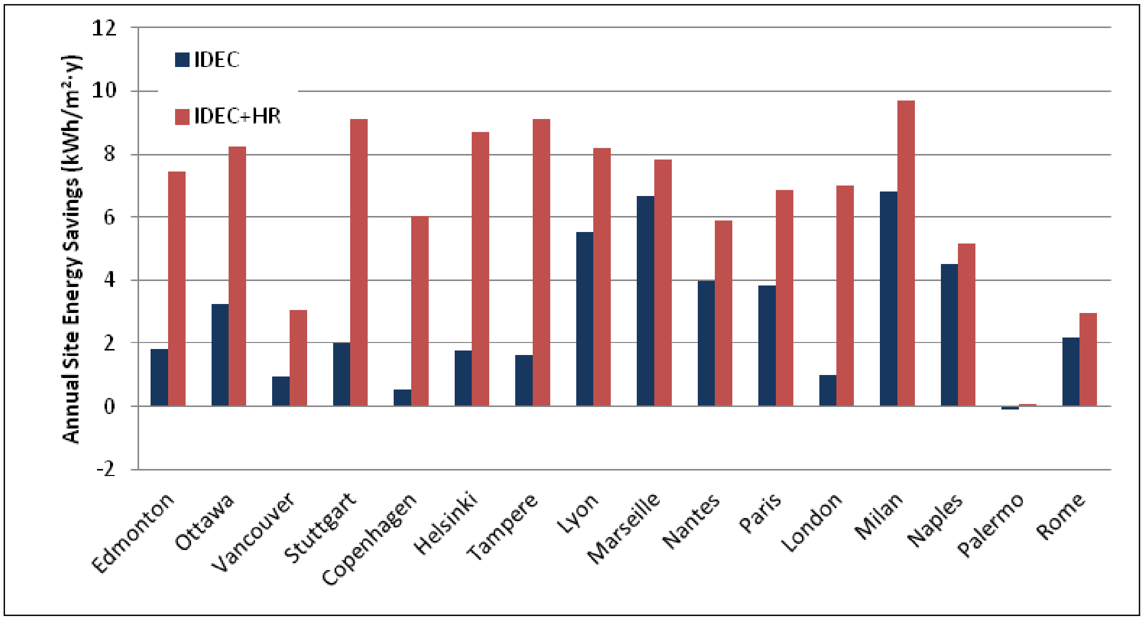

Figure 4.267. Annual energy savings for indirect evaporative cooling and indirect evaporative cooling with heat recovery – International locations.

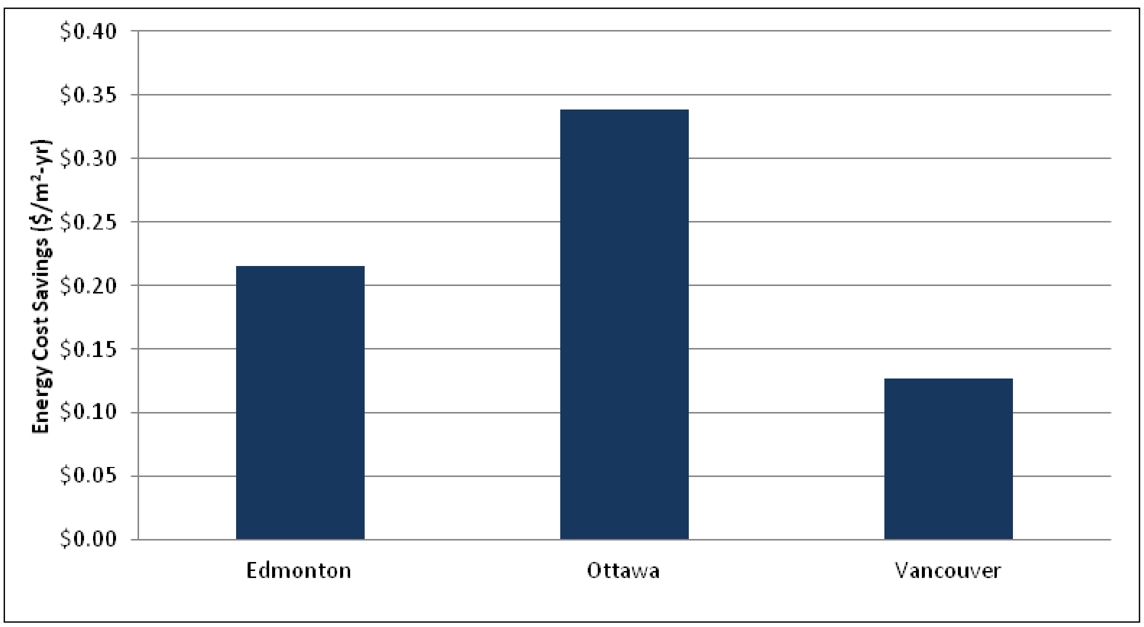

Figure 4.268. Annual energy cost savings for indirect evaporative cooling – Canadian locations.

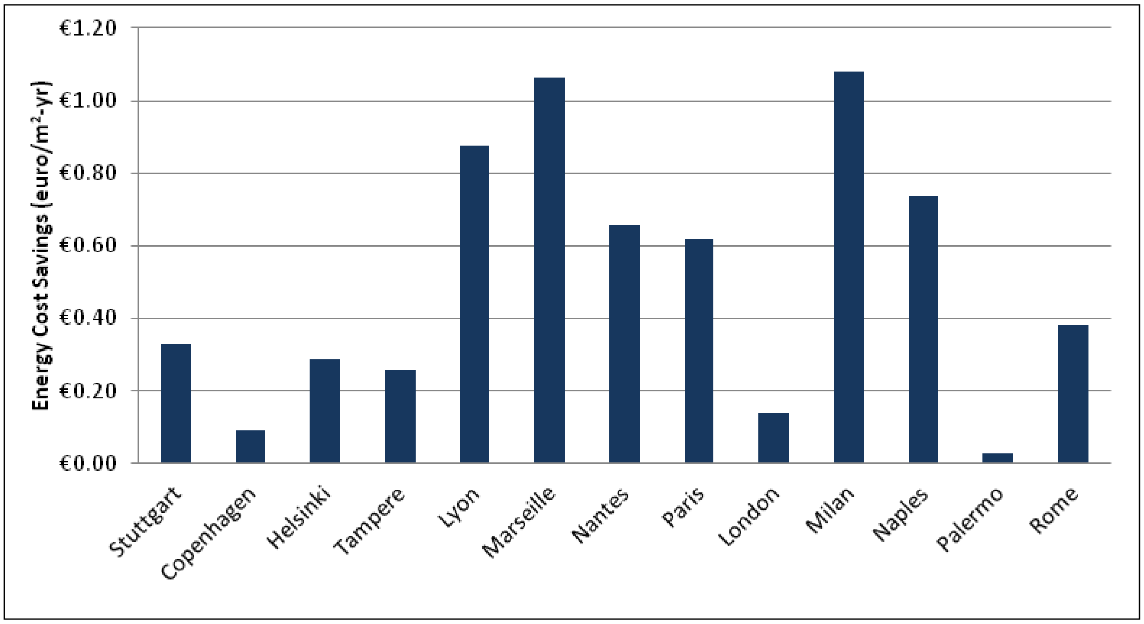

Figure 4.269. Annual energy cost savings for indirect evaporative cooling – International locations.

4.15 Hybrid Evaporative Cooling

A retrofit of a hybrid evaporative cooling system was simulated to understand the performance of a combined indirect and direct evaporative cooling system. The hybrid system consists of an indirect evaporative cooling component followed immediately by a direct evaporative cooling component. Aside from the additional component, this hybrid system was configured and controlled identically to the previous indirect evaporative cooling system. The direct component was modeled using a wet bulb effectiveness of 0.90.

The results for the hybrid evaporative cooling systems are shown in Figures 4.270 through 4.276. The same hot dry locations favorable for indirect evaporative cooling show potential with the hybrid system, but adding the direct component boosts the overall performance of the system by a few percent. However, high humidity is even more of a concern with direct evaporative cooling, and the direct evaporative section should be turned off when high humidity is of concern. The direct evaporative component may not be appropriate in humid locations.

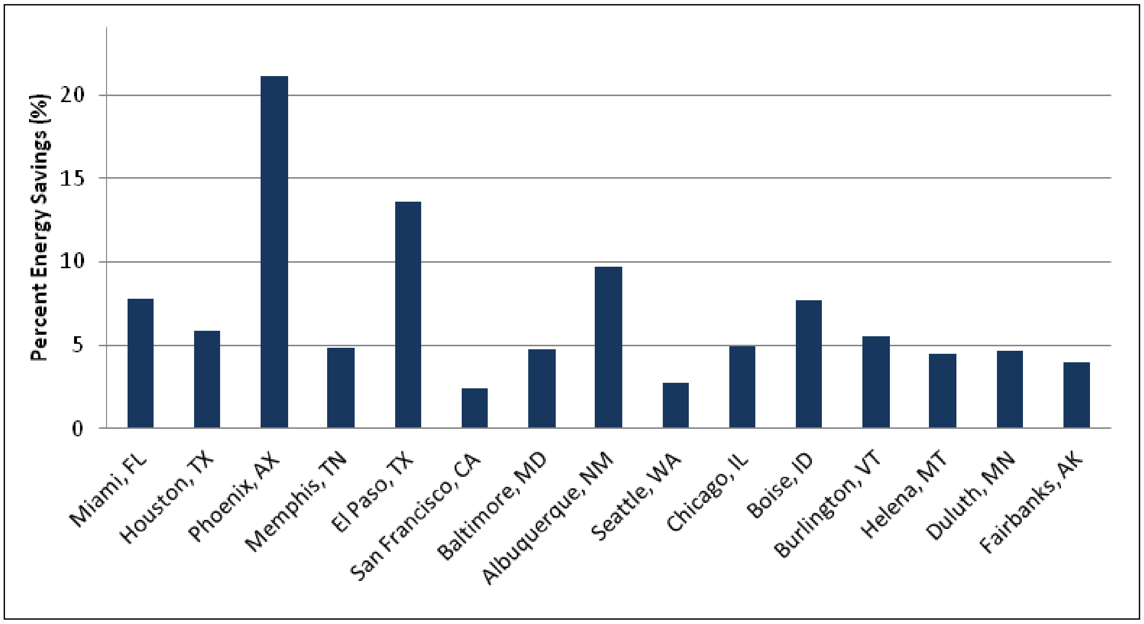

Figure 4.270. Percent energy savings for hybrid evaporative cooling.

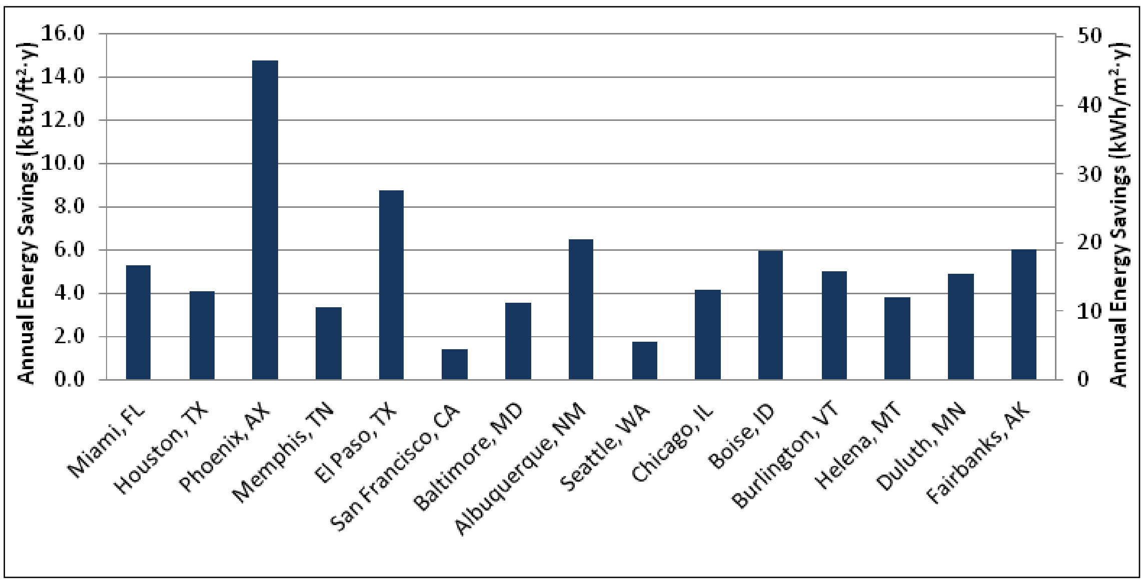

Figure 4.271. Annual energy savings for hybrid evaporative cooling.

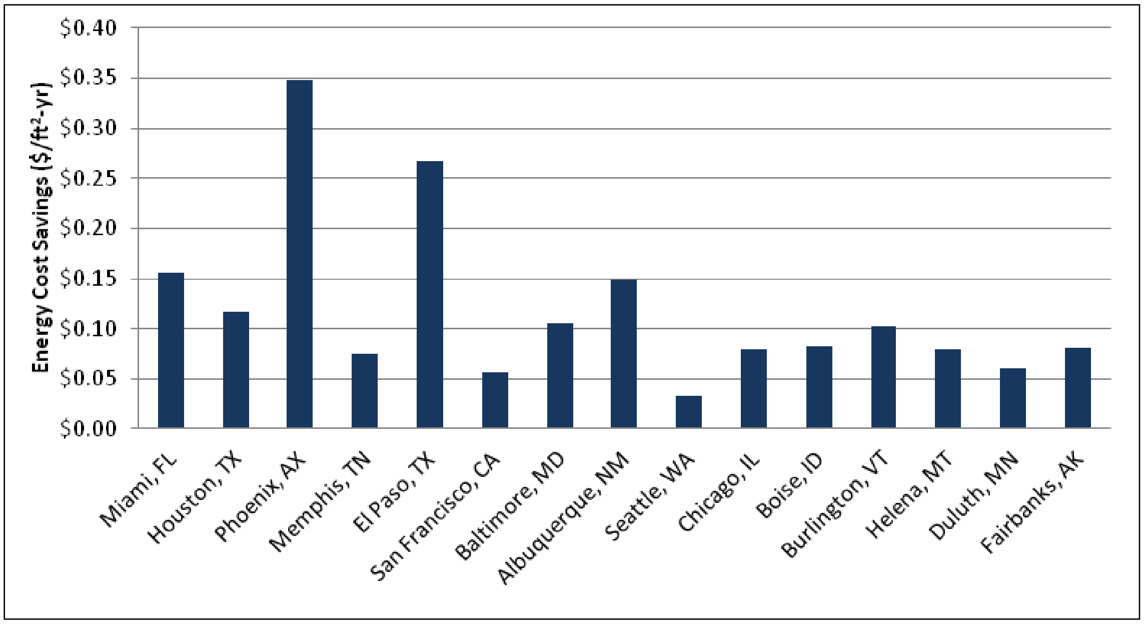

Figure 4.272. Annual energy cost savings for hybrid evaporative cooling.

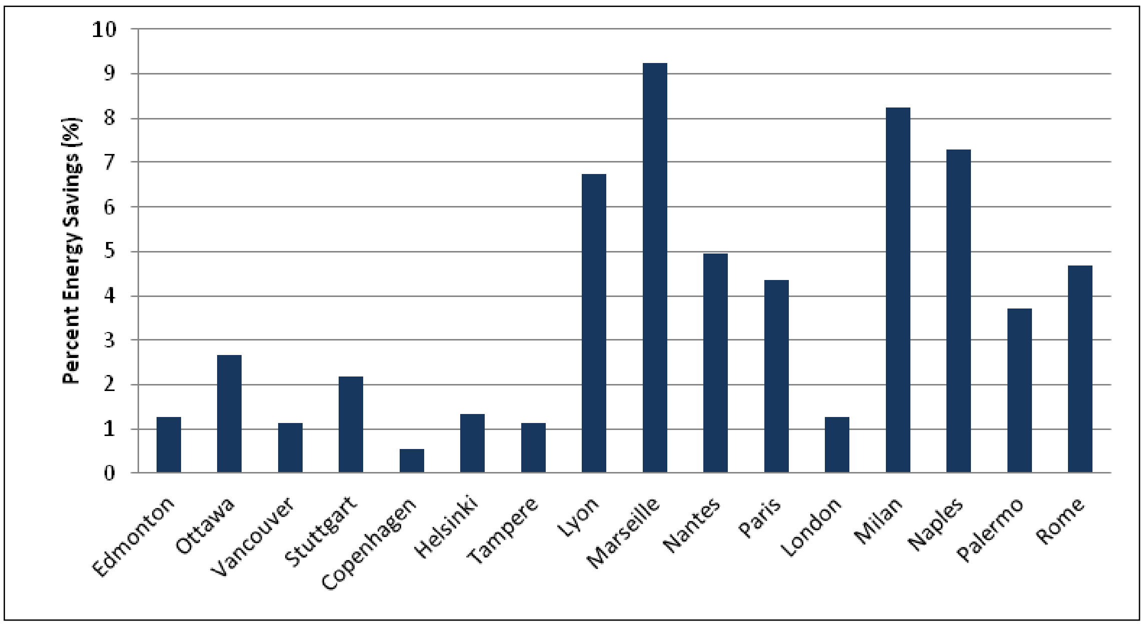

Figure 4.273. Percent energy savings for hybrid evaporative cooling – International locations.

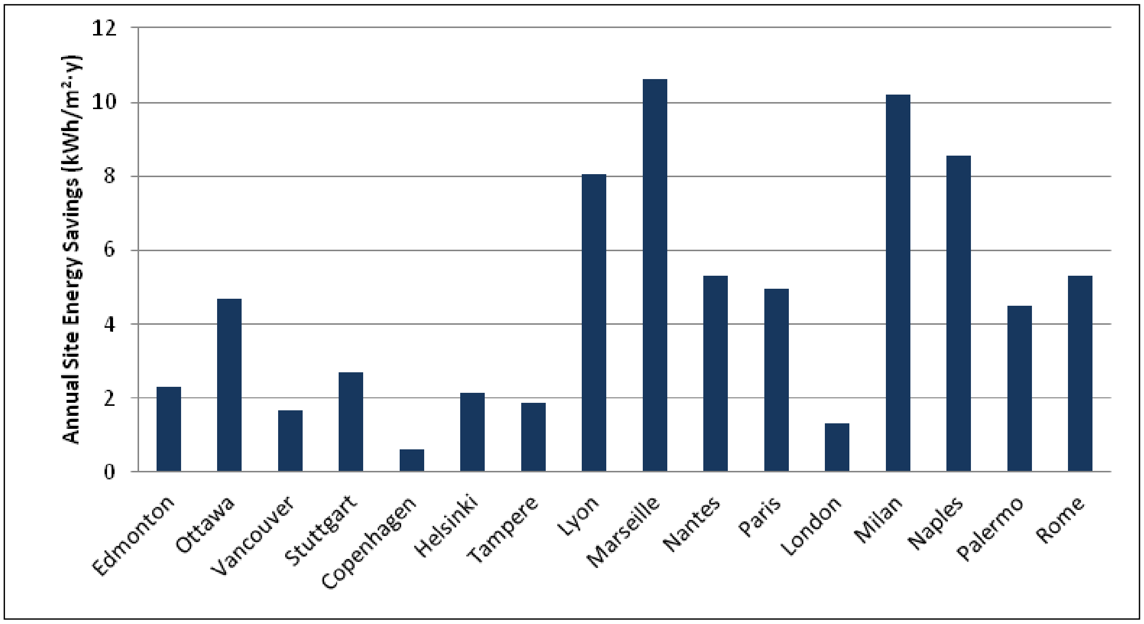

Figure 4.274. Annual energy savings for hybrid evaporative cooling – International locations.

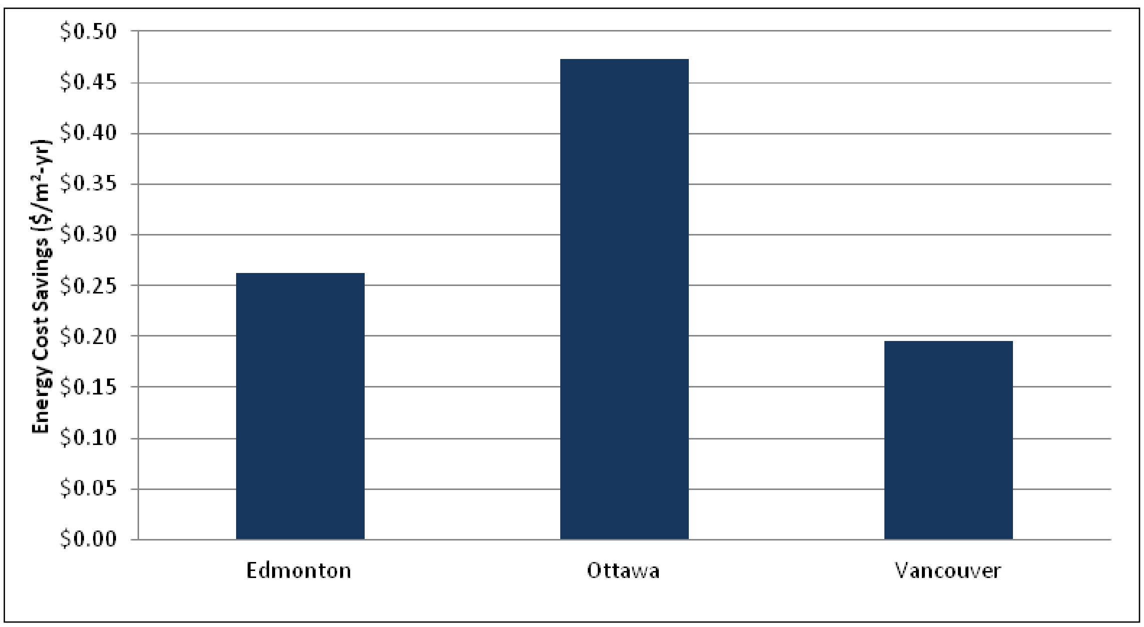

Figure 4.275. Annual energy cost savings for hybrid evaporative cooling – Canadian locations.

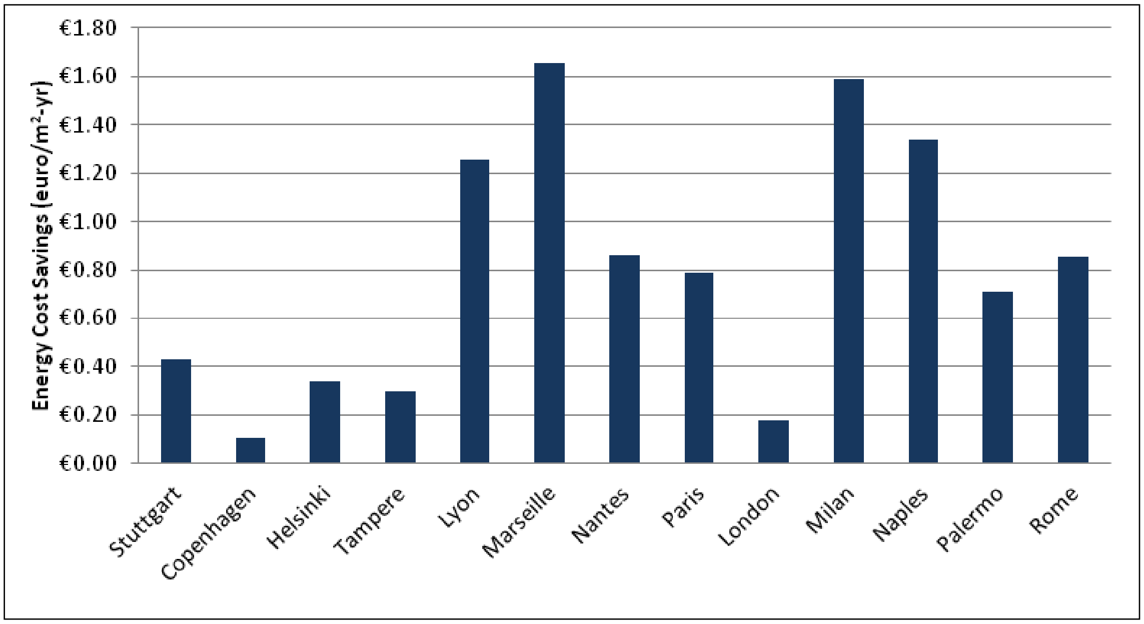

Figure 4.276. Annual energy cost savings for hybrid evaporative cooling – International locations.

4.16 DOAS with FCU

A DOAS in combination with a four-pipe FCU was simulated as a potential retrofit to the administration building. Only the U.S. locations were simulated with this technology. The DOAS consisted of central heating and cooling coils served by a gas-fired boiler and an air-cooled chiller. The DOAS is a constant volume system that provides the minimum ventilation air only during the office hours of operation. The DOAS does not provide economizer operation because of the constant speed fan and constant air flow rate. The supply-air temperature of the DOAS is governed by an outside air reset, which varied slightly with climate. The DOAS provides minimal heating through water coils supplied by a gas boiler and a small amount of cooling through a chilled water coil supplied by an air-cooled chiller. A key component of the DOAS is an energy recovery device between the outdoor air and relief air streams. The water loops feeding the DOAS are separate from the FCU system.

The results for this system are shown in Figures 4.277 through 4.279. The most significant energy savings were achieved in cold climates reflecting the benefit of the heat recovery. Energy savings in warm climates were modest and attributed to slightly better cooling efficiency of the chiller relative to the DX cooling system in the baseline. In all locations, there was an increase in electricity consumption from increased fan energy because of the increased pressure drop and a decrease in gas consumption because of the energy recovery component. The trade off of gas savings and electricity increase results in moderate energy cost savings in some locations and energy cost increases in other locations. Improved performance could be achieved with alternative system configurations and control strategies that minimizes the fan energy and optimizes the delivery of the space conditioning supply air. Systems design and operation for specific climates and applications are important for the best performance.

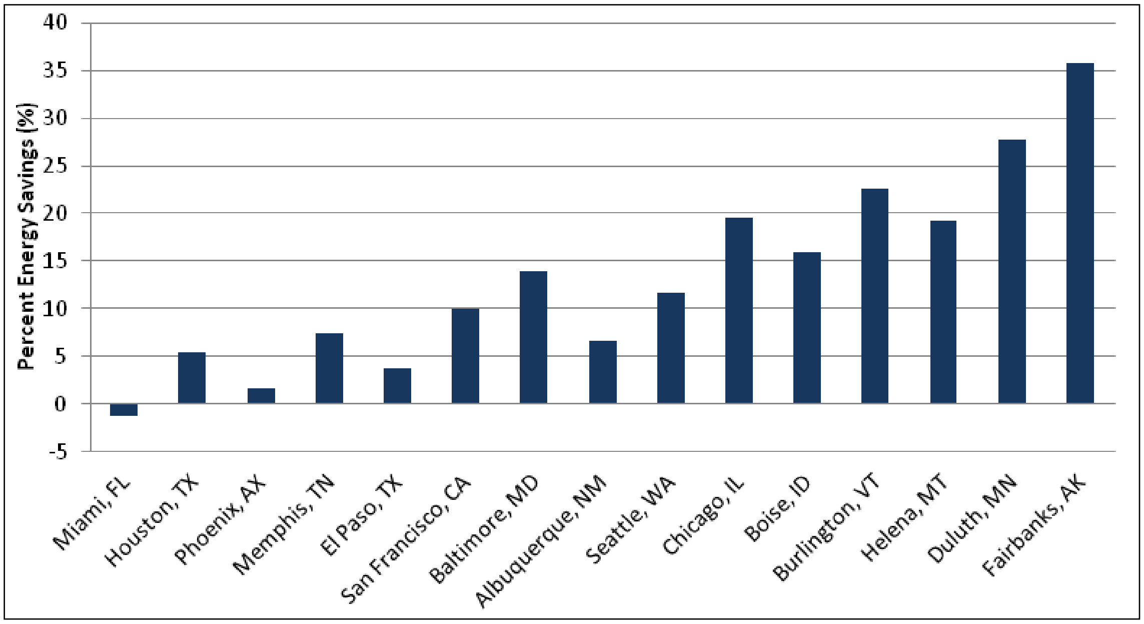

Figure 4.277. Percent energy savings for DOAS with FCU.

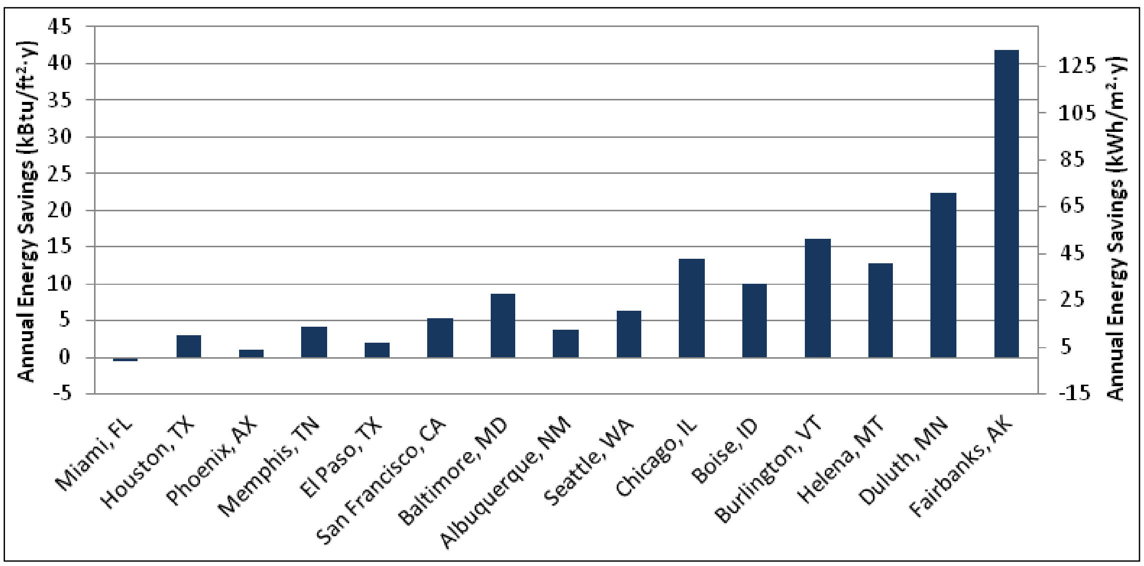

Figure 4.278. Annual energy savings for DOAS with FCU.

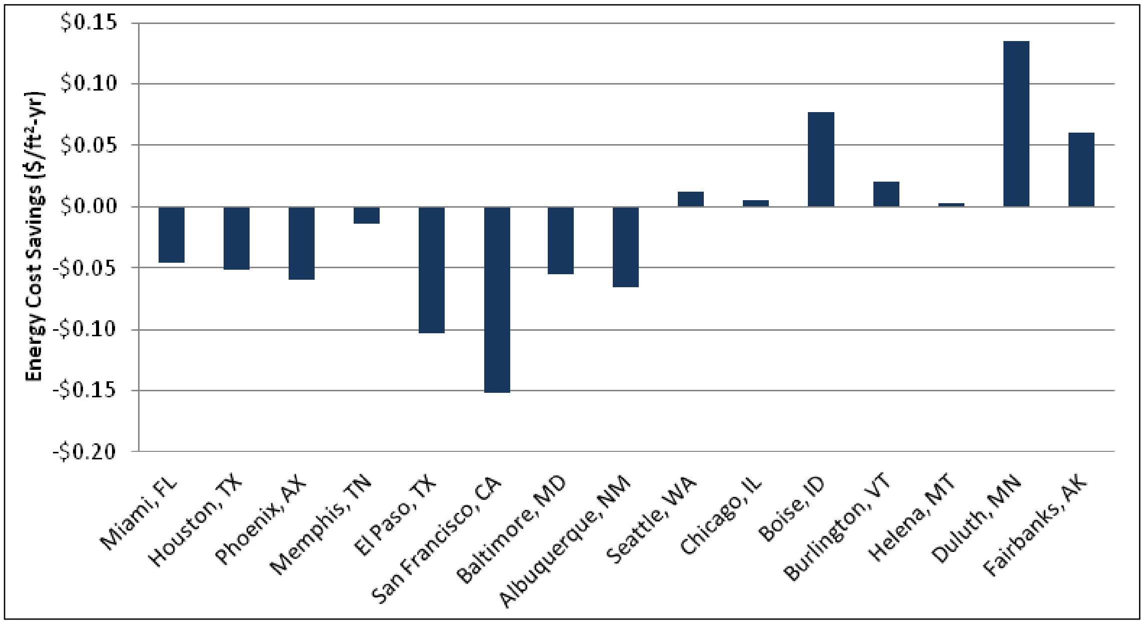

Figure 4.279. Annual energy cost savings for DOAS with FCU.

4.17 DOAS with Radiant Heating and Cooling

A DOAS in combination with radiant heating and cooling was evaluated. The DOAS of this retrofit was identical to the system model for the DOAS with FCU case. The radiant system consisted of actively heated and cooled panels embedded into the ceiling. The radiant panels are served by chilled water from a water-cooled chiller, and hot water from a gas boiler. The radiant system is controlled by mean radiant temperature instead of average space temperature as in the baseline system, which translates to a looser space temperature requirement while maintaining similar or perhaps even better comfort. The radiant system was controlled to turn off during cooling mode if the surface temperature reached the space dew point temperature to avoid condensation.

The results for this system are shown in Figures 4.280 through 4.286. Simulations show moderate energy savings in most U.S. climates, significant savings in the very cold climates, and increased energy consumption in three climates. The increased energy consumption is partially due to economizer operation as explained below and probably also due to a non-optimal control strategy for these climates. The results for the non-U.S. locations show significant energy savings in most climates. There are two driving factors for the observed energy savings of the radiant system retrofit. One is that there is reduced fan energy for the DOAS system with radiant heating and cooling as compared to the baseline system. Second, the mean radiant temperature control of the radiant system allowed a wider variation in the dry bulb temperature. Improved performance is possible with optimal system design and control for specific building designs and locations.

One drawback of the DOAS and radiant system as it was modeled is related to economizing. The baseline VAV system has an air-side economizer; however, the retrofit DOAS with a constant speed fan does not economize. The retrofit therefore shows greatly reduced performance in good economizing climates, a drawback that could be at least partly avoided by implementing a water side economizer to take full advantage of the higher chilled water temperature requirements of the radiant system compared to the baseline VAV system. This analysis did not attempt to implement a water side economizer; however, buildings being designed in good economizing climates should consider one, if implementing a radiant system.

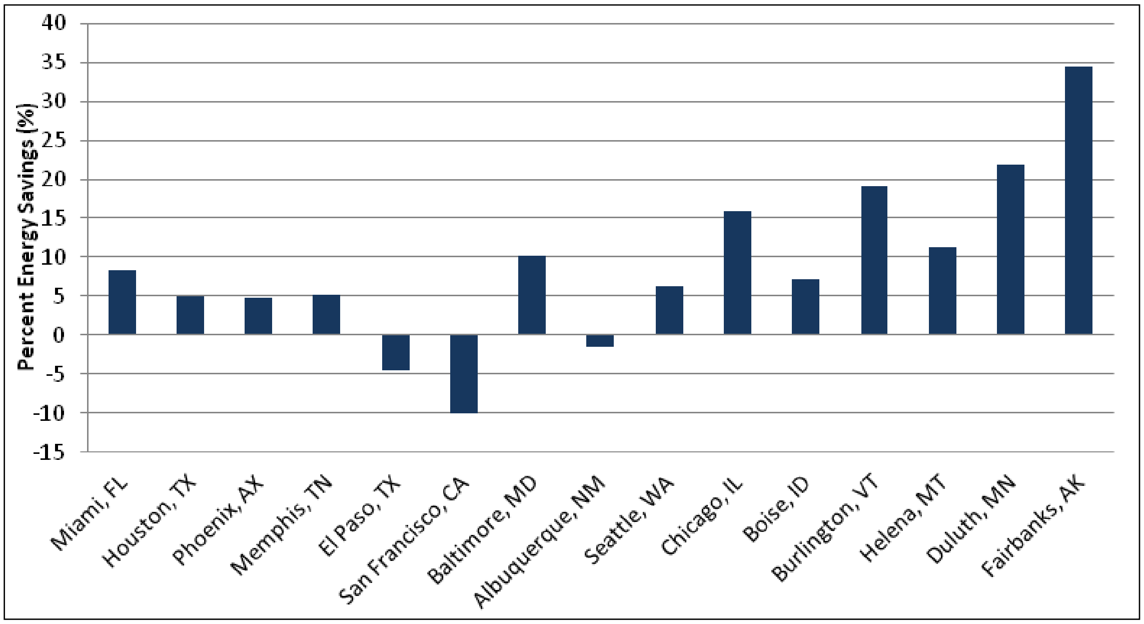

Figure 4.280. Percent energy savings for radiant system.

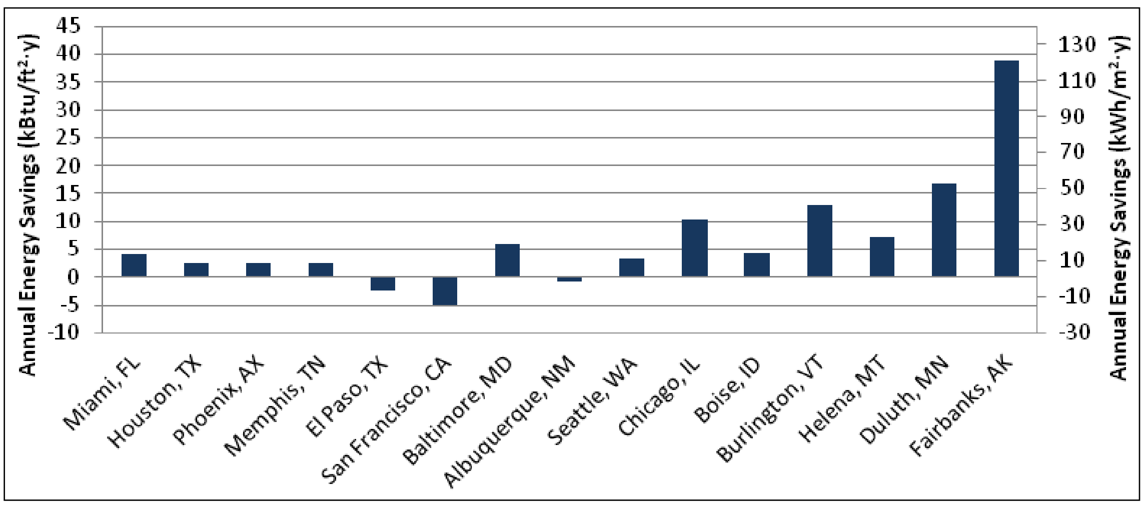

Figure 4.281. Annual energy savings for radiant system.

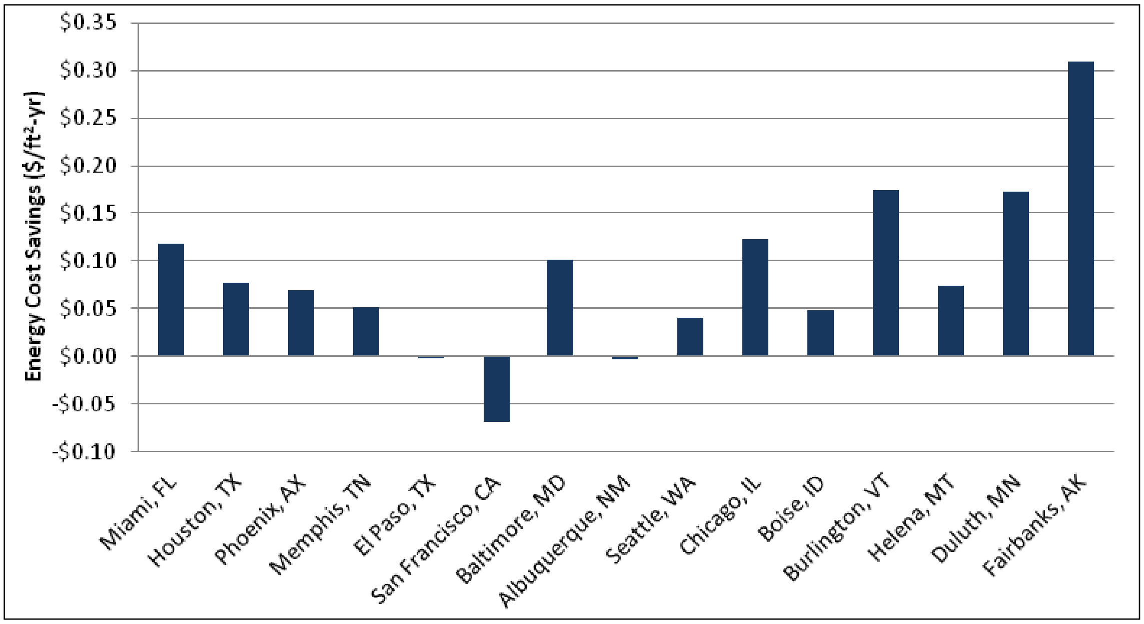

Figure 4.282. Annual energy cost savings for radiant system.

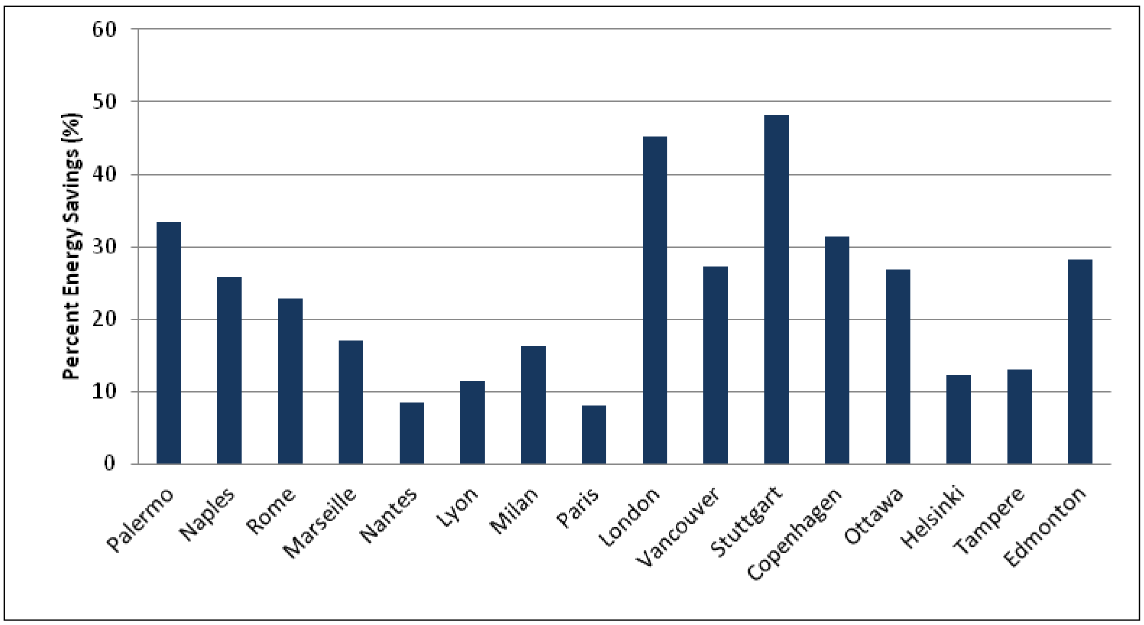

Figure 4.283. Percent energy savings for radiant system – International locations.

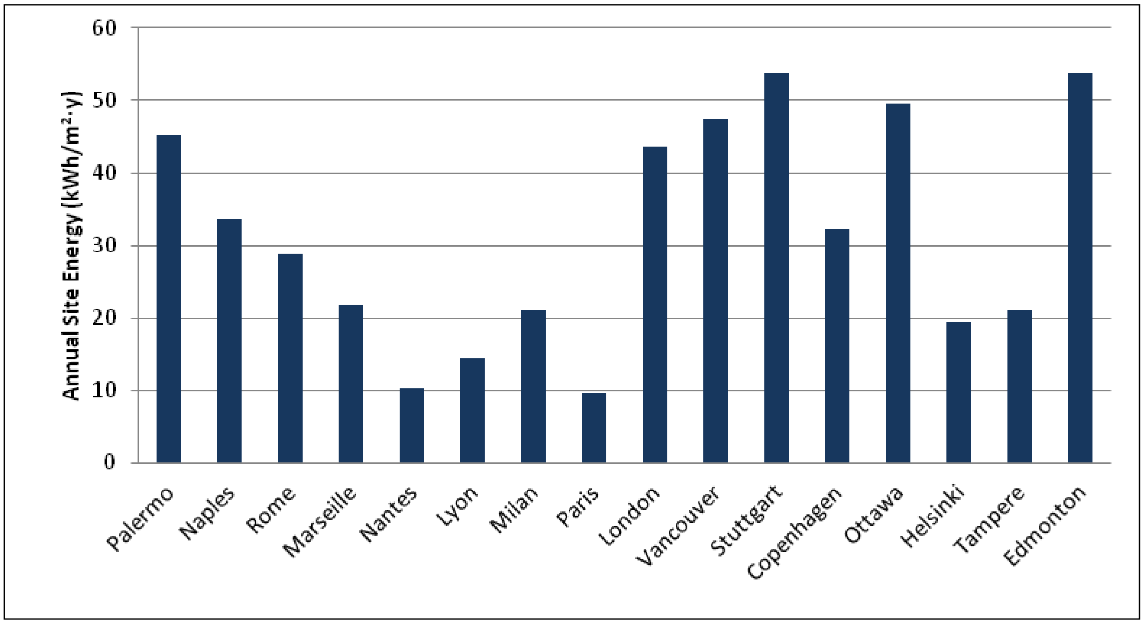

Figure 4.284. Annual energy savings for radiant system – International locations.

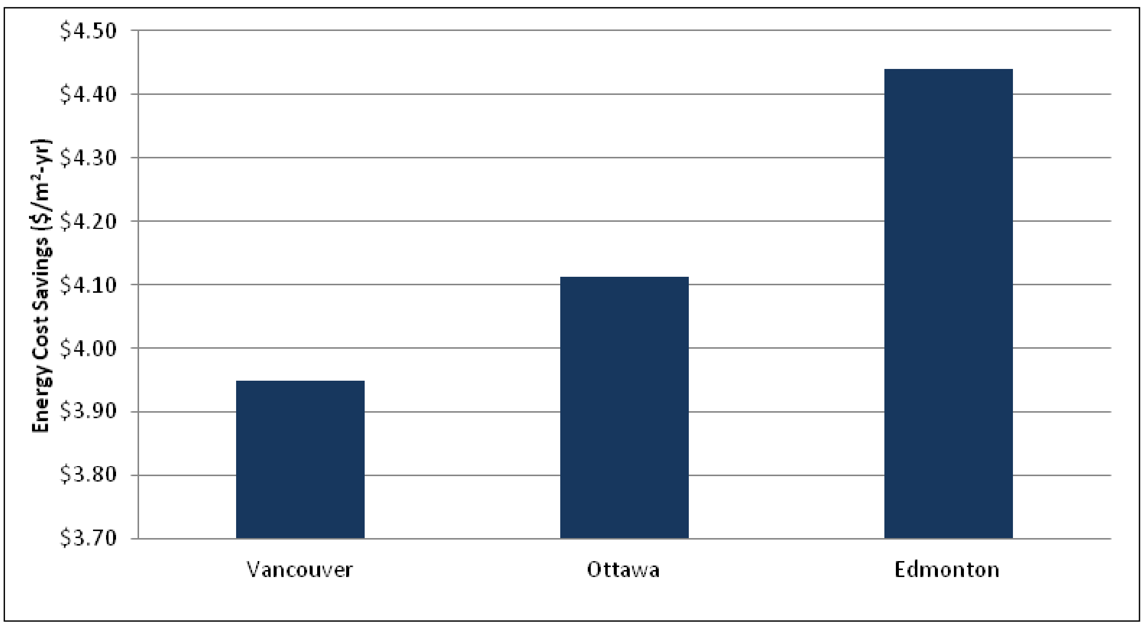

Figure 4.285. Annual energy cost savings for radiant system – Canadian locations.

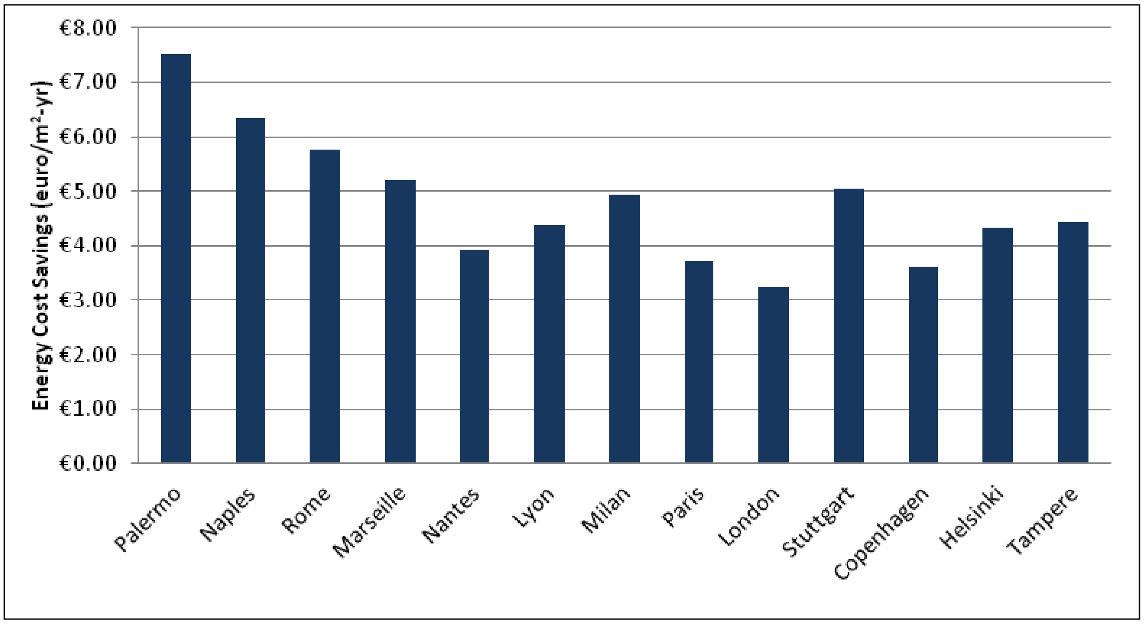

Figure 4.286. Annual energy cost savings for radiant system – International locations.

4.18 Ground Source Heat Pumps

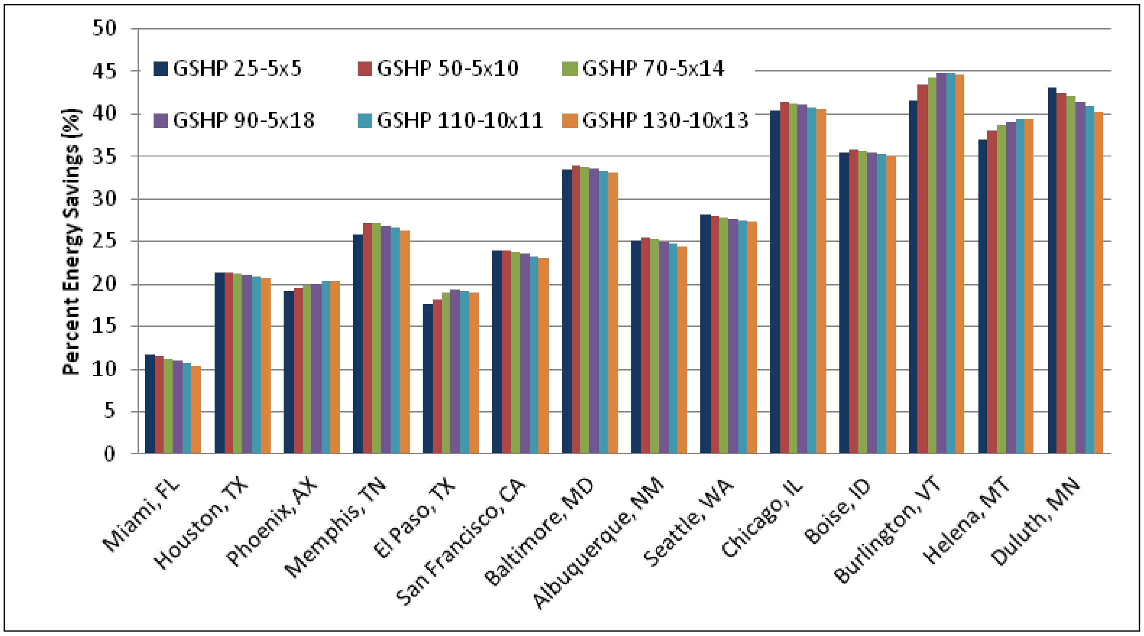

Figure 4.287. Percent energy savings for GSHPs.

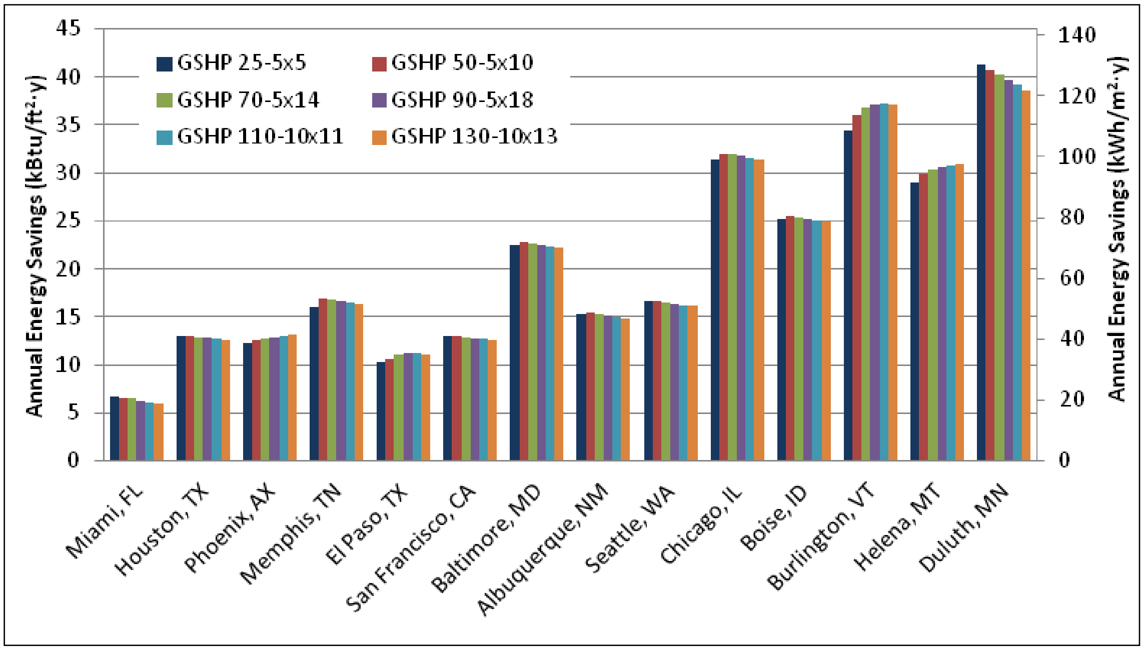

Figure 4.288. Annual energy savings for GSHPs.

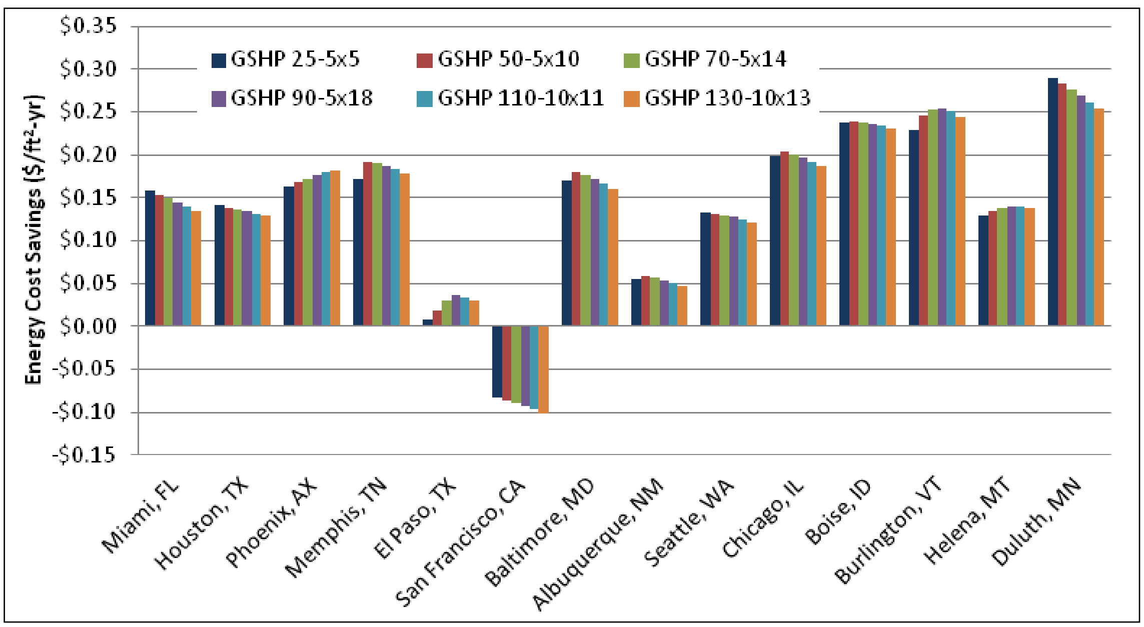

Figure 4.289. Annual energy cost savings for GSHPs.

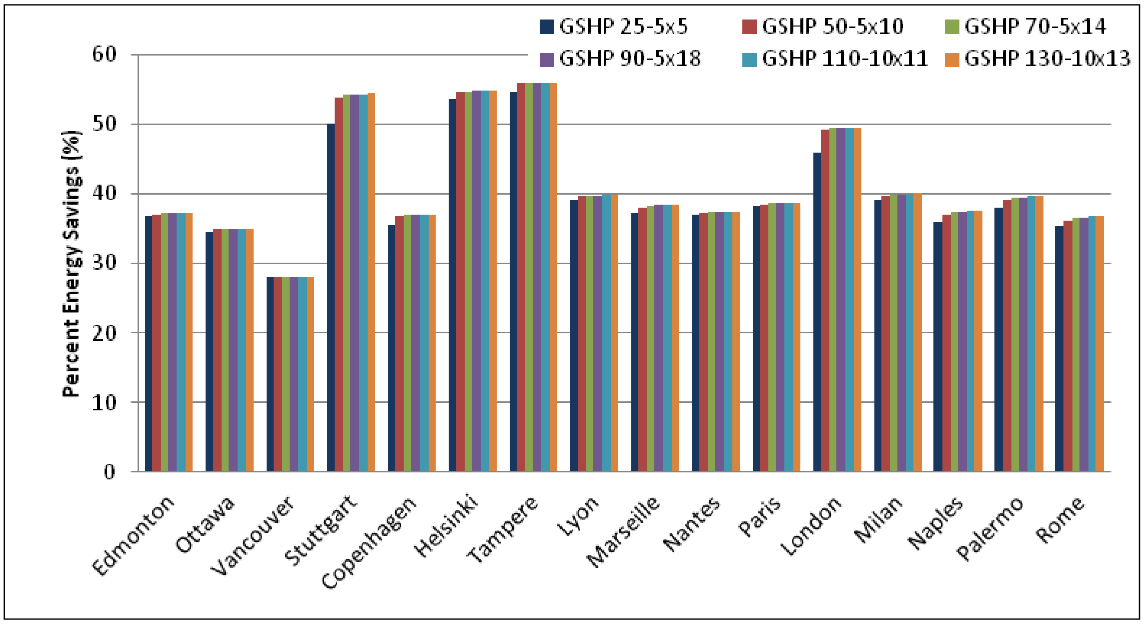

Figure 4.290. Percent energy savings for GSHPs – International locations.

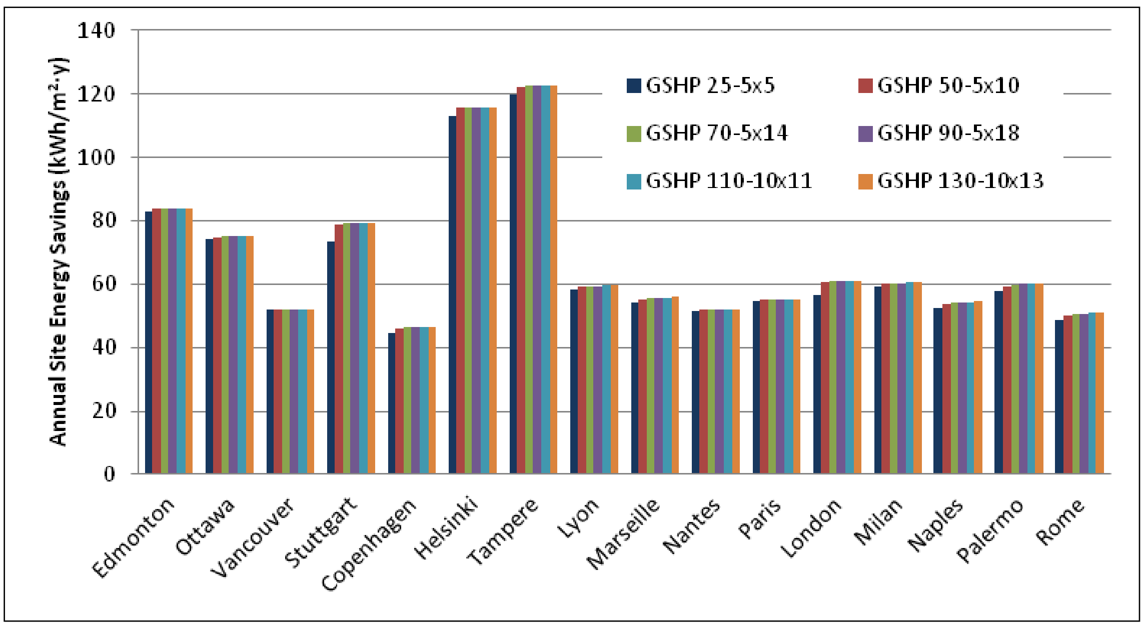

Figure 4.291. Annual energy savings for GSHPs – International locations.

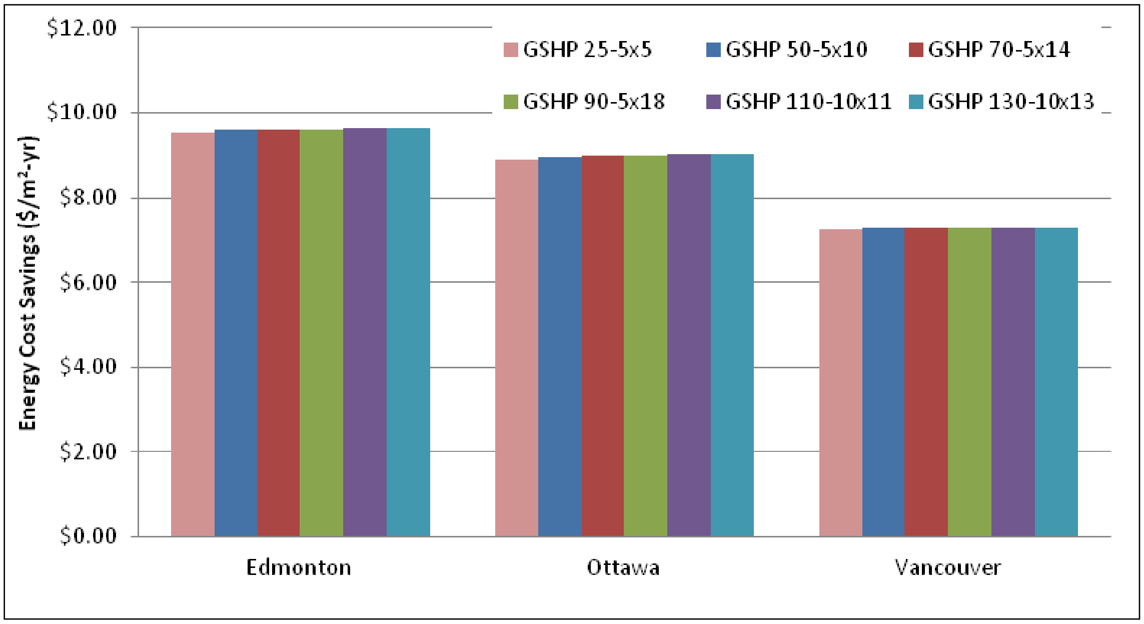

Figure 4.292. Annual energy cost savings for GSHPs – Canadian locations.

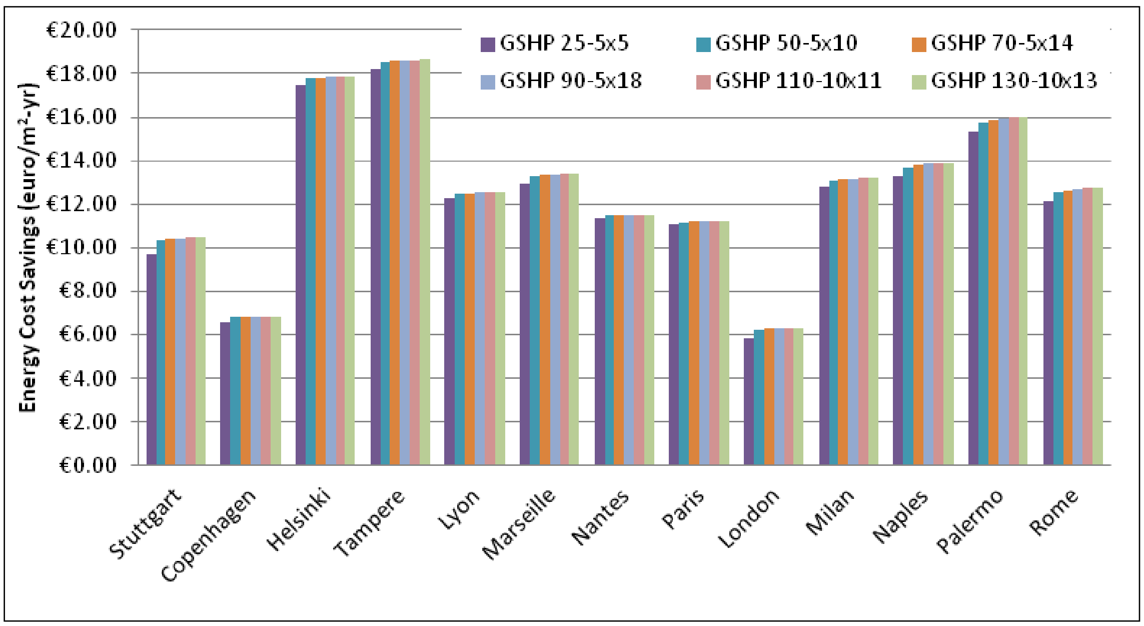

Figure 4.293. Annual energy cost savings for GSHPs – European locations.

4.19 Reheat Using Condenser Waste Heat

Cooling system condenser waste heat recovery was evaluated for both the U.S. locations and the international locations. Different approaches were taken for the U.S. and international locations because the systems types are different.

The U.S. administrative building has multizone air handlers served by central heating and cooling plants. The central air handlers cool or heat to a seasonal deck temperature and reheat at the zone terminals if necessary to trim to the individual zone loads. This retrofit provides waste heat from the chiller to the hot water plant serving the heating coils as required. Modeling this technology directly in EnergyPlus is possible; however, developing the model and control strategy is particularly cumbersome. To avoid this burden, the effect of the proposed retrofit was analyzed using a post processing technique. Hourly data of the chiller waste heat, and boiler energy consumption were reported by the baseline EnergyPlus simulation. The effect of heat recovery was quantified by subtracting available condenser waste heat from the boiler energy consumption at a single time step, and then integrating over time.

The existing international administrative facility consists of packaged single zone systems that do not actively control humidity and never use reheat. In this study, the benefit of retrofitting the building with a condenser waste heat-recovery system was evaluated by first creating a new baseline point of comparison with a system that used humidistats and conventional reheat. The new systems use more energy due to increased cooling and reheat; however, buildings in humid climates were also much drier. By introducing a new baseline, there is a fair comparison for the condenser waste heat-recovery system.

The results for this system are shown in Figures 4.294 through 4.300. The simulations show small energy savings in all U.S. climates.

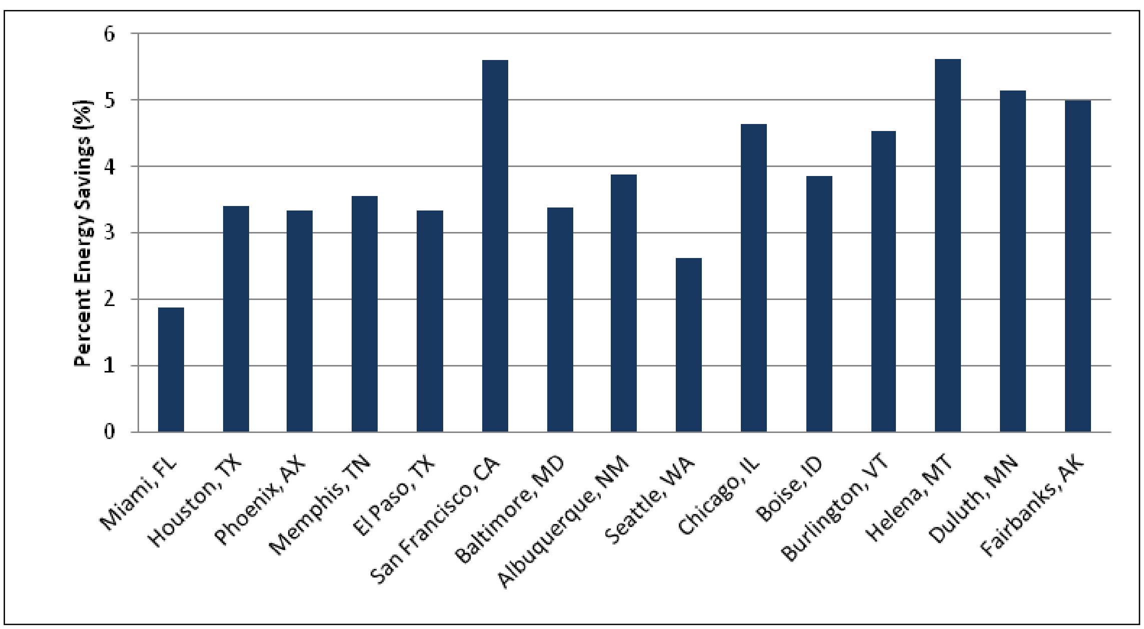

Figure 4.294. Percent energy savings for condenser waste heat recovery.

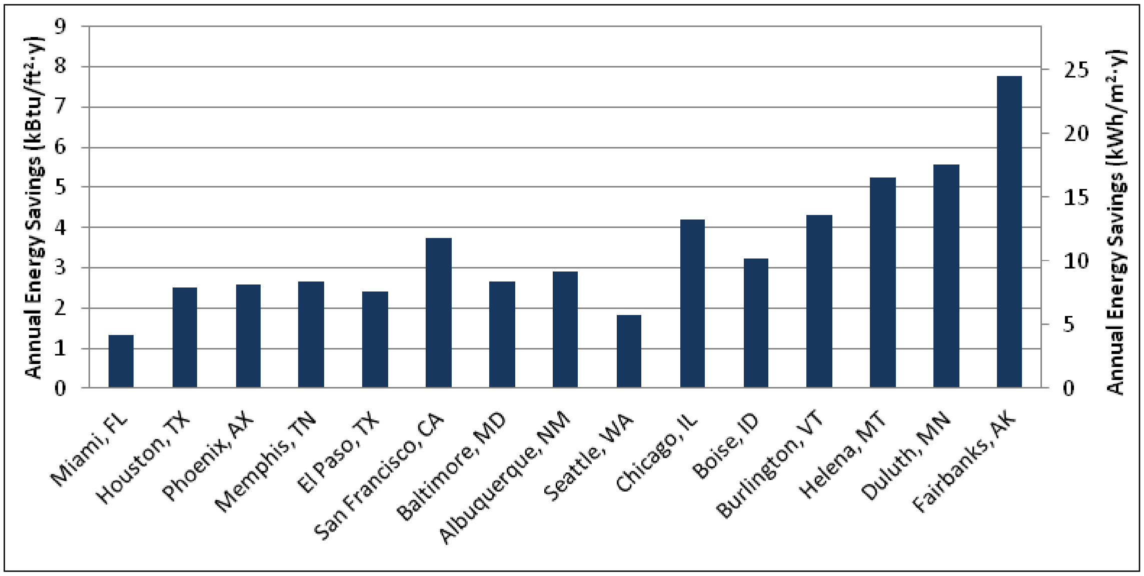

Figure 4.295. Annual energy savings for condenser waste heat recovery.

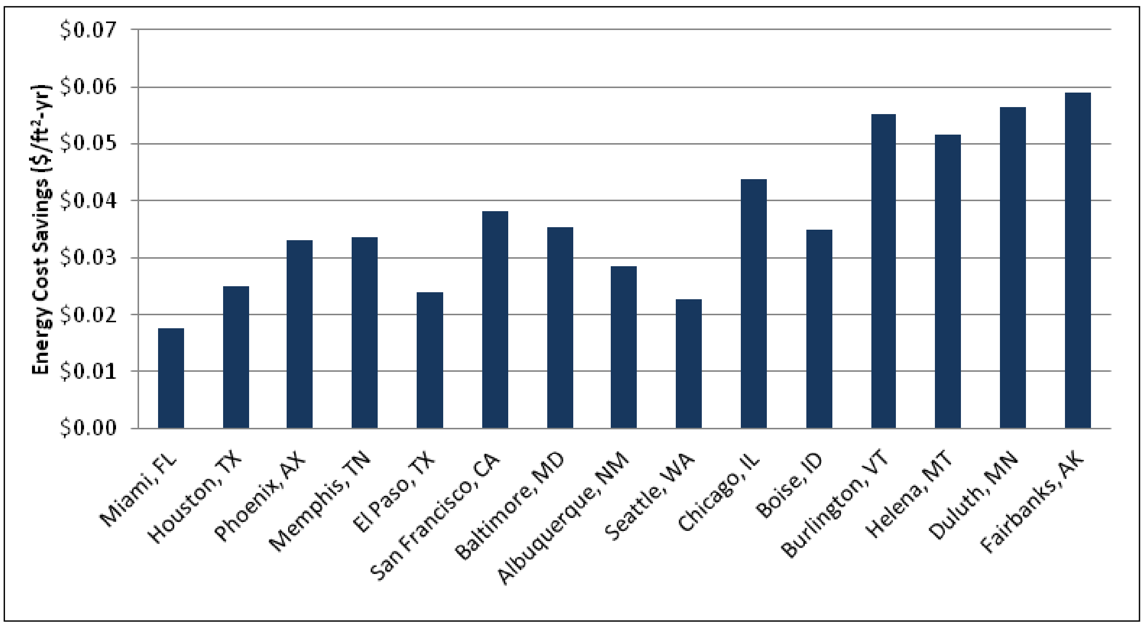

Figure 4.296. Annual energy cost savings for condenser waste heat recovery.

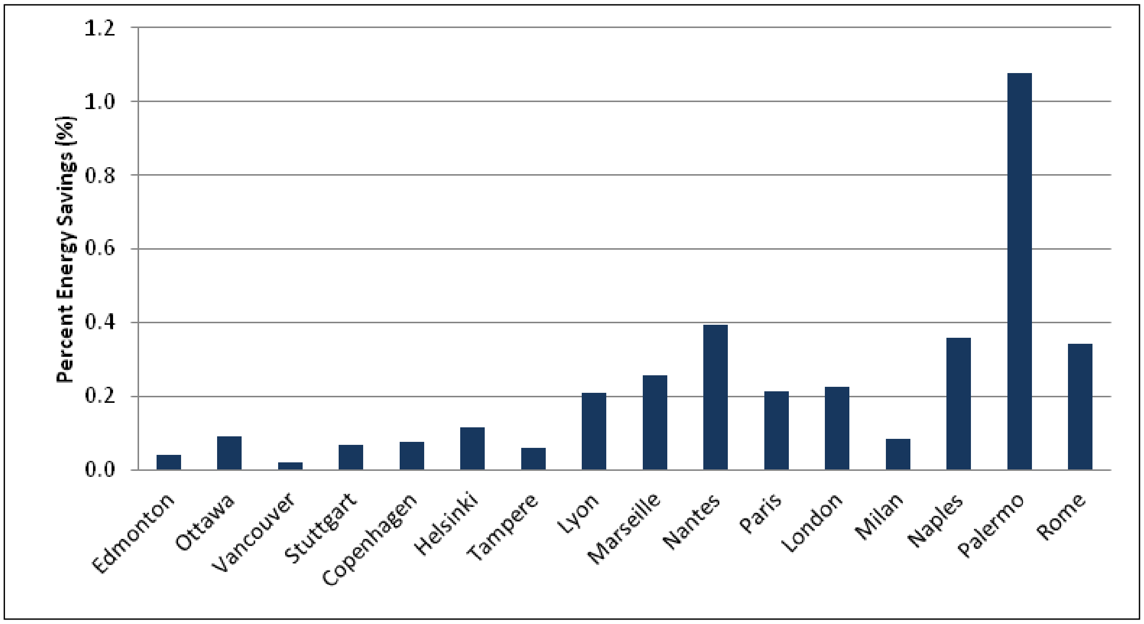

Figure 4.297. Percent energy savings for condenser waste heat recovery – International locations.

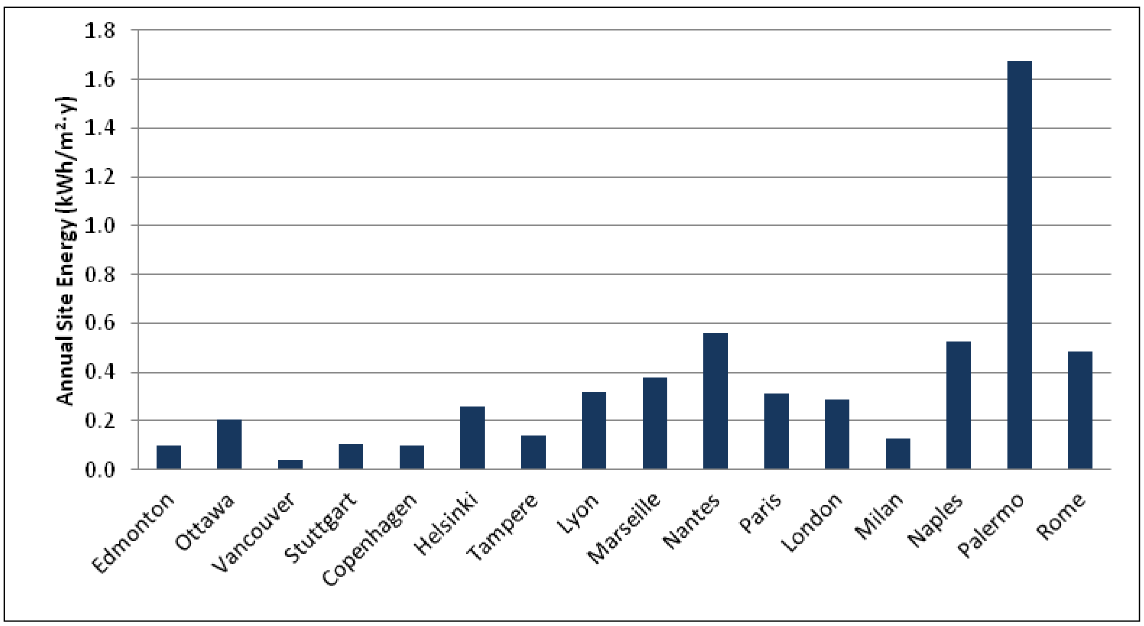

Figure 4.298. Annual energy savings for condenser waste heat recovery – International locations.

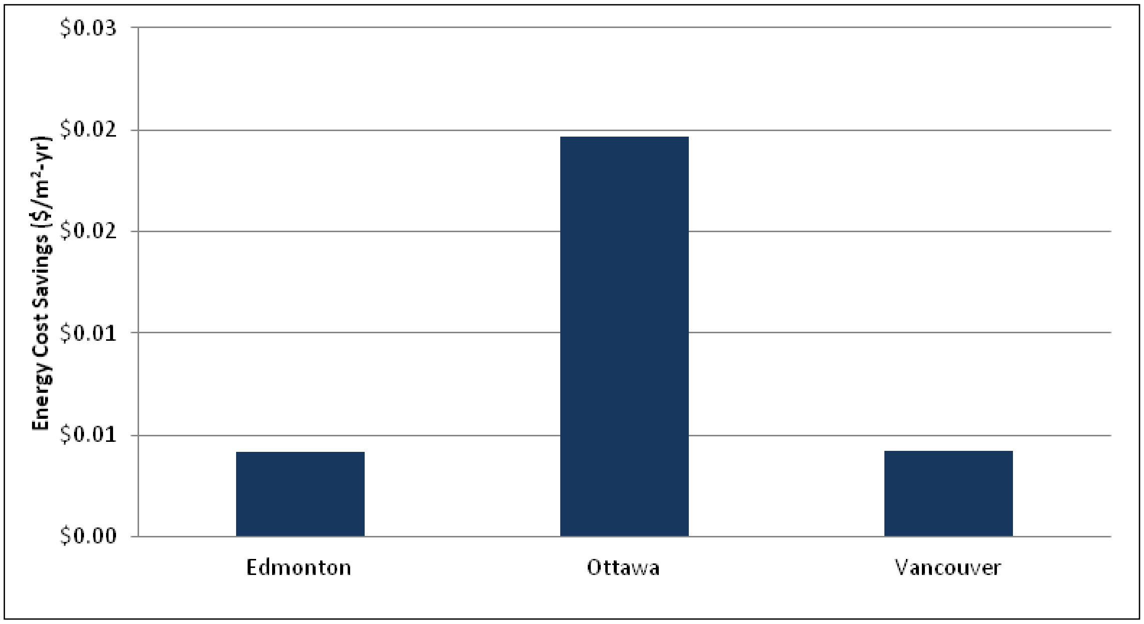

Figure 4.299. Annual energy cost savings for condenser waste heat recovery – Canadian locations.

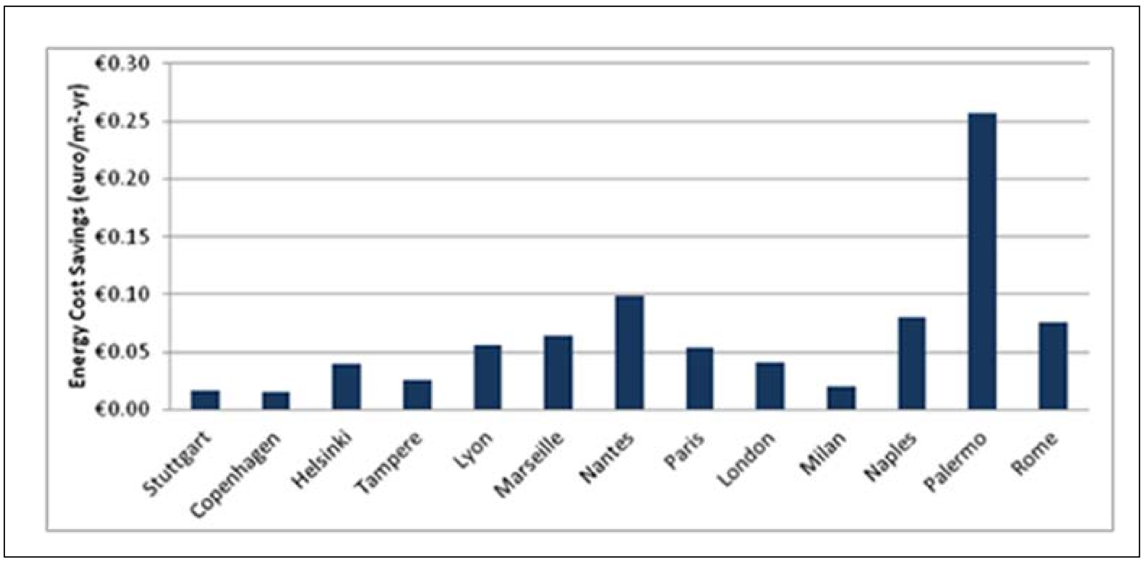

Figure 4.300. Annual energy cost savings for condenser waste heat recovery – European locations.

5 ECM Performance Data

5.1 Increased Wall Insulation

Table 5.1. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline (kBtu/sq ft·yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	9.35	9.50	9.78	9.83	9.88
Houston, TX	9.09	9.51	10.36	10.71	10.90
Phoenix, AZ	11.23	11.72	12.73	13.15	13.33
Memphis, TN	8.12	8.68	9.99	10.60	10.95
El Paso, TX	9.07	9.61	10.76	11.27	11.53
San Francisco, CA	13.93	14.91	16.86	17.63	18.04
Baltimore, MD	7.89	8.42	9.80	10.52	10.99
Albuquerque, NM	8.67	9.40	11.12	11.90	12.35
Seattle, WA	6.77	7.21	8.44	9.10	9.52
Chicago, IL	9.36	9.96	11.56	12.41	12.96
Boise, ID	9.74	10.50	12.43	13.40	13.97
Burlington, VT	9.40	9.85	11.15	11.92	12.43
Helena, MT	8.86	9.38	10.88	11.73	12.29
Duluth, MN	10.92	11.39	12.80	13.66	14.25
Fairbanks, AK	14.94	15.38	16.79	17.72	18.38

Table 5.2. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline (kWh/m^2·y).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	29.48	29.96	30.85	30.99	31.16
Houston, TX	28.67	29.98	32.68	33.77	34.37
Phoenix, AZ	35.40	36.97	40.15	41.47	42.03
Memphis, TN	25.61	27.38	31.49	33.42	34.52
El Paso, TX	28.59	30.32	33.93	35.53	36.36
San Francisco, CA	43.93	47.03	53.18	55.60	56.90
Baltimore, MD	24.89	26.56	30.91	33.17	34.65
Albuquerque, NM	27.35	29.64	35.07	37.53	38.95
Seattle, WA	21.34	22.75	26.62	28.68	30.01
Chicago, IL	29.53	31.40	36.45	39.14	40.86
Boise, ID	30.72	33.12	39.20	42.26	44.06
Burlington, VT	29.65	31.08	35.17	37.59	39.21
Helena, MT	27.93	29.57	34.30	36.98	38.75
Duluth, MN	34.45	35.91	40.35	43.07	44.92
Fairbanks, AK	47.12	48.51	52.96	55.88	57.97

Table 5.3. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline ($/sq ft·yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	$2.72	$2.76	$2.83	$2.84	$2.86
Houston, TX	$1.82	$1.88	$1.99	$2.03	$2.05
Phoenix, AZ	$2.32	$2.41	$2.58	$2.66	$2.68
Memphis, TN	$1.35	$1.43	$1.62	$1.70	$1.75
El Paso, TX	$1.64	$1.70	$1.82	$1.88	$1.91
San Francisco, CA	$1.92	$2.01	$2.20	$2.27	$2.31
Baltimore, MD	$1.35	$1.43	$1.62	$1.72	$1.80
Albuquerque, NM	$1.18	$1.26	$1.45	$1.53	$1.58
Seattle, WA	$0.90	$0.96	$1.12	$1.20	$1.25
Chicago, IL	$1.31	$1.39	$1.60	$1.71	$1.78
Boise, ID	$1.16	$1.24	$1.46	$1.57	$1.64
Burlington, VT	$1.59	$1.67	$1.87	$2.00	$2.08
Helena, MT	$1.15	$1.21	$1.40	$1.51	$1.58
Duluth, MN	$1.30	$1.36	$1.52	$1.62	$1.69
Fairbanks, AK	$1.74	$1.79	$1.95	$2.06	$2.14

Table 5.4. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline (kBtu/sq ft·yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	9.41	9.56	9.84	9.89	9.94
Houston, TX	14.19	14.72	15.80	16.20	16.29
Phoenix, AZ	15.36	15.93	17.08	17.54	17.60
Memphis, TN	20.25	21.33	23.50	24.34	24.77
El Paso, TX	16.70	17.53	19.02	19.63	19.75
San Francisco, CA	16.11	17.16	19.22	20.01	20.34
Baltimore, MD	27.91	29.52	32.69	33.94	34.77
Albuquerque, NM	23.67	25.11	27.94	29.05	29.54
Seattle, WA	26.55	28.18	31.45	32.76	33.51
Chicago, IL	36.42	38.56	42.84	44.53	45.82
Boise, ID	31.94	33.92	37.83	39.37	40.29
Burlington, VT	41.55	44.02	48.95	50.90	52.63
Helena, MT	40.48	42.99	48.03	50.01	51.66
Duluth, MN	52.91	56.10	62.39	64.88	67.34
Fairbanks, AK	73.13	77.49	86.21	89.67	93.56

Table 5.5. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline (kWh/m2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	16.73	17.53	18.09	18.31	18.41
Houston, TX	33.88	35.35	38.12	39.03	38.74
Phoenix, AZ	36.76	38.24	41.03	42.13	42.66
Memphis, TN	53.37	56.19	61.63	63.79	63.15
El Paso, TX	41.47	43.37	49.05	50.49	47.37
San Francisco, CA	41.21	43.78	47.24	48.65	48.82
Baltimore, MD	75.66	80.48	89.50	92.89	92.79
Albuquerque, NM	67.59	71.58	78.67	81.43	80.92
Seattle, WA	76.74	80.97	88.59	91.49	91.29
Chicago, IL	100.04	106.20	119.03	124.38	125.73
Boise, ID	89.32	95.12	105.95	110.38	110.78
Burlington, VT	115.96	122.88	137.91	143.79	147.04
Helena, MT	122.95	134.05	149.10	155.06	155.06
Duluth, MN	154.76	164.34	183.70	191.69	197.39
Fairbanks, AK	218.50	233.23	262.24	273.73	285.67

Table 5.6. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline ($/sq ftyr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	$2.73	$2.78	$2.85	$2.86	$2.88
Houston, TX	$2.86	$2.93	$3.07	$3.12	$3.12
Phoenix, AZ	$3.19	$3.29	$3.49	$3.57	$3.58
Memphis, TN	$3.39	$3.55	$3.86	$3.98	$4.04
El Paso, TX	$3.12	$3.22	$3.39	$3.46	$3.46
San Francisco, CA	$2.24	$2.34	$2.53	$2.61	$2.63
Baltimore, MD	$5.15	$5.39	$5.85	$6.03	$6.14
Albuquerque, NM	$3.39	$3.56	$3.87	$4.00	$4.04
Seattle, WA	$3.63	$3.84	$4.26	$4.42	$4.51
Chicago, IL	$5.19	$5.47	$6.03	$6.25	$6.42
Boise, ID	$3.82	$4.05	$4.50	$4.68	$4.78
Burlington, VT	$7.16	$7.56	$8.36	$8.66	$8.94
Helena, MT	$5.31	$5.63	$6.26	$6.50	$6.70
Duluth, MN	$6.37	$6.75	$7.49	$7.77	$8.06
Fairbanks, AK	$8.48	$8.97	$9.95	$10.34	$10.77

Table 5.7. Annual energy savings for wall insulation and reduced infiltration over the standard baseline - international locations (kWh/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	9.13	9.59	11.00	11.87	12.46
Ottawa	7.88	8.16	9.05	9.64	10.04
Vancouver	6.74	7.25	8.65	9.42	9.90
Stuttgart	10.24	11.20	13.37	14.35	14.90
Copenhagen	5.11	5.43	6.37	6.93	7.30
Helsinki	8.64	9.04	10.19	10.86	11.29
Tampere	9.17	9.59	10.81	11.52	11.99
Lyon	3.72	3.93	4.51	4.85	5.07
Marseille	1.88	1.98	2.25	2.40	2.50
Nantes	2.97	3.13	3.58	3.83	4.00
Paris	4.12	4.35	4.99	5.36	5.60
London	8.89	9.74	11.66	12.52	13.00
Milan	3.47	3.72	4.43	4.84	5.10
Naples	0.90	0.96	1.12	1.20	1.24
Palermo	0.01	0.01	0.02	0.02	0.02
Rome	0.96	1.03	1.21	1.30	1.35

Table 5.8. Annual energy cost savings for wall insulation and reduced infiltration over the standard baseline - Canadian locations ($/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	$1.65	$1.73	$1.99	$2.14	$2.25
Ottawa	$1.38	$1.43	$1.58	$1.68	$1.75
Vancouver	$1.13	$1.21	$1.43	$1.55	$1.62

Table 5.9. Annual energy cost savings for wall insulation and reduced infiltration over the standard baseline - European locations (euro/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Stuttgart	€ 2.42	€ 2.65	€ 3.16	€ 3.39	€ 3.52
Copenhagen	€ 1.21	€ 1.28	€ 1.51	€ 1.64	€ 1.73
Helsinki	€ 2.04	€ 2.14	€ 2.41	€ 2.57	€ 2.67
Tampere	€ 2.17	€ 2.27	€ 2.56	€ 2.72	€ 2.83
Lyon	€ 0.88	€ 0.93	€ 1.07	€ 1.15	€ 1.20
Marseille	€ 0.45	€ 0.47	€ 0.53	€ 0.57	€ 0.59
Nantes	€ 0.70	€ 0.74	€ 0.85	€ 0.91	€ 0.94
Paris	€ 0.98	€ 1.03	€ 1.18	€ 1.27	€ 1.32
London	€ 1.66	€ 1.82	€ 2.18	€ 2.34	€ 2.43
Milan	€ 0.82	€ 0.88	€ 1.05	€ 1.14	€ 1.21
Naples	€ 0.21	€ 0.23	€ 0.26	€ 0.28	€ 0.29
Palermo	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	€ 0.23	€ 0.24	€ 0.29	€ 0.31	€ 0.32

Table 5.10. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline- international locations (kWh/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	156.69	166.75	186.77	194.68	198.92
Ottawa	140.90	149.65	167.03	173.85	177.50
Vancouver	88.48	94.40	106.24	110.94	113.44
Stuttgart	32.29	35.31	42.17	45.24	46.98
Copenhagen	35.45	38.89	46.80	50.36	52.39
Helsinki	143.79	150.69	164.04	169.17	171.89
Tampere	149.33	156.59	170.69	176.13	179.03
Lyon	63.48	66.89	73.54	76.11	77.46
Marseille	40.79	42.69	46.17	47.39	48.00
Nantes	56.87	59.70	65.06	67.05	68.08
Paris	69.55	73.31	80.65	83.46	84.96
London	28.04	30.71	36.77	39.47	41.01
Milan	10.95	11.73	13.97	15.26	16.09
Naples	2.83	3.02	3.52	3.77	3.92
Palermo	0.04	0.04	0.05	0.05	0.06
Rome	3.03	3.24	3.80	4.09	4.26

Table 5.11. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline- Canadian locations ($/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	$9.03	$9.60	$10.72	$11.16	$11.40
Ottawa	$8.03	$8.51	$9.45	$9.82	$10.01
Vancouver	$4.88	$5.19	$5.78	$6.02	$6.14

Table 5.12. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline- European locations (euro/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Stuttgart	€ 2.42	€ 2.65	€ 3.16	€ 3.39	€ 3.52
Copenhagen	€ 2.66	€ 2.92	€ 3.51	€ 3.78	€ 3.93
Helsinki	€ 10.78	€ 11.30	€ 12.30	€ 12.68	€ 12.89
Tampere	€ 11.19	€ 11.74	€ 12.80	€ 13.20	€ 13.42
Lyon	€ 4.76	€ 5.01	€ 5.51	€ 5.71	€ 5.81
Marseille	€ 3.06	€ 3.20	€ 3.46	€ 3.55	€ 3.60
Nantes	€ 4.26	€ 4.48	€ 4.88	€ 5.03	€ 5.10
Paris	€ 5.21	€ 5.50	€ 6.05	€ 6.26	€ 6.37
London	€ 1.66	€ 1.82	€ 2.18	€ 2.34	€ 2.43
Milan	€ 0.82	€ 0.88	€ 1.05	€ 1.14	€ 1.21
Naples	€ 0.21	€ 0.23	€ 0.26	€ 0.28	€ 0.29
Palermo	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	€ 0.23	€ 0.24	€ 0.29	€ 0.31	€ 0.32

5.2 Increased Roof Insulation

Table 5.13. Annual energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline (kBtu/sq ft·yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	12.91	13.93	14.30	14.47	14.58
Houston, TX	13.12	13.93	14.14	14.27	14.40
Phoenix, AZ	15.21	15.49	15.64	15.77	15.90
Memphis, TN	13.65	14.27	14.48	14.64	14.78
El Paso, TX	11.38	11.99	12.15	12.23	12.32
San Francisco, CA	13.71	14.48	14.77	14.86	14.92
Baltimore, MD	15.75	16.37	16.62	16.80	17.00
Albuquerque, NM	14.40	15.06	15.30	15.44	15.55
Seattle, WA	11.63	12.22	12.45	12.65	12.79
Chicago, IL	20.27	20.85	21.12	21.31	21.51
Boise, ID	18.33	18.76	18.99	19.17	19.38
Burlington, VT	22.13	22.57	22.84	23.07	23.22
Helena, MT	20.31	20.81	21.10	21.30	21.47
Duluth, MN	28.39	28.81	29.10	29.30	29.45
Fairbanks, AK	41.00	41.48	41.83	42.08	42.29

Table 5.14. Annual energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline (kWh/m^2·yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	40.72	43.92	45.10	45.62	45.97
Houston, TX	41.38	43.93	44.60	45.01	45.40
Phoenix, AZ	47.97	48.86	49.32	49.74	50.13
Memphis, TN	43.03	45.01	45.67	46.17	46.61
El Paso, TX	35.89	37.81	38.32	38.56	38.85
San Francisco, CA	43.24	45.66	46.57	46.86	47.06
Baltimore, MD	49.68	51.63	52.42	52.98	53.61
Albuquerque, NM	45.42	47.48	48.26	48.68	49.03
Seattle, WA	36.67	38.52	39.26	39.89	40.32
Chicago, IL	63.94	65.74	66.59	67.21	67.83
Boise, ID	57.79	59.16	59.90	60.44	61.10
Burlington, VT	69.78	71.17	72.03	72.74	73.23
Helena, MT	64.06	65.63	66.55	67.18	67.70
Duluth, MN	89.53	90.87	91.76	92.41	92.88
Fairbanks, AK	129.31	130.82	131.90	132.72	133.36

Table 5.15. Annual energy cost savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline ($/sq ft·yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	$0.29	$0.31	$0.32	$0.32	$0.32
Houston, TX	$0.22	$0.24	$0.24	$0.25	$0.25
Phoenix, AZ	$0.28	$0.29	$0.29	$0.30	$0.30
Memphis, TN	$0.19	$0.20	$0.20	$0.20	$0.21
El Paso, TX	$0.15	$0.16	$0.17	$0.17	$0.17
San Francisco, CA	$0.15	$0.18	$0.19	$0.19	$0.19
Baltimore, MD	$0.18	$0.19	$0.19	$0.20	$0.20
Albuquerque, NM	$0.15	$0.16	$0.17	$0.17	$0.17
Seattle, WA	$0.12	$0.13	$0.13	$0.13	$0.14
Chicago, IL	$0.24	$0.25	$0.25	$0.25	$0.26
Boise, ID	$0.17	$0.18	$0.18	$0.18	$0.19
Burlington, VT	$0.29	$0.30	$0.30	$0.30	$0.31
Helena, MT	$0.25	$0.26	$0.27	$0.27	$0.27
Duluth, MN	$0.29	$0.29	$0.30	$0.30	$0.30
Fairbanks, AK	$0.40	$0.41	$0.41	$0.41	$0.41

Table 5.16. Annual energy savings for increased roof insulation and reduced infiltration over the standard baseline – international locations (kWh/m^2·yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	156.69	166.75	186.77	194.68	198.92
Ottawa	140.90	149.65	167.03	173.85	177.50
Vancouver	88.48	94.40	106.24	110.94	113.44
Stuttgart	32.29	35.31	42.17	45.24	46.98
Copenhagen	35.45	38.89	46.80	50.36	52.39
Helsinki	143.79	150.69	164.04	169.17	171.89
Tampere	149.33	156.59	170.69	176.13	179.03
Lyon	63.48	66.89	73.54	76.11	77.46
Marseille	40.79	42.69	46.17	47.39	48.00
Nantes	56.87	59.70	65.06	67.05	68.08
Paris	69.55	73.31	80.65	83.46	84.96
London	28.04	30.71	36.77	39.47	41.01
Milan	10.95	11.73	13.97	15.26	16.09
Naples	2.83	3.02	3.52	3.77	3.92
Palermo	0.04	0.04	0.05	0.05	0.06
Rome	3.03	3.24	3.80	4.09	4.26

Table 5.17. Annual energy cost savings for increased roof insulation and reduced infiltration over the standard baseline – Canadian locations ($/m^2·yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	$0.03	$0.05	$0.07	$0.08	$0.09
Ottawa	$0.02	$0.04	$0.05	$0.06	$0.06
Vancouver	$0.04	$0.06	$0.07	$0.07	$0.08

Table 5.18. Annual energy cost savings for increased roof insulation and reduced infiltration over the standard baseline – European locations (euro/m²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Stuttgart	€ 1.25	€ 1.56	€ 1.70	€ 1.78	€ 1.84
Copenhagen	€ 0.13	€ 0.21	€ 0.26	€ 0.29	€ 0.32
Helsinki	€ 2.12	€ 2.66	€ 2.91	€ 3.06	€ 3.15
Tampere	€ 2.25	€ 2.84	€ 3.10	€ 3.25	€ 3.35
Lyon	€ 0.28	€ 0.40	€ 0.47	€ 0.52	€ 0.55
Marseille	€ 0.17	€ 0.24	€ 0.28	€ 0.31	€ 0.33
Nantes	€ 0.24	€ 0.34	€ 0.40	€ 0.44	€ 0.46
Paris	€ 0.31	€ 0.45	€ 0.52	€ 0.57	€ 0.61
London	€ 0.85	€ 1.06	€ 1.16	€ 1.21	€ 1.25
Milan	€ 0.26	€ 0.37	€ 0.44	€ 0.48	€ 0.51
Naples	€ 0.09	€ 0.12	€ 0.14	€ 0.15	€ 0.16
Palermo	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	€ 0.09	€ 0.12	€ 0.14	€ 0.15	€ 0.16

5.3 Attic Insulation

Table 5.19. Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline (kBtu/sq ft·yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	3.56	4.34	4.58	4.65	4.72
Houston, TX	5.20	5.99	6.26	6.36	6.43
Phoenix, AZ	3.83	4.26	4.40	4.48	4.55
Memphis, TN	7.48	8.35	8.69	8.88	8.99
El Paso, TX	4.87	5.57	5.76	5.84	5.90
San Francisco, CA	5.35	6.10	6.35	6.43	6.49
Baltimore, MD	11.35	12.47	12.96	13.24	13.42
Albuquerque, NM	8.20	9.17	9.54	9.72	9.84
Seattle, WA	8.72	9.66	10.05	10.26	10.40
Chicago, IL	15.95	17.31	17.93	18.28	18.53
Boise, ID	11.98	13.10	13.59	13.88	14.07
Burlington, VT	19.40	20.85	21.52	21.92	22.18
Helena, MT	17.02	18.38	19.00	19.37	19.61
Duluth, MN	25.93	27.87	28.80	29.34	29.70
Fairbanks, AK	39.34	41.94	43.20	43.94	44.44

Table 5.20. Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline (kWh/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	11.23	13.68	14.43	14.68	14.87
Houston, TX	16.40	18.90	19.74	20.05	20.29
Phoenix, AZ	12.07	13.42	13.88	14.13	14.34
Memphis, TN	23.59	26.32	27.42	28.00	28.35
El Paso, TX	15.37	17.56	18.18	18.43	18.61
San Francisco, CA	16.88	19.25	20.02	20.29	20.46
Baltimore, MD	35.80	39.33	40.88	41.75	42.33
Albuquerque, NM	25.86	28.92	30.08	30.65	31.04
Seattle, WA	27.51	30.45	31.69	32.34	32.81
Chicago, IL	50.29	54.58	56.53	57.66	58.43
Boise, ID	37.77	41.31	42.87	43.77	44.39
Burlington, VT	61.17	65.74	67.86	69.12	69.95
Helena, MT	53.68	57.97	59.93	61.08	61.84
Duluth, MN	81.79	87.88	90.81	92.54	93.66
Fairbanks, AK	124.07	132.27	136.22	138.57	140.13

Table 5.21 Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline – International locations (kWh/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	186.76	185.60	185.38	185.24	185.13
Ottawa	183.33	182.34	182.18	182.09	182.01
Vancouver	172.29	173.12	173.31	173.38	173.38
Stuttgart	98.47	91.95	90.58	89.97	89.62
Copenhagen	96.56	94.91	94.56	94.35	94.25
Helsinki	165.81	158.18	157.20	156.71	156.43
Tampere	170.36	161.84	160.48	159.89	159.38
Lyon	122.07	121.60	121.51	121.50	121.49
Marseille	124.62	125.25	125.41	125.50	125.57
Nantes	115.17	115.42	115.50	115.57	115.61
Paris	115.50	114.92	114.82	114.79	114.77
London	84.64	79.33	78.17	77.65	77.36
Milan	137.45	136.03	135.79	135.65	135.56
Naples	141.28	142.21	142.25	142.27	142.25
Palermo	151.31	151.26	151.23	151.21	151.17
Rome	137.30	138.45	138.53	138.57	138.58

5.4 Cool Roofs

Table 5.22. Annual energy savings for cool roof (kBtu/sq ft-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	0.36	0.66
Houston, TX	0.23	0.40
Phoenix, AZ	0.18	0.20
Memphis, TN	0.12	0.21
El Paso, TX	0.15	0.14
San Francisco, CA	0.00	0.04
Baltimore, MD	0.03	0.06
Albuquerque, NM	0.05	0.05
Seattle, WA	0.03	0.04
Chicago, IL	-0.06	-0.06
Boise, ID	-0.02	-0.02
Burlington, VT	-0.06	-0.06
Helena, MT	-0.07	-0.07
Duluth, MN	-0.09	-0.09
Fairbanks, AK	-0.04	-0.04

Table 5.23. Annual energy savings for cool roof (kWh/m^2-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	1.14	2.09
Houston, TX	0.71	1.27
Phoenix, AZ	0.55	0.63
Memphis, TN	0.37	0.67
El Paso, TX	0.49	0.46
San Francisco, CA	0.01	0.13
Baltimore, MD	0.10	0.20
Albuquerque, NM	0.16	0.15
Seattle, WA	0.09	0.11
Chicago, IL	-0.17	-0.17
Boise, ID	-0.07	-0.08
Burlington, VT	-0.20	-0.20
Helena, MT	-0.23	-0.23
Duluth, MN	-0.28	-0.28
Fairbanks, AK	-0.14	-0.14

Table 5.24. Annual energy cost savings for cool roof ($/sq ft·yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	$1.80	$1.79
Houston, TX	$1.65	$1.64
Phoenix, AZ	$1.56	$1.56
Memphis, TN	$1.43	$1.43
El Paso, TX	$1.44	$1.44
San Francisco, CA	$1.73	$1.73
Baltimore, MD	$1.48	$1.48
Albuquerque, NM	$1.35	$1.35
Seattle, WA	$1.08	$1.08
Chicago, IL	$1.61	$1.61
Boise, ID	$1.10	$1.10
Burlington, VT	$2.18	$2.18
Helena, MT	$1.54	$1.54
Duluth, MN	$1.56	$1.56
Fairbanks, AK	$2.26	$2.26

5.5 Building Airtightness

Table 5.25. Annual energy savings for improved airtightness (kBtu/sq ft·yr).

Location	0.5 cfm/sq ft	0.25 cfm/sq ft	0.15 cfm/sq ft
Miami, FL	3.00	4.60	5.22
Houston, TX	5.64	8.25	9.24
Phoenix, AZ	5.33	7.76	8.67
Memphis, TN	8.98	13.14	14.71
El Paso, TX	6.35	8.86	9.75
San Francisco, CA	8.37	11.91	13.17
Baltimore, MD	12.62	18.56	20.84
Albuquerque, NM	9.64	13.89	15.48
Seattle, WA	11.70	16.89	18.82
Chicago, IL	16.36	24.04	26.98
Boise, ID	13.96	20.39	22.84
Burlington, VT	19.41	28.46	31.96
Helena, MT	17.32	25.19	28.18
Duluth, MN	23.98	35.25	39.60
Fairbanks, AK	35.09	51.79	58.27

Table 5.26. Annual energy savings for improved airtightness (kWh/m²·yr).

Location	0.5 cfm/sq ft	0.25 cfm/sq ft	0.15 cfm/sq ft
Miami, FL	9.46	14.52	16.47
Houston, TX	17.79	26.03	29.15
Phoenix, AZ	16.81	24.47	27.33
Memphis, TN	28.33	41.45	46.38
El Paso, TX	20.01	27.93	30.75
San Francisco, CA	26.38	37.57	41.54
Baltimore, MD	39.79	58.51	65.72
Albuquerque, NM	30.40	43.82	48.80
Seattle, WA	36.88	53.27	59.34
Chicago, IL	51.58	75.81	85.10
Boise, ID	44.03	64.31	72.01
Burlington, VT	61.21	89.74	100.78
Helena, MT	54.62	79.43	88.87
Duluth, MN	75.63	111.17	124.87
Fairbanks, AK	110.67	163.33	183.76

Table 5.27. Annual energy cost savings for improved airtightness ($/sq ft·yr).

Location	0.5 cfm/sq ft	0.25 cfm/sq ft	0.15 cfm/sq ft
Miami, FL	$0.08	$0.12	$0.14
Houston, TX	$0.09	$0.13	$0.15
Phoenix, AZ	$0.09	$0.13	$0.15
Memphis, TN	$0.12	$0.18	$0.20
El Paso, TX	$0.08	$0.11	$0.12
San Francisco, CA	$0.08	$0.11	$0.12
Baltimore, MD	$0.17	$0.25	$0.28
Albuquerque, NM	$0.10	$0.14	$0.16
Seattle, WA	$0.14	$0.20	$0.22
Chicago, IL	$0.19	$0.27	$0.30
Boise, ID	$0.15	$0.22	$0.24
Burlington, VT	$0.28	$0.40	$0.45
Helena, MT	$0.20	$0.27	$0.30
Duluth, MN	$0.26	$0.37	$0.41
Fairbanks, AK	$0.37	$0.52	$0.58

Table 5.28. Annual energy savings for improved airtightness – international locations (kWh/m²-yr).

Location	0.5 cfm/sq ft	0.25 cfm/sq ft
Edmonton	24.88	36.77
Ottawa	22.87	33.82
Vancouver	15.22	22.36
Stuttgart	15.73	23.17
Copenhagen	12.78	16.94
Helsinki	20.88	30.14
Tampere	22.24	32.20
Lyon	7.89	10.54
Marseille	3.26	3.71
Nantes	5.74	7.04
Paris	8.66	11.35
London	14.44	21.26
Milan	8.41	10.91
Naples	1.39	1.48
Palermo	0.02	0.02
Rome	1.58	1.69

Table 5.29. Annual energy cost savings for improved airtightness – Canadian locations ($/m²-yr).

Location	0.5 cfm/sq ft	0.25 cfm/sq ft
Edmonton	$4.37	$6.32
Ottawa	$3.83	$5.60
Vancouver	$2.39	$3.49

Table 5.30. Annual energy cost savings for improved airtightness – European locations (euro/m²-yr).

Location	0.5 cfm/sq ft	0.25 cfm/sq ft
Stuttgart	€ 3.72	€ 5.48
Copenhagen	€ 3.02	€ 4.00
Helsinki	€ 4.94	€ 7.12
Tampere	€ 5.26	€ 7.61
Lyon	€ 1.87	€ 2.49
Marseille	€ 0.77	€ 0.88
Nantes	€ 1.36	€ 1.66
Paris	€ 2.05	€ 2.68
London	€ 2.70	€ 3.98
Milan	€ 1.99	€ 2.58
Naples	€ 0.33	€ 0.35
Palermo	€ 0.00	€ 0.00
Rome	€ 0.37	€ 0.40

5.6 Advanced Windows

Table 5.31. Annual energy savings for advanced windows (kBtu/sq ftyr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	1.52	1.62	2.04	2.27	1.86	2.36	2.10	1.86
Houston, TX	2.52	2.82	2.97	3.27	3.11	3.44	3.39	3.43
Phoenix, AZ	2.48	2.79	2.97	3.32	3.15	3.51	3.46	3.52
Memphis, TN	2.58	3.10	2.97	3.33	3.44	3.59	3.77	4.13
El Paso, TX	2.77	3.24	3.10	3.35	3.51	3.56	3.74	4.04
San Francisco, CA	2.26	2.69	2.24	2.45	2.88	2.67	3.05	3.59
Baltimore, MD	3.49	4.24	3.95	4.43	4.71	4.82	5.14	5.73
Albuquerque, NM	2.41	3.20	2.75	3.11	3.53	3.43	3.84	4.48
Seattle, WA	3.46	4.02	3.70	4.18	4.47	4.57	4.91	5.47
Chicago, IL	4.51	5.60	5.22	5.87	6.21	6.38	6.79	7.56
Boise, ID	3.73	4.70	4.25	4.80	5.21	5.26	5.71	6.46
Burlington, VT	4.88	6.16	5.70	6.43	6.85	7.01	7.51	8.41
Helena, MT	4.10	5.41	4.88	5.59	6.07	6.17	6.71	7.69
Duluth, MN	5.74	7.47	6.83	7.76	8.34	8.46	9.14	10.36
Fairbanks, AK	8.64	11.18	10.68	11.96	12.41	12.84	13.51	15.00

Table 5.32. Annual energy savings for advanced windows (kWh/m^2-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	4.79	5.10	6.44	7.17	5.86	7.43	6.61	5.86
Houston, TX	7.94	8.88	9.38	10.32	9.82	10.84	10.68	10.82
Phoenix, AZ	7.81	8.81	9.36	10.48	9.94	11.08	10.91	11.11
Memphis, TN	8.13	9.78	9.36	10.49	10.86	11.32	11.89	13.01
El Paso, TX	8.73	10.22	9.77	10.57	11.06	11.23	11.78	12.74
San Francisco, CA	7.13	8.48	7.05	7.71	9.08	8.43	9.63	11.31
Baltimore, MD	11.00	13.38	12.46	13.98	14.85	15.18	16.22	18.08
Albuquerque, NM	7.60	10.10	8.68	9.80	11.12	10.82	12.11	14.14
Seattle, WA	10.91	12.67	11.66	13.18	14.09	14.41	15.47	17.26
Chicago, IL	14.21	17.66	16.47	18.53	19.58	20.12	21.43	23.83
Boise, ID	11.76	14.82	13.41	15.13	16.42	16.59	18.01	20.37
Burlington, VT	15.40	19.43	17.98	20.28	21.61	22.11	23.68	26.53
Helena, MT	12.94	17.05	15.38	17.62	19.15	19.44	21.17	24.25
Duluth, MN	18.09	23.56	21.54	24.48	26.32	26.69	28.82	32.68
Fairbanks, AK	27.24	35.26	33.66	37.72	39.13	40.48	42.61	47.32

Table 5.33. Annual energy cost savings for advanced windows ($/sq ftyr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	$0.04	$0.04	$0.06	$0.06	$0.05	$0.06	$0.06	$0.05
Houston, TX	$0.04	$0.05	$0.06	$0.06	$0.05	$0.06	$0.06	$0.06
Phoenix, AZ	$0.05	$0.05	$0.06	$0.06	$0.06	$0.07	$0.06	$0.06
Memphis, TN	$0.04	$0.05	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06
El Paso, TX	$0.04	$0.05	$0.05	$0.06	$0.05	$0.06	$0.06	$0.06
San Francisco, CA	$0.02	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.04
Baltimore, MD	$0.05	$0.06	$0.07	$0.07	$0.07	$0.08	$0.08	$0.09
Albuquerque, NM	$0.03	$0.04	$0.04	$0.04	$0.04	$0.05	$0.05	$0.05
Seattle, WA	$0.04	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06	$0.07
Chicago, IL	$0.06	$0.07	$0.07	$0.08	$0.08	$0.08	$0.09	$0.09
Boise, ID	$0.04	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06	$0.07
Burlington, VT	$0.08	$0.10	$0.09	$0.11	$0.11	$0.11	$0.12	$0.13
Helena, MT	$0.05	$0.07	$0.06	$0.07	$0.07	$0.08	$0.08	$0.09
Duluth, MN	$0.06	$0.08	$0.08	$0.09	$0.09	$0.10	$0.10	$0.11
Fairbanks, AK	$0.09	$0.12	$0.12	$0.13	$0.14	$0.14	$0.15	$0.16

Table 5.34. Simple payback relative to window I (years).

Location	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	4.3	1.7	4.5	5.6	8.7	9.9	15.0
Houston, TX	3.9	1.7	4.5	5.2	8.6	9.3	13.0
Phoenix, AZ	3.7	1.6	4.3	4.8	8.2	8.6	11.6
Memphis, TN	4.1	2.0	5.3	5.4	9.8	9.8	12.4
El Paso, TX	3.8	1.8	4.9	5.1	9.3	9.5	12.5
San Francisco, CA	6.7	3.5	9.1	8.9	17.0	16.3	19.8
Baltimore, MD	2.9	1.4	3.8	3.8	7.0	6.9	8.7
Albuquerque, NM	4.8	2.5	6.6	6.4	12.2	11.6	14.0
Seattle, WA	3.8	2.0	5.2	5.0	9.6	9.1	11.1
Chicago, IL	2.6	1.3	3.6	3.5	6.7	6.4	7.9
Boise, ID	3.6	2.0	5.2	4.9	9.6	8.9	10.6
Burlington, VT	1.9	1.0	2.6	2.6	4.9	4.7	5.7
Helena, MT	2.9	1.5	4.0	3.8	7.3	6.8	8.1
Duluth, MN	2.2	1.2	3.2	3.0	5.8	5.5	6.5
Fairbanks, AK	1.5	0.8	2.1	2.1	4.0	3.8	4.6

Table 5.35. Annual energy savings for advanced windows – international locations (kWh/m²·yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Edmonton	-7.23	-1.72	-4.07	-1.30	0.85	0.96	3.30	7.39
Ottawa	-6.03	-1.35	-3.18	-0.63	1.04	1.40	3.30	6.71
Vancouver	-2.44	-0.22	-1.86	-0.33	1.21	1.08	2.65	5.08
Stuttgart	2.08	14.34	7.14	15.45	22.22	22.90	30.13	41.75
Copenhagen	1.43	5.17	2.87	7.90	9.90	11.49	14.12	18.93
Helsinki	-17.65	-2.14	-7.68	5.34	10.26	15.24	22.09	34.89
Tampere	-18.81	-2.20	-8.01	5.46	10.63	15.79	22.99	36.60
Lyon	-8.40	-4.66	-7.47	-2.65	-0.16	1.11	4.05	8.99
Marseille	-7.42	-5.12	-8.33	-5.76	-2.91	-3.66	-1.06	2.51
Nantes	-8.16	-5.24	-8.39	-4.24	-1.47	-1.08	1.82	6.32
Paris	-9.31	-5.26	-8.32	-2.81	-0.11	1.37	4.62	10.14
London	4.11	13.88	6.73	13.77	20.55	20.26	27.17	37.93
Milan	-6.44	-3.79	-5.98	-3.25	-1.26	-0.85	1.32	4.87
Naples	-2.81	-2.07	-3.34	-2.32	-1.18	-1.42	-0.37	1.03
Palermo	-0.08	-0.07	-0.14	-0.10	-0.05	-0.07	-0.03	0.00
Rome	-3.26	-2.34	-3.78	-2.66	-1.37	-1.73	-0.56	1.01

Table 5.36. Annual energy cost savings for advanced windows – Canadian locations ($/m²·yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Edmonton	-$0.31	-$0.05	-$0.13	$0.00	$0.06	$0.09	$0.17	$0.34
Ottawa	-$0.25	-$0.04	-$0.09	$0.03	$0.07	$0.11	$0.17	$0.31
Vancouver	-$0.09	$0.01	-$0.04	$0.03	$0.07	$0.08	$0.14	$0.22

Table 5.37. Annual energy cost savings for advanced windows – European locations (euro/m²·yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Stuttgart	€ 0.12	€ 0.82	€ 0.41	€ 0.88	€ 1.27	€ 1.31	€ 1.73	€ 2.39
Copenhagen	€ 0.08	€ 0.30	€ 0.16	€ 0.45	€ 0.57	€ 0.66	€ 0.81	€ 1.08
Helsinki	-€ 1.01	-€ 0.12	-€ 0.44	€ 0.31	€ 0.59	€ 0.87	€ 1.26	€ 2.00
Tampere	-€ 1.08	-€ 0.13	-€ 0.46	€ 0.31	€ 0.61	€ 0.90	€ 1.32	€ 2.09
Lyon	-€ 0.48	-€ 0.27	-€ 0.43	-€ 0.15	-€ 0.01	€ 0.06	€ 0.23	€ 0.51
Marseille	-€ 0.42	-€ 0.29	-€ 0.48	-€ 0.33	-€ 0.17	-€ 0.21	-€ 0.06	€ 0.14
Nantes	-€ 0.47	-€ 0.30	-€ 0.48	-€ 0.24	-€ 0.08	-€ 0.06	€ 0.10	€ 0.36
Paris	-€ 0.53	-€ 0.30	-€ 0.48	-€ 0.16	-€ 0.01	€ 0.08	€ 0.26	€ 0.58
London	€ 0.19	€ 0.63	€ 0.30	€ 0.62	€ 0.93	€ 0.92	€ 1.23	€ 1.72
Milan	-€ 0.37	-€ 0.22	-€ 0.34	-€ 0.19	-€ 0.07	-€ 0.05	€ 0.08	€ 0.28
Naples	-€ 0.16	-€ 0.12	-€ 0.19	-€ 0.13	-€ 0.07	-€ 0.08	-€ 0.02	€ 0.06
Palermo	€ 0.00	€ 0.00	-€ 0.01	-€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	-€ 0.19	-€ 0.13	-€ 0.22	-€ 0.15	-€ 0.08	-€ 0.10	-€ 0.03	€ 0.06

5.7 External Roller Shades

Table 5.38. Annual energy savings for external roller shades (kBtu/sq ft-yr).

Location	Actively Controlled Shutters	Schedule Control Shutters
Miami, FL	2.29	1.16
Houston, TX	1.56	1.33
Phoenix, AZ	1.76	1.45
Memphis, TN	1.04	1.04
El Paso, TX	0.38	0.86
San Francisco, CA	-0.21	-0.35
Baltimore, MD	0.57	0.60
Albuquerque, NM	0.32	0.48
Seattle, WA	0.13	-0.13
Chicago, IL	0.40	0.40
Boise, ID	0.21	0.07
Burlington, VT	0.22	0.02
Helena, MT	0.09	-0.19
Duluth, MN	0.07	-0.40
Fairbanks, AK	0.02	-0.60

Table 5.39. Annual energy savings for external roller shades (kWh/m^2-yr).

Location	Actively Controlled Shutters	Schedule Control Shutters
Miami, FL	7.22	3.66
Houston, TX	4.90	4.18
Phoenix, AZ	5.54	4.56
Memphis, TN	3.27	3.29
El Paso, TX	1.18	2.71
San Francisco, CA	-0.67	-1.09
Baltimore, MD	1.80	1.89
Albuquerque, NM	1.02	1.50
Seattle, WA	0.42	-0.41
Chicago, IL	1.27	1.27
Boise, ID	0.67	0.24
Burlington, VT	0.69	0.07
Helena, MT	0.28	-0.59
Duluth, MN	0.23	-1.25
Fairbanks, AK	0.05	-1.91

Table 5.40. Annual energy savings for external roller shades – international locations (kWh/m²·yr).

Location	Actively Controlled Shutters	Schedule Control Shutters
Edmonton	-0.41	-2.27
Ottawa	0.46	-0.55
Vancouver	-0.27	-1.94
Stuttgart	-2.49	-4.20
Copenhagen	-0.25	1.30
Helsinki	-1.66	-2.33
Tampere	-1.62	-2.62
Lyon	-4.26	0.74
Marseille	-7.09	1.11
Nantes	-5.62	0.68
Paris	-4.16	0.11
London	-2.29	-5.20
Milan	-2.59	0.75
Naples	-2.12	0.50
Palermo	-0.24	0.01
Rome	-3.00	0.52

5.8 Exterior Light Shelves

Table 5.41. Annual energy savings for exterior light shelves (kBtu/sq ft·yr).

Location	Exterior Light Shelves
Miami, FL	0.60
Houston, TX	0.27
Phoenix, AZ	0.45
Memphis, TN	-0.11
El Paso, TX	-0.09
San Francisco, CA	-0.62
Baltimore, MD	-0.29
Albuquerque, NM	-0.59
Seattle, WA	-0.22
Chicago, IL	-0.37
Boise, ID	-0.42
Burlington, VT	-0.40
Helena, MT	-0.47
Duluth, MN	-0.62
Fairbanks, AK	-0.33

Table 5.42. Annual energy savings for exterior light shelves (kWh/m^2-yr).

Location	Exterior Light Shelves
Miami, FL	1.89
Houston, TX	0.86
Phoenix, AZ	1.43
Memphis, TN	-0.33
El Paso, TX	-0.27
San Francisco, CA	-1.96
Baltimore, MD	-0.91
Albuquerque, NM	-1.86
Seattle, WA	-0.68
Chicago, IL	-1.15
Boise, ID	-1.33
Burlington, VT	-1.26
Helena, MT	-1.47
Duluth, MN	-1.96
Fairbanks, AK	-1.04

Table 5.43. Annual energy savings for exterior light shelves – international locations (kWh/m^2-yr).

Location	Exterior Light Shelves
Edmonton	-0.02
Ottawa	-0.85
Vancouver	-0.98
Stuttgart	-2.25
Copenhagen	-2.34
Helsinki	-2.40
Tampere	-2.12
Lyon	-2.60
Marseille	-5.01
Nantes	-1.43
Paris	-5.01
London	-1.00
Milan	-1.74
Naples	-2.17
Palermo	-2.26
Rome	-1.99

5.9 Exterior Vertical Fins

Table 5.44. Annual energy savings for exterior vertical fins (kBtu/sq ft-yr).

Location	Vertical Fins
Miami, FL	0.74
Houston, TX	0.30
Phoenix, AZ	0.50
Memphis, TN	-0.19
El Paso, TX	-0.20
San Francisco, CA	-0.81
Baltimore, MD	-0.40
Albuquerque, NM	-0.80
Seattle, WA	-0.32
Chicago, IL	-0.49
Boise, ID	-0.60
Burlington, VT	-0.54
Helena, MT	-0.65
Duluth, MN	-0.81
Fairbanks, AK	-0.50

Table 5.45. Annual energy savings for exterior vertical fins (kWh/m^2-yr).

Location	Vertical Fins
Miami, FL	2.34
Houston, TX	0.93
Phoenix, AZ	1.57
Memphis, TN	-0.59
El Paso, TX	-0.62
San Francisco, CA	-2.56
Baltimore, MD	-1.28
Albuquerque, NM	-2.51
Seattle, WA	-1.01
Chicago, IL	-1.54
Boise, ID	-1.88
Burlington, VT	-1.71
Helena, MT	-2.04
Duluth, MN	-2.57
Fairbanks, AK	-1.58

Table 5.46. Annual energy savings for exterior vertical fins – international locations (kWh/m²·yr).

Location	Vertical Fins
Edmonton	-0.02
Ottawa	-0.86
Vancouver	-1.01
Stuttgart	-2.37
Copenhagen	-2.47
Helsinki	-2.47
Tampere	-2.14
Lyon	-2.69
Marseille	-4.17
Nantes	-1.86
Paris	-4.18
London	-1.03
Milan	-2.29
Naples	-1.85
Palermo	-1.94
Rome	-2.72

5.10 Energy Recovery Ventilator

Table 5.47. Annual energy savings for energy recovery ventilator (kBtu/sq ft·yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	1.04	1.22	1.48
Houston, TX	5.50	6.36	7.25
Phoenix, AZ	4.37	4.98	5.63
Memphis, TN	10.23	11.83	13.42
El Paso, TX	7.07	8.13	9.18
San Francisco, CA	11.53	13.27	14.96
Baltimore, MD	15.61	18.08	20.53
Albuquerque, NM	11.56	13.35	15.13
Seattle, WA	15.54	17.94	20.29
Chicago, IL	19.70	22.80	25.88
Boise, ID	17.17	19.86	22.51
Burlington, VT	23.38	27.07	30.71
Helena, MT	20.99	24.22	27.39
Duluth, MN	29.18	33.83	38.41
Fairbanks, AK	42.63	49.43	56.12

Table 5.48. Annual energy savings for energy recovery ventilator (kWh/m^2-yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	3.27	3.86	4.67
Houston, TX	17.33	20.06	22.85
Phoenix, AZ	13.78	15.72	17.74
Memphis, TN	32.27	37.30	42.32
El Paso, TX	22.31	25.64	28.95
San Francisco, CA	36.37	41.85	47.19
Baltimore, MD	49.22	57.00	64.75
Albuquerque, NM	36.47	42.10	47.70
Seattle, WA	49.00	56.57	63.98
Chicago, IL	62.12	71.91	81.60
Boise, ID	54.16	62.62	70.99
Burlington, VT	73.72	85.38	96.86
Helena, MT	66.19	76.37	86.39
Duluth, MN	92.03	106.69	121.11
Fairbanks, AK	134.44	155.87	176.96

5.11 Indirect Evaporative Cooling

Table 5.49. Annual energy savings for indirect evaporative cooling (kBtu/sq ft-yr).

Location	IDEC
Miami, FL	0.85
Houston, TX	0.84
Phoenix, AZ	12.97
Memphis, TN	2.20
El Paso, TX	7.86
San Francisco, CA	0.42
Baltimore, MD	2.62
Albuquerque, NM	6.01
Seattle, WA	1.00
Chicago, IL	3.81
Boise, ID	4.02
Burlington, VT	2.59
Helena, MT	2.88
Duluth, MN	1.53
Fairbanks, AK	1.07

Table 5.50. Annual energy savings for indirect evaporative cooling (kWh/m^2-yr).

Location	IDEC
Miami, FL	2.67
Houston, TX	2.66
Phoenix, AZ	40.89
Memphis, TN	6.94
El Paso, TX	24.78
San Francisco, CA	1.33
Baltimore, MD	8.27
Albuquerque, NM	18.96
Seattle, WA	3.17
Chicago, IL	12.00
Boise, ID	12.69
Burlington, VT	8.16
Helena, MT	9.08
Duluth, MN	4.83
Fairbanks, AK	3.39

5.12 Hybrid Evaporative Cooling

Table 5.51. Annual energy savings for hybrid evaporative cooling (kBtu/sq ft-yr).

Location	IDEC
Miami, FL	5.27
Houston, TX	4.07
Phoenix, AZ	14.76
Memphis, TN	3.35
El Paso, TX	8.75
San Francisco, CA	1.42
Baltimore, MD	3.54
Albuquerque, NM	6.51
Seattle, WA	1.73
Chicago, IL	4.18
Boise, ID	5.95
Burlington, VT	5.04
Helena, MT	3.84
Duluth, MN	4.91
Fairbanks, AK	6.03

Table 5.52. Annual energy savings for hybrid evaporative cooling (kWh/m^2-yr).

Location	IDEC
Miami, FL	16.61
Houston, TX	12.82
Phoenix, AZ	46.56
Memphis, TN	10.55
El Paso, TX	27.60
San Francisco, CA	4.48
Baltimore, MD	11.15
Albuquerque, NM	20.54
Seattle, WA	5.45
Chicago, IL	13.17
Boise, ID	18.77
Burlington, VT	15.90
Helena, MT	12.11
Duluth, MN	15.48
Fairbanks, AK	19.01

5.13 DOAS with FCU

Table 5.53. Annual energy savings for DOAS with FCU (kBtu/sq ft-yr).

Location	DOAS with Fan-Coil
Miami, FL	6.33
Houston, TX	6.62
Phoenix, AZ	8.42
Memphis, TN	10.03
El Paso, TX	6.27
San Francisco, CA	5.35
Baltimore, MD	15.53
Albuquerque, NM	12.14
Seattle, WA	13.14
Chicago, IL	22.06
Boise, ID	19.25
Burlington, VT	27.11
Helena, MT	25.04
Duluth, MN	35.71
Fairbanks, AK	54.56

Table 5.54, Annual energy savings for DOAS with FCU (kWh/m^2-yr).

Location	DOAS with Fan-Coil
Miami, FL	19.96
Houston, TX	20.88
Phoenix, AZ	26.56
Memphis, TN	31.64
El Paso, TX	19.77
San Francisco, CA	16.88
Baltimore, MD	48.97
Albuquerque, NM	38.29
Seattle, WA	41.43
Chicago, IL	69.56
Boise, ID	60.70
Burlington, VT	85.50
Helena, MT	78.96
Duluth, MN	112.60
Fairbanks, AK	172.07

5.14 DOAS with Radiant Heating and Cooling

Table 5.55. Annual energy savings for DOAS with radiant heating and cooling (kBtu/sq ft-yr).

Location	Radiant System
Miami, FL	25.72
Houston, TX	26.94
Phoenix, AZ	26.56
Memphis, TN	33.76
El Paso, TX	22.33
San Francisco, CA	22.74
Baltimore, MD	44.92
Albuquerque, NM	33.05
Seattle, WA	34.24
Chicago, IL	58.34
Boise, ID	47.95
Burlington, VT	67.85
Helena, MT	57.67
Duluth, MN	84.05
Fairbanks, AK	129.45

Table 5.56. Annual energy for DOAS with radiant heating and cooling (kWh/m^2-yr).

Location	Radiant System
Miami, FL	81.11
Houston, TX	84.95
Phoenix, AZ	83.77
Memphis, TN	106.47
El Paso, TX	70.43
San Francisco, CA	71.70
Baltimore, MD	141.66
Albuquerque, NM	104.24
Seattle, WA	107.99
Chicago, IL	183.98
Boise, ID	151.22
Burlington, VT	213.97
Helena, MT	181.87
Duluth, MN	265.06
Fairbanks, AK	408.22

Table 5.57. Annual energy for DOAS with radiant heating and cooling – international locations (kWh/m^2-yr).

Location	Radiant System
Edmonton	0.03
Ottawa	2.16
Vancouver	2.52
Stuttgart	5.53
Copenhagen	11.55
Helsinki	19.95
Tampere	19.18
Lyon	20.23
Marseille	65.85
Nantes	-10.28
Paris	83.95
London	32.79
Milan	42.92
Naples	70.52
Palermo	76.74
Rome	37.19

5.15 Ground Source Heat Pumps

Table 5.58. Annual energy saving for GSHPs (kBtu/sq ft-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	26.93	26.75	26.59	26.41	26.21	26.01
Houston, TX	30.87	30.83	30.73	30.60	30.45	30.29
Phoenix, AZ	26.49	26.62	26.73	26.78	26.79	26.75
Memphis, TN	37.51	39.94	40.18	40.02	39.81	39.57
El Paso, TX	26.02	26.34	26.47	26.59	26.64	26.61
San Francisco, CA	26.04	29.45	29.35	29.16	28.94	28.70
Baltimore, MD	42.50	50.30	51.59	51.49	51.32	51.10
Albuquerque, NM	32.19	37.57	38.87	38.73	38.52	38.27
Seattle, WA	28.97	36.70	39.23	39.30	39.10	38.88
Chicago, IL	52.24	59.44	63.44	65.41	65.55	65.34
Boise, ID	44.41	51.57	54.07	54.50	54.32	54.08
Burlington, VT	54.87	60.11	63.62	66.64	69.17	71.27
Helena, MT	48.95	52.11	54.23	56.07	57.59	58.89
Duluth, MN	65.18	66.79	67.82	68.64	69.25	69.78
Fairbanks, AK						

Table 5.59. Annual energy savings for GSHPs (kWh/m^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	84.91	84.36	83.84	83.29	82.67	82.02
Houston, TX	97.35	97.23	96.89	96.49	96.04	95.52
Phoenix, AZ	83.52	83.95	84.30	84.46	84.48	84.34
Memphis, TN	118.29	125.97	126.70	126.21	125.55	124.80
El Paso, TX	82.06	83.06	83.47	83.85	84.02	83.91
San Francisco, CA	82.11	92.86	92.56	91.95	91.25	90.52
Baltimore, MD	134.02	158.62	162.69	162.39	161.83	161.14
Albuquerque, NM	101.50	118.48	122.59	122.14	121.46	120.69
Seattle, WA	91.36	115.72	123.72	123.95	123.31	122.59
Chicago, IL	164.74	187.44	200.06	206.28	206.72	206.05
Boise, ID	140.04	162.62	170.50	171.87	171.29	170.54
Burlington, VT	173.05	189.55	200.64	210.16	218.12	224.77
Helena, MT	154.38	164.33	171.03	176.80	181.62	185.72
Duluth, MN	205.55	210.64	213.88	216.46	218.38	220.06
Fairbanks, AK						

5.16 Reheat Using Condenser Waste Heat

Table 5.60. Annual energy savings for reheat using condenser waste heat (kBtu/sq ft-yr).

Location	Heat Recovery
Miami, FL	9.03
Houston, TX	7.17
Phoenix, AZ	0.09
Memphis, TN	3.36
El Paso, TX	0.14
San Francisco, CA	0.04
Baltimore, MD	2.36
Albuquerque, NM	0.01
Seattle, WA	0.03
Chicago, IL	0.90
Boise, ID	0.00
Burlington, VT	0.80
Helena, MT	0.00
Duluth, MN	0.25
Fairbanks, AK	0.01

Table 5.61. Annual energy savings for reheat using condenser waste heat (kWh/m^2-yr).

Location	Heat Recovery
Miami, FL	97.21
Houston, TX	77.13
Phoenix, AZ	1.01
Memphis, TN	36.18
El Paso, TX	1.51
San Francisco, CA	0.41
Baltimore, MD	25.44
Albuquerque, NM	0.11
Seattle, WA	0.33
Chicago, IL	9.74
Boise, ID	0.00
Burlington, VT	8.57
Helena, MT	0.01
Duluth, MN	2.69
Fairbanks, AK	0.06

5.17 Grey Water Heat Recovery

Table 5.62. Annual energy savings for reheat using grey water heat recovery (kBtu/sq ft·yr).

Location		
Miami, FL		
Houston, TX		
Phoenix, AZ		
Memphis, TN		
El Paso, TX		
San Francisco, CA		
Baltimore, MD		
Albuquerque, NM		
Seattle, WA		
Chicago, IL		
Boise, ID		
Burlington, VT		
Helena, MT		
Duluth, MN		
Fairbanks, AK		

Table 5.63. Annual energy savings for reheat using grey water heat recovery (kWh/m^2·yr).

Location		
Miami, FL		
Houston, TX		
Phoenix, AZ		
Memphis, TN		
El Paso, TX		
San Francisco, CA		
Baltimore, MD		
Albuquerque, NM		
Seattle, WA		
Chicago, IL		
Boise, ID		
Burlington, VT		
Helena, MT		
Duluth, MN		
Fairbanks, AK		

5.18 Summary of Energy Model Schedules

Table 5.64. Hourly schedule values (hours 1-12).

Schedule	Type	Through	Day of Week	Hour of Day 1	2	3	4	5	6	7	8	9	10	11	12
Seasonal-Reset-Supply-Air-Temp-Sched	Temperature	3/31	All	16	16	16	16	16	16	16	16	16	16	16	16
		9/30	All	13	13	13	13	13	13	13	13	13	13	13	13
		12/31	All	16	16	16	16	16	16	16	16	16	16	16	16
ALWAYS_ON	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ALWAYS_OFF	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
Dual Zone Control Type Sch	Control Type	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
HTGSETP_SCH	Temperature	12/31	SummerDesign	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WinterDesign	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WD	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WE, Holiday	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			Other	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
CLGSETP_SCH	Temperature	12/31	SummerDesign	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WinterDesign	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WD	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WE, Holiday	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			Other	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
humidity schedule	Any Number	12/31	All	50	50	50	50	50	50	50	50	50	50	50	50
MinOA_Sched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
NOTHING	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
CONSTANT	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_OCC_SCH	Fraction	12/31	WD, SummerDesign	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.2	0.2	0.2	0.2
			Sat, WinterDesign	0.75	0.75	0.75	0.75	0.75	0.75	0.65	0.6	0.2	0.2	0.2	0.2
			Sun, Hol, Other	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.2	0.2	0.2	0.2
BLDG_LIGHT_SCH	Fraction	12/31	WD, SummerDesign	0.25	0.25	0.25	0.25	0.25	0.25	0.4	0.7	0.25	0.25	0.25	0.25
			Sat, WinterDesign	0.25	0.25	0.25	0.25	0.25	0.25	0.3	0.25	0.25	0.25	0.25	0.25
			Sun, Hol, Other	0.25	0.25	0.25	0.25	0.25	0.25	0.3	0.25	0.25	0.25	0.25	0.25
lobby Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_left Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_right Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
laundry Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_EQUIP_SCH	Fraction	12/31	WD, SummerDesign	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3
			Sat, WinterDesign	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.3
			Sun, Hol, Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5
lobby Equipt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
lobby Occupt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	0	0	0	0
			Sat	1	1	1	1	1	1	1	1	0	0	0	0
			Sun	1	1	1	1	1	1	1	1	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Occupt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	0	0	0	0
			Sat	1	1	1	1	1	1	1	1	0	0	0	0
			Sun	1	1	1	1	1	1	1	1	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
Activity level stair_left	Any Number	12/31	WD	160	160	160	160	160	160	160	160	160	160	160	160
			Sat	160	160	160	160	160	160	160	160	160	160	160	160
			Sun	160	160	160	160	160	160	160	160	160	160	160	160

Schedule	Type	Through	Day of Week	Hour of Day 1	2	3	4	5	6	7	8	9	10	11	12
			Other	160	160	160	160	160	160	160	160	160	160	160	160
stair_right Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_right Occupt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	0	0	0	0
			Sat	1	1	1	1	1	1	1	1	0	0	0	0
			Sun	1	1	1	1	1	1	1	1	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
MINOA_LAUNDRY_SCHED	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlenumHtg-SetP-Sch	Temperature	12/31	All	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
PlenumClg-SetP-Sch	Temperature	12/31	All	40	40	40	40	40	40	40	40	40	40	40	40
Zone Control Type Schedule	Control Type	12/31	SummerDesign	2	2	2	2	2	2	2	2	2	2	2	2
			WinterDesign	1	1	1	1	1	1	1	1	1	1	1	1
			Other	4	4	4	4	4	4	4	4	4	4	4	4
FanAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HVACOperationSchd	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
FanmodeSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
CoolingCoilAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	0	0	0	0
ReheatCoilAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	0	0	0	0
INFIL_SCH	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
Room solar hot water (SHW) Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Room SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Room SHW Temp Schedule	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
Room SHW Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
laundry SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry SHW Temp Schedule	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
laundry SHW Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
RoomSHW	Fraction	12/31	All	0	0	0	0	0	0	0.1	0.4	0.2	0	0	0
LaundrySHW	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlantOnSched	Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 1	COMPACT HVAC Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 4	COMPACT HVAC Any Number	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
WORK_EFF_SCH	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	Hour of Day 1	2	3	4	5	6	7	8	9	10	11	12
AIR_VELO_SCH	Any Number	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING_SCH	Any Number	04/30	All	1	1	1	1	1	1	1	1	1	1	1	1
		09/30	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ACTIVITY_SCH	Any Number	12/31	All	120	120	120	120	120	120	120	120	120	120	120	120
units_gr_lf Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_lf Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_lf Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_lf Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_gr_rt Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_rt Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_rt Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_rt Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_s_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_s_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_s_g Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_s_g Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_n_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_n_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_n_g Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_n_g Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_s Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_s Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_n Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_n Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_s Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_s Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_n Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_n Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
laundry Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
laundry Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
SWHSys1-Loop-Temp-Schedule	Temperature	12/31	All	54	54	54	54	54	54	54	54	54	54	54	54
SWHSys1 Water Heater Setpoint Temperature Schedule Name	Temperature	12/31	All	60	60	60	60	60	60	60	60	60	60	60	60
SWHSys1 Water Heater Ambient Temperature Schedule Name	Temperature	12/31	All	22	22	22	22	22	22	22	22	22	22	22	22

Table 5.65. Hourly schedule values (hours 12-24).

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
Seasonal-Reset-Supply-Air-Temp-Sched	Temperature	3/31	All	16	16	16	16	16	16	16	16	16	16	16	16
		9/30	All	13	13	13	13	13	13	13	13	13	13	13	13
		12/31	All	16	16	16	16	16	16	16	16	16	16	16	16
ALWAYS_ON	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ALWAYS_OFF	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
Dual Zone Control Type Sch	Control Type	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
HTGSETP_SCH	Temperature	12/31	SummerDesign	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WinterDesign	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WD	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WE, Holiday	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			Other	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
CLGSETP_SCH	Temperature	12/31	SummerDesign	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WinterDesign	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WD	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WE, Holiday	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			Other	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
humidity schedule	Any Number	12/31	All	50	50	50	50	50	50	50	50	50	50	50	50
MinOA_Sched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
NOTHING	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
CONSTANT	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_OCC_SCH	Fraction	12/31	WD, SummerDesign	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.7	0.7	0.8
			Sat, WinterDesign	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.5	0.75
			Sun, Hol, Other	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.5	0.75
BLDG_LIGHT_SCH	Fraction	12/31	WD, SummerDesign	0.25	0.25	0.25	0.25	0.25	0.25	0.7	0.7	0.7	0.7	0.5	0.4
			Sat, WinterDesign	0.25	0.25	0.25	0.25	0.25	0.25	0.7	0.7	0.7	0.7	0.5	0.4
			Sun, Hol, Other	0.25	0.25	0.25	0.25	0.25	0.25	0.7	0.7	0.7	0.7	0.5	0.4
lobby Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_left Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_right Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
laundry Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_EQUIP_SCH	Fraction	12/31	WD, SummerDesign	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.6	0.7	0.7	0.5	0.3
			Sat, WinterDesign	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5
			Sun, Hol, Other	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3
lobby Equipt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
lobby Occupt	Fraction	12/31	WD	0	0	0	0	0	1	1	1	1	1	1	1
			Sat	0	0	0	0	0	1	1	1	1	1	1	1
			Sun	0	0	0	0	0	1	1	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Occupt	Fraction	12/31	WD	0	0	0	0	0	1	1	1	1	1	1	1
			Sat	0	0	0	0	0	1	1	1	1	1	1	1
			Sun	0	0	0	0	0	1	1	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
Activity level stair_left	Any Number	12/31	WD	160	160	160	160	160	160	160	160	160	160	160	160
			Sat	160	160	160	160	160	160	160	160	160	160	160	160
			Sun	160	160	160	160	160	160	160	160	160	160	160	160
			Other	160	160	160	160	160	160	160	160	160	160	160	160
stair_right Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_right Occupt	Fraction	12/31	WD	0	0	0	0	0	1	1	1	1	1	1	1
			Sat	0	0	0	0	0	1	1	1	1	1	1	1
			Sun	0	0	0	0	0	1	1	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
MINOA_LAUNDRY_SCHED	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlenumHtg-SetP-Sch	Temperature	12/31	All	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
PlenumClg-SetP-Sch	Temperature	12/31	All	40	40	40	40	40	40	40	40	40	40	40	40
Zone Control Type Schedule	Control Type	12/31	SummerDesign	2	2	2	2	2	2	2	2	2	2	2	2
			WinterDesign	1	1	1	1	1	1	1	1	1	1	1	1

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
			Other	4	4	4	4	4	4	4	4	4	4	4	4
FanAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HVACOperationSchd	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
FanmodeSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
CoolingCoilAvailSched	Fraction	12/31	All	0	0	0	0	0	1	1	1	1	1	1	1
ReheatCoilAvailSched	Fraction	12/31	All	0	0	0	0	0	1	1	1	1	1	1	1
INFIL_SCH	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
Room SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Room SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Room SHW Temp Schedule	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
Room SHW Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
laundry SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry SHW Temp Schedule	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
laundry SHW Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
RoomSHW	Fraction	12/31	All	0	0	0	0	0	0	0.1	0.1	0.1	0	0	0
LaundrySHW	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlantOnSched	Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 1	COMPACT HVAC Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 4	COMPACT HVAC Any Number	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
WORK_EFF_SCH	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
AIR_VELO_SCH	Any Number	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING_SCH	Any Number	04/30	All	1	1	1	1	1	1	1	1	1	1	1	1
		09/30	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ACTIVITY_SCH	Any Number	12/31	All	120	120	120	120	120	120	120	120	120	120	120	120

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
units_gr_lf Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_lf Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_lf Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_lf Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_gr_rt Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_rt Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_rt Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_rt Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_s_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_s_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_s_g Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_s_g Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_n_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_n_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_n_g Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_n_g Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_s Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_s Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_n Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_n Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
units_3_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_s Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_s Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_n Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_n Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
laundry Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry Water Equipment Temp Schedule	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
laundry Water Equipment Hot Supply Temp Schedule	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
SWHSys1-Loop-Temp-Schedule	Temperature	12/31	All	54	54	54	54	54	54	54	54	54	54	54	54
SWHSys1 Water Heater Setpoint Temperature Schedule Name	Temperature	12/31	All	60	60	60	60	60	60	60	60	60	60	60	60
SWHSys1 Water Heater Ambient Temperature Schedule Name	Temperature	12/31	All	22	22	22	22	22	22	22	22	22	22	22	22

5.19 Office Buildings

5.19.1 Executive Summary

Retrofitting existing buildings for improved energy efficiency is not an easy task. Sorting through the range of options and selecting the most effective and cost-efficient measures to implement is difficult. This report provides one piece of the picture by evaluating the energy performance of 15 ECMs applied to an existing administration building in 15 US locations, 3 Canadian locations, and 13 European locations. Similar reports include the results for a barracks and an industrial building. This work was completed in support of the IEA ECBCS Programme, Annex 46: “Holistic Assessment Toolkit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (IEA 2010).

The premise of the project was to create baseline models for three building types (barracks, administrative building, and industrial facility) that are somewhat representative of existing buildings in the military and evaluate the performance of several ECMs in several locations representing a variety of climates using annual hourly whole building simulations. The baseline models are not intended to represent any one particular building, but are meant to be rough representations of typical buildings. Several assumptions had to be made to build the models and usually with very little knowledge of the buildings represented with this study. The results presented in this report should be viewed as a first screening to help understand relative performance of the ECMs within the limits of the assumptions applied in the modeling. When retrofitting a building, these results will help guide the building manager in selecting the most promising measures to consider. It is anticipated that additional analyses will be completed to understand the performance of the selected ECMs as applied to each building and economic situation.

Table 5.66 lists the 15 ECMs included in this report. There are eight envelope related measures and seven HVAC measures.

Table 5.66. ECMs included in the report.

Energy Conservation Measure	Energy Conservation Measure
Increased Wall Insulation	ERVs
Increased Roof Insulation	Indirect Evaporative Cooling
Attic Insulation	Hybrid Evaporative Cooling
Cool Roofs	DOAS with FCUs
Building Airtightness	DOAS with Radiant Heating and Cooling
Advanced Windows	GSHPs
Overhangs	Reheat Using Condenser Waste Heat
Exterior Vertical Fins	

For heating climates, the highest energy savings were achieved by ECMs that reduced the heating loads through reducing the envelope thermal conduction, reducing outside air into the building, and energy recovery. Reducing infiltration had a significant impact and combining insulation with improved airtightness provided very strong energy savings in cold climates. Energy recovery on the HVAC system was also a significant energy-saving ECM in the cold climates.

6 Technologies

6.1 Industrial

Cool Roofs

Application

Industrial buildings

Category

Building envelope

Concept

Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single-ply, liquid-applied, and metal panels. For roofing products, the values for solar reflectance and thermal emittance shall be determined by a laboratory accredited by a nationally recognized accreditation organization, such as the Cool Roof Rating Council CRRC-1 Product Rating Program, and shall be labeled and certified by the manufacturer.

To be considered “cool,” a roof must have a solar reflectance of 0.67 when tested in accordance with ASTM C1549, ASTM E903, or ASTM E1918 and, in addition, a minimum thermal emittance of 0.75 when tested in accordance with ASTM C1371 or ASTM E408, or a minimum Solar Reflective Index of 78 when determined in accordance with the Solar Reflectance Index method in ASTM E1980 where standard white is SRI = 100 and standard black has SRI = 0. An SRI can be determined by the following equations:

SRI = 123.97 – 141.35(x) + 9.655(x2)

where:

$$x = \frac{20.797 \times \alpha - 0.603 \times \varepsilon}{9.5205 \times \varepsilon + 12.0}$$

In which α is the solar absorbance (= 1 – solar reflectance) and ε is the thermal emissivity, which were derived from ASTM E1980 assuming a medium wind speed.

Description

Roofs are vulnerable to solar gain in summer and heat loss in winter. Dark, non-reflective roofing surfaces create heat island effects by absorbing energy from the sun and radiating it as heat. Solar reflectance is the fraction of solar energy that a roof reflects. Thermal emittance is a measure of the roof’s ability to radiate any heat absorbed back into the air, rather than into the building below. Both properties are measured on a scale of zero to one; the higher the values, the cooler the roof.

High-reflectance and high thermal emittance roofs (often referred to as “cool roofs”) can reflect heat instead of absorbing it, thereby reducing the building's interior temperature and the running time of the air-conditioning system. In winter, "cool" roofs might have a negative effect on the building energy consumption by increasing load on the heating system compared to standard roofs.

Types of cool roofs

Cool roof options exist for most traditional roofing materials. Each cool roof product offers a different level of reflectance and emissivity, as well as different costs. For flat-roofed buildings, metal roofs, coatings and membranes are feasible options. For sloped roofed buildings, metal roofs, reflective tiles and architectural shingles are feasible and more aesthetically pleasing (Figure 6.1).

Figure 6.1. TEMF building at Fort Bliss with a reflective white metal roof.

Metal roofs

Several metal roof products have earned the ENERGY STAR® label, thanks to the development of pigments that make metal roofs highly reflective. Cool metal roof products are extremely durable and, at a cost of approximately $2 per square foot, are generally less expensive than reflective tiles.

Membranes (single-ply)

Figure 6.2. Duro-Last Cool Zone® roofing system with a single-ply, 40 mil membrane roofing material and a polyvinyl chloride polymer blend demonstrated through the Navy Technology Validation (Techval) Program.

These flexible or semi-flexible pre-fabricated sheets consist of EPDM (ethylene-propylene-dieneterpolymer), PVC (polyvinyl chloride) or TPO (thermoplastic polyolefin). They can be applied over existing low-slope roofs using heat-sealed seams or caulk. Some are self-cleaning and mold resistant. The cost of single-ply roofing varies from $1.50 to $3 per square foot, including materials, installation and reasonable preparation work (Figure 6.2).

Coatings

Elastomeric, polyurethane or acrylic liquids are the consistency of thick paint. They can be applied over existing low-slope roofs with a roller or power sprayer and last from 10 to 20 years. Cool roof coatings may cost between $0.75 and $1.50 per square foot for materials and labor.

Reflective tiles

Clay or concrete tiles can incorporate special pigments that reflect solar energy while mimicking traditional colors, including green, brown and terra cotta. These tiles are extremely durable and especially suitable for new homes or for construction projects where a white roof might be aesthetically unacceptable (Figure 6.3). They cost approximately $3 per square foot.

Architectural shingles

These products resemble traditional roofing shingles but have the reflective properties characteristic of other cool roof materials. The shingles are available in a variety of colors, and the difference in cost between architectural shingles and conventional asphalt shingles is minimal (Figure 6.4). Reflective "cool roofs" which reduce the building cooling load, are available in many colors besides white, though roof color, has an impact on energy usage. Table 6.1 lists the reflectance and emittance values by roof type and color for new and aged roofing materials (ORNL).

(a) (b)

Figure 6.3. Reflective roof coating (a), and reflective roof membrane (b).

(a) (b) (c)

Figure 6.4. White metal roof (a), roof tile coatings (b), and architectural shingles (c) (http://www.elkcorp.com).

Table 6.1. Characteristics of reflective roofing materials.

Roofing Type	Color	New Solar Reflectance	Aged Solar Reflectance	New Thermal Emittance	SRI (ASTM E1980
Roof Coatings	White	0.70 – 0.85	0.50 –0.65	0.85	84 – 106
Roof Coatings	Grey or tan	0.70	0.50	0.85	84
Roof Coatings	Terra cotta or brown	0.40	0.30	0.85	43
Roof Coatings	Aluminized	0.50	0.40	0.50	42
Metal Paint	Red	0.25	0.25	0.83	22
Metal Paint	Terra cotta	0.35	0.35	0.83	36
Metal Paint	Bright red	0.35	0.35	0.83	36
Metal Paint	Beige/off white	0.55	0.55	0.83	63
Metal Paint	Tan	0.45	0.45	0.83	49
Metal Paint	Dark blue	0.25	0.25	0.83	22
Metal Paint	Medium to light blue	0.32	0.32	0.83	32
Metal Paint	Dark brown	0.25	0.25	0.83	22
Metal Paint	Medium to light brown	0.32	0.32	0.83	32
Metal Paint	Dark green	0.25	0.25	0.83	22
Metal Paint	Medium to light green	0.32	0.32	0.83	32
Metal Paint	White	0.65	0.65	0.83	77
Metal Paint	Bright white	0.70	0.70	0.83	84
Metal Paint	Black	0.25	0.25	0.83	22
Metal Paint	Dark grey	0.25	0.25	0.83	22
Metal Paint	Medium to light grey	0.35	0.35	0.83	36
Metal Paint	Pearlescent colors	0.35	0.35	0.75	32
Galvalume	Unpainted	0.65	0.55	0.05	45
Copper Metal	Unpainted	0.85	0.18	0.03	89
Galvanized Steel	Unpainted	0.40	0.20	0.50	26
EPDM Membrane	Black	0.05	0.10	0.85	0
TPO Membrane	White	0.80	0.60	0.85	99
TPO Membrane	Grey	0.50	0.40	0.85	57
PVC Membrane	White	0.80	0.60	0.85	99
PVC Membrane	Grey	0.50	0.40	0.85	57
Asphalt Shingle	Dark color	0.10	0.10	0.85	4
Asphalt Shingle	Light color	0.25	0.25	0.85	23
Modified Bitumen Cap Sheet	Dark color	0.10	0.10	0.85	4
Modified Bitumen Cap Sheet	Light color	0.25	0.25	0.85	23
Modified Bitumen Cap Sheet	White	0.50-0.60	0.40 – 0.45	0.85	57 - 71

Potential energy savings (qualitative)

Cool roofs are typically only installed during new construction or planned re-roofing projects. The cost of a cool roof versus a standard roof depends on the type of cool roof selected. In the case of industrial ventilated and heated (but not air-conditioned buildings), “cool roofs” reduce indoor air temperature during the hot part of the year and therefore improve worker’s comfort and productivity, and are cost effective in all climates. In cold climates, a cool roof can increase the heating load, since the solar radiation reflected by the cool roof would otherwise be absorbed, resulting in a warmer roof.

Potential energy savings (quantitative)

The cost of a cool roof versus a standard roof depends on the type of cool roof selected. Some cool roof products used for industrial buildings, e.g., metal roofs or membrane roofs, cost about the same as their traditional counterparts while others cost slightly more. Five factors affect the economics of a cool roof technology:

1. The solar reflectance and thermal emittance of the roof
2. The 'aged' solar reflectance of the roof. (Most roofing materials lose about 20% of their initial reflectance over time.)
3. The incremental initial cost (if any) of the cool roof.
4. The incremental cost (if any) of maintaining the cool roof.
5. The potential increase in the life expectancy of the roof.
6. The first three factors affect the simple payback calculation. All five factors affect the life cycle cost calculation. Energy savings and annual savings in productivity were analyzed by modeling a 50,000 sq ft (4645.152 m2) typical metal building with 20 ft. (6.1 m) high walls. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20 ft. (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.The cool roof was evaluated by direct comparison of the total building energy use reported by the base-case EnergyPlus simulation program output with the total building energy use reported by the cool roof-case simulation output. The cool roof-case results were generated by changing only those input parameters in the base case input file that were directly related to the cool roof.

Energy savings and payback calculation assumptions

Energy savings and payback analysis were based on cool roof premiums of $0.10/sq ft to $1.00/sq ft As mentioned before, a number of cool roof technologies are available at no premium. These technologies should be applied whenever possible, since their payback is immediate. Table 6.2 lists the roof parameters used to compare the two roofs.

Table 6.2. Performance for cool roof options.

	Solar Reflectance	Infrared Emittance
Cool Roof	0.82	0.92
Regular Roof	0.15	0.9

Simulation results

Since the cool roof technology saves energy only during the cooling season, and since the fans were required to run continuously during hours of operation, no energy savings are shown for this particular building. However, industrial buildings that rely entirely on ventilation air to maintain thermal comfort in the space may ‘overheat’, resulting in lost productivity and work stoppage. For these buildings, the 'cool roof' can improve thermal comfort in the space and may result in increased productivity. To completely account for the impact of the cool roof, a comfort analysis with some assessment of worker productivity is required. The ISO standard on thermal comfort (ISO 7730) specifies the 'wet bulb globe temperature' (WBGT), as the standard metric for determining the suitability of hot work environments. WBGT is calculated in EnergyPlus as the weighted average of the globe temperature and the natural wet bulb temperature. The natural wet bulb temperature measures the evaporative cooling effect of a wet bulb thermometer in natural convection.

The cool roof lowers the globe temperature (by lowering both the ceiling temperature and the air temperature, and improves both worker comfort and productivity. The **American Conference of Government Industrial Hygienists provides criteria for Heat Stress Exposure (WBGT values) and specifies required rest time for each hour that the WBGT exceeds certain thre**sholds. This criterion was used to calculate lost productivity for the year. As shown in Figures 6.5 and 6.6, the cool roof reduced work stoppages due to overheating of the ventilated building in every climate. In hot climates, the economic losses due to building overheating were very large reaching over 3500 hours for the hottest climate. This large number accounts for the total number of work-hours for the entire work force for the year.

The simulation results showed that for ventilated industrial buildings with high internal heat gains, the cool roof quickly paid for itself in every climate. At the highest premium level evaluated ($1.00/sq ft), the payback was less than 2.5 years (Figure 6.7). This was entirely a result of the calculated increase in productivity due to the cool roof. Figure 6.7 shows the expected payback for ventilated buildings with a fully burdened labor rate of $40/hour. The payback is immediate when cool metal painted roofs of membrane roofs are installed.

Level of maturity

5-20 years

Impact on indoor air quality and thermal comfort

For industrial buildings with only heating and ventilation, cool roofs can improve the comfort conditions (and hence productivity) in the space.

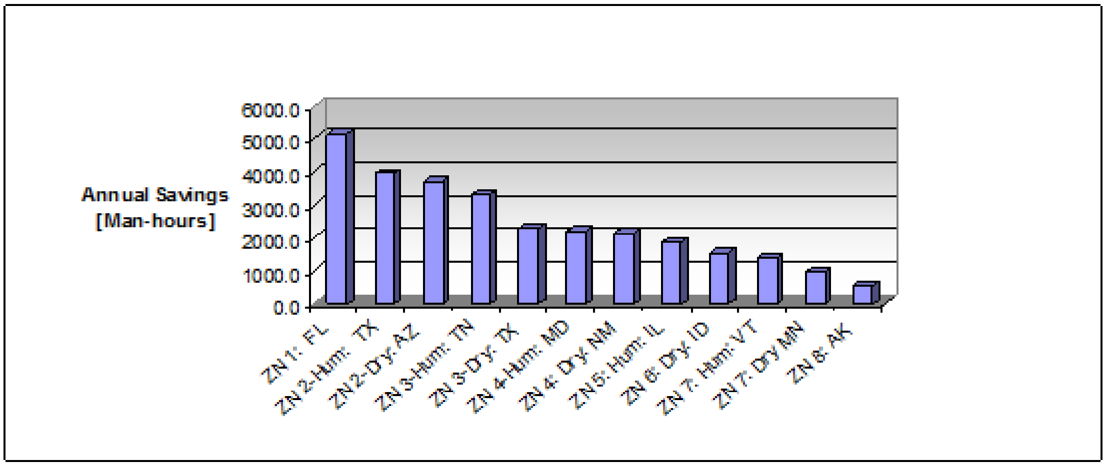

Figure 6.5. Annual savings in productivity due to cool roof.

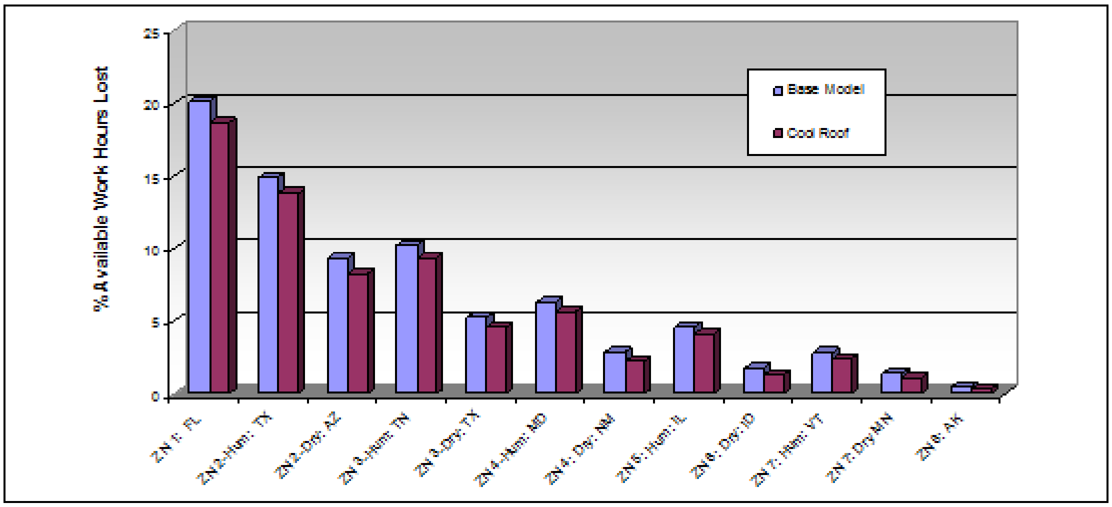

Figure 6.6. Percentage of available work hours lost annually due to overheating.

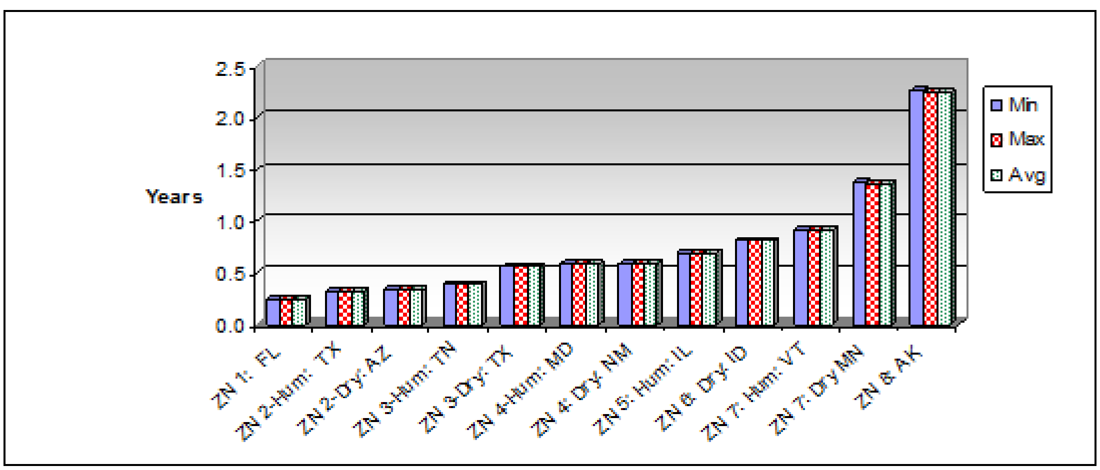

Figure 6.7. Estimated payback based on $1.00/sq ft cool roof cost premium for high, medium and low energy rates.

Climatic conditions necessary

In colder climates (DOE Zones 6-8), the amount of energy cost savings for a cool roof may be significantly less than in warmer climates and can be offset by increased energy use for heating.

In the case of industrial ventilated and heated (but not air-conditioned buildings), "cool roofs" are cost effective in all climates. They reduce indoor air temperature during the hot part of the year and therefore improves worker's comfort and productivity.

Contacts and major manufacturers

For specific projects use the Department of Energy's Cool Roof Calculator to calculate savings associated with cool roof technologies. List of the Energy Star "cool" roofing materials and manufacturers can be obtained from the following website:
http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_products

Also, a list of cool roof manufacturers and suppliers can be obtained from the Cool Roofs Rating Council Web site at: www.coolroofs.org

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Daylighting Application

Category

Industrial

Lighting

Concept

Installing skylights to reducing lighting costs (Figure 6.8) is not a new concept. Skylight technology, however, has advanced significantly in recent years. Modern “passive” skylights include a reflective tube that channels the light into the work area and a lens that diffuses the light evenly to produce a uniformly illuminated area. “Active” systems may include a rotating mirror assembly that tracks the sun.

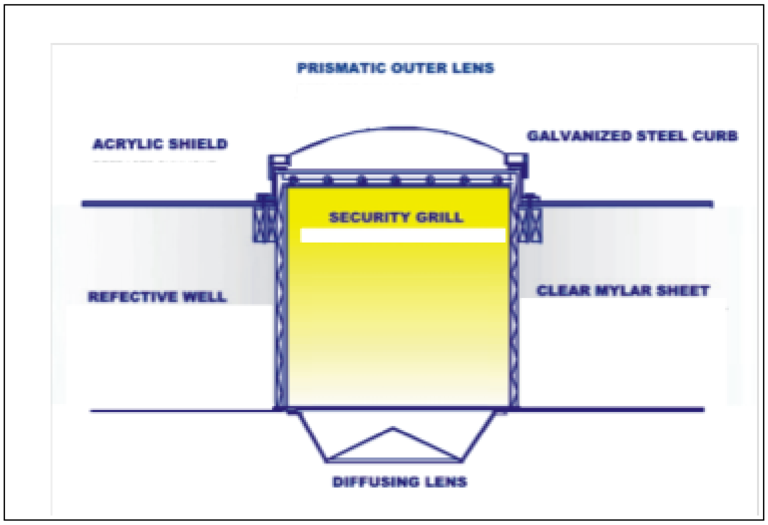
To automatically dim the lights, a photoelectric sensor is used to measure the amount of light in a zone. If the specified amount of light has been reached the controller turns off a bank of lights. Systems can be obtained to control only lights near windows or an entire building.

Small controllers can be used to control the banks of lights near windows and larger systems can control an entire building that is illuminated by natural lighting. The controls can be set to dim the lights once a certain level of light has been achieved. Proper lighting levels can be found in the IESNA Lighting Ready Reference. Typically, controls systems perform either “step” dimming that simply turns off certain banks of lights, or linear dimming which dims the lights until a minimum power level has been reached. Linear dimming, however, requires special dimming ballasts that are quite expensive and less efficient than standards ballasts above 50%.

Description

Electronic lighting is a major energy consumer in commercial buildings. In the base case for the industrial building roughly, 9% of the electricity consumed goes towards lighting. The energy used by lights is also discharged to the zone through heat, which must be removed by the air conditioning system during the cooling months, but can actually help warm the building during the heating months.

Figure 6.8. Warehouse application without (left) and with (right) skylights.



Source: www.daylighttechnology.com

Figure 6.9. Detailed schematic of modern skylight installation.

One of the best ways to decrease electricity used for electronic lighting is to use natural daylighting whenever possible and turn lights on only when needed. In the absence of attics and “drop ceilings,” retrofitting skylights (Figure 6.9) to an industrial building can be cost effective and relatively straightforward. The lights can be switched manually, but the most reliable and efficient way is to use an automatic control system.

Energy Savings (Qualitative)

Energy savings depend primarily on two factors: the available daylighting and the daytime electric lighting load that is replaceable. Industrial applications tend to be prime candidates for skylight retrofits due to the ease of installation.

Energy Savings (Quantitative)

Potential savings depend on the available daylight at the candidate location and the illumination required in the work space. If daylighting can completely replace electric lights during daytime work hours, savings for sunny, southern US climates (such as New Mexico and Texas) can exceed 40% of the annual lighting electric power consumption. For northern climates, savings on the order of 30% are more typical. Table 6.3 lists potential savings in these climates.

Table 6.3. Potential lighting energy savings for US locations.

Location	Annual lighting energy saving (%)		Location	Annual lighting energy saving (%)
Fairbanks, AK	28.4		Duluth, MN	36.9
Phoenix, AZ	44.3		ABQ, NM	43.6
Miami, FL	43.4		Memphis, TN	41.1
Boise, ID	39.7		El Paso, TX	44.3
Chicago, IL	34.3		Houston, TX	41.4
Baltimore, MD	38.7		Burlington, VT	37.2

Energy Savings and Payback Calculation Assumptions

A 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft (6.1 m) high walls was used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20 ft (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

Energy savings for the industrial building were calculated using the SkyVision Program (http://irc.nrc-cnrc.gc.ca/ie/lighting/daylight). The building was modeled in this program and the electric lighting power replaced by daylighting was calculated. Skylights were installed only in the shop areas (thermal, ventilation, and light fabrication) with the following characteristics:

- Total dimensions: 200 x 200 ft, 20-ft (height)
- Reflectance of walls (metallic) = 30%
- Reflectance of floor (concrete) = 30%
- Reflectance of ceiling (assumed) = 50%
- Skylight size 4 x 8 ft with 4-ft well
- Number of skylights = 25.

The cost of the system includes the installed cost of the skylight plus the installed cost of the electronic controls, and varies from $1000 to $1500 per skylight. Installed cost of the controls for an existing building could vary greatly depending on the current lighting wiring. For new construction, the addition of this system would likely only add a couple hundred dollars to the labor bill. For an industrial building application, on/off control of individual circuits is likely in the shop area. A multiple ballast controller will be specified for the office areas. For a retrofit application, 2 additional hours of labor per circuit were assumed. Table 6.4 lists the cost of retrofitting the industrial building.

Table 6.4. Estimated cost to retrofit an industrial building with daylighting.

	Number	Installed cost per unit	Total
Skylights	25	$1300	$32,500
Controls	20	$230	$4,600
Total			$37,100

Energy Savings and Payback Calculation Results

Energy savings for this system are shown in the figures below. For the ventilated industrial building, the average pay-back ranges from 4 to 9 years. For air-conditioned buildings, additional electrical savings of up to 25% could be expected depending on the efficiency of the air conditioning equipment. (See Figures 6.10–6.12.)

Level of Maturity

Hybrid daylighting technologies have been developed over the last 15 years.

Climatic Conditions Necessary

The technology works in any climate. The typical number of clear days in a climatic region should also be considered in the application of the technology

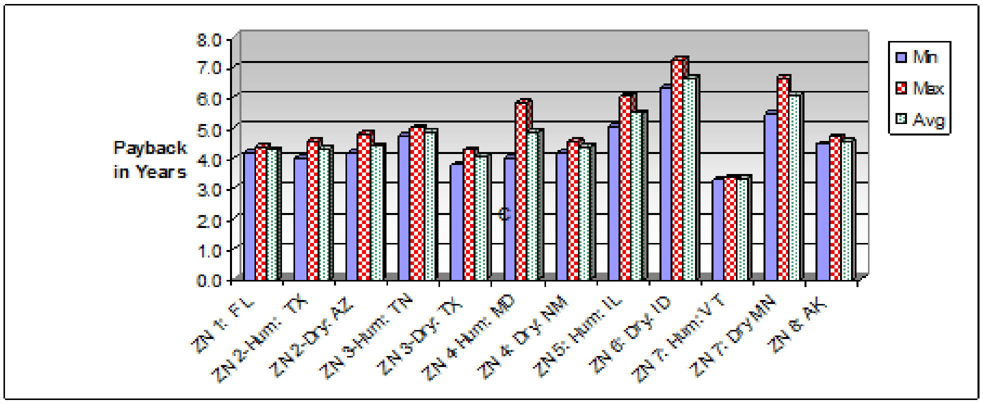


Figure 6.10. Estimated payback in years.

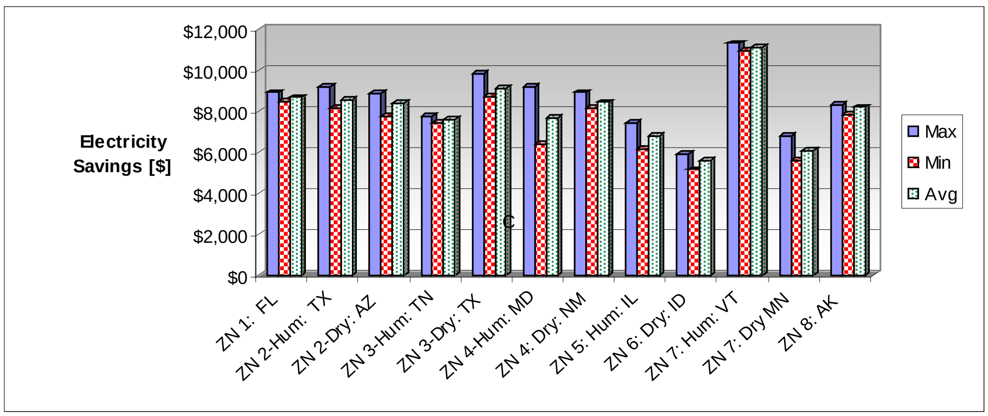


Figure 6.11. Annual electric savings due to daylighting.

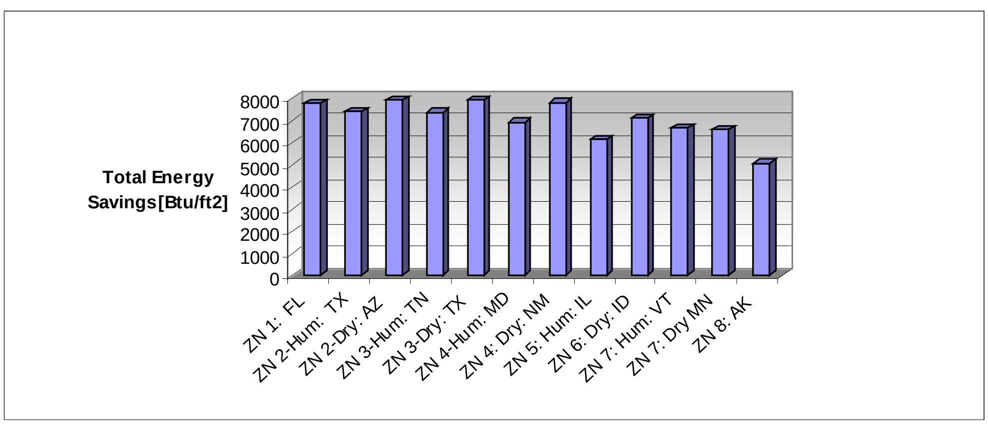


Figure 6.12. Total annual energy savings due to daylighting.

Manufacturers

A list of suppliers can be found when searched for “Industrial Daylighting Technology.”

References

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B. McCowan, and D. Birleanu. *Daylighting Application and Effectiveness in Industrial Facilities*. Energy Systems Laboratory, http://handle.tamu.edu/1969.1/5583

Destratification Fans

Application

Industrial Buildings.

Category

HVAC

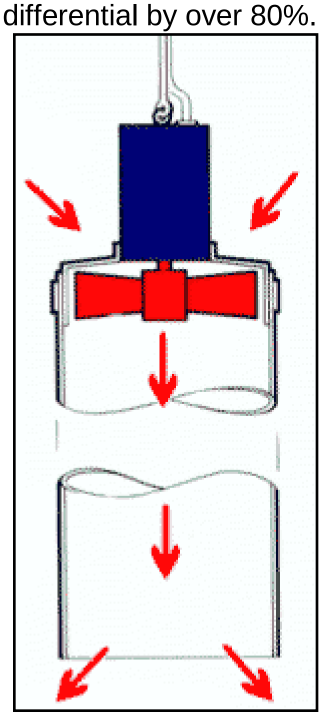
Concept

Thermal destratification fans bring hot air down to where the personnel and more important from an energy savings standpoint, where the thermostat is located. Axial flow fans mounted near the ceiling of industrial buildings may be used to destratify the space. For axial fans to be effective, in reducing energy costs, they should include a length of duct shown in Figure 6.13. The fans deliver warm air near the ceiling of the building to the occupied space below. Ductless destratification fans (see Figure 6.14) rely on a directed high speed jet to move warm air from the ceiling to the occupied zone. These fans are effective in spaces with ceilings as high as 60 ft.

Description

In facilities with high ceilings, thermal stratification during the heating season often results in air at the ceiling being much warmer than the air at the floor level. Locating heaters near the ceiling increases the stratification effect. Generally, temperatures increase from 0.5 °F to 1.0 °F per foot from floor to ceiling. If the air is stratified, the average temperature in the building will be higher than the thermostat set point, resulting in higher heating costs. Manufacturers claim thermal destratification fans reduce the floor-to-ceiling air temperature differential by over 80%.

Source: www.tombling.com



Source: http://www.tombling.com/images/duct-fan-large.jpg

Figure 6.13. Destratification fan.

Energy Savings (Qualitative)

Thermal destratification fans bring hot air down to where the personnel and more important from an energy savings standpoint, where the thermostat is located. This results in fewer and shorter heating equipment run cycles and subsequently less energy used for heating, and also reduces the amount of heat lost to ventilation and infiltration due to the overall reduction of energy being generated.

Source: www.airiusthermalequalizer.com

Figure 6.14. Airius model 40 destratification fan.

Energy Savings (Quantitative)

Manufacturers claim thermal destratification fans reduce the floor-to-ceiling air temperature differential by over 80%. These claims were verified by the Navy Techval program at two demonstration sites: Naval Surface Warfare Center Carderock Division (NSWCCD) West Bethesda, MD and Maryland Naval Support Activity (NSA) Crane, IN. Simulation of the destratification fan requires a detailed computational fluid dynamics (CFD) model and is beyond the scope of this project.

Energy Savings and Payback Calculation Assumptions

The ratio of the heating load due to stratification and the space heating load for a well mixed zone can be calculated as follows:

$$\frac{\dot{q}_{StratLoad}}{\dot{q}_{SpaceLoad}} = \frac{T_{exh} - T_{occ}}{T_{\mathrm{sup}} - T_{occ}}$$

where:

T_{exh} = the exhaust air temperature
T_{sup} = the supply air temperature
T_{occ} = the average occupied space temperature

Estimated savings are based on costs and measured energy savings at the Bethesda and Crane sites where over 60 Airius fans were installed. For these facilities, a 38% reduction in the heating load was recorded. This corresponds to a “stratified” condition with T_{exh} = 82.5 °F, T_{sup} = 90 °F and T_{occ} = 72 °F which gives a load ratio of 0.58 as calculated from the previous equation. The “destratified” case corresponds to T_{exh} = 75.5 °F, T_{sup} = 90 °F and T_{occ} = 72 °F to give a load ratio of 0.19. The reduction in the space heating load is calculated as the difference of the two ratios (0.58-0.19) or 38%.

The relevant cost information, design data, and estimated savings may be summarized as:

- Installed cost per fan (10 or less) $1,351/fan
- Installed cost per fan (50 or more) $825/fan
- Fan operating cost $80/fan/year
- Fan grid (30 ft ceilings or less) 1000 sq ft/fan

- Fan grid (40 to 60 ft ceilings) 700 sq ft/fan
- Reduction in heating load 38%.

A 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft (6.1 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20 ft (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

For the industrial building used in this study, 45 fans were specified to cover the 45,000 sq ft of industrial floor area. An installed cost of $1000 per fan was used for a total project cost of $45,000. The cost of operating the fans was scaled to regional electric costs.

Energy Savings and Payback Calculation Results

The payback and energy savings shown below were determined by simulating the base case building for each climate and adjusting the annual electric and gas usage according to the energy costs and energy savings measured in the Navy test cases discussed above.

The results show that for large facilities with high heating loads, the technology can be expected to pay back in less than 2 years. For smaller facilities with higher installation costs, payback times are longer. The Bethesda facility with only 7 fans had a payback of 5.2 years. This was due to the high cost of installation relative to the fan price.

The data in Figures 6.15 – 6.18 show that the cost of electricity to run the fans is more than offset by the gas savings in the buildings. Actual savings will depend on the condition of the building envelope and the amount of infiltration/exfiltration through the walls and building's roof.

Level of Maturity

Destratification fans have been a

Fans of the type shown above (blades in a housing creating an air stream andc.) have been available for fewer years. Destratification fans exist for virtually all situations.

Climatic Conditions Necessary

The technology is applicable to climates with heating loads only.

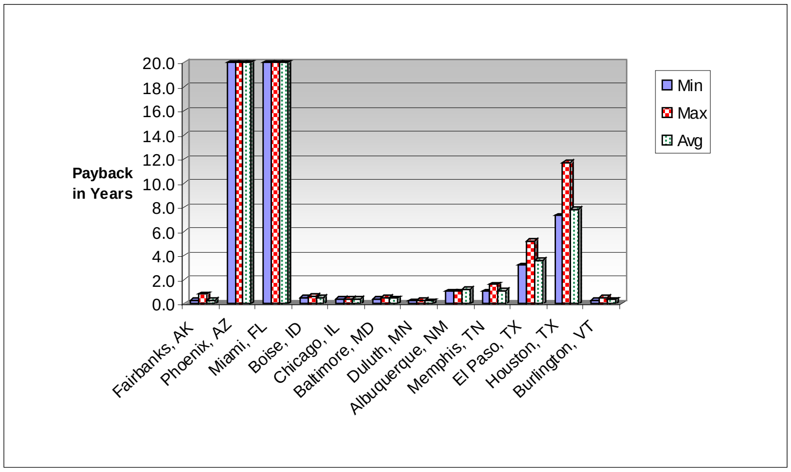


Figure 6.15. Estimated payback assuming 38% gas savings.

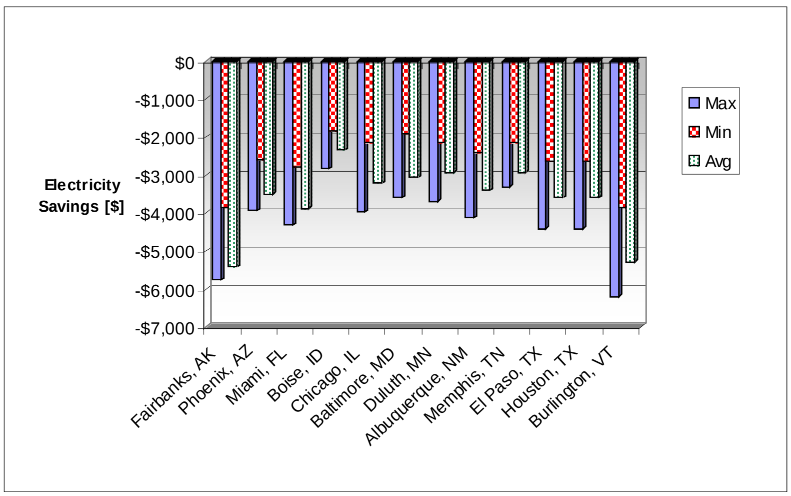


Figure 6.16. Estimated destratification fan electric use.

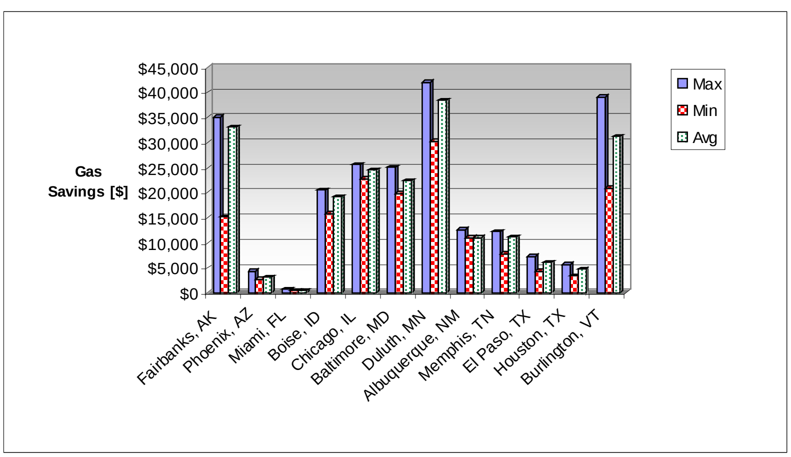


Figure 6.17. Estimated annual gas savings (specified as 38% of

base case use).

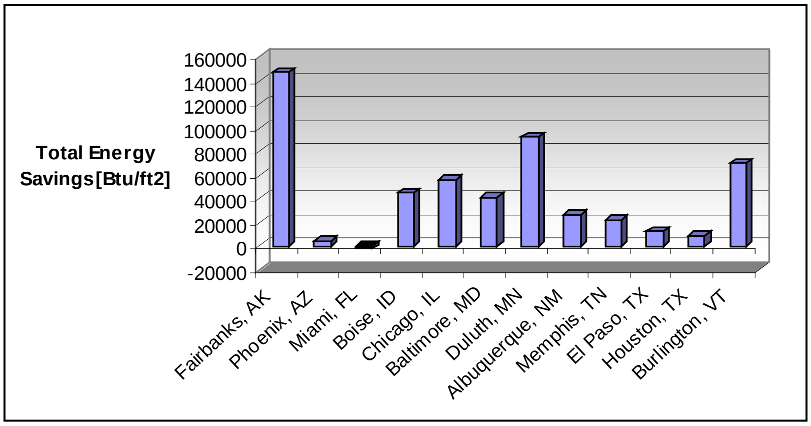


Figure 6.18. Estimated annual net savings per square foot of floor area.

Major Manufacturers

Major Warm Air Destratification Fan suppliers can be found at:
http://www.kellysearch.com/us-product-36694.html

Practical Experience

For demonstration results and additional information concerning destratification technology, contact:
Mr. Paul Kistler
Techval Program Manager
NAVFAC Engineering Service Center
Port Hueneme, CA 93041
Phone: (805) 982-1387
Email: paul.kistler@navy.mil

Displacement Ventilation

Application

Industrial and occupied spaces with high ceiling

Category

HVAC

Concept

The displacement ventilation concept applies specifically to industrial and occupied spaces with high ceilings. Displacement ventilation systems can improve thermal comfort and indoor air quality. In theory, warm air and contaminants are carried from the occupied space by buoyant plumes (Figure 6.19), and are not diluted by the fresh air as is the case for conventional fully mixed ventilation systems.

Application of the displacement concept can significantly reduce required ventilation flow rates since only the occupied zone (rather than the entire space) is being conditioned. In practice, however, the ventilation flow rates (and corresponding room air velocities) must be high enough to keep contaminants entrained in buoyant plumes and wall jets. The density of the contaminants (relative to the fresh air) and the quantity of contaminants produced in the space will determine the minimum ventilation flow rate for a given displacement ventilation application. Ideally, the room airflow pattern in a displacement system is straight up—from occupied to unoccupied zone—without recirculation between the two. In practice, significant mixing can occur in the lower zone (especially in industrial applications) and some mixing will also occur between the upper (unoccupied) and lower (occupied) zones.

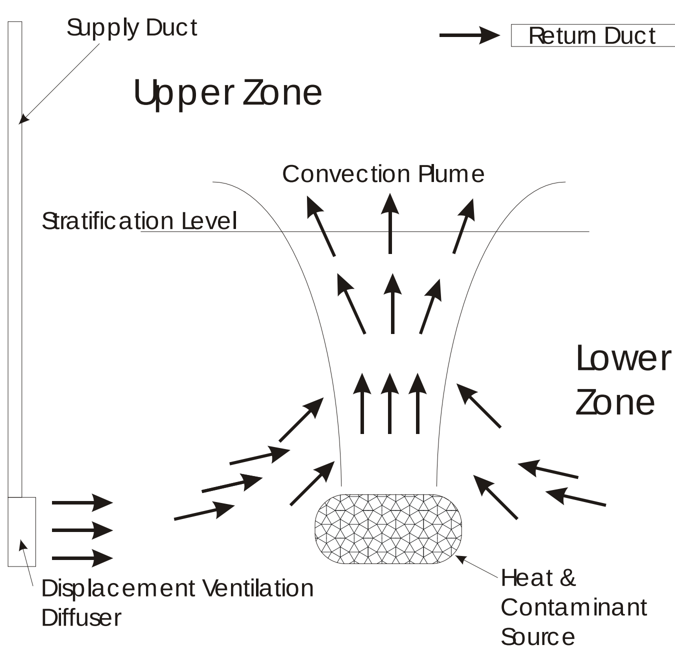


Figure 6.19. Displacement ventilation concept.

Description

A Displacement ventilation system introduces cool air at relatively low velocities at floor level. The low velocity air enters and fills the lower “occupied zone” and displaces warmer air to the top of the room. This creates a stratified room with a cool, conditioned occupied zone in the lower part of the space and a warm unoccupied zone in the upper part of the space. Hot plumes and buoyantly driven flows along walls carry hot air to the ceiling where it is then exhausted. In heating mode, displacement ventilation follows a mixed air flow pattern since the heated air naturally rises to the ceiling. An advantageous coupling of low energy technologies is a displacement ventilation system with de-stratification fans that operate during the heating season.

Displacement ventilation systems require that supply ducts be terminated near the floor (Figure 6.20). “Displacement diffusers” deliver fresh air at floor level through large opening at a relatively low velocity.

Figure 6.21 shows a typical temperature distribution in a space equipped with displacement air distribution systems. At the lower occupied level, the temperature remains cool. At the upper, unoccupied level, the air is much hotter due to natural buoyancy of the hot air.

Energy Savings (Qualitative)

For an industrial building with 20-ft ceilings, roughly two-thirds of the volume is unoccupied. Displacement ventilation systems can significantly reduce fan energy during the cooling season by reducing the ventilation air flow rate required to maintain thermal comfort and acceptable indoor air quality in the occupied zone. In heating season, the space will be well-mixed with required higher ventilation flow rates, which will also result a corresponding reduction in expected energy savings.

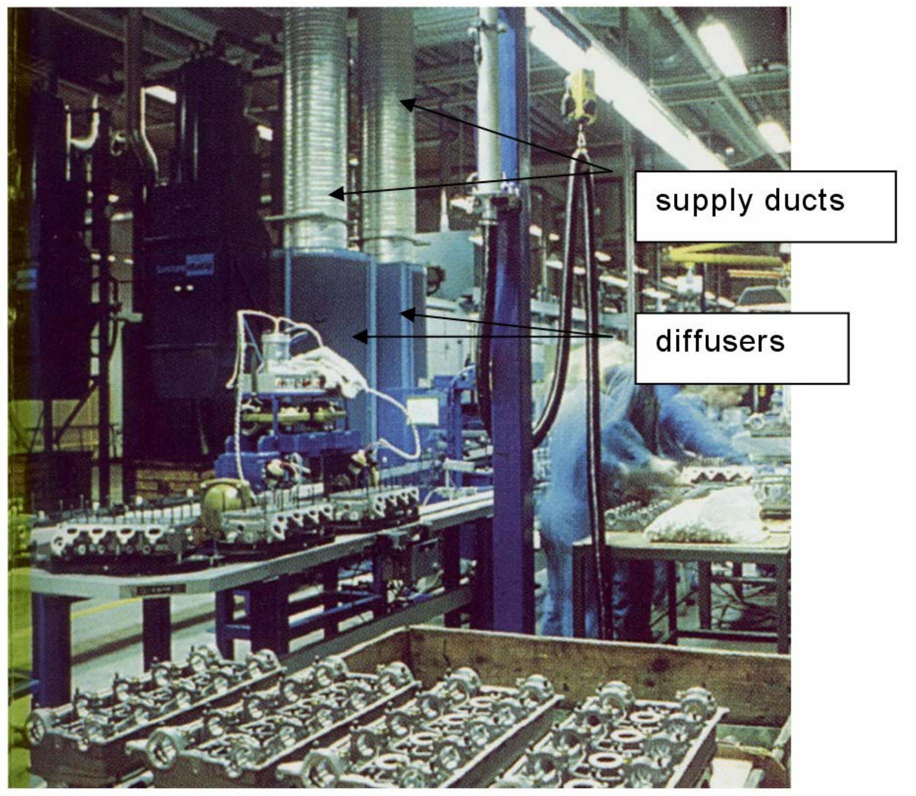


Figure 6.20. Industrial displacement ventilation system.

Energy Savings (Quantitative)

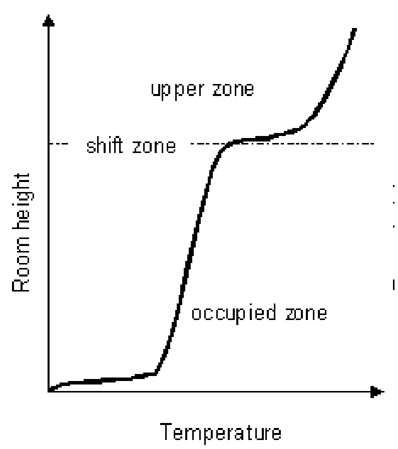


Figure 6.21. Graph illustrating temperature stratification resulting from the use of displacement air distribution.

The Centre for the Analyses and Dissemination of Demonstrated Energy Technologies (CADD) reported industrial case studies where displacement ventilation systems flow rates were 50–70% lower than comparable mixing ventilation flow rates (*Learning from Experiences with Industrial Ventilation*, Analyses Series No. 10, 1993). These flow rate reductions are applicable to thermal processing areas and light fabrication areas, but not to "high ventilation" processes (such as painting), which require high ventilation flow rates to entrain and move relatively dense contaminants from the space. Thermal stratification is not possible in the shipping area where the frequent opening of the loading dock doors ensure that the air is well mixed. In addition, office zones with 8-ft ceilings are not good candidates for displacement ventilation systems, since at least three-fourths of the space is occupied. Table 6.5 lists savings based on a 25–50% reduction in ventilation flow rate in two Industrial process zones

Table 6.5. Savings based on a 25–50% reduction in ventilation flow rate.

	BaseLine Ventilation Air Flow Rate	Displacement Ventilation System Airflow Rate
Light Fabrication Zone	4 ACH	2 ACH
Thermal Processing Zone	3 ACH	1.5 ACH

Energy Savings and Payback Calculation Assumptions

A 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft (6.1 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20 ft (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

Direct simulation of a displacement ventilation system requires detailed modeling of a space, its airflow patterns and its heat sources. For thermally intensive processes, displacement ventilation can generally reduce required comfort cooling airflow rates by 25% to 50% during the summer months. The cost of the system is relatively low. An industrial displacement ventilation system can be implemented by installing “flex-duct” drops from existing ceiling diffusers. The installed cost was estimated at $200/drop with 40 drops specified in the light fabrication area and 20 drops in the thermal processing area for a total installed cost of $12,000 for the industrial building model.

Energy Savings and Payback Calculation Results

Energy savings are calculated at 25% and 50% reductions in airflow rates to bracket the expected range of savings from a displacement ventilation system. Figures 6.22 and 6.23 show that a displacement ventilation system that achieves a 50% reduction in ventilation flow rate as proposed above easily pays for itself in less than 2 years in every climatic zone. Even a system that achieves only a 25% reduction in ventilation flow rates achieves a reasonably short payback in all climates. For industrial facilities with high internal gains, installing flex duct drops to deliver ventilation air directly to the occupied zone is a low cost option that can achieve significant savings.

Figures 6.24 and 6.25 show that savings are realized both from a reduction in fan power consumption and gas consumption. Figure 6.26 shows estimated total energy savings on a floor area basis for system achieving 25% reduction of ventilation flow rate.

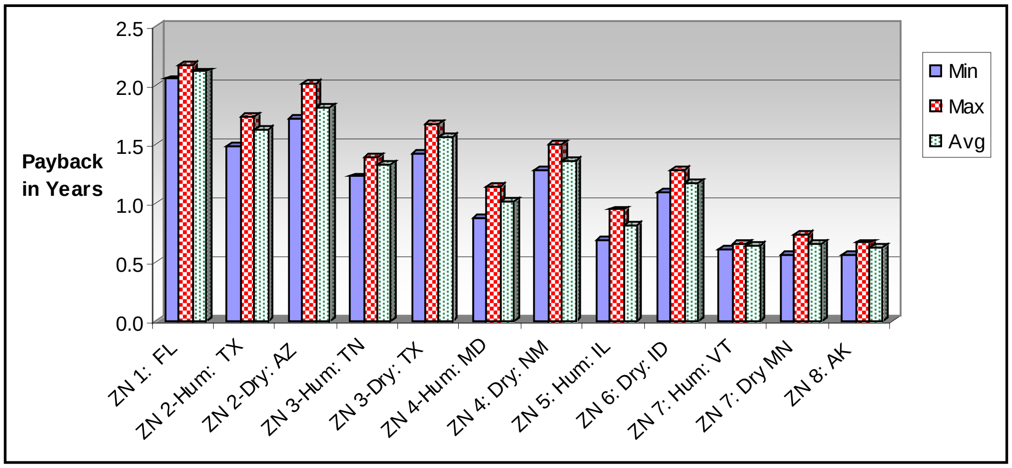


Figure 6.22. Estimated payback for system achieving 50% reduction of ventilation flow rate.

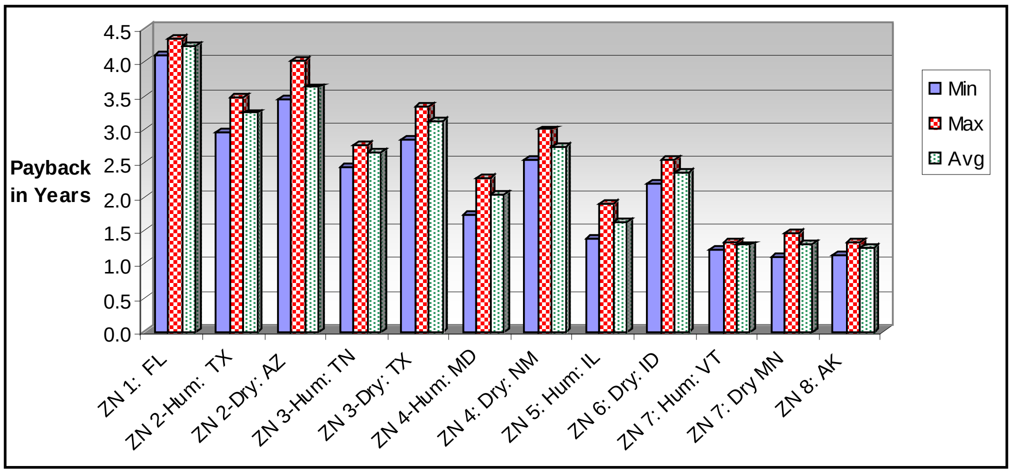


Figure 6.23. Estimated payback for system achieving 25% reduction of ventilation flow rate.

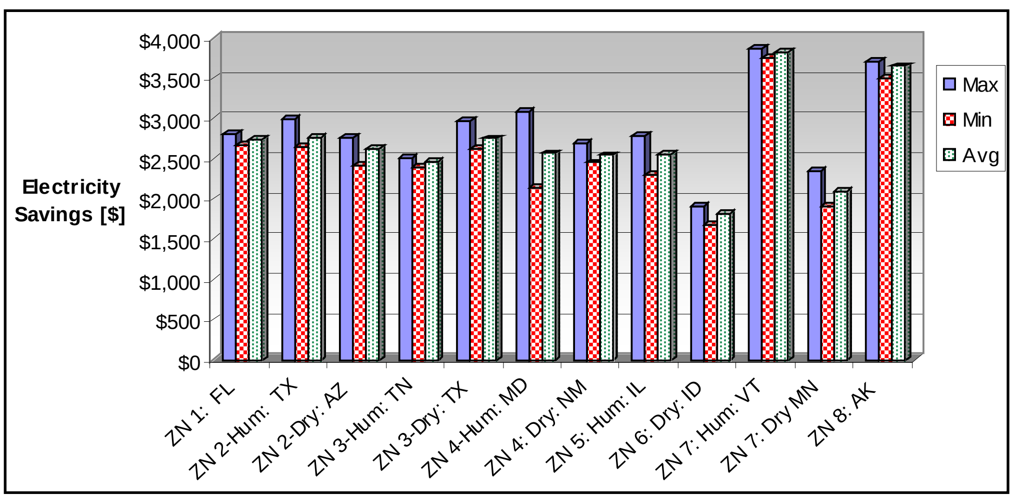


Figure 6.24. Estimated annual electricity savings for system achieving 25% reduction of ventilation flow rate.

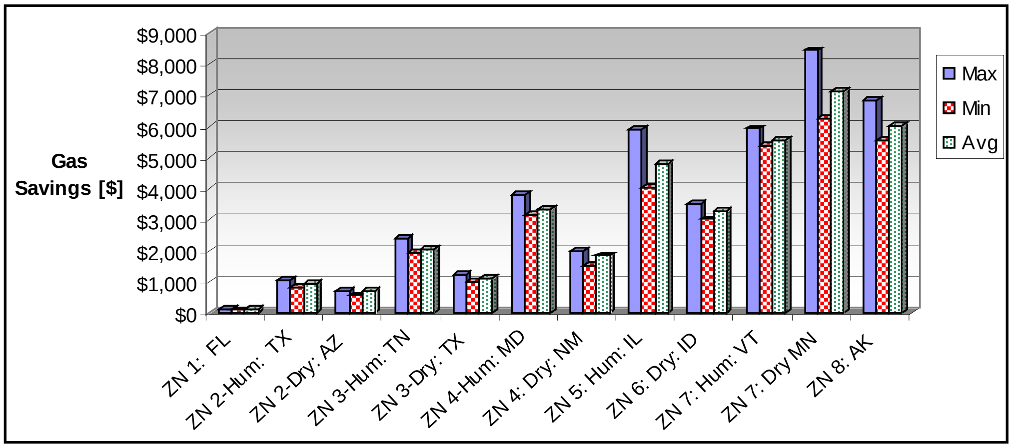


Figure 6.25. Estimated annual gas savings for system achieving 25% reduction of ventilation flow rate.

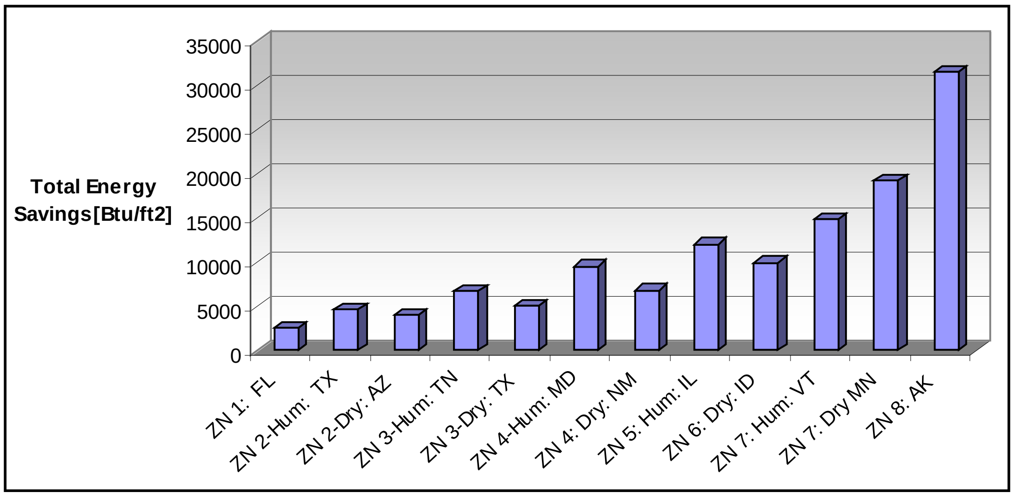


Figure 6.26. Estimated total energy savings on a floor area basis for system achieving 25% reduction of ventilation flow rate.

Level of Maturity

This technology has been applied to industrial applications for many years; since the 1980s, it has been successfully applied to office applications.

Impact on Indoor Air Quality

A properly designed displacement ventilation system can improve indoor air quality in the occupied zone by replacing (rather than diluting) contaminated air with fresh air.

Climatic Conditions Necessary

System operates better in spaces with cooling needs and high ventilation rates.

References and Major Manufacturers

Advanced Buildings Technologies and Practices Website, http://www.advancedbuildings.org/main_t_vent_displ_vent.htm

Price Website, http://www.price-hvac.com/catalog/J_all/default.aspx

Trox Technik Website http://www.troxtechnik.com/en/produkte/air_diffusers/displacement_flow_diffusers/index.php

Teuvo Aro and Krister Koivula. 1993. Learning from Experiences with Industrial Ventilation. CADDET Analysis Series No 10. Center for the Analysis and Decimination of Demonstrated Energy Technologies. CADDET, Sittard, The Netherlands.

A. Zhivov, P. Nielsen, G. Riskowski, and E. Shilkrot. “Displacement Ventilation for Industrial Applications”. HPAC Heating/Piping/Air Conditioning Engineering, March 2000. vol. 72, No. 3. pp 41-50.

A. Zhivov, P. Nielsen, G. Riskowski, and E. Shilkrot. “A Design Procedure for Displacement Ventilation. Part 1” HPAC Heating/Piping/Air Conditioning Engineering, November 2000. vol 72, No. 11. pp 39-49.

A. Zhivov, P. Nielsen, G. Riskowski, and E. Shilkrot. “A Design Procedure for Displacement Ventilation. Part 2.” HPAC Heating/Piping/Air Conditioning Engineering, May 2001. vol. 73, No. 5. pp 67-89.

H. Goodfellow and E. Tahti (eds.) Industrial Ventilation Design Guidebook. 2001. Academic Press.

Dock Seals

Application

Industrial

Category

Building envelope

Concept

The dock seal significantly reduces air infiltration at the loading dock by providing a seal between the truck and the building. The truck compresses the foam seal as it backs into the dock. When the building overhead door is opened to unload the truck, air infiltration is eliminated by the seal (Figure 6.27).

Figure 6.27. The dock seal and soft-sided shelter concepts.

Description

Compressible foam dock seals and soft-sided shelters are commonly used for large doors and openings for industrial buildings, mainly around loading docks and any vehicle entrances to the building.

Energy Savings (Qualitative)

By reducing air infiltration, the loading dock seal reduces building heating load. Since the building is not cooled, there are no savings during the cooling season.

Energy Savings and Payback Calculation Assumptions

The sealed and 'unsealed' cases were represented as "cracks" within the dynamic air flow model. Flow through the doors used crack representations for the sealed case and bi-directional flows when open. The assessment takes into account both temperature and pressure, which were re-assessed at each minute of the year. The analysis was based on 2 hours of "dock time" per day per door, which was scaled up to 8 hours per day for a busy dock.

The payback was calculated assuming four doors 11 ft wide and 14 ft, and a cost of materials, freight and installation of each door of $2755 per door, for a total of $11,020.

Energy Savings and Payback Calculation Results

The results shown in Figures 6.28 – 6.30 show estimated gas savings, energy savings per sq ft of the building area and a simple payback. The analysis shows that docks seals in heated but not cooled buildings result in significant energy savings only in cold climates and have a reasonable payback in climate zones 4–8.

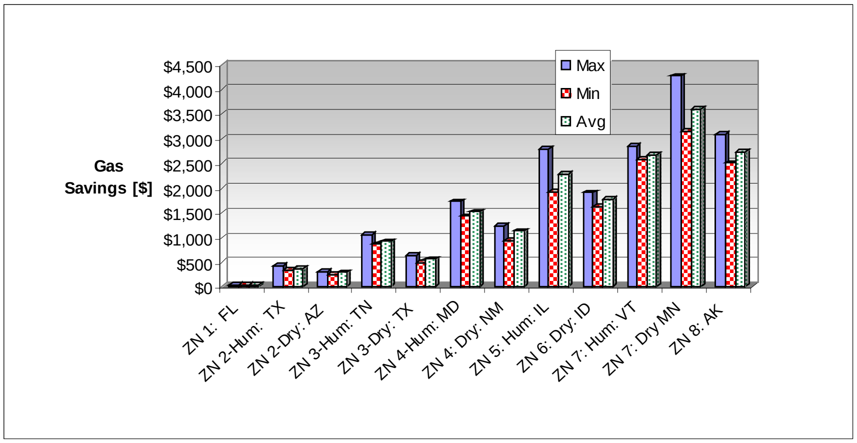


Figure 6.28. Estimated annual gas savings from installation of dock seals.

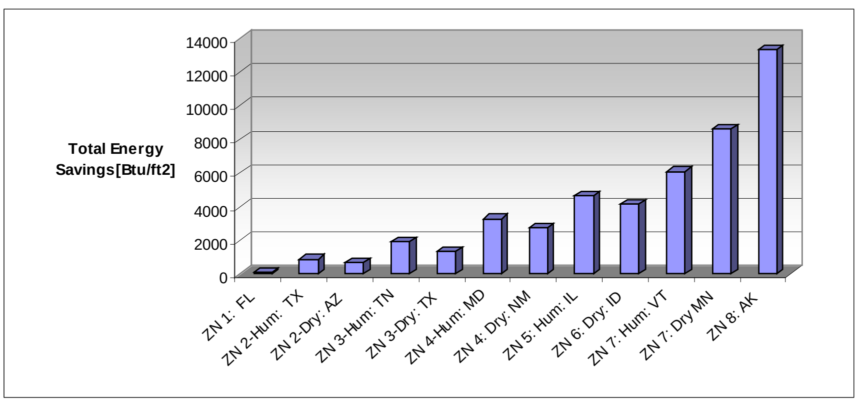


Figure 6.29. Estimated annual energy savings per unit total building area.

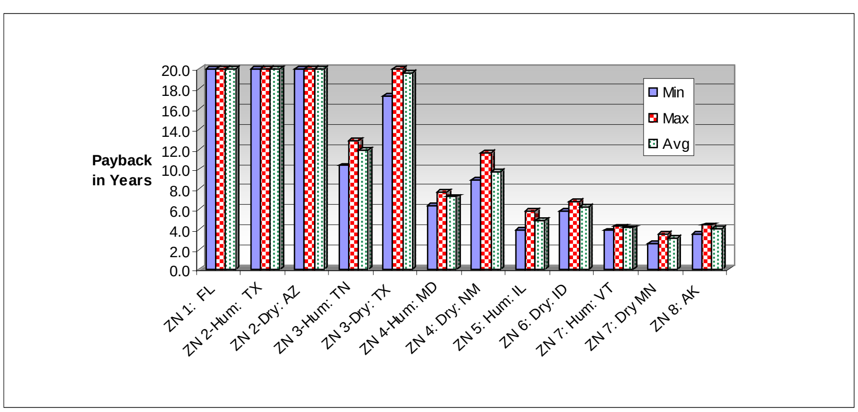


Figure 6.30. Estimated payback from installation of dock seals.

Level of Maturity

Dock seals have been a feasible technology for over 20 years.

Climatic Conditions Necessary

The technology may be applied in any climate, but is economical only in climate zones 4-6.

Impact on Indoor Air Quality

The system can improve indoor air quality by reducing infiltration at the loading dock area where idling truck engines can result in CO infiltration.

Energy Recovery in Paint Booths

Application

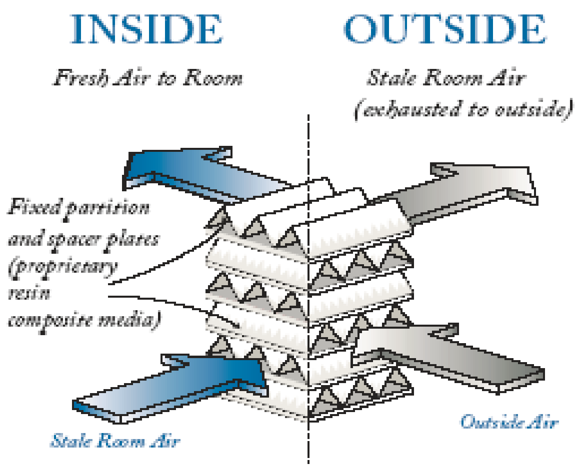
Industrial

Category

HVAC

Concept

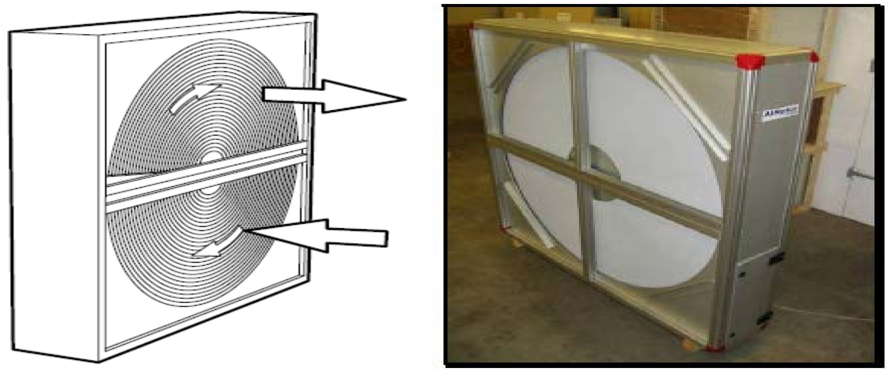
Two types of energy recovery ventilators (ERVs) are available for industrial applications. The compact cross-flow heat exchanger design shown below uses a resin-composite heat exchanger membrane to allow moisture transfer while keeping the air streams separate. Figure 6.31 shows a schematic of the compact heat exchanger core.



Source: www.renewaire.com

Figure 6.31. Schematic of the cross-flow heat exchanger in an ERV.

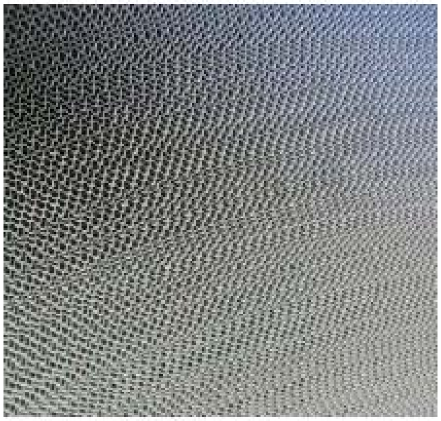
Rotary Heat Exchangers consist of a wheel that rotates through the hot and cold air streams (Figure 6.32). The horizontal bar located at the center of the wheel is an air seal that separates the relief air duct from the outside air duct.



Source: www.xetexinc.com

Figure 6.32. Rotary heat exchanger.

The core of the heat exchanger consists of densely packed fins (Figure 6.33). The desiccant-coated fins store both heat and moisture.



Source: www.xetexinc.com

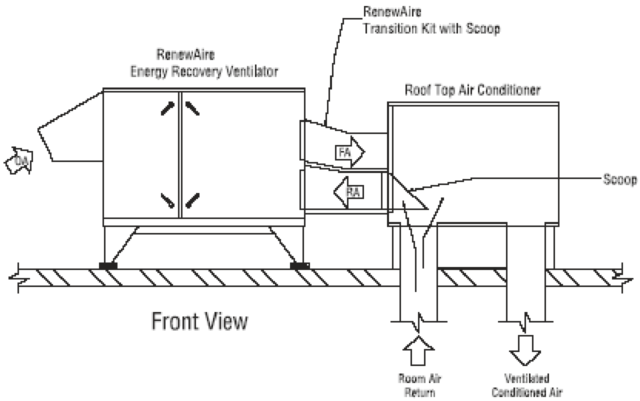
Figure 6.33. Densely packed fins of a rotary heat exchanger.

As the rotating wheel passes through the relief air stream, heat and moisture are transferred to or from the airstream as the wheel continues to rotate past the air seal and into the outside air stream. The heat transfer process is completed as the outside air stream is heated or cooled as it passes over the fins. The heated or cooled fins then pass back across the air seal into the relief air stream and the process is repeated.

Description

Using the exhaust air to pre-heat or pre-cool the incoming air can potentially save energy by reducing the load on the HVAC system. ERVS are packaged units containing a supply air stream fan, an exhaust air stream fan, and a compact cross-flow heat exchanger. ERVs transfer both heat and moisture across the heat exchanger. Heat recovery ventilators (HRV) are similar to ERVs, but HRVs do not transfer the moisture across the heat exchanger surface. The only physical difference between ERVs and HRVs is the membrane material or coating used in the heat exchanger. The housing, fans, filters, andc. remain the same.

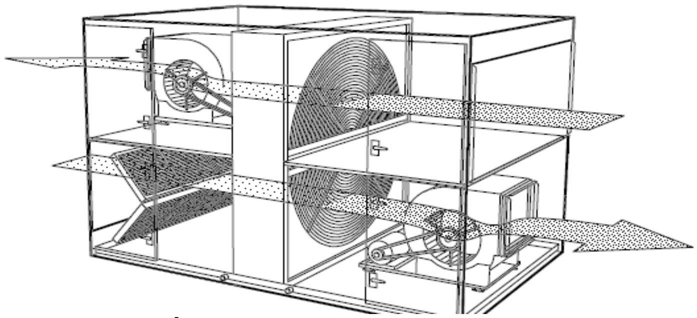
In industrial applications, ERVs and HRVs are relatively simple to retrofit to existing systems since they are added to the intake of the system. Figure 6.34 shows a drawing of the location of an ERV added to a roof-top air-conditioning system.



Source: www.renewaire.com

Figure 6.34. ERV attached to a roof-top air-conditioning system.

The units are typically packaged with booster fans to overcome the additional pressure drop of the heat exchanger or with fans sized to handle system airflow requirements (Figure 6.35).



Source: www.xetexinc.com

Figure 6.35. ERV with supply exhaust fans.

Energy Savings (Qualitative)

A 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft (6.1 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20 ft (6.1 m) high walls. Typical light industrial wall and roof constructions were used in modeling the building. The walls were insulated metal construction (R-4) and the roof is standard built up bitumen. The building is heated and ventilated, but work areas are not air-conditioned. The high thermal heat gain and ventilation area operate year-round with 100% outside air. Other areas operate with an economizer cycle with a minimum of 30% outside air.

The energy savings of the rotary heat exchanger was evaluated by direct comparison of the total building energy use reported by the base-case EnergyPlus* simulation program output with the total building energy use reported by the heat exchanger-case simulation output. The heat recovery-case results were generated by changing only those input parameters in the base case input file that were directly related to the heat exchanger.

* More information on the EnergyPlus energy simulation software is available through http://apps1.eere.energy.gov/buildings/energyplus/

Incoming air is automatically pre-heated or pre-cooled depending on the season. This can dramatically reduce the energy costs of ventilation resulting in significant energy savings. To maximize savings, the heat exchanger should be installed with bypass dampers so additional fan power is not required to overcome the heat exchanger pressure drop when conditions are not favorable to heat recovery.

Energy Savings (Quantitative)

For this application, a Xetex Heat Wheel was retrofit to the industrial ventilation zone (30,000 cfm). Table 6.6 lists the estimated cost of the installation,

Table 6.6. Estimated cost to retrofit a Xetex Heat Wheel to the industrial ventilation zone.

Item	Cost
Rotary heat exchanger	$20,000
Booster fans	$5,000
Ductwork modification and installation	$10,000
Total	**$35,000**

Energy Savings and Payback Calculation Assumptions

The heat exchanger was modeled in EnergyPlus assuming that a 0.4 in. w.g. pressure drop would result in a heat exchanger effectiveness of 77%. The additional fan power required to overcome the pressure drop was included in the calculation. The model assumed that bypass dampers were not in place and the supply fan was required to overcome the heat exchanger pressure drop for all hours.

Energy Savings and Payback Calculation Results

For the example building, the payback for this technology is less than 2 years in cold and moderate climates (Figure 6.36).

The payback for the example building is based on gas savings only. Electrical costs actually increased due to increased fan power (Figure 6.37). For air-conditioned buildings, savings in compressor power are typically much greater than increased fan power use, and savings are shown for both electricity and gas (Figures 6.38 – 6.40).

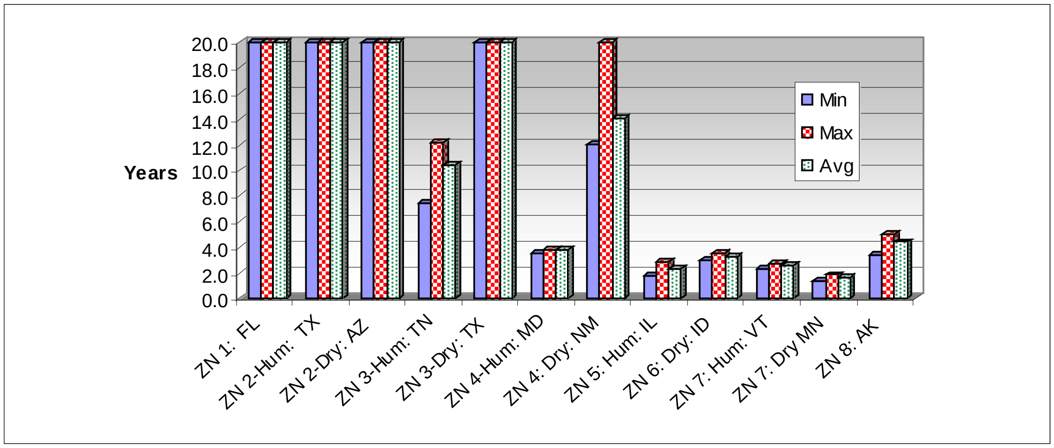


Figure 6.36. Estimated payback for installation of rotary heat exchanger.

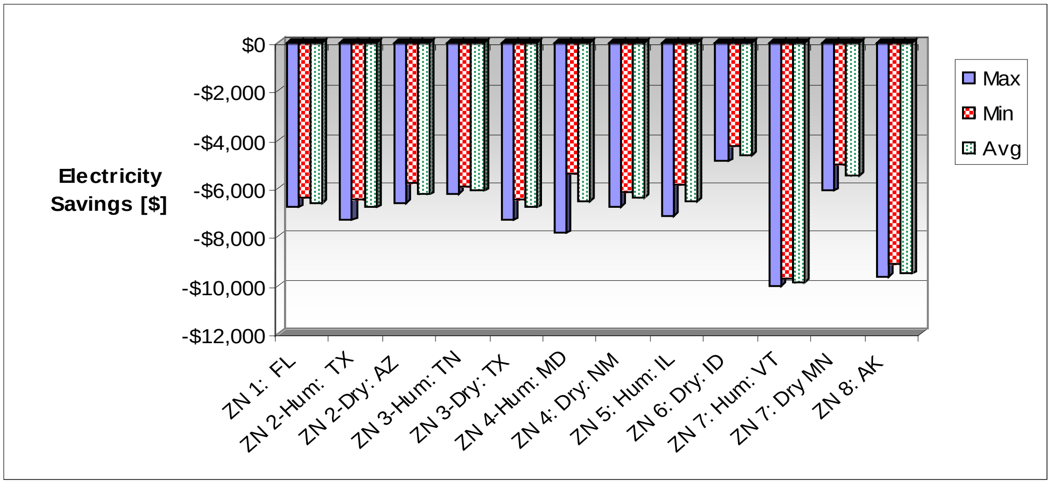


Figure 6.37. Increase in annual electrical fan power for ventilation only building.

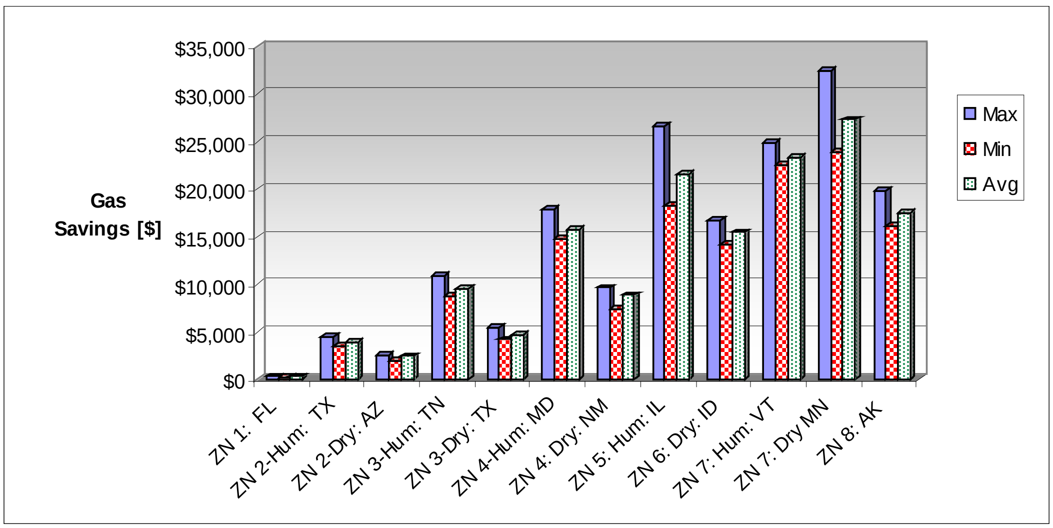


Figure 6.38. Estimated annual gas savings due to heat recovery.

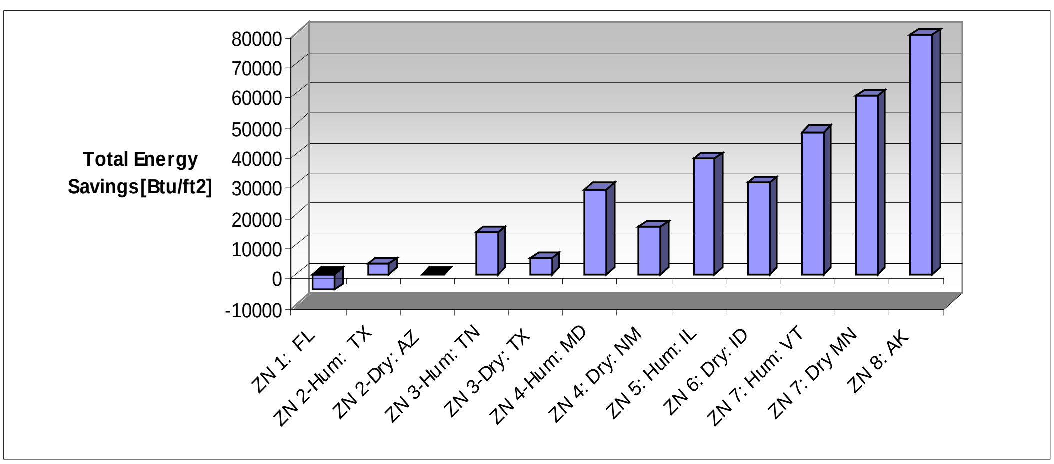


Figure 6.39. Estimated annual savings per square foot of floor area.

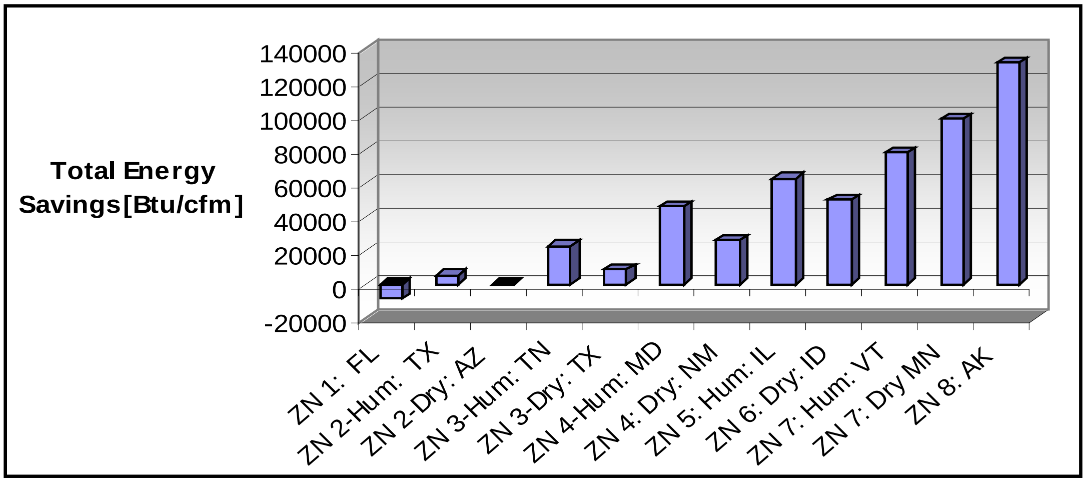


Figure 6.40. Estimated annual savings per ventilation zone cfm.

Level of Maturity

Heat wheel technology has been available in some form for over 30 years. Permeable membrane technology has been developed in the last 10 years.

Impact on Indoor Air Quality

The stale or polluted air is ventilated out of the zone while fresh outside air is brought into the zone. Since the two air streams never physically contact each other in the heat exchanger, the zone is ventilated while recovering heat. This improves the air quality while saving energy. Also, filters are located in the outside air stream to filter the incoming air.

Climatic Conditions Necessary

For ventilated buildings, the technology is applicable for cold and moderate climates. For air-conditioned buildings, the technology is applicable to all climates.

Contacts and Major Manufacturers

Xetex, www.xetexinc.com

RenewAire Website, www.renewaire.com

Fantech Website, www.fantech.net/hrv_erv.htm

Greenbuilder Website, http://www.greenbuilder.com/sourcebook/EnergyRecoveryVent.html

Envelope Sealing Systems: Radiant Barrier, and Spray Foam Insulation

Application

Industrial.

Category

Building Envelope.

Concept

Spray foam insulation systems eliminate both air infiltration paths and cold surfaces that moisture may condense on by direct application of a foam sealant/insulation to the metal skin of the industrial building. These systems provide three major benefits:

1. Reduced leakage through the building envelope

2. Increased insulation of the building envelope

3. Reduced condensation on interior surfaces.

Barrier systems rely on sheets of air-tight material stretched over the interior of walls and roof to eliminate air infiltration. The sheets are usually applied over a batt or board type insulation layer to form the interior surface of the wall or roof. The sheets must be overlapped and sealed (usually with caulk) at the edges as they are installed. Since barrier systems do not adhere to the building skin, any "leaks" in the barrier provide a potential path for warm air to reach cold surfaces with resulting condensation. Barrier systems must, therefore, be carefully installed and maintained. The radiant barrier system used in this comparative analysis provides three major benefits:

1. The low emissivity aluminum foil face significantly reduces radiant heat transfer to the space.

2. The "air-bubble" core increases the insulation of the building envelope

3. The laminated construction resists punctures and tears.

Description

Envelope sealing technologies for large metal industrial type buildings fall into two categories:

1. Spray foam sealants applied to the building interior

2. Barrier systems also applied to the building interior.

Spray foam sealants generally consist of a closed-cell polyurethane foam that is sprayed directly to the interior of the building steel cladding. The foam, which adheres to the building steel, is generally applied to a thickness of 1 in. or more. In addition to sealing against air infiltration, the foam provides an insulation value of approximately R-7 per inch.

Barrier systems are typically applied inside the building to cover batt or board insulation. The systems range from the simple application of polyethylene sheeting to more sophisticated systems such as the radiant barrier system shown in Figure 6.41.

Energy Savings (Qualitative)

Reduction of air infiltration is the primary energy saving mechanism for both spray foam and barrier systems. Spray foam, with an insulating value of approximately R-7 per inch, can be applied to thicknesses that eliminate the need for additional insulation. Some barrier systems, such as the radiant barrier system described above, save energy by reducing the thermal radiation exchange in the space and by providing some insulating value.

a. (Source: www.radiantbarrier.com)

b. (Source: www.fomofoam.com)

Figure 6.41. Radiant barrier (a), and spray foam (b).

Existing insulation must be stripped from the walls prior to application of spray foam. The system is therefore better suited for uninsulated buildings. Barrier systems are designed to be installed over existing insulation.

Energy Savings (Quantitative)

A 50,000 sq ft (4645.152 m^2) typical metal building with 20-ft (6.1 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area, and a loading dock area are single story with 20-ft (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

For the industrial building under consideration, approximately 600 ft of exterior wall are potential candidates for envelope sealing. At a minimum, the window elevation, which constitutes approximately 25% of the wall, will be sealed. The leakage analysis was performed on a wind-driven flow pressure network with a balanced fan system using the perimeter cracks around the windows as a baseline for envelope leakage. This analysis results in 3000 sq ft of sealed envelope (Table 6.7). By assuming that the cracks between the steel sheeting is the same as the perimeter window cracks (not a bad assumption in many cases!), the analysis may be extrapolated to the entire building wall area without loss of generality.

The spray foam and radiant barrier system have approximately the same insulating value per inch. The radiant barrier system is approximately ¼-in. thick while spray foams are typically applied from 1–3 in. thick. Installed costs of the two technologies are shown in the table below. For one case 3 in. of spray foam insulation was applied. For the other case, a radiant barrier system was installed. The lower end of the cost range was selected for the comparison.

Table 6.7. Cost to install sealing systems in an industrial building.

System	Thermal Resistance	Infrared Emittance	Installed Cost	Industrial Building
3 in. of closed-cell polyurethane	R-7 per inch	0.92	\$2-\$3 per sq ft for 3-in. application	\$3600
Radiant barriersystem	~R-7 per inch	0.15	\$1 - \$1.50 per sq ft	\$1800

Energy Savings and Payback Calculation Assumptions

The effect of blown-in polyurethane was calculated by adding a 3 in. layer of insulation to the window level (15%) of the exterior walls. The insulation had a density of 1.561 cu ft/lb$_m$ (25 m^3/kg), a conductivity of 0.012 BTU/hr-ft-ºF (0.0206 W/m-K) and a specific heat of 0.239 BTU/ lb$_m$-ºF (1000 J/kg-K). The insulation also had the following radiation properties: thermal absorbance of 0.92, solar absorbance of 0.30 and visible absorbance of 0.30. In addition to adding additional insulation, the infiltration rates of all zones except for shipping were recalculated based on a flow network, which assumed a balanced fan system and infiltration due to wind pressure on a leaky envelope. The analysis assumed that the total crack area was only the perimeter of the windows. For an unsealed sheet metal building, this is a conservative estimate. The analysis also assumed that sealing the envelope reduced the crack area by 50%.

The effect of the radiant barrier on infiltration was assumed to be identical to the spray foam. For the radiant barrier all exterior walls received ¼ in. of insulation. The insulation had a density of 1.561 cu ft/lb$_m$ (25 m^3/kg), a conductivity of 0.012 BTU/hr-ft-ºF (0.0206 W/m-K) and a specific heat of 0.239 BTU/lb$_m$-ºF (1000 J/kg-K). The insulation also had the following radiation properties: thermal absorbance of 0.15, solar absorbance of 0.15 and visible absorbance of 0.15.

Energy Savings and Payback Calculation Results

Sealing the envelopes around the windows resulted in very short payback periods in cold climates and in reasonable payback periods in all but the hottest climates (Figures 6.42 and 6.43). The payback period of the radiant barrier system was systematically lower than the spray foam system. This illustrates that the dominant effect is air infiltration, not envelope conduction.

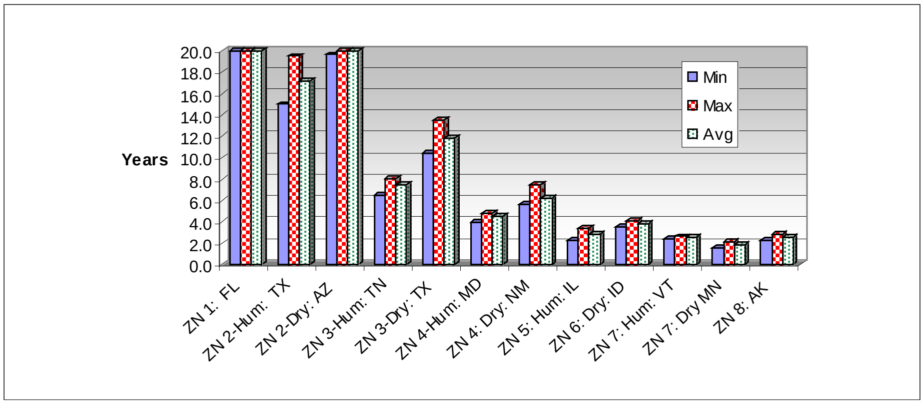


Figure 6.42. Radiant barrier estimated payback for high, low and medium energy rates.

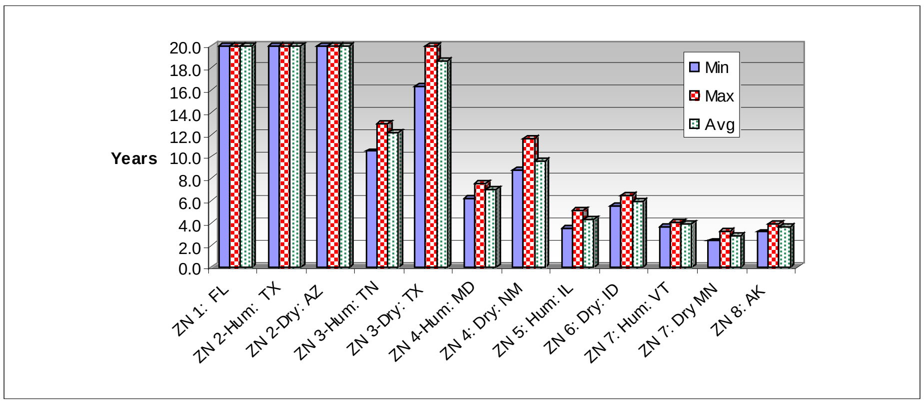


Figure 6.43. Spray foam estimated payback for high, low and medium energy rates.

Figure 6.44 shows that the spray foam insulation has added energy saving benefits in all climate conditions.

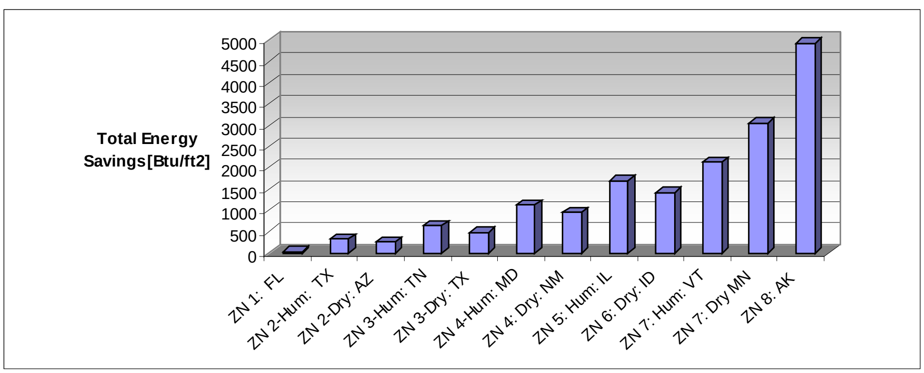


Figure 6.44. Spray foam insulation estimated total energy savings.

Figures 6.45 and 6.46 show gas savings for radiant barrier and spray foam systems. In different climate locations.

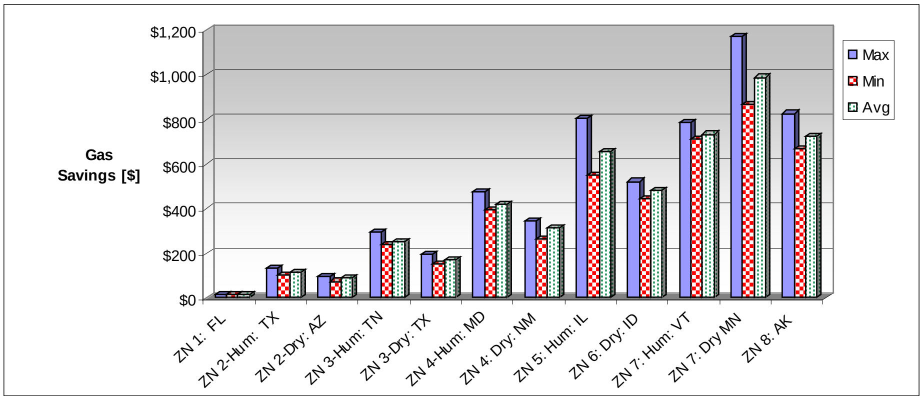


Figure 6.45. Estimated annual radiant barrier gas savings.

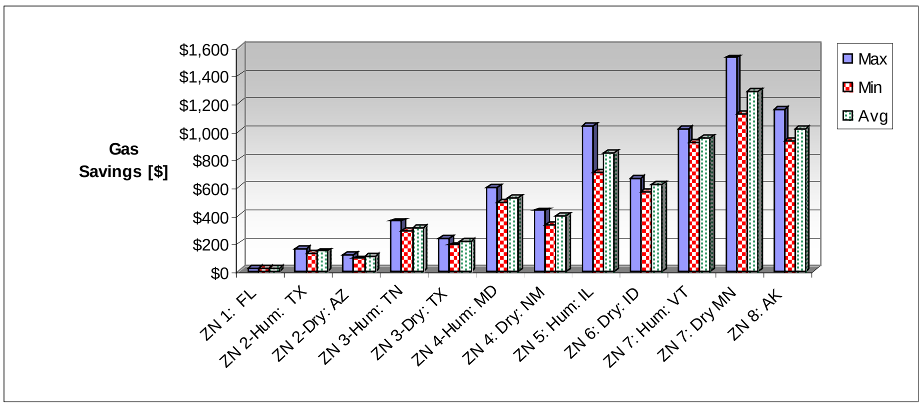


Figure 6.46. Estimated annual spray foam gas savings.

Level of Maturity

5-20 years

Impact on Indoor Air Quality

The system will reduce outside air infiltration. With a properly designed ventilation system, indoor air quality can be maintained.

Climatic Conditions Necessary

The technology is indicated only for cold climates and is effective only in reducing the heating load.

Contacts and Major Manufacturers

Spray Foam

Icynene Inc.
6747 Campobello Road
Mississauga, Ontario
L5N 2L7
Canada
Phone: (905) 363-4040
Toll free: (800) 758-7325

DEMILEC, Inc.
870 Cure Boivin
Boisbriand (Quebec)
J7G 2A7
Canada
Phone: (450) 437-0123

Radiant Barrier

Innovative Insulation, Inc.
6200 W. Pioneer Parkway
Arlington, TX 76013
Toll free: (800) 825-0123

Close Capture Exhaust System for Moving/Stationary Vehicles

Application

Industrial.

Category

Ventilation /vehicle exhaust capture systems.

Concept

Traditional ventilation systems for maintenance facilities include a general dilution system sized for approximately 1.5 cfm/sq ft outside air flow rate. This flow rate is based on ASHRAE Std. 62 and assumes that running vehicles are entering the building prior to attachment of the stationary close capture exhaust system. If the close capture system is attached before the vehicle enters the building, the general dilution rate can be assumed to be similar to mechanical or assembly shops (~0.5 cfm/sq ft) (Ventilation Guide for Automotive Industry, HPAC Engineering 2000).

Figure 6.47 shows a stationary hose reel type system (requiring ~1.5 cfm/sq ft dilution rate).

Figure 6.47. Stationary vehicle exhaust system in the maintenance shop.

Reduction in the general dilution rate from 1.5 cfm/sq ft to 0.5 cfm/sq ft can be achieved by means of well designed suction rail or pivoting boom systems. Vehicles are connected to these systems prior to entering the facility and remain attached while moving in and out of the facility (Figures 6.48 and 6.49).

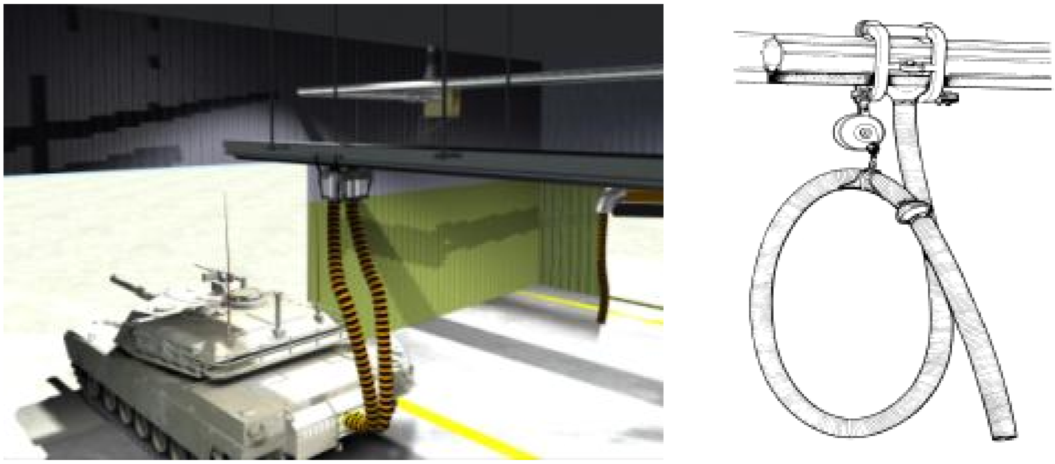


Figure 6.48. Suction rail systems.

Figure 6.49. Boom systems.

Vehicle Exhaust Extraction systems can be classified as non-enclosing or enclosing. Under-floor exhaust systems and pit ventilation systems are examples of non-enclosing systems. They are typically used in high volume vehicle production facilities. Enclosing type exhaust systems typically have a flexible hose with a tail-pipe adapter. The hose can be mounted on a stationary reel, an overhead rail extraction system or a swinging boom. Enclosing systems are normally classified as “sealed” or “non-sealed.”

Sealed type exhaust systems use a tailpipe adapter, which makes an airtight seal between the exhaust tailpipe and the flexible exhaust ventilation hose. The attachment of this nozzle is usually through the use of an air-filled bladder made of synthetic rubber which conforms to the size of the vehicle’s tailpipe. This eliminates the escape of exhaust gases when the vehicle is being accelerated or run at high idle. This system has a low operating air volume flow rate. Table 6.8 lists approximate airflow rates to be extracted per vehicle from the exhaust pipe using a sealed-fit tailpipe adapter. The capture effectiveness of sealed exhaust systems is high and for design purposes can be considered 90% or higher.

Table 6.8. Airflow rates to be extracted per vehicle from the tail pipe using a sealed *fit tailpipe adapter (Source: Ventilation Guide for Automotive Industry, HPAC Engineering 2000).*

Sealed Fit Tailpipe Adapter			
Veh. Type**	**Engine Power (hp)**	**Airflow rate cfm (m3/h)**	**Hose size**
LDGV	<130	300 (510)	3-in.
LDGT	< 175	450 (765)	4-in.
HDGV	< 250	500 (850)	4-in.
LDDV	< 325	500 (850)	4-in.
LDDT	< 400	500 (850)	4-in.
HDDV	< 500	750 (1275)	5-in.
ORV	< 600	1000 (1700)	6-8-in.

**Notes:
LDGV: Light-duty gasoline-fueled vehicles, up to 6000 lb GVW
LDGT: Light-duty gasoline-fueled trucks, up to 8500 lb GVW
HDGV: Heavy-duty gasoline-fueled vehicles, 8501+ lb GVW
LDDV: Light-duty Diesel vehicles, up to 6000 lb GVW
LDDT: Light-duty Diesel trucks, up to 8500 lb GVW
HDDV: Heavy-duty Diesel vehicles, 8501+ lb GVW

Non-sealed systems use a loosely fitting tailpipe adapter. This system requires a higher air flow rate than a sealed system to maintain negative pressure control of the exhaust gases emitted by the vehicle. The nozzle is usually attached by means of a mechanical device such as a vice-grip clamp or spring clip. For non-sealed exhaust systems the capture effectiveness is below 75%. Table 6.9 lists approximate airflow rates to be extracted per vehicle from the exhaust pipe using a non-sealed fit tailpipe adapter.

Table 6.9. Airflow rates to be extracted per vehicle from the exhaust pipe using an open-fit non-sealing tailpipe adapter (Source: Ventilation Guide for Automotive Industry, HPAC Engineering 2000).

Non-sealed Fit Tailpipe Adapter			
Veh. Type**	**Engine Power (hp)**	**Airflow rate cfm (m^3/h)**	**Hose size**
LDGV	< 130	450 (765)	4-in.
LDGT	< 175	600 (900)	5-in.
HDGV	< 250	750 (1250)	5-in.
LDDV	< 325	750 (1275)	5-in.
LDDT	< 400	750 (1275)	5-in.
HDDV	< 500	1125 (1910)	6-in.
ORV	< 600	1500 (2500)	8-in.

**Notes:
LDGV: Light-duty gasoline-fueled vehicles, up to 6000 lb GVW
LDGT: Light-duty gasoline-fueled trucks, up to 8500 lb GVW
HDGV: Heavy-duty gasoline-fueled vehicles, 8501+ lb GVW
LDDV: Light-duty Diesel vehicles, up to 6000 lb GVW
LDDT: Light-duty Diesel trucks, up to 8500 lb GVW
HDDV: Heavy-duty Diesel vehicles, 8501+ lb GVW

Selection of the hose for a particular application depends on exhaust temperature and flow rate. Selection of the nozzle depends on the size and configuration of the tail-pipe or exhaust grill. In most small vehicle maintenance and repair facilities, it is uncommon for several vehicles to drive in or out of the facility simultaneously. Likewise, it is uncommon to run all the engines in the facility at the same time. Typically, a demand-controlled local exhaust system is sized for a maximum duty cycle of 50% of the total available capacity thereby reducing the size of the exhaust duct, fan as well as its operating airflow rate. The exhaust airflow rate is controlled using a variable frequency drive (VFD) and a pressure sensor installed in the main duct.

Demand based control of the local exhaust system is initiated by a mechanical damper that opens when the hose is pulled down from the reel. Each of these mechanical dampers initiates the activation of air flow from a specific hose reel during maintenance operations. The system fan ramps up or down to accommodate the number of hose reels activated without affecting the airflow through other reels.

Description

Vehicle exhaust capture systems trap and remove by-products of the engine combustion process (gas or Diesel) without contaminating the building air. Vehicle exhaust fumes contain hydrocarbons (HC), nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxides (SOx), carbon dioxide (CO2) and approximately 100 other volatile organic and acidic compounds.

Energy Savings (Qualitative)

By installing a rail or boom system, which allows for external connection of the to the exhaust hose, the outside ventilation requirements of the facility can potentially be reduced from 1.5 cfm/sq ft to 0.5 cfm/sq ft.

Energy Savings (Quantitative)

A vehicle maintenance facility with typical light industrial wall and roof constructions was modeled in the EnergyPlus computer simulation program. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The facility is heated and ventilated, with no air-conditioning in the maintenance bays. The annual fan energy and heating coil gas consumption based on an outdoor air ventilation flow rate of 1.5 cfm/sq ft were calculated for the facility. Savings were calculated by linearly scaling the base case fan energy and gas consumption to correspond to an outdoor ventilation flow rate of 0.5 cfm/sq ft. The economic analysis is based on a 12 bay facility.

Energy Savings and Payback Calculation Assumptions

The following assumptions were made in the analysis:

- Each vehicle station in the facility was 10 m x 20 m x 10m.
- Installed cost per vehicle station of a rail system is $5833.
- Installed cost per vehicle station of boom system is $8333.

Energy Savings and Payback Calculation Results

Figures 6.50 and 6.51 show the simple payback for both the rail and boom systems. The less costly rail system shows a payback of less than 6 years in moderate and cold climates. The boom system shows a payback of less than 8 years in the same climates.

Figures 6.52 – 6.54 show estimated energy savings for the rail or boom system for different climate locations. Since fan power savings were similar for all locations, the electricity savings plot primarily shows the effect of energy prices. As expected, gas savings are negligible in the hottest climates.

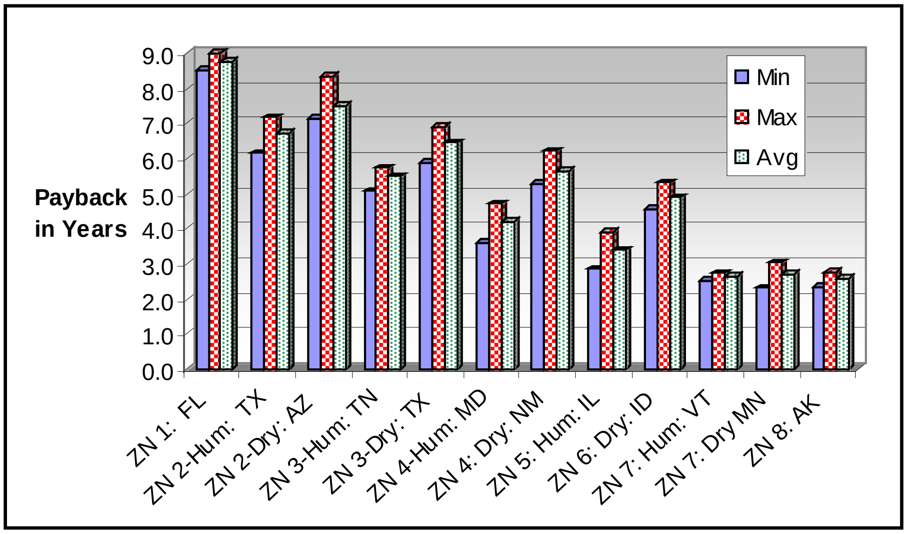


Figure 6.50. Estimated simple payback for rail system.

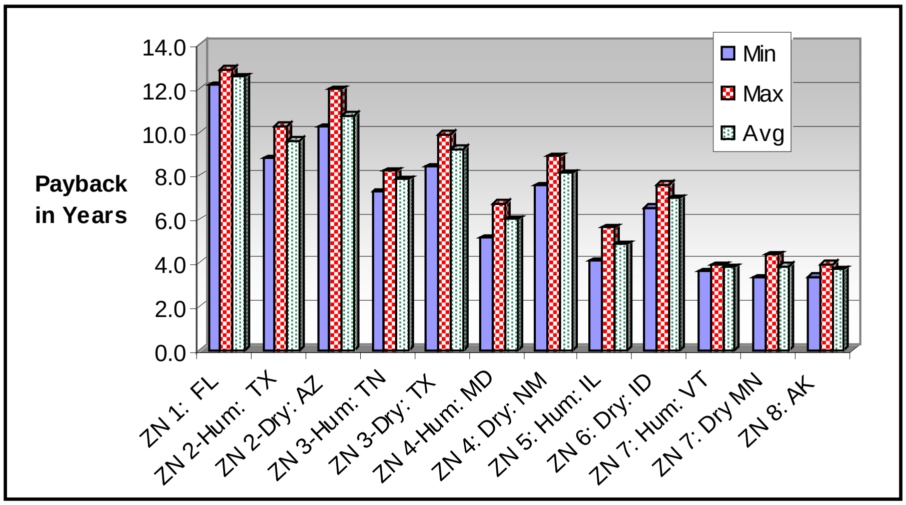


Figure 6.51. Estimated simple payback for boom system.

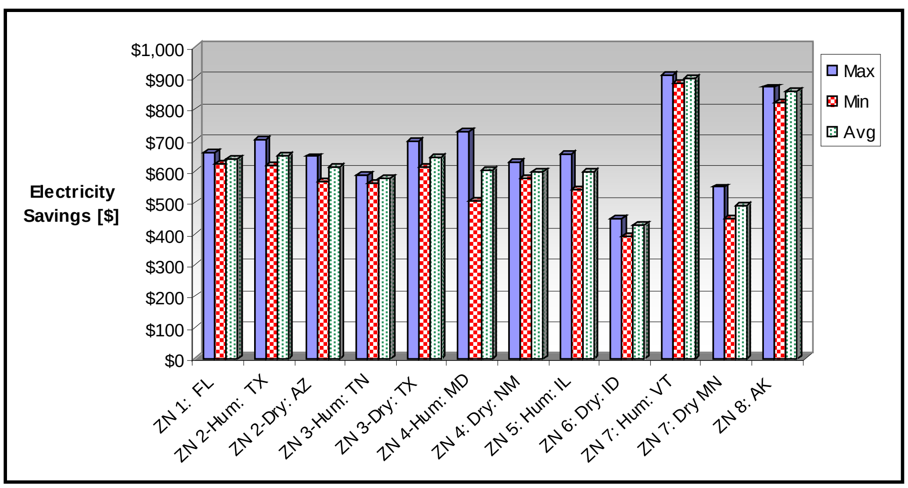


Figure 6.52. Estimated annual electricity savings for rail or boom system.

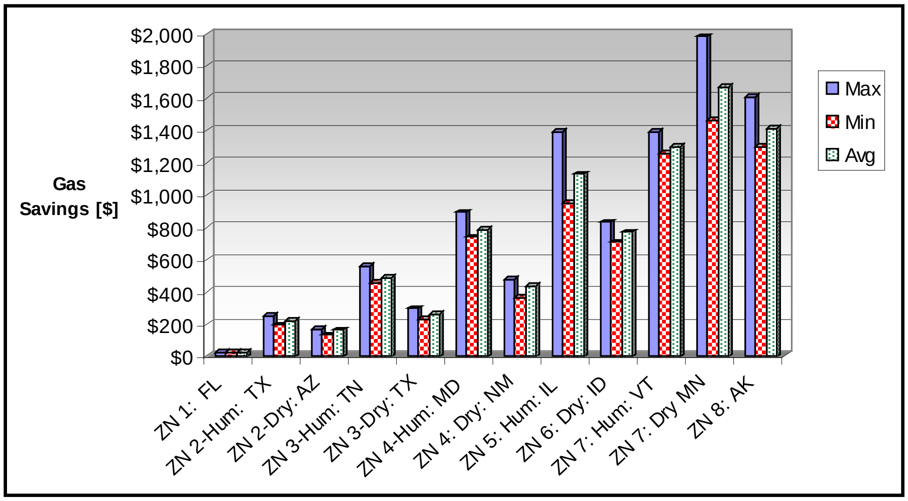


Figure 6.53. Estimated annual gas savings for rail or boom system.

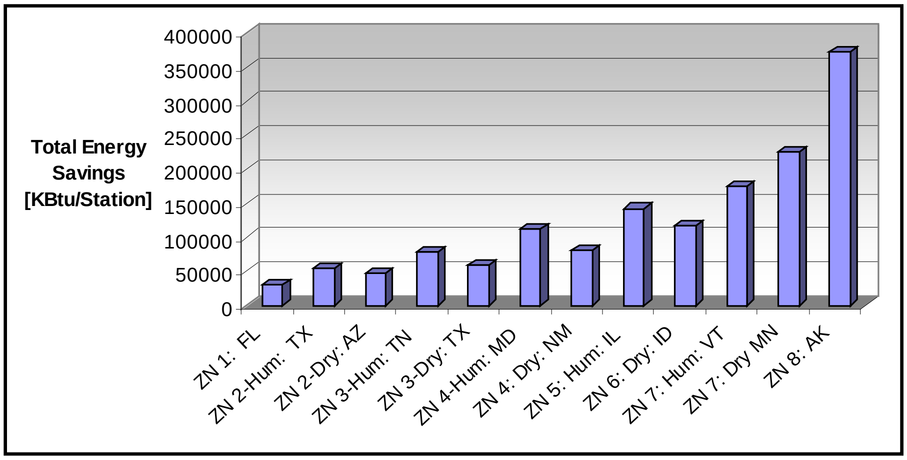


Figure 6.54. Estimated annual total savings per station.

Level of Maturity

This is a fully mature technology.

Climatic Conditions Necessary

The technology works equally well in any climate.

Impact on Indoor Air Quality

The technology improves indoor air quality.

Contacts and Major Manufacturers

PlymoVent, Airflow Systems, Nederman, Eurovac and Local Exhaust and Ventilation Company are major manufacturers of local exhaust ventilation.

High-Speed Roller Doors for Large Openings

Application

Industrial.

Category

Building envelope.

Description

High speed doors perform the same function as normal garage style overhead doors, but they do so much faster. High speed doors can open at a speed of up to 8 ft/s (2.4 m/s) and can be controlled by automatic ground strips or photo sensors. By opening and shutting quicker they significantly reduce air infiltration while the doorway is being used.

Concept

High speed doors have many advantages over normal overhead doors. The first and most obvious advantage is the speed with which the door opens and closes. A standard overhead door operates at about 8 in./s (20 cm/s) while a high speed door operates at up to 100 in./s (2 m/s). For example, a standard 10-ft (~3-m) door would take roughly 15 seconds to fully open while a high speed door takes only one and a quarter seconds. With their ability to be controlled by a ground strip or photoelectric sensor, a forklift can drive up to a high speed door and have it open without the driver having to slow down, and the door shuts as soon as the driver passes. With the speed at which the door operates a minimum amount of infiltration occurs and no time in machine/man hours are wasted waiting for the doors to open. Another very nice feature of high speed doors is that they are designed to "break away" if hit. Therefore, if a forklift is driving too fast and runs into a high speed door, the bottom of the door will simply swing away from the frame causing no damage to the door or frame. The door can be reattached to the frame without tools. Figure 6.55 shows a standard high speed door (left) and an example of the breakaway device (right).

Source: Rytec website (www.rytec.com).

Figure 6.55. High speed doors (a) inside view, and (b) in action.

Potential Energy Savings (Qualitative)

The main energy saving mechanism is a reduction in air infiltration due to open doors without a corresponding loss in productivity.

Potential Energy Savings (Quantitative)

Budgetary prices were received for three different sizes of three different models. All three door models are manufactured by Rytec Corp.

1. The PredaDoor PD5500 model is recommended for smaller exterior openings such as shipping bay doors. The PredaDoor would also work well on the 10 x 10-ft openings assuming there would not be abnormally high wind loads or positive/negative pressures.

2. The Fast-Seal FS1000 model is recommended for all exterior openings; however, this would probably be overkill for shipping bay doors. The Fast-Seal has separate curtain tensioning and counterbalance systems to allow it to handle high wind loads/pressures as well as to allow for larger door sizes.

3. The Spiral model is recommended for any opening where both high-speed, high-cycle operation and full security is required. The spiral is constructed out of metal instead of fabric to allow it to maintain the security advantage offered by standard over head doors while still offering the high speed operation of the fabric doors.

Table 6.10 below lists the estimated cost for this technology, including materials, freight and installation. It is important to realize installation costs vary significantly across the nation. With this in mind the reference at Rytec doors quoted the prices on the high side for installation and freight so the actual installed cost might be significantly lower depending on location. The cost differential between high speed doors and standard overhead doors is typically on the order of 15%. For this analysis a cost differential of $6,000 for the four overhead doors in the shipping area is used. The life expectancy of Rytec high speed doors is roughly one million cycles.

Table 6.10. Estimated cost for high-speed roller door technology.

	8-ft wide x 8-ft high*	10-ft wide x 10-ft high	15-ft wide x 15-ft high
PredaDoor PD5500	$10,000.00	$11,000.00	$16,000.00
Fast-Seal FS1000	$13,000.00	$15,000.00	$21,000.00
Spiral (round head)	$19,000.00	$21,000.00	$26,000.00

* 8 ft = ~2.4 m; 10 ft = ~3 m; 15 ft = ~4.57 m

Energy Savings and Payback Calculation Assumptions

A 50,000 sq ft (4645 m^2) typical single-story, metal building with 20 ft. (~6 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area, and a loading dock area. The modeled building was of typical light industrial wall and roof construction, i.e., the walls were insulated metal construction (R-4) and the roof was of standard, built-up bitumen. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

This analysis is based on the shipping zone only. A relatively low duty cycle for the base case was specified with the doors opening twice per hour for 6 to 12 minutes at a time. The high speed doors were also opened twice per hour and were assumed to be open for 4 to 10 minutes. A flow network assuming a balanced system and using outside pressures based on weather file wind speeds and wind directions was set up to calculate the flow rate through the doors. Since the flow network is independent of other simulation parameters, energy savings for higher duty cycles were calculated by linearly extrapolating the low duty cycle results.

Energy Savings and Payback Calculation Results

For this technology, energy savings are tied closely to the number of cycles expected for the door. The low duty cycle resulted in paybacks in excess of 20 years for all climates (Figure 6.56). Doubling the duty cycle to 4 times per hour resulted in reasonable payback times in cold climates. It should also be noted that a shipping zone is not an ideal application for the high speed overhead door technology. The doors have the capability of reducing door open time by a factor of 10 in high-duty-cycle, low-open-time applications (e.g., fork lift traffic between buildings). Figure 6.57 shows that this technology realizes gas savings only in heating mode for the ventilation only industrial building. Figure 6.58 shows total energy savings for this scenario based entirely on the gas savings.

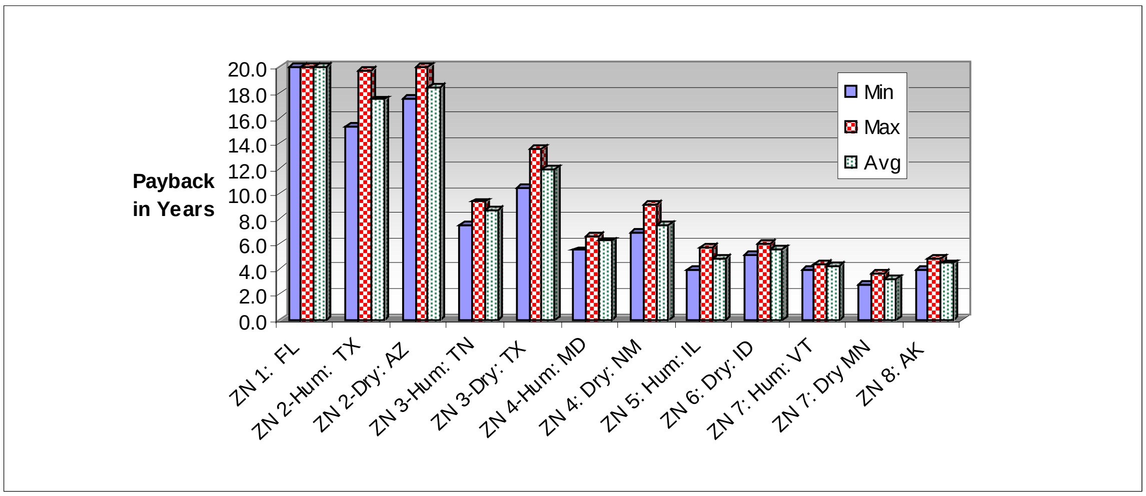


Figure 6.56. Estimated payback for high speed roller doors.

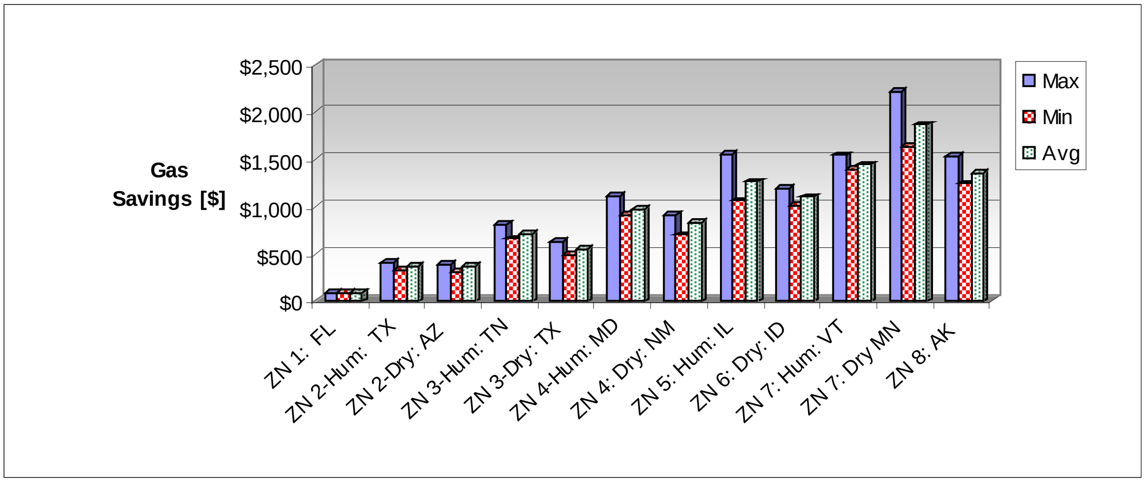


Figure 6.57. Estimated gas savings for high speed roller doors.

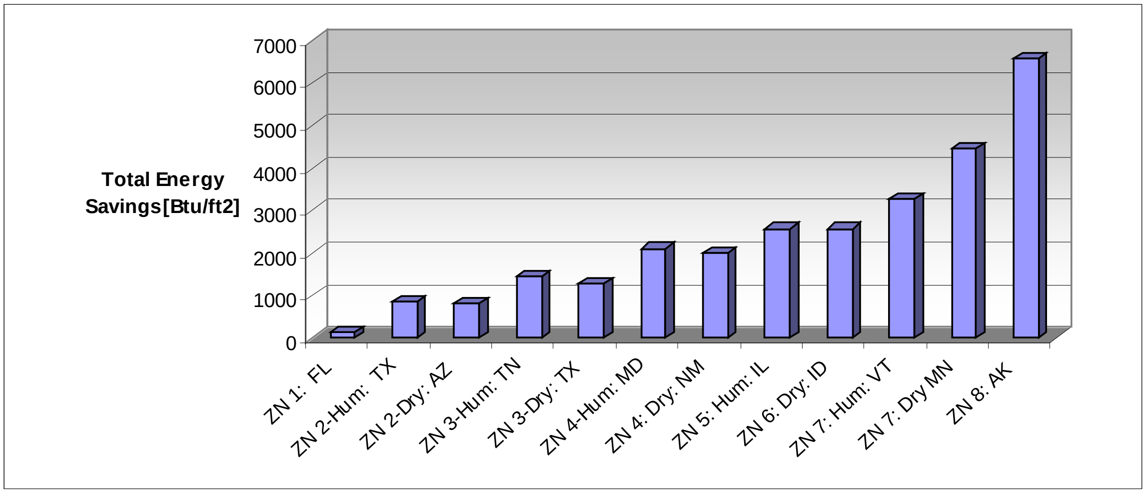


Figure 6.58. Estimated total energy savings for high speed roller doors.

Level of Maturity

High speed doors have been a feasible technology for over 20 years and are applicable in virtually all situations.

Climatic Conditions Necessary

The technology may be applied in any climate.

Impact on Indoor Air Quality

The system will reduce outside air infiltration. With a properly designed ventilation system, indoor air quality can be maintained.

Contacts and Major Manufacturers

Rytec Corporation
www.rytec.com
Brian Harahan
Government National Accounts Manager
Rytec Corp.
One Cedar Parkway
Jackson, WI 53037
(262) 677-6104 direct phone
(262) 677-6504 direct fax
(262) 339-7450 cell

Note: The ***Thomas Registry*** lists 22 manufacturers under "Doors: High Speed,"
http://www.thomasnet.com/nsearch.html?cov=NA&heading=23733009&sa=95902094&navsec=relbox

High Temperature Radiant Heaters

Application

Industrial buildings

Category

HVAC

Concept

The radiant heating concept achieves thermal comfort in a space at lower air temperatures and significantly lower ventilating air flow rates. Heaters which can be mounted at very high levels – up to 100ft, provide comfort at floor level, without heating the entire volume of air in the space. Radiant systems avoid the problem of air stratification in the space typical of convective heating systems in industrial applications. This characteristic of radiant heating systems makes them ideal for industrial buildings with high ceilings and the potential for high infiltration rates. Maintenance and aviation hangar buildings are ideal candidates for radiant systems because they typically have very large interior spaces with high ceilings and large doors that are frequently open.

Description

Over the years three distinct forms of radiant heating systems have been developed which operate at three distinct temperature bands; low, medium and high intensity.

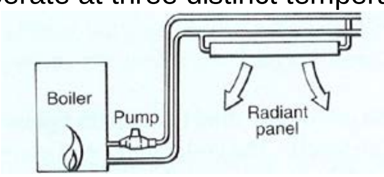


Figure 6.59. Low intensity radiant heater.

Low Intensity (140-392°F): The low temperature range comprises all systems using water or steam as the initial heat distributor (Figure 6.59). As the radiant output is directly related to absolute temperature to the fourth power then the total heat output in a radiant form is low as a greater proportion of the heat is given to convection. This is natural convection and can only rise, thus adding very little comfort to the lower levels in a building. Medium temperature hot water (MTHW) at approximately 230°F is circulated from an oil– or gas-fired boiler to radiant panels mounted at high level. The panels emit radiant heat, warming occupants and objects at floor level. Typically these systems require additional fans to move stratified air to the floor.

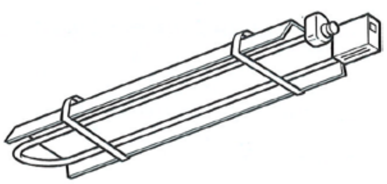


Figure 6.60. Low intensity radiant heater.

Medium Intensity (392-1292°F): The medium temperature range consists of electric sheathed elements, radiant tubes – direct fuel fired and re-circulated hot air ducts – all ’black’ surfaces (Figure 6.60). In this temperature band, the proportion of radiation to convection is much more favorable and represents optimum efficiency. Steel can be used as a heat transfer medium and, under the operating conditions; its emissivity is near to black body.

These heaters are typically suspended from roof structure or even can be wall mounted. A gas burner fires into a tube which then emits radiant heat. The reflector focuses the heat (radiant flux) to ground level. The products of combustion are vented from the tube by a vacuum fan, and this can be connected to a flue to discharge outside. Units vary from the simple U-tube, to interconnected systems with a common extract fan. Mounting heights can vary from 10ft to 100ft, and thus can be suitable for a wide variety of building heights.

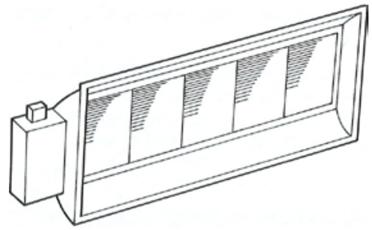


Figure 6.61. High intensity radiant heater.

High Intensity (1472 - 3632°F): The high temperature band is produced by incandescent electric or gas heated surfaces (Figure 6.61). The peak radiant output is high but much of the heat cannot be extracted, due to high exhaust gas temperature (1652°F surface = 1652°F exhaust gas). The equipment operating in this band is a gas fired surface combustor, also referred to as an open flame spot heater. As per Manufacturer's recommendations an additional mechanical venting system is required at a rate of 4 cfm per 1,000 btu/h, to exhaust the products of combustion from the facility. The units comprise ceramic plaques mounted in polished reflectors. Natural gas or propane is burned in the plaque assembly, and the radiant heat emitted is reflected to ground level. Because the radiant temperature is greater than that of the U-tube type heaters, the units are smaller for the power output but provide a restrictive spread of radiant effect. Control is via a 'black bulb' radiant temperature sensor. Mounting heights vary from 13ft to 32ft.

Figure 6.62. Radiant gas fired heating system.

Gas Fired Radiant Tube Heaters: Because of their overall flexibility and radiant output, gas fired radiant tubes are considered the most effective way of heating industrial buildings and aviation hangars (Figure 6.62). The infra-red heat passes through the air without heating it and is absorbed by cooler objects upon contact, including floors and equipment, creating a comfortable all-round radiant warmth at occupant level, without wastefully heating the whole volume of the building or the roof space. Because radiant heat can be controlled directionally, only the occupied areas of the building need to be heated, which enables considerable energy savings to be realized.

The objective of a radiant tube heating system is to ensure that the people in the building are comfortably warm. After all, without people that need for heating any building becomes largely superfluous. The human body experiences a sensation of comfortable warmth when it is giving heat to its surroundings. If the body emits too much heat it feels cold. Conversely, if the body cannot emit sufficient heat it feels too hot. By the correct application of a radiant tube heating system comfort levels can be optimized. Radiant heat warms object and surfaces, increasing the mean radiant temperature and reducing the body's loss of heat to its surroundings. In addition by eliminating air movement, convective loss of heat from the body will also be reduced.

Energy Savings (Qualitative)

Savings generated by implementing a radiant gas-fired heating system would be based on the following factors:

1. Initial capital costs.

2. Fuel and energy costs (natural gas or propane, electricity).

3. Material properties in heated space.

Energy savings are primarily achieved by operating the radiant heater at a lower thermostat setting, and by reducing ventilation flow rates to the minimum required to maintain good air quality in the space. For a radiant system, equivalent thermal comfort can be achieved with an air temperature anywhere from 3 F to 5 F lower than what is required for convective systems. Radiant heater manufacturers report savings in fuel costs anywhere from 12% to 50% just by implementing the radiant tube heaters.* The highest potential savings are realized for thermally stratified buildings with high ceilings. For these applications the radiant system can provide occupant comfort at significantly reduced ventilative flow rates, depending on the fresh air requirements of the space.

Energy Savings (Quantitative)

A 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft. (6.1 m) high walls is used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20 ft. (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

The high temperature radiant heaters were evaluated by direct comparison of the total building energy use reported by the base-case EnergyPlus simulation program output with the total building energy use reported by the radiant heater-case simulation output. The radiant heater was installed in the light fabrication and the shipping zone. The thermostat was lowered by 3.5 °F in these zones and the ventilative flow rate was reduced by 25%

For the model industrial building the radiant system was specified as 10, 120,000 Btu/hr. radiant tubes at an installed cost of $32,000 for the entire system. The first cost of the radiant system is typically less than the first cost of a convective system.

<u>Energy Savings and Payback Calculation Assumptions</u>

The HIGH TEMP RADIANT SYSTEM model was used to simulate these heaters. Gas heaters were specified, so combustion efficiency was included as well. Due to the highly directional nature of radiant system, the percentage of total energy from the heater to each surface was specified, with the floor being the obvious target for the majority of the heat. The air temperature set point schedule was lowered by 3.5 F to provide the same

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* http://www.reverberray.com/fsstudies.html

thermal comfort as the convective system and the ventilation flow rate was reduced by 25% to account for savings related to thermal destratification of the space.

The first cost of the radiant system is typically less than the first cost of a convective system. If a convective system is not required for cooling or maintenance of indoor air quality, the payback on the radiant system is immediate. This analysis assumes the 'worst case' scenario in which a radiant system operates along with a ventilation system. For this case the ventilation system is downsized by 25%. Savings in both gas consumption and fan energy offset the initial cost of the radiant system.

Energy Savings and Payback Calculation Results

Even with no credit for reducing the capital cost of the system, the radiant system pays back in less than 4 to 6 years for all but the warmest climate (Figure 6.63). Both gas and electric fan power savings were realized by installing the radiant system as shown in the following figures.

Figures 6.64 and 6.65 show electricity and gas savings for the high ceiling case. Electricity savings reflect the fan energy that is saved during the heating months by a 25% reduction in the ventilating flow rate for the light fabrication and shipping zones. This reduction is due to elimination of thermal stratification in the space by radiant heat transfer to the occupants and floor area of the zone.

Figure 6.66 shows the net energy savings for the high temperature radiant case. The net savings include reduction in fan energy due to the effect of the radiant system on thermal stratification and the reduction in gas use due to the lower thermostat setting and the lower heating load as previously discussed.

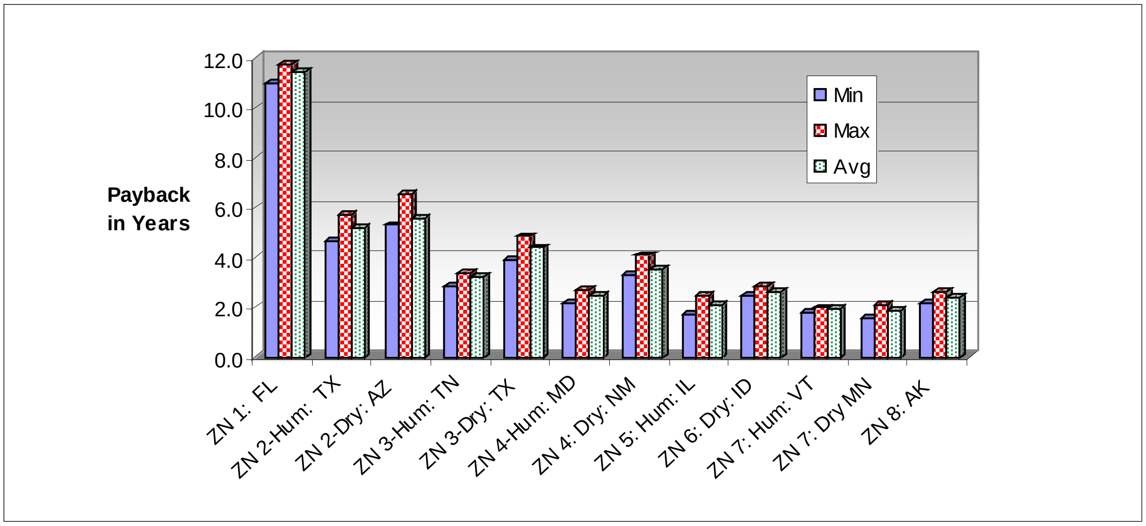


Figure 6.63. Estimated payback for the radiant system.

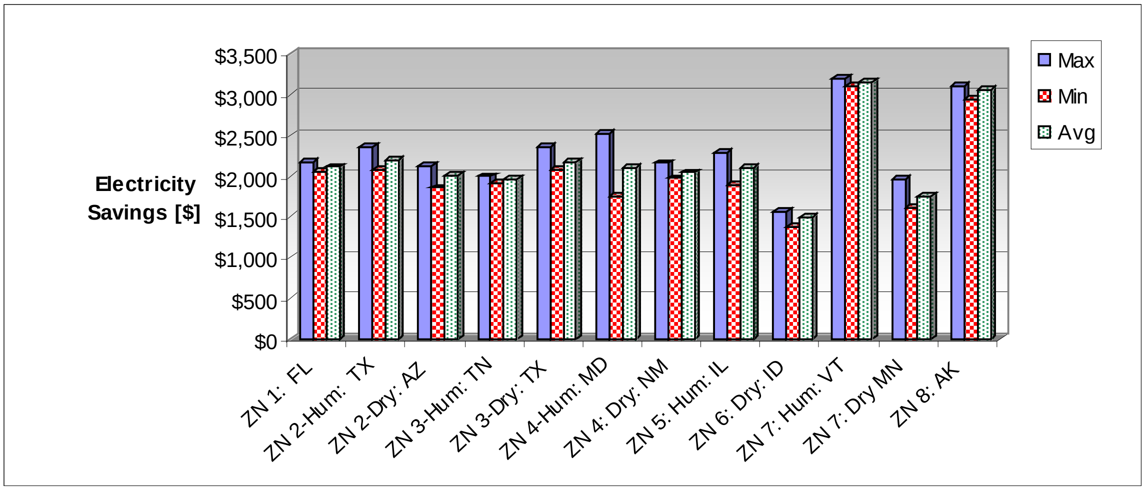


Figure 6.64. Estimated annual electric savings for high temperature radiant system.

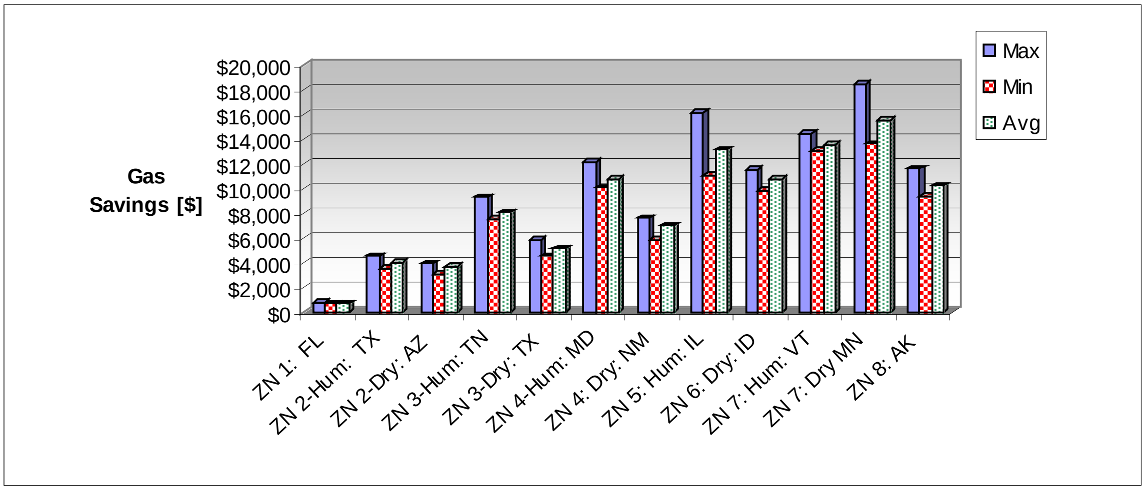


Figure 6.65. Estimated annual gas savings for high temperature radiant system.

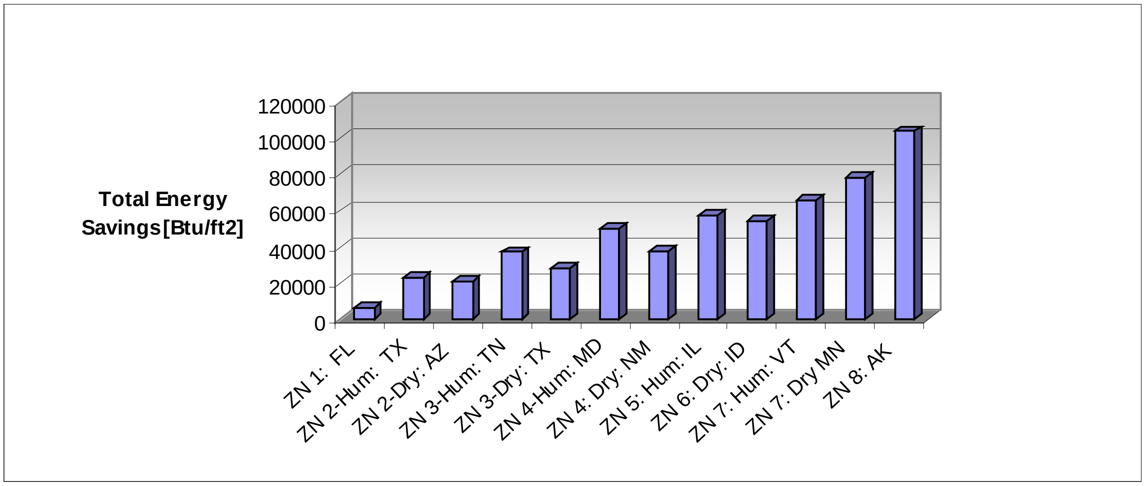


Figure 6.66. Estimated total annual energy savings per square foot for radiant system.

Level of Maturity

20 years.

Impact on Indoor Air Quality

None for vented systems.

Climatic Conditions Necessary

This technology is a ‘heating only’ technology and is therefore not applicable to hot climates.

Contacts and Major Manufacturers

Listed through URL:
http://www.medibix.com/CompanySearch.jsp?cs_choice=c&clt_choice=t&treepath=17514&stype=i

Reduce Air Flow in Paint Booths by Using Variable Frequency Drives

Application

Industrial.

Category

HVAC.

Concept

To implement VFD control of multiple paint booths, shut-off dampers are required to isolate booths that are not in operation. An interlock between the paint booth equipment and a two position ("open" or "closed") damper drive solenoid provides primary control for the VFD. As paint booths come on line, the damper associated with that booth opens resulting in a drop in duct pressure. A pressure sensor in the main duct near the fan inlet, senses the pressure drop and increases the fan speed to maintain the setpoint pressure in the duct. For this configuration, control dampers (Figure 6.67) are required for each paint booth. A single pressure transducer and VFD (Figure 6.68) are required for the system.

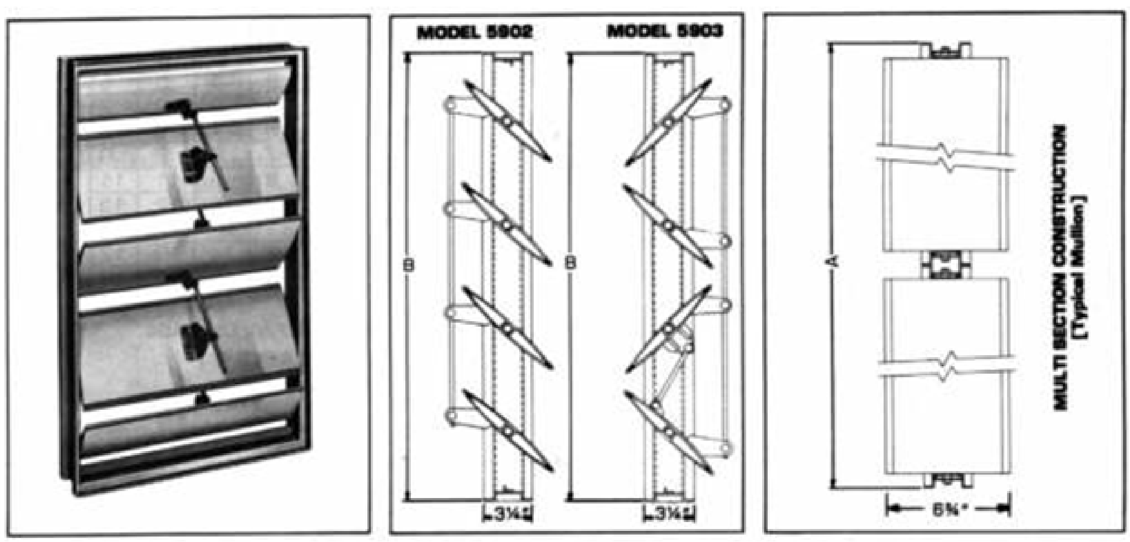
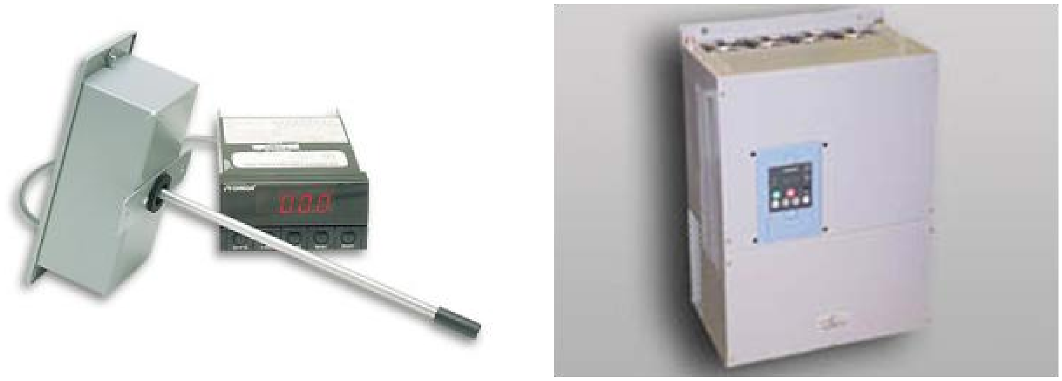


Figure 6.67. HVAC control dampers.



(a) (b)

Figure 6.68. Pressure transducer (a), and variable speed drive (b).

Installing a variable speed drive can yield significant savings, but the feasibility of the retrofit is typically determined by accessibility to ductwork and control wiring. The conversion involves installing a VFD actuated by a duct pressure sensor and a control damper actuated by a programmable controller.

Description

Operating paint booth ventilation fans when the paint booth is not in use can result in significant energy losses. If the ventilation fan purges a single paint booth, then a simple interlock between the paint booth equipment can be used to turn the fan off when the booth is not in use. If the ventilation fan purges multiple paint booths, however, a variable frequency drive is required to optimally control the fan speed to purge only those paint booths that are in operation.

Energy Savings (Qualitative)

The savings associated with this energy conservation measure are tied closely to the number of paint booths served by a single fan and the variability of paint booth operation. If the paint booths operate at full capacity for the entire shift, then variable speed fan control will obviously result in no energy savings. If the diversity of the operation is high, installing VFDs may yield significant savings.

Energy Savings (Quantitative)

A 50,000 sq ft (4645.152 m^2) typical metal building with 20-ft (6.1 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20-ft (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is a standard built up bitumen roof. The building is heated and ventilated, with no air-conditioning in the work areas. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

Table 6.11 lists typical pricing for the required components. A fixed cost is associated with the VFD and pressure transducer and an incremental cost with the control damper that must be installed in the exhaust duct for each hood. A simple isolation damper with a two-position solenoid is sufficient for this application. Potential savings increase as the system adds more paint booths with high diversity.

Table 6.11. Typical costs for VFD components.

	Item	Est. Labor	1 VFD
Siemens VFD, 240 V 50 HP	$4500	$1500	$6,000
HVAC Control Dampers (1 per booth)	$1000	$500	$6,000
Omega duct pressure transducer	$250	$100	$400
Total (4 booth sys.)			**$12,400**

Energy Savings and Payback Calculation Assumptions

Savings were calculated directly from the base case "ventilation zone" fan energy. Since savings depend on both the number and the diversity of paint booths, savings are calculated on a Btu/cfm reduction in flow rate. Payback is estimated for a four-paint booth configuration with 15% and 20% reductions in airflow rate.

Energy Savings and Payback Calculation Results

Figure 6.69 shows the payback for a four-booth system with an overall reduction in outside air flow rate of 15%, and Figure 6.70 shows the payback for a four-booth system with an overall reduction in outside air flow rate of 20%. The payback is under 2 years for the coldest climates and under 4 years for all but the warmest climates. Savings in "cooling only" climates represent reduction in fan power only. For mechanically-cooled buildings, reducing the coil load would realize significant additional savings.

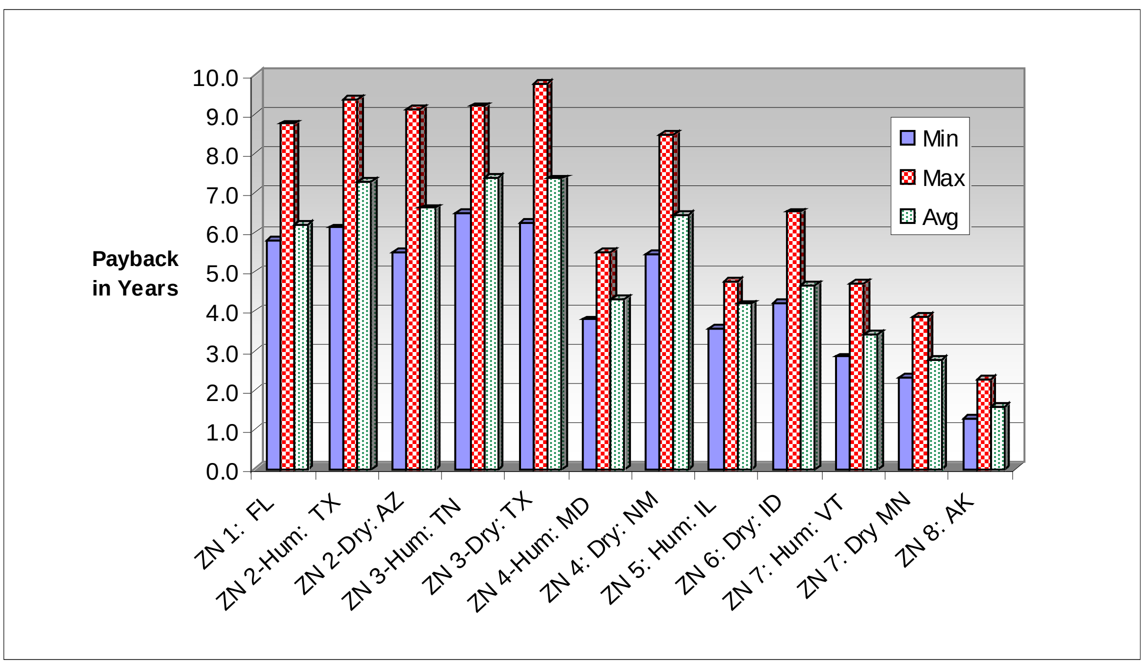


Figure 6.69. Payback for four booths with 15% reduction in system air flow.

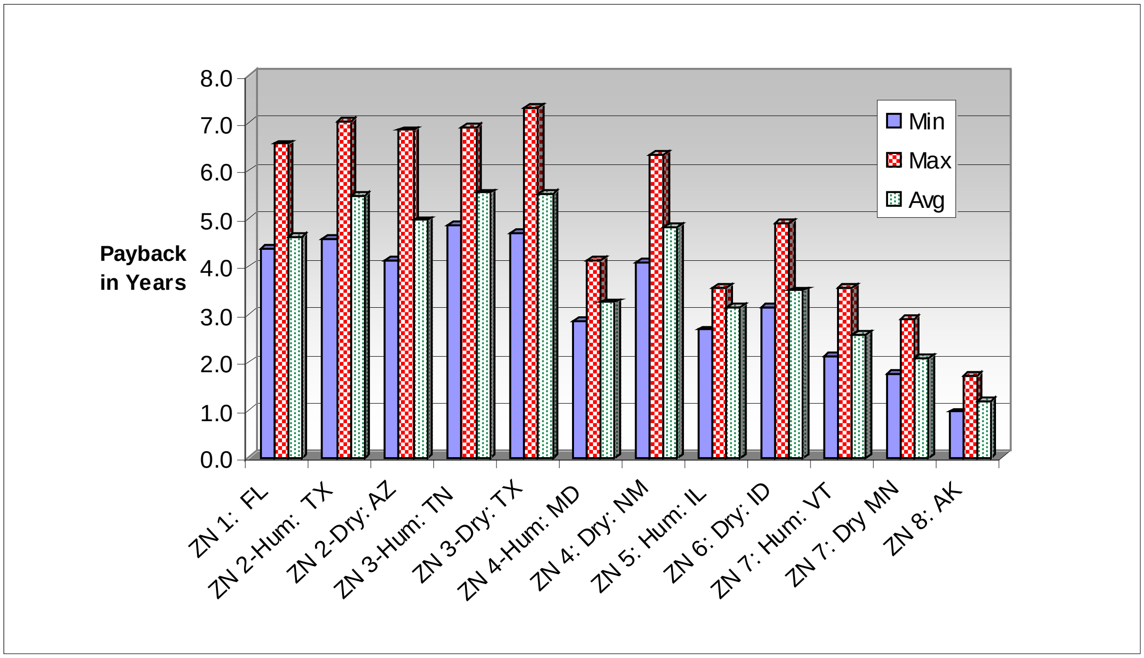


Figure 6.70. Payback for four booths with 20% reduction in system air flow.

Figure 6.71 shows annual energy savings as Btus per cfm reduction in the outside air flow rate. Such a graph can be used to estimate savings for this ECM for specific paint booth applications where reliable estimates of potential reductions in outside air flow rates are available.

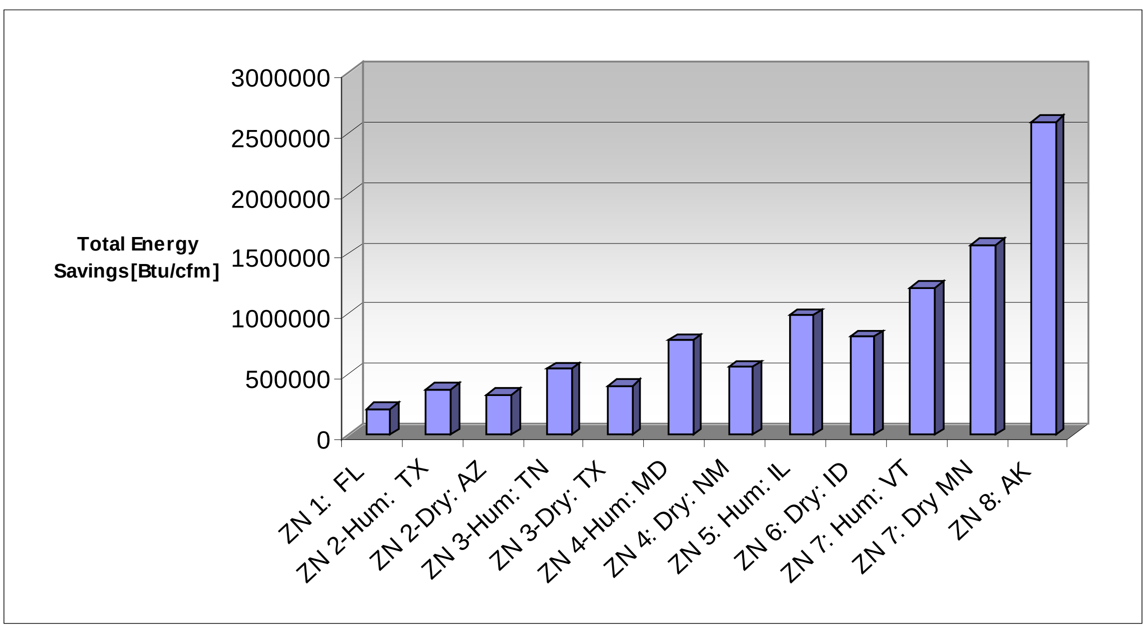


Figure 6.71. Annual energy savings (Btus) per cfm reduction in the outside air flow rate.

Level of Maturity

20 years

Climatic Conditions Necessary

This ECM is applicable to all climates. In hot climates, shortest paybacks will be realized for mechanically cooled buildings.

Impact on Indoor Air Quality

None

Contacts and Major Manufacturers

Contacts and major manufacturers are listed through URL:

http://www.processregister.com/AC_Variable_Frequency_Drives/Suppliers/pid682.htm

Recirculation with Filtration

Application

Industrial, commercial, institutional.

Category

HVAC.

Concept

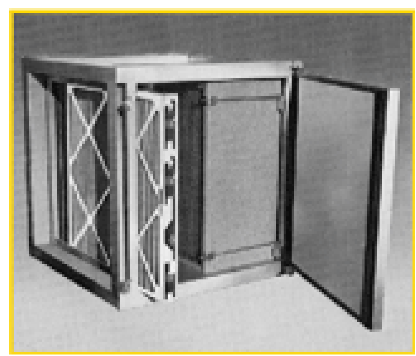
Energy is saved by filtering and recirculating ventilation air instead of bringing in outside air. The technology is applicable to industrial processes that generate high particulate loads, but do not generate toxic or oxygen displacing gases.

Description

To maintain indoor air quality, many industrial HVAC systems operate with high outside air flow rates to dilute contaminants in the building and remove them with the exhaust air. For some industrial processes, the contaminants can be removed by filtration and energy is saved by reducing energy use for heating the ventilation air supplied at reduced rate. A filtration system with recirculation is achieved by adding a filter and "mixing box" (Figure 6.72). The filter housing and filter must be designed for the particulate load of the processes in the industrial building zone.

Source: http://www.plenums.com

a. mixing box



Source: http://www.camfil.com

b. HEPA filter with housing

Figure 6.72. Elements of recirculation system with filtration.

Mixing boxes, which control the fraction of fresh outside air that is mixed with recirculated return air, can be retrofit in to any existing air handling system. Most manufacturers of packaged rooftop units, which are commonly used in industrial applications, offer mixing boxes as optional equipment for their units. Filter housing and filters can be retrofit into any existing duct system. Additional fan power will be required to overcome the pressure drop associated with the filter.

Energy Savings (Qualitative)

In general reducing the outside air flow rate results in significant savings for both cooling and heating. For the industrial building with no mechanical ventilation, however, fan electric use in the summer months will increase due to the increased pressure drop through the filter. This cost will be more than offset by savings in gas use during the heating season for all heating climates. An optimal operating strategy would bypass the filter and run with 100% outside air in the summer for the ventilation only (no mechanical cooling) case.

Energy Savings (Quantitative)

The cost of retrofitting the system with filters and a mixing box can vary significantly depending on the location and the accessibility of the equipment. For the industrial building a cost of ~$35/100 cfm was used for a total cost of $25,000 for the building.

Energy Savings and Payback Calculation Assumptions

This ECM was simulated by modifying the outside air schedule. A 50,000 sq ft (4645.152 m^2) typical metal building with 20-ft (6.1 m) high walls are used for the study. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area and a loading dock area are single story with 20-ft (6.1 m) high walls. Typical light industrial wall and roof constructions are used in modeling the building. The walls are insulated metal construction (R-4) and the roof is standard built up bitumen. The building is heated and ventilated, and the work areas are not air-conditioned. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

The recirculation ECM set the minimum outside air fraction to 20%. Therefore, when it is more economical to recirculate the indoor air, it will recirculate up to 80% of the air. The ECM also increases the fan pressure drop from 2.4-in. H_2O (600 Pa) to 3.2-in. H_2O (800 Pa) to account for the pressure drop over the filters. This ECM was only performed for the industrial zones.

Energy Savings and Payback Calculation Results

In cold and moderate climates, this technology has excellent payback potential (Figure 6.73).

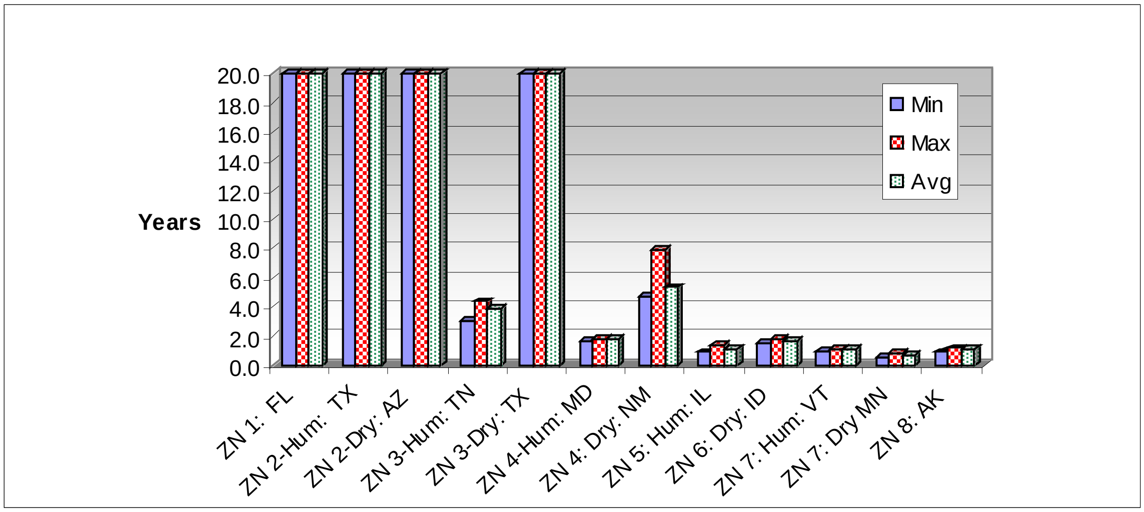


Figure 6.73. Payback potential for the recirculation system with filtration.

Additional savings would be realized for buildings with mechanical cooling. For the ventilated industrial building used in this example, the system never saved energy during the cooling season, since filtration alone would not lower the cooling load. Figure 6.74 shows the increase in electric energy use due to the increased fan pressure drop across the filters.

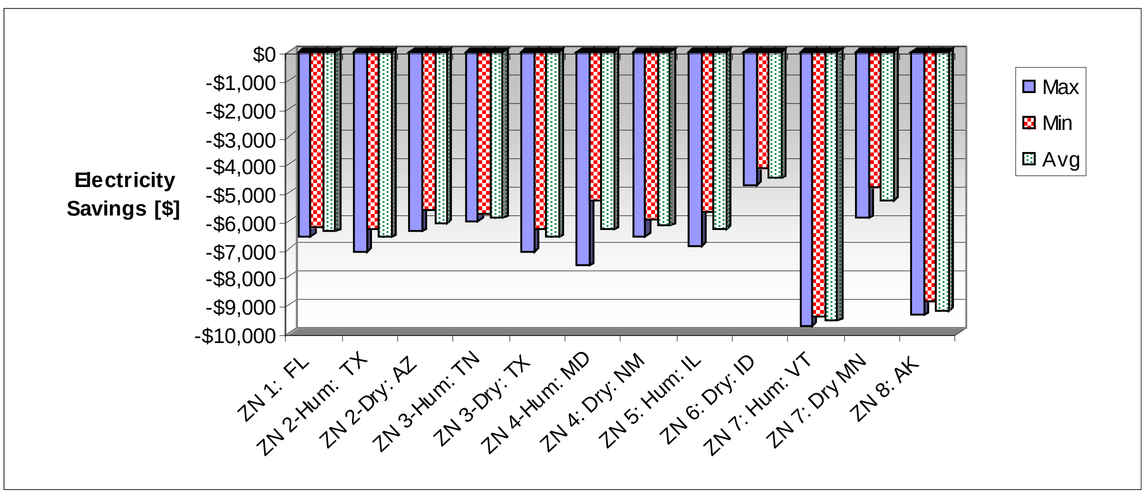


Figure 6.74. Increase in annual electrical fan power.

Heating season gas savings (Figure 6.75) however, more than outweighed the additional fan energy costs and provided significant overall savings in all but the warmest climates (Figure 6.76).

Level of Maturity

20 years.

Impact on Indoor Air Quality

This technology has no impact on indoor air quality. However, systems with recirculation require adequate ventilation to eliminate non-filtered contaminants build-up.

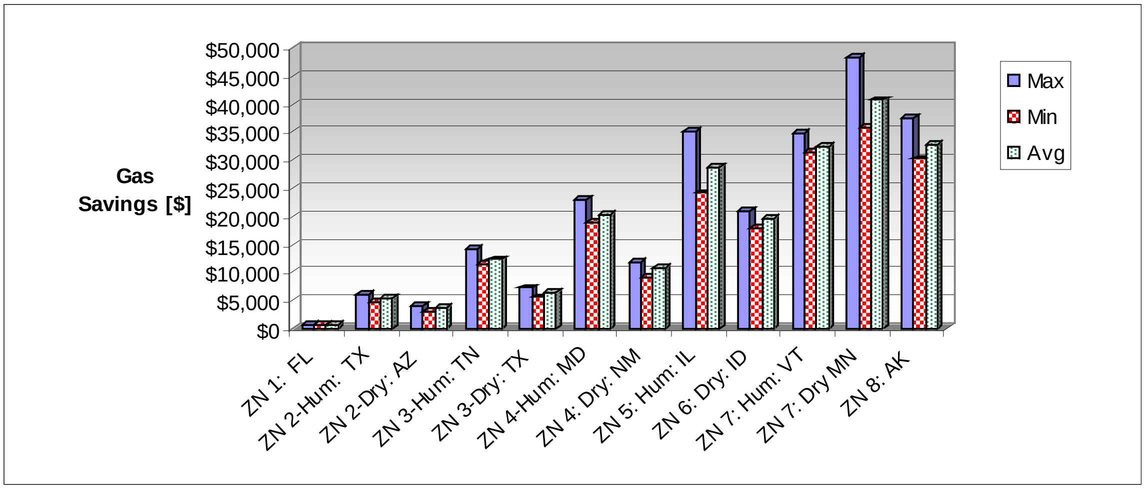


Figure 6.75. Annual heating energy savings.

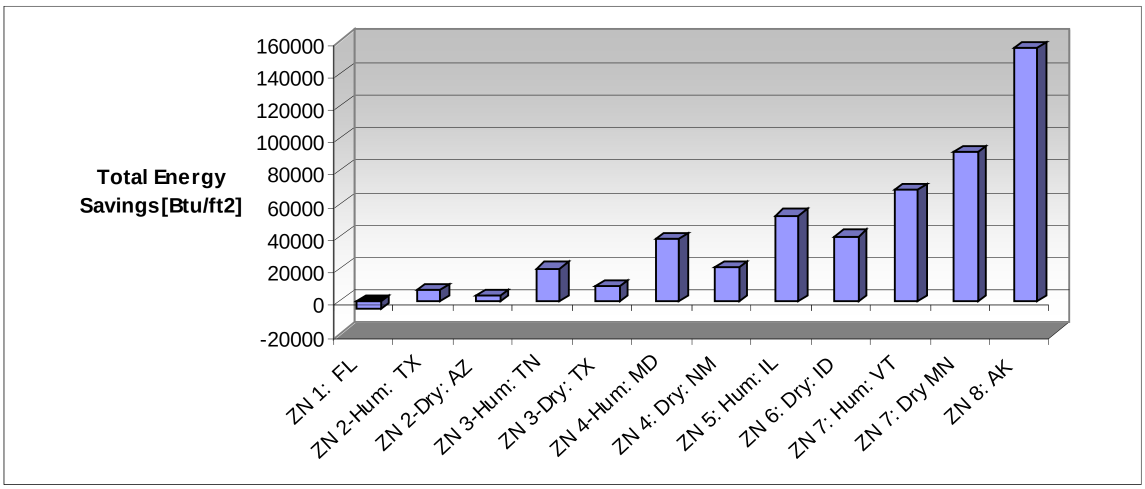


Figure 6.76. Total energy savings.

Climatic Conditions Necessary

None.

Contacts and Major Manufacturers

Numerous manufacturers manufacture filters and mixing boxes:

http://www.plenums.com

http://www.camfil.com

http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/eii/M144-20-2003E.cfm

Solar Wall for Outdoor Air Preheating

Application

Industrial.

Category

HVAC System.

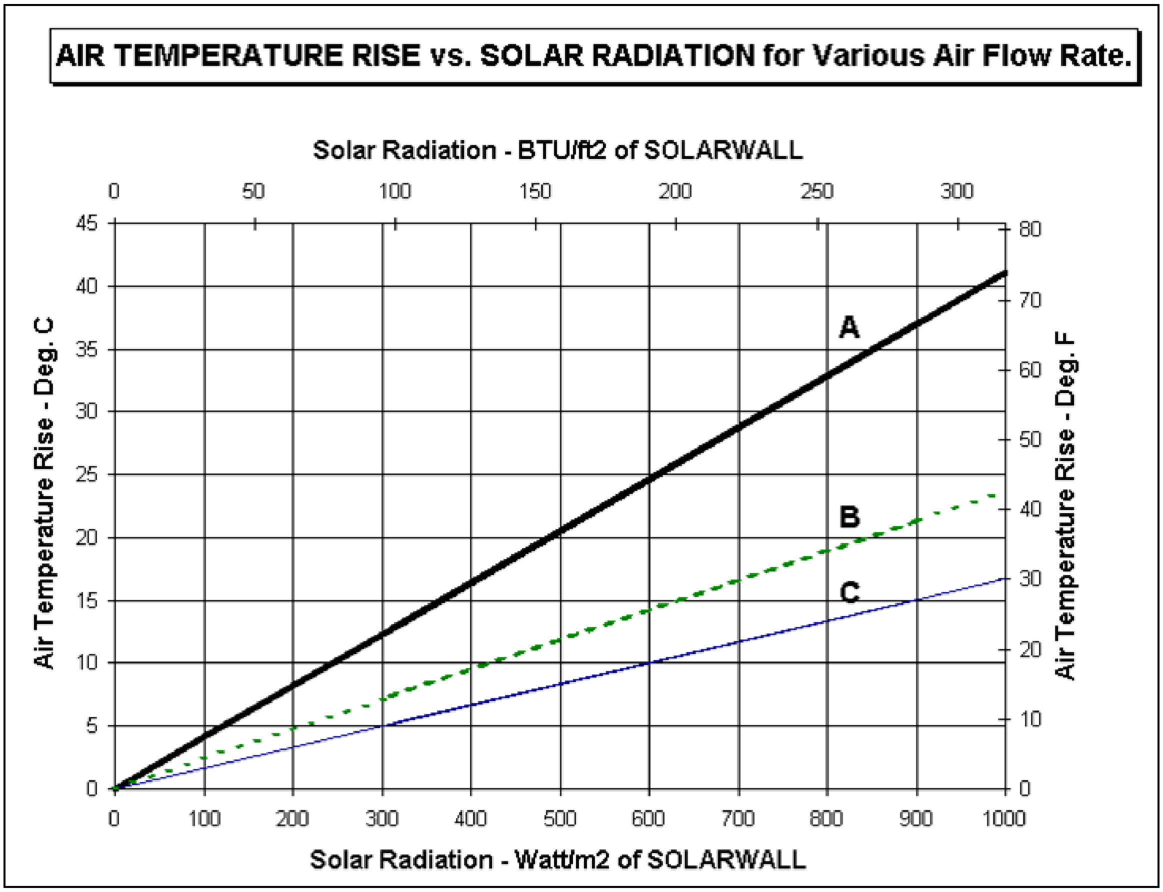
Concept

The performance of an unglazed, perforated ("transpired") solar wall depends primarily on four parameters: (1) the solar reflectance of the wall, (2) the orientation of the wall, (3) the size and spacing of the perforations in the wall, and (4) the pressure drop maintained by the ventilation system across the wall. The solar reflectance is primarily affected by the coating applied to the solar wall. In general, darker colors have a lower reflectance, and thus absorb a greater fraction of incident solar radiation. The orientation of the wall also greatly affects its performance. The intensity of the incident solar radiation depends on the cosine of the "angle of incidence," the angle between the outward facing normal of the surface and the "line of sight" to the sun. Walls that more directly face the sun will receive more solar radiation. In winter months in the northern hemisphere, south facing walls perform best. The cost effectiveness of applying solar collectors to east and west facing walls (to catch morning and afternoon sun) must be analyzed on a case-by-case basis.

The size and spacing of the perforations along with the pressure drop across the wall due to the operation of the ventilation system largely determines the impact of wind speed and wind direction on the solar wall performance. For a properly designed wall with small closely spaced perforations and a relatively high pressure drop, the laminar boundary layer created by suction at the wall will largely negate the effects of changing wind speed and wind direction. Figure 6.77 shows the temperature rise of incoming air versus solar radiation intensity for different airflow rates. For low ventilation airflow rates, the temperature rise can be as large as 75 °F. For high airflow rates, the temperature rise can be as large as 30 °F.

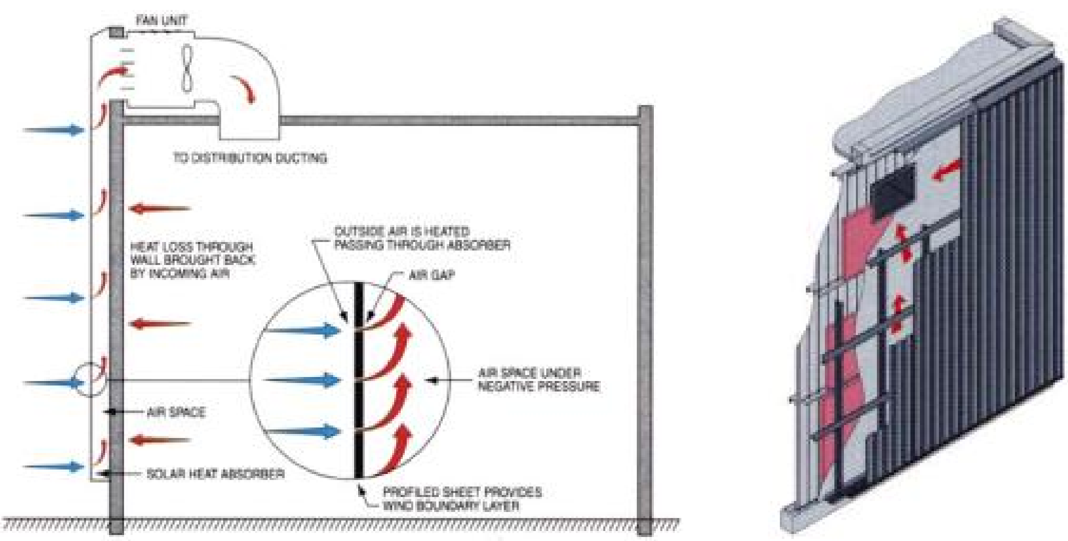
Description

An unglazed "solar wall" preheats ventilation air by drawing make-up air through a perforated steel or aluminum plate that is warmed by solar radiation. The solar wall consists of perforated steel or aluminum cladding attached to the south façade of a building with an air gap between the existing wall and the cladding. The solar wall is dark-colored to absorb the maximum amount of solar radiation. Air is drawn through the small holes in the wall and is heated at the same time. The warm air rises to the top of the wall and is drawn into the building's ventilation system (Figure 6.78).



Source: www.solarwall.com

Figure 6.77. Temperature rise vs. solar radiation intensity: (A) low flow rate, (C) high flow rate.



Source: www.solarwall.com

Figure 6.78. Air flows through a solar wall (a) and typical installation (b).

Energy Savings (Qualitative)

Transpired solar wall technology is beneficial in applications where: (1) heating loads exist, (2) a high ventilation flow rate is required, and (3) a large south-facing facade is available for cladding. The shortest payback is achieved by designing a system that will maintain an adequate pressure drop across the wall during all or most hours of operation. In the summer, the ventilation air is drawn directly into the HVAC system, bypassing the solar wall. The air in the cavity behind the solar wall naturally flows through holes at the top of the cladding.

Energy Savings (Quantitative)

The installed cost of a transpired solar wall system varies from $20/sq ft for a basic industrial application (left below) to $25/sq ft for an architecturally designed façade (Figure 6.79b)

a. Typical Industrial Application

b. Architecturally Designed Façade

Figure 6.79. Transpired solar wall applications.

<u>Energy Savings and Payback Calculation Assumptions</u>

The study used a 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft (6.1 m) high walls. The work zones consist of a high thermal heat gain area, a high ventilation area, a light fabrication area, and a loading dock area of single story structure with 20-ft (6.1 m) high walls. The building was modeled using typical light industrial wall and roof constructions. The walls are insulated metal construction (R-4) and the roof is standard built up bitumen. The building is heated and ventilated, and the work areas are not air-conditioned. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

The solar wall was evaluated by directly comparing the total building energy use reported by the base-case EnergyPlus simulation program output with the total building energy use reported by the solar wall-case simulation output. The solar wall-case results were generated by changing only those input parameters in the base case input file that were directly related to the solar wall. 1937 sq ft (180 m^2) of solar wall was added to the south wall of the building. The collector preheated outside air delivered to the light fabrication zone. The transpired collector had the following properties:

- Diameter of perforations: 0.00525 ft (0.0016 m)
- Perforation pitch: 0.055 ft (0.01689 m)
- Perforation pattern: Triangle
- Thermal emissivity: 0.9
- Solar emissivity: 0.9

- Thickness of plenum: 0.328 ft (0.1 m)
- Collector thickness: 0.00282 ft (0.00086 m).

This study assumed a cost of $20/sq ft, which is a typical new construction cost for industrial buildings.

Energy Savings and Payback Calculation Results

The results (Figures 6.80 – 6.82) show that savings were significant in every climate that required heating. For the industrial building with high ventilation flow rates, the average payback was under 6 years for all heating dominated climates.

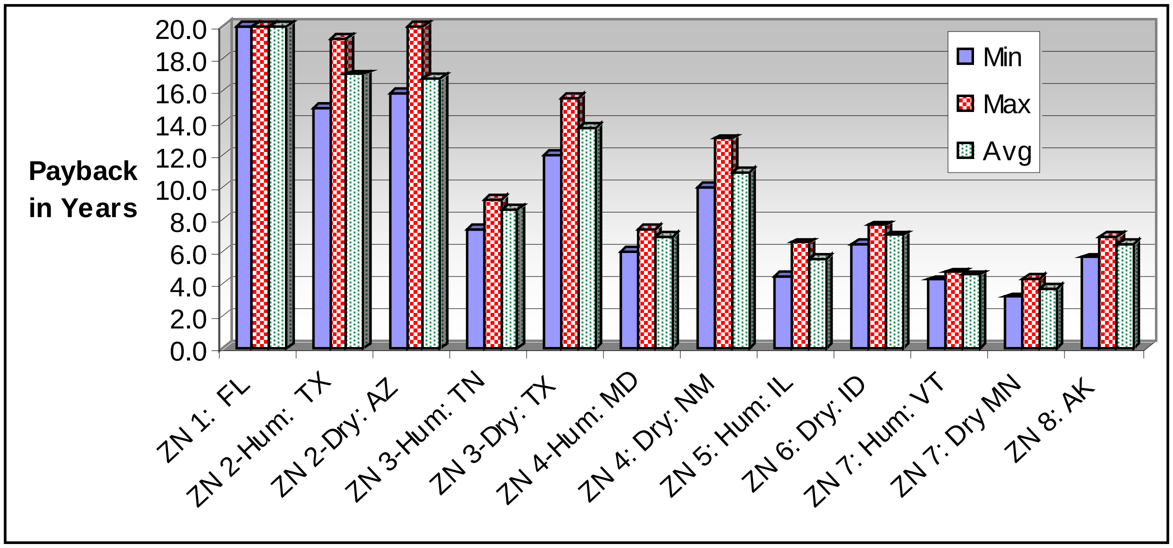


Figure 6.80. Transpired solar wall estimated payback shown for high, medium, and low energy rates.

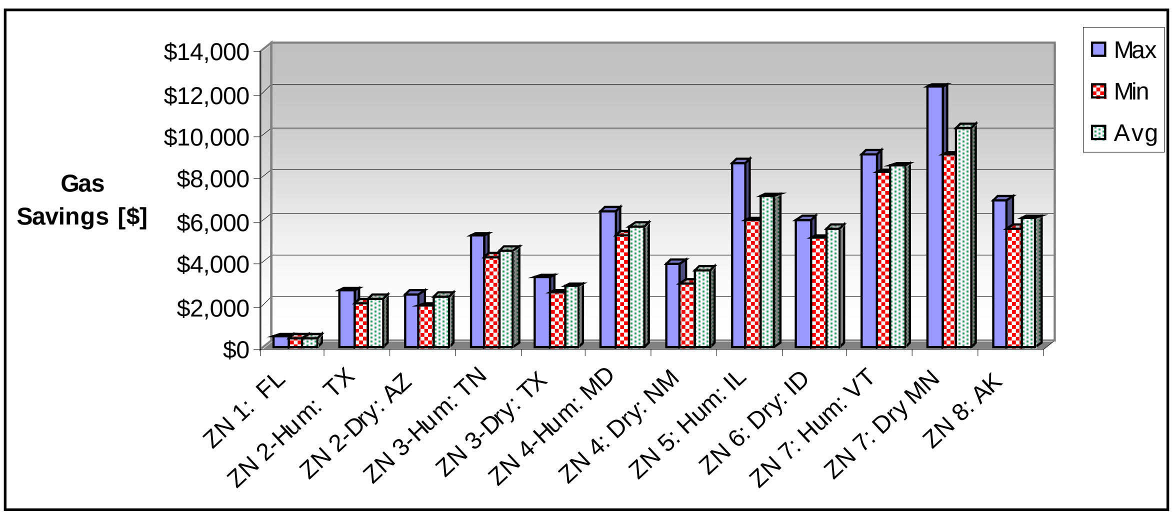


Figure 6.81. Transpired solar wall estimated gas savings shown for high, medium, and low energy rates.

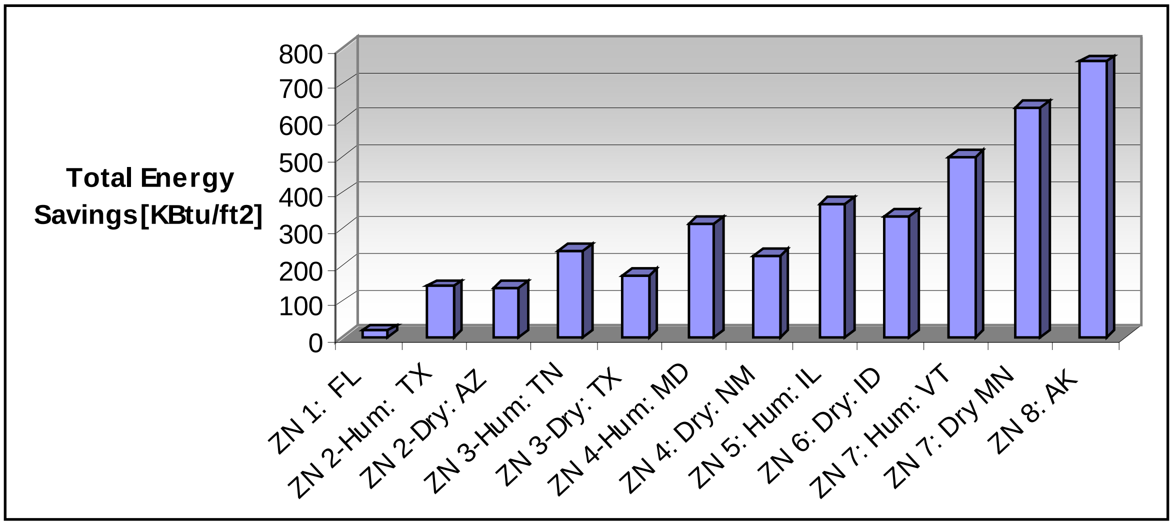


Figure 6.82. Transpired solar wall total annual energy savings per square foot of collector area.

Level of Maturity

The technology was first proposed in the early 1990s and is supported by research results from the National Renewable Energy Laboratory and field experience.

Impact on Indoor Air Quality

None.

Climatic Conditions Necessary

The technology works equally well in any climate. However, it is a heating technology that will find its major application in cold and temperate climates. The typical number of clear days in a climatic region should also be considered in the application of the technology.

Contacts and Major Manufacturers

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-3000
http://www.nrel.gov/learning/re_solar_process.html

Conserval Engineering Inc.
200 Wildcat Rd.
Toronto, ON M3J2N5
(416) 661-7057
info@solarwall.com | www.solarwall.com

Spectrally Enhanced Lighting

Application

Commercial, educational, and industrial.

Category

Lighting.

Concept

Lighting efficiency is measured through a unit called “efficacy,” which is lumens per Watt. Lumens are a measurement of the light output of a lamp and are used in lighting calculations to attain appropriate levels for performing visual tasks (Figure 6.83). The lumen is based on 80-year old science that presumes the eye’s response to light is limited to a very narrow field of view. Recent findings show that, when the spectral properties of the peripheral lighting are shifted to include more blue, our eyes respond the same as if the lighting levels were increased – the pupils of our eyes get smaller, spaces seem brighter, and we see things more clearly.

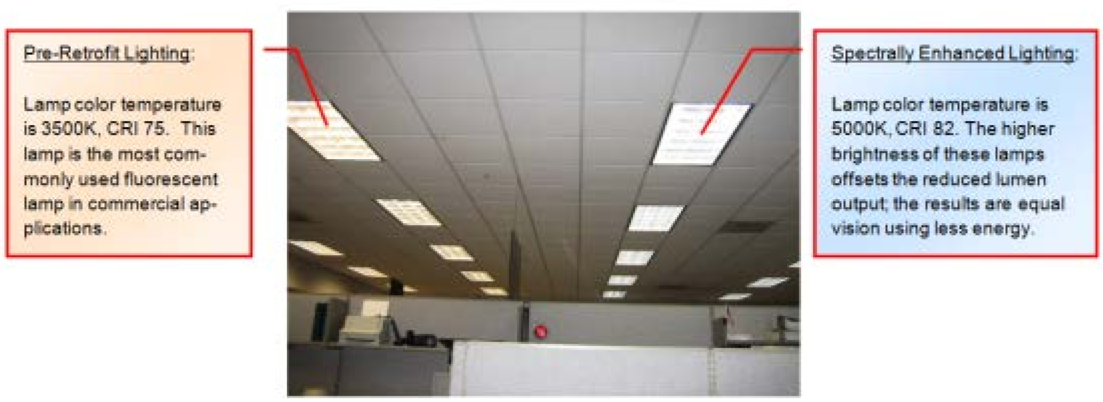


Figure 6.83. Warm color lighting on the left, spectrally enhanced lighting on the right.

By spectrally enhancing the color properties of fluorescent lighting to include more blue, we can use less energy to achieve the same level of visual ability. Changing the color of fluorescent lighting is relatively easy; it is simply a matter of changing the mix of phosphors that are applied to the inside wall of the glass fluorescent tube. By adding more blue phosphors into the phosphor mix, the resultant light becomes more visually efficient, and mathematical formulas have now been developed to convert this gain in visual efficiency to energy efficiency.

The new metric used in Spectrally Enhanced Lighting calculations is the S/P value, which is a ratio of the amount of light that affects the peripheral photoreceptors to the light that affects the central view photoreceptors. The S/P value is therefore a more accurate measurement of how lighting affects vision; the higher the S/P ratio, the better the lighting will be for visual acuity and therefore visual efficiency. In general, lamps with higher S/P values have higher Correlated Color Temperatures (CCT) and Color Rendering Indexes (CRI), two common characteristics found in lamp catalogs. The lamps used in Spectrally Enhanced Lighting are therefore high CCT and CRI lamps, such as the 5000K, 82 CRI lamp often labeled “850” or “SPX50.” These lamps are used in conjunction with lower ballast factor (BF) ballasts, de-lamping, or installing fewer fixtures to achieve more energy efficient lighting.

Description

Lighting consumes approximately 30% of electricity used in nonresidential buildings. The predominant light source used in these applications is fluorescent lighting, and the technologies that have traditionally been driving the efficiency of these lighting systems are the lamps and the ballasts that start and operate the lamps.

Recent findings in lighting science have demonstrated that the color of lighting can also affect the energy efficiency of lighting systems. Using higher color temperature fluorescent lighting and new, extra-efficient electronic ballasts can attain energy savings of 20 to 40% as compared to more commonly used fluorescent lighting systems. These savings can be achieved through simple lamp/ballast retrofits. The products are commonly available without paying any premium for the lamps or the ballasts.

Energy Savings (Qualitative)

In existing buildings, Spectrally Enhanced Lighting energy savings are achieved through simple lamp/ballast changeouts that are commonly performed by lighting retrofit contractors or lighting maintenance companies. Because these retrofits include changing out the ballasts, it is most common to combine the efficiencies of Spectrally Enhanced Lighting with the most efficient ballasts available to maximize the savings. In new construction, the savings are achieved through improved lighting designs that require fewer lamps and ballasts and/or fewer lighting fixtures.

There is little if any incremental cost to using Spectrally Enhanced Lighting when comparing this to installing more traditional lighting systems; therefore this technology has immediate payback when compared to doing a lighting installation with lower color temperature lighting. In addition, Spectrally Enhanced Lighting provides permanent reductions of electric load and therefore automatically reduce demand load at peak hours. The return on the investment can be quite substantial in areas with high peak demand charges.

Energy Savings (Quantitative)

The potential energy savings depends on the existing lighting that is in the candidate space (or the proposed lighting for new construction) and the illumination requirements. In general, we assume that the Spectrally Enhanced Lighting will be installed to achieve the same level of visual ability as is in the existing facility (or is being planned in new construction). By using Spectrally Enhanced Lighting, the lumen output of the lamps can be reduced, while the visual ability is maintained by the increased brightness perception and visual acuity the enhanced spectrum provides. The reduction in lumens translate directly to the energy savings. Table 6.12 shows the potential for the 850 Spectrally Enhanced lamp alone, and then with the addition of extra-efficient ballasts as compared to other lamps and standard ballasts commonly used in commercial applications.

Energy Savings and Payback Calculation Assumptions

A building tenant has 50,000 sq ft of open office space with 2 x 4 ft lensed luminaires on 8 x 10 ft spacings, (total 625 luminaires). Each luminaire has (three) 735 T8 lamps and a three-lamp, normal (0.87) ballast factor electronic ballast. The lighting system was installed in the mid-90s. The ballast data shows that each luminaire consumes 90 Watts, so the total wattage for the lighting system is 56,250 Watts. The system is on for an average 12 hours per day, five days a week plus some weekend hours, for a total assumed 3,500 annual hours of use. The annual energy consumed by the lighting system is therefore 197,000 kWh.

The 850 Spectrally Enhanced Lighting allows us to reduce the lumens per luminaire by 32% and obtain the same visual ability. For the purposes of this illustration, we will de-lamp the luminaire to two lamps and change the ballast to extra-efficient instant-start electronic ballasts with the same ballast factor (0.87) to achieve this one-third reduction. This new wattage of the lighting system is now 53 Watts per luminaire at a cost of $40.00 each.

Table 6.12. Energy savings when using spectrally enhanced high-lumen f32 t8 / 850 lamps and extra-efficient electronic ballasts.

Baseline F32 T8 lamp with Standard Electronic Instant-Start Ballast	Lumen Reduction & Energy Savings from 850 Lamp alone	Total Energy Savings from 850 Lamp and improved ballast
F32T8 / 730	37%	44%
F32T8 / 735	32%	40%
F32T8 / 741	22%	30%
F32T8 / 830	25%	32%
F32T8 / 835	20%	27%
F32T8 / 841	11%	18%
CRI and CCT are often combined into a three-digit number where the first number represents the CRI and the last two digits represent the CCT; for example, an 850 lamp is one with a CRI in the 80s, and a high CCT of 5000K; a 730 lamp is one with a CRI in the 70s and a low CCT of 3000. 80 CRI lamps in this comparison are High-Lumen lamps; 70 CRI Lamps are not available as High-Lumen lamps.		

Energy Savings and Payback Calculation Results

The cost to change the lighting system is $25,000 and the annual energy savings are 81,000 kWh. The annual energy cost savings will depend on the utility rates (Figure 6.84).

The calculations underlying the data in Table 6.12 do not include the additional potential for reduced cooling costs resulting from lowered heat generation by the new lighting system. In addition, the new lamps have longer life spans, and will provide additional savings over the life of the system by lowering the maintenance costs of lamp replacement. The benefits of installing new ballasts are also significant, since the existing ballasts are approximately 10 years old and approaching the end of their life. The new system life will be approximately 15 years, and based on the life of the new lamps (24,000 hours), the lamps will require changing only twice over the life of the system.

The energy savings from this approach result in a 1-3 year payback for regions where the electric utility rates are $0.10 per kWh or higher. Eighty percept of these savings are attributable to Spectrally Enhanced Lighting, and 20% to the use of higher efficiency electronic ballasts. These cost savings are the result of permanent load reductions. Paybacks might be better in areas where peak demand charges are even higher than those used in this example.

Level of Maturity

Spectrally Enhanced Lighting is a mature technology that has been investigated by the US Department of Energy for nearly 20 years. The latest field studies on Spectrally Enhanced Lighting involved three independent buildings that had their existing lighting systems changed to 850 Spectrally Enhanced lamps and electronic ballasts. The study concluded that the energy savings were as predicted by the formulas and that there was no difference in occupant satisfaction between the pre-retrofit lighting and the Spectrally Enhanced lighting. The technology is currently being considered in committee by the IESNA, but has not received official adoption; practitioners are therefore encouraged to design systems that meet or exceed minimum IESNA requirements.

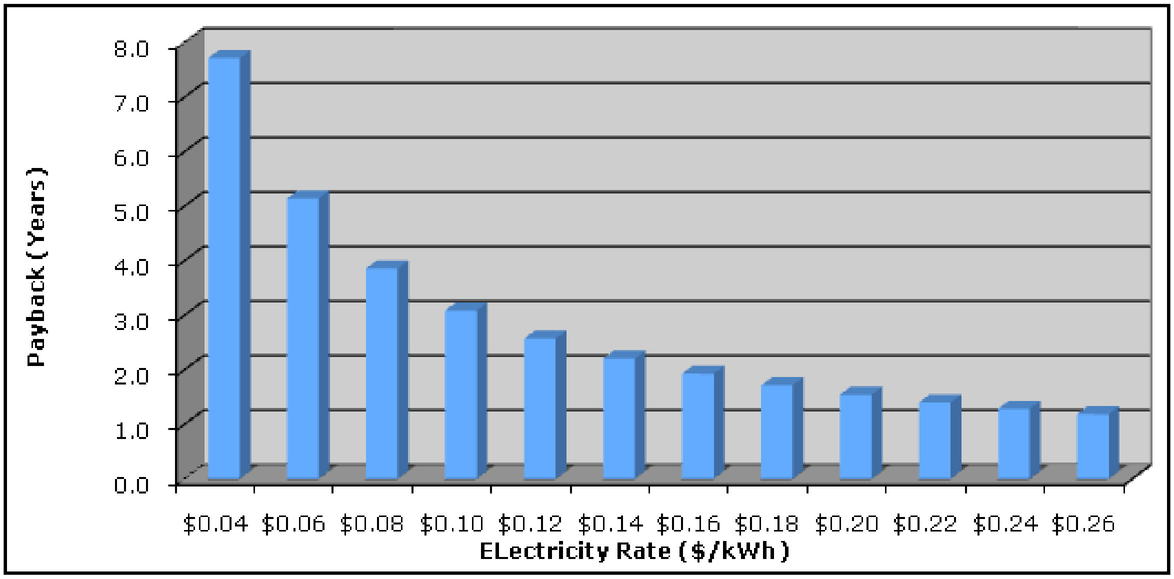


Figure 6.84. Spectrally enhanced lighting simple payback.

The 2004 DOE field study that tested lighting levels and occupant acceptance is available through:

http://www.eere.energy.gov/buildings/info/documents/pdfs/final_ucop_report_0304.pdf

The 2006 DOE field study that installed Spectrally Enhanced Lighting in three buildings is available through:

http://www.eere.energy.gov/buildings/info/documents/pdfs/selpies_economics_validation_083006.pdf

Impact on Indoor Air Quality

None

Climatic Conditions Necessary

This technology works in any climate.

Major Manufacturers

All major lamp manufacturers make 850 lamps as a standard product. In addition, General Electric, Philips, and Sylvania each have various other products that are Spectrally Enhanced products, with some fluorescent lighting having CCTs of 6500, 8000, and 17000K.

There are a number of possible lamp/ballast combinations that can achieve the desired results. Matching the lamps to the correct ballasts is a very important aspect of this lighting method; be sure to check with the lamp manufacturer to ensure that the ballasts being considered are compatible with the lamps being chosen. Typically, the lamp manufacturers also produce their own ballasts, and some lamp/ballast systems are eligible for extended warranties.

T8 Linear Fluorescent Lighting

Application

Industrial, commercial, and residential buildings.

Category

Lighting.

Concept

High efficiency fluorescent lighting can offer significant energy savings over T12 lighting while providing the same lumen levels. In addition, reducing energy consumption for lighting also reduces heat generation in the building, lowering the cooling load in summer.

Description

High-performance T8 (HPT8) lamps—also known as super T8s—offer higher efficiency levels, longer lamp life, and longer lamp warranties than their standard counterparts. A high-lumen, long-life T8 lamp and low-watt electronic ballast generate the same total light output as a regular T8 and use less energy. Super T8s are typically rated to last 4,000 hours longer than standard T8 or T12 lamps. The newest T8s promise 30,000 to 60,000 hours of life. High performance T8 linear fluorescent lighting, or "Super T8 lighting" offers extended lifetime and improved efficacy of the components, but the technology comes with an additional cost premium.

Today's high efficiency fluorescent lamps are thin—only 1 in. (25.4 mm) in diameter—and have the designation "T8" stamped on the lamp. Super high efficiency T8 fluorescent lamps combined with high efficiency ballasts cost less to operate because they use up to 25 percent less energy than standard T8 lighting systems. Replacing larger-diameter ("T12") fluorescent lamps (1.5 in [38.1 mm]) can yield an even greater potential for savings. Depending on the wattage and ballasts, super T8 lighting systems use 44% less energy than a T12 lighting system.

The labels "T12" and "T8" refer to diameters of lamp tubes. Thus a T12 lamp has a diameter of 12/8 in., or 1.5 in. (38.10 mm). Typically, a narrower lamp is more energy-efficient. Since the T8 is 8/8 in., or 1 in. (25.4 mm) in diameter, it is a more energy-efficient lighting mechanism than the T12. T-8 lamps are available a variety of lengths, and they also come in either straight or U-shaped lamps.

Energy Savings (Quantitative)

Lamps and ballasts should be upgraded together to ensure compatibility and energy savings. Four-ft (1.2 m) T8, 32W lamps are preferred over 4-ft T12, 34W ("reduced wattage") lamps to take advantage of a wider selection of efficient ballast models (Table 6.13). Reduced wattage T12 lamps are unsuitable for low-temperature applications due to starting difficulties in cold conditions.

Energy use and performance of a fluorescent lamp depend on of the ballast performance and the fixture which, together with the lamps, make up a luminaire.

Table 6.14 lists savings of 18% to 23% that are achievable when transitioning from conventional T8s to Super T8s. This in turn translates into an annual energy cost savings of $2.62 per two-lamp fixture. From a T12 to Super T8 system, a 28 to 45% energy reduction can be achieved, which results in an energy cost savings of $8.78 per two-lamp fixture per year. There is also potential for additional savings from the reduced cooling load for the building in summer.

Table 6.13. Efficiency recommendations for T8 vs. T12 lamps.

Efficiency Recommendation		
Lamp Type	**Recommended**	**Best Available**
4-ft Lamps		
T8, 32W	2800 lumens[a] or more	3000 lumens
T12, 34W	2800 lumens or more	2900 lumens
8-ft Lamps		
T8, 59W	5700 lumens or more	5950 lumens
T12, 34W	2800 lumens or more	2900 lumens
8-ft Lamps		
T8, 59W	5700 lumens or more	5950 lumens
T12, 60W	5600 lumens or more	6000 lumens
U-Tube Lamps		
T8/U, 31-32W	2600 lumens or more	2850 lumens
T12/U, 34W	2700 lumens or more	2760 lumens

Table 6.14. Energy savings of Super T8 lighting over conventional lighting technology.

Lighting Technology	**Light Output (mean lumens/W)**	**Energy Savings**	
		Over Original T12	**Over Conventional T8**
Magnetic T12 with energy-saving ballast and 34W halophosphor lamps	54	—	—
Conventional T8 with instant-start ballast and 32W 700 series CRI lamps	75	28%	—
Super T8 with programmed-start ballast and 32W 800+ series CRI lamps	92	41%	18%
Super T8 with instant-start ballast and 32W 800+ series CRI lamps	98	45%	23%

Payback Period

Based on a database of more than 180 lighting conversion projects implemented at US government facilities, the average cost of projects to convert T-12 to T-8 lighting in standard buildings is about $0.68 per kWh of electricity saved per year. Thus the simple payback of T-8 conversion projects is a simple function of the cost of electricity (Table 6.15).

Table 6.15. Payback calculator for converting T12 to T8 lighting.

Electricity price, $/kWh	Simple payback, yrs	Electricity price, $/kWh	Simple payback, yrs
0.04	17.0	0.12	5.7
0.05	13.6	0.13	5.2
0.06	11.3	0.14	4.9
0.07	9.7	0.15	4.5
0.08	8.5	0.16	4.3
0.09	7.6	0.17	4.0
0.10	6.8	0.18	3.8
0.11	6.2		

Results

Interior lighting represents approximately 29% of the energy consumed in the commercial building each year. Lowering this percentage has the potential to reduce the emissions of carbon dioxide and other air pollutants generated during electricity production. Other benefits include:

- **Lower maintenance costs** – Longer equipment life reduces both your maintenance and disposal costs. T8 lamps are rated from 18,000 to 30,000 hours – equivalent to 5–6 years in a typical office application – when matched with the correct ballast.
- **Quiet** – T8s operate more quietly than T12s, eliminating the “hum” often associated with fluorescent lighting systems.
- **Cooling load reductions** – Electronic ballasts consume fewer watts than magnetic ballasts. Lighting systems generate less heat, which reduces cooling loads.
- **Reduced lamp flicker** – Electronic ballasts drive fluorescent lamps at 20 kilohertz (kHz), a frequency well beyond the visible range of flicker to the human eye. Thus significantly reducing eye strain.
- **Improved light** – T8 lamps have a higher Color Rendering Index (CRI) than common T12 lamps. The CRI measures the ability of a light source to reproduce the colors of various objects being lit by the source.

Level of Maturity

Mature.

Climatic Conditions Necessary

Not applicable.

References

Sources

Ly, Peter. “Navy Techval Project Report: High Performance (Super) T8 Fluorescent Lighting.” May 2007.

Federal Energy Management Program website: http://www1.eere.energy.gov/femp/procurement/eep_fluortube_lamp.html

For More Information

- FEMP's *Federal Lighting Guide* (http://www1.eere.energy.gov/femp/pdfs/fed_light_gde.pdf [1.7 MB, 53 pp]) provides helpful guidance on lighting projects.
  Phone: (877) 337-3463.
- American Council for an Energy-Efficient Economy (ACEEE) publishes the Guide to Energy-Efficient Commercial Equipment (http://aceee.org/press/ceg.htm), which includes a chapter on lighting.
  Phone: (202) 429-0063.
- The Lighting Research Center (http://www.lrc.rpi.edu/) has valuable information covering various lighting systems,
  Phone: (518) 276-8716
- E SOURCE (http://www.esource.com/) publishes *Lighting Technology Atlas* (available to member organizations),
  Phone: (303) 440-8500.
- Lawrence Berkeley National Laboratory provided supporting analysis for this recommendation.
  Phone: (202) 646-7950.

Turn-Off Idling Equipment

Application

Industrial.

Category

HVAC.

Concept

Using a scheduling format to turn off the equipment during non-operating time intervals will decrease electric energy usage, reduce the cooling load on the air-conditioning equipment, and increase the longevity of the equipment.

Description

Simply turning off equipment when not in use can provide significant savings for some applications. A significant fraction of industrial process equipment is designed to be turned off by the operator when not in use. Simple timer switches (Figure 6.85) can reduce energy costs associated with operator's forgetting to turn off their equipment at the end of their shift.

Figure 6.85. Industrial timer switch.

The thermostat is also programmed to "set back" the ventilation system heating setpoint during non-occupied times (for office spaces) and "down-times" for fabrication, processing and shipping areas.

Energy Savings (Qualitative)

The level of savings achieved by this ECM depends on the type and number of electrically powered machines in the facility. Since the cost of the ECM is so low, and since the cost scales linearly with savings, a favorable payback is guaranteed. Therefore, whenever possible, this measure should be applied.

Energy Savings (Quantitative)

Timer switches range in price from $100 for a simple mechanical timer switch to $180 for a programmable timer switch. Installation costs can vary from 1 to 4 hours depending on the accessibility of the wiring. For the industrial building, it was assumed that 20 switches were installed in the fabrication zone and 10 switches in the thermal processing zone for a total of 30 switches. Table 6.16 shows the total estimated cost of installing timer switches in the light fabrication and thermal processing areas of the industrial building.

Table 6.16. Cost of installing timer switches in selected areas of an industrial building.

	Number of Switches	Installed Cost per Switch	Total
Light Fabrication Areas	20	$300	$6,000
Thermal Processing Area	10	$300	$3,000

Energy Savings and Payback Calculation Assumptions

The study used a 50,000 sq ft (4645.152 m^2) typical metal building with 20-ft (6.1 m) high walls. The work zones consisted of a high thermal heat gain area, a high ventilation area, a light fabrication area, and a loading dock area, all of a single story structure with 20-ft (6.1 m) high walls. The building was modeled using typical light industrial wall and roof construction. The walls were insulated metal construction (R-4) and the roof is standard built-up bitumen. The building is heated and ventilated, and the work areas were not air-conditioned. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

Since expected energy savings vary greatly for this conservation measure, two scenarios were evaluated. First, it was assumed that turning equipment off when not in use would cut the energy usage by 10%, the equipment energy usage data was changed to reflect this assumption. Second, minimum energy savings to achieve a payback of less than 2 years were estimated.

Energy Savings and Payback Calculation Results

Figure 6.86 shows that, for a 10% reduction in equipment power use, the timer switches pay for themselves in just a few months. Figure 6.87 shows that only a 2% reduction in equipment power use is required to achieve a 3.5 year payback or less. For most situations where equipment is occasionally left on, savings of 2% or more can easily be achieved by turning off the equipment.

The cost effectiveness of switching off idling equipment results in a significant reduction in electricity use year round. Figures 6.88, 6.89, and 6.90 show the electric, heating, and net energy savings for a 10% reduction in electric equipment use energy savings for a 10% reduction in electric equipment use. However in the heating season, the effect is to shift the heating load from electric to gas. For the ventilated building, savings in the cooling load are not realized, since the building is not mechanically cooled at night. For mechanically cooled buildings, the increase in the cost of heating the building would be more than offset by the reduction in the cost of mechanical cooling.

Level of Maturity

This technology has been available for many years.

Impact on Indoor Air Quality

None.

Climatic Conditions Necessary

This energy conservation measure is effective in all climates. Savings are enhanced in hot climates where mechanical cooling is used.

Contacts and Major Manufacturers

Honeywell, Intermatic, Dayton, Paragon, Diehl.

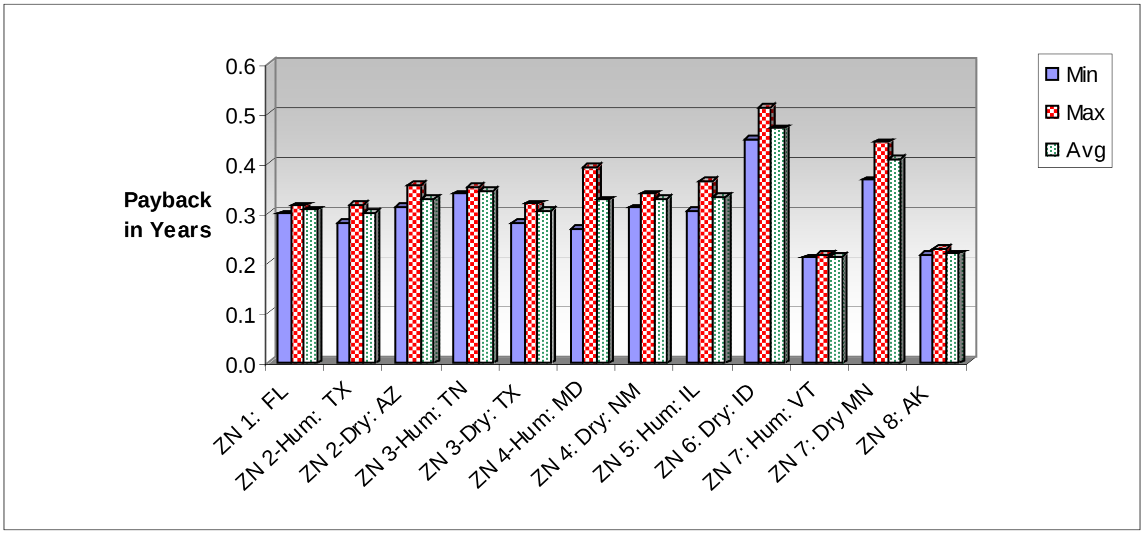


Figure 6.86. Estimated payback for 10% reduction in electric equipment use.

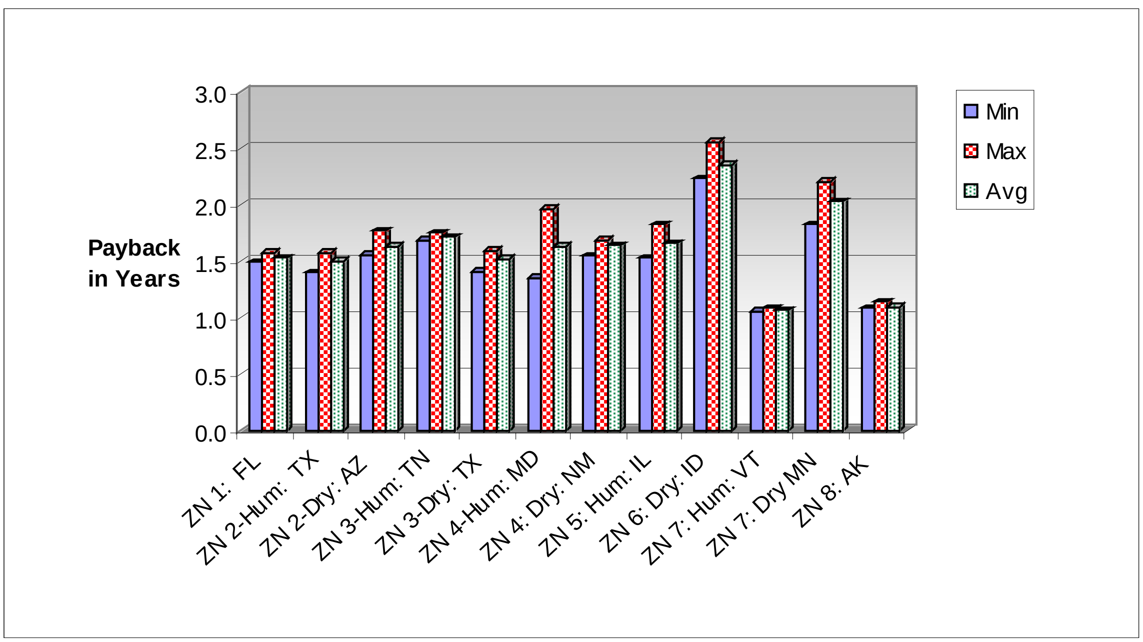


Figure 6.87. Estimated payback for 2% electric equipment use.

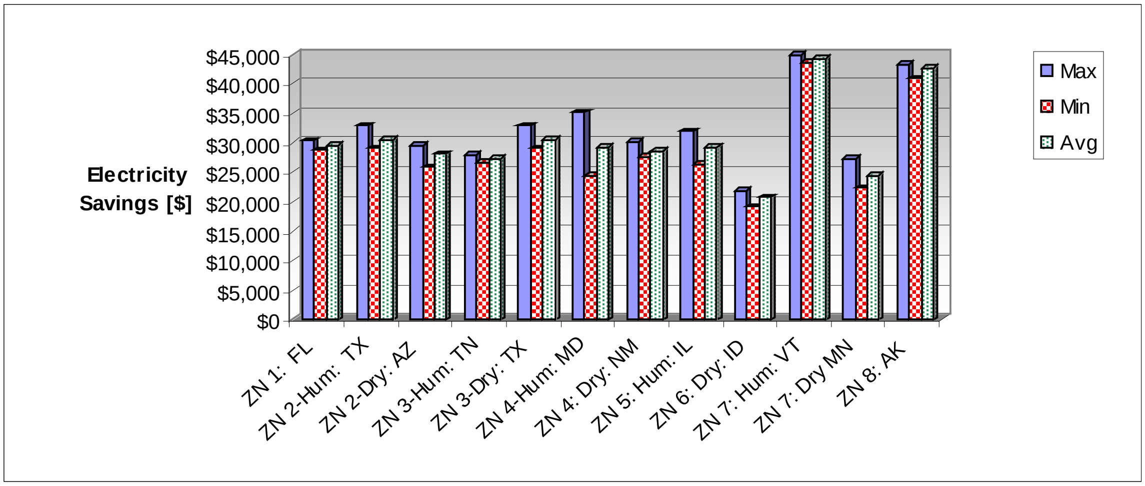


Figure 6.88. Estimated electric savings for a 10% reduction in electric equipment use.

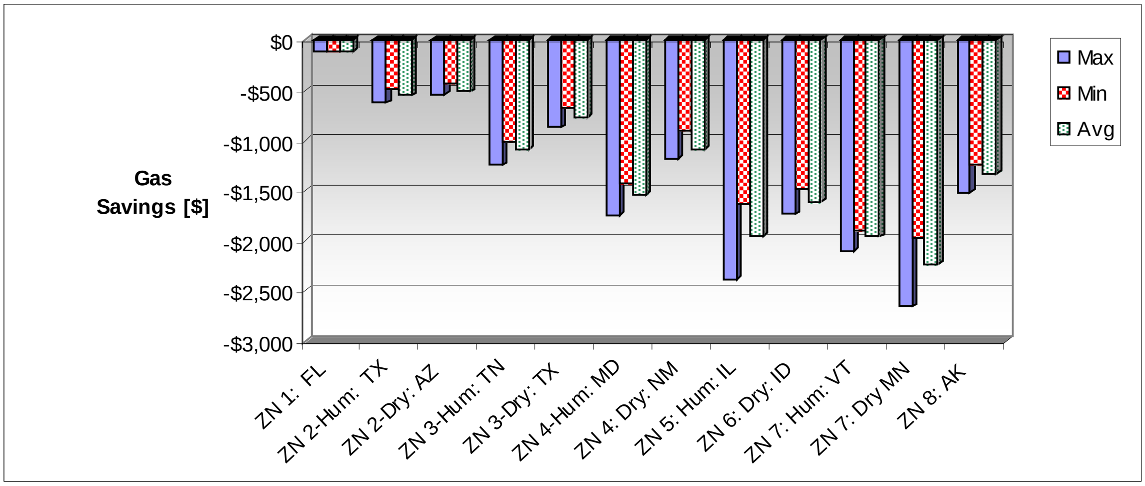


Figure 6.89. Estimated increase in heating cost for a 10% reduction in electric equipment use.

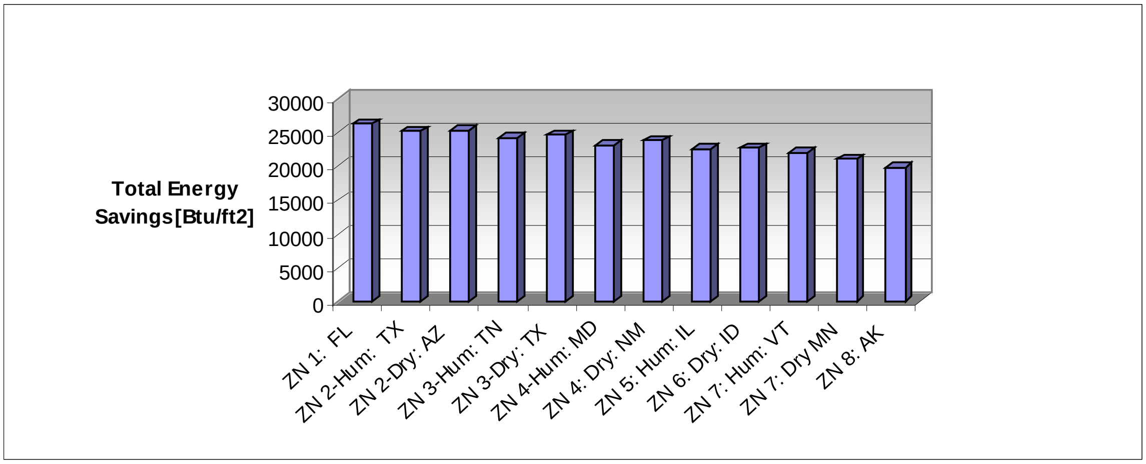


Figure 6.90. Estimated net energy savings for a 10% reduction in electric equipment use.

Lighting Controls: Exterior Lighting Control

Application

Commercial, industrial, residential.

Category

Lighting.

Concept

Exterior lighting that is left on during daylight hours or when an area is unoccupied wastes energy. Simple controls are available to eliminate this wasted lighting energy, However, the appropriate type of lighting and type of control should be matched to the expected tasks within the lighted space.

Description

A very effective automated control system with a low initial cost is a photocell, or “twilight sensor,” connected to lighting circuit relay control. The photocell in this system senses a decrease in ambient light levels at dusk and turns the lights on. At dawn, the photocell turns the lights off when it senses sufficient light. Outdoor light sensos should be mounted facing south, in an unshaded area (since shadows which would cause the lights to come on when daylight is still present).

Another effective control system is a “time clock switch,” which is programmed to turn the lights on and off automatically. Basic time clocks control the lights daily and at a set time. The basic time clock is effective at latitudes nearer to the equator where the length of daylight varies little throughout the year. For most latitudes, an “astronomical” time clock is a preferred option because it provides automatic reprogramming to adjust for the variations in length of daylight. This allows the control to provide greater energy savings than a regular time clock, especially at higher latitudes. These controls may require additional work for the maintenance staff, as programming might be slightly more involved. Power outages may cause time clocks to fall out of phase with actual usage schedules so some form of battery backup and periodic checks for accuracy of the time are needed.

Some exterior lights are only necessary periodically throughout the night and can be turned off when not needed. In this way, energy savings can be further increased by using both a photocell control as well as a time clock. The photocell will turn the lights on and off depending on available light levels, while the time clock turns the lights off when exterior lights are no longer needed such as after the building closes, or an exterior space is not in use.

If the building is open 24 hours, or has the possibility of visitors at anytime of the night, occupancy sensors, also known as “motion detectors,” can be implemented to reduce energy consumption more than a photocell or timer alone. These controls can either switch or dim the lights during certain periods of non-use. Pairing an occupancy sensor with either a time clock or photocell will prevent the lights from switching on and off during the day. Exterior fluorescent applications (in warmer climates) and exterior LED lighting can effectively be switched or dimmed when no motion is detected, resulting in significant energy savings.

LED lighting technologies are initially more expensive. At present costs, replacing an existing lighting system would not be cost effective; however, implementing this kind of control system at a new building site would likely have a reasonable payback.

High Intensity Discharge Lamps (HID) are often used outdoors because of their high efficacy and long lamp life, but they are not considered appropriate for occupancy sensor control. When they are switched on, it can take them 10 minutes to warm up, so when they are turned off, it can take 1-15 minutes before they can be turned back on to begin the warm up process again. This inability to cycle rapidly makes HID lamps with an occupancy sensor impractical for this application. Table 6.17 and 6.18, respectively list potential energy savings for buildings with set schedule of occupancy/vacancy, and for buildings open 24 hrs a day..

Energy Savings

Table 6.17. Potential energy savings for buildings with set schedule of occupancy/vacancy.

Existing Controls	**Suggested Control Applications**	**Anticipated Savings (from current exterior lighting loads)**
None: On 24 hrs/day	Photocell mounted on southern facing wall or roof where no shadows will obscure it	50%
Manual Switching	Photocell mounted on southern facing wall or roof where no shadows will obscure it	10 to 50%
Photocell	Analyze building use; determine whether time clock to turn lights off after activity hours would be practical for certain areas or all exterior lighting	up to 50%
Time Clock	Observe performance of controls throughout year; determine if lights are switching at ideal time; if not, initiate seasonal adjustments of control –or upgrade to an astronomical time clock and/or photocell control	up to 20%
Astronomical Time Clock	Observe performance of controls throughout year; determine if lights are switching at ideal time; upgrade to photocell/time clock combination if feasible	10%

Table 6.18. Potential energy savings for buildings open 24 hours a day.

Existing Controls	Suggested Control Applications*	Anticipated Savings (from current exterior lighting loads)
None: On 24 hrs/day	Photocell mounted on southern facing wall or roof where no shadows will obscure it	50%
Manual Switching	Photocell mounted on southern facing wall or roof where no shadows will obscure it	10 to 50%
Photocell	If lighting technology permits, consider pairing with occupancy sensor	50%
Time Clock	Observe performance of controls throughout year; determine if lights are switching at ideal time; if not, initiate seasonal adjustments of the control –or upgrade to an astronomical time clock and/or photocell control	16%
Astronomical Time Clock	Observe performance of controls throughout year; determine if lights are switching at ideal time; upgrade to photocell/time clock combination if feasible	10%

* To further increase energy savings in all cases, consider the addition of occupancy sensors. If a fluorescent system requires replacement ballasts, step-dimming ballast replacements coupled with an occupancy sensor and photocell would yield the highest energy savings at the smallest initial cost. If a new lighting system is required, consider a similar control system with LED exterior lighting to further decrease energy consumption and improve maintenance issues.

Results

Payback Period

Pairing the correct controls with the appropriate exterior lighting needs could save considerable energy. Total exterior lighting wattage varies greatly depending on the application and area covered. One may calculate the payback and annual energy savings depending on individual site characteristics by using the following formula:

$$Y_{Payback} = \frac{Cost}{TD_A * E_{Rate} * (W/1000)}$$

where:

$Y_{Payback}$	=	years for energy savings to pay for new technology
Cost	=	initial cost of investment in new technology
TD_A	=	annual difference in length of time lights are operated before and after change in lighting controls
W	=	wattage controlled by new control system.

Environmental Benefits

Energy prices are rising and conservation is becoming more and more important. Eliminating excessive consumption at times when there is no need for exterior lighting is an effective and compromise-free way to reduce wasted energy. Reducing the hours of operation that the lights are on will also prolong the life of each lamp and therefore reduce the quantity of lamps deposited in landfills.

References

Duffie, John A., and William A. Baeckman. 1974. Solar Energy Thermal Processes. New York: John Wiley & Sons.

Vehicle Vestibule

Application

Industrial.

Category

Building envelope.

Concept

Large industrial doors allow the ingress of considerable volumes of outside air, especially when there is a substantial difference between the inside and outside temperature (Figure 6.91). Unless doors are on the leeward side of the building, wind can also enhance air exchanges.

A vestibule works in two ways. First, working spaces of the building are exposed to a buffer space rather than to the outside environment. Second, the introduction of a second door allows an operating configuration that ensures that there is always one closed door between the working area and the outside environment.

In cold weather operation, the doors operate in sequence. First, the outer door opens to allow the vehicle into the vestibule and once inside the outer door is closed as the inner door opens. Vehicle emissions are limited either by using exhaust capture within the vestibule or by enforcing an engine off policy prior to outer door closing. In hot weather, vehicle vestibules can revert to a door opening configuration that allows heat within the building to escape.

Assessments were done by representing the physical opening of the doors within the model and calculating, at each minute of the year, the flow of air within the vestibule and the shipping and receiving based on the current conditions in the room, the ambient conditions and the state of the doors. The door opening configurations included a variety of vehicle sizes and number of openings.

Figure 6.91. Examples of large industrial facility doors protected by a vestibule.

Description

Industrial buildings requiring frequent vehicular access can reduce unwanted air ingress by installing vehicle sized vestibules adjacent to shipping and receiving facilities. Figure 6.92 shows a typical vestibule added to the industrial building model. Vehicular vestibules can be designed to match the standard façade of the building, however, because they are essentially unconditioned buffer spaces savings can be made in their construction. Assuming that there is sufficient room at the site, the addition of a vehicle vestibule presents few technical or architectural challenges. It should not be necessary to replace existing doors.

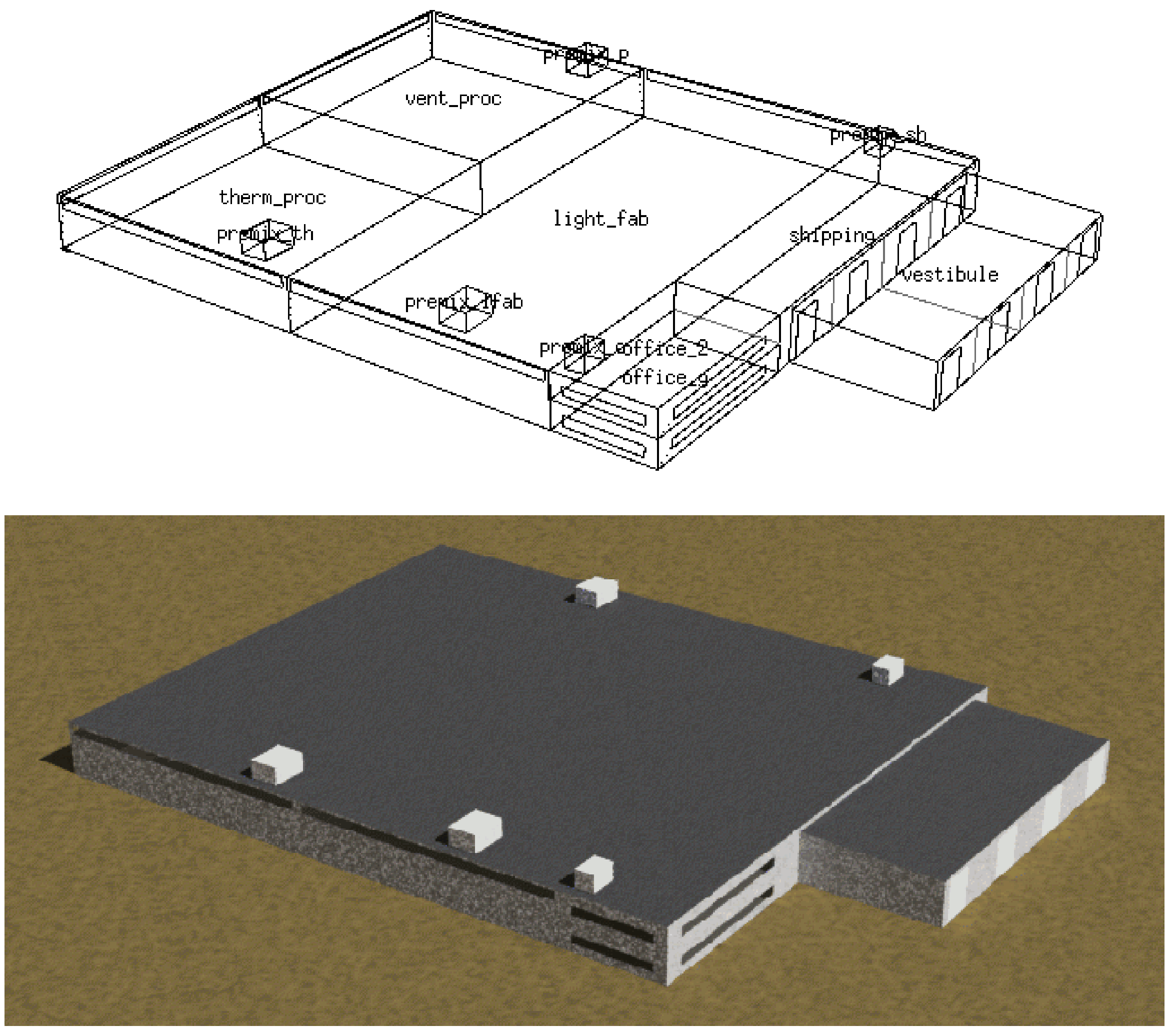


Figure 6.92. Vestibule added to industrial building model.

Energy Savings (Qualitative)

Reduction of air infiltration into the shipping and receiving zone is the primary energy saving mechanism. Reduced heat exchange via the doors and walls in contact with the vestibule is a secondary energy saving mechanism. A vehicle vestibule has little or no impact on other portions of the building.

The assessments indicated that the vestibule tended to moderate the environment workers were exposed to. For example if it were 20 °C inside, it would tend to be 10 °C in the vestibule when it was at freezing outside. Because the difference in temperature is less, the doors need not be as well insulated to protect workers and when the doors do open the draft perceived by the workers is much less than it would be for a direct outside connection.

Vestibule benefits are greater in locations with many hours at or below freezing and their inclusion can reduce the capacity of heating as well as running costs. Performance would be neutral when the ambient temperatures during the day are close to working temperatures. A strict door opening configuration in hot weather would reduce cooling loads if the working spaces were air-conditioned (although this was not specifically assessed).

Energy Savings (Quantitative)

A 50,000 sq ft (4645.152 m^2) typical metal building with 20 ft (6.1 m) high walls was used for the study. The work zones consisted of a high thermal heat gain area, a high ventilation area, a light fabrication area, and a loading dock area with single story, 20 ft (6.1 m) high walls. Typical light industrial wall and roof constructions were used in modeling the building. The walls were insulated metal construction (R-4) and the roof is standard built up bitumen. The building is heated and ventilated, and the work areas were not air-conditioned. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. Other areas operate with an economizer cycle with a minimum of 30% outside air. For this comparison, only the reduction in infiltration in the shipping area was considered.

The costs for a vehicle vestibule depend on a number of factors such as decisions to match the current façade and roof treatment, in which case the vestibule would have roughly the same cost per unit of area as the industrial building shell (about $15/sq ft). If a minimal cost approach is followed a cost as low as $13/sq ft could be achieved.

Constructing an “internal vestibule” is the often most cost effective approach to vestibule construction. This requires allocating existing building space for the vestibule and simply installing partitions and, if necessary adapting the fan system for the vestibule. For example, in the model industrial building, it may be possible to convert all or part of the shipping area to a vestibule by installing larger overhead doors constructing a partition to isolate the vestibule area from the rest of the building. Table 6.19 lists the model building cost for equivalent four-bay external and internal vestibules.

Table 6.19. Model building cost for equivalent four-bay external and internal vestibules.

	Installed Cost	**Industrial building**
External vestibule	$13 per sq ft floor area	$74858
	Total	**$74858**
Internal vestibule		
Partition	$2.50 per sq ft wall area	$5000
New overhead doors	$2,000 ea	$8,000
	Total	**$13,000**

Energy Savings and Payback Calculation Assumptions

The vestibule and doors and door opening configuration were represented explicitly within the model, and a dynamic air flow assessment was used to model the natural and pressure driven flows and their interaction with the mechanical air within the building. Flow through the doors used crack representations when closed and bi-directional flows when open. The assessment takes into account both temperature and pressure, which were re-assessed at each minute of the year. The door opening cycle was either 5 minutes or 10 minutes with a few periods where less than perfect control was achieved. The Assessments used the same façade, roof and door construction as the rest of the building.

The payback was calculated based on an installed cost of $74858 for the external vestibule and $13,000 for the internal vestibule. A high traffic application of nearly 100 door openings per day per door was used.

Energy Savings and Payback Calculation Results

The total energy savings are significant (Figures 6.93 and 6.94). Savings result from the reduction of the space heating load due to a reduction of air infiltration. Figure 6.95 shows the estimated payback on the internal vestibule is from 1 to 6 years in cold climates. External vestibules are difficult to justify on the basis of energy savings alone (Figure 6.96). Other factors related to the work environment, productivity, and scheduling may improve the economic analysis.

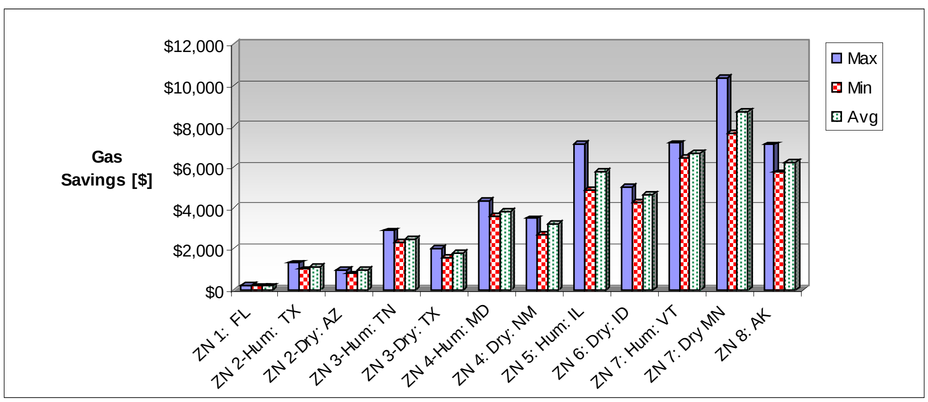


Figure 6.93. Estimated annual gas savings.

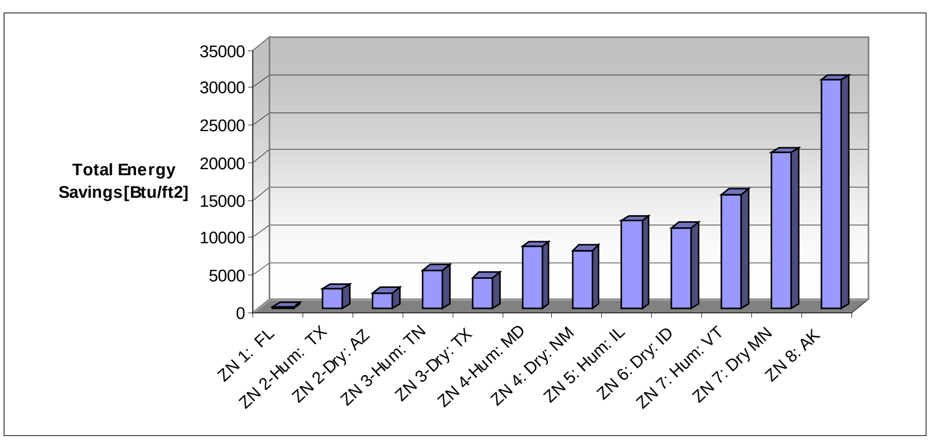


Figure 6.94. Estimated annual savings.

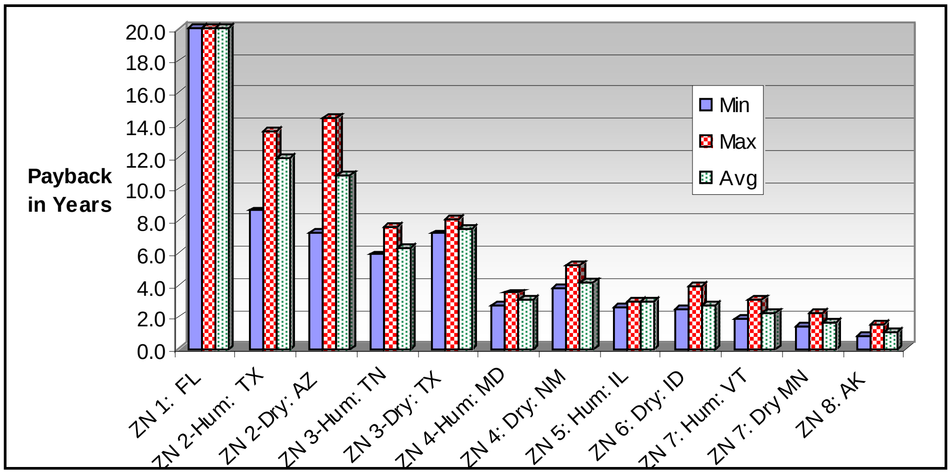


Figure 6.95. Estimated payback for internal vestibule.

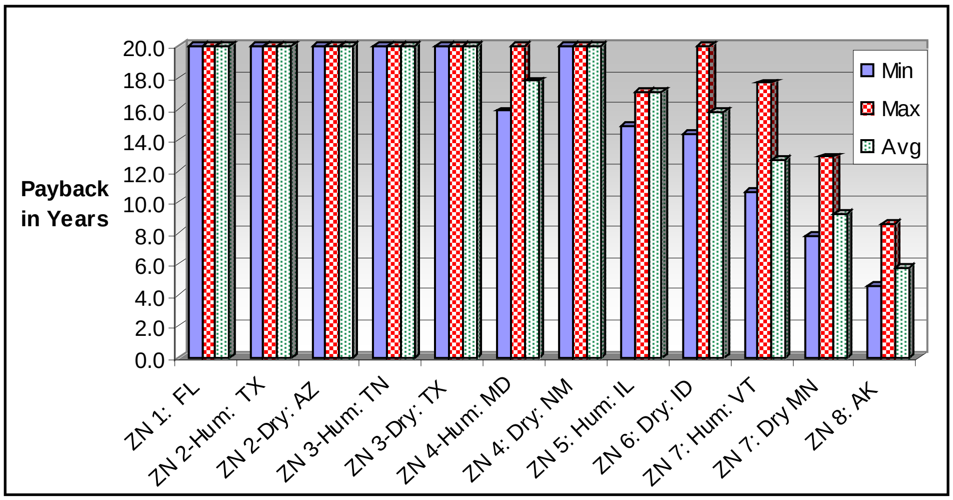


Figure 6.96. Estimated payback for external vestibule.

Level of Maturity

More than 20 years.

Impact on Indoor Air Quality

The system will reduce outside air infiltration. With a properly designed ventilation system, indoor air quality can be maintained.

Climatic Conditions Necessary

The application of this technology makes more sense in cold locations. If adjacent spaces are air-conditioned then vestibules might also be a consideration in hot/humid locations.

Contacts and Major Manufacturers

Essentially any contractor who can match the design and construction standard required would be suitable. There are no custom components required although there is some benefit in upgrading the door opening hardware to enforce proper operation of the doors.

VFD Drives To Balance Airflow with Production Rates

Application

Industrial, office.

Category

HVAC.

Concept

To balance air flow rate with production rates, production schedules would typically be read by the programmable controller, and would then be converted to a desired flow rate, and ultimately to a damper setting. The controller would position the damper to achieve the desired flow rate. The VFD, responding to the change in duct pressure, would adjust the fan speed in accordance with the damper setting. Figure 6.97 shows the typical components required for a variable frequency drive (VFD) system (programmable controller, HVAC control dampers, variable speed drive, and duct pressure transducer).

Source: **http://www.tombling.com/images/duct-fan-large.jpg**
Programmable controller

Variable speed drive

Pressure transducer

Figure 6.97. VFD system.

Although significant savings can be realized by installing a variable speed drive, the feasibility of the retrofit is typically determined by accessibility to ductwork and control wiring. The conversion involves installation of a VFD actuated by a duct pressure sensor and a control damper actuated by the programmable controller

Description

Balancing airflow with production is achieved by the use of a programmable controller to control fan operation in accordance with a production schedule. The schedule is entered into the programmable controller, which then provides overall supervisory control to the systems VFDs.

Energy Savings (Qualitative)

For many industrial processes, production rates are a good indicator of ventilation requirements. Potential savings for this type of control are largely a function of the production rate schedule. For “just-in-time” manufacturing processes that result in highly variable production rates, production rate based ventilation control can result in significant savings.

Energy Savings (Quantitative)

The study used a 50,000 sq ft (4645.152 m^2) typical metal building with 20-ft (6.1 m) high walls. The work zones consisted of a high thermal heat gain area, a high ventilation area, a light fabrication area, and a loading dock area, all of single-story structure with 20-ft (6.1 m) high walls. The building was modeled using typical light industrial wall and roof construction. The walls were insulated metal construction (R-4) and the roof was standard built up bitumen. The building is heated and ventilated, and the work areas were not air-conditioned. The high thermal heat gain and high ventilation area operate with 100% outside air year-round. The other areas operate with an economizer cycle with a minimum of 30% outside air.

Table 6.20 lists typical pricing for the required components. The cost of the variable speed drive varies significantly depending on the required power.

Table 6.20. Typical pricing for required VFD components.

	item	Est. Labor	Industrial Building 3 VFDs
Siemens VFD 240 V 50 HP	$4500	$1500	$18,000
Omega duct pressure transducer	$250	$100	$1200
Programmable controller	$800	$200	$3000
Total (50 hp)			**$22,200**

<u>Energy Savings and Payback Calculation Assumptions</u>

Since expected energy savings for this ECM depend on production schedules, savings were calculated for a range of ventilation flow rates. Variable production resulting in fan power savings (i.e., airflow rate reductions) of 5%, 10% and 20% in the three industrial process zones.

<u>Energy Savings and Payback Calculation Results</u>

For this ECM, the most useful metric is the total energy savings per cfm reduction (Figure 6.98). The plot shows the total estimated annual energy savings per cfm reduction in both the outside and the overall air flow rate in the three production zones.

Annual payback times were calculated for a 5%, 10%, and 20% reduction in air flow rate

(Figures 6.99, 6.100, 6.101, respectively). Results showed a 10% reduction in a payback period of less than 4 years in cold and moderate climates, and a 20% reduction in a payback of less than 4 years in all but the hottest climates.

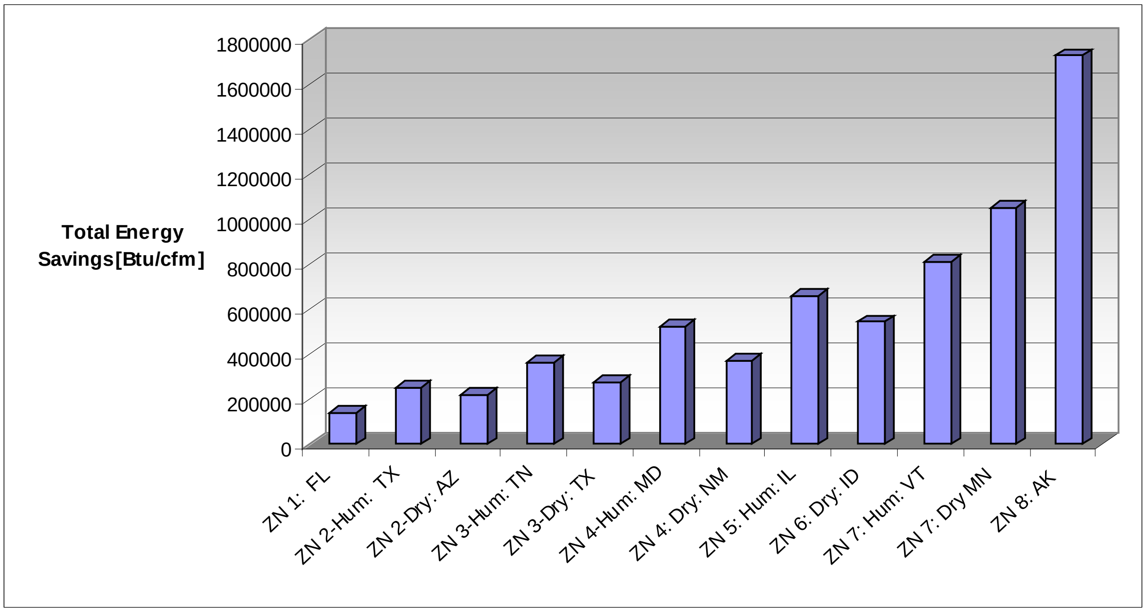


Figure 6.98. Estimated annual energy savings per cfm reduction in air flow rate.

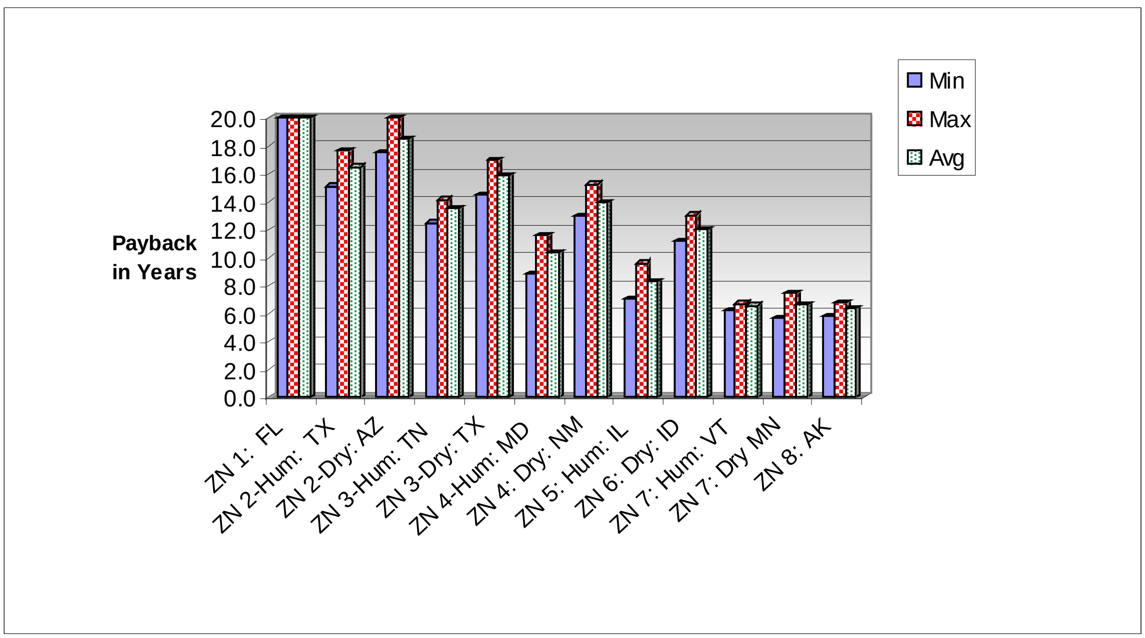


Figure 6.99. Estimated payback for 5% reduction in air flow rate.

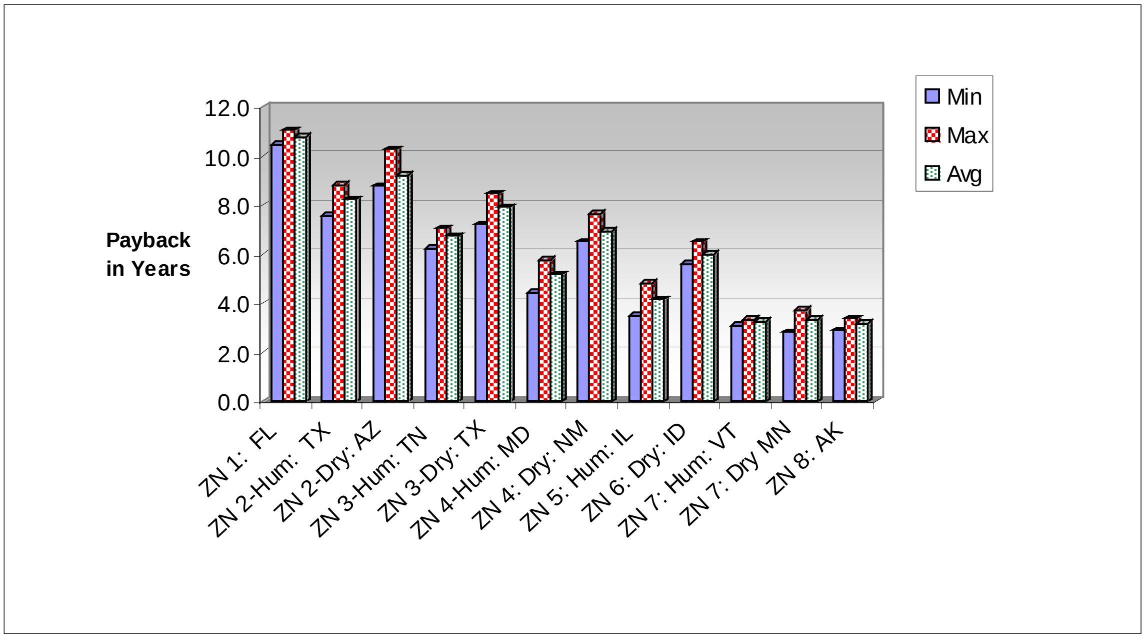


Figure 6.100. Estimated payback for 10% reduction in air flow rate.

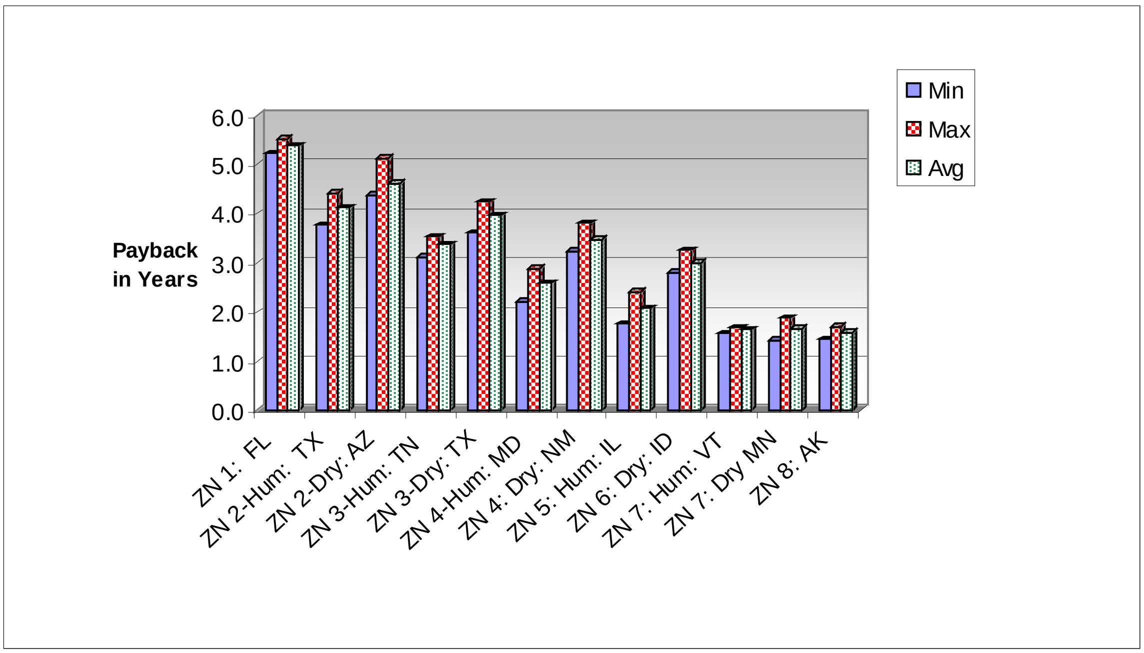


Figure 6.101. Estimated payback for 20% reduction in air flow rate.

Figures 6.102 and 6.103 show estimated electric and gas savings for the 10% reduction case. Note that electric savings reflect fan power only, since this industrial building is not mechanically cooled. For mechanically cooled buildings, electric savings are expected to be significantly higher.

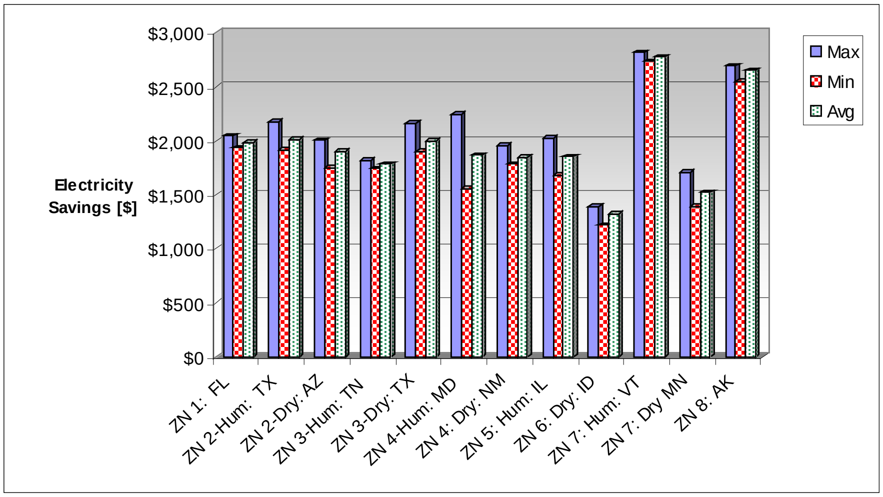


Figure 6.102. Estimated electric savings for 10% airflow reduction case.

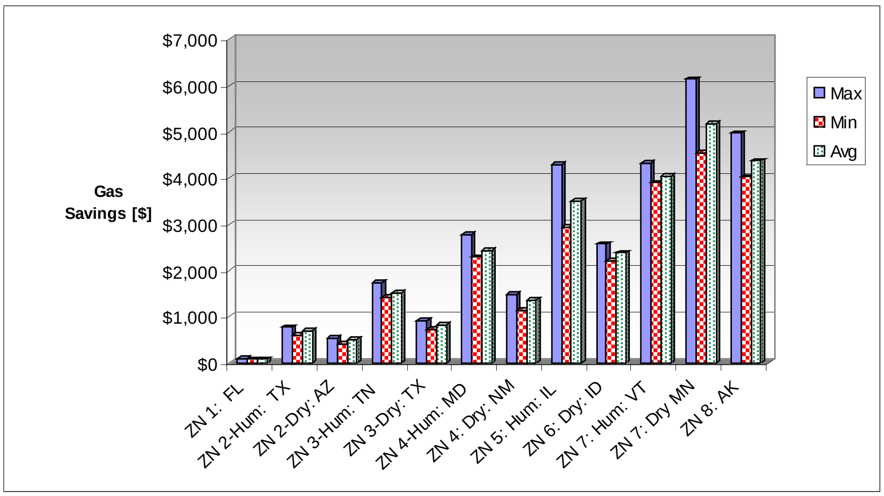


Figure 6.103. Estimated gas savings for 10% airflow reduction case.

Level of Maturity

20 years.

Climatic Conditions Necessary

This technology is applicable to all climates, however for “cooling” only climates, a reasonable payback will only be seen for mechanically cooled buildings.

Impact on Indoor Air Quality

None.

Contacts and Major Manufacturers

Contacts and major manufacturers are listed at:
http://www.processregister.com/AC_Variable_Frequency_Drives/Suppliers/pid682.htm

Demand-Based Local Exhaust System for Welding Shops

Application

Industrial

Category

Ventilation, Welding

Concept

Demand-based control of the local exhaust system is initiated by either a current (inductive) sensor attached to the welding machine or by the light produced by welding (light sensor). Each of these sensors initiates the activation of air flow from a specific hood during actual weld time. The system fan ramps to accommodate the number of hoods activated without affecting airflows through other hoods. A demand-based system allows for reduction of exhaust duct, fan, and a filter size and its operating airflow rate. It also reduces the size and operating airflow of the make-up air system. The exhaust airflow rate is controlled using a variable frequency drive (VFD) and a pressure sensor installed in the main duct. A demand-controlled local exhaust system is typically sized for not more than 50% of the total airflow rate exhausted through all hoods (maximum capacity of the standard constant volume system). Installation of the demand-based local exhaust system is economical when the system has at least three extraction hoods and applies to welding processes with duty cycles under 70%.

Figures 6.104 and 6.105 illustrate the principle of the demand-based local exhaust system for a typical welding shop. It shows a variable flow exhaust fan with a VFD drive and a pressure sensor and a duct system with flexible exhaust arms with motorized dampers. Each damper is controlled independently with a light sensor. Demand-based local exhaust ventilation systems includes extraction arms with the hood allowing an easy positioning close to the welding area by the welder. Demand-based system has an automatic control, does not require additional actions from the welder and is robust to handle the production environment. Figure 6.106 shows typical components of a demand-controlled system. Extraction arms installed in welding areas connect to the central extraction system and have individual automatic dampers operated from light or inductive sensors. The central system has a fan with a variable frequency drive (VFD) pressure transmitter.

Figure 6.104. Demand-based local exhaust system for 24-work stations at the New England Institute of Technology.

Figure 6.105. Demand-based local exhaust system for a typical welding shop.

Auto Start Mechanisms		Automated Dampers		VFD	
•Inductive Sensor for welding (MCC-005) •Light sensor for welding (LS-12)	These system initiation devices are designed for starting systems and stopping systems so that operators can go about their normal tasks and the source capture systems become a part of their operations. This maximizes effectiveness, minimizes operating cost and maintains operator productivity all while improving air quality in a facility.	•Automated dampers -4" MD-100 -6" MD-160 -8" MD-200 -10" MD-250 -12" MD-315 •Heavy duty construction for high static pressure •Low Voltage 24 volt control with ICE-LC •Easy Installation with built in seal •ICE-LC has built in stepdown transformer and timer	Automated dampers in conjunction with auto start components allow for use of the source capture systems needed. This maximizes system effectiveness, minimizes operator errors and minimizes energy use.	•Variable Frequency Drives for 1.5 HP to 30 HP, 240 volt and 460 volt •Built in set-up for manual control, automated control using a pressure transmitter and remote start/stop.	A VFD used in conjunction with a pressure transmitter, automated dampers and damper controls will regulate a source capture system to provide the right amount of air only at the locations where it is needed. This can allow a system to provide the full amount of ventilation when needed but at other times operate at as low as 10% full load. This saves energy.

Figure 6.106. Control components required for demand-based welding operation.

Description

Local exhaust ventilation systems capture air contaminants at their source. These systems remove contaminated air and thus reduce the workers exposure to welding-generated fumes. The type of local exhaust used depends on the method and conditions of welding, the type of welding equipment, the amount of consumables used, the size of the welded components, and shop space factors. Capturing airborne particles and gases at their source before they spread throughout the building environment, is the most effective way to increase indoor air quality and improve worker environment and safety. Flexible arms with easy for the welder positioning of the hood close to the contaminant source can reduce exhausted and make-up airflow rates, thereby reducing energy consumption for air transportation, heating, cooling, and filtration. The demand-controlled ventilation system exhausts contaminated air from each welding stations only during the welding process.

Energy Savings (Qualitative)

Demand-based local exhaust ventilation has reduced installed costs since ventilation is sized for at least 50% of the similar system with the constant exhausted flow rate. Correspondingly, it requires smaller make-up air system. Reduced energy consumption is due to the lower energy for exhaust and supply air transportation, air cleaning and heating, or cooling of the make-up air.

Energy Savings (Quantitative)

This study used a 20,000 sq ft light fabrication shop, part of a 50,000 sq ft metal building with 20-ft high walls. Typical light industrial wall and roof constructions were used in modeling the building. The walls were insulated metal construction (R-4); the roof was standard built up bitumen. The building is heated and ventilated with no air-conditioning in the work areas. The light fabrication area operates with an economizer cycle with a minimum of 30% outside air.

The data in Table 6.21 provide a comparison between installed cost for demand-based and constant air volume extraction systems with 5, 10 and 20 extraction arms applied to small and large welding areas (the size of the welding area effects the type and the size of extraction arm and thus its costs). The airflow rate evacuated through each hood is approximately 750 cfm. The constant volume exhaust system is sized for the total airflow rate exhausted through all hoods (750 cfm x N), while the demand-based system is sized for only 50% of that amount (375 cfm x N). The size and air flow rates of make-up systems are matching corresponding exhaust systems. While the airflow rate of the CAV is constant throughout the operation hours, the airflow rate exhausted by the demand-based system can be reduced throughout its operation in average by ~30% (this number is on conservative side and depends on the welding process duty cycle and the work load).

Table 6.21. Installed cost for demand-based and constant air volume extraction systems.

Work size area		5 work stations	10 work stations	20 work stations
Large	DBS	$ 50,000 2250 CFM @ 10-in. S.P. 7.5 HP (operates in average at 60%)	$ 75,000 3750 CFM @ 10-in. S.P. 15 HP (50%) capacity	$ 150,000 7500 CFM @ 10-in. S.P. 25 HP (50%) capacity
	CAV	$ 30,000 3750 CFM @ 10-in. S.P. 10 HP (operates at 100% capacity)	$ 50,000 7 500 CFM @ 10-in. S.P. 25 HP (operates at 100% capacity)	$ 100,000 15000 CFM @ 10-in. S.P. 50 HP (operates at 100% capacity)
Small	DBS	$ 40,000 2250 CFM @ 10-in. S.P. 7.5 HP (operates on average at 60%)	$ 60,000 3750 CFM @ 10-in. S.P. 15 HP (50%) capacity	*$ 100,000* 7500 CFM @ 10-in. S.P. 25 HP (50%) capacity
	CAV	$ 15,000 3750 CFM @ 10-in. S.P. 10 HP (operates at 100% capacity)	$ 30,000 7500 CFM @ 10-in. S.P. 25 HP (operates at 100% capacity)	$ 75,000 15000 CFM @ 10-in. S.P. 50 HP (operates at 100% capacity)

Estimated Costs for New Installation of Demand-based Welding System

The incremental cost of retrofitting an existing welding operation with a demand-based system is much less. In this case, the exhaust ducts, fans and arms are already in place. Only the control components shown in the figure above must be included. Table 6.22 lists the estimated costs for the control components. For smaller systems, the cost per workstation is slightly higher ($1400 per hood for five workstation systems) and for larger systems, the cost is lower ($1000 per hood for 20 workstation systems).

Table 6.22. Estimated cost for control components.

Item	Item	Est. Labor	Industrial Building (10 stations)
Variable frequency drive	$400	$1000	$5,000
Duct pressure transducer	$250	$100	$400
Damper controls and automated dampers	$400	$100	$5,000
Light and inductive sensors	$160	$100	$2600
Total (for 10 workstation system)			**$13,000**

Energy Savings and Payback Calculation Assumptions

Savings were estimated on a cost basis of $1,000, $1,300 and $1,400 per workstation. The costs shown in the above table corresponds to 10 work stations in small working areas and represents the mid-range of the cost spectrum. Energy savings were based on an outside airflow reduction of 375 cfm per workstation due to hood efficiency plus an additional 30% outside airflow reduction (112.5 cfm per workstation) due to duty cycle savings.

Energy Savings and Payback Calculation Results

Figures 6.107 – 6.112 show that the payback for this technology is can be less than 2 years in cold climates. Payback would be significantly improved for hot climates with mechanical cooling. For ventilation only, summer savings consist of a reduction in fan power only; this alone is not enough to recommend the technology.

Annual electric power, gas savings and total energy savings are also estimated on an annual basis per hood.

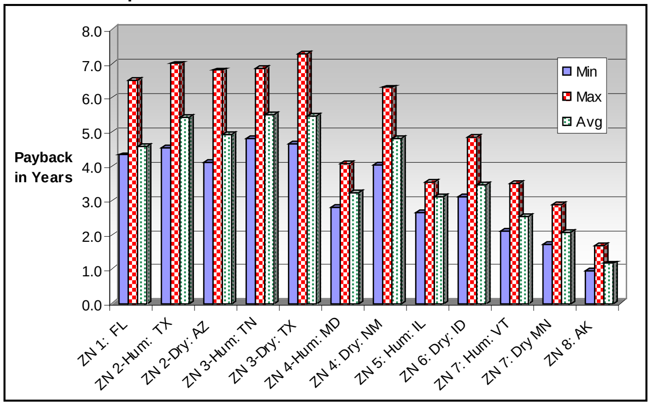


Figure 6.107. Estimated payback based on a 20 workstation system.

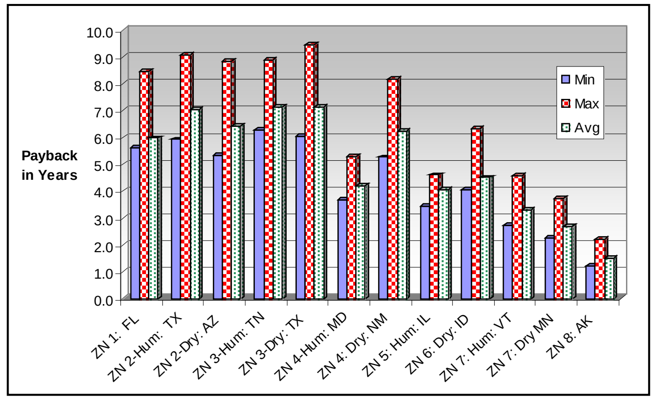


Figure 6.108. Estimated payback based on a 10 workstation system.

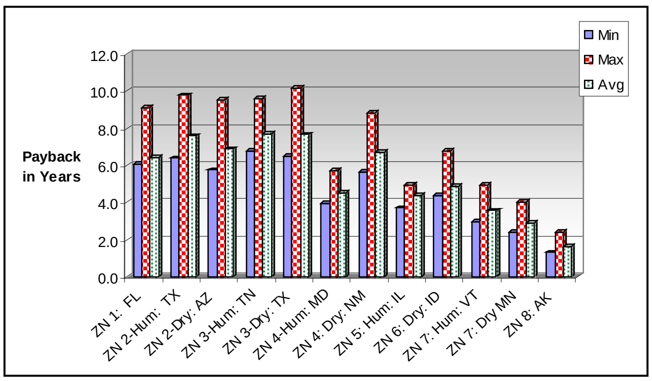


Figure 6.109. Estimated payback based on a 5 workstation system.

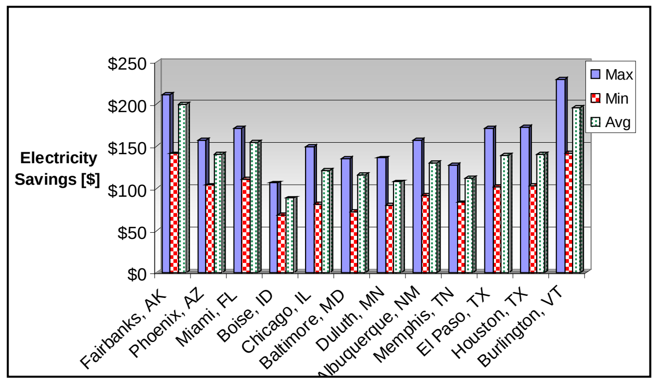


Figure 6.110. Estimated annual electric power savings per hood.

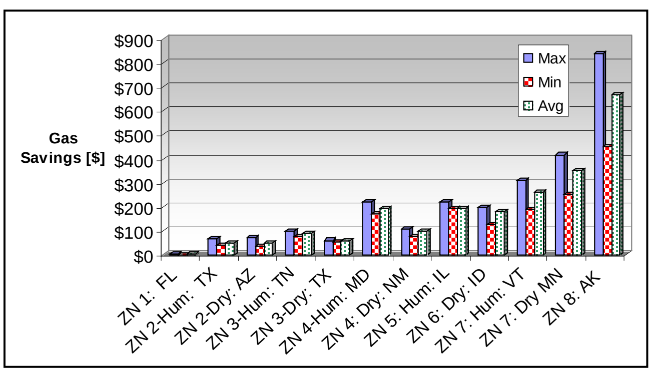


Figure 6.111. Estimated annual gas savings per hood.

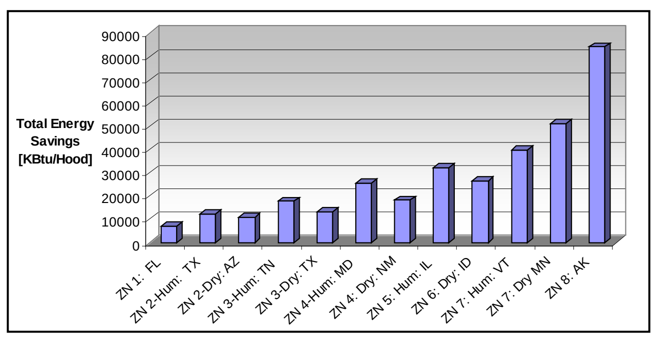


Figure 6.112. Estimated annual energy savings per hood.

Level of Maturity

This technology has been on the market for 7 years.

Impact on Indoor Air Quality

Use of local exhaust ventilation significantly improves indoor air quality specifically in the worker's breathing zone.

References

Alexander M. Zhivov, Mike C.J. Lin, Alfred Woody, William M Worek, Michael J. Chimack and Robert A. Miller. 2006. Energy and Process Optimization and Benchmarking of Army Industrial Processes, ERDC/CERL Technical Report: TR-06-25.

Barnkow S. Energy Savings with a Scalable Source Capture Ventilation. 2004. Presented at the "In-dustrial Process and Energy Optimization" workshop. Gettysburg, PA, February 2004. ERDC/CERL. CD-ROM.

6.1 Barracks/Dormitories

Duct Insulation

Application

Barracks, dormitories, offices.

Category

HVAC.

Concept

Ducts distribute air that has been conditioned by a mechanical system throughout the building, and are also frequently used to return air to that mechanical system. Ducts must be well insulated and properly sealed to perform their function effectively and to reduce energy loses so they can deliver the proper temperature air to the conditioned space, reduce heating and cooling losses, and prevent condensation on duct surfaces.

Similar to other types of insulation, duct insulation provides a resistance to heat flow, which tends to reduce energy loses from ducts as they transport conditioned air to the conditioned spaces. Since supply ducts are typically located in unconditioned spaces, including some which are located external to the building spaces, the possibility for energy losses to the ambient or unconditioned space is high. By insulating the ducts to an effective level, building owners and operators can be assured that most of the heating or cooling produced by the mechanical systems is delivered to the spaces requiring conditioning. Depending on the application, return ducts may or may not be insulated to the levels of supply ducts.

Insulation on ducts also helps to reduce condensation on duct surfaces when systems are operating in a cooling mode in climates with high ambient wet bulb temperatures. Condensation can reduce the effectiveness of the insulation by saturating it, and over time, can also degrade the insulating material. If the insulation contains facing material with air barrier qualities, it can also help to minimize the energy impacts of duct leakage.

Description

Duct insulation comes in a variety of forms depending on the intended application. The market for the insulation technologies is fairly mature and the products available tend to be utilized is specific applications. The following insulating materials are generally used to insulate supply ducts:

- Fiberglass duct wrap factory-laminated to a vapor retarder and applied to the exterior of sheet metal ducts.
- Fiberglass duct liner with coated or matt-faced airstream surfaces applied to the inside of a sheet metal ductwork with fasteners and adhesives.
- Fiberglass duct board with reinforced aluminum air barrier and water vapor retarder fabricated into ducts at site or at contractor’s premises. The edges are grooved to facilitate joining.
- Phenolic foam duct board, which is thermo-bonded to foil facing on both sides, reinforced with glass tissue mesh, and aluminum flanged.

Of the four types of products used for duct insulation, duct wraps are the most common. Duct liners, which have superior sound absorption properties, when noise reduction is an important objective. Figure 6.113 shows a typical duct wrap roll; Figure 6.114 shows typical duct board.

Figure 6.113. Duct wrap roll (Photo courtesy of Knauf Insulation, USA).

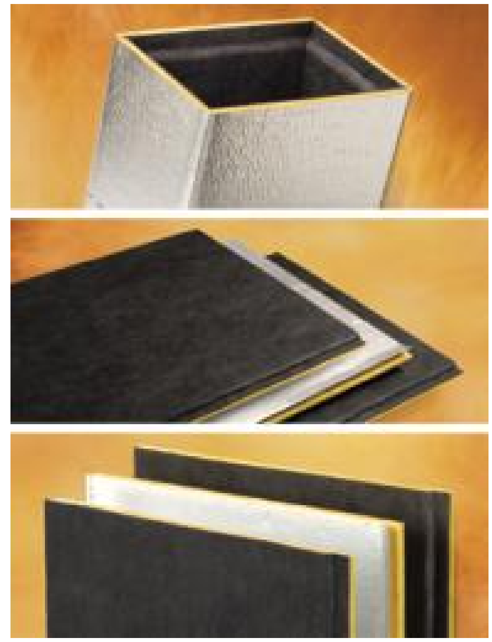


Figure 6.114. Fiber glass duct board (Photo courtesy of Knauf Insulation, USA).

Out of the four product types, the phenolic foam board duct systems are considered to be high performance systems suitable for industrial and high-end commercial applications. The manufacturers of these systems supply the entire range of components, accessories, special tools, and machinery for the fabrication and installation. Phenolic foam board duct systems are usually somewhat lighter, occupy less space, and can be installed in shorter time and at lower costs with superior air leakage and energy performance than the other types.

Energy Savings (Qualitative)

The level of duct insulation suitable to meet a broad criteria for cost effectiveness is contained in the ASHRAE Standard 90.1 (in the United States) and summarized in the *Sourcebook for Efficient Air Duct Systems* (for European countries). Table 6.23 lists representative duct insulation levels for combined heating and cooling, and for return ducts.

Table 6.23. Insulation levels for supply and return ducts.

Supply Ducts - Combined Heating and Cooling			
Climate Zone	Exterior	Ventilated Attic	Unconditioned Spaces
3-Hot	R-6 (R-1.06)	R-6 (R-1.06)	R-3.5 (R-0.62)
5-Moderate	R-6 (R-1.06)	R-6 (R-1.06)	R-3.5 (R-0.62)
7-Cold	R-8 (R-1.41)	R-6 (R-1.06)	R-3.5 (R-0.62)
Return Ducts			
All	R-3.5 (R-0.62)	R-3.5 (R-0.62)	R-3.5 (R-0.62)

While the duct insulation levels listed in Table 6.23 were subjected to an economic analysis that resulted in optimal economic thickness being selected for various (supply and return duct) applications in various climate zones, these levels may not be adequate for condensation control in all climates (Crall 2006). New public-domain software tools are available to help determine effective insulation thicknesses for both energy conservation and condensation control.

Empirical field studies have shown that the levels of insulation on ductwork in existing buildings, which represent approximately 98% of the building stock, are largely at a nominal thermal resistance of R-4 (R-0.707) (DOE 2000), which is often suboptimal. This represents a very good opportunity for energy savings for Energy Service Companies (ESCO s) and other retrofitters who wish to improve the energy efficiency of existing buildings.

The energy saving potential of a well-sealed and well-insulated thermal distribution system cannot be overemphasized. Numerous studies by multiple agencies i.e., Lawrence Berkeley Laboratory (LBNL), Brookhaven National Laboratory (BNL) and Florida Solar Energy Centre (FSEC) have shown that both duct leakage and duct heat transfer significantly degrades heating and cooling efficiencies in a wide variety of existing buildings.

Chapter 26 of the ASHRAE Handbook-Fundamentals deals with the insulation of mechanical systems, and the related design objectives are outlined as follows:

- *Energy conservation*: Reducing undesirable heat loss/gain in the air stream in the thermal energy distribution system
- *Personnel protection*: To keep surface temperatures of hot surfaces below burn threshold and avoid contact burns;
- *Condensation control*: To keep the surface temperatures of cold surfaces below the dew-point temperature of the surrounding and avoid condensation.

Energy Savings (Quantitative)

The cost of various duct and insulation systems depends to a great extent on the location of the building, the length of duct runs, the level of insulation and the desired supply air temperatures. The data in Table 6.24 provide an example of the costs and potential paybacks based on a duct system with the following characteristics:

- Design Pressure: 249 Pa (1.0 in WG)
- Design Duct Air Temp: 12.8 °C (55 °F)
- Design Velocity: 60.9 m/sec (1200 fpm)
- Ambient Air Temp: 26.7 °C (80 °F)
- Duct Width: 91.4 cm (36 in.)
- Duct Length: 15.24 m (50 ft)
- Duct Height: 45.7 cm (18 in.).

One of the leading manufacturers of the duct insulation systems reported in 2004 that in view of the steep increase in steel prices, fiber glass duct boards have become increasingly cost competitive. The steel price index was tracked using the producer price index for steel. It was seen that after peaking in 2008, the index is exhibiting a downward trend. It is likely that the above assertion may continue to be valid.

The sensitivity of heat loss and gain for both small and large ducts was evaluated as well. A small rectangular duct (30.5 x 15.2 cm [12 x 6 in.]) was evaluated against a larger rectangular duct (91.4 x 45.7 cm [36 x 18 in.]) for heat gain in the summer cooling mode and heat loss in the winter heating mode. Both ducts were metal and insulated with duct wrap of 12 kg/m^3 (0.75pcf). The data in Table 6.25 summarize the performance of the two insulated ducts.

Table 6.24. Cost of fiber glass duct board, un-insulated metal ducts, metal lined, and metal wrapped ducts.

		Unsealed Metal 26 GA (Un-insulated)*	Metal Lined (1-in., 1.5 PCF Duct Liner)	Metal Wrapped (1.5-in., 0.75 PCF Duct Wrap)	Fiber Glass Air Duct Board (1-in. Thick EI 475)
Materials & Accessories ($/$m^2$ [$/sq ft])	Ductwork	0.068 (0.734)	0.068 (0.734)	0.068 (0.734)	0.101 (1.09)
	Insulation	N/A	0.043 (0.46)	0.026 (0.29)	Incl.
	Subtotal	0.068 (0.734)	0.111 (1.194)	0.095 (1.024)	0.101 (1.09)
Labor: Fabrication & Installation ($/$m^2$ [$/sq ft])	Ductwork	0.273 (2.938)	0.273 (2.938)	0.273 (2.938)	0.220 (2.37)
	Insulation	N/A	0.133 (1.43)	0.145 (1.56)	Incl.
	Subtotal	0.273 (2.938)	0.431 (4.368)	0.418 (4.498)	0.220 (2.37)
Total Installed Cost ($/$m^2$ [$/sq ft])		0.341 (3.672)	0.517 (5.562)	0.513 (5.522)	0.322 (3.46)
R- value		N/A	0.74 (4.2)	0.74 (4.2)	0.76 (4.3)
Performance comparison					
Leakage (ft^3/min) (m^3/sec)		0.102 (216)	0.013 (27)	0.013 (27)	0.013 (27)
Total Energy Loss (Btu/hr) (w)		6,118 (20,882)	1,766 (6,028)	1,587 (5,416)	150 (5,129)
Energy cost ($/sq ft) ($/m^2)		0.437 (4.7)	0.126 (1.36)	0.113 (1.22)	0.108 (1.16)
Installed Cost ($/sq ft) ($/m^2)		0.411 (4.42)	0.704 (7.57)	0.706 (7.59)	0.383 (4.12)
Payback Period (years)		Baseline	1.52	1.46	Initial Cost Less than baseline

Table 6.25. Performance of insulated ducts.

	Cooling Heat Gain	Heating Heat Loss
Small Duct	14.9 w/m (15.52 Btu/hr/ft)	19.4 w/m (20.23 Btu/hr/ft)
Large Duct	45.6 w/m (47.47 Btu/hr/ft)	58.3 w/m (60.69 Btu/hr/ft)

Results

Potential Energy Savings vs. Thickness and Operating Conditions

Potential energy savings for any given condition may be compared using the 3EEPlus software from NAIMA. Figure 6.115 shows a plot using the conditions described above. The plot shows that, even with 2.54cm (1 in.) duct wrap corresponding to an insulation level of about R-4 (R-0.707), the heat gain in the duct is dramatically reduced by 85%. The steady state surface temperature of the duct however is computed at 24.6 °C (76.3 °F). If the dew point of the surrounding air at 26.7 °C (80 °F) DB is higher than the duct surface temperature, there would be moisture condensation on the duct surface with multiple adverse impacts.

Optimization of Duct Insulation and Design Considerations

Appropriate levels of duct insulation are optimized based on the amount of cooling energy gains and heating energy losses. These values will vary depending on climate and the length and severity of the conditioning seasons. The ducts are generally designed to maintain a 9 °C (20 °F) temperature difference between the temperature of the air and the surface temperature of the duct. This will usually maintain and economically optimum performance while preventing condensation on the duct surfaces. Supply and return ducts are usually insulated, but exhaust ducts are usually not insulated. In cases where energy recovery is being done on the exhaust air stream exhaust ducts should be insulated to improve the quality of energy recovery.

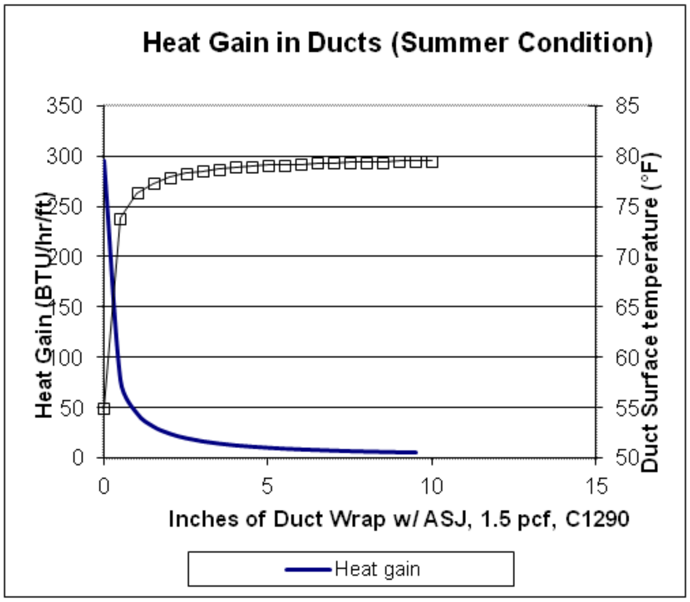


Figure 6.115. Heat gain in ducts and duct surface temperature in summer conditions.

Level of Maturity

Mature.

Climatic Conditions Necessary

Not applicable.

Manufacturers

CertainTeed Corp.
750 E. Swedesford Road
Valley Forge, PA 19482
800-233-8990

Knauf Insulation
One Knauf Drive
Shelbyville, IN 46176
800-825-4434

Johns Manville
PO Box 5108
Denver, CO 80217
800-654-3103

Guardian Building Products, Inc.
PO Box 207
Greenville, SC 29602
800-569-4262

Owens Corning
One Owens Corning Parkway
Toledo, OH 43659
800-GET-PINK

Note: A full list of manufacturers may be obtained from the trade association North American Insulation Manufacturers Association (NAIMA), which is accessible though URL: www.naima.org).

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Malmstrom, T., J. Andersson, F. R. Carrie, P. Wouters, and C. H. Delmotte. 2002. Sourcebook for efficient air duct systems in Europe. Final Report of the European AIRWAYS Project (Save II Program – Project 4.1031/Z/99-158 – DG TREN).

US Department of Energy (DOE). 2000. Solicitations for the Small Business Innovation Research and Small Business Technology Transfer Programs.

Xu, T., O. Bechu, R. Carrié, D. Dickerhoff, W. Fisk, E. Franconi, Ø. Kristiansen, R. Levinson, J. McWilliams, D. Wang, M. Modera, T. Webster, E. Ring, Q. Zhang, C. Huizenga, F. Bauman, and E. Arens. December 1999. Commercial Thermal Distribution Systems. Final Report of the Environmental Energy Technologies Division, LBNL and Center for Environmental Design Research, University of California Berkeley to the California Institute for Energy Efficiency (CIEE) and California Energy Commission (CEC), LBNL-44320.

Retrofitting Lighting Systems To Correct Light Levels

- Application: Barracks
- Category: Lighting

Concept

One of the easiest and most cost effective methods for saving energy is to design lighting systems to the correct light level for the tasks being performed, avoiding excessive lighting.

Description

The amount of effort required to maintain a typical lighting system is minimal. As lamps burn out, they are replaced with the same type of lamp to ensure that light levels remain consistent. While this is acceptable for spaces where an efficient and well-designed lighting system is in place, this type of maintenance in an over-lit space simply maintains the same level of wasted energy by foregoing an opportunity to retrofit using a more efficient type of bulb.

Lighting systems are most effectively designed based on the light levels or illuminance required for the tasks performed within each building space. The accepted authority for appropriate illuminance levels is the Illuminating Engineering Society of North America (IESNA). The IESNA publishes a comprehensive handbook along with supplemental Recommended Practice Guides that provide tables of appropriate illuminance data. However, many systems do not specifically follow this guidance, and instead use previous designs or historical design rules of thumb, causing spaces to be over-lit.

Most lighting designed and installed prior to 1985 is too much by today's standards, as overhead lighting was designed for low contrast print reading tasks at levels of 750-1000 lux (lumens per square meter). Current office operations primarily involve computer-based and higher quality printed tasks such that the recommended light levels are now around 300 and 500 lux.

Another consideration in lighting design is the application of daylighting when it is available. Even in spaces with available daylight, lighting systems typically must be designed to meet required light levels without daylight because of the possibility of space occupancy at night. However, spaces with daylight are likely over-lit the majority of the time, since they are occupied primarily during the day, with the electric lights on whether or not they are needed. Having a separate control for the lights such as a photocontrol or dimmer ensures their use as an effective and supplementary light source. If controls are not applied, excessive energy is also being used to operate the mechanical cooling needed to offset the heat load caused by the lighting. It is true that in some climates, the extra lighting can reduce heating needs but this rarely offsets the extra cooling required, and can be accomplished much more efficiently. Sunlight through windows and skylights also increases the temperature by solar heat gain, and must also be considered for effective daylighting design.

The light output provided by lamps progressively degrades throughout the lamp's life. Older T12 lamp technologies degraded up to 80% of their initial output, so spaces were designed to be purposely over-lit to accommodate this lamp characteristic and ensure ample light levels as shown in Figure 6.116. Today's T8 fluorescent lamps degrade much less throughout their lives, so compensating for degradation is unnecessary.

When group relamping (i.e., bulb replacement) occurs, overdesign becomes even less important since the lamps are replaced before they drop to their lowest light output.

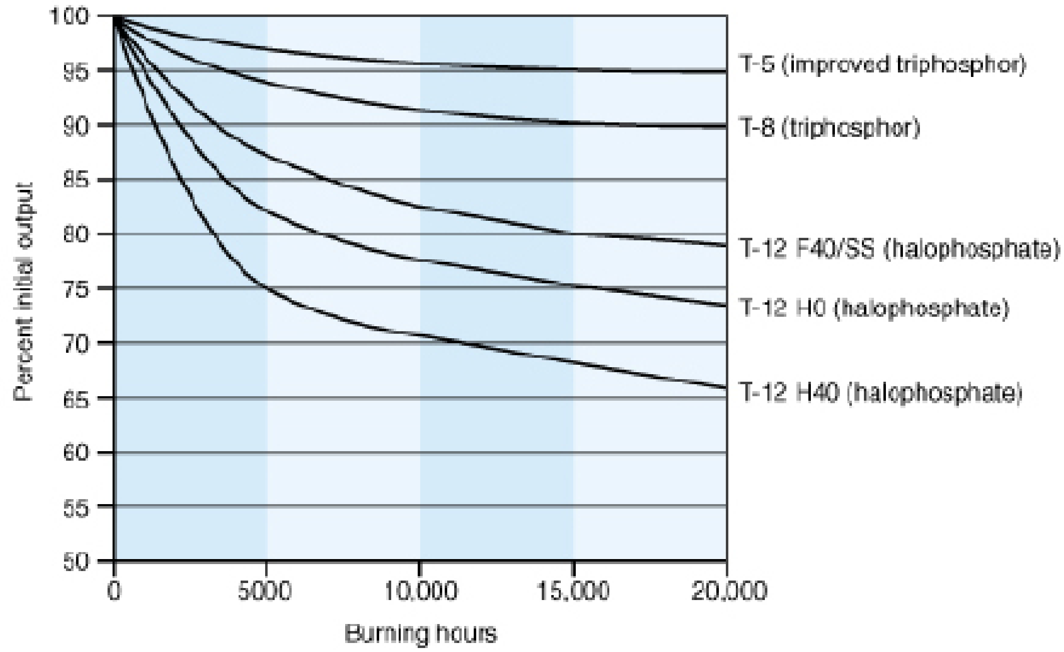

Figure 6.116. Lamp Lumen Depreciation (IESNA handbook).

Solutions for Over-lit Spaces

The first step in resolving this problem is identifying where over-lighting exists. Horizontal surface light level recommendations are provided by IESNA and are commonly measured in lux using an illuminance meter (also known as a “light meter”). Table 6.26 provides recommendations of target light levels in common spaces found in barracks and similar spaces. The illuminance targets are simply a guideline, and if measurements show light levels to be within a 20% variance, changing the lighting system will likely not be cost effective.

Measurements should be taken with the light sensor apparatus parallel to the floor (or work surface) at the height noted in Table 6.26. This is the height above the floor where most work is done and therefore the level at which the measurement should be taken and compared with levels in Table 6.26. Note that this is an average value, so multiple measurements should be taken and then averaged for comparison. In daylighted spaces, light measurement should be taken at night to see if light levels are too high without the contribution of daylight.

Table 6.26. Recommended minimum illuminance levels.

Building type	Space type	Maintained luminance at working level (lux)	Measurement (working) Level (1 meter = 3.3 feet)
Barracks/dormitories	Bedrooms	300	at 0.0 m
	Laundry	300	at 1.0 m
Office buildings	Single offices	400	at 0.8 m
	Open plan offices	400	at 0.8 m
	Conference rooms	300	at 0.8 m
	Copy room	100	at.80 m
Dining facilities	Self-service dining	100	at 0.8 m
	Kitchen	500	at 1.0 m
Sport facilities	Exercise room	300	at 0.1 m
Circulation areas	Corridors	50	at 0.1 m
	Stairs	50	at 0.1 m
	Restrooms	300	at 1.0 m

If light levels are too high, consider the corrective actions in Table 6.27 to correct them. For spaces with daylighting, also apply the control recommendations in the table for maximum benefits both in terms of lighting quality and energy savings.

One possible correction option noted in the table is the application of ballasts with a selected "ballast factor". Ballasts are the mechanisms that provide the proper electrical conditions to start and operate fluorescent lamps. A lamp's initial lumen output (amount of light produced by a lamp) is tested in a laboratory on a reference ballast. The reference ballast has a ballast factor of one, meaning it powers the lamp at full light output. A ballast that can only power the lamp at half of its full light output is said to have a ballast factor of 0.5. The choice of a particular ballast factor can be a tool for achieving the desired light output. The determination of an appropriate ballast factor must be done in conjunction with other space variables such as luminaires' efficiency and room surface reflectance, and therefore should be done with professional input.

If adjusting the ballast factor still does not correct light output and other recommendations from Table 6.27 have been found impractical, the less effective option of "delamping" could be considered. This delamping option should be considered as a last resort because it may adversely affect the intended beam spread from the luminaires and create dark areas in the space and make luminaires appear unmaintained. Three and four-lamp luminaires may incorporate two separate ballasts. Delamping by removing one ballast and the lamps it is driving may provide the required effect. Note that removing lamps only will **not** provide the expected energy reduction because the associated ballast will continue to draw power. If a lamp is taken out, the ballast operating it must be removed as well.

Table 6.27. Recommended action to correct spaces that are overlit.

	Best Option	Alternate Option
T12	Replace inefficient T12 lighting system with new T8 or T5 luminaires optimally located and spaced. The new system may reduce the number of luminaires to attain appropriate light levels.	If a complete new lighting design is not feasible, a T8 lamp and ballast retrofit with an appropriately chosen ballast factor and/or lower output lamp may provide the required reduction in illuminance (see text on ballast factor).
T8s or T5s	Consider relocating luminaires if spaced too close together (and relocation would not create dark spots). Alternatively, new luminaires with lower light output per luminaires could be installed.	If relocation is not possible, consider changing the light output of the lamps by replacing the ballasts with one having a more appropriate ballast factor to reduce lighting levels. A lower light output lamp could also be installed (see text on ballast factor).
CFL/ Incandescent	Incandescent lamps should be replaced with CFLs if applicable. If a space is too bright and lighted with CFLs, a lower wattage should be used	
Daylight Available	Provide separate daytime controls with a photocontrol, dimmer, or a manual switch at minimum controlling the lights in the daylight area separate from other lighting.	
*Implementation costs may vary depending on the choice and existing space conditions and should be considered for each application.		

Energy Savings:

Energy savings from lowering light levels can be calculated by using the following formula:

$$\text{Savings}_A = T_A * \frac{(W_c - W_n)}{1000} * E_{rate},$$

where:

- Savings_A = annual energy savings (dollars)
- T_A = annual amount of time lights are on
- W_c = current total wattage in the space
- W_n = new total retrofitted wattage
- E_{rate} = local utility's energy rate in dollars per kWh

In spaces with linear fluorescent lamps, it should be determined what type of fluorescent lamps and ballasts are being used. Rapid start, or program start ballast/lamp combinations use up to 4W more than an instant start lamp/ballast combination per lamp. If T12 systems are being retrofitted, or a T8 lamp/ballast combination is being replaced, use instant start ballasts and lamps for maximum energy savings. However, fluorescent lamps cannot be dimmed on these ballasts, and if dimming is necessary, program start ballasts must be used.

The estimation of percentage electricity energy savings on a whole building basis for a typical year (kWh/Yr) is provided for comparative use in Table 6.28 below. The table provides an estimated savings percentage of whole building electricity use from locations having various weather patterns based on a percentage reduction in total building light power density (LPD) from 10 to 70%. The table values also reflect the expected reduction in electricity use of HVAC equipment due to reduced cooling because of reduced lighting energy (heat).

Table 6.28. Reduction in whole building electricity use per year from reduction in lighting power.*

Representative weather location	Percent reduction in total lighting power						
	10%	20%	30%	40%	50%	60%	70%
San Francisco, CA	3.9	7.7	11.5	15.4	19.2	23.1	26.9
Seattle, WA	3.8	7.6	11.4	15.3	19.1	22.9	26.8
Boise, ID	3.6	7.1	10.5	14.1	17.7	21.3	24.8
Burlington, VT	3.0	6.0	9.1	12.1	15.1	18.1	21.1
Duluth, MN	2.9	5.9	8.8	11.8	14.7	17.7	20.6
Helena, MT	3.0	5.9	8.9	11.9	14.8	17.8	20.8
Chicago, IL	3.0	5.9	8.9	11.9	14.9	17.9	20.9
Albuquerque, NM	3.6	7.2	10.8	14.4	18.0	21.6	25.2
Baltimore, MD	3.5	7.0	10.5	14.0	17.5	21.0	24.5
Fairbanks, AK	2.7	5.4	8.1	10.8	13.5	16.2	18.9
El Paso, TX	3.5	7.0	10.4	13.9	17.5	21.0	24.4
Memphis, TN	3.3	6.5	9.8	13.1	16.4	19.6	22.9
Houston, TX	3.1	6.2	9.2	12.3	15.4	18.5	21.6
Phoenix, AZ	3.0	5.9	8.9	11.9	14.9	17.8	20.8
Miami, FL	2.7	5.5	8.2	10.9	13.6	16.4	19.1

* Includes savings from reduced lighting use and reduced HVAC electricity for cooling

Find the estimated percentage reduction in total lighting power in the climate zone most representative of the building's location. Then, use the reduction in whole building electricity use (from the table) to determine whole building energy reduction:

Estimated annual energy savings (kWh/Yr)	=	Percent reduction in whole building energy use	x	Building area effected by change	x	LPD for building area

Psychological Considerations:

In office settings where people are accustomed to existing high light levels, it can be disappointing to have light levels lowered. Often, when light levels drop occupants of the space will complain that they no longer have sufficient light and are unhappy. An often effective approach to relighting a space is to promote the installation of a new and better lighting system with potential benefits such as less glare, better for computer use, andc. This approach will typically only be effective if the space is being redesigned to promote the comfort of the occupants. If simple lamp/ballast delamping is done, the occupants may feel cheated by realizing the only change made was a reduction in their light levels. It has been found that occupants accept change more readily if they understand why it is occurring. If the only change evident in the lighting is a reduction in light levels, it might be appropriate to supply occupants with supplemental individual lighting to help ease the transition from an over-lit space to a space illuminated to meet the actual lighting requirements.

References:

NLPIP: Guide to Selecting Frequently Switched T8 Fluorescent Lamp-Ballast Systems.

IESNA 9th Edition Handbook, 200, Illuminating Engineering Society of North America.

Building Airtightness

Application

Dormitories, barracks, multi-family residential buildings.

Category

Building envelope.

Concept

While experts seek to improve the energy efficiency of buildings through proper insulation, the airtightness of a building enclosure or envelope is a significant factor that is often overlooked. Uncontrolled air transfer through the enclosure, as well as convection, markedly increases the energy required to heat, cool, and control humidity in buildings. Investigations of building enclosure problems indicate that air leakage is a leading cause of moisture problems. These problems include: mold and durability problems in exterior walls and other cavities connected to the exterior; excessive rain penetration into wall cavities; poor indoor temperature and humidity control; high heating and air-conditioning costs; and compromised noise, fire and, smoke control measures. In colder climates, the problems of air leakage include icicles on exterior facades (e.g., see Figure 6.117), spalling of masonry, premature corrosion of metal parts in exterior walls, high wood moisture content and rot, excessive rain penetration, and indoor temperature and humidity control problems. In hot humid climates, infiltrating air can cause mold due to condensation on cold air-conditioned surfaces. Sealing penetrations and reducing the chimney effect of interior ventilation can address these concerns.

Description

Improving building airtightness first requires identifying leaks, and then fixing them. When the building does not have assemblies with a designated layer selected as the airtight layer, or when the airtight layers of adjacent assemblies are not joined together, air leakage is the result. The most common problems show up in between adjacent assemblies, in particular, the wall-to-roof juncture, eaves projections where the structure penetrates the wall, metal deck with flutes open to the exterior, canopies and soffits, wall to foundation connections, and window-to-wall air barrier; these kinds of problems cause "orifice" and "channel" air flow. Occasionally building materials are selected that are not tight enough by air barrier standards, causing "diffuse" air flow. In existing buildings, operable windows and doors are generally candidates for either replacement or re-gasketing and weatherstripping.

Figure 6.117. Cold climate exfiltration problems (left) and hot humid air infiltration problems (right).

Diagnostic techniques for identifying leaks (Figure 6.7) generally include:

- Blower door pressurization test (ASTM E779) and theatrical fog (ASTM E1186), which can demonstrate air leakage pathways.
- Small smoke pencils and depressurization of the building, which can be helpful in pinpointing air leak locations and severity.
- Pressurization or depressurization (climate dependent), which, accompanied by infrared thermography, can be helpful.

Fixing such problems can be challenging due to the difficulty of accessing gaps through hard or expensive finishes.

Application of air barrier theory in a building design requires the selection of a component or layer in an assembly to serve as the airtight layer. The building envelopes of office buildings, office portions of mixed office and open space (e.g., company operations facilities), dining, barracks and instructional/training facilities should be designed and constructed with a continuous air barrier to control air leakage into, or out of, the conditioned space. Another best practice is the clear identification of all air barrier components of each envelope assembly on construction documents and detailing of the joints, interconnections, and penetrations of the air barrier components (Figure 6.119).

Figure 6.118. Smoke pencil (left) and theatrical fog (center) for leakage pathways; infrared thermography (right) for heat.

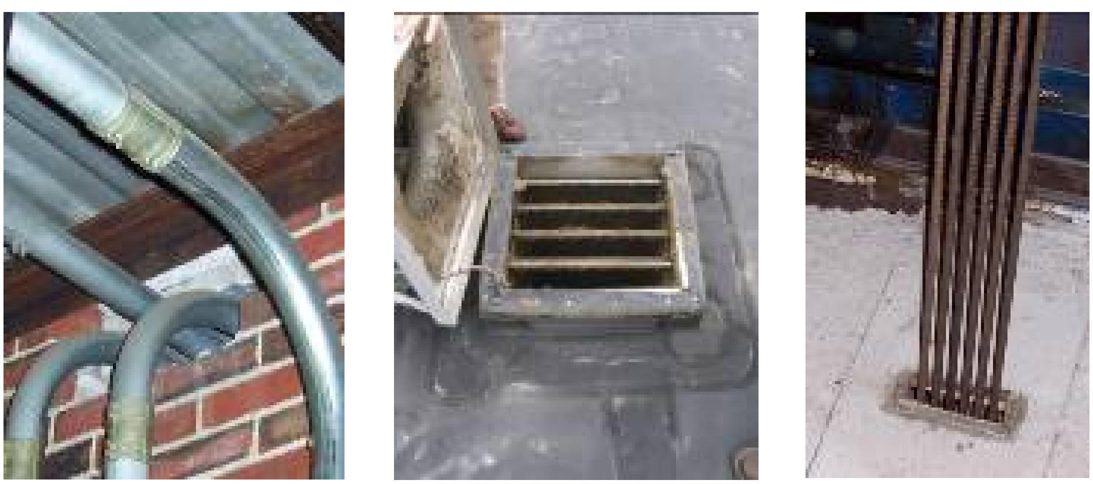

Figure 6.119. Unsealed penetrations (left); open louvers to vent shafts (middle); elevator cable holes can be made tighter (right).

Boundary limits of the building air barriers must also be clearly identified, in addition to the zone or zones to be tested for building air tightness on the drawings. The air barrier material must be structurally supported to withstand the maximum positive and negative air pressures it will be exposed to, and have an air permeance not to exceed 0.02 L/s*m^2 @ 75 Pa (0.004 cfm/sq ft @ 1.57 psf) when tested according to ASTM E 2170. The material should be joined together with tape, sealant, andc. to form an assembly, the air permeance of which must not exceed 0.2 L/s*m^2 @75 Pa (0.04 cfm/sq ft @1.57 psf), when tested according to ASTM E 2357. Assemblies of materials are joined together into an entire building enclosure, a six-sided box, including below-grade elements and slab if part of the heated envelope, that should not leak more than 1.25 L/s*m^2 @75 Pa (0.25 cfm/sq ft @1.57 psf) when tested according to ASTM E 779 or similar test. Penetrations of the air barrier must be sealed.

Trace a continuous plane of air-tightness throughout the building envelope and make all moving joints flexible and seal them. Support the air barrier so as to withstand the maximum positive and negative air pressure to be placed on the building without displacement or damage, and transfer the load to the structure. Seal all penetrations of the air barrier. If any unavoidable penetrations of the air barrier by electrical boxes, plumbing fixture boxes, and other assemblies are not airtight, make them airtight by sealing the assembly and the interface between the assembly and the air barrier or by extending the air barrier over the assembly. The air barrier must be durable to last the anticipated service life of the assembly. Do not install lighting fixtures with ventilation holes through the air barrier.

Provide a motorized damper in the closed position and connected to the fire alarm system to open on call and fail in the open position for any fixed open louvers such as at elevator shafts. Damper and control to close all ventilation or make-up air intakes and exhausts, atrium smoke exhausts and intakes, andc. when leakage can occur during inactive periods. Compartmentalize garages under buildings by providing air-tight vestibules at building access points. Provide air-tight vestibules at building entrances with high traffic. Compartmentalize spaces under negative pressure such as boiler rooms and provide make-up air for combustion.

Existing buildings undergoing major renovations, especially the ones located in cold or hot and humid climates should be sealed to the same standard as newly constructed ones. The need for and reasonableness of destructive analysis of the state of the existing air barrier should be evaluated based on the type of renovation and cost. This can be challenging due to difficulty in accessing gaps through hard or expensive finishes. Removable ceiling tiles allow easy access to problem areas; walls require destructive access through finishes to expose gaps such as around windows. Occasionally if a gap is found, it may be possible to blind-seal with spray polyurethane foam injected through holes drilled in the drywall. For large holes, bulkheads can be built from studs and drywall sealed with spray polyurethane foam (SPF); smaller gaps up to 50 mm (2-in.) sealed with one part SPF; larger gaps sealed with two-component SPF. Note that stuffing glass-fiber insulation in cracks is not useful, because glass-fiber merely acts as a dust filter and allows air under a pressure differential to pass through.

Sealing air leakage in this priority order (cf. Energy and Process Assessment Protocol, Appendix E):

1. Top of building
    - Attics
    - Roof/wall intersections and plenum spaces
    - Mechanical penthouse doors and walls
    - HVAC equipment gaps at sleeves
    - Other roof penetrations

2. Bottom of building
    - Exterior soffits and canopies connected to the interior.
    - Ground floor access doors with no vestibules, weather-stripping problems,
    - Underground parking access doors
    - Exhaust and air intake vents
    - Pipe, duct, cable and other service penetrations into core of building
    - Sprinkler hanger penetrations, inspection hatches and other holes
    - Seal core wall to floor slab
    - Crawl spaces

3. Vertical shafts
    - Gasket stairwell fire doors
    - Fire hose cabinets or toilet room recessed accessories connected to shafts
    - Plumbing, electrical, cable and other penetrations within service rooms
    - Elevator room venting, reduce size of cable holes, electric rooms venting, firestop and seal bus bar openings

4. Exterior Walls
    - Weatherstrip windows, doors, including balcony/patio doors and seal window trim
    - Exhaust fans and ducting
    - All service penetrations
    - Baseboard heaters
    - Electrical receptacles
    - Baseboards

5. Compartmentalize
    - Garages
    - Vented mechanical rooms
    - Garbage compactor rooms
    - Emergency generator rooms
    - High voltage rooms
    - Shipping docks
    - Elevator rooms
    - Workshops.

Energy Savings (Qualitative)

For typical buildings, increasing building air tightness can easily result in a 10% energy saving. Savings of 15% to 25% are not uncommon.

Energy Savings (Quantitative)

This report presents the effects on annual energy use and energy cost from improving building air tightness for a barracks. A baseline infiltration rate is established and two levels of improvement were modeled. Infiltration is a difficult parameter to obtain good data on. Every building has different leakage characteristics, and the infiltration varies with operation of the building and ambient conditions. Three representative air tightness levels were modeled for this exercise as shown in Table 6.29. The first value is used as the baseline and comes from expert opinion of the typical state of existing buildings based on pressurization tests. The other two values are considered to represent reasonable performance improvements achievable with a medium effort and a best effort for sealing existing buildings.

Table 6.29. Infiltration leakage rates.

Source	Leakage Rate at 0.3 in w.g. (75 Pa) cfm/sq ft (L/s/m^2)	Leakage Rate at 0.016 in w.g. (4 Pa) cfm/sq ft (L/s/m^2)	Air Changes per Hour at 0.016 in w.g. (4 Pa)
Baseline	1.0 (5.07)	0.15 (0.65)	0.97
Good practice for air sealing retrofit	0.50 (2.54)	0.074 (0.33)	0.48
Best practice for air sealing retrofit	0.25 (1.27)	0.037 (0.16)	0.24

The infiltration values at these leakage rates and pressures were calculated based on the total wall and flat roof area of the building, then converted to a pressure of 0.016 in w.g. (4 Pa), assuming a flow coefficient of 0.65. The infiltration is assumed to be constant with no variation with the operation of the HVAC systems. The HVAC systems in the barracks are individual packaged systems that run independently and do not pressurize the building.

To estimate the achievable savings, a number of pre- and post-retrofit, year-long simulations were performed using the EnergyPlus 3.0 building energy simulation software, which models heating, cooling and ventilation flows through buildings, among other criteria. The baseline building is assumed to be an existing barracks, dormitory or multi-family building built either to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone (Baseline 1) or to have been built prior to 1960, using typical construction practices of the time with little or no insulation (Baseline 2). The barracks are three stories high with an area of 30,465 sq ft (2,691 m^2) and include 40 two-bedroom apartment units, a lobby on the main floor and laundry rooms on each floor. The barracks were assumed to be unoccupied during the hours of 8 a.m. – 5 p.m. Monday through Friday. Further details on the barracks and the baseline heating, ventilation, and air-conditioning (HVAC) systems used are included in (Benne 2009).

Building airtightness was evaluated for 15 US locations and 16 international locations. The US locations were selected as representative cities for the climate zones by the Pacific Northwest National Laboratory. Flat utility tariffs were assumed for each location (i.e., no energy demand charges are included). The US energy costs are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008). The climate characteristics, energy costs and building details and construction parameters of all 31 simulations are in (Benne 2009).

Results

Figures 6.120 and 6.122 show the results for the improving the building air tightness for each climate zone. The energy savings are based on total building site energy consumption. Energy savings of nearly 25% are seen in the coldest climates studied (Figure 6.120). Expected savings from airtightness improvements decrease in warmer climates. These savings translate to roughly $0.10-0.50 per sq ft (Figure 6.121). The results can vary significantly with the modeling assumptions; therefore, the results from real building projects will vary from the simulated results.

Similarly, costs vary quite a bit depending on the needs of the building. For this analysis, the cost to achieve 0.50 cfm/sq ft was estimated to be $15,700; to achieve 0.25 cfm/sq ft, the cost was estimated to be $34,140**.** This includes attic sealing costs of $8,200 and top floor sealing costs of $7,500 to achieve 0.50 cfm/sq ft. Additional weatherization for the two bottom floors and sealing doorways to achieve 0.25 cfm/sq ft would add approximately $18,440. Figure 6.122 shows the average simple payback period for each climate zone studied. Improving building air tightness is usually cost-effective in all but mild climates.

Level of Maturity

Air barrier technology is in its early stages of development. While the concept is not new, the principles of maintaining and effective air barrier have not been widely applied. The design and construction communities are just beginning to wrestle with the concepts of airtightness and to develop more effective ways — diagnosis techniques, materials, and remediation procedures — to improve building air tightness. In the United Kingdom, commercial and office buildings are required to be tested before occupancy to meet Part L air leakage requirements. In the United States, the US Army Corps of Engineers has recently adopted similar testing requirements. Air sealing existing buildings is specialized technology and requires specialized expertise.

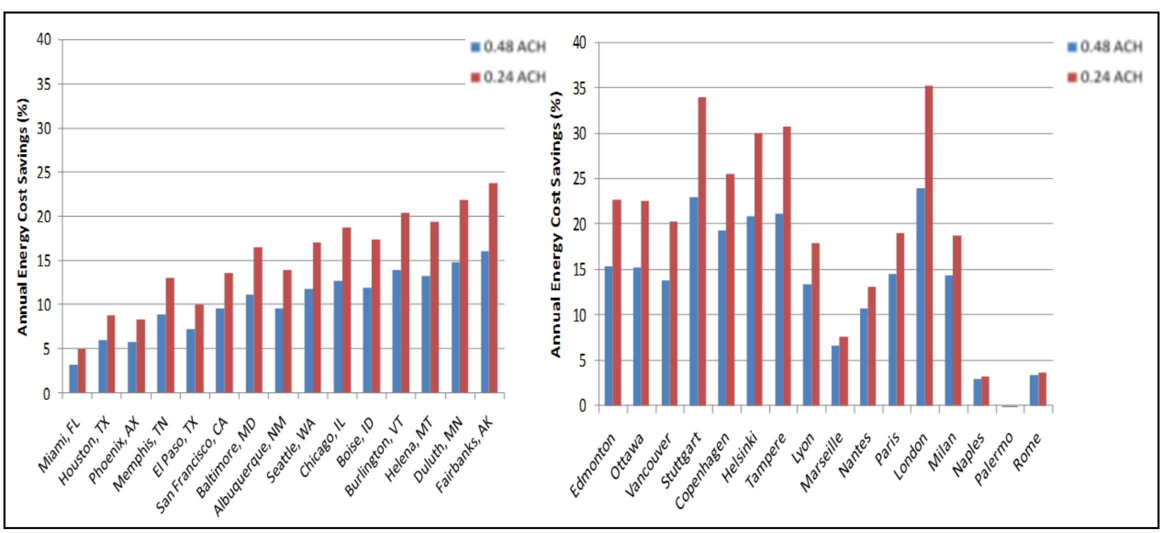

Figure 6.120. Percent annual energy savings for US (left) and international (right) locations.

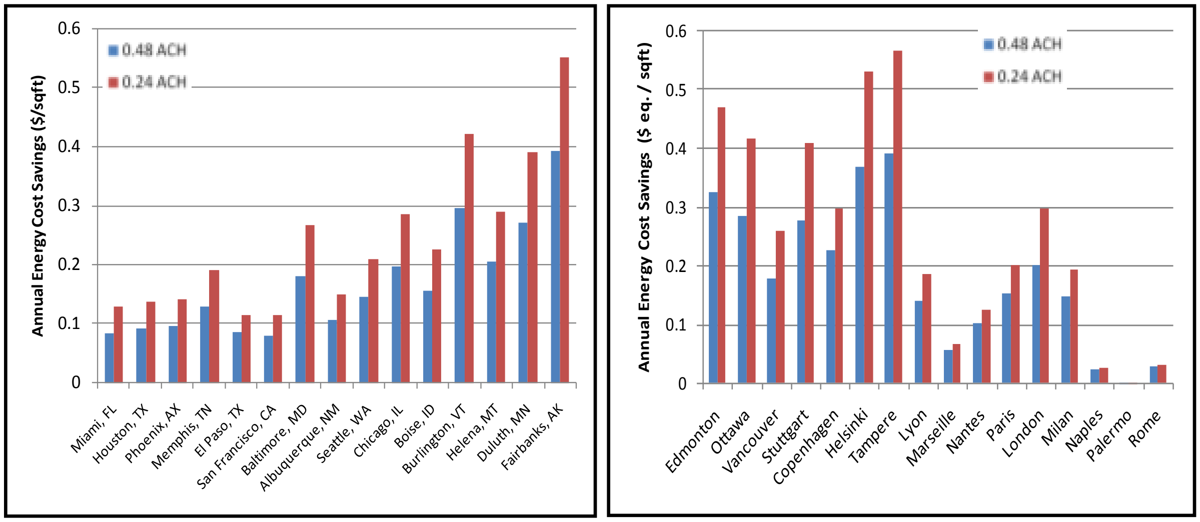

Figure 6.121. Annual energy cost savings per unit area for US (left) and International (right) locations.

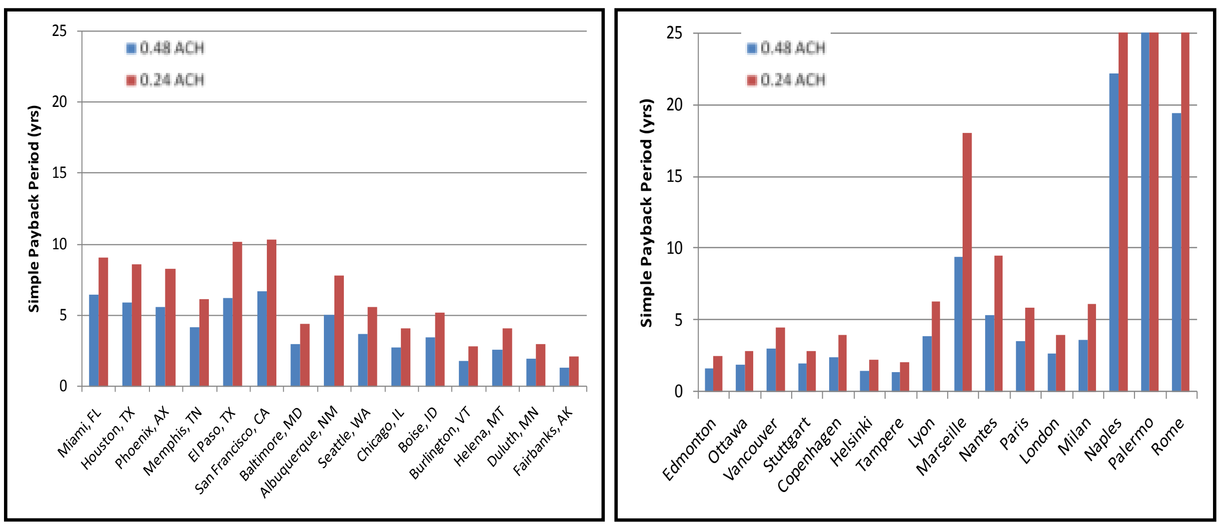

Figure 6.122. SPB period for US (left) and international (right) locations.

Impact on Indoor Air Quality

Techniques to improve air tightness have been motivated as much by air quality concerns and mold/fungus/moisture control as by energy savings. A major impact is seen from reducing infiltration, including the ability to better control the HVAC system, reducing mold and microbial generation, improving infection control, and addressing pollutant migration problems.

Climatic Conditions Necessary

The technology works in any climate but is most effective in colder climates.

Manufacturers

A list of manufacturers and contractors can be found on the Air Barrier Association's website http://www.airbarrier.org

Existing Airtightness Standards

The following airtightness performance criteria are based on the "air leakage rate of the building envelope" as defined by ASHRAE 90.1 -2004 addendum z. It is the area of the enclosure based on the building enclosure pressure boundary, in other words, the "six-sided box," including slab area and below grade components within the conditioned space; "air permeability" as defined in the UK and "Normalized Leakage Rate at 75 Pa" or NLR_{75} as defined in Canada.

- United Kingdom Part L energy requirements (including Australian requirements) require buildings other than single-family dwellings to be air sealed to an airtightness of 10 m^3/hr*m^2@50 pascals per m^2 surface area; this is converted to 13 m^3/hr*m^2 or 3.6 L/s*m^2 @75 pascals surface area—assuming n=0.65 (Potter 2007).
- In the UK, normal practice for commercial buildings is 5 m^3/hr*m^2@50 pascals per m^2 surface area (6.5 m3/hr*m^2 or 1.8 L/s*m^2 @75 pascals per m^2 surface area—assuming n=0.65) (ATTMA, BSRIA).
- UK best practice for commercial buildings is 2 m^3/hr@50 pascals per m^2 surface area (2.6 m^3/hr or 0.72 L/s*m^2 @75 pascals per m^2 surface area—assuming n=0.65) (ATTMA, BSRIA).
- ASHRAE Addendum z to 90.1 - 2004 allows 2 L/s*m^2 @ 75 Pa for whole buildings, 0.2 L/s*m^2 @ 75 Pa for assemblies and 0.02 L/s*m^2 @ 75 Pa for air barrier materials.
- The US Army Corps of Engineers airtightness requirement is set at 1.25 L/s*m^2 @ 75 Pa surface area.
- Massachusetts requirements are for air barrier materials, maximum permeance of 0.02 L/s*m^2 @ 75 Pa
- Canada's National Model Building Code has a requirement of maximum air permeance of 0.02 L/s*m^2 @ 75 Pa for air barrier materials, with a recommendation of maximum 0.1 L/s*m^2 @ 75 Pa for assemblies of materials.

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Exterior Wall Insulation

Application

Barracks / Dormitories / Multi-family housing

Category

Building Envelope

Concept

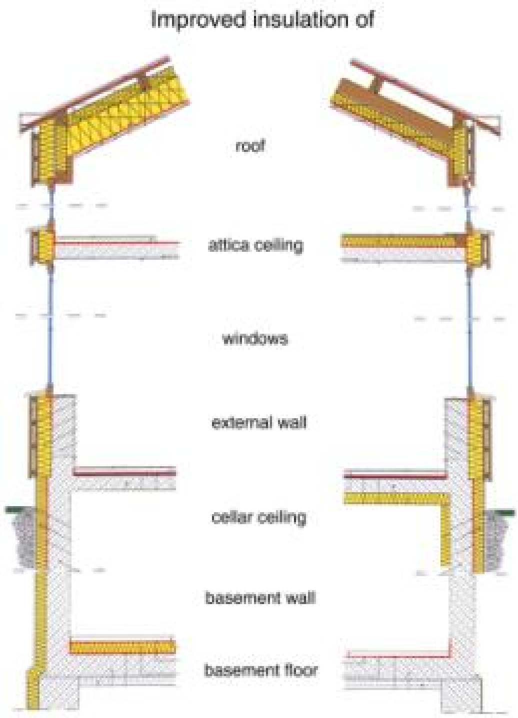


Figure 6.123. Example of building insulation in Berlin. Two different applications of insulation material (marked in yellow) in the roof are: (left) all insulation in the roof (heated attic); (right) one insulation layer above the attic ceiling, another insulation layer in the below the rafters (attic as a buffer zone). The basement insulation on left includes radiant floor heating whereas on the right the insulation layer is under the basement ceiling (unheated basement).

For older buildings, often the only practical method to improve the thermal resistance of its envelope is installing external insulation. The type of insulation technology used affects the thermal performance of the building envelope, including reduction of thermal bridging, air leakage, and vapor and water penetration. Thermal performance of the building walls, along with other envelope elements (Figure 6.123), influences the energy demand of a building in two ways. It affects annual energy consumption and thus operating costs for building heating, cooling and humidity control. It also influences peak loads, which determine the size of heating, cooling, and ventilation equipment and, therefore impact investment costs.

This document focuses on one of the typical methods to improve the thermal resistance of external walls: external insulation using expanded polystyrene with a weather-resistant facing. The exterior insulation finish system (EIFS) is attached to the existing exterior wall using a system of anchors and adhesive (Figures 6.124 and 6.125).

Description

In retrofit projects, older buildings can be insulated from the outside (Figure 6.126a) or the inside (Figure 6.126b). All things considered, the best way to insulate a building wall is on the outside as this minimizes problems with thermal bridges and does not reduce the usable floor area. Sufficient exterior insulation prevents the space within the wall cavity from reaching the dew point temperature and reduces the risk of condensation. Current external insulation technologies offer different color and texture options and improve the appearance of the façade.

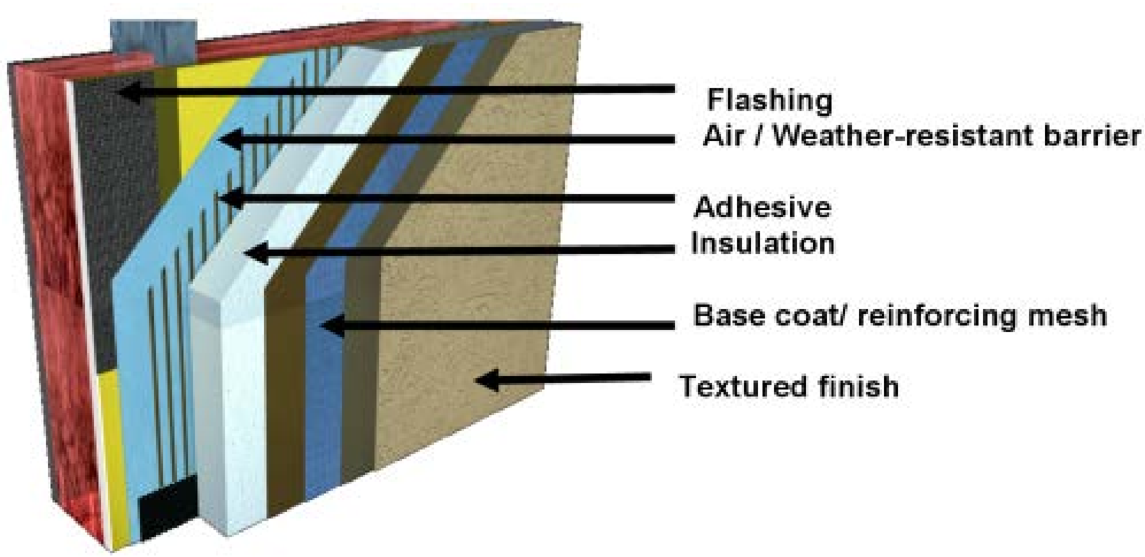


Figure 6.124. EIFS construction with drainage.

Figure 6.125. Mineral wool insulation covered with plaster for the application on the external wall (www.rockwool.dk).

a. b. c.

Figure 6.126. Retrofitted Army barracks with exterior insulation (a), interior insulation of the retrofitted administrative building at the Rock Island Arsenal (b, c).

However, external insulation may not be appropriate for some types of buildings (e.g., historic buildings). In such cases, internal insulation shall be used when necessary. The interior of the wall structure can be insulated with fiberglass (blown or batts), mineral wool, foam, or other materials. Insulation can also be applied to the interior surface of the walls, or a combination of wall cavity insulation and interior surface insulation may be used. The choice of techniques and materials depends on the wall structure, building use, current furnishings, and need to preserve interior space, andc.

While the energy savings of a specific increase in wall R-value (with proper vapor barrier and sealing of wall openings) will be the same whether the insulation is applied externally or internally, the costs of internal insulation can vary widely depending on product, materials, requirements for interior finishing, and costs of accessing the wall from the interior. Insulating the wall from inside will also entail more inconvenience for the building’s residents and disruption of activities. Internal insulation reduces usable floor area and may have poorer aesthetics. Because the technology choice and cost of internal wall insulation is so building-specific, this document focuses on EIFS only. However, the energy savings estimates for EIFS can be applied to projects where internal insulation is being considered.

EIFS increases a building envelope’s R-value by about R-3.85 per inch. Typically, 1, 2, 4, 6 or 8 in. (2.54, 5.08, 10.16, 15.24 or 20.32 cm) thicknesses are installed. Up to 40 cm of insulation can be glued and anchored to the wall [7]. Sometimes, anchor systems limit the thickness of insulation. For each thickness of insulation, there are two alternative installation types. The less expensive option is known as a “face-sealed system,” where the outermost layer of the exterior facade is sealed to help repel moisture. Alternatively, a more expensive “drainage system” option avoids moisture buildup within the wall by installing a barrier behind the actual insulation. This barrier is able to remove any moisture that penetrates the outer layer, thereby preventing mold or fungal growth, corrosion of the building wall and/or freezing in winter. Such events could lead to separation of the EIFS from the building wall, creating a path for more moisture intrusion. Differences in the two installation methods have negligible effect on the energy performance of the building; however, the difference is reflected in the cost of installation and prevention of water damage.

State-of-the-art insulation technologies include:

- high efficient insulation materials with lower thermal conductivity
- graphite embedded EPS (expanded polystyrene)
- high performance plaster systems
- vacuum insulation systems.

An example of higher insulation thickness/lower thermal conductivity insulation is mineral wool/polystyrene with a thermal conductivity of 0.030/0.035 instead of "regular" 0.040 W/mK.

Graphite embedded EPS reduces the radiant heat transfer and reduces thermal conductivity by about 20%. It requires less than half the raw materials of conventional EPS.

Different types of high performance plaster systems include:

- Integration of glass bubbles into the structure: Glass bubbles result in absorption of sun, less convective heat losses, increase of useful gains from direct and diffuse radiation during the heating season, and 15-20 % lower energy losses compared to a conventional plaster system;
- Combination of infrared (IR)-coatings with a lotus effect: The paint protects the plaster better against rainwater absorption, provides lower conductivity throughout the year, and leads to higher surface temperatures;
- Phase change materials on interior plaster: Micro-encapsulated wax droplets in plaster result in extra thermal capacity, better performance at temperature peaks, and an increase of passive solar gains in winter and decrease of overheating in summer.

Vacuum insulation systems that use evacuated silica gel material covered by a high performance aluminum foil have thermal conductivity reduced by more than a factor of ten compared to conventional material. They also enable smaller thicknesses of insulation compared to EPS.

Potential Energy Savings (Qualitative)

The reduced thermal conductivity from retrofitting a building with EPS typically results in 10 to 40% energy savings, depending on the initial level of insulation and the climate. Energy savings tend to taper off quickly beyond 2 in. of insulation in warmer climates, but colder climates often benefit significantly with additional thickness of insulation, because protection from a larger temperature differential is needed. Therefore, thicker insulation layers are most cost effective to install in colder climate zones. In addition to energy saving and investment cost reduction (from being able to install smaller sized HVAC equipment), a better insulated building provides other significant advantages, including higher thermal comfort because of warmer temperatures on the interior surfaces in winter and lower temperatures in summer. This also results in a lower risk of mold growth on internal surfaces.

EIFS also offers benefits during construction of new buildings. For instance, the system offers significant savings on construction costs, compared to a brick veneer system. The light weight of EIFS could also offer potential savings in the building's structural steel as the weight of the façade is reduced. In addition to contributing to energy cost savings, decreased infiltration improves air quality inside the building by keeping much dust, pollen, and car exhaust from entering. Also, reduction in drafts, noise and humidity contribute to the comfort of individuals inside the building.

Potential Energy Savings (Quantitative)

This analysis examines the effect on annual energy use and costs of retrofitting an existing barracks with improved exterior wall construction. To estimate the achievable savings, a number of pre- and post-retrofit year-long simulations were done using the EnergyPlus 3.0 building energy simulation software, which models heating, cooling and ventilation flows through buildings, among other criteria.

The baseline building is assumed to be an existing barracks, dormitory or multi-family building built either to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone (Baseline 1) or to have been built prior to 1960, using typical construction practices of the time with little or no insulation (Baseline 2). The barracks are three stories high with an area of 28,965 sq ft (2,691 m^2) and include 40 two-bedroom apartment units, a lobby on the main floor and laundry rooms on each floor. The barracks were assumed to be unoccupied during the hours of 8 a.m. – 5 p.m. Monday through Friday. Further details on the barracks and the baseline heating, ventilation, and air conditioning (HVAC) systems used are included in [5].

The application of EIFS was evaluated for 15 US locations and 16 international locations. The US locations were selected as representative cities for the climate zones by the Pacific Northwest National Laboratory [4]. Flat utility tariffs were assumed for each location (i.e., no energy demand charges are included). The US energy costs are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008). The climate characteristics, energy costs, and building details and construction parameters of all 31 simulations are in [5].

The data in Tables 6.30 and 6.31, respectively, summarize several different systems modeled for US and international locations. Along with the added insulation, improvements in the air tightness of the barracks were modeled. Air tightness improvements ranged from the baseline of 1.00 cfm/sq ft at 75 Pa to 0.85 cfm/sq ft at 75 Pa. Proper installation of the EIFS on the walls and around windows and doors should reduce infiltration to some extent. The full 15% reduction (to 0.85 cfm/sq ft at 75 Pa) modeled might require some additional work to seal the barracks, which is not included in the cost estimates. Best practice is to improve the building's airtightness at the same time as the EIFS installation, using the same construction crew; the additional costs for ensuring proper window and door frame sealing are minimal while the EIFS is being installed. Therefore, the 15% reduced infiltration is assumed in all the analyses presented here.

Table 6.30. US scenario descriptions.

Building Walls Tested	Baseline	Wall Construction	Additional Insulation (sq ft·hr·ºF/Btu)	Air Leakage (cfm/sq ft @ 75 Pa)
Baseline 1	—	Wood framing with fiberglass insulation and brick facade	—	1.00
Baseline 2	—	Same as Baseline 1, but pre-1960 construction	—	1.00
1-in. EPS	1	Baseline with 1 in. EPS	R-3.85	0.85
2-in. EPS	1	Baseline with 2 in. EPS	R-7.70	0.85
4-in. EPS	1	Baseline with 4 in. EPS	R-15.4	0.85
6-in. EPS	1	Baseline with 6 in. EPS	R-23.1	0.85

Building Walls Tested	Baseline	Wall Construction	Additional Insulation (sq ft·hr·°F/Btu)	Air Leakage (cfm/sq ft @ 75 Pa)
8-in. EPS	1	Baseline with 8 in. EPS	R-30.8	0.85
1-in. EPS	2	Baseline with 1 in. EPS	R-3.85	0.85
2-in. EPS	2	Baseline with 2 in. EPS	R-7.70	0.85
4-in. EPS	2	Baseline with 4 in. EPS	R-15.4	0.85
6-in. EPS	2	Baseline with 6 in. EPS	R-23.1	0.85
8-in. EPS	2	Baseline with 8 in. EPS	R-30.8	0.85

Table 6.31. International scenario descriptions.

Scenario	Description	Additional Insulation (sq ft·hr·°F/Btu)	Air Leakage (cfm/sq ft @ 75 Pa)
Baseline	Represents current construction	—	1.00
2-in. EPS	Baseline with 2 in. EPS	R-7.70	0.85
4-in. EPS	Baseline with 4 in. EPS	R-15.4	0.85
6-in. EPS	Baseline with 6 in. EPS	R-23.1	0.85
8-in. EPS	Baseline with 8 in. EPS	R-30.8	0.85

Two baseline scenarios were used when studying the US locations to describe potential existing conditions of barracks prior to a retrofit:

- Baseline 1: This baseline accounts for pre-retrofit barracks with exterior walls consisting of wood framing with fiberglass insulation and brick façade meeting the minimum requirements of ASHRAE Standard 90.1-1989.
- Baseline 2: This baseline also accounts for pre-retrofit barracks with exterior walls consisting of wood framing and brick facade. However, in this scenario, the existing building is assumed to have been built using pre-1960 typical construction practices with no prior insulation incorporated.

Tables 6.32 and 6.33, respectively, list cost estimates for each type of insulation for US and international locations. Recommended practice is to use the drainage system. In humid climates, any flaw in the vapor barrier, either from mistakes in installation or post-installation penetrations of the vapor barrier or façade, can result in condensation within the wall. Because of the prevalence of this type of problem, provision for drainage is essential in warm, humid climates. In colder climates such as Europe, face-sealed EIFS (i.e., without the drainage) is prevalent. However, even in cold climates, penetrations in the vapor barrier or façade can allow moisture intrusion in summer or winter. Unrepaired, this can result in significant moisture-caused damage or fungal growth. Government buildings and public housing (i.e., not privately-owned residences) are more likely both to experience damage from careless usage or vandalism and to not have such damages repaired promptly. Thus, even for Europe, use of the drainage system in public buildings is recommended. For the purposes of this analysis, the EIFS with a drainage system is the only system investigated.

Table 6.32. US retrofit costs for external insulation ($/sq ft).

System Thickness	1 in.	2 in.	4 in.	6 in.	8 in.
Face-Sealed	7.00	7.20	7.60	8.00	8.40
Drainage	8.00	8.20	8.60	9.00	9.40
Insulation Only	0.20	0.40	0.80	1.20	1.60

Table 6.33. International retrofit costs for external insulation.

Scenario	Face-Sealed System			Drainage System		
	CAD/m^2	EUR/m^2	GBP/m^2	CAD/m^2	EUR/m^2	GBP/m^2
2-in. EPS	63.94	41.34	32.64	95.91	62.00	48.96
4-in. EPS	74.06	47.88	37.81	106.03	68.55	54.13
6-in. EPS	83.97	54.29	42.87	115.94	74.95	59.18
8-in. EPS	93.88	60.70	47.93	125.85	81.35	64.23

Results

Figure 6.127 shows the HVAC energy savings achievable with various thicknesses of insulation in selected US locations. These energy savings can also translate to reduced HVAC system capacity required to heat or cool the building. Baseline 1 assumes the building meets ASHRAE Standard 90.1-1989; such buildings will already have some insulation in cold climates but little to no wall insulation in warm climates. For cold climates, the EIFS in Baseline 1 yields up to about 10% reduction in HVAC energy use (for 8 in. EIFS compared to the baseline). Such savings would usually result in a negligible to small capital cost savings for the HVAC system. For hot and humid climates, on the other hand, an HVAC peak energy savings of 20% can be expected (for 8 in. EIFS compared to the baseline, which is typically an uninsulated building); this could represent a significant capital cost savings if the building's HVAC system is renovated along with the building's envelope.

The EIFS installed in Baseline 2, which is applied to pre-1960 construction with no insulation, results in much greater savings in HVAC energy use in cold climates (approximately 40% savings). Baseline 2 scenarios in hotter climates typically see savings ranging from 20% to 40%, since Baselines 1 and 2 for these climate zones are usually identical or very close.

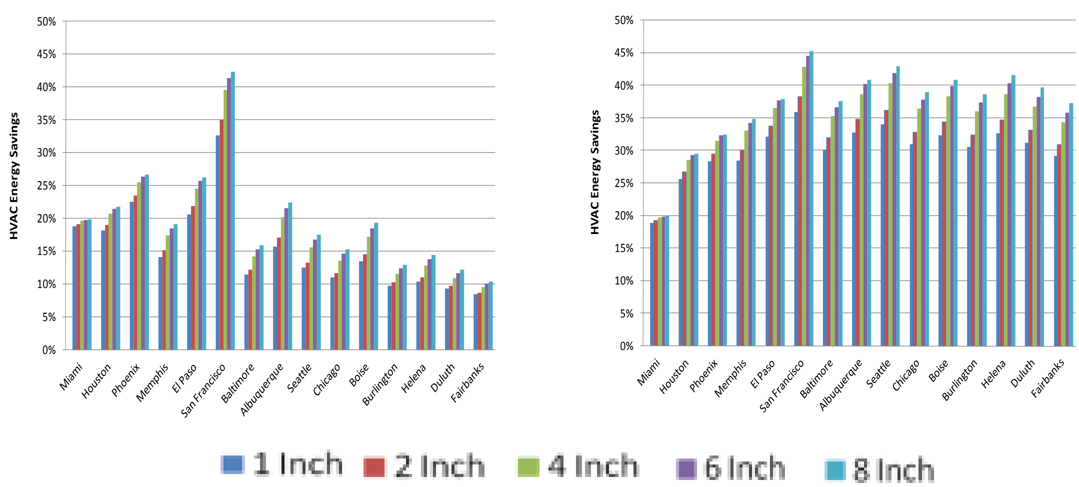


Figure 6.127. HVAC annual percentage energy savings for Baselines 1 (left) and 2 (right).

Figure 6.128 shows the expected annual energy cost savings for US locations in Baselines 1 and 2. When comparing to the Baseline 1 building, warmer climates (e.g., Miami, FL) see average savings between $0.15-0.30 per sq ft depending on the EIFS thickness; however, these buildings are not as likely to see significant increases in savings beyond a 1- to 2-in. layer of insulation. Colder climates (e.g., Boise, ID), however, see average savings of only $0.10-0.20 per sq ft for the first inch of EIFS because the building already is insulated (ASHRAE 90.1-1989). Such buildings in colder climates do tend to benefit from additional insulation thickness. This can be seen when comparing to the Baseline 2 building with no pre-retrofit insulation. The warmer climate buildings exhibit similar cost savings as in Baseline 1, because the Baseline 1 buildings have little wall insulation. The greatest savings are seen in colder climate zones since they have the largest temperature differential to overcome, and unlike Baseline 1 (which already has appropriate levels of insulation for specific climate zones), Baseline 2 cold climate buildings have little insulation. Energy cost savings for international locations (Figure 6.129) show similar results.

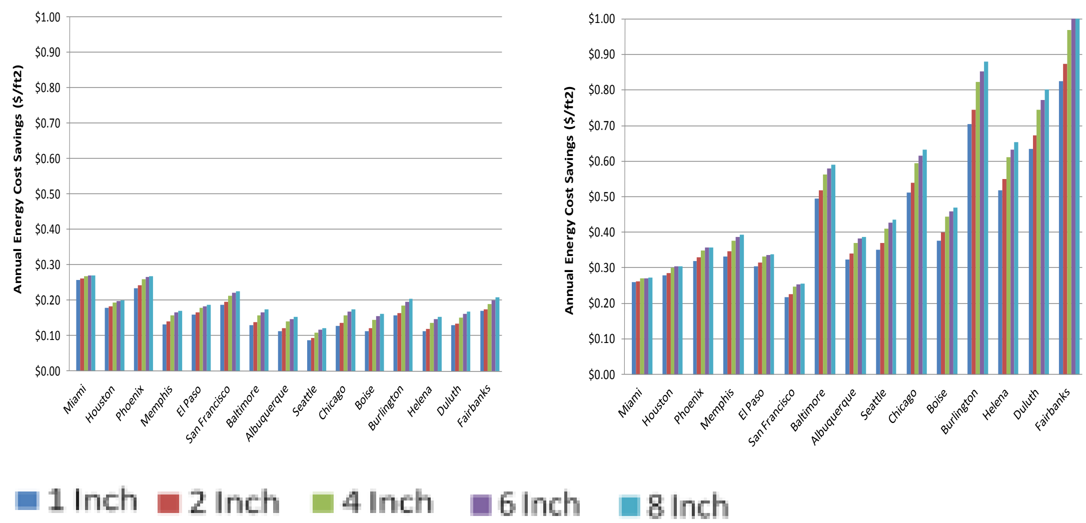
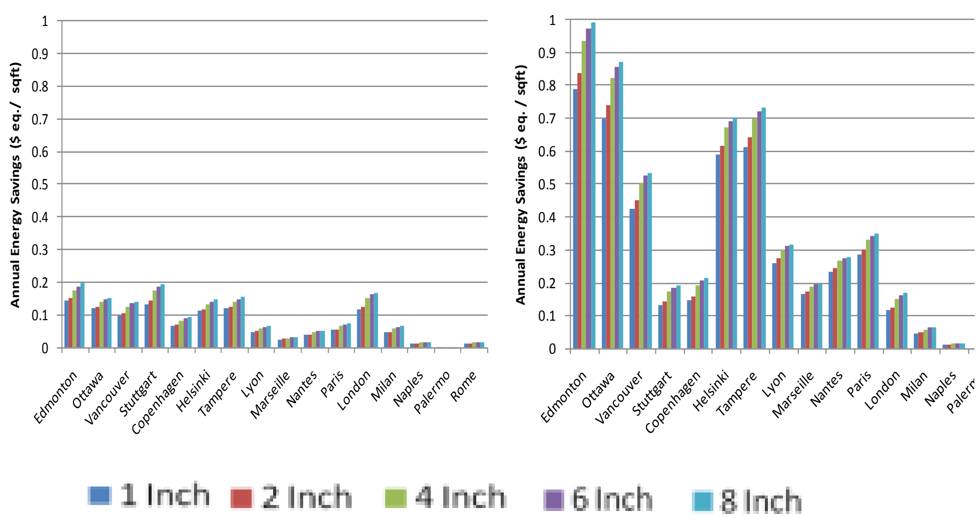


Figure 6.128. Annual energy cost savings for Baselines 1 (left) and 2 (right) for US locations.



Dollar equivalents are based on exchange rates obtained while preparing this report; they are subject to variation.

Figure 6.129. Annual energy cost savings for Baselines 1 (left) and 2 (right) for international locations.

A rough indicator of the economic feasibility of EIFS is the ratio of capital cost to annual energy savings, sometimes referred to as "simple payback" (SPB). (The simple payback period for the US locations is calculated based on the annual energy cost savings combined with estimates of the retrofit cost. Interest and inflation are neglected.) As previously mentioned, results from only the drainage EIFS are presented. Figure 6.130 shows SPB for Baselines 1 and 2, respectively. The SPB period is much shorter in Baseline 2 because more significant energy savings are realized due to there being no prior insulation. Furthermore, Figure 6.131 shows that Baseline 1 buildings have similar SPB since insulation installed in accordance with ASHRAE 90.1-1989 is designed to match the climate zone. Overall, buildings with no prior insulation are much better candidates for external wall insulation, especially in colder climates. Figure 6.132 shows the SPB period for international locations. Heike Erhorn-Kluttig and Hans Erhorn [8] give additional insulation design guidance.

Summary Guidance

Wall insulation is most cost-effective in cold climates. Buildings in hot climates will also benefit from increasing wall R-value. However, the benefit per inch of insulation tends to be less than in cold climates because the temperature differential between the building interior and ambient air is greater in cold weather (e.g., ΔT of about 15 – 25 °C, about 30 – 40 °F) than in hot weather (e.g., ΔT of about 10 – 15 °C, about 20 – 30 °F). Existing buildings in warm climates are likely to have little to no pre-existing wall insulation. In colder climates, they are likely to already have been insulated to some extent. While adding insulation to a warm or moderate climate building may result in appreciable energy reduction in terms of percent, the magnitude of energy saved is smaller, and therefore the cost savings are smaller. The primary costs of EIFS are the initial set-up (project preparation, scaffolding, andc.) and the façade. *Therefore, if a building's façade needs repair or replacement, adding insulation though EIFS is strongly recommended.* The cost of the insulation itself is small compared to the rest of the project. *For new construction, insulation to the extent possible should be included when constructing the walls. For a retrofit project requiring a new façade, it is recommended to install the maximum amount of insulation physically possible.*

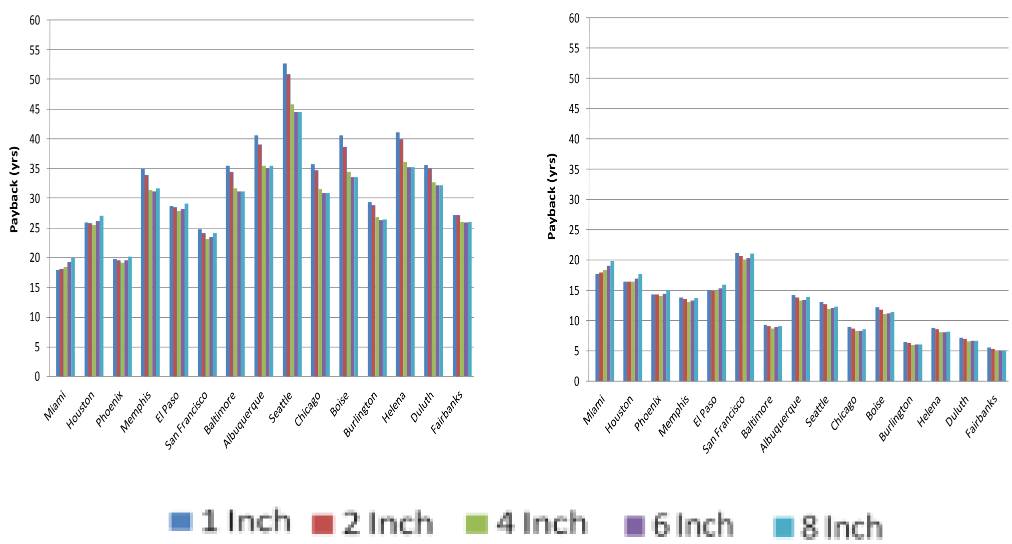


Figure 6.130. SPB period for Baselines 1 (left) and 2 (right) with drainage system installation.

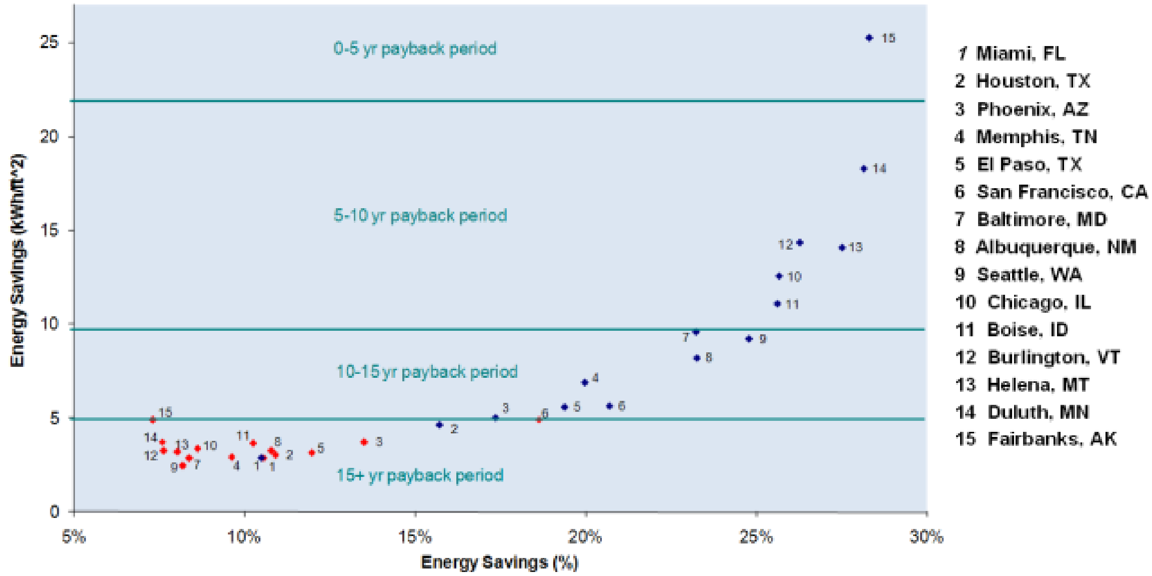


Figure 6.131. Comparison of SPB periods for Baselines 1 (Red) and 2 (Blue) with 4-in. thickness (US locations).

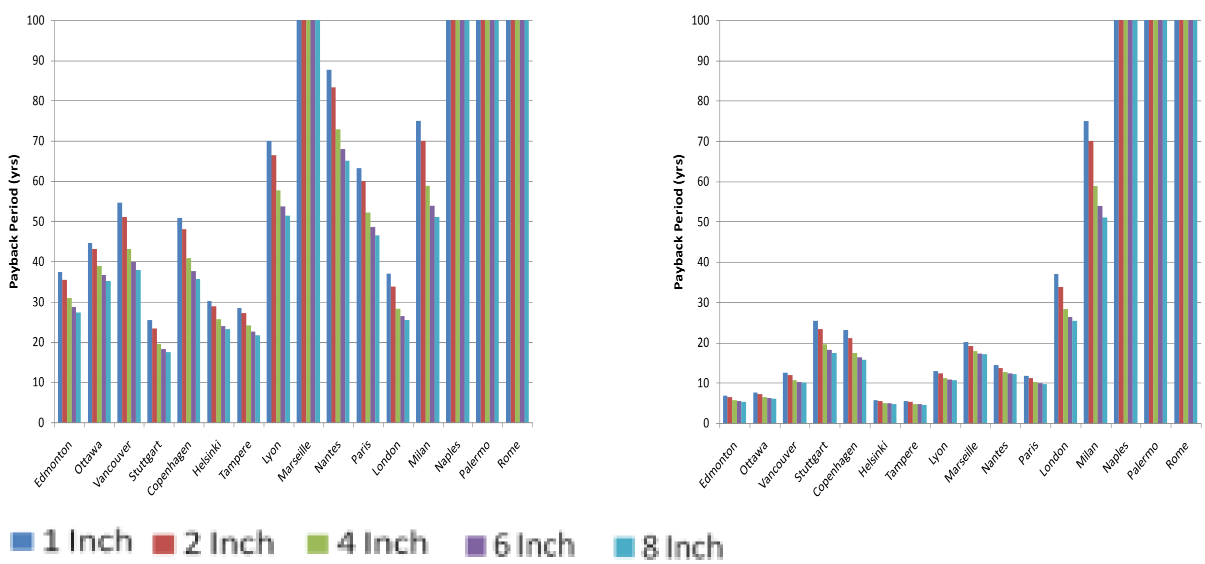


Figure 6.132. SPB period in years for EIFS with drainage system – international sites.

While the cost of additional insulation is small compared to the cost of the wall or façade, it is not negligible. The "optimal" level of insulation based on life cycle costs can be determined from building energy simulation models. For retrofit projects in moderate climates, an additional layer of 5 cm (2 in.) of insulation of may be sufficient (adding R 8), and 4 in. (R 15) should be considered in hot climates. For cold or very cold climates, additional insulation thickness (up to 20 cm or 8 in., R 30) is usually justified. Table 6.34 lists broad guidance for application of EIFS for several scenarios.

Table 6.34. General guidance for application of EIFS.

Climate	Building Scenario: Existing new construction or façade repair/replace project?	Building Scenario: Some Existing Insulation? (ASHRAE 90.1-1989)	Add Insulation? No / Yes-Minimal (2 – 4 in.)/ Yes–Max (6 to 8 inch)
Mild	No	No	No
		Yes	No
	Yes	No	Yes-Minimal to 4 in.
		Yes	Yes-Minimal
Hot/Tropical	No	No	Yes-Minimal to 4 in.
		Yes	No
	Yes	No	Yes-Minimal to 4 in.
		Yes	Yes-Minimal
Cold	No	No	Yes-Max
		Yes	Yes-Minimal to 4 in.
	Yes	No	Yes-Max
		Yes	Yes- add 4 in. or more
Extreme Cold	No	No	Yes-Max
		Minimal	Yes-Max
		Yes	Yes-total should be 6 in. or more
	Yes	No	Yes-Max
		Yes	Yes-Max

Major Manufacturers

Insulation material and system manufacturers:

- BASF Aktiengesellschaft: http://www.basf.de
- Rockwool: www.rockwool.com
- Isover: www.isover.com
- STO: www.sto.com
- IVPU-Industrieverband Polyurethan-Hartschaum e.V.: http://www.ivpu.de/
- North American Insulation Manufacturers Association (NAIMA): http://www.naima.org/main.html
- Dryvit - http://www.dryvit.com/

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M. Deru and K. Benne, *Army Baseline Building Description: Barracks Facility - International Locations*, NREL, March 2009.

Pilot project *Ultrahaus Rottweil*, installed 1995.

Heike Erhorn-Kluttig and Hans Erhorn, "Innovative Insulation," BRITA in PuBs, EU 6th framework programme Eco-building, Fraunhofer-Institut fuer Bauphysik IBP, TREN/04/FP6EN/S.07.31038/503135, 2007.

Window Replacement

Application

Dormitories, barracks, multi-family apartment buildings.

Category

Building envelope.

Description

Windows allow daylight into the building and provide occupants with visual contact with their surroundings. They protect against the outdoor climate and transmit solar energy that may contribute to a reduction of energy consumption in winter. However, windows are the least insulating part of the building thermal envelope. Older windows are commonly single-pane, and have rotten or damaged frames or frames with thermal bridges, cracked glass, locks that do not work, and leaky, poorly fitting sashes. When older windows are to be replaced for other than energy efficiency reasons, install high efficiency window systems.

Concept

Which window options are considered energy efficient depends on the climate. In a cold climate, a window's ability to retain heat inside the building is most important, whereas the capacity to block heat gain from the sun and infiltration is a priority in warm climates (Figures 6.133 and 6.135).

The main energy parameters of a window are its insulation value, transparency to solar radiation, and airtightness (Figure 6-136). The most significant factors to consider in selecting window systems are U-Factor, Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) of light. In addition, a window assembly's Air-Leakage (AL) is a critical measure of the airtightness of the installed window system. Airtightness is usually measured in cubic meters (cubic feet) per minute of air leakage (i.e., $m^3/min/m^2$ [cu ft/min/sq ft]) for a given framed area of the window at a specific pressure difference.

The U-Factor is affected by the number of glazing layers, glazing coatings or tints, gas fill and frame type incorporated into a given window product. The SHGC and VT are affected by a window product's number of glazing layers and by any glazing coatings or tints. Non-operable windows are the most airtight design.

Potential energy savings (Qualitative) Impact on the Indoor Environment

Replacing older windows with high efficiency windows may substantially improve thermal comfort and present an important opportunity for energy savings, allow reduction of the size and heating and cooling loads on HVAC equipment. More airtight windows reduce uncomfortable drafts. Decreased transmission of solar heat (during the cooling season) and warmer interior glazing surface temperatures (during the heating season) directly improves the comfort of building occupants. Window tints control glare while retaining good transmittance of visible light into the occupied space for daylighting purposes.

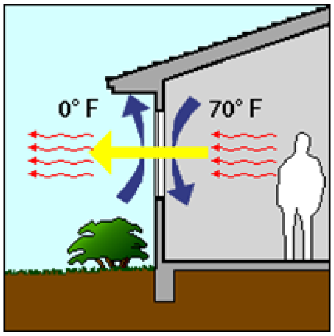

Figure 6.133. Heat flow.

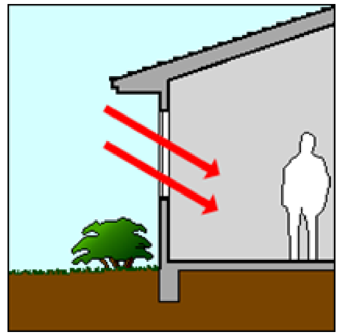

Figure 6.134. Solar heat gain.

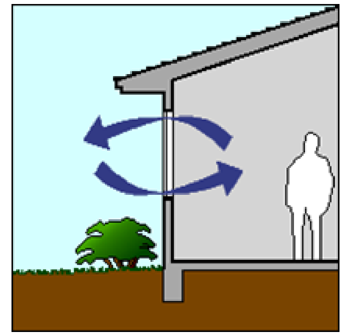

Figure 6.135. Air leakage.

Source: Efficient Windows Collaborative (www.efficeintwindows.org)

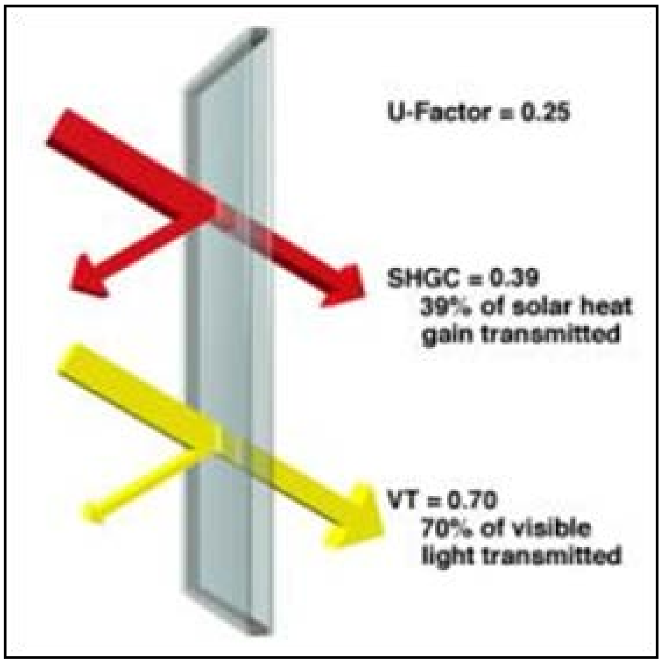

Figure 6.136. Critical window performance parameters.

Potential Energy Savings (Quantative)

The National Renewable Energy Laboratory (NREL) conducted a study [1] to evaluate energy savings from window replacement using EnergyPlus software to simulate energy use of a representative three story Army barrack building. The study modeled the impact of replacing existing windows that conformed to ASHRAE Standard 90.1-1989 (for the United States) and other countries' national codes for the 1980s with currently available window technologies. Table 6.35 lists the windows evaluated in the study and their performance characteristics. Tables 6.36 and 6.37 list the reduction in energy use of window replacements, as compared with base windows.

Table 6.35. Performance parameters and costs of modeled windows.

Window Options with Default Performance Values								
Window No.	Glazing Type	Frame Type	U-Factor imp./metric	SHC	VT	AL imp./metric	Installed Cost	Cost Premium*
I	2-pane, tinted	Aluminum	0.76/4.3	0.56	0.51	0.2/0.06	$300	Baseline
II	2-pane, uncoated	Non-metal	0.49/2.8	0.56	0.59	0.2/0.06	$350	Baseline
A	2-pane, low-solar-gain, low-E	Aluminum, thermal break	0.47/2.7	0.33	0.55	0.2/0.06	$325	$25
B	2-pane, low-solar-gain, low-E	Non-metal	0.34/1.9	0.30	0.51	0.2/0.06	$375	$25
C	2-pane, low-solar-gain, low-E	Non-metal	0.36/2.0	0.49	0.54	0.2/0.06	$375	$25
D	3-pane, low-solar-gain, low-E	Non-metal	0.26/1.4	0.25	0.40	0.1/0.03	$450	$100
E	3-pane, high-solar-gain, low-E	Non-metal	0.27/1.5	0.38	0.47	0.1/0.03	$450	$100
F	3-pane, high-solar-gain, low-E	Non-metal, insulated	0.18/1.0	0.40	0.50	0.1/0.03	$500	$150
The cost premium compares the installed cost of currently available premium efficiency window options with that of currently available standard replacement window options (I & II) of the equivalent frame material (e.g., aluminum or non-metal).								

Table 6.36. US window thermal properties used as a base for analysis.

City	Window U-Value (Btu/hr·°F·sq ft)	Window U-Value (W/m^2·K)	Window SHGC	Window to Wall Ratio (%)
Miami, FL	1.08	6.14	0.61	7.3
Houston, TX	1.08	6.14	0.61	7.3
Phoenix, AZ	1.08	6.14	0.61	7.3
Memphis, TN	0.56	3.19	0.63	7.3
El Paso, TX	1.08	6.14	0.61	7.3
San Francisco, CA	0.56	3.19	0.63	7.3
Baltimore, MD	0.56	3.19	0.63	7.3
Albuquerque, NM	0.56	3.19	0.63	7.3
Seattle, WA	0.56	3.19	0.63	7.3
Chicago, IL	0.56	3.19	0.63	7.3
Boise, ID	0.56	3.19	0.63	7.3
Burlington, VT	0.49	2.77	0.61	7.3
Helena, MT	0.49	2.77	0.61	7.3
Duluth, MN	0.49	2.77	0.61	7.3
Fairbanks, AK	0.49	2.77	0.61	7.3

Table 6.37. Canadian and European window thermal properties used as a base for analysis.

City	Window U-Value (Btu/hr·°F·sq ft)	Window U-Value ($W/m^2·K$)	Window SHGC	Window to Wall Ratio (%)
Edmonton, CAN	0.56	3.19	0.627	7.3
Ottawa, CAN	0.49	2.77	0.610	7.3
Vancouver, CAN	0.49	2.77	0.610	7.3
Copenhagen, DNK	0.51	2.90	0.281	16.7
Helsinki, FIN	0.36	2.02	0.226	33.7
Tampere, FIN	0.36	2.02	0.226	33.7
Lyon, FRA	0.49	2.78	0.763	25.4
Marseille, FRA	0.49	2.78	0.763	25.4
Nantes, FRA	0.49	2.78	0.763	25.4
Paris, FRA	0.49	2.78	0.763	25.4
Stuttgart, DEU	0.51	2.90	0.281	33.7
Milan, ITA	0.49	2.78	0.763	16.2
Naples, ITA	0.49	2.78	0.763	16.2
Palermo, ITA	0.49	2.78	0.763	16.2
Rome, ITA	0.49	2.78	0.763	16.2
London, UK	0.51	2.90	0.281	33.7

Window I in Table 6.35 is considered a “base line” window with respect to the commonly used replacement window practice for DOE climate zones 1A through 3A, Window II is a “baseline” window for climate zones 3B through 7A. For purposes of this study, Window C was selected as a “baseline” window for Climate Zone 8A. Windows A through F represent currently available premium grade windows.

Energy costs used in this study were based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008). The EnergyPlus analysis shows that improved window technologies will achieve annual site energy use savings intensities for the US and non-US locations (Figures 6.137 and 6.138).

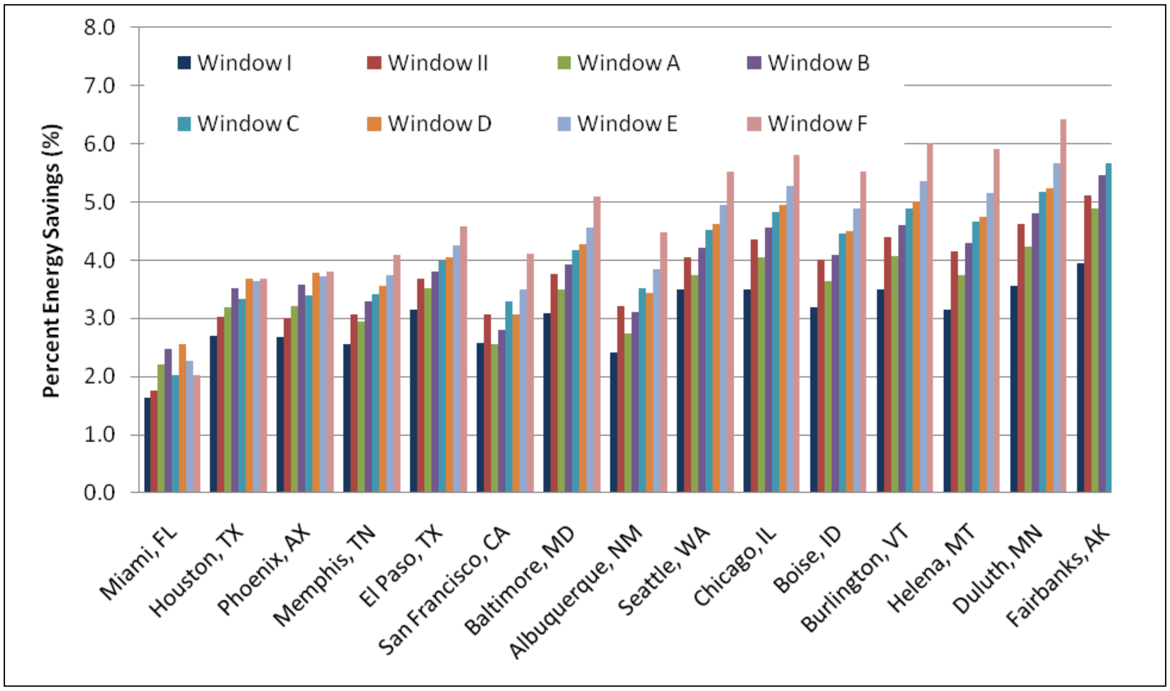

Figure 6.137. Percent of energy savings for modeled barracks facility in 15 US locations.

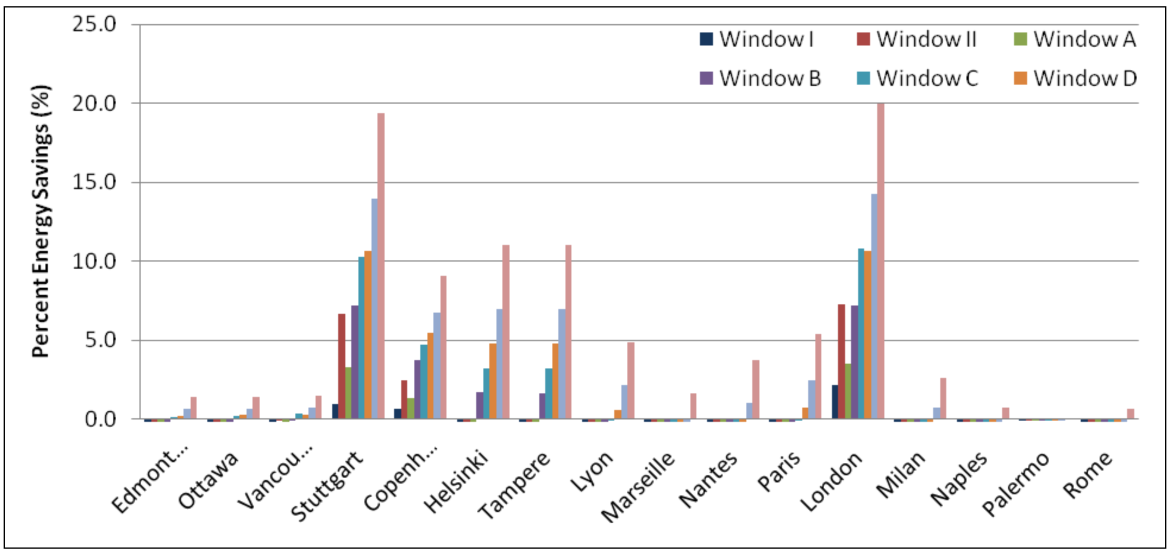

Figure 6.138. Percent of energy savings for modeled barracks-type facility in Canadian and European locations.

For each location, the "base" case is compared to the predicted performance of retrofitting the building with each of the eight modeled window types. Simulation results show that the improved windows will have the most significant impact in the colder climates. Comparison of results for different location (especially for Canadian and European cities) shows the energy savings significantly depend on country codes and practices at the time the building was constructed, both of which affect the baseline.

Replacement Cost Considerations

Table 6.35 lists anticipated installed costs for the various retrofit options per square meter of installed window. Note the difference in the last two columns of Table 6.35. The next to last column is the actual (absolute) installed cost of each window and the last column is the delta (premium) cost of each window when compared to the installation of a current baseline quality window of the equivalent frame material (e.g., aluminum or non-metal) listed in Table 6.38.

For a window replacement project that is targeting energy conservation alone, one should carefully consider the "Installed Cost" column as this figure will have to be considered in the economic analysis. On the other hand, for a major renovation project or a project to replace failed/failing window systems, the installed costs of baseline windows are a sunk cost. Therefore, for these projects one should consider cost premium. In many cases, the marginal cost of the most energy efficient window options might prove to be a good economic investment.

Table 6.38. Conventional retrofit options.

Zone	Climate	Representative US City	Conventional Options
1A	Very hot – humid	Miami, FL	Window I
2A	Hot – humid	Houston, TX	Window I
2B	Hot – dry	Phoenix, AZ	Window I
3A	Warm – humid	Memphis, TN	Window I
3B	Warm – dry	El Paso, TX	Window II
3C	Warm – marine	San Francisco, CA	Window II
4A	Mixed – humid	Baltimore, MD	Window II
4B	Mixed – dry	Albuquerque, NM	Window II
4C	Mixed – marine	Seattle, WA	Window II
5A	Cool – humid	Chicago, IL	Window II
5B	Cool – dry	Boise, ID	Window II
6A	Cold – humid	Burlington, VT	Window II
6B	Cold – dry	Helena, MT	Window II
7A	Very cold	Duluth, MN	Window II
8A	Subarctic	Fairbanks, AK	Window C

Retrofit Project Options and Considerations

One's motivation for considering a window replacement project will impact the evaluation process. For example, the approach for evaluating a project to achieve energy savings will be different than a project that is being planned for other purposes, such as replacing failed/failing windows or as part of a major building renovation. In the ensuing discussion, we assume a viable project to be one that achieves a payback of 10 years or less Comparison of these two approaches using the US locations as an example.

Energy Conservation Projects

In the case of energy conservation projects, one wishes to determine if a basic window replacement project using current baseline window technologies will save enough energy to offset the project costs and achieve a reasonable payback. Figure 6.139 shows the modeled payback for replacement of the ASHRAE 90.1-1989 windows with currently available baseline windows. Window I (aluminum frame) was chosen as the baseline replacement window for Climate Zones 1A, 2A, 2B and 3A because the additional strength of an aluminum frame is warranted in hurricane susceptible areas. Based on the results shown in Figure 6.139, an energy conservation window replacement project in most of climates except for cold climates (Zones 5A and 6 through 8) would be considered not to be viable.

Major Renovation or Repair Projects

For major building renovation projects or projects to replace failed or failing windows, one can assume that the cost of replacing the existing windows with currently available conventional replacement windows is a sunk cost. For these projects, one should conduct an analysis to determine if the additional cost of premium replacement windows rather than conventional replacement windows can be justified.

The marginal installed cost ([$C_{premium}$] – [$C_{conventional}$]) is divided by the marginal annual energy savings ([$S_{premium}$] – [$S_{conventional}$]) to arrive at the payback for the investment in premium quality replacement windows. Note that although a window replacement project in Zone 3C (San Francisco) is not justifiable for an energy conservation project, for a major renovation or repair project, we assume that the original windows will be replaced anyway. As a result, installation of conventional replacement windows is a sunk cost. Therefore, even in Zone 3C, one should perform an analysis to determine if premium quality windows can be justified.

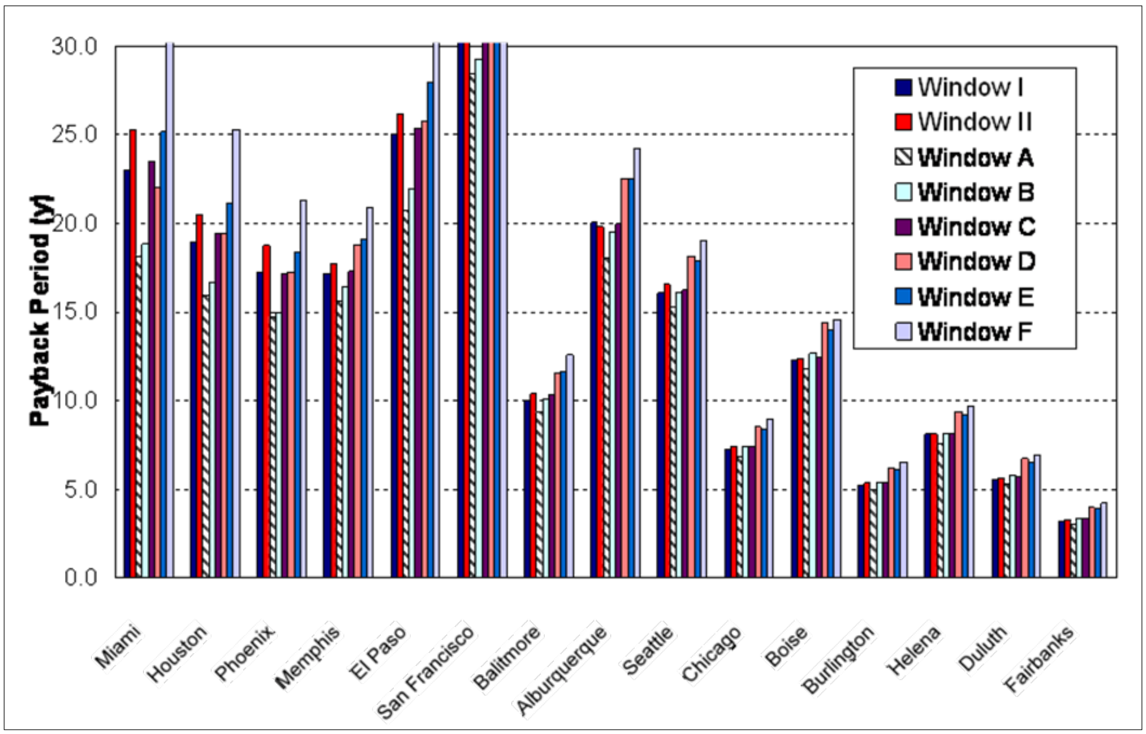

Figure 6.139. Modeled payback results of an *energy conservation project* using absolute retrofit cost and energy savings compared to a baseline window type.

Figures 6.140 – 6.142 show the results of an engineering analysis for renovation/repair projects in the 15 climate zones. For each of the climate zones, at least two high performance replacement window options satisfy the assumed 10-year payback criteria. Table 6.39 lists recommended premium retrofit window options (renovation/repair projects).

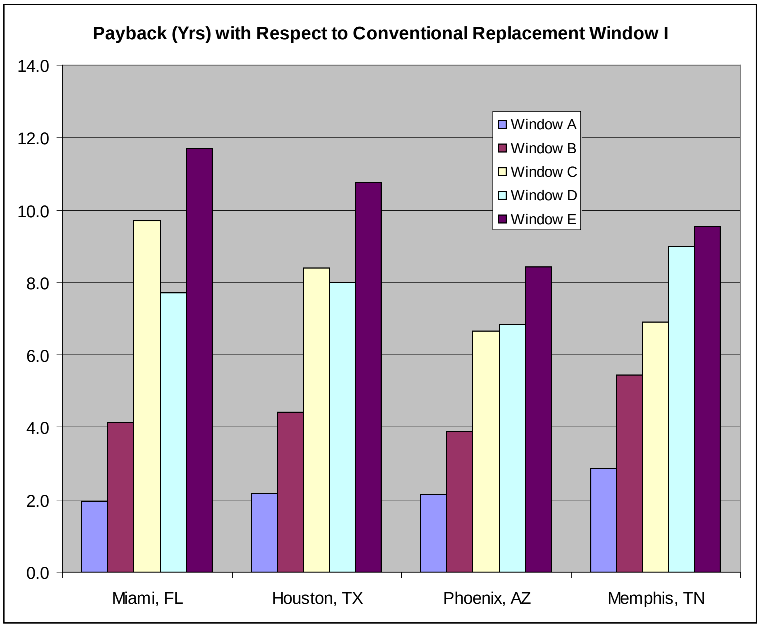

Figure 6.140. Modeled payback results of upgrading to premium quality replacement windows from current baseline quality replacement windows (Zones 1A, 2A, 2B, and 3A) for a *major renovation or repair project*.

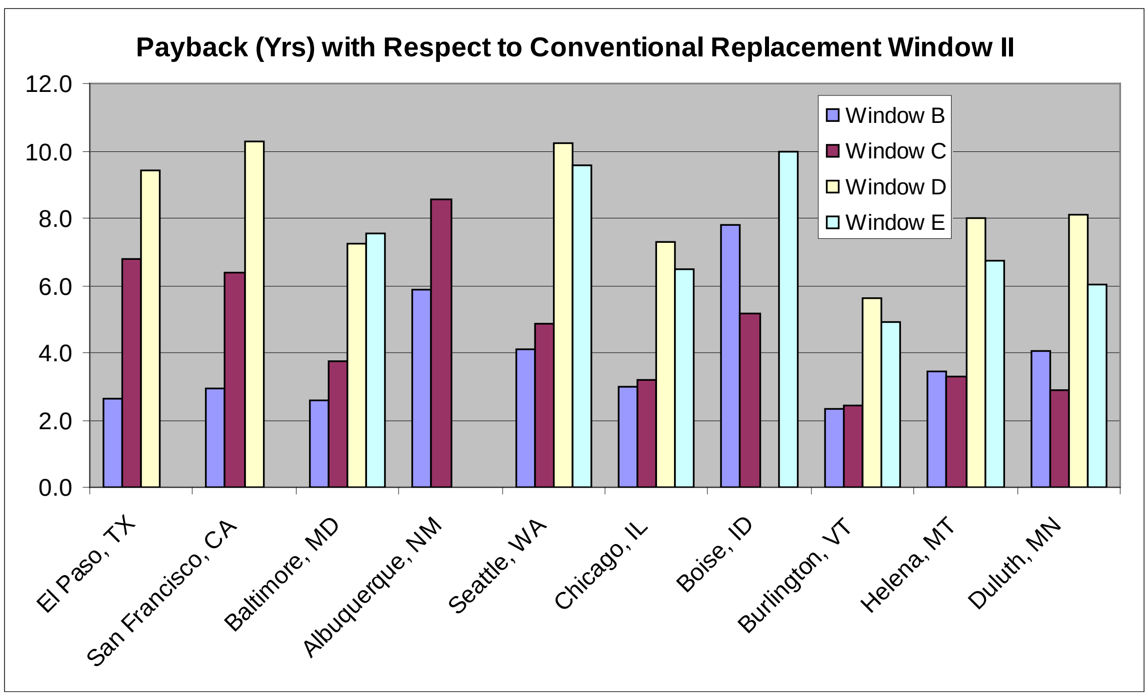

Figure 6.141. Modeled payback results of upgrading to premium quality replacement windows from current baseline quality replacement windows (Zones 3B, 4A, 4B, 4C, 5A, 5B, 6A, 6B and 7A) for a *major renovation or repair project*.

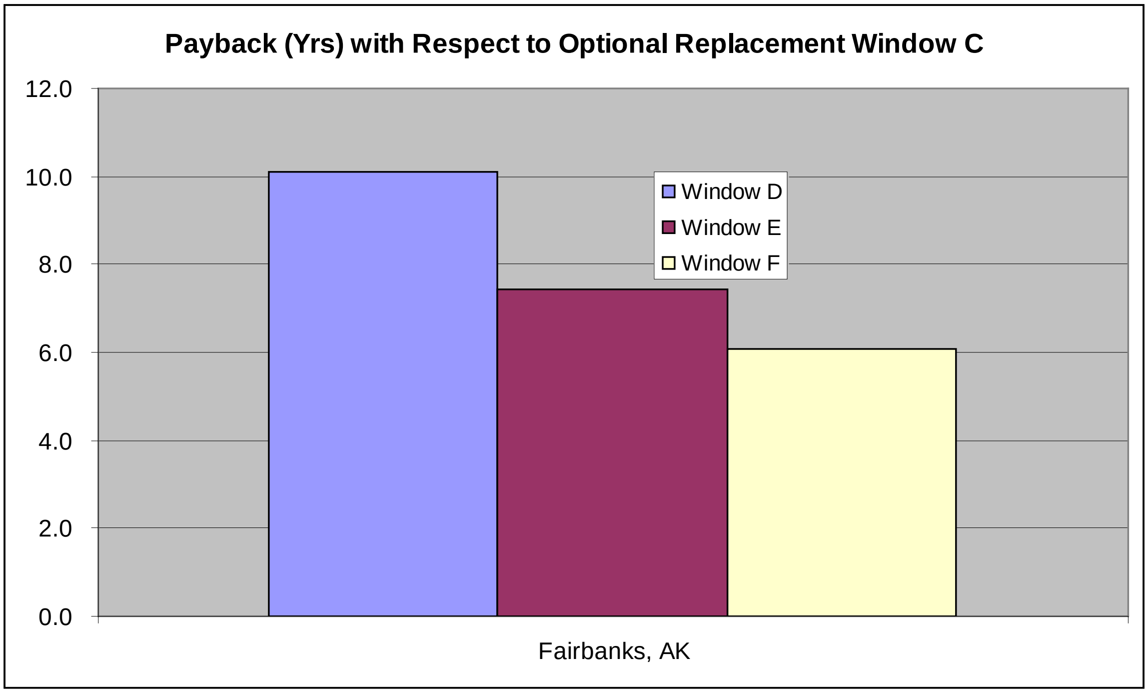

Figure 6.142. Modeled payback results of upgrading to premium quality replacement windows from current baseline quality replacement windows (Zone 8) for a *major renovation or repair project.*

Table 6.39. Recommended premium retrofit window options (renovation/repair projects).

Climate	Premium Options
Very hot – humid	A,B,C,D
Hot – humid	A,B,C,D
Hot – dry	A,B,C,D
Warm – humid	A,B,C,D,E
Warm – dry	B,C,D
Warm – marine	B,C
Mixed – humid	B,C,D,E
Mixed – dry	B,C
Mixed – marine	B,C,E
Cool – humid	B,C,D,E
Cool – dry	B,C,E
Cold – humid	B,C,D,E
Cold – dry	B,C,D,E
Very cold	B,C,D,E
Subarctic	E,F

Environmental Issues

The use of high efficiency windows will reduce the heating, cooling, and lighting requirements of buildings. This results in less energy use and less greenhouse gas production attributable to these buildings.

Experiences/Lessons Learned

Modern window technologies are mature and ready for use. They have a significant energy saving potential not only compared to single-pane windows, but also compared to older double-pane windows with low-quality frame construction. Assuming a 10-year payback threshold, energy conservation projects to replace such windows with modern advanced windows is justifiable in all climate zones except for marine climate (e.g., San Francisco). For major building renovation projects or projects that are initiated to replace failed or failing windows, the cost of baseline replacement windows can be considered a sunk cost. In such cases, installations of premium quality replacement windows options is economically justifiable.

Major Manufacturers

Unbiased information on energy-efficient windows, descriptions of how they work, and recommendations for their selection and use is available from:

- The National Fenestration Rating Council (NFRC), http://www.nfrc.org/
- Efficient Windows Collaborative (EWC),http://www.efficientwindows.org/

References

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Grey Water Heat Recovery

Application

Barracks, dormitories multi-family apartment buildings.

Category

Water.

Concept

A Gravity-Film Heat Exchanger (GFX) is a vertical counterflow heat exchanger that extracts heat out of drain water and applies it to preheat the cold water to be mixed with hot water for use in a shower (Figure 6.143). The CFX consists of a 2- to 4-inch central cooper pipe (that carries the warm wastewater) with ½-in. cooper coils wound around the central pipe. Heat is transferred from the wastewater passing through the large, central pipe to the cold water simultaneously moving upward through the coils on the outside of the pipe. The coils are flattened a little to increase the contact area and improve heat transfer. The system is beneficial for use with showers where the use of hot and cold water and the production of waste-water from the shower occur at the same time.

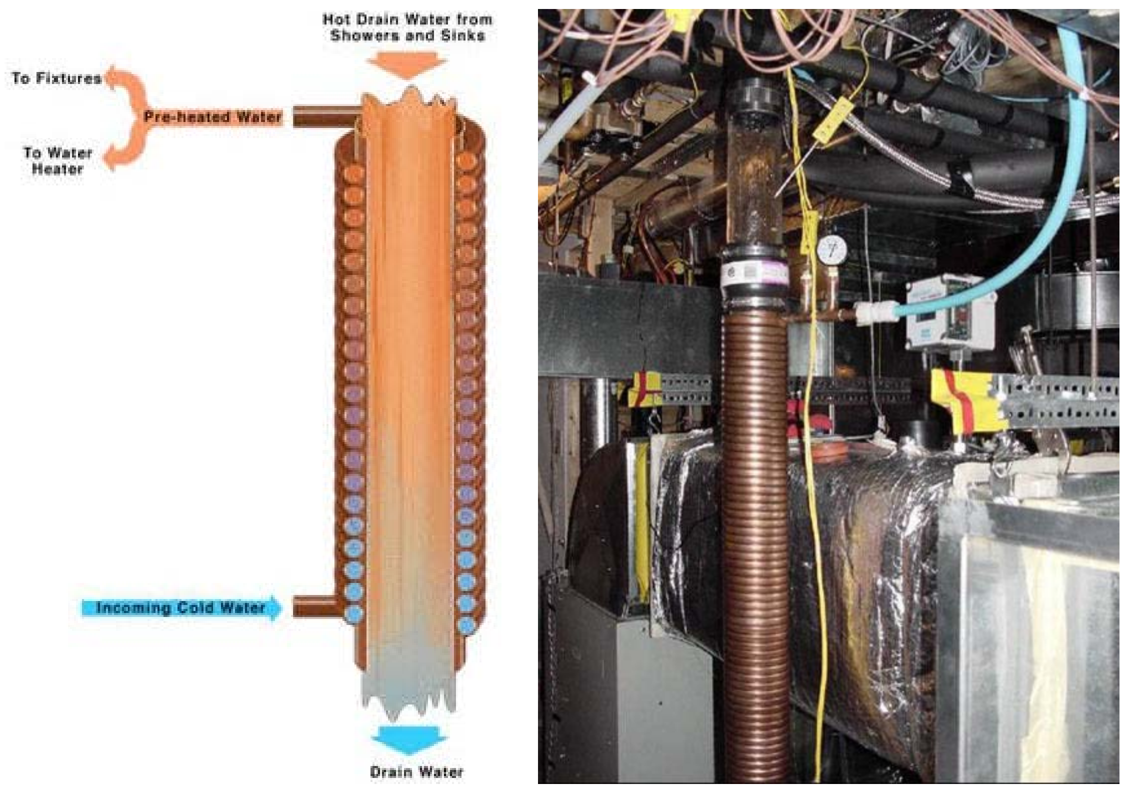

Figure 6.143. GFX system schematics and installation example.

Description

Domestic hot water (DHW) is one of the major heating energy users in the Army barracks, dormitories, and in multi-family apartment buildings. Approximately 80 to 90% of hot water energy goes literally “down the drain.” GFX technology was developed on a US Department of Energy (DOE) grant to capture heat carried by hot water, and in 2002 received a Green Product Award. This technology is compatible with all types of water heating systems, including solar water heating systems. While shower water usage per single shower head in permanent party barracks and dormitories may be comparable with a shower water usage in residential buildings, it may be much higher in training barracks or billets with common shower areas. The payback period for such barracks should be shorter.

Energy Savings (Qualitative)

Energy savings occur due to the use of waste water heat to preheat cold water mixed with hot water for use in a shower; cold water preheating reduces hot water usage. In addition to conserving energy, GFX allows size reduction of the hot water storage tanks and (in the case of solar water heating) size reduction of solar water heaters.

According to Oak Ridge National Laboratory, this technology has been found to save 25 to 30 percent of total water-heating energy needed for showers. With an average usage rate of 30 gal/day per occupant at 110 °F (43 °C), depending on location and climate, DHW can consume more up to 60% of the total annual heating energy supplied to barrack buildings and be the dominant hot water consumer during the non-heating season.

Energy Savings (Quantitative)

Annual energy use and savings were analyzed for a barrack/dormitory baseline building built to meet the minimum requirements of ASHRAE Standard 90.1-1989. The prototype building is three stories high, has an area of 30,465 sq ft, 40 two-bedroom apartment units, a lobby on the main floor, and laundry rooms on each floor. Payback calculations assumed that each GFX system serves 20 apartments and that the average cost of each of two systems’ retrofit (including the cost of 4-in. heat recovery unit and drain lines, its transportation and installation) is about $850.

Energy savings (Figure 6.144) differ between climates varying between 3% and 7% of the total barrack building energy use (at 25% energy recovery). While placing of GFX system for each shower is not cost efficient, installation of one heat exchanger for a group of showers produces a reasonable pay-back of 2 to 5 years (Figure 6.145).

Level of Maturity

Gravity Film heat eXchanger (GFX) technology has been developed over the last 10 years.

Climatic Conditions Necessary

The technology works in any climate.

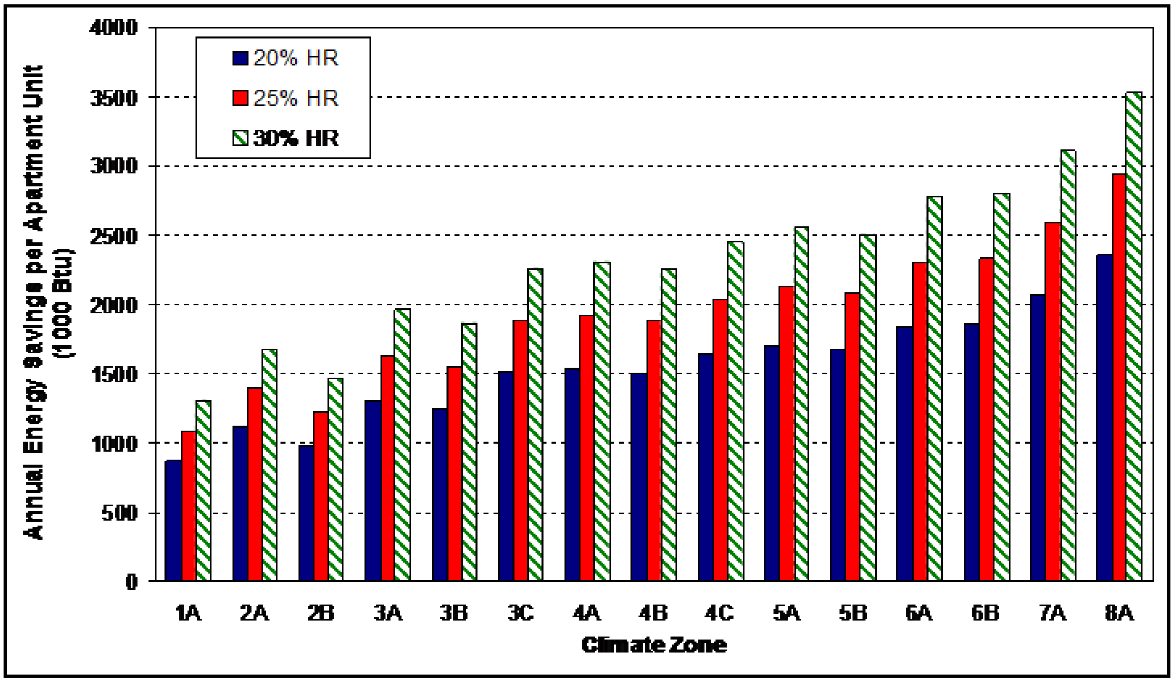

Figure 6.144. Annual energy savings per apartment unit with different heat recovery efficiency.

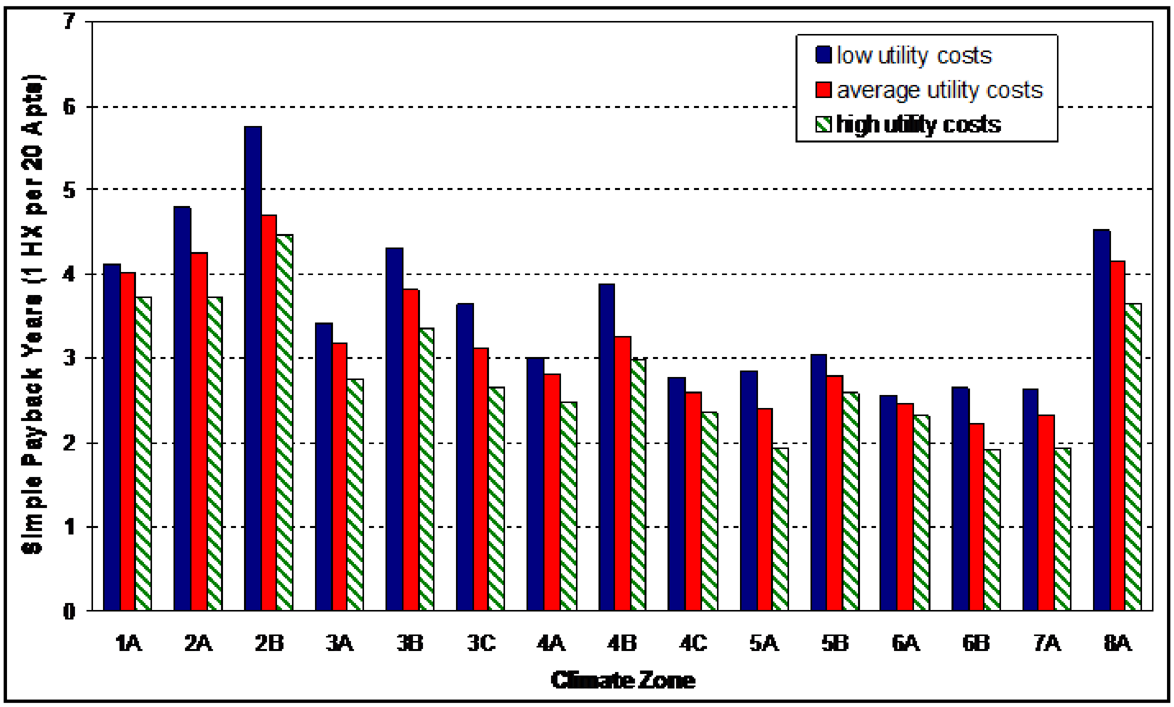

Figure 6.145. Simple payback, years with low, average and high utility rates for the heat recovery system servicing 20 apartments.

Manufacturers

www.gfxtechnology.com/

www.endlessshower.com

www.oikos.com/gfx/

References

J.J. Tomlinson. GFX Evaluation. Oak Ridge, TN: Oak Ridge National Laboratory. August2000, www.eere.energy.gov/buildings/emergingtech/printable/page2d.html

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). *ANSI/ASHRAE/IESNA Standard 90.1-1989 Energy Efficient Design of New Buildings except Low-Rise Residential Buildings.* 1989. Atlanta, GA: ASHRAE.

R.S. Briggs, R.G. Lucas, and T. Taylor. “Climate Classification for Building Energy Codes and Standards: Part 2 - Zone Definitions, Maps and Comparisons.” *Technical and Symposium Papers*. January 2003. Chicago, IL: ASHRAE Winter Meeting.

Efficient Occupancy Sensor Lighting Control

Application

Barracks.

Category

Lighting.

Concept

One of the major reasons for excessive energy usage in buildings is the lights being left on when the building is unoccupied. Ensuring that the lights are turned off when spaces are vacated is a simple and effective way to reduce energy consumption.

Description

Lowering energy consumption from lighting in occupied spaces involves lessening both the installed wattage and the time the lights are on. Retrofitting office spaces, restrooms, residences, and other multi-use military spaces could be as straightforward as implementing the proper controls. Occupancy sensor technology that detects occupancy through motion provides the most effective method of ensuring that lights are on only when necessary.

There are two primary occupancy sensor technologies that are effective for lighting controls:

- Passive infrared (PIR) sensors, which are useful in small, intermittently occupied spaces such as offices, small storage spaces, and lunch rooms. PIR sensors require an uninterrupted line of sight to the occupants in the space, and detectable movement occurring frequently enough to keep the lights from turning off while the space is still occupied.
- Ultrasonic sensors, can be more expensive initially, but they are also generally more sensitive to slight movements within a space. They do not need a direct line of sight to the movement to work effectively.

Dual technology or hybrid occupancy sensors are also available. They turn the lights on when both the PIR and ultrasonic mechanisms detect movement, and will remain on as long as either continues to detect motion. These dual technology sensors reduce the likelihood of lights coming on due to movement outside of the desired control area (e.g., in a hallway outside of an office). A potentially simpler method of controlling these false switchings is the use of manual-on sensors that must be manually activated, but will automatically turn lights off. In spaces where this type of false switching might be an issue and a manual on control is not practical, a hybrid motion detector would be ideal.

The effective use of occupancy sensors requires appropriate placement within the space. Wall mounting is typically the simplest installation, because the sensor can simply replace existing wall switches However, this is very practical in small spaces. In spaces where PIR technology is being used, it is important that no furniture or partitions block the sensor from occupied spaces. Ceiling mounted occupancy sensors are very effective in both large and small spaces, but their higher initial cost is more justifiable in larger spaces where they control more lights and are required for wider area coverage.

Another consideration with occupancy sensor applications is the lighting technology being controlled. Fluorescent lamps have a lifetime of 10,000 to 20,000 hours, based on a test protocol of being on for three hours each time they are switched. More frequent switching can lower the operating life. This potential loss of lamp life is usually more than offset by the energy savings associated with more defined lighting controls. It is prudent to avoid occupancy-based control of lighting in spaces that are occupied on a repeated intermittent basis. However, it is not likely that any space types commonly found in barracks would be operated in this manner. Intermittent switching may occur in some spaces due to the false switching described earlier, but the use of manual-on or dual technology sensors should eliminate this. Any space that is lit primarily with HID lamps is not considered to be a good application for an occupancy sensor, because it can take up to 20 minutes for the lights to warm up after an occupant is detected.

Other considerations with occupancy sensor control include the off time delay setting and the manual-on and manual-off options.

- The “off time delay” setting determines the time the sensor waits to turn the lights off when it stops sensing motion; this can be adjusted. If the time delay is too long and the lights remain on for as long as 20 minutes after motion is detected, the potential energy savings can be reduced to less than 50% of the savings of the same system with no time delay. However, if the time delay is too short, the lights have a greater chance of being switched off while the room is still occupied. To achieve the ideal time delay setting, it is important to appropriately set the delay for the space type and occupancy patterns.
- Additional control options for occupancy sensor systems can be used to further optimize the lighting needs for particular spaces. Vacancy sensors (manual-on) controls that require an occupant to activate the lights when entering a space (instead of automatically coming on) eliminate any possibility of the lights turning on in an unoccupied space. They are also useful in daylighted spaces where the daylight might be sufficient and electric lights unnecessary. The occupancy sensor would still provide automatic shutoff when the last occupant has left the space. A vacancy sensor control option provides greater control for the users in the space and is very useful in spaces where lights will need to remain off while inhabited for presentations and other low light needs.

Table 6.40 lists recommendations for occupancy sensor application in typical offices and barracks, where the application would be considered cost effective under typical operating conditions. The space types are categorized as “Public,” “Temporary/Multiple (T/M) Occupancy,” or “Private.” This refers to the sense of ownership an occupant has for each space, which has been shown to relate directly to how much energy savings can be expected.

Public spaces have the highest potential for energy savings. These are spaces that are generally accessed by any occupant at any time. This tends to encourage occupants to leave lights on as a courtesy to other potential occupants. Typical spaces of this type include restrooms, lunch rooms, hallways and copy rooms.

Temporary/Multiple (T/M) Occupied spaces have moderate potential for energy savings. Occupants typically access these spaces for a specific purpose and time. This leads occupants to consider turning off lights at least when they are finished using the space. A typical space of this type is a conference room that is commonly scheduled for occupancy.

Private spaces generally have the lowest energy savings potential. These are spaces that are typically small (an thus have low total wattage) and are controlled by one person. This perceived personal responsibility tends to encourage its user to turn lights on and off according to actual space occupancy.

There are additional public spaces that were not discussed in the present economic analysis. Large open office spaces are often too variable to provide generalized guidance. Often, occupancy sensors can be used effectively in these spaces. However, attaining the proper coverage area with multiple units increases the initial cost. Additionally, increased occupancy decreases the potential savings as the lights are used more. Significant savings can be provided by zoning large office plans with multiple lighting circuits and dedicated sensors. This would detect motion specifically in the area of the lights it is controlling. As this type of zoning is not always feasible, the minimum recommendation for these spaces is a time clock that shuts all the lights off at the end of the workday or during the night.

Table 6.40. Occupancy sensor application recommendations.

	Space Types	Recommended Technology	Suggested Time Delay	Additional Notes
		Offices		
Public Spaces	Restrooms	Ultrasonic	5 min.	
	Hallways	Ultrasonic	2 min.	
	Lunch room	PIR* (or) ultrasonic	5 min.	Vacancy sensor, especially if daylit
	Copy rooms	PIR* (or) ultrasonic	5 min.	Vacancy sensor, especially if daylit
T/M Occupied Spaces	Conference rooms	PIR* (or) ultrasonic	5 min.	Manual on/manual off
	Storage	PIR	2 min.	Vacancy Sensor
	Shared office	Ultrasonic (or) hybrid	2 min.	Vacancy sensor, especially if daylit
Private Spaces	Private offices	Ultrasonic	2 min.	Vacancy sensor
		Barracks		
Public Spaces	Lounge	Ultrasonic	5 min.	Manual on/manual off
	Laundry rooms	PIR	2 min.	Vacancy sensor
	Hallways	Ultrasonic	2 min.	
	Cafeteria	Ultrasonic	2 min.	
Private Spaces	Bedrooms	Ultrasonic (or) manual switches	5 min.	Vacancy sensor

* PIR sensors were used in the financial analysis, as they can typically be implemented at a lower initial cost. In all three of these spaces, PIR should only be used if able to provide the appropriate coverage area and can effectively be installed without any obstructions between it and the spaces it is intended to monitor. Ultrasonic sensors would be more effective in larger spaces such as shared offices with more than three or four people, or where the sensor is required to sense motion at a greater distance.

** Suggested time delay applies to the first technology in the Recommended Technology column. It is only suggested as a recommended starting point for the commissioning process.

Energy Savings

The energy savings from occupancy sensor control will vary depending on the type of space and occupants, the electric utility rate, and the wattage that is controlled by each occupancy sensor. The following formula can be used to determine the simple payback of an occupancy sensor if the application, sensor cost, annual hourly savings, or the wattage controlled are different than those represented in Table 6.41:

$$Y_{payback} = \frac{Cost}{(WHours_A * E_{Rate} * (W/1000))}$$

where:

$Y_{Payback}$ = years for energy savings to pay for technology
Cost = initial cost of occupancy sensor
$WHours_A$ = annual hours of wasted light
W =wattage controlled by sensor
E_{Rate} = electric utility rate ($/kWh).

Table 6.42 lists an estimation of percentage electricity energy savings on a whole building basis for a typical year (kWh/Yr). The table provides an estimated savings percentage of whole building electricity use from various weather locations based on a percentage reduction in total building light power density (LPD) from 10 to 70%. The table values also include the expected reduction in electricity use of HVAC equipment associated with the reduced cooling required because of reduced lighting energy (heat) to the building. This table's data can be applied by first estimating the overall building reduction in lighting power (kW) associated with the application of occupancy sensor controls. This might be easiest accomplished by using the "Annual Hourly Savings" in Table 6.41 for each sensor application to attain an estimate of whole building percent reduction in lighting power in Table 6.42. The corresponding percentage reduction in electricity use per year from the table can then be used to estimate yearly energy use per year for that control application as follows:

Estimated annual energy savings (kWh/Yr) = Percent reduction in whole building energy use x Building area controlled x LPD for building area

Table 6.41. Values and assumptions used in occupancy sensor cost analysis.

	Space Type	Annual Hourly Savings	Assumed Schedule	Annual Hourly Usage (kWh)	Annual Hourly Savings (kWh)	LPD* (W/sq ft)	Assumed Standard Room Sizes (sq ft)	Recommended Technology**
Offices								
Public Spaces	Restrooms	53%	50 hrs/wk	2600	1378.0	0.9	150	Ultrasonic
	Hallways	25%	50 hrs/wk	2600	650.0	0.5	980	Ultrasonic
	Lunch room	23%	50 hrs/wk	2600	598.0	0.9	400	PIR
	Copy rooms	55%	50 hrs/wk	2600	1430.0	1.3	100	PIR
T/M Occupied Spaces	Conference rooms	44%	50 hrs/wk	2600	1144.0	1.3	260	PIR
	Storage	55%	50 hrs/wk	2600	1430.0	0.8	75	PIR
	Shared office	24%	50 hrs/wk	2600	624.0	1.1	500	Ultrasonic
Private Spaces	Private office	33%	40 hrs/wk	2080	686.4	1.1	135	Ultrasonic
Barracks								
Public Spaces	Lounge	23%	24/7	8760	2014.8	1.2	1000	Ultrasonic
	Laundry rooms	55%	24/7	8760	4818.0	0.6	210	PIR
	Hallways	25%	24/7	8760	2190.0	0.5	980	Ultrasonic
	Cafeteria	55%	15 hrs/day	2600	1430.0	0.9	1500	Ultrasonic
Private Spaces	Bedrooms	55%	12 hrs/day	4380	2409.0	1.1	144	Ultrasonic

* As required based on ASHRAE 90.1 2007.

** Representative of cost used in financial analysis (PIR=$75.30, Ultrasonic=$135.40, and Hybrid= $203.50). Recommendations were based on typical use patterns of the said spaces and are the best control option if the space is typical in size, occupancy pattern, and use as what is "normal" for that type of space.

Table 6.42. Reduction in whole building electricity use per year from reduction in lighting power.*

Representative weather location	Percent reduction in total lighting power						
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**
San Francisco, CA	3.9	7.7	11.5	15.4	19.2	23.1	26.9
Seattle, WA	3.8	7.6	11.4	15.3	19.1	22.9	26.8
Boise, ID	3.6	7.1	10.5	14.1	17.7	21.3	24.8
Burlington, VT	3.0	6.0	9.1	12.1	15.1	18.1	21.1
Duluth, MN	2.9	5.9	8.8	11.8	14.7	17.7	20.6
Helena, MT	3.0	5.9	8.9	11.9	14.8	17.8	20.8
Chicago, IL	3.0	5.9	8.9	11.9	14.9	17.9	20.9
Albuquerque, NM	3.6	7.2	10.8	14.4	18.0	21.6	25.2
Baltimore, MD	3.5	7.0	10.5	14.0	17.5	21.0	24.5
Fairbanks, AK	2.7	5.4	8.1	10.8	13.5	16.2	18.9

Representative weather location	Percent reduction in total lighting power						
	10%	20%	30%	40%	50%	60%	70%
El Paso, TX	3.5	7.0	10.4	13.9	17.5	21.0	24.4
Memphis, TN	3.3	6.5	9.8	13.1	16.4	19.6	22.9
Houston, TX	3.1	6.2	9.2	12.3	15.4	18.5	21.6
Phoenix, AZ	3.0	5.9	8.9	11.9	14.9	17.8	20.8
Miami, FL	2.7	5.5	8.2	10.9	13.6	16.4	19.1

* Includes savings from reduced lighting use and reduced HVAC electricity for cooling

Results

Payback Period

Figures 6.146 and 6.147 show the simple payback of each space. The payback period was calculated using lighting loads, assumed space size and operating hours with the occupancy sensor technology represented in 6.147. These figures do not account for HVAC energy reduction.

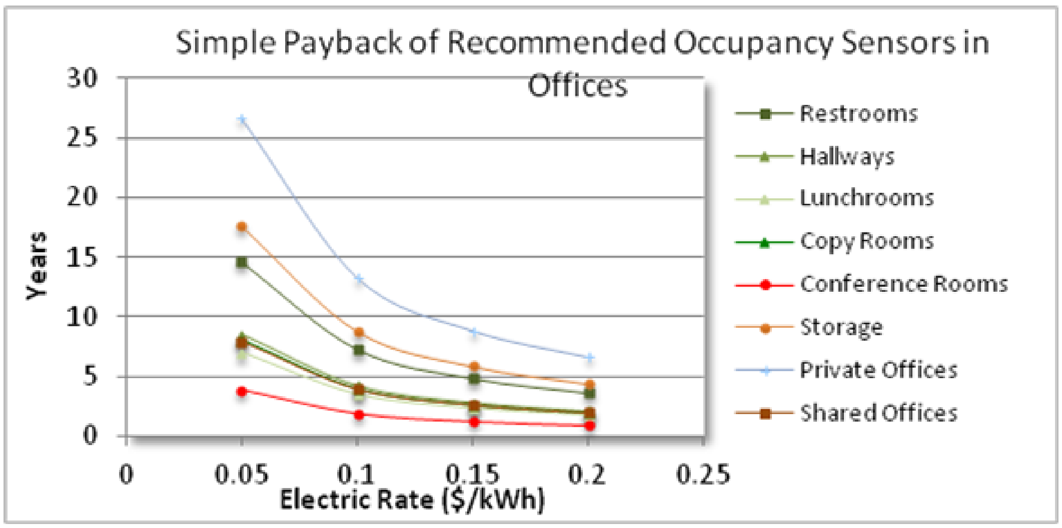

Figure 6.146. Simple payback of recommended occupancy sensors in offices.

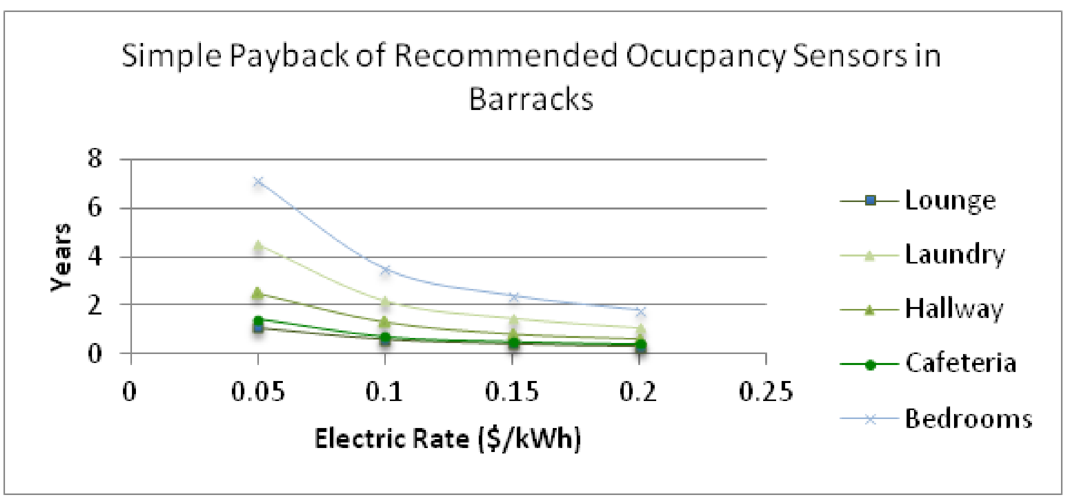

Figure 6.147. Simple payback of recommended occupancy sensors in barracks.

Environmental Benefits

Lowering energy consumption is one of the most important things that can be done today to minimize negative effects on the environment. Regardless of the time and effort put forth educating building occupants of the importance of conserving energy, lights will still be left on. Occupancy sensors ensure that lights are only on when they are being used, directly lowering energy consumption and reducing CO_2 emissions that are released into the atmosphere.

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Retrofitting Lighting Systems to Correct Light Levels

Application

Barracks.

Category

Lighting.

Concept

One of the easiest and most cost effective methods for saving energy is to design lighting systems to the correct light levels for the tasks being performed, thereby avoiding excessive lighting.

Description

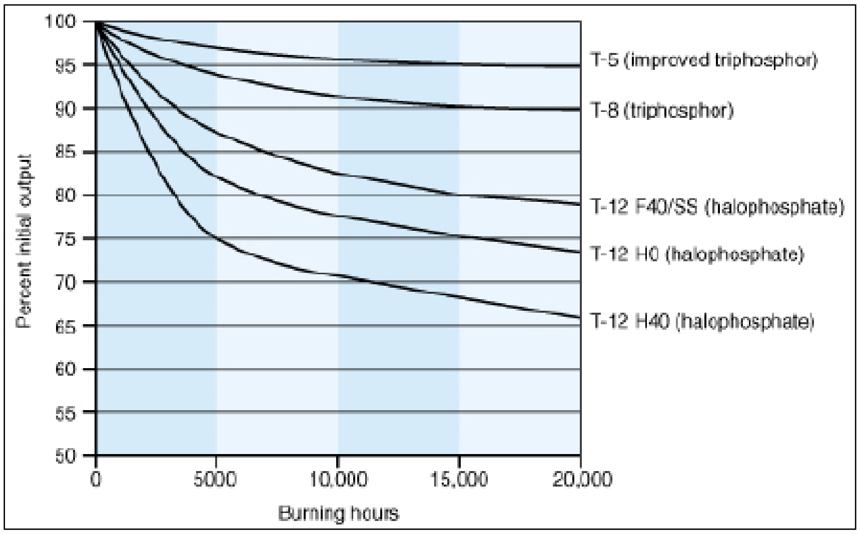
The amount of effort required to maintain a typical lighting system is minimal. As lamps burn out, they are replaced with the same type of lamp to ensure that light levels remain consistent. While this is acceptable for spaces where an efficient and well-designed lighting system is in place, this type of maintenance in an over-lit space simply maintains the same level of wasted energy by foregoing an opportunity to retrofit using a more efficient type of bulb.

Lighting systems are most effectively designed based on the light levels or illuminance required for the tasks performed within each building space. The accepted authority for appropriate illuminance levels is the Illuminating Engineering Society of North America (IESNA). The IESNA publishes a comprehensive handbook along with supplemental Recommended Practice Guides that provide tables of appropriate illuminance data. However, many systems do not specifically follow this guidance, and instead use previous designs or historical design rules of thumb, causing spaces to be over-lit.

By today's standards, most lighting designed and installed prior to 1985 is too bright. In the past, overhead lighting was designed for low contrast print reading tasks at levels of 750-1000 lux (lumens/m^2). Current office operations primarily involve computer-based and higher quality printed tasks such that the recommended light levels are now around 300 and 500 lux.

Another consideration in lighting design is the application of daylighting when it is available. Even in spaces with available daylight, lighting systems typically must be designed to meet required light levels without daylight because of the possibility of space occupancy at night. However, spaces with daylight are likely over-lit the majority of the time, since they are occupied primarily during the day, with the electric lights on whether or not they are needed. Having a separate control for the lights such as a photocontrol or dimmer ensures their use as an effective and supplementary light source. If controls are not applied, excessive energy is also being used to operate the mechanical cooling needed to offset the heat load caused by the lighting. It is true that in some climates, the extra lighting can reduce heating needs, but this rarely offsets the extra cooling required, and can be accomplished much more efficiently. Sunlight through windows and skylights also increases the temperature by solar heat gain, and must also be considered for effective daylighting design.

The light output provided by lamps progressively degrades throughout the lamp's life. Older T12 lamp technologies degraded up to 80% of their initial output, so spaces were designed to be purposely over-lit to accommodate this lamp characteristic and ensure ample light levels (Figure 6.148). Today's T8 fluorescent lamps degrade much less throughout their lives so compensating for degradation is unnecessary. When group relamping occurs, overdesign becomes even less important since the lamps are replaced before they drop to their lowest light output.



Source: IESNA handbook

Figure 6.148. Lamp Lumen Depreciation.

Solutions for Over-lit Spaces

The first step in resolving this problem is identifying where over-lighting exists. IESNA provides horizontal surface light level recommendations, which are measured in lux using an illuminance meter (also known as a "light meter"). Table 6.43 provides recommendations of target light levels in common spaces found in barracks and similar spaces. The illuminance targets are simply a guideline, and if measurements show light levels to be within a 20% variance, changing the lighting system will likely not be cost effective.

Measurements should be taken with the light sensor apparatus parallel to the floor (or work surface) at the height noted in Table 6.43. This is the height above the floor where most work is done and therefore the level at which the measurement should be taken and compared with levels in Table 6.43. Note that this is an average value, so multiple measurements should be taken and then averaged for comparison. In daylighted spaces, light measurement should be taken at night to see if light levels are too high without the contribution of daylight.

Table 6.43. Recommended minimum illuminance levels.

Building type	Space type	Maintained luminance at working level (lux)	Measurement (working) Level (1 meter = 3.3 feet)
Barracks/dormitories	Bedrooms	300	at 0.0 m
	Laundry	300	at 1.0 m
Office buildings	Single offices	400	at 0.8 m
	Open plan offices	400	at 0.8 m
	Conference rooms	300	at 0.8 m
	Copy room	100	at 0.80 m
Dining facilities	Self-service dining	100	at 0.8 m
	Kitchen	500	at 1.0 m
Sport facilities	Exercise room	300	at 0.1 m
Circulation areas	Corridors	50	at 0.1 m
	Stairs	50	at 0.1 m
	Restrooms	300	at 1.0 m

If light levels are too high, consider the corrective actions in Table 6.44 to correct them. For spaces with daylighting, also apply the control recommendations in the table for maximum benefits both in terms of lighting quality and energy savings.

One possible correction option noted in the table is the application of ballasts with a selected “ballast factor.” Ballasts are the mechanisms that provide the proper electrical conditions to start and operate fluorescent lamps. A lamp’s initial lumen output (amount of light produced by a lamp) is tested in a laboratory on a reference ballast. The reference ballast has a ballast factor of one, meaning it powers the lamp at full light output. A ballast that can only power the lamp at half of its full light output is said to have a ballast factor of 0.5. The choice of a particular ballast factor can be a tool for achieving the desired light output. The determination of an appropriate ballast factor must be done in conjunction with other space variables such as luminaires’ efficiency and room surface reflectance, and therefore should be done with professional input.

If adjusting the ballast factor still does not correct light output and other recommendations from Table 6.44 have been found impractical, the less effective option of “delamping” could be considered. This delamping option should be considered as a last resort because it may adversely affect the intended beam spread from the luminaires and create dark areas in the space and make luminaires appear unmaintained. Three and four-lamp luminaires may incorporate two separate ballasts. Delamping by removing one ballast and the lamps it is driving may provide the required effect. Note that removing lamps only will **not** provide the expected energy reduction because the associated ballast will continue to draw power. If a lamp is taken out, the ballast operating it must be removed as well.

Table 6.44. Recommended action to correct spaces that are over-lit.

Type	Best Option	Alternate Option
T12	Replace inefficient T12 lighting system with new T8 or T5 luminaires optimally located and spaced. The new system may reduce the number of luminaires to attain appropriate light levels.	If a complete new lighting design is not feasible, a T8 lamp and ballast retrofit with an appropriately chosen ballast factor and/or lower output lamp may provide the required reduction in illuminance (see text on ballast factor).
T8s or T5s	Consider relocating luminaires if spaced too close together (and relocation would not create dark spots). Alternatively, new luminaires with lower light output per luminaires could be installed.	If relocation is not possible, consider changing the light output of the lamps by replacing the ballasts with one having a more appropriate ballast factor to reduce lighting levels. A lower light output lamp could also be installed (see text on ballast factor).
CFL/ Incandescent	Incandescent lamps should be replaced with CFLs if applicable. If a space is too bright and lighted with CFLs, a lower wattage should be used	
Daylight Available	Provide separate daytime controls with a photocontrol, dimmer, or a manual switch at minimum controlling the lights in the daylight area separate from other lighting.	

* Implementation costs may vary depending on the choice and existing space conditions and should be considered for each application.

Energy Savings

Energy savings from lowering light levels can be calculated by using the following formula:

$$Savings_A = \frac{T_A * (W_c - W_n) * E_{rate}}{1000},$$

where:

- $Savings_A$ = annual energy savings (dollars)
- T_A = annual amount of time lights are on
- W_c = current total wattage in the space
- W_n = new total retrofitted wattage
- E_{rate} = local utility's energy rate in dollars per kWh.

In spaces with linear fluorescent lamps, determine what type of fluorescent lamps and ballasts are being used. Rapid start, or program start ballast/lamp combinations use up to 4W more than an instant start lamp/ballast combination per lamp. If T12 systems are being retrofitted, or a T8 lamp/ballast combination is being replaced, use instant start ballasts and lamps for maximum energy savings. However, fluorescent lamps cannot be dimmed on these ballasts, and if dimming is necessary, program start ballasts must be used.

Table 6.45 lists the estimation of percentage electricity energy savings on a whole building basis for a typical year (kWh/Yr) (for comparison). Table 6.45 lists the estimated savings percentage of whole building electricity use from locations having various weather patterns based on a percentage reduction in total building light power density (LPD) from 10 to 70%. The listed values also reflect the expected reduction in electricity use of HVAC equipment due to reduced cooling because of reduced lighting energy (heat).

Table 6.45. Reduction in whole building electricity use per year from reduction in lighting power.*

Representative weather location	Percent reduction in total lighting power						
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**
San Francisco, CA	3.9	7.7	11.5	15.4	19.2	23.1	26.9
Seattle, WA	3.8	7.6	11.4	15.3	19.1	22.9	26.8
Boise, ID	3.6	7.1	10.5	14.1	17.7	21.3	24.8
Burlington, VT	3.0	6.0	9.1	12.1	15.1	18.1	21.1
Duluth, MN	2.9	5.9	8.8	11.8	14.7	17.7	20.6
Helena, MT	3.0	5.9	8.9	11.9	14.8	17.8	20.8
Chicago, IL	3.0	5.9	8.9	11.9	14.9	17.9	20.9
Albuquerque, NM	3.6	7.2	10.8	14.4	18.0	21.6	25.2
Baltimore, MD	3.5	7.0	10.5	14.0	17.5	21.0	24.5
Fairbanks, AK	2.7	5.4	8.1	10.8	13.5	16.2	18.9
El Paso, TX	3.5	7.0	10.4	13.9	17.5	21.0	24.4
Memphis, TN	3.3	6.5	9.8	13.1	16.4	19.6	22.9
Houston, TX	3.1	6.2	9.2	12.3	15.4	18.5	21.6
Phoenix, AZ	3.0	5.9	8.9	11.9	14.9	17.8	20.8
Miami, FL	2.7	5.5	8.2	10.9	13.6	16.4	19.1

* Includes savings from reduced lighting use and reduced HVAC electricity for cooling.

Find the estimated percentage reduction in total lighting power in the climate zone most representative of the building's location. Then, use the reduction in whole building electricity use (from the table) to determine whole building energy reduction.

Estimated annual energy savings (kWh/Yr)	=	Percent reduction in whole building energy use	x	Building area effected by change	x	LPD for building area

Psychological Considerations

In office settings where people are accustomed to existing high light levels, it can be disappointing to have light levels lowered. Often, when light levels drop occupants of the space will complain that they no longer have sufficient light and are unhappy. An often effective approach to relighting a space is to promote the installation of a new and better lighting system with potential benefits such as less glare, better for computer use, andc. This approach will typically only be effective if the space is being redesigned to promote the comfort of the occupants. If simple lamp/ballast delamping is done, the occupants may feel cheated by realizing the only change made was a reduction in their light levels. It has been found that occupants accept change more readily if they understand why it is occurring. If the only change evident in the lighting is a reduction in light levels, it might be appropriate to supply occupants with supplemental individual lighting to help ease the transition from an over-lit space to a space illuminated to meet the actual lighting requirements.

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Roller Shutters

Application

Dormitories, barracks, residential buildings

Category

Building envelope

Concept

Roller shutters have been widely used in Europe for decades and are increasingly being used in North America. Their original use was to provide security, prevent theft and vandalism, and protect homes and businesses from hurricane damage. However, roller shutters can also provide external shade designed to reduce radiant heat gain through a window when the space is not occupied, thus reducing the load on the air-conditioning system, or in some cases, eliminate the need to use air-conditioning altogether. The shutters shade the windows, which reduces solar heat gain and increases the envelope R-value to some extent by providing a dead air space outside the windows. (However, since the shades are not air-tight, the air space between the shade and the window does have infiltration.) This fact sheet estimates the effects on annual energy use and costs as a result of retrofitting an existing barracks with exterior roller shutters.

Description

Shutters are closed during the day, when cooling is required. Shutters may be operated manually or with a motor. Motorized operation may be controlled manually (by the occupant) or may be initiated by a local sensor or a building energy management system. One motorized option uses solar panels and a battery to power the motor; this reduces the need to run wires through the wall to the motor. Because the shade is located close to the window and usually has some insulation, it can also increase the thermal resistance of the window opening. They may also be closed at night if the outdoor temperature is below the heating system set point, to increase the thermal resistance of the building envelope. The shutters are rolled up and retracted when not needed. Figure 6.149 shows a standard half-round roller shutter and an actual installation of shutters in a building.

Energy Savings (Qualitative)

Roller shutters are most effective in warm climates where they can reduce solar heat gain through the windows. Barracks with large amounts of south-facing fenestration are the best candidates for this measure. For warm climates with large south-facing fenestration, external shutters may yield savings up to 5%. The European Solar-Shading Organization claims savings of up to 10%.

For cooler climates, the energy savings are not as significant. However, where the number of cooling degree days is low, it is possible that the use of roller shades may enable the building to maintain acceptable comfort levels without using an air-conditioning system. For a new building or an existing building that requires replacement of major renovation of its space cooling system, the roller shutters may provide a less expensive alternative to the air-conditioner.

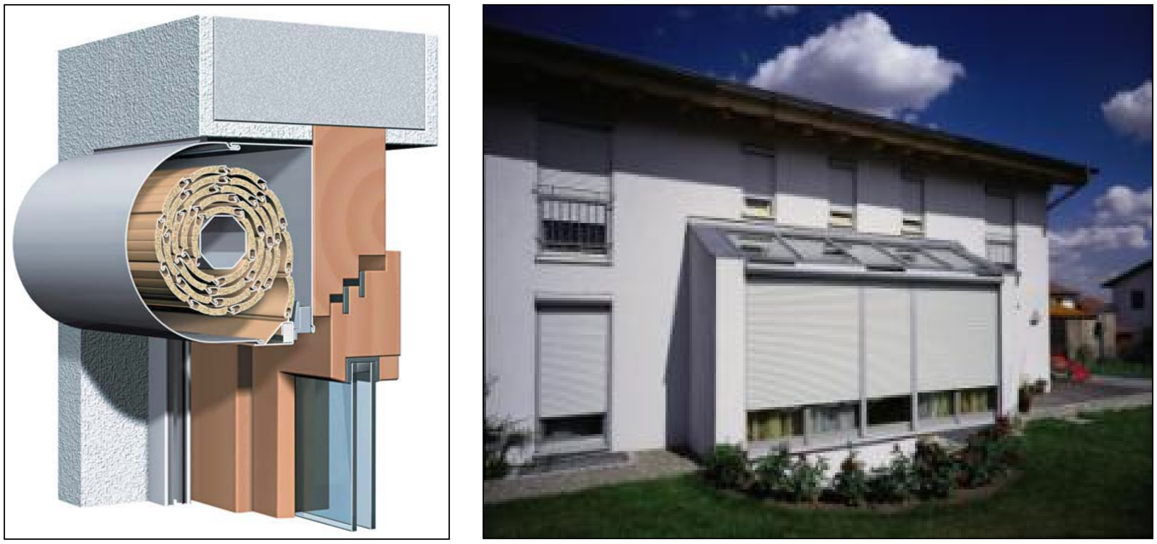

Figure 6.149. Standard half-round roller shutter (left) and application to residential building (right).

Additional qualitative benefits of roller shutters include building security, privacy, and protection from the elements. The shutters eliminate visibility into the building and provide a physical barrier at entries, often deterring attempted break-ins. Other much sought-after qualities that roller shutters provide are increased privacy and reduced light and noise. Finally, most shutters provide enhanced protection from strong storms (e.g., hurricane winds).

Energy Savings (Quantitative)

To estimate the savings that can be achieved through the use of roller shutters, a number of pre- and post-retrofit simulations were performed with EnergyPlus 3.0, which models heating, cooling, and ventilation flows in buildings, among other characteristics. The rolling shutter being considered consists of aluminum slats that are filled with a regular-density polyurethane foam core. Table 6.46 lists the technical details of this specific shutter.

Insulation is provided mainly by the void between the window and roller shutter. Figure 6.150 shows the thermal resistance of a window opening dependent on the air gap between shutter and window. A distance of at least 40 mm (about 1.5 in.) is optimal, approximately doubling the thermal resistance. Behind a closed shutter, there is an almost stationary air layer with the known insulating effect. Due to the low material thickness, the shutter’s self-insulation remains negligible.

The baseline building in this analysis is assumed to be an existing barracks built to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone. The building is three stories high with an area of 30,465 sq ft (2,691 m^2) and includes 40 two-bedroom apartment units, a lobby on the main floor, and laundry rooms on each floor. References [6] (USA) and [7] (international) characterize the building and its baseline heating, ventilation, and air-conditioning (HVAC) system.

Table 6.46. Rolling shutter specifications.

Specification	IP Units	SI Units
U – Value (without air gap between slat and window glass)	5.43 Btu/h·°F·sq ft	30.9 (W/m^2·K)
Solar transmittance	0.0	0.0
Solar reflectance	0.5	0.5
Visible transmittance	0.0	0.0
Visible reflectance	0.5	0.5
Thermal emissivity	0.9	0.9
Thermal transmittance	0.0	0.0
Air gap (distance between slat and window glass)	1.5 in	0.038 m

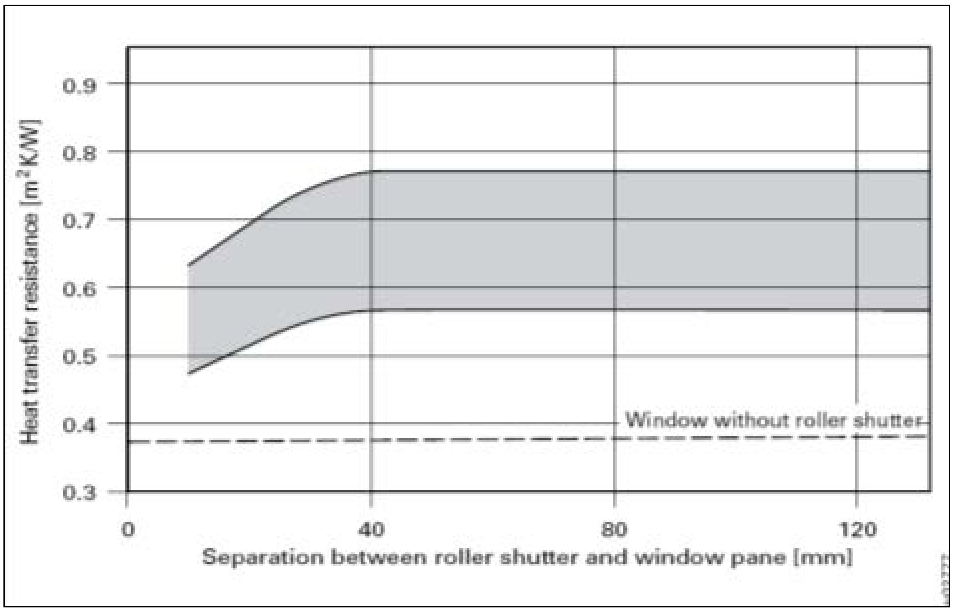

Figure 6.150. Thermal resistance versus window-shutter gap (outer edge of window pane to inner edge of shutter).

Fifteen US locations were selected to represent fifteen 15 US climate zones. The US locations were selected as representative cities for the climate zones by the Pacific Northwest National Laboratory [8]. Flat utility tariffs were assumed for each location (i.e., no energy demand charges are included). The energy costs are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008).

It was assumed that all of the units are occupied during the evening and night and unoccupied during the day. The thermostat setpoints were set back for heating and set up for cooling during unoccupied hours. (References [6] and [7] provide additional details.) Several control strategies were considered for opening and closing the window shutters. Shutters can be operated manually, by a time clock and motor-driven mechanism, or by a sensor-controlled system to open and close the shutters at times when solar radiation and heat gain through the windows are greatest. This document assumes that the shutters are operated according to the basic time schedule listed in Table 6.47.

In addition to this time schedule, two building orientations were considered. One orientation positioned the building such that the glazing faced north and south, while the other orientation rotated the building 90 degrees, facing the glazing to the east and west. The shutters were modeled on the south facing windows in the first orientation and on both the east and west facing windows in the second orientation. The maximum savings from reduced heat gain occurs in south-facing windows. The data in Table 6.48 summarize the scenarios.

A budgetary estimate of the cost of a motorized rolling shutter for a window 3 X 4 ft. (0.9 X 1.2 m) would be about $760 (not including installation). A manually operated (no motor) shutter would be about $500. Assuming that only one side of the building is retrofit with roller shutters (20 double windows per side), the installed cost per building is estimated to be about US$18,000 per building.

Table 6.47. Shutter open/close schedule.

Day of Year	Hours	Shutter Position
Jan 1 – May 1	12:00 am – 6:00 am	Closed
	6:00 am – 10:00 pm	Open
	10:00 pm – 12:00 am	Closed
May 1 – October 31	12:00 am – 8:00 am	Open
	8:00 am – 5:00 pm	Closed
	5:00 pm – 12:00 am	Open
October 31 – December 31	12:00 am – 6:00 am	Closed
	6:00 am – 10:00 pm	Open
	10:00 pm – 12:00 am	Closed

Table 6.48. Scenario descriptions.

Scenario	Description
North/South Building Orientation – Baseline	Glazing without shutters
East/West Building Orientation – Baseline	Glazing without shutters
North/South Building Orientation – Shutters	Short south wall glazing with shutters
East/West Building Orientation – Shutters	Long south wall glazing with shutters

Results

Figures 6.151 and 6.152 show annual energy savings that can be achieved with roller shutter installations for the 15 selected US locations as well as selected international locations. Buildings in warmer climates with large southern-exposed walls received the most energy savings. Overall, annual energy savings of up to 2.5% were seen in the most favorable conditions. Colder cities typically saw little to no energy improvements from the installation of roller shutters. Negative energy savings shown in the figures for Fairbanks, AK, and other colder cities reflect increased winter energy use if the shutters are closed during sunny but cold times. In fact, since the insulating value of the shutters is less than the benefits from solar heat gain through the windows, in these cities the shutters would not be operated in winter, resulting in the same winter energy use with and without shutters (i.e., they would not actually increase energy usage).

The European Solar-Shading Organization (ESSO) commissioned a study on the energy savings possible from roller shutters [9] that estimated up to 10% energy savings in a building. The ESSO study used the CAPSOL energy simulation program. It found that, for middle European cities, such as Brussels and Budapest, "the total solar energy in spring and autumn are high and both free solar heat gains and reduced cooling loads justify the systematic use of solar shading in every efficient building." [9] To satisfy European Union directives to reduce emissions of climate change gases, ESSO could quantify the benefits of external blinds to reduce carbon emissions incurred while heating or cooling the building. Figure 6.153 summarizes the demand (i.e., HVAC capacity) reduction predictions of the ESSO study. The energy savings estimates from the ESSO study are significantly higher than the EnergyPlus simulations (on the order of 5 – 10% for ESSO versus up to 2.5% for EnergyPlus). The pattern of benefits of the ESSO study for Europe mirror those of the US simulations: external shutters can effectively reduce cooling energy in sunny climates and can reduce (or, in marginal cooling climates, eliminate) air-conditioning capacity.

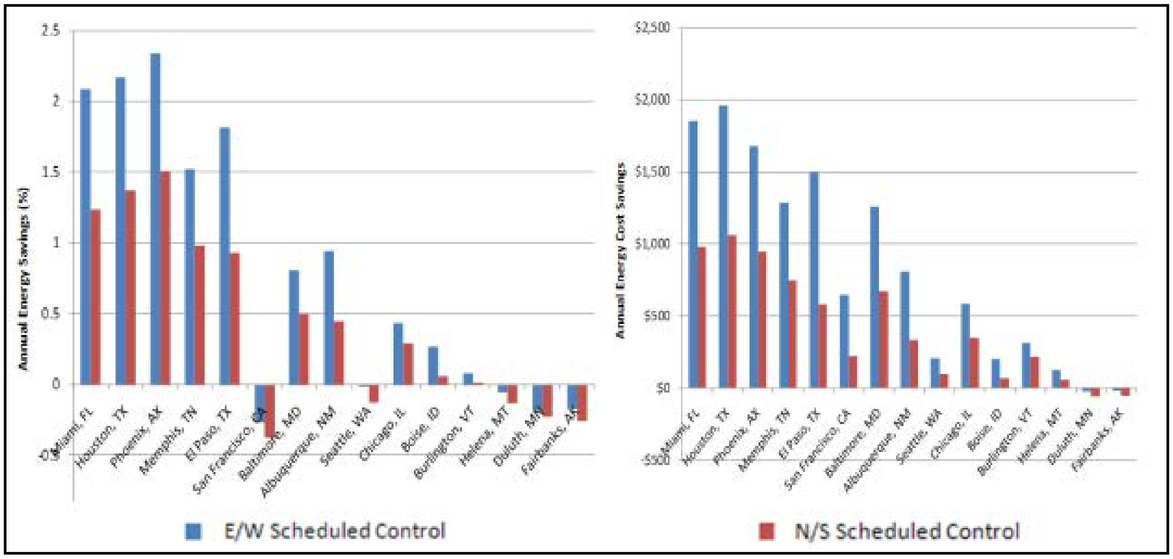

Figure 6.151. Annual energy cost savings for US cities from roller shutters.

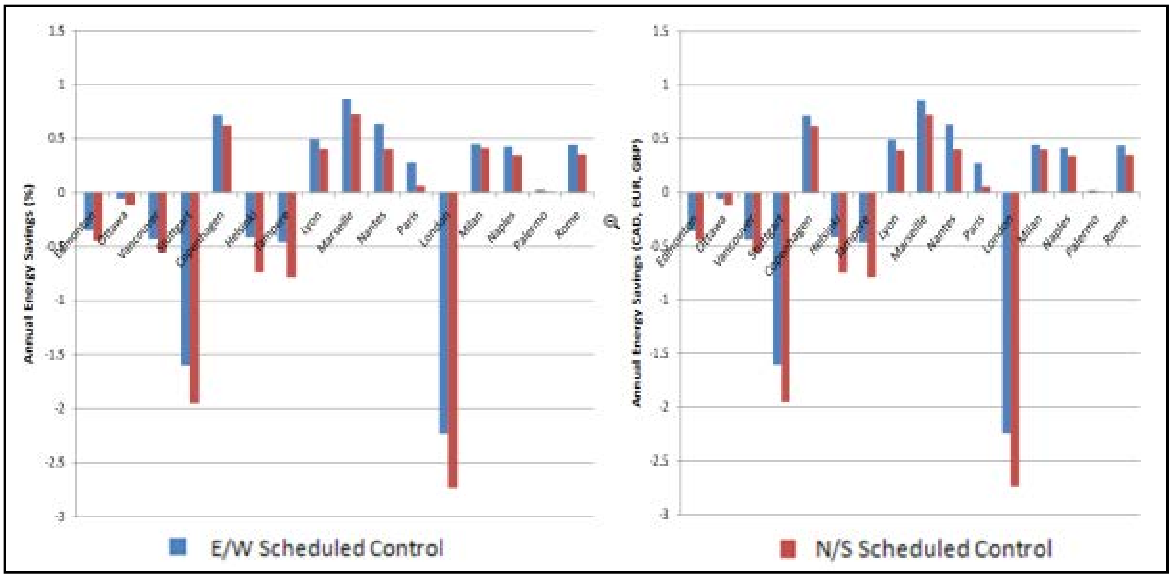

Figure 6.152. Annual energy cost savings for international locations from roller shutters.

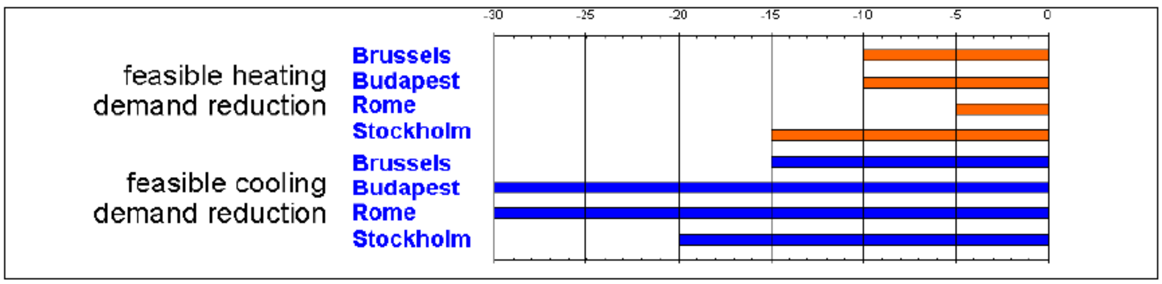

Figure 6.153. Reduced heating and cooling demands predicted from use of external blinds (ESSO Study 9).

For E/W oriented buildings (i.e., large south-facing wall), it was assumed that roller shutters would be installed for the 20 apartments on the south side only at a cost of about $18,000 for the building. This yields a simple payback, based on energy savings only, of 9 to 15 years for hot locations such as Miami, Houston, Phoenix, Memphis, El Paso, and Baltimore. The simulations assumed low emissivity windows, typical of installations in the late 1980's and later. Where the building's windows use clear glass, the external shades can be expected to save significantly more energy – possible 3 to 5 times as much as with the low-E glass. External shades may be a less expensive and less intrusive upgrade than window replacement.

In moderate climates, capital cost savings could justify installing external shades that allow the air-conditioning system to be significantly reduced in size, or even entirely eliminated. Such climates would be characterized by a short cooling season where the summer nights are significantly cooler than the days, enabling natural ventilation or a direct outdoor air system (DOAS) to cool the building at night. This would be especially well-suited for a barracks or dormitory that would be unoccupied during the hottest hours of the day. Where external shade could substitute for an apartment's fan coil unit during a building renovation, a first cost savings of $2,000 – $4,000 per apartment is possible.

Level of Maturity

Mature product, readily available.

Climatic Conditions Necessary

Most appropriate for hot climates. However, for climates that require marginal amounts of space cooling, the judicious use of roller shades could eliminate the need for air-conditioning in the building.

Manufacturers

Rollac Shutter of Texas, Inc., Pearland, TX (www.rollac.com)
Roll-A-Shield, Inc. of Phoenix, Tempe, AZ (www.rollashield.com)
WAREMA International (www.warema.com)

References

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Vestibules

Application

Barracks, offices.

Category

Building envelope – air tightness.

Description

A vestibule is an enclosed lobby adjacent to a building entrance (Figure 6.154). Vestibules create a secondary air space at a doorway to reduce infiltration of outdoor air and exfiltration of conditioned air while the primary door is open. This reduces energy use by the building heating and air-conditioning systems. Vestibules can also provide security benefits for government buildings by preventing unauthorized entry. Vestibules can be retrofit to existing buildings. While vestibules are usually custom built structures, some manufacturers produce pre-fabricated units that can be assembled on-site.

Chapter 8 of the 2003 International Energy Conservation Code (IECC) requires new commercial buildings to include vestibules (Section 802.3.6). Chapter 5 of the 2006 IECC (Section 502.4.6) has similar requirements, as do ANSI/ASHRAE/IESNA Standards 90.1-2001 (Section 5.5.3.4), and 90.1-2004 (Section 5.4.3.4). Essentially, these codes require vestibules on the primary entrance doors leading from spaces in a building greater than or equal to 279 m^2 (3000 sq ft). Both the IECC and 90.1 have similar requirements regarding the requirements for and configuration of vestibules. However, 90.1-2001 and 90.1-2004 exempt vestibules in buildings with less than four stories.

Figure 6.154. Vestibule in office building setting.

Concept

The double set of doors that comprises a vestibule greatly reduces the flow of air through an entrance. Automatic operation prevents a clear passage for air flow, since one set of doors is always closed. In addition, the volume of air trapped between the portals acts as a buffer to the transfer of heat through the vestibule. When there is no traffic the trapped volume or air is an effective insulator that increases the thermal resistance of the passageway. Vestibules can be designed as separate attachments to exiting doors (Figure 154) or can be created by adding a second consecutive door in an existing hallway adjacent to the entrance door (Figure 6.155). To further reduce infiltration, air can be supplied into the space between two doors of the vestibule, pressurizing the space to create an "air lock."

Energy Savings (Qualitative)

The purpose of a vestibule is to reduce infiltration (and thus cooling, heating, and latent load) into a space that includes doors with high volume of pedestrian traffic. These doors are typically used by the general public to access public areas and have a higher usage rate than a door classified for personnel use. Vestibules reduce the infiltration losses (or gains) from wind and stack effect by creating an air lock entry. The stack effect caused by naturally occurring warm air rising, is greater in taller buildings than in low rise construction. For this reason, ANSI/ASHRAE/IESNA 90.1-2001 and 90.1-2004 exempt vestibules in buildings less than four stories. In low-rise commercial buildings, wind exposure depends on the building's orientation and is a greater infiltration driver than is the stack effect.

Figure 6.155. Vestibule in existing hallway.

Energy Savings (Quantitative)

The infiltration flow rate through door openings is a function of the rate at which the door is opened and closed and the wind pressure on the door. The methodology shown in the ASHRAE (1992) Cooling and Heating Load Calculation Manual was used to estimate the energy saving effects of vestibules. It was assumed that, on average, the number of people who entered or left the building was 100 people/hour/door. The wind pressure was estimated by first obtaining the average annual wind speed using location specific weather data. Wind pressure for each location was then calculated as:

$$\text{Pressure} = \tfrac{1}{2} \times (\text{density of air}) \times (\text{wind speed})^2 \times (\text{shape factor})$$

where the wind speed is in m/s and the density of air is in kg/m^3.

The shape factor (drag coefficient) depends on the shape of the body. It has order of magnitude 1 and is dimensionless. In this case, the pressure is expressed in units of kg/m/s^2 i.e., N/m^2. Tables in the ASHRAE Cooling and Heating Load Calculation Manual were used to estimate a traffic coefficient, C=3500, and the expected infiltration rate for a double door with no vestibule. The vestibule was assumed to completely eliminate air infiltration through the door. Tables 6.49 and 6.50 summarize the Simulation inputs.

Table 6.49. Calculation of pressure and infiltration for Europe and Canada locations.

Locations	Wind speed (m/s)	T_{avg} (°C)	Density kg/m^3	pressure		No vestibule infiltration	
				N/m^2	in. water	cfm	kg/m^3
Palermo	3.43	18.02	1.206	7.109	0.029	390	0.184
Naples	2.60	16.29	1.213	4.099	0.017	220	0.104
Rome	3.75	15.78	1.216	8.549	0.034	450	0.212
Milan	0.91	11.75	1.233	0.509	0.002	80	0.038
Marseille	4.97	14.79	1.219	15.035	0.061	720	0.340
Lyon	3.14	11.84	1.232	6.079	0.024	350	0.165
Nantes	3.86	12.20	1.230	9.157	0.037	500	0.236
Paris	4.02	11.10	1.235	9.963	0.040	520	0.245
Stuttgart	2.83	9.03	1.245	4.996	0.020	300	0.142
London	3.23	10.18	1.240	6.447	0.026	350	0.165
Copenhagen	6.10	8.27	1.248	23.216	0.094	900	0.425
Helsinki	3.83	5.11	1.262	9.234	0.037	500	0.236
Tampere	2.86	4.24	1.265	5.169	0.021	300	0.142
Ottawa	4.11	5.67	1.259	10.625	0.043	570	0.269
Vancouver	3.34	9.72	1.241	6.931	0.028	390	0.184
Edmonton	3.62	2.69	1.273	8.329	0.034	450	0.212

Table 6.50. Calculation of pressure and infiltration for US locations.

Locations	Wind speed (m/s)	T_{avg} (°C)	Density Kg/m^3	Pressure		No vestibule infiltration	
				N/m^2	in. of water	(cfm)	(m^3/s)
Miami, FL	3.62	23.18	1.185	7.752	0.031	410	0.193
Houston, TX	3.44	20.32	1.197	7.087	0.029	390	0.184
Phoenix, AZ	2.88	22.72	1.187	4.934	0.020	300	0.142
Memphis, TN	3.65	16.98	1.211	8.067	0.033	410	0.193
El Paso, TX	3.70	17.94	1.206	8.256	0.033	450	0.212
San Fran., CA	4.67	13.78	1.224	13.326	0.054	675	0.319
Baltimore, MD	3.93	13.15	1.227	9.451	0.038	520	0.245
Albuquerque, NM	3.89	13.63	1.224	9.267	0.037	500	0.236
Seattle, WA	2.58	11.82	1.232	4.110	0.017	220	0.104
Chicago, IL	4.56	9.93	1.240	12.881	0.052	660	0.311
Boise, ID	3.38	11.15	1.235	7.034	0.028	390	0.184
Burlington, VT	4.02	11.83	1.232	9.937	0.040	520	0.245
Helena, MT	3.26	7.10	1.253	6.649	0.027	350	0.165
Duluth, MN	4.63	3.95	1.267	13.552	0.055	690	0.326
Fairbanks, AK	2.45	-1.53	1.293	3.880	0.016	220	0.104

Figures 6.156 to 6.163 show the simulation results. Figures 6.156 and 6.157 show the estimated annual energy savings for office buildings in the United States, Canada, and Europe. Savings were calculated as follows:

%Savings = (Base elec. use + Base Gas Use) - (vest. elec. use + vest. Gas Use) /

(Base elec.use + Base Gas Use)*100

The results show that vestibule savings are a strong function of winds peed and a weak function of temperature. Thus, Chicago, IL, the “Windy City” shows annual savings that are twice what could be expected in Fairbanks. AK even though the annual temperature in Fairbanks is approximately 10 °C (50 °F) less than that of Chicago. Payback calculations were based on a $500 “low cost” vestibule and a $2500 high cost vestibule. It should be noted that the “payback” discrepancy between Canadian and US barracks and dormitories is due to the fact that the Canadian dormitories are ventilated, but not air-conditioned.

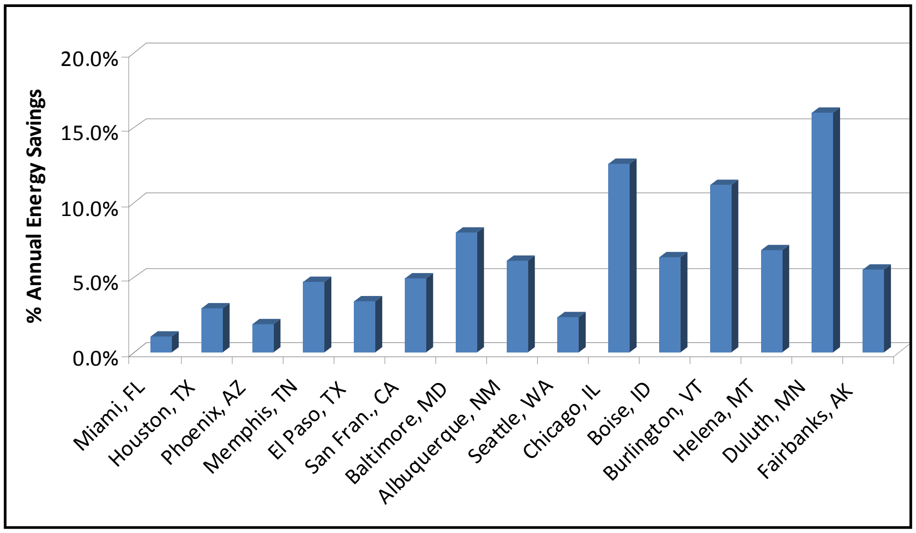

Figure 6.156. Estimated annual energy savings for US office buildings with vestibules.

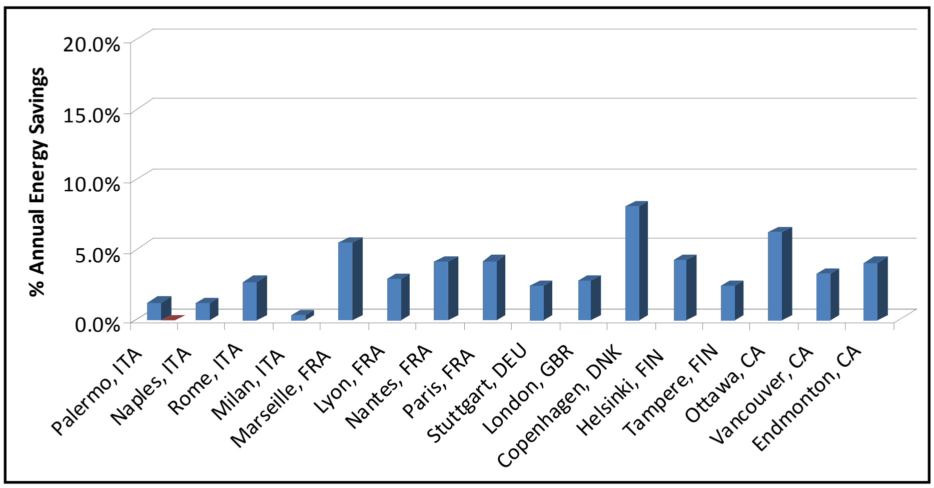

Figure 6.157. Estimated annual energy savings for European and Canadian office buildings with vestibules.

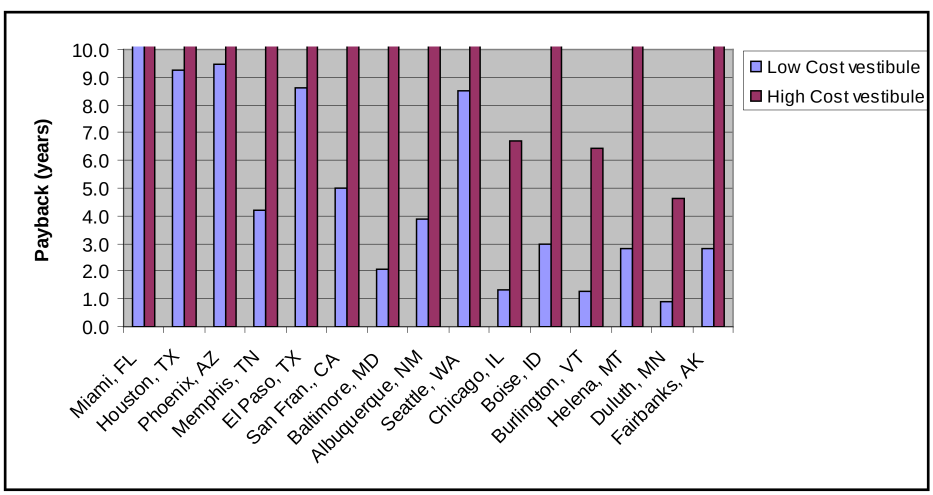

Figure 6.158. Estimated payback for high and low cost office vestibules in the United States.

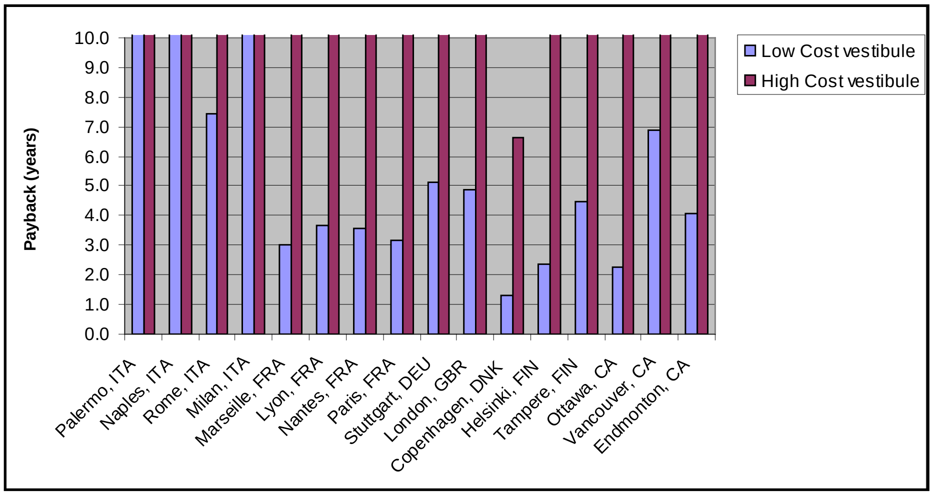

Figure 6.159. Estimated payback for high and low cost office vestibules in Europe and Canada.

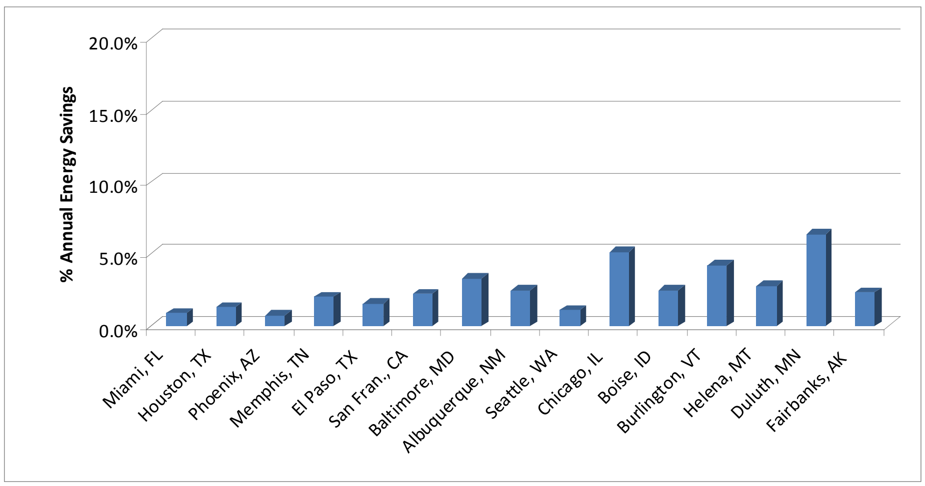

Figure 6.160. Estimated annual energy savings for US dormitories and barracks with vestibules.

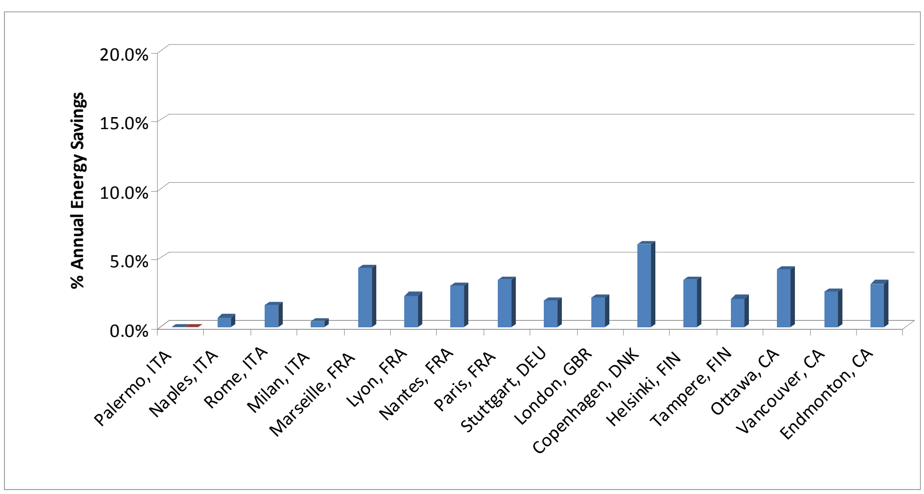

Figure 6.161. Estimated annual energy savings for European and Canadian and dormitories and barracks with vestibules.

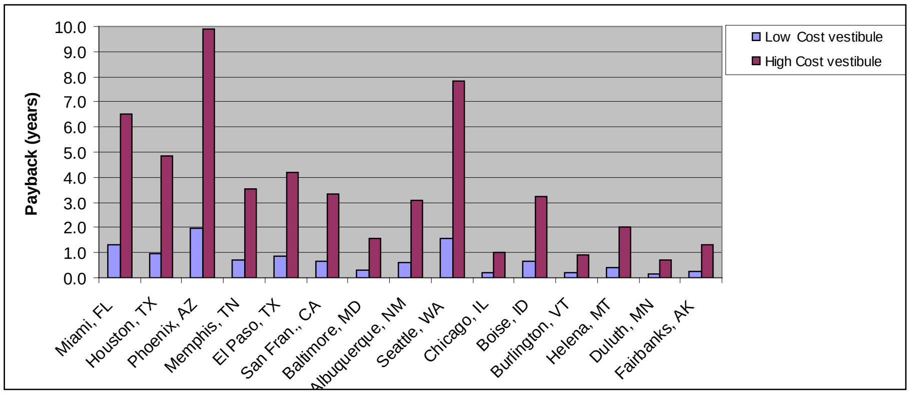

Figure 6.162. Estimated payback for high and low cost dormitory vestibules in the United States.

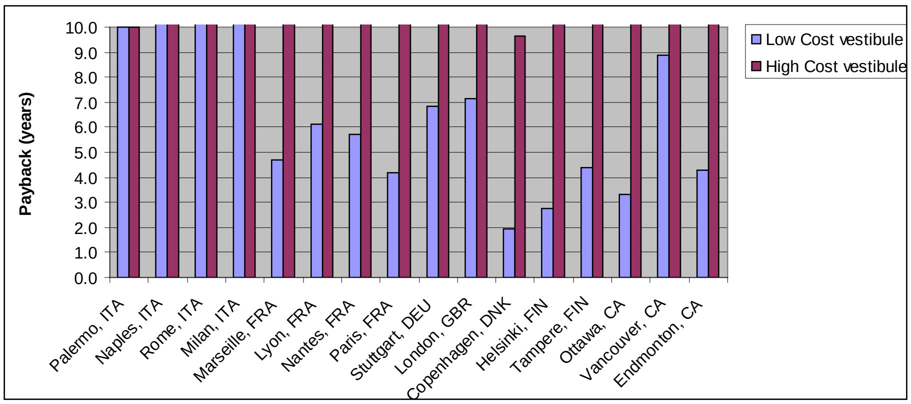

Figure 6.163. Estimated payback for high and low cost dormitory vestibules in Europe and Canada.

Level of Maturity

Mature.

Impact on Indoor Air Quality

Vestibules have little or no impact on indoor air quality. In humid climates, vestibules reduce a latent load entering the building and may prevent mold growth on the surfaces of the space adjacent to the entrance. Vestibules also improve thermal comfort on workplaces located close to the entrance.

Climatic Conditions Necessary

Although vestibules are generally considered most cost-effective in cold climates, the high cost of air-conditioning compared to heating makes this energy conservation measure useful in any climate where wind-driven infiltration is a significant factor.

Major Manufacturers

Manufacturers of security vestibules include NovaComm and Diebold. Retrofit vestibules for energy conservation are usually construction projects, designed by architects and installed by construction firms.

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6.2 Office Buildings

Building Airtightness

Application

Office and administrative buildings

Category

Building envelope

Concept

While experts seek to improve the energy efficiency of buildings through proper insulation, the airtightness of a building enclosure or envelope is a significant factor that is often overlooked (Figure 6.164). Uncontrolled air transfer through the enclosure, as well as convection, markedly increases the energy required to heat, cool and control humidity in buildings. Investigations of building enclosure problems indicate that air leakage is a leading cause of moisture problems. These problems include mold and durability problems in exterior walls and other cavities connected to the exterior, excessive rain penetration into wall cavities, poor indoor temperature and humidity control, high heating and air conditioning costs and compromised noise, fire and smoke control measures. In colder climates the problems of air leakage include icicles on exterior facades, spalling of masonry, premature corrosion of metal parts in exterior walls, high wood moisture content and rot, excessive rain penetration, and indoor temperature and humidity control problems. In hot humid climates infiltrating air can cause mold due to condensation on cold air conditioned surfaces. Sealing penetrations and reducing the chimney effect of interior ventilation can address these concerns.

Description

Improving building airtightness requires first identifying leaks, and then fixing them. When the building does not have assemblies with a designated layer selected as the airtight layer, or when the airtight layers of adjacent assemblies are not joined together, air leakage is the result. The most common problems show up in between adjacent assemblies, in particular, the wall-to-roof juncture, eaves projections where the structure penetrates the wall, metal deck with flutes open to the exterior, canopies and soffits, wall to foundation connections and window-to-wall air barrier; these kinds of problems cause “orifice” and “channel” air flow. Occasionally building materials are selected that are not tight enough by air barrier standards, causing “diffuse” air flow. In existing buildings, operable windows and doors generally are candidates for either replacement or re-gasketing and weatherstripping. Diagnostic techniques for identifying leaks (Figure 6.165) generally include:

- Blower door pressurization test (ASTM E779) and theatrical fog (ASTM E1186) can demonstrate air leakage pathways;
- Small smoke pencils and depressurization of the building can be helpful in pinpointing air leak locations and severity.
- Pressurization or depressurization (climate dependent) accompanied by infrared thermography can be helpful.

Fixing such problems can be challenging due to the difficulty of accessing gaps through hard or expensive finishes (Figure 6.166).

Figure 6.164. Cold climate exfiltration problems (left) and hot humid air infiltration problems (right).

Figure 6.165. Smoke pencil (left) and theatrical fog (center) for leakage pathways; infrared thermography (right) for heat.

Figure 6.166. Unsealed penetrations (left); open louvers to vent shafts (middle); elevator cable holes can be made tighter (right).

Application of air barrier theory in a building design requires the selection of a component or layer in an assembly to serve as the airtight layer. The building envelopes of office buildings, office portions of mixed office and open space (e.g., company operations facilities), dining, barracks and instructional/training facilities should be designed and constructed with a continuous air barrier to control air leakage into, or out of, the conditioned space. Another best practice is the clear identification of all air barrier components of each envelope assembly on construction documents and detailing of the joints, interconnections and penetrations of the air barrier components.

Boundary limits of the building air barriers must also be clearly identified, in addition to the zone or zones to be tested for building air tightness on the drawings. The air barrier material must be structurally supported to withstand the maximum positive and negative air pressures it will be exposed to, and have an air permeance not to exceed 0.02 L/s*m^2 @ 75 Pa (0.004 cfm/sq ft @ 1.57 psf) when tested according to ASTM E 2170. The material should be joined together with tape, sealant, andc. to form an assembly, whose air permeance must not exceed 0.2 L/s*m^2 @75 Pa (0.04 cfm/sq ft @1.57 psf), when tested according to ASTM E 2357. Assemblies of materials are joined together into an entire building enclosure, a six-sided box, including below-grade elements and slab if part of the heated envelope, that should not leak more than 1.25 L/s*m^2 @75 Pa (0.25 cfm/sq ft @1.57 psf) when tested according to ASTM E 779 or similar test. Penetrations of the air barrier must be sealed.

Trace a continuous plane of air-tightness throughout the building envelope and make all moving joints flexible and seal them. Support the air barrier so as to withstand the maximum positive and negative air pressure to be placed on the building without displacement or damage, and transfer the load to the structure. Seal all penetrations of the air barrier. If any unavoidable penetrations of the air barrier by electrical boxes, plumbing fixture boxes, and other assemblies are not airtight, make them airtight by sealing the assembly and the interface between the assembly and the air barrier or by extending the air barrier over the assembly. The air barrier must be durable to last the anticipated service life of the assembly. Do not install lighting fixtures with ventilation holes through the air barrier.

Provide a motorized damper in the closed position and connected to the fire alarm system to open on call and fail in the open position for any fixed open louvers such as at elevator shafts. Damper and control to close all ventilation or make-up air intakes and exhausts, atrium smoke exhausts and intakes, andc when leakage can occur during inactive periods. Compartmentalize garages under buildings by providing air-tight vestibules at building access points. Provide air-tight vestibules at building entrances with high traffic. Compartmentalize spaces under negative pressure such as boiler rooms and provide make-up air for combustion.

Existing buildings undergoing major renovations, especially the ones located in cold or hot and humid climates should be sealed to the same standard as newly constructed ones. The need for and reasonableness of destructive analysis of the state of the existing air barrier should be evaluated based on the type of renovation and cost. This can be challenging due to difficulty in accessing gaps through hard or expensive finishes. Removable ceiling tiles allow easy access to problem areas; walls require destructive access through finishes to expose gaps such as around windows. Occasionally if a gap is discovered it may be possible to blind-seal with spray polyurethane foam injected through holes drilled in the drywall. For large holes, bulkheads can be built out of studs and drywall sealed with spray polyurethane foam (SPF); smaller gaps up to 50 mm (2”) can be sealed with one part SPF; larger gaps can be sealed with two-component SPF. Note that stuffing glass-fiber insulation in cracks is not useful, because glass-fiber merely acts as a dust filter and allows air under a pressure differential to pass through.

Air leakage sealing is suggested in this order of priority:

1. Top of building
    - Attics
    - Roof/wall intersections and plenum spaces
    - Mechanical penthouse doors and walls
    - HVAC equipment gaps at sleeves
    - Other roof penetrations

2. Bottom of Building
    - Exterior soffits and canopies connected to the interior.
    - Ground floor access doors with no vestibules, weather-stripping problems,
    - Underground parking access doors
    - Exhaust and air intake vents
    - Pipe, duct, cable and other service penetrations into core of building
    - Sprinkler hanger penetrations, inspection hatches and other holes
    - Seal core wall to floor slab
    - Crawl spaces

3. Vertical shafts
    - Gasket stairwell fire doors
    - Fire hose cabinets or toilet room recessed accessories connected to shafts
    - Plumbing, electrical, cable and other penetrations within service rooms
    - Elevator room venting (reduce size of cable holes, vent electric rooms, firestop and seal bus bar openings)

4. Exterior Walls
    - Weatherstrip windows, doors, including balcony/patio doors and seal window trim
    - Exhaust fans and ducting
    - All service penetrations
    - Baseboard heaters
    - Electrical receptacles
    - Baseboards

5. Compartmentalize
    - Garages
    - Vented mechanical rooms
    - Garbage compactor rooms
    - Emergency generator rooms
    - High voltage rooms
    - Shipping docks
    - Elevator rooms
    - Workshops.

Potential Energy Savings (Qualitative)

For typical buildings, increasing building air tightness can easily result in a 10% energy saving. Savings of 15% to 25% are not uncommon.

Potential Energy Savings (Quantitative)

This report presents the effects on annual energy use and energy cost from improving building air tightness for an office building. A baseline infiltration rate is established and two levels of improvement were modeled. Infiltration is a difficult parameter on which to obtain good data. Every building has different leakage characteristics, and the infiltration varies with operation of the building and ambient conditions. Three representative air tightness levels were modeled for this exercise (Table 6.51). The first value is used as the baseline and comes from expert opinion of the typical state of existing buildings based on pressurization tests. The other two values are considered to represent reasonable performance improvements achievable with a medium effort and a best effort for sealing existing buildings.

The infiltration values at these leakage rates and pressures were calculated based on the total wall and flat roof area of the building, then converted to a pressure of 0.016 in w.g. (4 Pa), assuming a flow coefficient of 0.65. The infiltration is assumed to be constant with no variation with the operation of the HVAC systems. The HVAC systems in the office building are individual packaged systems that run independently and do not pressurize the building.

Table 6.51. Infiltration leakage rates.

Source	**Leakage Rate at 0.3 in w.g. (75 Pa) cfm/sq ft (L/s/m^2)**	**Leakage Rate at 0.016 in w.g. (4 Pa) cfm/sq ft (L/s/m^2)**	**Air Changes per Hour at 0.016 in w.g. (4 Pa)**
Baseline	1.0 (5.07)	0.15 (0.65)	0.97
Good practice for air sealing retrofit	0.50 (2.54)	0.074 (0.33)	0.48
Best practice for air sealing retrofit	0.25 (1.27)	0.037 (0.16)	0.24

To estimate the achievable savings, a number of pre- and post-retrofit year-long simulations were performed using the EnergyPlus 3.0 building energy simulation software, which models heating, cooling and ventilation flows through buildings, among other criteria. The baseline building is assumed to be an existing office building built either to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone (Baseline 1) or to have been built prior to 1960, using typical construction practices of the time with little or no insulation (Baseline 2). The office building is four stories high with an area of 23,250 sq ft (2,160 m^2) and is assumed to be occupied during the hours of 8 AM – 5 PM Monday through Friday. Further details on the office building and the baseline heating, ventilation, and air conditioning (HVAC) systems used are included in (Benne 2009).

Building airtightness was evaluated for 15 US locations and 16 international locations. The US locations were selected as representative cities for the climate zones by the Pacific Northwest National Laboratory. Flat utility tariffs were assumed for each location (i.e., no energy demand charges are included). The US energy costs are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008). The climate characteristics, energy costs and building details and construction parameters of all 31 simulations are in (Benne 2009).

Results

The results for the improving the building air tightness for each climate zone are shown in Figures 6.167 through 6.169. The energy savings are based on total building site energy consumption. Energy savings of approximately 10-15% are seen in the coldest climates studied, as shown in Figure 6.167. Expected savings from airtightness improvements decrease in warmer climates. This translates to up to $0.16 per sq ft., according to Figure 6.168. The results can vary significantly with the modeling assumptions; therefore, the results from real building projects will vary from the simulated results.

Similarly, costs vary quite a bit depending upon the needs of the building. For this analysis, the cost to achieve 0.50 cfm/sq ft was estimated to be $12,600; to achieve 0.25 cfm/sq ft, the cost was estimated to be $34,800. This includes attic sealing costs of $6,600 and top floor sealing costs of $6,000 to achieve 0.50 cfm/sq ft. Additional weatherization for the three bottom floors and sealing doorways to achieve 0.25 cfm/sq ft would add approximately $22,200. Figure 6.169 shows the average simple payback period for each climate zone studied. Improving building air tightness to some degree is usually cost-effective in all but mild climates.

Level of Maturity

Air barrier technology is in its early stages of development. While the concept is not new, the principles of maintaining an effective air barrier have not been widely applied. The design and construction communities are just beginning to wrestle with the concepts of airtightness and to develop more effective ways – diagnosis techniques, materials, and remediation procedures – to improve building air tightness. In the United Kingdom, commercial and office buildings are required to be tested before occupancy to meet Part L air leakage requirements. In the United States, the US Army Corps of Engineers has recently adopted similar testing requirements. Air sealing existing buildings is specialized technology and requires specialized expertise.

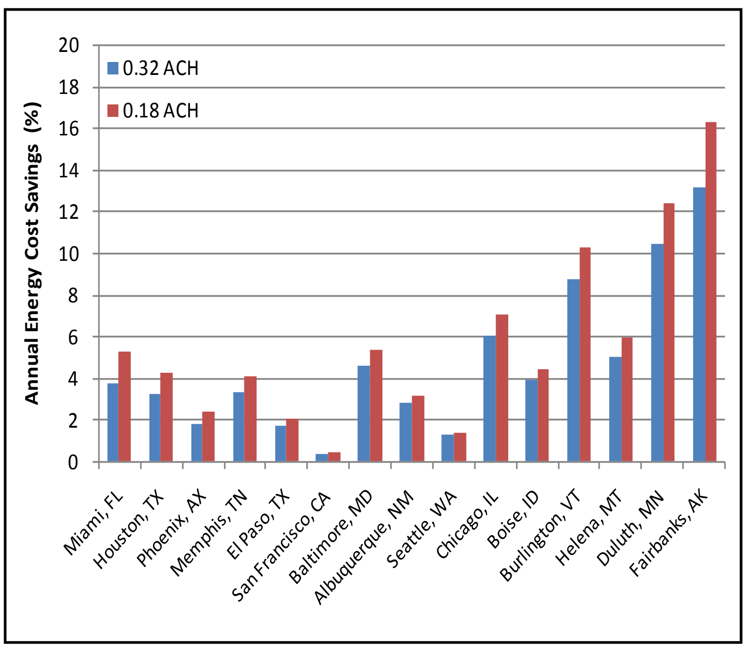

Figure 6.167. Percent annual energy savings for US (left) and international (right) locations.

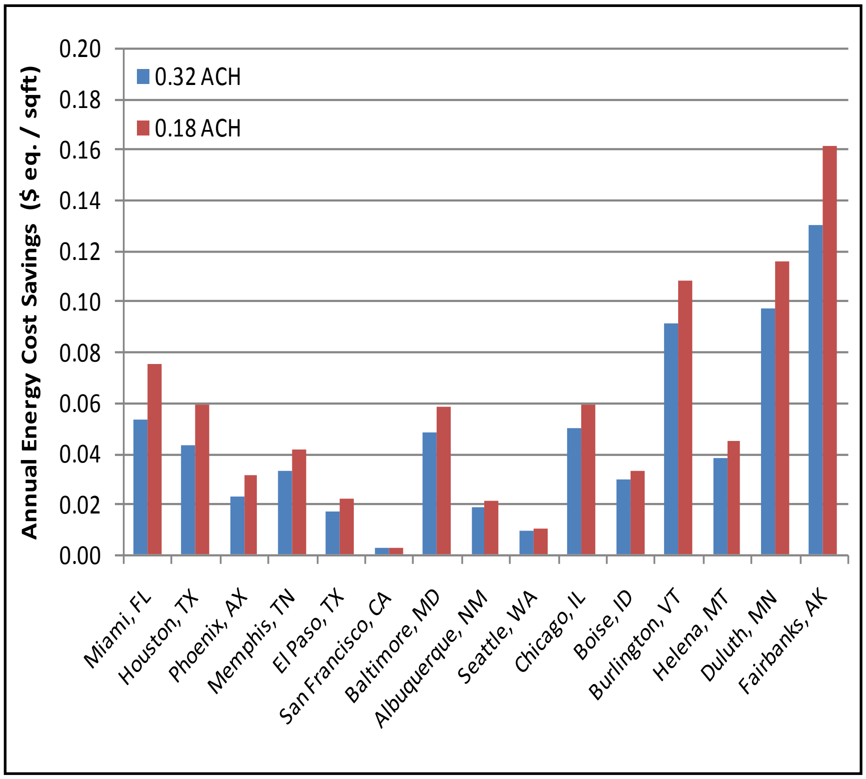

Figure 6.168. Annual energy cost savings per unit area for US (left) and international (right) locations.

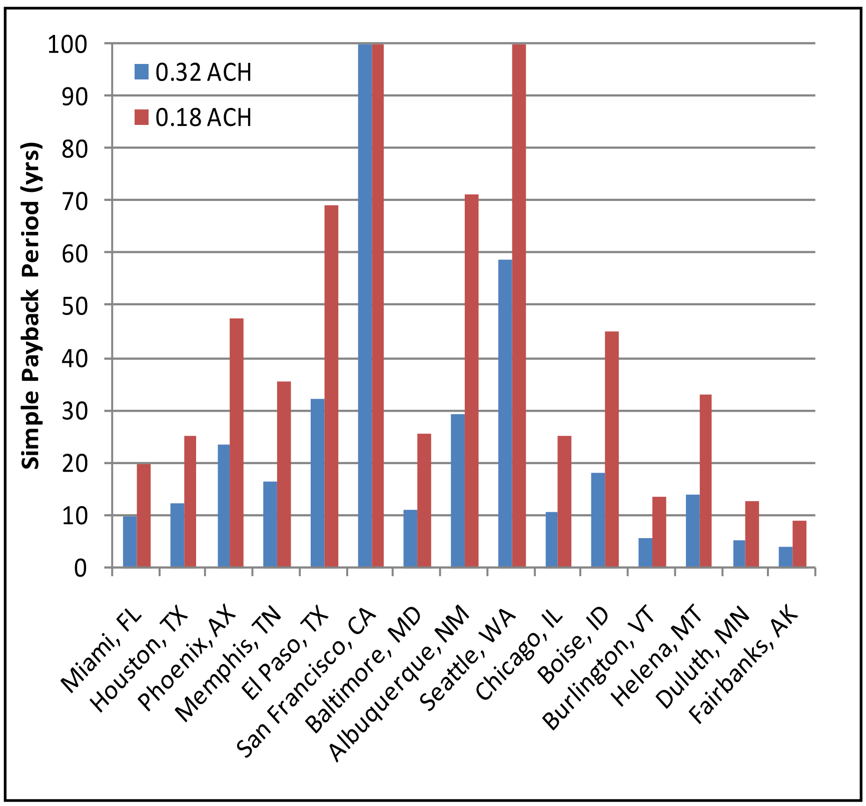

Figure 6.169. SPB period for US (left) and international (right) locations.

Impact on Indoor Air Quality

Techniques to improve air tightness have been motivated as much by air quality concerns and mold/fungus/moisture control as by energy savings. A major impact is seen from reducing infiltration, including the ability to better control the HVAC system, reduce mold and microbial generation, improve infection control, and address pollutant migration problems.

Climatic Conditions Necessary

The technology works in any climate but is most effective in colder climates.

Major Manufacturers

A list of manufacturers and contractors can be found on the Air Barrier Association's website http://www.airbarrier.org

Existing Airtightness Standards

The following airtightness performance criteria are based on the "air leakage rate of the building envelope" as defined by ASHRAE 90.1 -2004 addendum z. It is the area of the enclosure based on the building enclosure pressure boundary, in other words, the "six-sided box", including slab area and below grade components within the conditioned space; "air permeability" as defined in the United Kingdom and "Normalized Leakage Rate at 75 Pa" or NLR_{75} as defined in Canada.

- UK Part L energy requirements (including Australian requirements) require buildings other than single-family dwellings to be air sealed to an airtightness of 10 m^3/hr*m^2@50 pascals per m^2 surface area; this is converted to 13 m^3/hr*m^2 or 3.6 L/s*m^2 @75 pascals surface area—assuming n=0.65 (Potter 2007).
- In the United Kingdom, normal practice for commercial buildings is 5 m^3/hr*m^2@50 pascals per m^2 surface area (6.5 m3/hr*m^2 or 1.8 L/s*m^2 @75 pascals per m^2 surface area—assuming n=0.65) (ATTMA, BSRIA).
- UK best practice for commercial buildings is 2 m^3/hr@50 pascals per m^2 surface area (2.6 m^3/hr or 0.72 L/s*m^2 @75 pascals per m^2 surface area—assuming n=0.65) (ATTMA, BSRIA).
- ASHRAE Addendum z to 90.1 - 2004 allows 2 L/s*m^2 @ 75 Pa for whole buildings, 0.2 L/s*m^2 @ 75 Pa for assemblies and 0.02 L/s*m^2 @ 75 Pa for air barrier materials.
- The US Army Corps of Engineers airtightness requirement is set at 1.25 L/s*m^2 @ 75 Pa surface area.
- Massachusetts requirements are for air barrier materials, maximum permeance of 0.02 L/s*m^2 @ 75 Pa.
- Canada's National Model Building Code has a requirement of maximum air permeance of 0.02 L/s*m^2 @ 75 Pa for air barrier materials, with a recommendation of maximum 0.1 L/s*m^2 @ 75 Pa for assemblies of materials.

Acknowledgement

Tony Woods of Canam Building Envelope Specialists was an eloquent and energetic proponent of improving building envelope integrity. He was a pioneer in developing innovative methods to diagnose and correct building envelope flaws. "From bungalow to skyscraper, school to government, and all points in between, Woods improved the

performance of almost every type of structure." [Building Performance Institute] His seminal contributions to this technology were immense; he will be missed and, we hope, remembered.

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Exterior Wall Insulation

Application

Office or administrative buildings.

Category

Building envelope.

Concept

Often the only practical method to improve the thermal resistance of an older building's envelope is by installing external insulation. The type of insulation technology used affects the thermal performance of the building envelope, including reduction of thermal bridging, air leakage, and vapor and water penetration. Thermal performance of the building walls, along with other envelope elements, influences the energy demand of a building in two ways. It affects annual energy consumption and thus operating costs for building heating, cooling and humidity control. Thermal performance also influences peak loads, which will determine the size of heating, cooling. and ventilation equipment and will in turn impact investment costs.

This information sheet focuses on one typical method to improve the thermal resistance of external walls: the use of external insulation using expanded polystyrene with a weather-resistant facing. The exterior insulation finish system (EIFS) is attached to the existing exterior wall using a system of anchors and adhesive.

Description

In retrofit projects, older buildings can be insulated from the outside (Figure 6.170a) or the inside (Figure 6.170b). All things considered, the best way to insulate a building wall is on the outside as this minimizes problems with thermal bridges and does not reduce the usable floor area. With sufficient exterior insulation, the dew point temperature should not occur within the wall cavity, thus reducing the risk of condensation. Current external insulation technologies offer different color and texture options and improve the façade's appearance.

However, external insulation may not be approved for use with some buildings (e.g., historic buildings). In such cases, internal insulation may be used. The interior of the wall structure can be insulated with fiberglass (blown or batts), mineral wool, foam, or other materials. Insulation can also be applied to the interior surface of the walls, or a combination of wall cavity insulation and interior surface insulation may be used. The choice of techniques and materials depends on the wall structure, building use, current furnishings and need to preserve interior space, andc.

a. b. c.

Figure 6.170. Retrofitted Army barracks with exterior insulation (a), interior insulation of the retrofitted administrative building at the Rock Island Arsenal (b, c).

While the energy savings of a specific increase in wall R-value (with proper vapor barrier and sealing of wall openings) will be the same whether the insulation is applied externally or internally, the costs of internal insulation can vary widely depending on product, materials, requirements for interior finishing, and costs of accessing the wall from the interior. Insulating the wall from inside is more likely to inconvenience the building's residents and disrupt activities. Internal insulation reduces usable floor area and may have poorer aesthetics. Because the technology choice and cost of internal wall insulation is so building-specific, this technology fact sheet focuses on EIFS only. However, the energy savings estimates for EIFS can be applied to any project that is considering internal insulation.

EIFS increases a building envelope's R-value by about R-3.85/in. Typically, thicknesses of 1, 2, 4, 6, or 8 in. (~2.5, 5, 10, 15, or 20 cm) are installed. Up to 40 cm (15.72 in.) of insulation can be glued and anchored to the wall [6]. Sometimes, anchor systems limit the thickness of insulation. Each thickness of insulation may use one of two alternative installation types. The less expensive option, known as a "face-sealed system," uses a sealed outermost layer of the exterior facade to help repel moisture. The more expensive "drainage system" (Figure 6.171) option uses a barrier installed behind the actual insulation to avoid moisture buildup within the wall by removing any moisture that penetrates the outer layer, thereby preventing mold or fungal growth, corrosion of the building wall, and/or freezing in winter. Moisture intrusion could lead to separation of the EIFS from the building wall, creating a path for more moisture intrusion. Differences in the two installation methods have negligible effect on the energy performance of the building; the primary difference is reflected in the cost of installation and prevention of water damage.

State-of-the-art insulation technologies include:

- high efficient insulation materials with lower thermal conductivity
- graphite embedded expanded polystyrene (EPS)
- high performance plaster systems
- vacuum insulation systems.

An example of higher insulation thickness/lower thermal conductivity insulation is mineral wool/polystyrene with a thermal conductivity of 0.030/0.035 instead of "regular" 0.040 W/mK.

Graphite embedded EPS reduces the radiant heat transfer and reduces thermal conductivity by about 20%. It requires less than half the raw materials of conventional EPS.

Different types of high performance plaster systems include:

- *Integration of glass bubbles into the structure*: Glass bubbles result in absorption of sunlight, less convective heat losses, increase of useful gains from direct and diffuse radiation during the heating season, and 15-20% lower energy losses compared to a conventional plaster system;
- *Combination of infrared (IR)-coatings with a lotus effect*: The paint protects the plaster better against rainwater absorption, provides lower conductivity throughout the year, and leads to higher surface temperatures;
- *Phase change materials on interior plaster*: Micro-encapsulated wax droplets in plaster result in extra thermal capacity, better performance at temperature peaks, and an increase of passive solar gains in winter and decrease of overheating in summer.

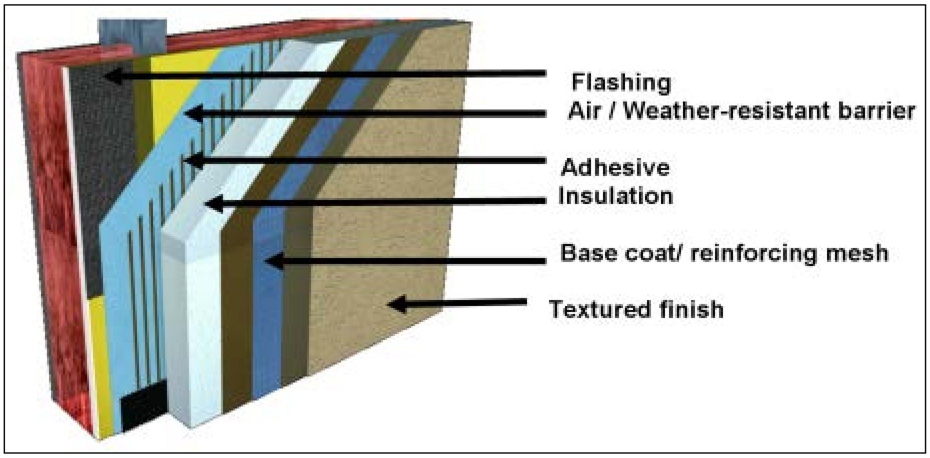

Figure 6.171. EIFS construction with drainage.

Vacuum insulation systems that use evacuated silica gel material covered by a high performance aluminum foil have thermal conductivity reduced by more than a factor of ten compared to conventional material. They also enable smaller thicknesses of insulation compared to EPS.

Energy Savings (Qualitative)

The reduced thermal conductivity from retrofitting a building with EPS typically results in 10 to 40% energy savings, depending on the initial level of insulation and the climate. Energy savings tend to taper off quickly beyond 2 in. (~5 cm) of insulation in warmer climates, but colder climates often benefit significantly with additional thickness of insulation, because protection from a larger temperature differential is needed. Therefore, thicker insulation layers are more cost effective to install in colder climate zones. In addition to energy saving and investment cost reduction (from being able to install smaller sized HVAC equipment), a better insulated building provides other significant advantages, including higher thermal comfort because of warmer temperatures on the interior surfaces in winter and lower temperatures in summer. This also results in a lower risk of mold growth on internal surfaces.

EIFS also offers benefits during construction of new buildings. For instance, the system offers significant savings on construction costs, compared to a brick veneer system. The light weight of EIFS could also offer potential savings in the building's structural steel as the weight of the façade is reduced. In addition to contributing to energy cost savings, decreased infiltration improves air quality inside the building by keeping much dust, pollen, and car exhaust from entering. The consequent reduction in drafts, noise, and humidity contribute to the comfort of individuals inside the building.

Energy Savings (Quantitative)

This analysis examined the effect on annual energy use and costs of retrofitting an existing office building with improved exterior wall construction. To estimate achievable savings, a number of pre- and post-retrofit year-long simulations were performed using the EnergyPlus 3.0 building energy simulation software, which models heating, cooling, and ventilation flows (among other criteria) through the subject buildings.

The baseline building is assumed to be an existing administrative facility built either to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone (Baseline 1) or to have been built prior to 1960, using typical construction practices of the time with little or no insulation (Baseline 2). The office building is four stories high with an area of 23,250 sq ft (2,160 m^2) and is assumed to be occupied during the hours of 8 a.m. – 5 p.m. Monday through Friday. Reference [4] includes Further details on the office building and the baseline heating, ventilation, and air-conditioning (HVAC) systems used.

The application of EIFS was evaluated for 15 US locations and 16 international locations. The US locations were selected as representative cities for the climate zones by the Pacific Northwest National Laboratory (PNNL) [3]. Flat utility tariffs were assumed for each location (i.e., no energy demand charges are included). The US energy costs are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008). Reference [4] details the climate characteristics, energy costs, building details, and construction parameters of all simulations. Reference [5] provides design guidance for application of wall insulation for non-US locations.

Tables 6.52 and 6.53 summarize several modeled different systems for US and international locations, respectively. Along with the added insulation, improvements in the air tightness of the office building were modeled. The air tightness improvements ranged from the baseline of 1.0 to 0.85 cfm/sq ft (5.24 – 4.45 $m^3/sec/m^2$) at 75 Pa. Proper installation of the EIFS on the walls and around windows and doors is expected to reduce infiltration to some extent. The full 15% reduction (to 0.85 cfm/sq ft [4.45 $m^3/sec/m^2$] at 75 Pa) modeled might require some additional work to seal the building, which is not included in the cost estimates. Best practice is to improve the building's airtightness at the same time as the EIFS installation, using the same construction crew; the additional costs for ensuring proper window and door frame sealing are minimal while the EIFS is being installed. Therefore, the 15% reduced infiltration is assumed in all the analyses presented here.

Table 6.52. US scenario descriptions.

Building Walls Tested	Baseline	Wall Construction	Additional Insulation	Air Leakage (cfm/sq ft @ 75 Pa)	Air Leakage ($m^3/sec/m^2$ @ 75 Pa)
Baseline 1	—	Wood framing with fiberglass insulation and brick facade	—	1.00	5.24
Baseline 2	—	Same as Baseline 1, but pre-1960 construction	—	1.00	5.24
1-in. EPS*	1	Baseline with 1 in. EPS	R-3.85	0.85	4.45
2-in. EPS*	1	Baseline with 2 in. EPS	R-7.70	0.85	4.45
4-in. EPS*	1	Baseline with 4 in. EPS	R-15.4	0.85	4.45
6-in. EPS*	1	Baseline with 6 in. EPS	R-23.1	0.85	4.45
8-in. EPS*	1	Baseline with 8 in. EPS	R-30.8	0.85	4.45
1-in. EPS*	2	Baseline with 1 in. EPS	R-3.85	0.85	4.45
2-in. EPS*	2	Baseline with 2 in. EPS	R-7.70	0.85	4.45
4-in. EPS*	2	Baseline with 4 in. EPS	R-15.4	0.85	4.45
6-in. EPS*	2	Baseline with 6 in. EPS	R-23.1	0.85	4.45
8-in. EPS*	2	Baseline with 8 in. EPS	R-30.8	0.85	4.45

*1 in. – 2.5 cm; 2 in = 5.1 cm; 4 in. = 10.2 cm; 6 in = 15.2 cm; 8 in = 20.3 cm.

Table 6.53. International scenario descriptions.

Scenario	Description	Additional Insulation	Air Leakage (cfm/sq ft @ 75 Pa)	Air Leakage ($m^3/sec/m^2$ at 75 Pa)
Baseline	Represents current construction	—	1.00	5.24
2-in. EPS*	Baseline with 2 in. EPS	R-7.70	0.85	4.45
4-in. EPS*	Baseline with 4 in. EPS	R-15.4	0.85	4.45
6-in. EPS*	Baseline with 6 in. EPS	R-23.1	0.85	4.45
8-in. EPS*	Baseline with 8 in. EPS	R-30.8	0.85	4.45

*2 in = 5.1 cm; 4 in. = 10.2 cm; 6 in = 15.2 cm; 8 in = 20.3 cm.

Two baseline scenarios were used when studying the US locations to describe potential existing conditions of barracks prior to a retrofit:

- Baseline 1: This baseline accounts for pre-retrofit barracks with exterior walls consisting of wood framing with fiberglass insulation and brick façade meeting the minimum requirements of ASHRAE Standard 90.1-1989.
- Baseline 2: This baseline also accounts for pre-retrofit barracks with exterior walls consisting of wood framing and brick facade. However, in this scenario, the existing building is assumed to have been built using pre-1960 typical construction practices with no prior insulation incorporated.

Tables 6.54 and 6.55, respectively, list cost estimates for each type of insulation for US and international locations. Recommended practice is to use the drainage system. In humid climates, any flaw in the vapor barrier, either from mistakes in installation or post-installation penetrations of the vapor barrier or façade, can result in condensation within the wall. Because of the prevalence of this type of problem, provision for drainage is essential in warm, humid climates. In colder climates such as Europe, face-sealed EIFS (i.e., without the drainage) is prevalent. However, even in cold climates, penetrations in the vapor barrier or façade can allow moisture intrusion in summer or winter. Unrepaired, this can result in significant moisture-caused damage or fungal growth. Government buildings and public housing (i.e., not privately-owned residences) are more likely both to experience damage from careless usage or vandalism and to not have such damages repaired promptly. Thus, even for Europe, the use of the drainage system in public buildings is recommended. (This analysis investigated the EIFS with a drainage system only.)

Results

Figure 6.172 shows the HVAC energy savings achievable with various thicknesses of insulation in selected US locations. These energy savings can also translate to reduced HVAC system capacity required to heat or cool the building. Baseline 1 assumes the building meets ASHRAE Standard 90.1-1989; such buildings will already have some insulation in cold climates, but little to no wall insulation in warm climates. For cold climates, the EIFS in Baseline 1 yields up to about 10% reduction on average in HVAC energy use (for 8-in. [20-cm] EIFS compared to the baseline). Such savings would usually result in a negligible to small capital cost savings for the HVAC system. For hot and humid climates, on the other hand, an HVAC energy savings of 20% can be expected (for 8-in. [20.3-cm] EIFS compared to the baseline, which is typically an uninsulated building); this could represent a significant capital cost savings if the building's HVAC system is renovated along with the building's envelope.

Table 6.54. US retrofit costs for external insulation ($/sq ft).

System Thickness	1 in.*	2 in.*	4 in.*	6 in.*	8 in.*
Face-Sealed	7.00	7.20	7.60	8.00	8.40
Drainage	8.00	8.20	8.60	9.00	9.40
Insulation Only	0.20	0.40	0.80	1.20	1.60
*1 in. = 2.5 cm; 2 in = 5.1 cm; 4 in. = 10.2 cm; 6 in = 15.2 cm; 8 in = 20.3 cm.					

Table 6.55. International retrofit costs for external insulation.

Scenario	Face-Sealed System			Drainage System		
	CAD/m^2	EUR/m^2	GBP/m^2	CAD/m^2	EUR/m^2	GBP/m^2
2-in. EPS*	63.94	41.34	32.64	95.91	62.00	48.96
4-in. EPS*	74.06	47.88	37.81	106.03	68.55	54.13
6-in. EPS*	83.97	54.29	42.87	115.94	74.95	59.18
8-in. EPS*	93.88	60.70	47.93	125.85	81.35	64.23
*2 in = 5.1 cm; 4 in. = 10.2 cm; 6 in = 15.2 cm; 8 in = 20.3 cm.						

The EIFS installed in Baseline 2, which is applied to pre-1960 construction with no insulation, results in much greater savings in HVAC energy use in cold climates (approximately 35-40% savings). Baseline 2 scenarios in hotter climates typically see savings ranging from 20% to 40%, since Baselines 1 and 2 for these climate zones are usually identical or very close.

Figure 6.173 shows expected annual energy cost savings for US locations in Baselines 1 and 2. When comparing to the Baseline 1 building, warmer climates (e.g., Miami, FL) see average savings of about $0.10/sq ft ($1.11/m^2). These buildings are not as likely to see significant increases in savings beyond a 1–2-in. (2.5–5 cm) layer of insulation. Colder climates (e.g., Boise, ID) also only see average savings of about $0.10 per sq ft or less for the first inch of added EIFS because the building already is insulated (ASHRAE 90.1-1989). Such buildings in colder climates do tend to benefit from additional insulation thickness. This is seen when comparing to the Baseline 2 building with no pre-retrofit insulation. The warmer climate buildings exhibit only slightly higher cost savings as in Baseline 1, because the Baseline 1 buildings have little wall insulation. The greatest savings accrue in colder climate zones since they have the largest temperature differential to overcome, and unlike Baseline 1 (which already has appropriate levels of insulation for specific climate zones), Baseline 2 cold climate buildings have little insulation. Energy cost savings for international locations (Figure 6.174) show similar results.

A rough indicator of the economic feasibility of EIFS is the ratio of capital cost to annual energy savings, sometimes referred to as "simple payback" (SPB). (The simple payback period for the US locations is calculated based on the annual energy cost savings combined with estimates of the retrofit cost. Interest and inflation are neglected.) As previously mentioned, results from only the drainage EIFS are presented. Figure 6.175 shows SPB for Baselines 1 and 2, respectively. The SPB period is much shorter in Baseline 2 because more significant energy savings are realized due to there being no prior insulation. Furthermore, Figure 6.176 shows that Baseline 1 buildings have similar SPB since insulation installed in accordance with ASHRAE 90.1-1989 is designed to match the climate zone. Overall, buildings with no prior insulation are much better candidates for external wall insulation, especially in colder climates. Figure 6.177 shows the SPB period for international locations. Reference [5] provides additional insulation design guidance for international locations.

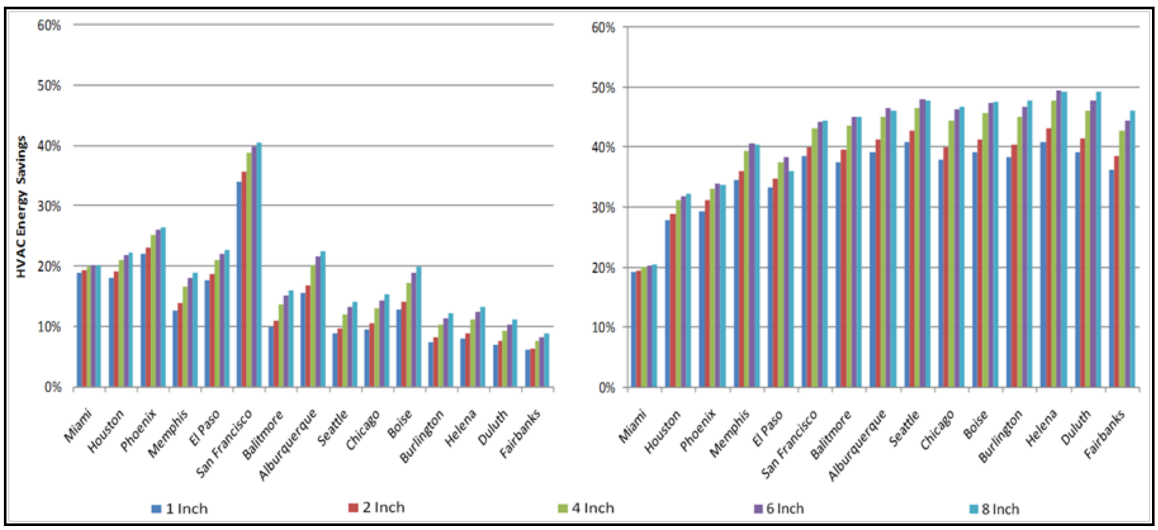

Figure 6.172. HVAC annual percentage energy savings for baselines 1 (left) and 2 (right).

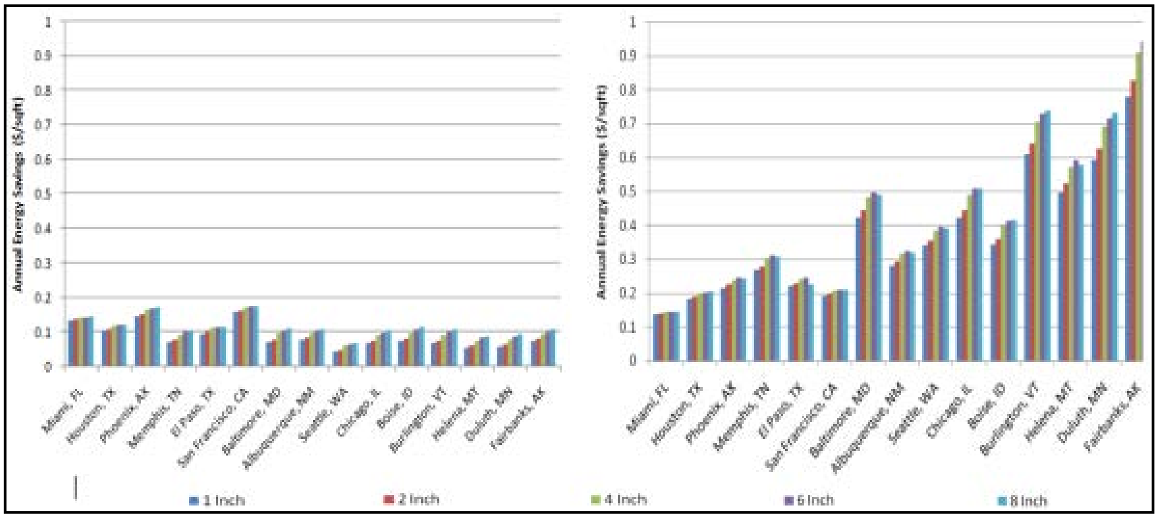

Figure 6.173. Annual energy cost savings for baselines 1 (left) and 2 (right) for US locations.

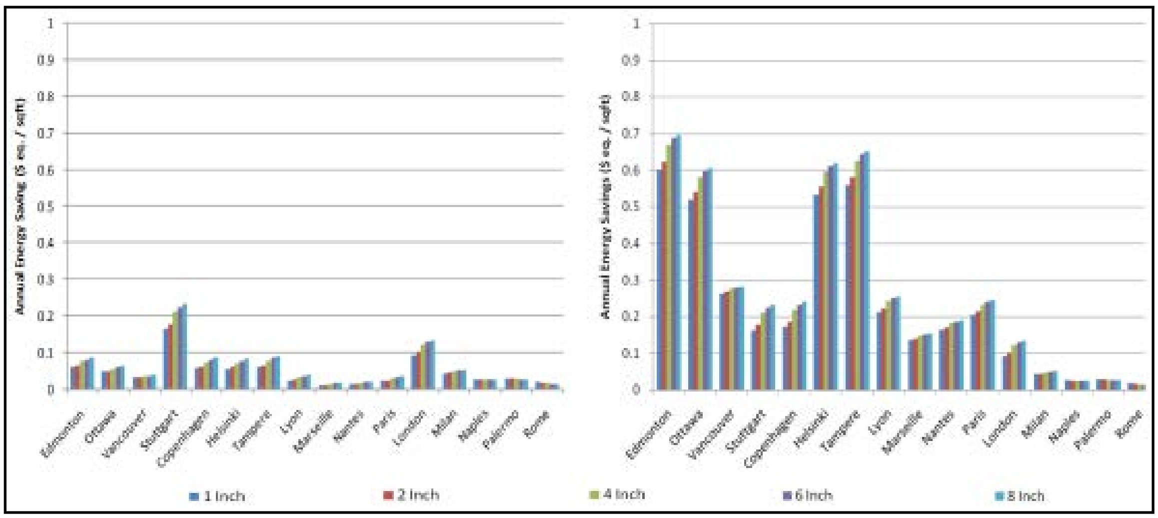

Figure 6.174. Annual energy cost savings for baselines 1 (left) and 2 (right) for international locations.*

* Dollar equivalents are based on exchange rates obtained while preparing this report; they are subject to variation.

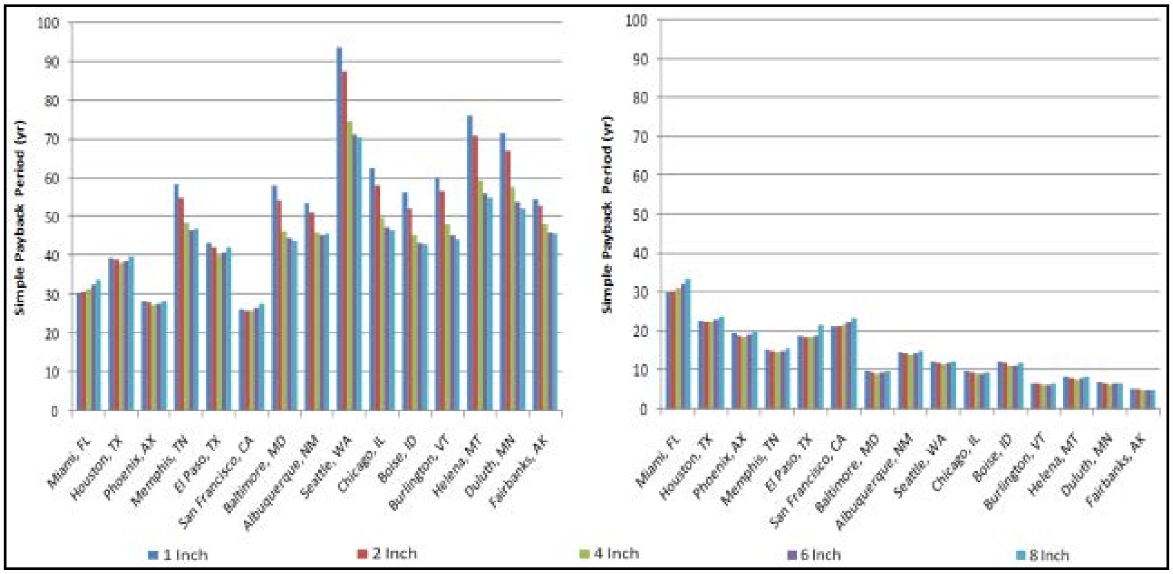

Figure 6.175. SPB period for baselines 1 (left) and 2 (right) with drainage system installation.

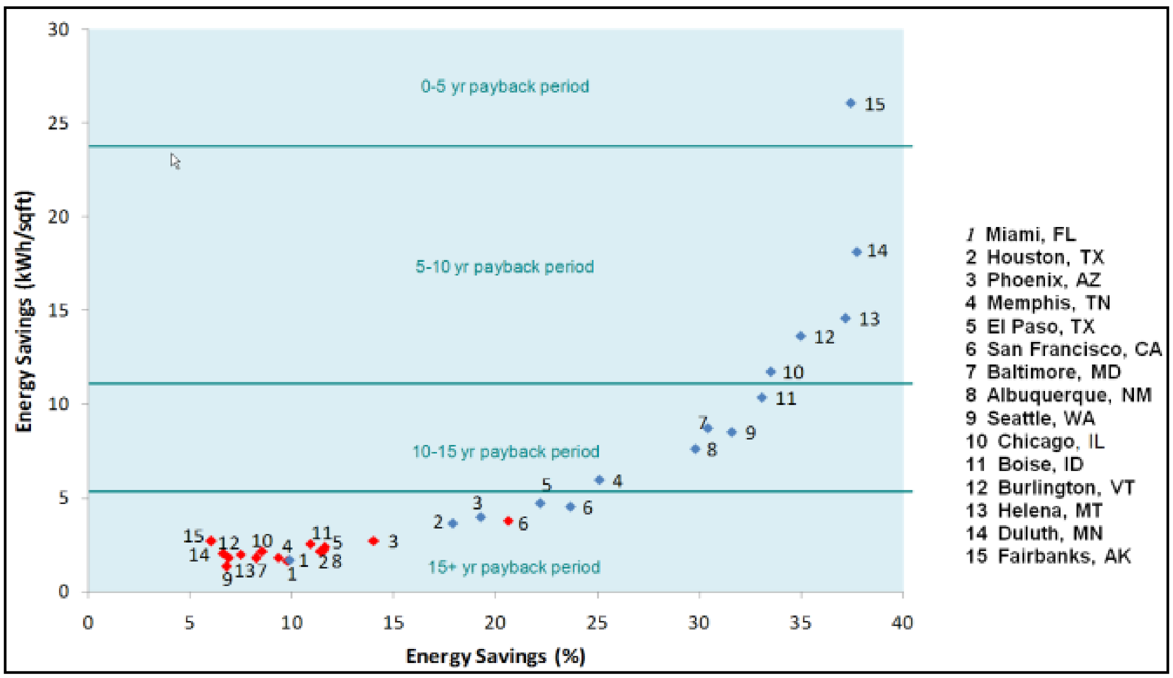

Figure 6.176. Comparison of SPB periods for baselines 1 (Red) and 2 (Blue) with 4-in (~102-mm). thickness, US Locations.

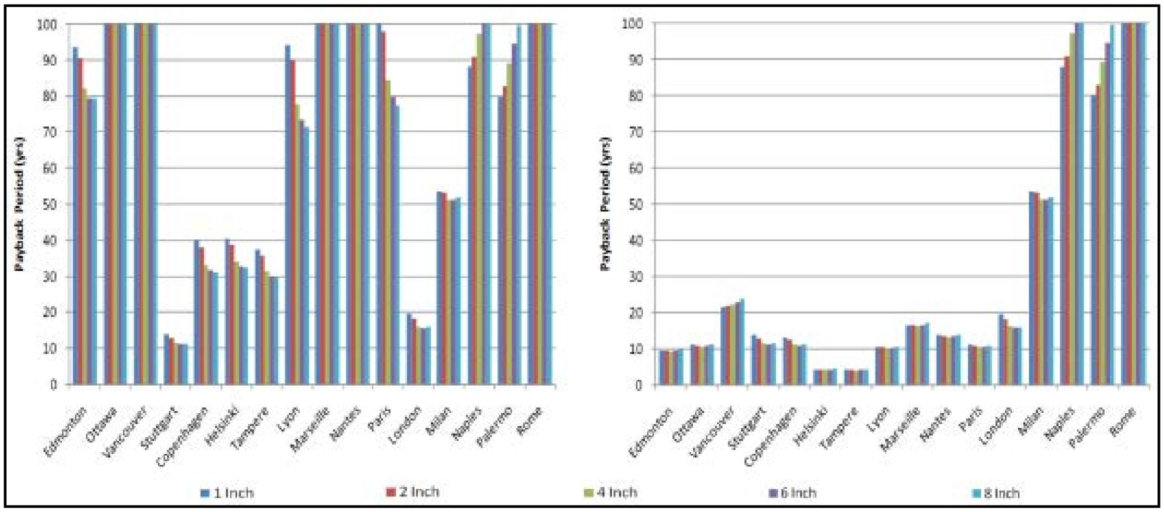

Figure 6.177. SPB period for baselines 1 (left) and 2 (right) with drainage system installation – international sites.

Summary Guidance

Wall insulation is most cost-effective in cold climates. Buildings in hot climates buildings will also benefit from increasing wall R-value, but the benefit per inch of insulation tends to be less than in cold climates because the temperature differential between the building interior and ambient air is greater in cold weather (e.g., ΔT of about 15–25 °C [~30–40 °F]) than in hot weather (e.g., ΔT of about 10 – 15 °C [~20 – 30 °F]). Existing buildings in warm climates are likely to have little to no pre-existing wall insulation. Buildings in colder climates are likely to already have been insulated to some extent. While adding insulation to a warm or moderate climate building may result in appreciable energy reduction in terms of percent, the magnitude of energy saved is smaller, and therefore the cost savings are smaller. The primary costs of EIFS are the initial set-up (project preparation, scaffolding, andc.) and the façade. *Therefore, if a building's façade needs repair or replacement, adding insulation though EIFS is strongly recommended.* The cost of the insulation itself is small compared to the rest of the project. *For new construction, insulation to the extent possible should be included when constructing the walls. For a retrofit project requiring a new façade, it is recommended to install the maximum amount of insulation physically possible.*

While the cost of additional insulation is small compared to the cost of the wall or façade, it is not negligible. The "optimal" level of insulation based on life cycle costs can be determined from building energy simulation models. For retrofit projects in moderate climates, an additional layer of 2 in. (~5 cm) of insulation of may be sufficient (adding R-8), and 4 in. (10.2 cm, R-15) should be considered in hot climates. For cold or very cold climates, additional insulation thickness (up to 8 in. [20 cm] R-30) is usually justified. Table 6.56 provides broad guidance for application of EIFS for several scenarios.

Major Manufacturers

Insulation material and system manufacturers:

- BASF Aktiengesellschaft: http://www.basf.de
- Rockwool: www.rockwool.com
- Isover: www.isover.com
- STO: www.sto.com

- IVPU-Industrieverband Polyurethan-Hartschaum e.V.: http://www.ivpu.de/
- North American Insulation Manufacturers Association (NAIMA): http://www.naima.org/main.html
- Dryvit - http://www.dryvit.com/

Table 6.56. General guidance for application of EIFS.

Climate	Building Scenario: Existing new construction or façade repair/replace project?	Building Scenario: Some Existing Insulation? (ASHRAE 90.1-1989)	Add Insulation? No / Yes-Minimal (2 – 4 in.)/ Yes–Max (6 to 8 in.)*
Mild	No	No	No
		Yes	No
	Yes	No	Yes-Minimal to 4 in.
		Yes	Yes-Minimal
Hot/Tropical	No	No	Yes-Minimal to 4 in.
		Yes	No
	Yes	No	Yes-Minimal to 4 in.
		Yes	Yes-Minimal
Cold	No	No	Yes-Max
		Yes	Yes-Minimal to 4 in.
	Yes	No	Yes-Max
		Yes	Yes- add 4 in. or more
Extreme Cold	No	No	Yes-Max
		Minimal	Yes-Max
		Yes	Yes-total should be 6 in. or more
	Yes	No	Yes-Max
		Yes	Yes-Max
*2 in = 5.1 cm; 4 in. = 10.2 cm; 6 in = 15.2 cm; 8 in = 20.3 cm.			

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Replacing Incandescent Lamps with Compact Fluorescents

Application

Commercial and residential buildings.

Category

Lighting.

Concept

Incandescent lamps, commonly known as “bulbs,” are still widely used today in downlighting, track lighting and accent lighting applications because of their low cost and simplicity. Twenty-four percent of energy consumption from lighting in non-residential buildings is used to operate incandescent lamps. In most applications, they can be replaced with fluorescent technology that provides similar capability at much lower energy cost and potential maintenance savings.

Description

Figure 6.178. Standard screw-based CFL.

The standard incandescent lamp (Figure 6.178) can be inexpensive to purchase, but factors such as relatively short lamp life and low efficiency make it less effective over time compared to fluorescent lighting technology. Compact Fluorescent Lamps, or CFLs, have been an efficient replacement option for incandescent applications for many years but early issues of color, size and cost inhibited their effective and widespread use. However, improvements in the technology in recent years have solved these issues, and CFLs are currently a very effective option for most lighting applications. These improvements have allowed for a decrease in the size of CFLs, making them an appropriate replacement in almost all incandescent applications. Their color rendering properties (the ability of the light to accurately represent true colors) have also advanced significantly along with an improvement in Correlated Color Temperature (CCT). CCT is the metric that distinguishes how cold (blue) or warm (yellow) the light appears. In the past, high CCT has deterred people from using CFL lamps in residential or office settings because of their cold appearance. CFLs can now be purchased with a variety of different CCTs, from the warm, yellow look of an incandescent (about 2700K) lamp to a crisp bluish-white (4100 K).

There are two primary approaches to retrofitting current lighting systems with CFLs. The first is a simple replacement of the screw-in incandescent lamp with a similar screw-in CFL. These screw-in CFLs are self ballasted (that is, they include the lamp and the required ballast) and cost as little as $2[*]. A second approach is to replace the lighting fixture with one that is designed with hard-wired ballast and plug-in sockets that will only accept CFL lamps. The initial cost is usually more expensive (up to $78), and requires

[*] Costs are based on comparable products available publicly on the US retail market

more specific matching of lamps when they need to be replaced, but it also eliminates the possibility of their replacement with less efficient incandescent lamps. The self-ballasted screw-in lamp is the easiest option, but if "take-back" (later replacement with less efficient incandescent lamps) is an issue, the hard-wired fixture should be considered.

In either option, there are a few application considerations. First, do not choose a replacement based on the manufacturer's recommendation alone. The lumen output of the existing incandescent lamp should be compared to the lumen output of the replacement, which should be listed on both the CFL and incandescent lamp packages. The light output of CFLs degrade 4% more on average than incandescent lamps, so unless a space is over-lit, a CFL with a greater initial light output than the incandescent lamp it is replacing should be chosen. Also, consider the size of the CFL replacement. Most CFLs comparable to the incandescent lamp they are replacing will fit in the same socket. CFL size does increase with wattage, so it is important to ensure the lamp with the correct light output will fit.

Energy Savings (Qualitative)

Potential energy savings are directly linked to lamp wattage, and most importantly, the amount of time the lighting is used. In spaces that are occupied for long periods of time, the energy saving potential is large. Over $70 dollars can be saved annually in a hallway lit with four standard 75-watt incandescent lamps on for 8 hours a day, everyday.*

Additional types of savings can be substantial, but they are too variable to include in a simple payback analysis. For example, costs associated with maintaining the lighting systems are reduced because CFL lamps only need to be replaced 10% as often as incandescent lamps. Also, in climates requiring air conditioning, the lower heat generated by CFLs also reduces the building's cooling requirement. (Conversely, during winter heating seasons, the "waste" heat generated by an incandescent bulb contributes positively to heating the building.)

Energy Savings (Quantitative)

Payback is a simplified measure of the time needed to pay the additional cost of a replacement technology with the expected energy savings. Figure 6.179 shows an example of the calculated payback for replacing a 75W incandescent ($0.50, 1,000-hr rated life) with a 13W CFL replacement ($3.00, 5,000-hr rated life) at different utility rates and during different weekly operating hours. Savings do not reflect the expected reduction in maintenance.

Results

Payback Period

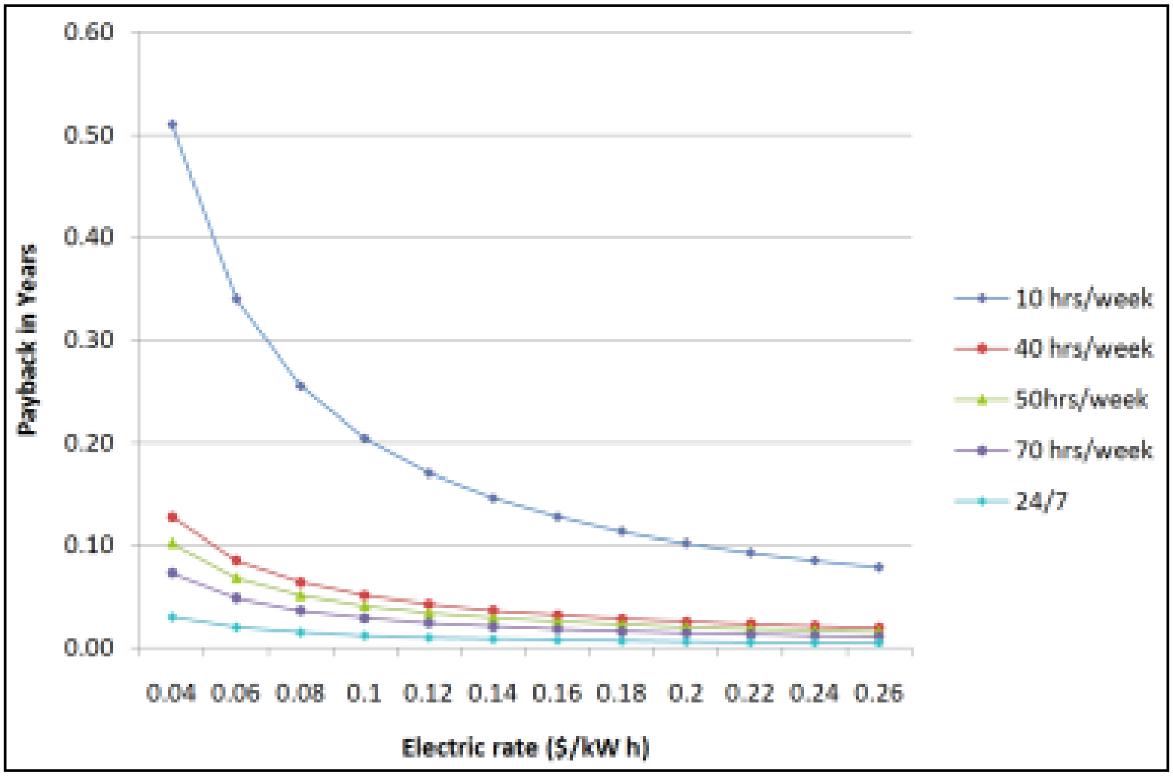

Figure 6.179. Simple payback of incandescent retrofit with CFLs.

The simple payback of this change in the lighting system is relatively quick when compared to other energy efficient lighting upgrades. One may calculate a more precise payback with actual cost, rated life, utility rates and wattage values with the following formula:

$$Y_{Payback} = \_\_ \ C_1-[(L_1/L_2)*C_2] \ \_\_\_, \ T_A*E_{Rate}*(W/1000)$$

where:

L_1 =rated life of CFL
L_2 =rated life of incandescent lamp
$Y_{Payback}$ = length of time (years) for energy savings to pay for technology
C_1 = cost of CFL
C_2 =cost of incandescent lamp
T_A =annual length of time lights are operated
W =wattage savings old wattage-new wattage.

Note: With the widespread availability of CFLs in recent years, they are often less expensive than incandescent lamps once length of use is considered. If the numerator in the equation is negative, the payback for CFL implementation is instantaneous and all decreases in energy will be savings.

There will also be a reduction in HVAC costs during the cooling season since CFLs produce less heat than incandescent lamps. Table 6.57 lists The estimation of percentage electricity energy savings on a whole building basis for a typical year (kWh/Yr). This provides an estimated savings percentage of whole building's electricity use for various weather locations based on a percentage reduction in total building light power density (LPD) from 10 to 70%. The table values include the expected reduction in electricity use of HVAC equipment associated with the reduced cooling required from reducing lighting energy (heat) to the building.

Table 6.57. Reduction in whole building electricity use per year from reduction in lighting power.*

Representative weather location	Percent reduction in total lighting power						
	10%	20%	30%	40%	50%	60%	70%
San Francisco, CA	3.9	7.7	11.5	15.4	19.2	23.1	26.9
Seattle, WA	3.8	7.6	11.4	15.3	19.1	22.9	26.8
Boise, ID	3.6	7.1	10.5	14.1	17.7	21.3	24.8
Burlington, VT	3.0	6.0	9.1	12.1	15.1	18.1	21.1
Duluth, MN	2.9	5.9	8.8	11.8	14.7	17.7	20.6
Helena, MT	3.0	5.9	8.9	11.9	14.8	17.8	20.8
Chicago, IL	3.0	5.9	8.9	11.9	14.9	17.9	20.9
Albuquerque, NM	3.6	7.2	10.8	14.4	18.0	21.6	25.2
Baltimore, MD	3.5	7.0	10.5	14.0	17.5	21.0	24.5
Fairbanks, AK	2.7	5.4	8.1	10.8	13.5	16.2	18.9
El Paso, TX	3.5	7.0	10.4	13.9	17.5	21.0	24.4
Memphis, TN	3.3	6.5	9.8	13.1	16.4	19.6	22.9
Houston, TX	3.1	6.2	9.2	12.3	15.4	18.5	21.6
Phoenix, AZ	3.0	5.9	8.9	11.9	14.9	17.8	20.8
Miami, FL	2.7	5.5	8.2	10.9	13.6	16.4	19.1

* Includes savings from reduced lighting use and reduced HVAC electricity for cooling, where:

Reduction in lighting power = Number of lamps replaced x Difference in wattage

To determine the whole building energy savings, first determine the reduction in lighting power. Then, find the reduction in whole building energy consumption in the climate zone most representative of the building's location. Then, use the reduction in whole building electricity use (from the table) to determine whole building energy reduction:

$$\text{Estimated annual energy savings (kWh/yr)} = \text{\% reduction in whole building energy use} \times \text{Building area affected by change} \times \text{LPD for building area}$$

<u>Application Considerations</u>

CFL lamps are a great way to save energy without compromising light levels or lighting quality in public spaces such as building lobbies, hallways, restrooms, lunch rooms, or recreation rooms, as well as general downlighting or task lighting applications in offices. Private spaces that are still lighted with incandescent lamps such as bedrooms could also be a cost effective application. There are, however, certain applications where CFL retrofits may not be appropriate immediately. Spaces that have very little use such as a utility closet do not offer much total energy to be saved, and therefore replacement is most cost-effective only when the incandescent lamp burns out. CFL technology also may not be effective in applications that require a very directional or strong beam of light that highlights art or provides focused and specific task lighting.

Environmental Benefits

Eliminating or minimizing the use of incandescent lamps will provide energy savings. Maintenance costs should also be reduced as the CFL lamp will last longer and need fewer replacements. A further benefit is the manufacturing energy saved from the production of one CFL versus the approximately 10 incandescent lamps used to cover the same amount of operating time.

One important consideration when using any type of fluorescent lamp is ensuring that the spent lamps is recycled. A fluorescent lamp contains some mercury which can have environmental repercussions if not disposed of properly. Each state follows specific rules and regulations regarding the disposal of fluorescent lamps. At least one retail organization (The Home Depot) has recently started a fluorescent recycling program for all types of fluorescent lamps. A similar program base-wide should be considered to make recycling easier and more complete.

Level of Maturity

Mature.

Climatic Conditions Necessary

Not applicable.

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NLPIP: Screwbase Compact Fluorescent Lamp Products. June 1999.

Intelligent Lighting Controls: Daylighting

Application

Commercial and Residential Buildings

Category

Lighting

Concept

Daylight can be a very effective light source for interior spaces during the day using sidelighting (windows) and/or toplighting (skylights or roof monitors). The use of daylighting can also provide significant energy savings, but only if the proper lighting controls are installed and operated correctly. Without appropriate controls, energy is wasted due to over-lighting the space, and to the increase in cooling load required to counteract the heat emitted from unnecessary electric lighting.

Description

Figure 6.180. Various photosensors.

Daylighting control systems need to be carefully designed to be effective. Typical barracks and smaller office buildings will have limited daylighting opportunities. However, larger spaces within these buildings such as offices, storage areas, training (and other general activity) rooms could be good candidates.

A first step in incorporating lighting controls is to determine which zones (spaces) benefit from daylight. Light levels are highest near windows, with a drastic reduction in illuminance farther away. Therefore, in spaces with windows, it is best to identify control zones as areas parallel to the window to reduce large variations in daylighting contribution across a single zone. Areas with skylights will typically be considered one large uniform zone for control purposes.

Daylighting control systems are comprised of four main components: the electric lighting system, the photosensor (Figure 6.180), the controller, and dimming or switching controls. In all daylight control applications, the electric lighting system (luminaires) that will respond to daylighting availability needs to be identified, and its circuiting for lighting control zones determined. A photosensor is then necessary to measure incoming daylight or the total illuminance in a space, and to provide a signal for the adjustment of the electric lights accordingly. The lighting control operates by modulating the current provided to the lamp through the input control of the ballast. The last element in the system is the dimming or switching mechanism, which receives the command signal from the controller and responds by adjusting the light output. Often, the individual daylighting control elements are integrated into a single simplified form (control/dimming mechanism wired directly to photosensor). As long as all four components are represented and commissioned well, the daylighting system will have the potential to save energy.

The most effective lighting control automatically dims the electric lighting, either with a step dimming or continuous dimming ballast that receives a signal from the photosensor. The two most widely used control methods, continuous dimming and step dimming, are both appropriate for most spaces. Differences between the two methods are:

- Continuous Dimming
  - Provides uniform indiscriminate balance of daylighting/electric light
  - Higher initial cost ($30-$74 per continuous dimming ballast)
  - Commissioning can be done remotely (without removing ballast)
- Step Dimming
  - More potential to save energy since lights are off completely when there is ample daylight
  - Greater variety of implementation strategies (i.e., step switching ballast, or three or four lamp luminaires wired to turn one or two lamps off)
  - Lower initial cost than continuous dimming ballasts
  - Any changes in preset dimming levels must be adjusted manually.

Another control method is simple on-off control activated when daylight is sufficient to provide 100% of the light needed. Although this system has the least expensive initial cost, it is not considered appropriate in many applications because it decreases savings potential and the abrupt on-off can be disruptive to occupants. These controls are still recommended, however, in spaces of low or short term occupancy.

Research has shown that photosensor costs range from $12 to $120 each, but

are generally between $50 and $59. When a daylighting control system is designed, it is important to use dimming ballasts that are compatible with the specific photosensor type. Photosensor manufacturers will typically provide a list of compatible ballasts, as well as recommendations of sensor placement that should be considered.

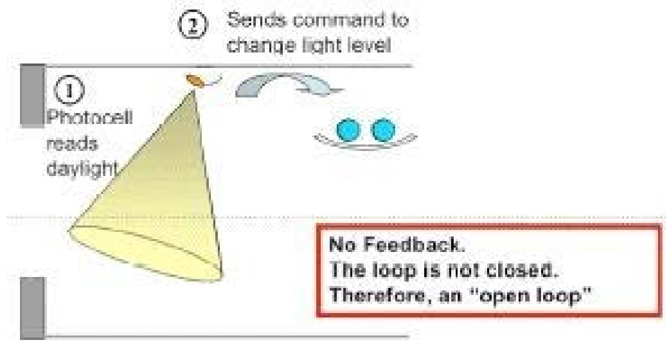

photo courtesy of automatedbuildings.com

Figure 6.181. Open loop control system.

For both switching and dimming control systems, the placement of the daylighting photosensor is critical for effective control, and is applied in either an "open-loop" or "closed loop" system. The open-loop system has the photocell read the sunlight entering the space, and the control is calibrated to provide the appropriate amount of electric light for the work surface Figure 6.181. This is the easiest application of the photosensor, as it only needs to be aimed generally in the direction of the incoming sunlight. These systems can be very cost effective, particularly in large spaces, since one photosensor can control numerous zones. In general, these open loop systems provide lower energy savings than a closed loop system because they do not permit the same level of precision in maintaining consistent light levels.

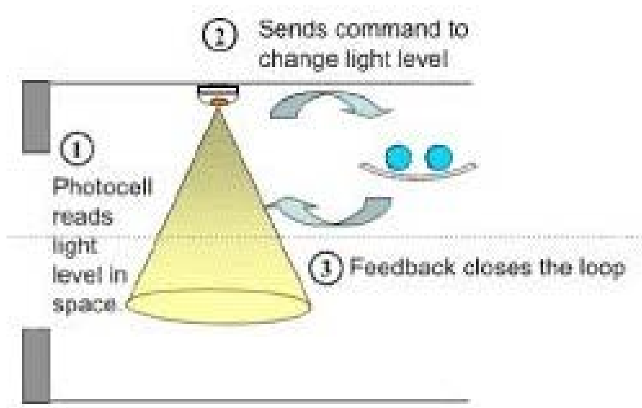

photo courtesy of automatedbuildings.com

Figure 6.182. Closed loop control system.

In the closed loop system, the photocell reads the light level reflected off the work surface. This is related to the light level provided on the surface by the electric lights and daylight, and allows for better control as it is directly based on the needs of the work surface (Figure 6.182). However, the input to the photocell with this system is much more difficult to control or anticipate. Changes to the work surface such as a dark surface covered in paper or changes in space layout/furniture will be sensed by the photocell, and this can affect the amount of light delivered to the space.

Energy Savings

Daylighting savings are difficult to quantify due to the variability in daylit spaces from site location, fenestration design, building orientation, hours of use and control systems.

However, based on research done for code development, the applications listed in Table 6.58 have been found to be cost effective for most locations at average energy rates of around $0.08/kWh. Smaller daylit spaces, locations with lower energy rates, and spaces with very little window area and/or very dark glazing should be analyzed on an individual basis to determine cost effectiveness.

Table 6.58. Applications found to be cost effective for most locations.

Daylighting Type	Cost Effective Applications	Application Suggestions
Existing Sidelighting	Sidelit spaces greater than 93 m^2 (1000 sq ft) where there are no obstructions blocking the windows (i.e., top of existing adjacent structures are less than twice as high above the windows as their distance away from the windows)	Provide separate circuiting and controls for electric lights in daylit spaces (typically, daylighting can be used within 4.5 m (14.8 ft) of windows). If possible, eliminate indoor shading devices that block all daylight and replace with exterior shading devices or light shelves that reduce glare.
Existing Toplighting	Toplit Spaces greater than 371 m^2 (3992 sq ft) where the lighting power density is greater than 5.4 w/m^2 (0.5 w/sq ft)	Implement photocontrols that dim electric lights to appropriate levels.

Table 6.59 lists the estimation of percentage electricity energy savings on a whole building basis for a typical year (kWh/yr). This provides an estimated savings percentage of whole building electricity use for various weather locations based on a percentage reduction in total building lighting power density (LPD) from 10 to 70%. The table values also include the expected reduction in electricity use of HVAC equipment associated with the reduced cooling required because of reduced lighting energy (heat) added in the building interior.

Table 6.59. Reduction in whole building electricity use per year from reduction in lighting power.*

Representative weather location	Percent reduction in total lighting power						
	10%	20%	30%	40%	50%	60%	70%
San Francisco, CA	3.9	7.7	11.5	15.4	19.2	23.1	26.9
Seattle, WA	3.8	7.6	11.4	15.3	19.1	22.9	26.8
Boise, ID	3.6	7.1	10.5	14.1	17.7	21.3	24.8
Burlington, VT	3.0	6.0	9.1	12.1	15.1	18.1	21.1
Duluth, MN	2.9	5.9	8.8	11.8	14.7	17.7	20.6
Helena, MT	3.0	5.9	8.9	11.9	14.8	17.8	20.8
Chicago, IL	3.0	5.9	8.9	11.9	14.9	17.9	20.9
Albuquerque, NM	3.6	7.2	10.8	14.4	18.0	21.6	25.2
Baltimore, MD	3.5	7.0	10.5	14.0	17.5	21.0	24.5
Fairbanks, AK	2.7	5.4	8.1	10.8	13.5	16.2	18.9
El Paso, TX	3.5	7.0	10.4	13.9	17.5	21.0	24.4
Memphis, TN	3.3	6.5	9.8	13.1	16.4	19.6	22.9
Houston, TX	3.1	6.2	9.2	12.3	15.4	18.5	21.6
Phoenix, AZ	3.0	5.9	8.9	11.9	14.9	17.8	20.8
Miami, FL	2.7	5.5	8.2	10.9	13.6	16.4	19.1

* Includes savings from reduced lighting use and reduced HVAC electricity for cooling

Find the estimated percentage reduction in total lighting power in the climate zone most representative of the building's location. Then, use the reduction in whole building electricity use (from the table) to determine whole building energy reduction:

Estimated annual energy savings (kWh/Yr)	=	Percent reduction in whole building energy use	x	Building area affected	x	LPD for building area controlled

Additional Guidance for Daylighting in New Construction/Renovation

If skylights are being installed in a space, follow these general guidelines:

- Always use clear glass with a high Visible Transmittance (VT). Including a highly reflective light well will help minimize glare.
- If sunlight entering the space directly causes a glare problem, use supplemental diffusers or baffles.
- Horizontal skylights are most effective in overcast climates, lower latitudes, and areas that do not receive much snow.
- Vertical skylights are best suited in hot climates that require shading from high summer sun in the winter, and in higher latitudes.

With professional assistance, the ideal tilt angle of the skylights can be determined for a given location to reduce solar heat gain while providing sufficient daylight.

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7 Case Studies: 75 Case Studies

Aerosol Duct Sealant at Naval Station Newport, RI

Photo

Figure 7.1. Bldg. 1268 at Naval Station Newport RI viewed from the Southeast.

Project Summary

This work demonstrated aerosol duct sealant technology on four buildings at four different Navy facilities around the country, including Bldg. 1268 at the Naval Station Newport, RI (Figure 7.1). Data on thermal energy and fan power was collected before and after the duct sealant material was applied (Table 7.1). Annual energy and cost savings were predicted based on a typical weather year for each site.

The installation of the duct sealant product was supervised by SEI Group, Inc. The data in Table 7.2 summarize energy cost savings, installation costs, and simple payback period.The data in Table 7.3 summarize the impact from the duct sealant on thermal energy and fan power.

The use of cooling energy at Bldg. 1268, Newport increased between the baseline and post-sealing periods. This increase is not the result of the technology, but from some other suspected change in building operation or condition between the 2005 and 2006 cooling seasons. One probable explanation is an increase in mission-related occupant-hours. Assuming that the only energy savings at this site was from a reduction in fan power (17,797 kWh/yr [58,021.00Btu/yr] and $2,136/yr); the simple payback period for the technology application at this site was 11.1 years. No heating energy savings were realized at this site. The primary heating for the building is from perimeter zone hot water fin tube convectors, and only negligible heating of the supply-air stream occurs in the supply-air-handling unit.

The following section outlines a very simple decision tool that identifies buildings/systems for which the decision to seal can be made without significant analysis. To use this tool, the duct systems at the Naval Station Newport, RI were divided into five categories.

Table 7.1. Summary of annual energy and cost savings at the demonstration sites.

Location/Status		Chiller Energy (kWh)	Chiller Energy Cost (2006$)(1)	Heating Energy (kBtu)	Heating Energy Cost (2006$)(1)	Fan Energy (kWh)	Fan Energy Cost (2006$)(1)	Total Energy Cost (2006$)
Bldg. 1268, NS Newport	Pre-sealant	41,933	$5,032	0	$0	90,240	$10,829	$15,861
	Post-sealant	50,032	$6,004	0	$0	72,443	$8,693	$14,697
	Savings	-8,099	-$972	0	$0	17,797	$2,136	$1,164
(1) Annual energy cost savings are based on local unit energy prices for each Navy installation.								

Table 7.2. Annual energy cost savings and simple payback estimate, Bldg. 1268, Newport, RI.

Parameter	Cost
Annual Energy Cost Savings ($/yr)[1]	$2,136[3]
Installation Costs ($)[2]	$23,701
Simple Payback (yr)	11.1
Cooling Degree Day Based on 65 °F (CDD65)	693

1 Annual energy cost savings are based on local unit energy prices for each Navy installation.

2 Installation costs provided by SEI Group, Inc. Costs include design engineering, materials and installation. Costs associated with the site selection, research investigation and demonstration aspects of the project are excluded to the extent practicable. Because the duct sealant process was demonstrated in limited areas, rather than the whole building, fixed set up costs per site may be greater than normal as a percentage of total costs. Total installation costs of $21,270 were divided between the two areas based on gross square footage by the Pacific Northwest National Laboratory (PNNL).

3 Newport energy savings used for determining the payback period are based on fan energy savings only. It is the opinion of the research team that the increase in cooling energy, as identified in Table 7.1, should be attributed to an unknown change in condition at the facility and not counted against the duct sealant process.

Table 7.3. Applicability of duct sealant on Navy bases – decision advice.

System	Laboratory supply	Laboratory exhaust	Toilet/shower exhaust, ventilation supply or exhaust	Large office supply	Constant volume packaged system
Key Feature	100% outside air	Type of construction – welded seams (tight) vs. slip and drive (leaky)	Generally poorly sealed	Leakage downstream vs. upstream of terminal boxes	Existence of insulation above ceiling
General Leakage Indicators	Test and Balance reports; Visible dust streaks on duct work, ceilings near supply diffusers, or electrical boxes; Comfort complaints				
Specific Leakage Indicator	Pressure control problems	Pressure control problems	Spot measurements of flows	Duct Blaster test of downstream leakage	Duct Blaster test of leakage
Approximate Sealing Price: ($/sq ft building space)	$0.30-$0.70	$0.20-$0.50	$0.10-$0.40	$0.30-$0.80	$0.40-$1.00
Leakage Range (% Fan Flow)	5-40%	5-40%	10-80%	5-30%	10-50%

Site

Bldg. 1268 at Naval Station Newport, RI, at 41.48 N latitude, 71.34 W longitude.

- CDD (based on 65 °F [18.33 °C]) – 606 (Providence, RI)
- HDD (based on 65 °F [18.33 °C]) – 5884 (Providence, RI)

Building Description/Typology

Newport, RI. Bldg. 1268 at Naval Station Newport, RI is an approximately 75,600 sq ft (6.98m^2), three-story training building with mostly classroom and office space. The building is approximately 20 years old.

Previous Heating, Ventilation, Cooling and Lighting Systems

Bldg. 1268, the mechanical room at Naval Station Newport in Rhode Island, is located at the east end of the first floor. There are three air-handling units (AHUs), AHU-1, AHU-2 and AHU-3, one serving each floor. AHU-1 provides fully conditioned air to the entire first floor through 22 VAV induction boxes. None of the induction boxes on the first floor have reheating coils. The primary space heating is from fin tube radiators and cabinet heaters in the perimeter zones.

Two 100-ton liquid chillers are also located in the mechanical room and provide chilled water to the cooling coils of all three AHUs. The chillers are approximately 20 years old with an assumed coefficient of performance (COP) of 2.7. Two air-cooled condensing units are located outside, southeast of the building.

At the start of the baseline monitoring, the building was in the process of converting the source of hot water for space heating from the central steam plant to two natural-gas-fired package boilers installed in the first floor mechanical room. The conversion was completed by the start of the heating season in October 2005. These boilers deliver hot water for space heating of the entire building, through the heating coils in each of three AHUs, fin tube radiators along the perimeter spaces of the buildings, some cabinet heaters, and some VAV box reheating coils.

Both the supply and return-air fans (RAFs) for AHU-1 are VAV systems using VFD controls. AHU-1 has ducted returns. Table 7.3 lists the supply and return fan schedules for AHU-1. The duct sealing project included the supply and return ducts serving the first floor. The supply and return ducts are located in a ceiling plenum. There is no insulation above the suspended ceiling. For the supply-air system, ducts located upstream and downstream of the VAV boxes will be sealed. All of the return ductwork was sealed.

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Table 7.4. Bldg. 1268 AHU-1 supply and return fan schedule.

Unit No.	Service	Designed Air Flow (cfm)	External Static Pressure (in. w.c.)	Fan RPM	Motor HP	Minimum Outside Air (%)
AHU-1	1st floor supply air	16,680	2.6	1185	20	14
RAF-1	1st floor return air	14,455	1.0	739	5	NA

Retrofit Energy Savings Features

Energy consumption is reduced by sealing air leaks in the duct work, which limits the amount of air the fans must move through the air distribution systems. This, in turn, reduces the power the fan motor consumes. Sealing air leaks in the work also reduces the thermal energy lost in the space heating and cooling systems. The purpose of this technology demonstration is to document sample leakage rates and the extent to which the leakage rate can be reduced. This demonstration also seeks to document the extent to which reducing leaks in the duct work will also result in a potential reduction in space heating and cooling energy in commercial building applications, where the duct work is frequently located within the building shell and, in many designs, within the partially conditioned space (i.e., the ceiling plenum). The objective of this series of demonstrations is to document the extent to which fan motor, space cooling, and space heating energy can be reduced.

The following rules of thumb can help to make quick decisions on whether duct sealing is appropriate:

1. **Laboratory Supply and Laboratory Exhaust** systems are worth sealing whenever it can be confirmed that they leak, as the impacts of leakage in these systems are larger than in any other duct system because of the large flow rates, the high fan power, and the heating/cooling loads associated with 100% outside air. Two ways to know that these systems leak are Test and Balance reports or problems with being able to control pressures. Note that, while hospitals usually use 100% outside air as well, scheduling sealing in hospitals tends to be difficult.

2. **Toilet/Shower Exhaust, Ventilation Supply, or Exhaust** systems are usually worth sealing. These systems are typically not very well sealed at initial construction. There are some (but unfortunately not very many) exceptions to this observation. As most of the cost is in mobilization, the cost effectiveness is highest when there are multiple vertical shafts to be sealed from the same roof or penthouse. If there is some question about whether or not a particular system is leaking, a significant difference in the measured flows at grilles on the bottom and top floors is usually a good indicator of leakage.

3. **Large Office Supply** systems often benefit from sealing, particularly downstream of terminal boxes, as leakage in these duct sections is often not sealed very well at initial construction. It is also relatively cost-efficient to measure the leakage in a sample of downstream duct sections to determine whether sealing the entire building makes sense.

4. **Constant Volume Packaged Systems** are usually worth sealing as long as the ducts are located above a ceiling, and there is insulation on the ceiling. A lack of additional insulation on the roof, or the existence of vents on the roof make these applications even more cost effective. If there are questions about the amount of

leakage in these systems, a Duct Blaster test (that takes approximately 1 hour), or the sealing results from the first system sealed, can be used to estimate leakage in systems that have not yet been sealed.

Resulting Energy Savings

Duct sealant was applied to the first floor supply and return ductwork located in the ceiling plenum. For the supply-air system, ducts located upstream and downstream of the VAV boxes were sealed. All of the return ductwork was sealed.

A three-parameter (outdoor air temperature, wet bulb temperature, and solar radiation) regression-based model was developed for both the pre- and post-sealing daily average cooling energy. A different model was constructed for occupied (weekdays) and unoccupied days (weekend and holiday). Normalized annual cooling energy was estimated by applying the models to daily weather conditions using Providence, RI typical meteorological year data for the cooling season. The cooling season was defined as the days when the building's chillers were operational, i.e., May 5 through November 15.

Pre- and post-sealant weather normalized chiller energy data sets were developed. The assumed chiller COP of 2.7 was used to convert the measured cooling coil energy to chiller energy. Chilled water pumping energy and line loss were not included in the estimate. Figure 7.2 shows the relationship between the outdoor air temperature and the cooling energy and Table 7.5 lists the monthly cooling energy use. Cooling energy consumption after the duct sealing is higher than before the sealing by an average of 19%. Although there appears to be significant scatter and overlap in the annual weather normalized pre/post data sets, statistical tests comparing the two data sets indicates that the increase in energy consumption between the pre/post data is statistically significant. As the data in Table 7.5 show, the most significant increase is in the peak cooling months of July and August.

Because the technology should have reduced energy use, not increased it, the increase is likely the result of some other undocumented change to the building operation or condition. Discussions with the site indicate that no changes were made to the way the cooling system was operated between the 2005 cooling season and the 2006 cooling season. The only other explanation for the increase is that the internal gains in the building changed between the two cooling seasons. One possible cause is an increase in mission-related occupancy-hours in the building; i.e., there were more people in the building for more hours. The net effect of this would be an increase in cooling load that more than offset the decrease from the duct sealing. Monitoring and validation for quantifying the changes in internal heat gains would be impractical, if not impossible, to achieve, and therefore was not included in the monitoring plan for this area of the building.

An analysis of the daily average supply and return fan motor power indicated that the fan power was not dependent on weather conditions (Figure 7.3). Bin methodology was used to predict the normalized annual fan energy consumption. Therefore, a daily average of fan motor energy consumption was estimated for the pre- and post-sealing monitoring periods, and for occupied and unoccupied days. Within each temperature bin, these four daily values were multiplied by the normal number of days in each in that bin category to estimate the normalized annual energy consumption. Table 7.6 lists the annualized fan motor energy consumption and savings. The energy consumption shown is for both the supply and return fan motors. The total fan energy savings from the duct sealant application is approximately 17,664 kWh (58,021 Btu) per year.

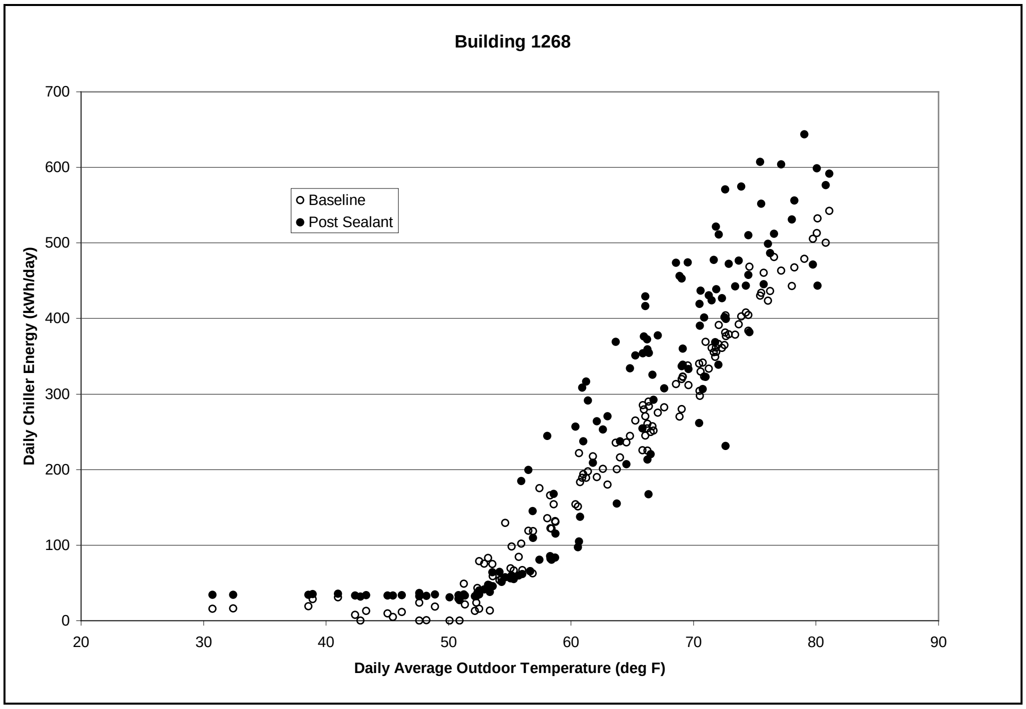

Figure 7.2. Bldg. 1268 chiller energy as a function of outdoor air temperature.

Table 7.5. Bldg. 1268 projected monthly chiller energy.

Month	Pre-Seal Chiller Energy (kWh)	Post-Seal Chiller Energy (kWh)	Chiller Energy Savings (kWh)	% Savings
May	3,686	3,676	10	0
Jun	7,600	9,319	-1,719	-23
Jul	10,993	13,729	-2,736	-25
Aug	9,744	12,070	-2,325	-24
Sept	6,333	8,032	-1,700	-27
Oct	2,367	2,015	352	15
Nov	1,210	1,191	19	2
Annual	41,933	50,032	-8,099	-19

Natural gas boilers deliver hot water for space heating of the entire building through the heating coils in each of three AHUs, fin tube radiators in the perimeter spaces of the building, some cabinet heaters and some VAV box reheating coils. The site energy manager at the start of the demonstration indicated that the primary space heating is from the perimeter radiators, with negligible heating of the supply air at the AHUs. This condition was confirmed by the monitoring data (Figure 7.4).

The data in Table 7.7 summarize the annual energy and cost savings resulting for this technology. The cooling energy cost increased by $972 while the fan energy decreased by $2,136 per year using the site's FY2006 blended electric rate of $0.12 per kWh.

Given there are no quantifiable cooling energy savings from the duct sealing technology at this site, and the only savings are from reduced fan power, the simple payback period is 11.1 years with a cost of $23,701 for applying the duct sealing as provided by SEI Group.

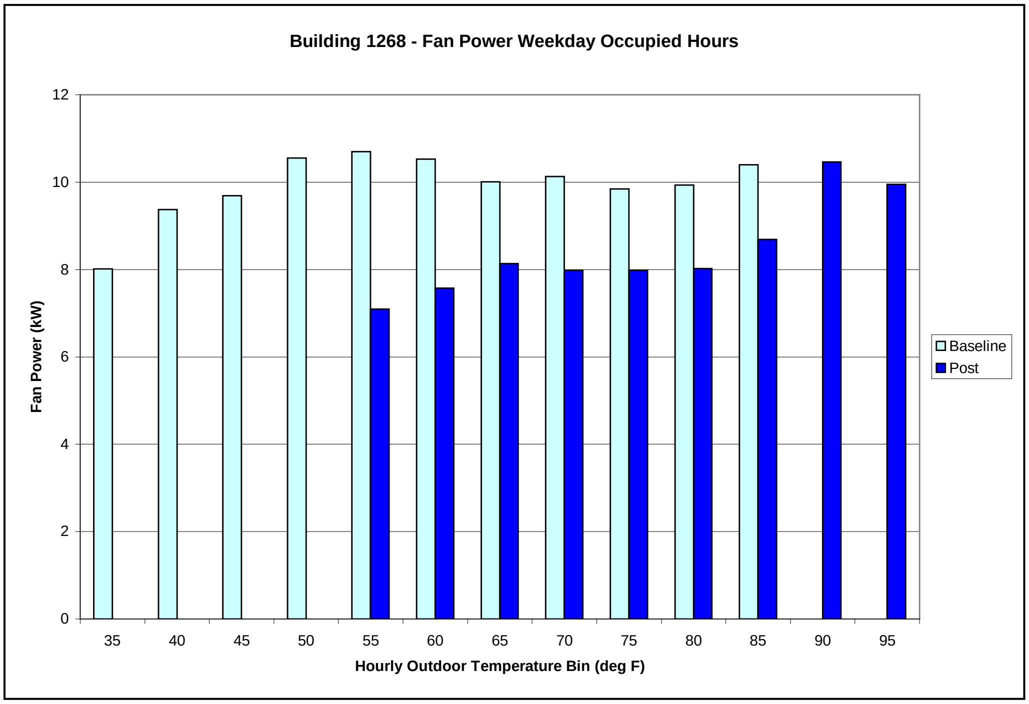

Figure 7.3. Bldg. 1268 pre- and post-sealing total fan power as a function of outdoor air temperature for weekday.

Table 7.6. Predicted normalized annual fan motor energy consumption for Bldg. 1268.

	Heating Season		**Cooling Season**		**Total**		**Savings**	
Bin (°F)	**Pre-Seal Fan Energy (kWh/yr)**	**Post-Seal Fan Energy (kWh/yr)**	**Pre-Seal Fan Energy (kWh/yr)**	**Post-Seal Fan Energy (kWh/yr)**	**Pre-Seal Fan Energy (kWh/yr)**	**Post-Seal Fan Energy (kWh/yr)**	**Fan Energy (kWh/yr)**	**Percent**
-5	17	14			17	14	2	15%
0	50	42			50	42	7	15%
5	92	81			92	81	10	11%
10	643	606			643	606	37	6%
15	905	829			905	829	76	8%
20	1,248	1,229	27	19	1,275	1,248	27	2%
25	2,511	2,339	156	142	2,667	2,481	186	7%
30	3,776	3,322	464	356	4,240	3,678	563	13%
35	4,920	4,341	1,067	732	5,987	5,073	914	15%
40	4,604	4,193	2,101	1,446	6,705	5,639	1,066	16%
45	4,004	3,451	3,757	2,611	7,761	6,061	1,700	22%
50	2,318	1,716	6,550	4,535	8,868	6,251	2,617	30%
55	971	717	9,150	6,434	10,122	7,151	2,971	29%
60	457	332	9,168	6,955	9,625	7,287	2,338	24%
65	127	92	9,035	7,388	9,162	7,481	1,681	18%
70	44	40	9,353	7,699	9,397	7,740	1,657	18%
75			6,879	5,765	6,879	5,765	1,115	16%
80			4,026	3,426	4,026	3,426	599	15%
85			1,385	1,196	1,385	1,196	189	14%
90			435	395	435	395	40	9%
Total	26,685	23,344	63,555	49,099	88,534	70,871	17,664	20%

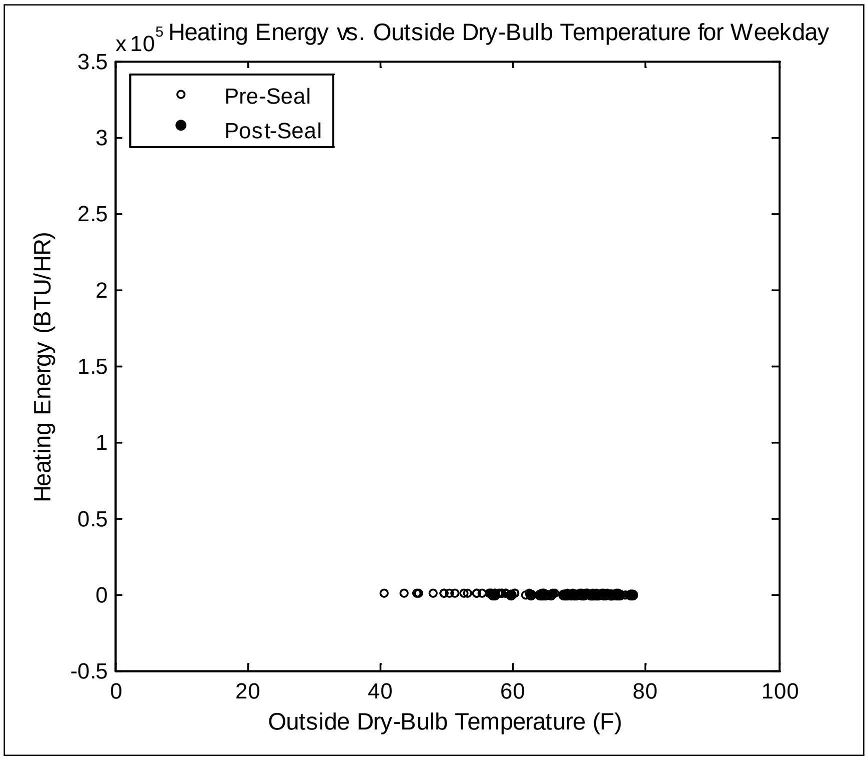

Figure 7.4. Bldg. 1268 pre- and post-sealant heating energy as a function of outdoor air temperature during the heating season.

Table 7.7. Bldg. 1268 estimated annual energy and cost savings.

	Chiller		Fan	
	Energy (kWh)	**Energy Cost $**	**Energy (kWh)**	**Energy Cost $**
Baseline	41,933	$5,032	90,240	$10,829
Post-Sealant	50,032	$6,004	72,443	$8,693
Savings	-8,099	-$972	17,797	$2,136

User Evaluation

Not applicable

Renovation Costs

$23,701

Experiences/Lessons Learned

Energy Use Saved

9698 kWh/year (33,099,274.00Btu/year)

Environmental Impact

None

Economics

11.1 year simple payback

Practical Experiences of Interest to a Broader Audience

None

Resulting Design Guidance

Working.

General Data

Address of Project

Newport, RI

Existing or New Case Study

New case study

Date of Report

September 2007

Acknowledgements

Project Sponsor: Commander, Naval Installations Command (CNIC)

Designer: SEI Group, Inc.

General Contractor: PNNL

Case Study Author: Naval Facilities Engineering Command (NAVFAC) Engineering Service Center (Mr. Ben Wilcox)

References

Additional information concerning this project can be obtained by contacting:

Techval Program Manager
NAVFAC Engineering Service Center
Port Hueneme, CA 93041
Phone: (805) 982-1387

Provincial Environmental Protection Agency Building, Bozen, Italy

General Data

Figure 7.5. View of the building after retrofit.

Address of project	via Renon 4, 39100 Bolzano, Italy
Year of construction	1954
Year of renovation	2000/2006
Total floor area	After: 3,500 m^2
Number of occupants	110

Project Summary

The project deals with the architectural reorganization and the energy retrofit of the Provincial Environmental Protection Agency Building, Bozen, Italy, which was previously a postal office of the city Bozen, to host new offices of the Provincial administration (Figure 7.5). The aim was to build the first public building in Italy, following the "Passivhaus" guidelines (which maintain a comfortable interior climate without active heating and cooling systems), with a 12 kWh/m^2y energy need.

Retrofit Features

To achieve the Passivhaus goal, the retrofit included interventions both on the building envelope and the HVAC system. Envelope treatment included an increase of the insulation; a study was also done to ensure that natural light entered through the windows, and the use of vegetation on the rooftop. The HVAC system consists of a main ventilation system with heat recovery, connected to a regeneration group integrated with a refrigerator. A photovoltaic electricity production system has been installed on part of the façades. The work ended in 2006.

Site, Typology

Figure 7.6. Localization of the city Bozen and of the building.

Site

The building is located across from the central station in the city of Bozen, in northern Italy, near the border with Austria (Figure 7.6). The location is completely surrounded by mountains (Table 7.8).

Table 7.8. Bozen location and climate.

Parameter	Measure
Latitude	46°29' N
Longitude	11°20' E
Altitude	262 m
Mean annual temperature	12.6 °C
Mean winter temperature	7.0 °C
Climate description	2791 HDD

Typology/Age

The building is an office building, with a compact shape (Figure 7.7) and a regular distribution of openings on the facades (Figure 7.8). Originally a three-storey building, a 1975 renovation was added a fourth floor.

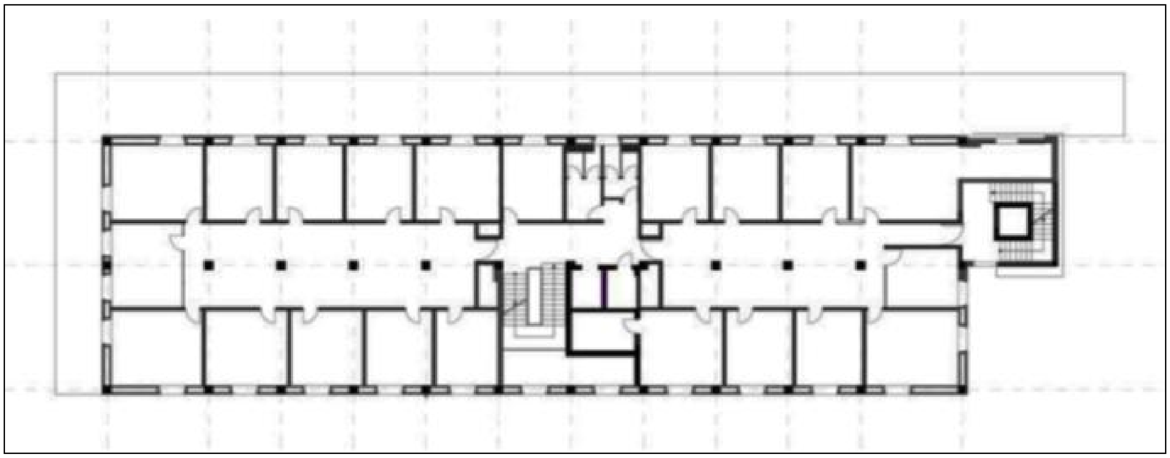

Figure 7.7. Plan of the type floor of the building after retrofit.

Figure 7.8. Northwestern façade of the building after retrofit.

Before Retrofit

Building Construction

The building was built in 1954, as a rectangular three-storey building, plus an underground floor (Figure 7.9). At the ground floor there was a short canopy to cover the platform of the station. On one side there was a separated tower, which hosted the emergency stairs and the elevators.

The building has a typical concrete punctual structure, which strongly characterizes façade. The envelope was masonry construction without relevant insulation. The windows were regularly distributed in the facade, and had the smallest allowable size.

A 1975 partial renovation added a fourth smaller floor, with different characteristics.

Heating/Ventilation/Cooling and Lighting Systems

The heating system was made by a traditional gas boiler with radiators. No air-conditioning system or cooling system was installed.

Figure 7.9. View of the building before retrofit.

Problems/Damages

The main problem was the thermal bridge produced by the short canopy at the ground floor, which is completely built in metal.

Retrofit Concept

The renovation includes interventions on the building structure, building construction, and technical system. The fourth floor, added in 1975, was demolished and replaced by two new floors of the same shape, size, and structure as the original building.

Building Construction

The thermal performance of the walls was increased through a 35 cm coat insulation, to reach a global U-value of 0.092 W/m^{2}K (Figure 7.10). The outer surface was painted white to avoid summer overheating.

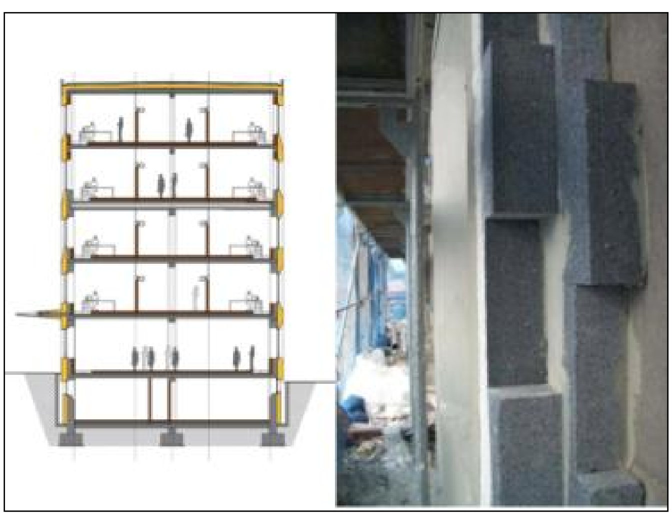

Figure 7.10. Section and picture illustrating the insulation added to the original walls by the renovation project.

The windows were replaced with taller ones, which meet the upper slab, and are triple glazed to achieve a mean glazing U-value of 0.85 W/m^{2}K. They have been provided with tilted side, made by premade pieces of expanded polystyrene (EPS) (insulation), to ensure the entrance of natural light and the view of outside differently for every room. The thermal bridges produced by the tilted sides have been studied to avoid a consistent decrease of the thermal performance of the building (Figure 7.11).

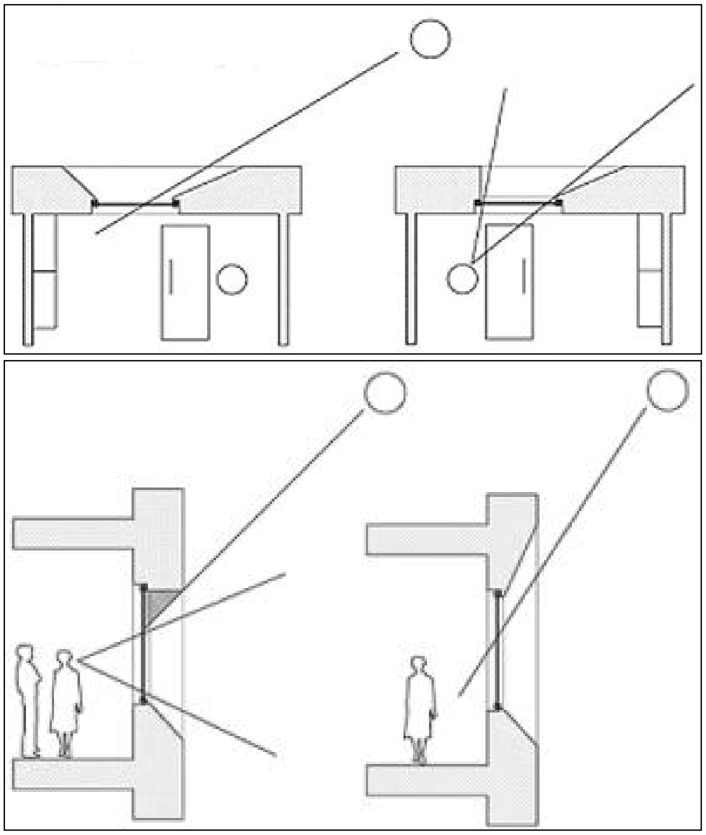

Figure 7.11. Schemes showing the effectiveness of the tilted sides of the windows.

A green roof was installed to achieve a high insulation level and to avoid summer overheating.

In the side tower, after the replacement of the windows, a metal grid has been mounted on the whole surface to help the installation of the photovoltaic (PV) system.

All the internal walls were demolished to create custom office rooms. The new walls are made of 2.50 masonry structure surmounted by fixed windows, which provide acoustic insulation and allow natural light to reach the central corridor to avoid energy waste by turning on the artificial lighting (Figure 7.12).

Figure 7.12. View of the interior of the building after retrofit.

Heating/Ventilation/Cooling and Lighting Systems

The whole building is treated by an air-conditioning system with regenerative heat recovery (Figure 7.13). Since heating and cooling needs are minimized by the building design, both the heating and the cooling systems are integrated in the air-conditioning system. The heating generation system is a condensing boiler with a maximum power of 60 kW.

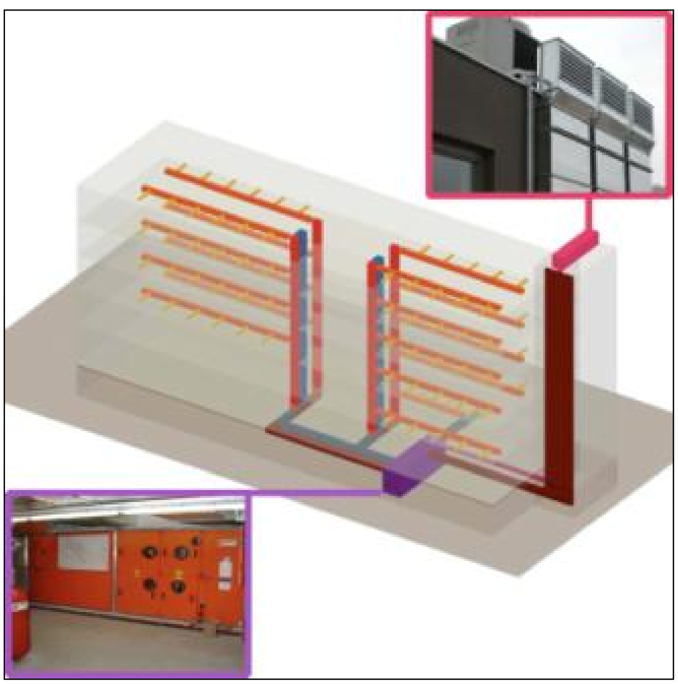

Figure 7.13. Scheme that illustrates the air-conditioning system.

Polycristal PV cells (212 m^2) were installed on the side tower a surface, on three sides (east, south, and west) for a total design capacity of 26.73 kWp (Figure 7.14).

Figure 7.14. View of the PV cells installed on the tower.

Energy Savings

The energy savings are due both to a decrease of the climatization needs and to the decrease of artificial lighting use, thanks to the changes in the building construction (Figure 7.15). The total amount of savings in the building management has been calculated to be around the 90%.

The final energy use for heating, which is the one considered in the Italian certification system, has been calculated to be 12 kWh/m^{2}y.

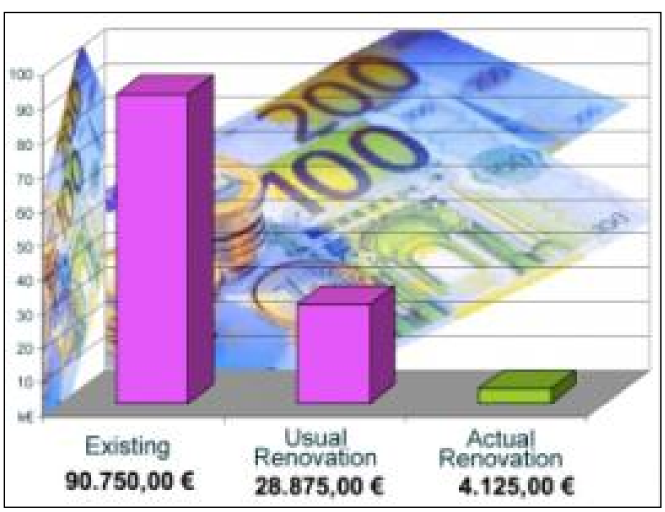

Figure 7.15. Comparison between the heating costs related to the different possible versions of the building.

User Evaluation

No information available.

Renovation Costs

The total renovation cost was of 7,600,000 €.

The only facade part was of 413,187 €, divided into:

- 161,392 € for the new windows;
- 144,294 € for the insulation;
- 107,501 € for the new facade parts.

The possible energy saving connected to the decrease of gas use has been calculated as follows:

- previous annual gas use: 90,750 €;
- annual gas use connected with a standard renovation: 28,875 €;
- annual gas use of the retrofitted building: 4,125€.

Because of this calculation, the payback time has been calculated in 5 years (Figure 7.16).

The cost for the installation of the PV modules was of 320,000 €.

Lessons Learned

No information available.

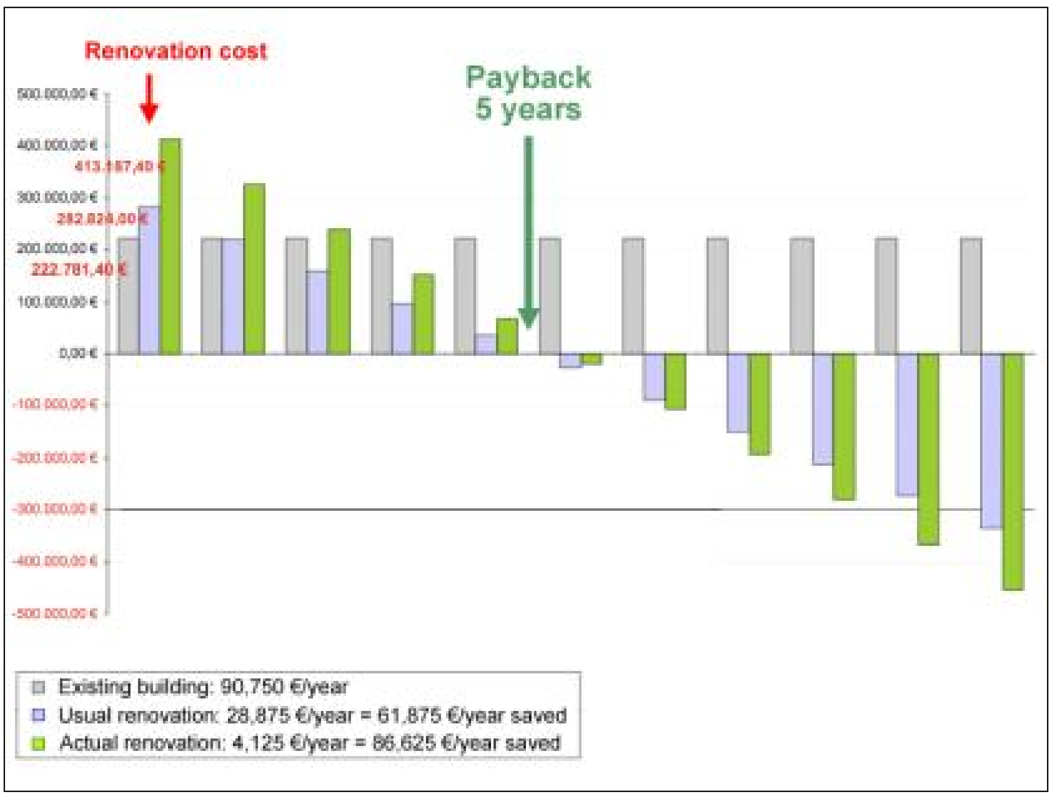

Figure 7.16. Overall costs related to the different possible versions of the building.

Additional Information

Builder: Zimmerhofer GmbH
Architect: Michael Tribus Architecture
Engineer: Ivo Kofler
Air-conditioning system: Schmidhammer GmbH
Electrical system: Electro Obrist GmbH
Link: www.expost.it

Retrofit for Energy Conservation Using Infrared Radiant Heat at Third Squadron Bagotville, Quebec, Canada

Photo

Figure 7.17. Hangar at Third Squadron Bagotville.

Project Summary

This project was designed to quantify the net savings on heating bills for two airplane hangars (Figure 7.17) using infrared heating technology. Before the retrofit, Hangar 6 used an air curtain system at the entrances and Hangar 7 used forced air to keep the buildings warm. A retrofit was performed to install infrared heaters to provide more efficient and effective heat in both hangars. The data in Table 7.9 describe both hangars.

Table 7.9. Description of hangars 6 and 7.

Building	Hangar 6	Hangar 7
Year of renovation:	2005-6	2005-6
Total floor area (m^2):	3,420 m^2	4,480 m^2
Occupant capacity:	Unknown	Unknown
Occupied hours: not specified. Must be available 24 hours/day, 7 days/week.		

Site

The air force base is located in the Saguenay Region of Quebec, 200 km north of Quebec City between Chicoutimi and La Baie [1].

Building Description/Typology

What makes the study of these two hangars particularly interesting is the constraints and characteristics of the Bagotville infrared installation. The hangars are in a cold climate and have large doors. Some zones in each hangar are classified as hazardous locations, requiring explosion-proof equipment.

General Information

In 2004, a contract between Optima Energy and Canada Defense Construction (Canadian government) was signed. Between 2005 and 2006, energy savings measures were installed (Figure 7.18). The Maricor Group engineered the infrared radiant heating in the airplane hangars.

Architectural Drawing

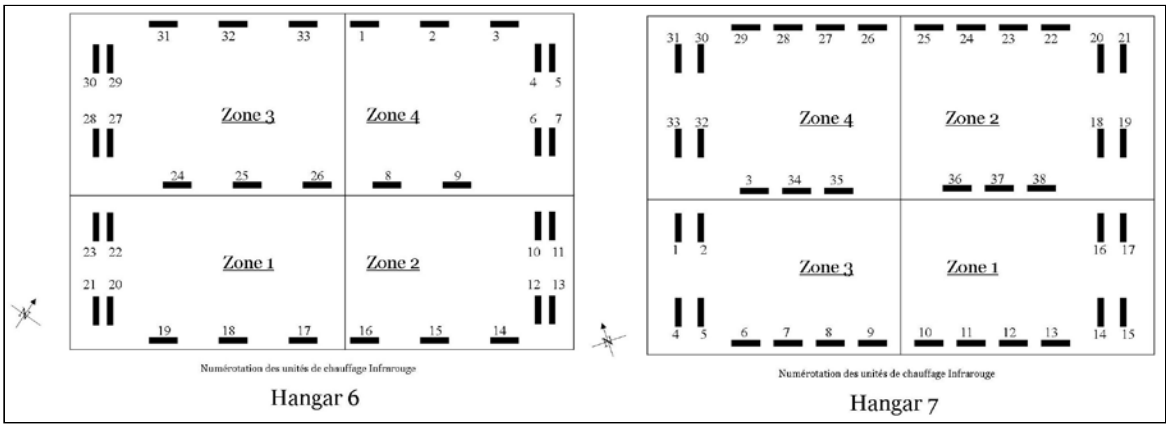

Figure 7.18. Thirty-three infrared units installed in Hangar 6; 38 installed in Hangar 7.

Previous Heating, Ventilation, Cooling and Lighting Systems

Before the retrofit, Hangar 6 used curtains of heated air to trap warm air in the space, and Hangar 7 used forced air from low-lying vents to keep the buildings warm. These methods waste fuel dollars, and are inefficient at heating large spaces, as the heat rises to the upper levels of the hangar, away from the personnel, who work are on the lower level.

Retrofit Energy Savings Features

Retrofit System Description

Thirty-three infrared heating units were installed in Hangar 6, and 38 units in Hangar 7. Figure 2 shows the installation configuration, with heaters around the perimeter and down the middle of each building.

Energy-Saving Concept

The ultimate source of radiated heat is the sun, which generates vast amounts of infrared heat through gas consumption. This infrared heat passes directly through space and warms the surface of the earth, and is, in fact, the energy source that makes life possible on earth. On a sunny day in winter, the sun's warmth comforts us even though the air around us is below comfort temperature. Gas-fired infrared heaters are sometimes called "mini suns" because they rely on gas consumption (either propane or natural gas) to generate heat. Infrared heat warms people and objects at occupancy level, not the air in the room [1] (Figure 7.19).

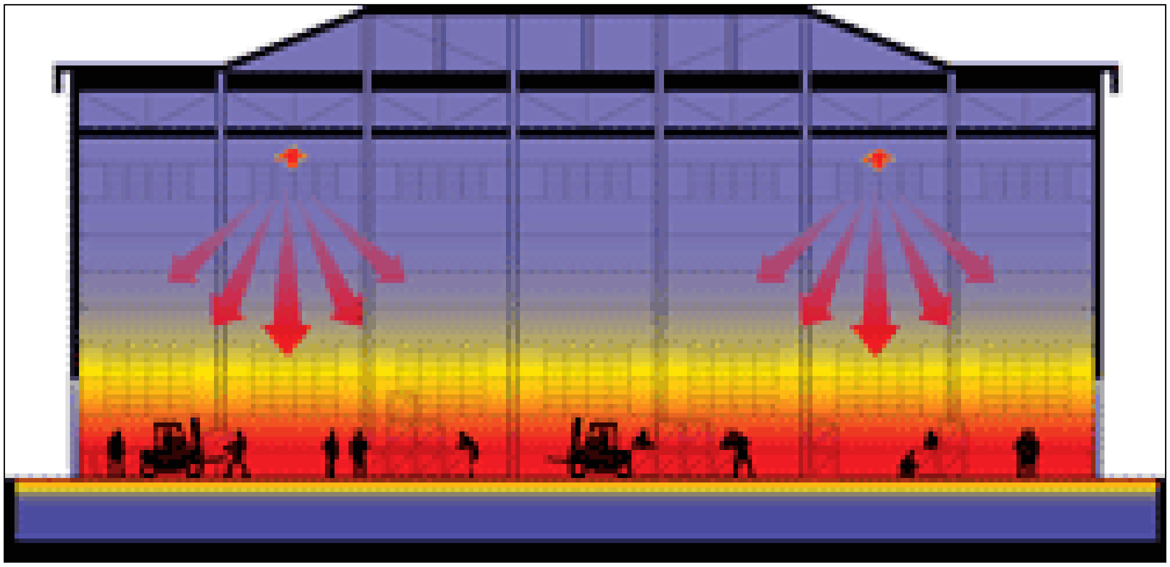

Figure 7.19. How radiant heats at ground level.

Heating

This project transferred the load from the existing forced-air ventilation air heating systems in Hangars 6 and 7 to the infrared heaters that radiate heat down from the ceilings.

Resulting Energy Savings

The use of infrared heating units at these facilities once is calculated to provide savings of $63,400/yr.

User Evaluation

Significant cost savings on utility bills were demonstrated.

Renovation Costs

The total installation cost for this case study was $393,000 (Canadian).

Experiences/Lessons Learned

Energy Use

Use of radiant heat reduced the required capacity of the Hangar 7 heating system by 50%. With a forced-air system, Hangar 7 used a capacity of 1,940 kW capacity were used; with the 38 infrared heating units, only 985 kW are needed (i.e., 0.433 kW/m^2 before, vs. 0.22 kW/m^2 after).

Impact on Indoor Climate

For buildings with no cooling, this technology has an impact on thermal comfort and productivity only. No direct impact on air quality was observed.

Economics

The money saved on energy costs, especially over a long period of time, can be significant. When considering the total cost of the project vs. the annual savings, the simple payback is:

$393,000 (6.2 yrs) = $63, 400/yr

Practical Experiences of Interest to a Broader Audience

This technology has been successfully used in many different types of applications: car showrooms, hockey arenas, fire departments, stables, on patios, soccer stadiums, various manufacturing facilities and churches. Use of this infrared heating technology not only saves money by reducing gas consumption, but also reduces the amount of CO_2 emitted into the atmosphere to mitigate climate change.

Resulting Design Guidance

There are two possible positions for placement of the infrared heating units, interior and perimeter (Figure 7.20). There are two different intensities of radiant heaters, low and high. Also, there are two types of controls, a thermostat that combines radiant and ambient temperature controls, and exhaust air dampers. Choice of the placement and intensity of the heaters depends on energy and use design studies. Radiant temperature controls (i.e., operative temperature) are highly recommended (instead of control based solely on ambient air temperature) to reduce energy consumption by heating to achieve occupant comfort, since dry bulb temperature will not reflect the radiant contribution to operative temperature.

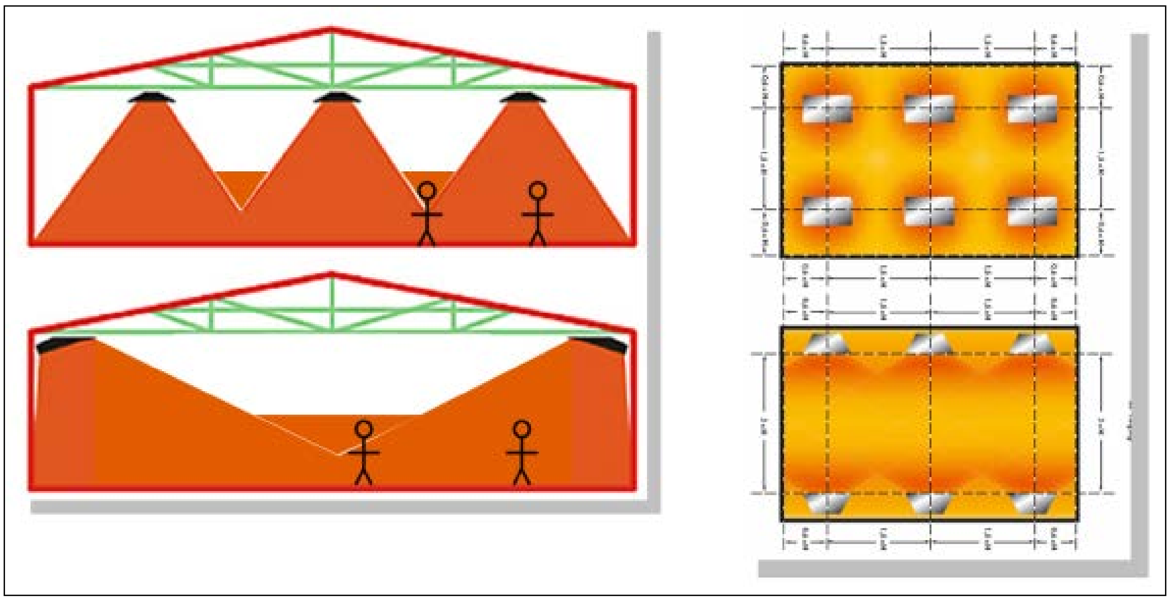

Figure 7.20. Interior versus perimeter placement.

General Data

Address of the Project

Canadian Forces Base Bagotville, CP 5000 SUCC BUREAU-CHIEF, LARK QC GOV 1A0

Existing or New Case Study

New

Date of Report

2008

Acknowledgements

Project Sponsor: Optima Energy and Canada Defense Construction

Designer: Maricor Group (Schwank Group)

Case Study Authors: Mr. Gilles Porter, Optimira Energy

Mr. Frederic Desjardins, The Maricor Group

References

1. http://www.schwankgroup.com/en/heat-faq.asp

2. http://www.airforce.forces.gc.ca/3w-3e/index-eng.asp

Points of Contact

Mr. Gilles Porter at (905) 673-2050 (gilles.porlier@optimira.com)

Mr. Frederic Desjardins at (506) 857-8880 (fdesjardins@maricor.ca)

A Retrofit for Energy Conservation Using Cool Metal Roof Technology in Paulding County, GA, USA

Photos

Figure 7.21. Lillian C. Poole Elementary School.

Figure 7.22. Bessie L. Baggett Elementary School (1).

Project Summary

This project was designed to quantify the net savings on cooling bills for Poole Elementary (Figure 7.21) using a coating of paint on the roof containing highly reflective infrared (IR) pigments known as cool metal roof technology. A control school, Baggett Elementary (Figure 7.22), with a conventional coating, was used as a basis for comparison.

Two identical schools were built within the same county, one with the new roof technology, and the other having a traditional roof. Both feature Hunter Green Kyner 500-based paint, and the differences in the cooling bills were monitored during a 3 ½ year time frame [2]. Roofs generally retain solar energy, rather than reflecting it, causing a rise in temperature within the building. Thus, the cooling system must work harder to counteract this effect, resulting in higher energy costs. Coating the roof with a highly reflective pigment that has greater reflectance as well as higher emittance of solar energy lowers the roof temperature, and therefore, the heat conducted to the building. Such a coating on metal roofs is one of five types of cool roof technology [2].

Site

Lillian C. Poole Elementary and Bessie L. Baggett Elementary Schools
Paulding County, GA (Figure 7.23)
Latitude: 33.9 N/Longitude: 84.8 W
Altitude: 318m (1043 ft).

The warmest month is July with an average maximum temperature of 32 °C (89.3 °F); the coldest month of the year is January with an average minimum temperature of -2 °C (28.5 °F).

Figure 7.23. Google Earth Map showing location of Paulding County, GA (3).

Building Description/Typology

Typology/Age

Each roof is manufactured by Architectural Metal Systems (AMS) of Eufaula, AL, and has an R-15 vinyl-faced blanket insulation over the purlins and 6 in. of R-19 batt insulation at the ceiling [4] (Figure 7.24).

General Information

Year of construction:	2002-2003
Year of subject renovation:	Not applicable (technology installed as new construction)
Total floor area (m^2):	90,000 sq ft

One school had IR-reflected coating painted on roof, other remained same for comparison

Architectural Drawing:

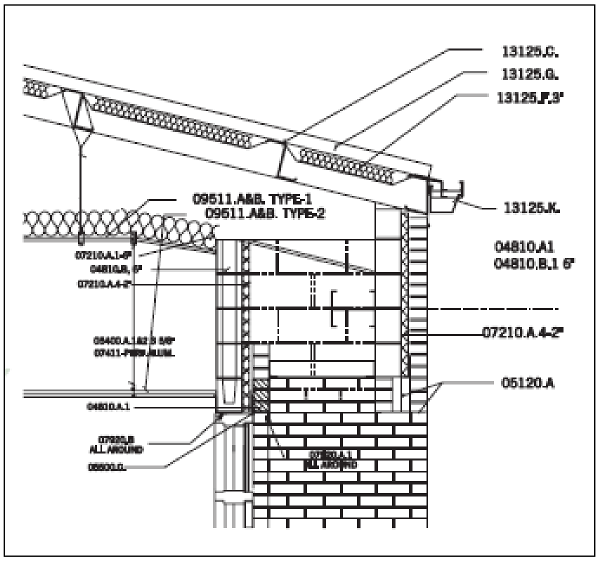

Figure 7.24. Diagram showing construction of cool roof materials.

Previous Heating, Ventilation, Cooling and Lighting Systems

This project did not involve changes to any of these existing systems.

Retrofit Energy Savings Features

Retrofit System Description

Most roof types accommodate a retrofit metal roof on top of the original structure without major modifications. Other types of cool roof technology, such as membranes and coatings, can be applied as a retrofit as long as the surface is dry and dust-free [2]. A retrofit was not performed in this particular case study, as the schools were new construction.

Energy-Saving Concept

Cool roof technology increases the solar reflectance and the thermal emittance of the roof material. A high solar reflectance means that the roof will reflect (rather than absorb) a higher fraction of incident solar radiation, and a high thermal emittance means that the roof will transfer heat to the relatively cold sky at a higher rate. Solar radiation primarily falls in the visible spectrum (46%) and the near-infrared spectrum (49%). A 'cool roof' is achieved by reflecting radiation in the visible spectrum (by using a light colored roof material) and by maximizing radiation heat transfer to the 'cold' sky in the infrared spectrum (by using a high emittance roof material).

Building Improvement

Lowering the temperature of the roofing materials prolongs their lifespan and delays the expense of installing a new roof. Both schools kept their existing (identical) HVAC systems.

Resulting Energy Savings

The annual energy savings at Poole Elementary were nearly $15,000 in the 2006-2007 school year alone. Considering that the projected lifetime of the coating is 35 years, a total savings of $525,000 is achievable, not including the likely increase in fuel prices [2].

User Evaluation

Significant cost savings on utility bills were demonstrated. This savings to the taxpayer could be used to fund other educational programs or facilities.

Renovation Costs

For this case study, there was no difference in the initial cost between the roofs at Poole Elementary and Baggett Elementary Schools. However, if a building were retrofitted with a metal roof, there is no difference in cost associated with a cool roofing material chosen [2].

Experiences/Lessons Learned

Energy Use

Poole Elementary saved about 13% of their annual energy consumption, but cool roof technology has the potential to lower cooling costs by as much as 40% [2].

Environmental Impact

For buildings with no cooling, this technology has an impact on thermal comfort and productivity only. Reduction in energy consumption in buildings with air-conditioning results in greenhouse gas reduction as well.

Economics

The cost of a cool metal roof can be the same as a traditional roof, depending on the type of material chosen. The money saved on energy costs, especially over a long period of time, can be significant. Additionally, keeping roofing materials cooler also prolongs their life expectancy, thus delaying the expense of installing a new roof.

Practical Experiences of Interest to a Broader Audience

This technology is most applicable in warmer climates, and could lead to a reduction in the urban heat island effect by reducing ambient air temperatures and inhibiting smog formation. Air pollution would also be decreased by reducing amount of fossil fuels burned to cool the buildings. Also, the roof material is made from recycled materials, which can be recycled again. For all of these reasons, cool metal roofs help qualify for Leadership in Energy and Environmental Design (LEED)® certification [4].

Oak Ridge National Laboratory's (ORNL's) Building Technology Center completed a 3-year study to evaluate the energy efficiency and service life of metal roofing systems. The results are available at www.coolmetalroofing.org. Overall, the study showed that metal panels maintain high levels of reflectance even after continued exposure to the elements over many years. The panels maintained high levels of emittance which, in some cases, increased slightly. Also, both painted and unpainted metal panels maintain their energy efficiency better over time than any of the other roofing systems studied. Lawrence Berkeley National Laboratory and the National Renewable Energy Lab [4] have also done other studies on cool roof technology.

Resulting Design Guidance

There are five categories of cool roof material available. If intended for a flat-roofed industrial building, then metal roofs, coatings, and membranes are the best option. If intended for a sloped residential roof, then reflective tiles and asphalt shingles are better since aesthetics are often an issue. Cool roof technology is typically installed during new construction or reroofing projects [2].

General Data

Address of Project

Lillian C. Poole Elementary 1002 Wayside Ln. Dallas, GA 30132	Bessie L. Baggett Elementary 948 Williams Lake Rd. Powder Springs, GA 30127

Existing or New Case Study

Existing

Date of Report

November 2007

Acknowledgements

Project Sponsor: Cool Metal Roofing Coalition
Designer: AMS and Roy Denney and Steve McCune of Southern A&E in Austell, GA
General Contractor: AMS, Roy Denney and Steve McCune of Southern A&E, Austell, GA
Case Study Authors: Cool Metal Roofing Coalition

References

1. Photos: Robert Scichili Associates, Inc. and Green Metal Consulting, Inc.
2. Cool Roofs: Putting a Lid on Energy Use. USDOE's Office of Energy Efficiency and Renewable Energy Building Technologies Program, the IEA ECBCS Programme, and the US Army Corps of Engineers.
3. http://maps.google.com/maps?hl=en&tab=nl
4. Case Study: Metal Roofing Goes to School for Big Energy Savings, Cool Metal Roofing Coalition, Pittsburgh, PA.

Point of Contact

Scott Kriner, Metal Construction Association
(610) 966-2430
skriner1@verizon.net

Retrofitting of University Dormitories City Vert-Bois, Montpellier, France

Photos

Figure 7.25. South view of the building after retrofitting.

General

Project Summary

Year of construction:	1968
Year of retrofit:	2003
Total floor area (m^2):	2485
Total heated floor area (m^2):	2289
Number of housings:	166 before retrofitting and 120 (studios) after retrofitting
Area of each housing:	10 m² before retrofitting and 15 m² after retrofitting
Occupied hours:	12 to 13 hours every day (18h – 8/9h).

The University campus of Vert-Bois was built in 1968 in Montpellier and features six buildings (Figure 7.25) in a green park, close to the University Paul Valery. The six buildings are identical in same structure. Oriented north-south, they had 166 rooms and collective toilets before retrofitting.

In 2003 the bathroom accommodations (washbasin, toilet, and shower) were reconfigured into the rooms, and the facades and roofs were also renovated (Figures 7.26 – 7.28). The new facades will not require heavy maintenance (except periodic new paint) for years. This case study focuses on Building D of the University City, where rooms were transformed into studios in 2003.

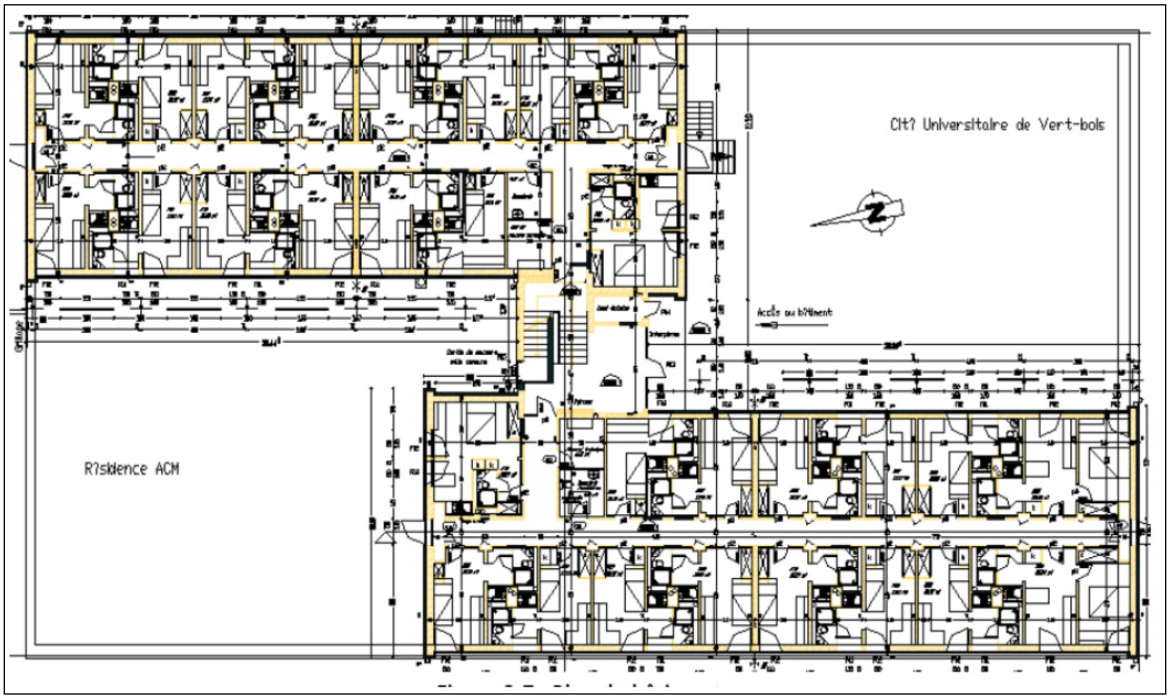

Figure 7.26. First floor (2 blocks).

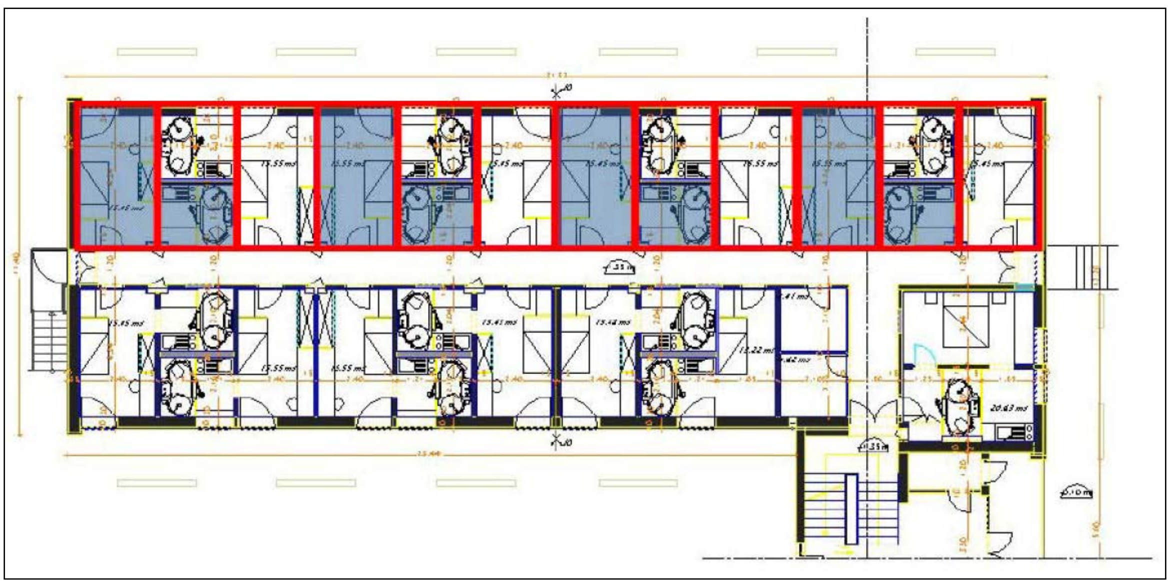

Figure 7.27. Indoor distribution in a floor (East block).

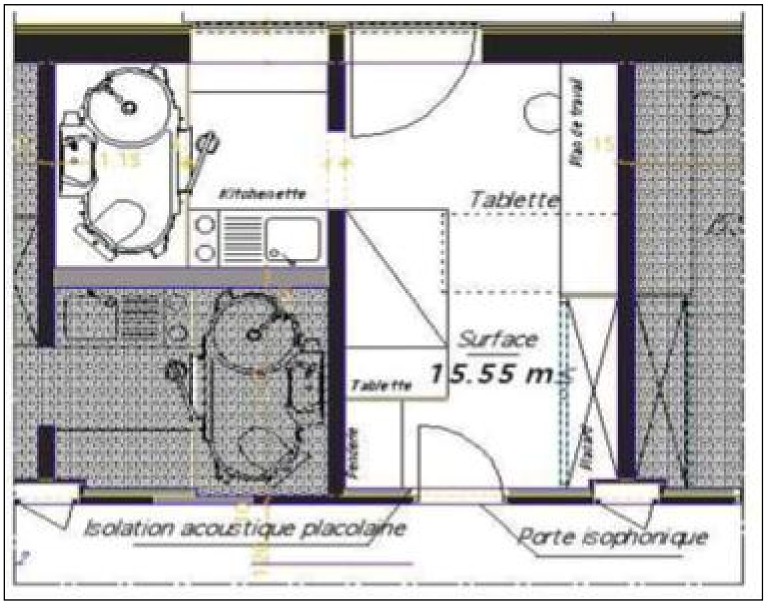

Figure 7.28. Floor plan of one housing unit.

<u>Site</u>

The university dormitory Vert-Bois is located in the north of Montpellier, in the southeast of France.

Latitude	Longitude	Altitude	Mean annual temperature	Minimum average temperature	Maximum average temperature	Heating Degree Days
43.4 deg N	3.5 deg E	70 m above sea level	14.2 °C	9.3 °C	19.1 °C	1841 (base 18 °C)

<u>Typology/Age</u>

The main function of Bldg. D is that of a student dormitory. The building consists of two blocks (east and west), with a common stairwell. The building has four floors, although the west block has an additional half-floor (Figure 7.29).

Figure 7.29. View of dormitories before retrofitting.

In 2001, a decision was made to retrofit the building. The initial project aimed to redistribute the internal building spaces to increase the size of dwellings; 166 rooms with areas of 10 m² each were transformed into 120 studios of 15m²; kitchen areas and bathroom blocks (shower, washbasin, and toilets) were configured into each studio. This retrofit was undertaken with a "green" approach to environmental quality, with two main purposes:

- to improve the indoor comfort of the occupants: thermal (summer and winter), visual and acoustical
- to minimize the impact of the building on the environment, mainly through energy and water savings.

Heating/Ventilation/Cooling and Lighting Systems Before Retrofit

Before 2003, the building had two sources of energy: electricity and gas. Heating and domestic hot water were provided by two gas boilers of 337 kW each. The central control depends on the outside temperature. The local control is regulated by thermostatic valves on the radiators. The heating thermostat is set to 20 °C in winter.

Air ventilation is a simple ventilation flow with a renewal rate of 0.6 vol./hour. Thermal insulation was poor due to the simple glazing and uninsulated walls (consisting of plaster, 30 cm of raw concrete, and a coating). Also, the east-west orientation of the building is unfavorable to summer comfort since it receives the morning and evening sun. (The west orientation is source of overheating late in the afternoon.)

Retrofit Concept

Outside insulation (10 cm thick) with a metallic cladding was added to cover the building envelope (Figure 7.30). A low- emissivity double glazing was also installed. Several different approaches were taken to reduce overheating:

- Outside terraces with vegetation were added.
- Solar protection was incorporated.
- Simple thermo-mechanical ventilation was installed.

In each housing unit, artificial lighting is provided by three wall luminaries equipped with energy-saving 13W lamps, placed on the front door, at the entrance of the kitchen, and at the head of the bed; and by three fluorescent tubes for the desk, and two of 18W in the bathroom and on the kitchen washbasin. The lighting power ratio is 7.5 W/m^2.

Exterior glazed surfaces (windows) were enlarged to take advantage of natural lighting, and the inside walls in each housing were painted in white.

The acoustical insulation was improved by providing double walls and soundproofed doors. (This achieved an acoustical decrease of 30 dB.)

The following low energy devices were installed:

- CFL
- lighting timers in the corridors
- low energy refrigerators
- new gas boilers.

Low-water consumption equipment was installed:

- thermostatic mixer taps (for washbasins and showers)

- faucet aerators for washbasins
- pulsed shower heads
- toilets with a double capacity flush (3/6 liters).

This retrofit project provided an opportunity to install renewable energy technologies. Solar collectors (indirect type with forced circulation and external heat exchanger) provide energy for domestic hot water (Figure 7.31). There are four hot water tanks: three with 1000 liters of storage, one with 2000 liters. Photovoltaic panels (48 modules, Figure 7.32) were installed; generated electricity is used directly in the different dormitories on the university campus.

Figure 7.30. Outside insulated envelope.

Figure 7.31. Solar collectors on the roof.

Figure 7.32. Photovoltaic panels.

Heating Results

Gas is the only source of energy for heating and production of domestic hot water. The energy consumption meters are common with all the buildings of the university campus. However, the invoices and the energy optimization of consultancy society provide consumption information. Before rehabilitation, the energy consumption of the building (for heating, hot domestic water and cooling) is estimated at 200 kWhep/m².year, and after rehabilitation, 55 kWhep/m².year (energy primary [Figure 7.33]). An accurate assessment of energy consumption of the building requires the implementation of metering.

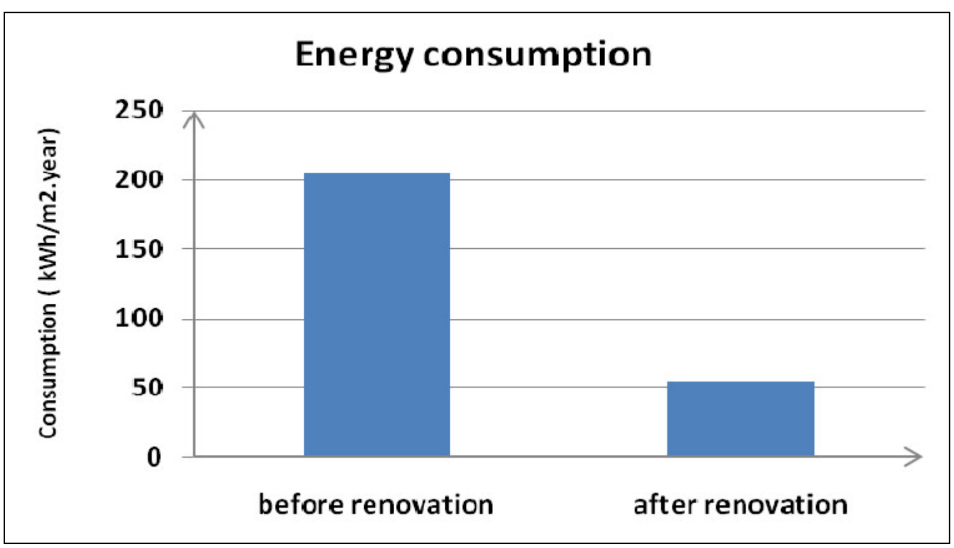

Figure 7.33. Evaluation of energy consumption.

User Evaluation

Based on a questionnaire and surveys done in May 2008, it was found that:

1. The IAQ is considered “medium.” CO2 measurements taken in different studios were satisfactory (between 300 and 500 ppm). However, indoor air is never perceived as very fresh and some students noted significant moisture in their apartments. Students the building’s temperature in summer as too warm.

2. Students are still slightly disturbed by ambient noise, especially by conversations in the neighborhood and by outside noise. The sound pressure levels are measured, inside the studio apartment, closed windows and doors, being between 25 and 30 dB, which is satisfactory.

3. The lighting in the building, while perceived as uniform, non-glare, and fairly stable, is often considered too dark. Lighting is generally considered “average.”

4. Indoor illumination, whether in natural or artificial light, is perceived as “average.” Some studios are poorly exposed, which reduces natural lighting. The vegetation on balconies and walls can block natural lighting. Students on the ground floor appear to be most bothered by poor lighting.

Renovation Costs

Total cost:	2,027,877.00 €
Total cost per studio apartment:	16,898.98 €
Financing:	
State and Regional endowment:	1,640,994.00 €
Loan (4.13%, 15 years):	213,000.00 €
Subsidies (ENR, andc.):	133,466.00 €
CROUS:	40,417.00 €

Lessons Learned

Some practical experiences of interest to a broader audience include:

- The total insulation of the envelope of the building, including outside insulation, and insulation of roofs and floors, significantly reduces heating needs.
- Still, the total building insulation without a thermal regulation strategy of the envelope (hybrid or natural ventilation, external solar protection, bioclimatic techniques) generates a risk of overheating in summer.
- The vegetation of the facades and balconies requires continuous maintenance, but helps to shade the building from the sun and can improve summer comfort levels in inhabited areas.
- The building’s east-west orientation makes sunscreens necessary and increases the need for artificial lighting in the morning and evening.
- The larger windows permit natural the sun’s light and heat to enter during the winter, and reduce the need for artificial lighting and heating.
- This heavy renovation provided an opportunity to develop solutions using onsite renewable energy: solar collectors for heating domestic water, and photovoltaic panels for generating electricity.
- The introduction of solar equipment requires changes in the building’s energy policy and equipment maintenance.

- The installation of energy sub-meters should improve the energy management in the building.
- The architectural changes improve the integration of the building with its environment.
- The retrofitting (principle: three rooms of 10m² transformed into two studios of 15m²) generally improves the students' living and working conditions.
- A bulletin board in the residence hall is used to highlight renewable energy use by showing current solar energy production and external climatic parameters. An newsletter on eco-living, describing the green building approach and implementation, is also distributed to students.

Info

References

Address of project:	Cité Universitaire Vert-Bois 192, rue de la Chênaie 34096 Montpellier CEDEX 5
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A Retrofit for Energy Conservation Using Daylighting Technology at Navy/ Marine Corps Buildings

Photos

Figure 7.34. Philadelphia Bldg. 542, NSWCCD, most lights off, sunny day after upgrade.

a.

b.

Figure 7.35. MCAS Yuma Bldg. 545 Gymnasium: (a) Lights on before retrofit 2200 hours; (b) Lights off after retrofit 1330 hours.

a.

b.

Figure 7.36. MCAS Yuma Bldg. 227 Search & Rescue Hangar: (a) before upgrade, lights on ; (b) after upgrade lights off.

Figure 7.37. MCAS Yuma Bldg. 530, Warehouse.

Project Summary

A recent Department of Defense study concluded that the most cost effective renewable solar technology is daylighting. Several Department of the Navy installations were well ahead of the study and have successfully implemented daylighting projects. The details of the buildings and projects vary (Figures 7.34 – 7.37). Some projects installed skylights and daylighting controls. Some buildings already had skylights or significant window area, and those projects just installed daylighting controls. Some projects bundled daylighting controls with lighting upgrades.

In general, installing daylighting skylights and daylighting controls into existing shops, warehouses, hangars, and gymnasiums has been cost effective in higher electric rate areas of Southern California and Arizona. Project paybacks have ranged from 6.5 to 8.5 years.

There are also opportunities in low-to-moderate electric rate areas, especially when lighting or controls upgrades are planned for buildings with existing daylight. For some building types, including most offices, daylighting is best incorporated in new construction.

Site

The individual case studies are discussed more in depth below.

Building Description

Type/Age:	Daylighting technology was installed in office buildings, warehouses, shops, gymnasiums, and hangars. The age of these buildings was not specified.
General:	The cost of electricity per kWh in California is relatively higher than the rest of the country, ranging from \$0.12-0.13/kWh. At the time of this project, the cost of electricity in Yuma, AZ was \$0.086/kWh, \$0.073/kWh in Philadelphia, PA, and the cost of electricity was about \$0.20/kWh in Hawaii.
Architectural Drawing:	Not provided
Process Description:	Funding for this technology and its installation was provided by various contracts: Energy Savings Performance Contracts (ESPCs), Utility Energy Savings Contracts (UESC), and the Conservation Investment Program (ECIP). Two companies, the Energy Service Company (ESCO) and NORESCO, were contracted to do the installation.
Previous Heating, Ventilation, AC, Lighting Systems:	The corrugated metal buildings do not have air-conditioning, but in the remainder of the buildings, there are various types of HVAC systems. The previous lighting systems consisted of HID light fixtures.

Description of the Problem

High electricity costs, primarily resulting from electricity used to light the building when occupied.

Solution

The Naval Base chose to take advantage of existing natural light and more efficient lighting fixtures and controls. High-pressure sodium light fixtures (400W) were replaced with 250W metal halide fixtures, with ballasts dimmable to 50%. Skylights were installed to provide more natural lighting.

Retrofit Energy Technology Features

Daylighting systems use natural lighting to replace or supplement electric lighting during daytime hours. They have the potential to cut energy use, reduce peak demand, and create a more desirable indoor environment. Reducing electric lighting also reduces internal heating loads and, therefore, lowers space cooling requirements. Daylight can be introduced to the space through windows or skylights. Modern high-performance daylighting systems are designed to improve lighting distribution and minimize glare. Daylight is guided from the upper lens to the room through a reflective shaft. A diffuser at the bottom of the shaft distributes the light and minimizes glare. Air spaces built into the system reduce the heat loss or gain typically experienced with standard skylights. Lighting maintenance costs will also be reduced with the use of a complete controlled daylighting system. Lamps and ballasts will require less frequent replacement if run hours are reduced. Daylighting systems can be either passive or active. Active systems use mirrors that track the sun to increase the hours of useful sunlight available for illuminating interior spaces.

Energy-Saving/Process Improvement Concept

Installing daylighting skylights and daylighting controls into existing shops, warehouses, hangars, and gymnasiums has been cost effective in higher electric rate areas of Southern California and Arizona. Project paybacks have ranged from 6.5 to 8.5 years. Lights in these types of buildings are usually not gradually dimmed in response to changes in daylight levels, but are turned on and shut off, often in stages. No economics were generated for office daylighting systems installed during renovations, such as the offices in San Diego and Port Hueneme. It is unlikely that as retrofits these installations would meet cost effectiveness criteria required for most energy project funding, but likely that such systems could be cost effective in new construction. There may also be opportunities to install skylights as roofs are replaced.

New HVAC System

NA

Resulting Energy Savings

Not specified

Renovation Costs

Not specified

User Evaluation

Conclusions apply to select building types where lights can be turned on and off, usually in steps or stages, such as high ceiling shops, warehouses, hangars, and gymnasiums. Additional building types may be good candidates for new construction.

In areas with high electric rates, a high percentage of sunny days, and a roof in good condition, install daylighting skylights and controls. If the lighting upgrades are appropriate, install at the same time.

If the existing building has skylights, replace them with high-efficiency daylighting skylights and controls. If lighting upgrades are appropriate, install them at the same time.

If the existing building has significant window area that provides sufficient light for a large area of the building, install daylighting controls. If lighting upgrades are appropriate, install them at the same time.

Daylighting upgrades are nearly always cost effective when implemented into new construction.

Experiences/Lessons Learned

Energy Use: Not specified

Impact on IAQ: NA

Economics: Not reported for all cases. See Section11 Site Information.

Practical Experiences of Interest to a Broader Audience: Similar techniques can be applied with great success in the reduction of energy consumption from lighting, mainly in large commercial and industrial type buildings.

Resulting Design Guidance: Roof repair may be necessary to support the installation of new skylights. In this study, one office even had a problem with too much light; it required shading to be installed over the skylight.

The Energy Manager offered the following guidance:

- **Light Levels:** Have the contractor base the design according to winter lighting levels to make sure the level is adequate year round. Consider installing the photocell sensor in the space, rather than locating it at one of the daylighting skylights. The ambient light conditions internal to the building are very different than where the light level enters. As the sun moves, the lighting levels change in the space during the day. Take some actual measurements of lighting levels throughout the day. Base the savings on actual light levels rather than estimated hours of sunlight during work hours.
- **Space Utilization Changes:** In some buildings with daylighting, occupants have added high shelving or a workspace in a corner. The installed daylighting system did not meet the lighting requirement for the changed workspace so occupants turned the lights on by using the bypass timer to get light to that section.
- **Follow Up on the Installations:** See how the users actually operate the system. Most people like the extra light the daylighting skylights provide, but some also like to use the bypass timers.
- **Seismic Upgrades:** Some buildings could not be retrofitted because seismic upgrades within the buildings took away space that could have been used to install daylighting skylights. The buildings could not be retrofitted because a guaranteed level of light could not be achieved without the lights being left on.

Site Information and Economics

<u>San Diego, CA. Naval Base San Diego, Naval Air Station North Island, and Naval Amphibious Base Coronado</u>

Daylighting skylights and daylighting controls were installed in 2002 in 29 buildings using an ESPC. The ESCO was asked to consider daylighting in all of their assigned buildings.

The ESPC delivery order included cost and savings for lighting upgrades, skylights, and lighting controls for the 29 buildings recommended for daylighting, as well as lighting upgrades for an additional 27 buildings. In most cases, HID light fixtures were replaced with T5 fluorescent or bi-level metal halide fixtures as part of the delivery order. Roof repair for three buildings was required to support the installation of new skylights, and was included in the delivery order. At an average electrical cost of $0.13/kWh, simple payback for the bundled energy conservation measure was 7.7 years (excluding utility grant money received).

Most of the skylights installed are high-performance daylighting skylights. In some corrugated metal buildings, corrugated polycarbonate panels were installed as a lower cost alternative. These buildings do not have air-conditioning, so heat loss was not a factor in San Diego’s mild climate.

Electric lights are controlled by daylight levels during normal work hours, though occupants have control of manual overrides to turn on lights. Overrides are generally on 2-hour timers. The lighting control system is programmed to shut off lights outside of normal work hours.

Several Defense Logistics Agency (DLA) and Fleet Industrial Supply Center (FISC) warehouses were originally constructed with skylights and high-pressure sodium lights. An FY 2004 fully funded UESC project replaced 400W high-pressure sodium light fixtures with photosensor-controlled 250W metal halide fixtures with ballasts that are dimmable to 50%. The first DLA project had a simple payback of 4.7 years at $0.12/kWh. Additional warehouses have been upgraded following the success of the first project.

Skylights were installed in the upper floor of one office as part of a major renovation during the West Coast energy crisis. Lights are switched manually by building occupants. Lighting appears adequate. Only 10 to 20% of electric lights were on at the time of the Techval site visit. One private office initially had a problem with too much light from the skylight, and shading had to be installed.

<u>Camp Pendleton, CA. Marine Corps Base Camp Pendleton</u>

Camp Pendleton has employed several funding mechanisms to develop and install daylighting technologies including UESC and the Energy Conservation Investment Program (ECIP). Projects have been implemented in five separate phases and have affected over 60 buildings. The first project was completed in 2003, when daylighting skylights, daylighting controls, and HID lighting fixture replacements were installed in 19 shop, warehouse, and physical fitness buildings using UESC contract. In 2004, an additional 12 maintenance and warehouse facilities were outfitted with skylights and daylighting controls. Projects continued in 2005 when another nine shop and warehouse facilities were retrofitted with daylighting technologies. A project to be completed in 2006 will affect another 30 shop and warehouse facilities. At the completion of the latest project, Camp Pendleton will have over 1 million sq ft of building space using daylighting technologies.

Overall, these technologies have improved facilities and provided significant energy savings to the installation. All projects to date have improved lighting levels, increased customer comfort and satisfaction while enhancing mission requirements.

On average the simple payback for the installation of skylights, lighting controls, and reconfiguration of electrical circuiting is approximately 8.5 years at an electrical rate of $0.12/kWh. Lighting controls are standalone, not tied to the base EMCS. Replacing HID light fixtures with high output fluorescent fixtures, which was done concurrently with the daylighting initiatives have an average simple payback of 2.8 years.

The scope of work for the daylighting upgrades required each building to be completed and accepted before work was started on another building. The process of accepting the completed building included review of documented before and after lighting levels.

Electric lights are controlled by daylight levels during normal work hours. Lighting controls keep lights off before and after normal work hours and occupants have control of manual overrides to turn on lights after their normal work hours. Occupants do not have manual control of lights during normal work hours. After-hours overrides are on 2-hour timers. The daylighting control systems can turn electric lamps or fixtures on or off in two stages to maintain required footcandle levels of the buildings. Electric lights are rarely required most of the day at Camp Pendleton in buildings with daylighting.

Skylights are installed in one office building, but lights are manually controlled by building occupants. The skylights were installed in the energy manager's building to evaluate the technology before implementing in other buildings. Most electric lights were off in buildings with daylighting skylights at the time of the Techval site visit.

Camp Pendleton, CA. Marine Corps Air Station Camp Pendleton

Daylighting skylights, lighting controls upgrades, and lighting fixture upgrades were installed in seven hangars, two shops, and a warehouse using an ESPC with NORESCO. Most of the existing light fixtures were high-pressure sodium, and they were replaced with T5 high output fluorescent fixtures. The project was in the commissioning phase at the time of the Techval site visit.

The simple payback of the bundled lighting energy conservation measure was 8.5 years at an electrical rate of $0.12/kWh.

In the hangars, electric lights are controlled by daylight levels. When daylight footcandle levels meet one preset threshold, some of the lamps or fixtures are shut off. When daylight footcandle levels meet the light level required for the building, all electric lights are shut off. Lighting controls keep lights off before and after normal work hours. In the smaller shops and warehouse, the potential savings from shutting off the installed lightingWage did not justify the cost of lighting controls, so skylights were installed and occupants will be expected to turn off lights when they are not required. The energy manager has a successful education and awareness program in place for those buildings.

Skylights with internal dimming louvers are installed in classrooms where light levels need to be lowered on occasion. This is an option that is available where required, but it would be difficult to justify the additional cost for most applications.

Part of the project installation testing required that skylight roof penetrations be tested with a water hose. No leaks were found from the skylight installations.

Miramar, CA. Marine Corps Air Station Miramar

Active daylighting skylights and lighting controls were installed in one hangar at Marine Corps Air Station (MCAS) Miramar a number of years ago. The tracking mirrors are built into the daylighting skylights, so are protected from the weather. Although the active system installation is considered successful, Miramar is using passive daylighting skylights on additional buildings. The energy manager believes that passive daylighting does an adequate job, and is not opting for the additional cost for active tracking on new daylighting projects.

Daylighting skylights and daylighting controls are currently being installed in three additional hangars, three gymnasiums, and several warehouses. The daylighting projects include upgrading HID lighting to high output fluorescent lighting in some buildings. The lights will have automatic photosensor controls, but will not use dimming ballasts. Simple payback for the daylighting upgrades is approximately 6 to 8 years at $0.12/kWh average blended electrical rate.

Miramar has a number of buildings that were constructed with skylights. They have found that replacing the original skylights with daylighting skylights increases the available light and reduces the heat transferred to the building. They are upgrading the lighting and lighting controls at the same time, and have found this daylighting upgrade to be very cost effective, since new roof penetrations are not required.

Twentynine Palms, CA. Marine Air Ground Task Force Training Command Twentynine Palms

Twentynine Palms installed 400, 4X4 daylighting skylights with daylighting controls into 14 buildings under a 2003 ESPC project. The buildings vary in usage, but are generally warehouse and maintenance spaces.

The Energy Manager offers some lessons learned from their installations:

- **Light Levels**. Have the contractor design to winter lighting levels to make sure the level is good year round. Consider installing the photocell sensor in the space, rather than locating it at one of the daylighting skylights. The ambient light conditions internal to the building are very different than where the light level is taken. As the sun moves, the lighting levels change in the space during the day. Take some actual measurements of lighting levels throughout the day. Base the savings on actual light levels rather than estimated hours of sunlight during work hours.
- **Space Utilization Changes**. In some buildings with daylighting, occupants have added high shelving or a workspace in a corner. The installed daylighting system did not meet the lighting requirement for the changed workspace, so the occupants turned the lights on by using the bypass timer to get light to that section.
- **Follow up on the Installations**. See how the users actually operate the system. Most people like the extra light the daylighting skylights put into the space, but some also like to use the bypass timers.

- **Seismic Upgrades.** Some buildings could not be retrofit because seismic upgrades within the buildings took away space that could have been used for installing daylighting skylights. The buildings could not be retrofit because a guaranteed level of light could not be achieved without the lights being left on.

Kaneohe Bay, HI. Marine Corps Base Kaneohe

Five main hangars had existing skylights, but no daylighting controls. The base replaced existing 1000W metal halide fixtures with a larger number of smallerWage dual reflector pulse start metal halide fixtures, and also installed photosensors and DDC. Eighty percent of the light fixtures are controlled by daylight levels. Twenty percent of the building's fixtures in the center of the hangar bay are left on during the normal work shift. The upgrades have resulted in a 50% reduction in energy used by the hangar bay lighting. Light levels and light distribution have improved since the retrofit, and there have been no occupant complaints.

Lights that are normally controlled by DDC photosensors and timers can be manually switched to "off' or “auto.” The systems are remotely monitored through the DDC, and lights are being operated automatically, as planned.

The base is planning additional daylighting projects for one remaining hangar and for several warehouses. For future daylighting projects they will consider dimmable metal halide and high output fluorescent lighting.

Yuma, AZ. Marine Corps Air Station Yuma

Daylighting skylights and daylighting controls were installed in 2002 in 20 shops, warehouses, hangars, and the gymnasium using UESC funding. Simple payback for one set of buildings was approximately 6.5 years at $0.086/kWh average blended electrical rate. Yuma’s rate structure includes a demand ratchet, so shutting off lights during the hottest part of the summer saves money all year.

Electric lights are controlled by daylight levels, and are off when daylight levels are sufficient. In most buildings, manual override is available to the building’s duty maintenance marine, who has the key to the control panel. In a small percentage of buildings, manual switching is available to all building occupants.

MCAS Yuma has before and after footcandle readings on file in the energy manager’s office as well as the industrial hygienist’s office to show occupants that they have more light from their skylights than they did from their electric lights. They publish this information periodically in the base newsletter.

Active sunlight tracking is installed for the gymnasium skylights. The site wanted to try one active system, but has concluded that in most cases it is probably not worth the additional cost, and that they would probably be better off to just put in another skylight if they needed more light.

One shop building in Yuma has experienced problems with skylights. Two inner and outer diffusers blew away during high winds and had to be replaced. It is thought that this is due to high positive pressure created in the building from the evaporative coolers, and fasteners to hold the diffusers in place should have been put in at the time of installation, but were missing. Properly installed daylighting skylights should remain intact even under high wind conditions.

Philadelphia, PA. Naval Surface Warfare Center Carderock Division, Philadelphia Site

The HID fixtures were replaced with long-life induction fluorescent lighting fixtures. Each fixture has two lamps and two ballasts. The controls were programmed for shutting off lights outside normal work hours and for shutting off either half or all of the lamps when daylight through existing windows was sufficient. The building is long and narrow with significant window area. The largest contribution to savings is from the lower totalWage of installed lighting and the unoccupied shut down of lights. The incremental cost to include the photosensor and program the existing DDC system to shut off lamps in response to daylight levels was considered insignificant to the overall project cost. The payback for the additional daylighting controls is estimated at 5 years at an electrical rate of $0.073/kWh. The building-level electric meter has shown a 70% reduction in the building's electrical use since the upgrade.

General Data

Address of the project:	San Diego, CA, Camp Pendleton, CA, Yuma, AZ, Kaneohe Bay, HI, and Philadelphia, PA
Point of Contact (POC) information:	Techval Program Manager NAVFAC Engineering Service Center Port Hueneme, CA 93041 Phone: (805) 982-1387
Date of the report:	February 2008
Project Sponsor:	Commander Naval Installations Command (CNIC)

References

Wilcox, Ben. “Daylighting Technology at Navy/Marine Corps Buildings” project summary. NAVFAC Engineering Service Center.

A Retrofit for Energy Conservation Using Demand-Controlled Ventilation in Birmingham, AL, USA

Photo

Figure 7.38. Handheld CO_2 sensor with cfm/person calculation and data logging capability.

Project Summary

In this Federal Energy Management Program (FEMP) case study, the cost and energy savings implications of retrofitting a Birmingham, AL building for CO_2–based ventilation control are assessed. A preliminary assessment of the office building used in this case study demonstrated significant potential energy savings. These savings are compared to the actual performance of the building after 6 months of operating with CO_2 control. The results show that the actual savings exceeded the predicted savings.

Demand-controlled ventilation (DCV) systems with carbon dioxide (CO_2) sensors (Figure 7.38) have the ability to monitor the levels of CO_2 in the air inside the building and use data collected by the sensors to regulate the amount of outside air used for ventilation. The potential for energy savings is that the indoor air is conditioned only to the extent required by occupancy of the building or of specific rooms. As an example, the ventilation to sporadically-used conference rooms can be kept to a minimum unless the CO_2 sensors indicate that the room is occupied.

Site

Birmingham, AL is located just north of the center of the state, at 33-29’02” N latitude, 086-48’35” W longitude. This location falls within ASHRAE 90.1-2004 Climate Zone 11. Design weather data at this location is characterized by the following:

- CDD (based on 65 °F) – 1,697
- HDD (based on 65 °F) – 2,763

Cooling Design Temperature – 0.4% occurrence

Dry Bulb Temp (°F)	*Mean Coincident Wet Bulb Temp (°F)*
86.2°	70.6°

Heating Design Temperature – 99.6% occurrence

Dry Bulb Temp (°F)
-14°

Building Description/Typology

Typology/Age

The building was a privately owned, non-government, 30-story Class A office building. It had been retrofitted with a CO_2–based ventilation control system in 2001, as well as a fully functional state-of-the-art digital building control system. The building had also been upgraded to qualify for the EnergyStar label awarded by the USEPA to buildings having met qualifying energy efficiency standards.

Utility costs in this region were relatively low compared to the rest of the country. However, using the USDOE EIA energy intensity indices, the case study building was found to consume about 30% more energy than similar buildings in the region. Based on this, the opportunity for further energy conservation still existed.

Spot measurements of CO_2 concentrations were taken and found to be below 700-800 ppm. This corresponded to a ventilation rate in the range of 28-35 cfm/person, well over the original design target of 20 cfm/person for this building. This finding further indicated that the building would be a good candidate for energy savings through DCV.

General

Year of construction: Not provided
Year of renovation: 2001
1,452,604 kWh of electricity and 12,998 therms of steam saved a year

Architectural Drawings

Not provided.

Previous Heating, Ventilation, Cooling and Lighting Systems

Before the retrofit, the building had a fully functional state-of-the-art digital building control system installed and was recently awarded the EnergyStar label by USEPA for buildings with high-energy efficiency standards. Note that this project did not involve changes to existing heating, cooling or lighting systems. It only dealt with upgrading the ventilation system.

Retrofit Energy Savings Features

Retrofit System Description

DCV using CO_2 sensors comes in two technologies: advanced gas sensing and an air-handling system that uses data from the sensors to regulate ventilation. CO_2 sensors continually monitor the air in a conditioned space. Since people exhale CO_2, the difference between the indoor and outdoor concentrations is a direct indication of the occupancy and/or activity level within the space. The sensors send CO_2 readings to the ventilation controls, which increase ventilation automatically when CO_2 concentrations in a zone rise above a specified level. Non-dispersive infrared CO_2 sensors are the type most widely used.

Energy-Saving Concept

Building codes require a minimum amount of fresh air to ensure adequate air quality. To comply, ventilation systems often operate at a fixed rate based on an assumed occupancy. Energy is wasted in conditioning this excess air when building occupancy is lower than assumed. To avoid the problems associated with an excess or shortage of fresh air, a HVAC system can employ DCV to adjust the amount of ventilation air supplied to an indoor space according to the occupancy level. CO_2 sensors have emerged as the primary technology for monitoring occupancy and implementing DCV.

Building

To make the necessary upgrades to the building, some work to the building was required, including installing a minimum of four CO_2 sensors and two VFD drives on each of the air intakes for each floor, and then interfacing these devices to the building control system, programming the building control system to take the CO_2 transmitter signal and regulate air delivery on each floor based on in-space CO_2 levels, moving and replacing the building static pressure sensor, and installing variable-speed drives on the building exhaust fans.

Resulting Energy Savings

Building energy simulations projected that an annual savings of greater than $81,293 would be achievable based on normalized climatic data. These predicted savings were equivalent to a 10% reduction in total energy costs, an average of $3,000 in savings per floor annually, and $0.22 per square foot of gross area per year. The actual savings were even greater than predicted, and this was likely due to three factors (Table 7.10):

1. Replacement and relocation of the building pressurization sensor probably improved energy savings, but savings were not predicted for this improvement.

2. Time-of-day schedules were reprogrammed based on actual occupancy, and building exhaust fans were adjusted to minimum levels during unoccupied hours. That change probably contributed additional energy savings to predicted savings.

3. The year 2001 was milder than 2000 and had 20% fewer CDD and 4% fewer HDD.

Table 7.10.Summary of before-and-after energy performance.

Energy Cost	2000 Jan–June	2000 July–Dec	2001 Jan–June	2001 July–Dec*
Electricity kwh	6,357,000	7,609,500	6,606,000	6,219,000
Electricity ($)	$305,136	$365,256	$317,088	$298,512
Steam (therm)	71,918	75,838	84,523	22,960
Steam ($)	$64,007	$67,496	$75,225	$20,434
Total ($)	$369,143	$432,752	$392,313	$318,946
Annual ($)		$801,895		$711,260
6 month savings comparing July–Dec 2000 vs 2001				
Electric ($)				$66,744
Steam ($)				$47,061
Total ($)				$113,805

*CO_2 Control in Operation

User Evaluation

According to the facility manager, the tenants were satisfied with the comfort levels in the space following the retrofit and no longer complained of high humidity levels in the building during summer months. Because the logged CO_2 data showed the space to be significantly over-ventilated, reducing ventilation with CO_2 control reduced the amount of humid outside air drawn into the building and allowed the cooling system to maintain better control of humidity.

Renovation Cost

The total cost of the building upgrade, including equipment and labor, was estimated at $178,800, which also included $15,000 for the pre-project trend analysis. Based on the projected cost savings of $81,293, the CO_2 upgrade project was projected to yield a 2.2-year simple payback.

Experiences/Lessons Learned

Energy Use

Utility rates for the building were very low: $0.48/kWh during the base year of 1999; overall energy costs for the base year were $1.61 sq ft/year, representing 117,992 Btu/sq ft/year. This energy intensity before the renovation was 30% higher than that of other similar buildings in the region according to the USDOE EIA energy intensity indices, despite the building's EnergyStar rating. Of the total energy consumed by the building in the year 2000, 84.55% was spent on electricity for a total of 13,966,500 kWh or $670,742 annually; the maximum peak load was 3,318 kW. Of the remaining energy consumed by the building, 13.81% was spent on steam for a total of 7,810,000 lb at a cost of $122,581 annually.

Impact on IAQ

By monitoring the CO_2 level constantly within the building, the amount of ventilation air was based on the fluctuating needs of building occupants, rather than on a preset fixed formula. DCV reduced the amount of outside air coming into the ventilation systems, saving energy and reducing the humidity, mold and mildew problems previously experienced.

Economics

The potential of CO_2-based DCV for energy savings is estimated from $0.05 to more than $1/sq ft annually. The highest payback can be expected in high-density spaces in which occupancy is variable and unpredictable (e.g., auditoriums, some school buildings, meeting areas, and retail establishments), in locations with high heating and/or cooling demand, and in areas with high utility rates. CO_2-based DCV does not interfere with economizers or other systems that introduce outdoor air into a building for cooling. Economizer operation overrides DCV when conditions warrant economizer use. Buildings that use evaporative cooling may not benefit from DCV during the cooling season.

Practical Experiences of Interest to a Broader Audience

Costs for sensors have dropped by about 50% over the last several years as the technology has matured and become more widely used. Sensors typically cost about $250 to $260 each, uninstalled. For a new system, the installed cost will generally be about $600 to $700 per zone. For a retrofit system, the cost will depend on what type of control system the building has and the degree of difficulty of installing signal and power wiring. As an alternative to a wired system, installing a wireless sensor system can be quicker and less expensive, as such systems are battery powered. Given the advances in battery technology and microprocessor-controlled power management, sensors can be expected to operate for 2-3 years before they require a battery change.

This study was based on a 15-year time frame, as that is the lifetime of most electronic control devices. Also, no periodic maintenance costs were assumed, as the sensors used were self-calibrating. However, this type of sensor only accounts for about a third of sensors on the market today; other types of sensors require calibration every 3 to 5 years.

Resulting Design Guidance

For CO_2 control to work properly, all other HVAC systems must be in good operating order. Previously undetected problems may add cost to an upgrade project. Therefore, a CO_2 –related investigation should be conducted to identify such problems before beginning.

General Data

Address of Project

Birmingham, AL.

Existing or New Case Study

New.

Date of the Report

March 2004.

Acknowledgement

Project Sponsor: USDOE/EERE
Designer: Not provided
General Contractor: Not provided
Case Study Authors: Mr. James R. Sand, Oak Ridge National Laboratory

References

Demand-Controlled Ventilation Using CO_2 *Sensors*. Federal Technology Alert. FEMP. USDOE/EE-0293.

A Retrofit for Energy Conservation Using Two-Wheel Desiccant System Technology in Maryland

Photo

Figure 7.39. Engelhard/ICC two-wheel desiccant systems (TWDS) rooftop unit.

Project Summary

TWDS are desirable because they remove moisture from the air before it enters a conditioned space, thus lowering overall humidity. The objective of this case study was to evaluate the cost effectiveness and energy conservation potential of the TWDS as it conditions the air to the appropriate comfort levels for the dining area occupants.

The desiccant system installed was manufactured by Engelhard/ICC and has a 1600 cfm generating capacity. It was installed in 1994 as a collaboration between Engelhard/ICC, APG, and the Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratories (CERL) to demonstrate desiccant technology under the Army's Facilities Engineering Applications Program (FEAP). While several rooftop air-conditioning units serve the entire building, CERL elected to evaluate just the dining facility because it exhibits higher occupant density (Figure 7.39).

The performance monitoring at this site is only partial, as no historical utility billing information is available. Several variables were recorded at 15-minute data intervals from August 1994 through January 1995, including: outdoor dry bulb temperature and relative humidity, process dry bulb temperature and relative humidity (supply), process air flow rate, run time of the unit, regeneration air temperature, electricity consumption, and regeneration gas consumption.

Site

Aberdeen Proving Ground is located approximately 40 miles northeast of Baltimore, in the upper corner of Maryland, at 39°28’24”N latitude, 76°8’27”W longitude. This location falls within the ASHRAE 90.1-2004 Climate Zone 4. Design weather data at this location is characterized by:

- CDD – 1403
- HDD – 4654
- Cooling Design Temperature
- Dry Bulb Temp: 94 °F
- Mean Coincident Wet Bulb Temp: 75 °F
- Heating Design Temperature Dry Bulb Temp: 10 °F.

Building Description/Typology

Typology/Age

The building is an Army-owned Burger King franchise that is representative of a typical fast food restaurant.

General Information

Year of construction:	Not provided
Year of renovation:	1994
Total floor area (m^2):	Not provided
Total occupant rooms area (m^2):	Not provided
Occupant capacity:	Exact number unknown, but dining room chosen for study because of highest occupant density
Number of occupant rooms:	One
Size (m^2):	Not provided
Windows/glass area (m^2):	Not provided
Occupants per room:	Not provided
Occupied hours:	24 hours every day of the week

Previous Heating, Ventilation, Cooling and Lighting Systems

For the purposes of this case study, the only relevant systems are ventilation and AC. Initially, the dining area had two packaged rooftop units (5-ton and 7.5-ton) supplying 700 cfm of ventilation out of a total supply flow rate of 5,000 cfm. Although the peak design load matched the equipment’s nominal capacity (12.5-ton) for the dining area, the components of the load (sensible and latent) did not match the equipment capacities. At the design conditions, the nominal capacity of the two units was reduced from 12.5 tons to 10.5 tons, approximately 13% below the design load, because of supply fan reheat and other losses. The total latent capacity of the units at the design conditions was also less than the required design latent capacity. This shortage was exacerbated by off-design conditions, in which the latent component of the total load did not drop off nearly as quickly as the sensible component. Because of these problems, the two packaged units were unable to dehumidify and cool the air simultaneously, frequently resulting in hot and humid conditions in the dining area. Installation of the TWDS has resulted in the latent load from ventilation and internal gains being handled efficiently. The TWDS has operated reliably as designed.

Retrofit Energy Savings Features

Retrofit System Description

The design concept was to separate the sensible (internal gains) and latent (ventilation and internal latent) cooling functions. The sensible cooling was handled by the existing rooftop unit and the latent cooling was accomplished by installing a new TWDS, which replaced an existing 5-ton rooftop unit. By separating the cooling functions, the effectiveness of the conventional vapor compression system and the desiccant-based system was maximized.

The TWDS combines a rotary desiccant wheel with a high-effectiveness rotary heat-exchanger wheel (Figure 7.40). This combination transfers some of the "sensible penalty" associated with the desiccant wheel over to the regeneration air stream. The unit uses a propane-fired steam boiler for the remainder of the regeneration heat, which is housed within the desiccant unit.

There are four possible operating modes for desiccant systems: recirculation, pure ventilation, makeup, and mixed. However, for this study, the TWDS was operated in makeup mode (Figure 7.41), which means that the source of both process and regeneration air is outdoors. The outside air is passed through the desiccant wheel where it is dehumidified and then cooled as it passes through the sensible heat-wheel. The warm dry air is directed to the conditioned space by its own concentric diffuser at ceiling level, and the return air is cooled by the existing 7.5-ton packaged rooftop unit. Dry air from the TWDS and the cool air streams only mix inside the dining area.

Architectural Drawing

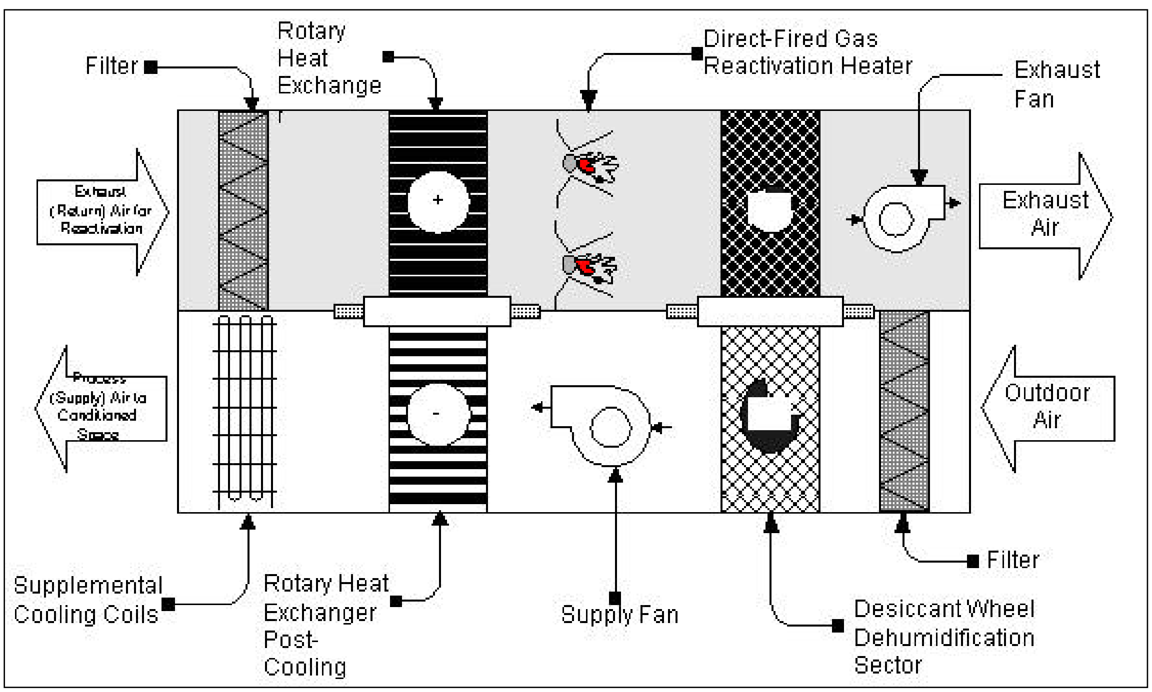

Figure 7.40. Schematic of the two-wheel desiccant system.

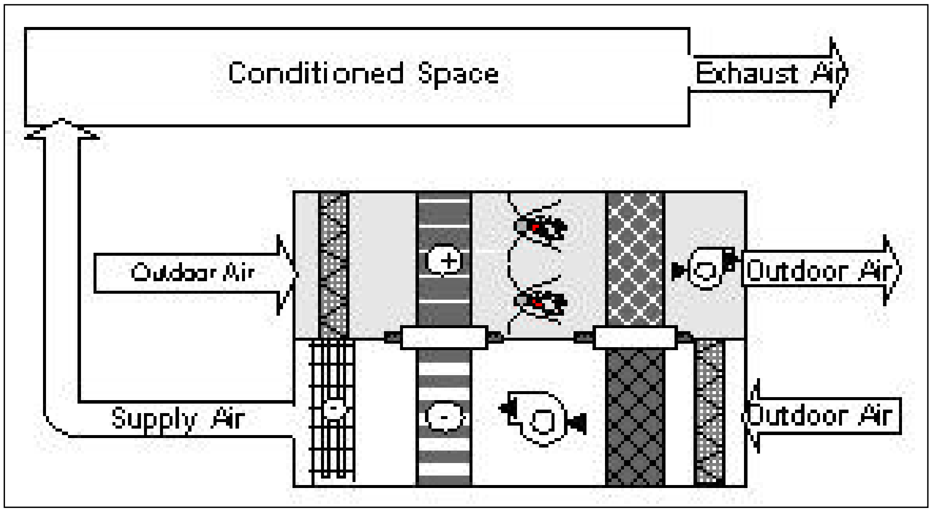

Figure 7.41. Makeup operating mode.

Energy-Saving Concept

A small increase in local emissions will occur, because of the use of a fossil fuel- (gas or propane) fired heater for regeneration. However, there will also be a decrease in utility emissions, because of reduced electric energy use. Desiccant systems reduce the cooling load on the conventional system; therefore, smaller conventional systems can be used, reducing the use of ozone-depleting chlorofluorocarbons (CFCs).

Building

The primary improvement is better management of humidity and a more comfortable environment.

Heating

The existing 5-ton rooftop unit was replaced with a new 1600 cfm TWDS to work in tandem as a hybrid system with an existing 7.5-ton air-conditioning unit.

Resulting Energy Savings

Energy savings could not be measured, as there was no historical data. Simulation models, such as DOE2, must be used to compare TWDS with conventional systems.

User Evaluation

Improvements in operating conditions were immediately noticed by the restaurant employees and customers.

Renovation Cost

The first cost of a desiccant system is higher than that of a conventional system. To offset this disadvantage, innovative designs using hybrid systems are often required. The 1600-cfm TWDS (without additional vapor compression cooling) was installed at a cost of between \$5/cfm and \$8/cfm.

Experiences/Lessons Learned

Energy Use

The daily average electric demand was around 4 kW, and the daily average gas consumption was around 30 cu ft/h. The gas consumption in winter reflects the nighttime heating energy consumption.

Impact on Indoor Climate

Air quality is greatly improved, in addition to reducing operating costs, as it is less humid and thus more comfortable.

Economics

Desiccant systems are sized based on airflow rate, or cfm, and so costs are usually given in $/cfm. For large projects, the typical cost can be estimated at $5/cfm, while on smaller projects (less than 1,000 cfm) it can cost up to $8/cfm. The installation costs can vary based on differing site requirements; for example, if installing a hybrid system, the vapor compression system is an additional cost.

Although the desiccant technology has been employed for several decades, its use was limited to industrial and military sectors. The market potential in those sectors was estimated to be between $50 and $60 million in the early 1990s (Mei and al. 1992). No concrete estimates are available either for the commercial buildings sector or for the Federal sector because wider applications of the technology are only now being investigated.

Practical Experiences of Interest to a Broader Audience

TWDS technology has much potential in the Federal sector to reduce operating cost, while simultaneously improving IAQ, but the main impediments to use of these systems are lack of familiarity, assurance and education about these benefits. The technology is especially useful for conditioning storage spaces, ice arenas that operate in summer, hospital operating rooms and most supermarkets. In a situation where the existing conventional system is unable to provide sufficient latent cooling capacity, a TWDS can be integrated with the existing system. In such a situation, the first cost usually favors a TWDS over a conventional system. It is usually not economical to install a desiccant system in situations where the design space dew point requirement is higher than 50 °F, or where the latent to total capacity ratio is less than 25%.

Resulting Design Guidance

The desiccant systems are generally designed for outdoor installation. Most commercial desiccant systems are mounted on rooftops. The units are installed on concrete pads located as close as possible to the gas and electrical interfaces. If the desiccant unit is equipped with an evaporative cooler, it will need water supply. In some large systems, a communication point may be needed to remotely monitor the unit's operation. Clearance may not be an issue for rooftop-mounted units; units installed in enclosed spaces must have sufficient side access clearance for maintenance.

General Data

Address of Project

Aberdeen Proving Ground, MD

Existing or New Case Study

New

Date of Report/Revision No.

April 1997

Acknowledgement

Project Sponsor:	The Army's FEAP Program
Designer:	The TWDS was manufactured by Engelhard/ICC
General Contractor:	Aberdeen Proving Ground and the US Army Construction Engineering Research Laboratories (USACERL)

Acknowledgements

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References

1. "Federal Technology Alert: Two-Wheel Desiccant Dehumidification System." Srinivas Katipamula, April 1997.

Contact

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Thermal Destratification Technology at West Bethesda, MD

Photos

Figure 7.42. A destratification fan.

Project Summary

The Navy Energy Program's Techval team has completed an assessment of destratification technology. The contract lead on the Techval assessment was SEI Group Incorporated (SEI). The technology has been shown to be cost effective in heated high bay areas, but an upfront evaluation of the space is recommended. Destratification technology was installed and evaluated at two Navy sites, including Bldg. 9 at the Naval Surface Warfare Center Carderock Division (NSWCCD) West Bethesda, MD. At the Bethesda site, six destratification fans (Figure 7.42) were installed and monitored for 3 months.

Destratification technology was chosen for evaluation as the technology can economically and reliably provide improved thermal control to save energy and provide improved IAQ. With these qualities, destratifiers have many potential usage opportunities in the Navy.

The objective of these evaluations was to determine whether the destratification technology are cost effective, and if installed in Navy facilities, whether they will help the Navy meet its energy reduction goals. The desired goal is for the technology to reduce energy use without any maintenance issues with a simple payback of less than 10 years.

Thermal destratification technology has the potential to save energy and money. The Bethesda evaluation site showed 40% energy and cost savings with a good (5.2 year) simple payback.

Based on the thermal destratification evaluations, to best determine potential energy savings, parameters of a facility need to be evaluated before project initiation. The evaluation project performed by the Navy Techval team showed facilities having a well insulated and sealed envelope near the ceiling have more savings potential. It is also evident that facilities with higher ceilings have more savings potential. Also, sites are more cost effective where the cost of electricity to power the destratification fans is low and the energy cost to run the heating system is high. Installations with electric heating systems will have a greater benefit from this technology as the fans draw low amounts of energy compared to an electric heating system. This was seen at the Bethesda site.

Before project initiation, to help determine the potential savings of a project, the destratification profile should be obtained. This can be economically completed using temperature probes and data loggers. Spaces with a “classic” destratification profile, such as seen at Bethesda, offer the best savings potential.

Site

The NSWCCD West Bethesda, MD (Figure 7.43) is located in the Washington DC area, at 42.53 N latitude, 71.10 W longitude.

- CDD (based on 65 F) – 973 (Washington DC, Dulles airport)
- HDD (based on 65 F) – 5006 (Washington DC, Dulles airport)

Figure 7.43. Google maps showing the location of West Bethesda, MD.

Building Description/Typology

Bldg. 9 was selected as the test facility in West Bethesda (Figure 7.44). The space known as the ‘Green Room’ was the only portion of the building to receive the destratification fan system. The room is about 140 ft long and 50 ft wide with a ceiling height of 27 ft at the highest point. Six fans cover this 7,000-sq ft area. The recommended 1000 sq ft per fan is for up to 40 ft in ceiling height. At one end, there is a 40-ft by 16-ft mezzanine used only as a storage area. Fixed walls and curtains enclose the area beneath the mezzanine where several machines are located. At the other end of the room, there are two utility rooms; each is 8 x 6 ft. The structure is a metal frame building with a concrete floor and metal siding on the walls and roof. The walls and ceiling are well insulated with fiber batting insulation. There are 6-ft windows set 4 ft off of the floor in about one-fourth of the wall space. These are double glazed windows and appear to be in good shape.

A single electric heat pump heats the room. There are 14 heating system diffusers, at the ceiling, about the same height as the fans. Figure 3 shows their locations.

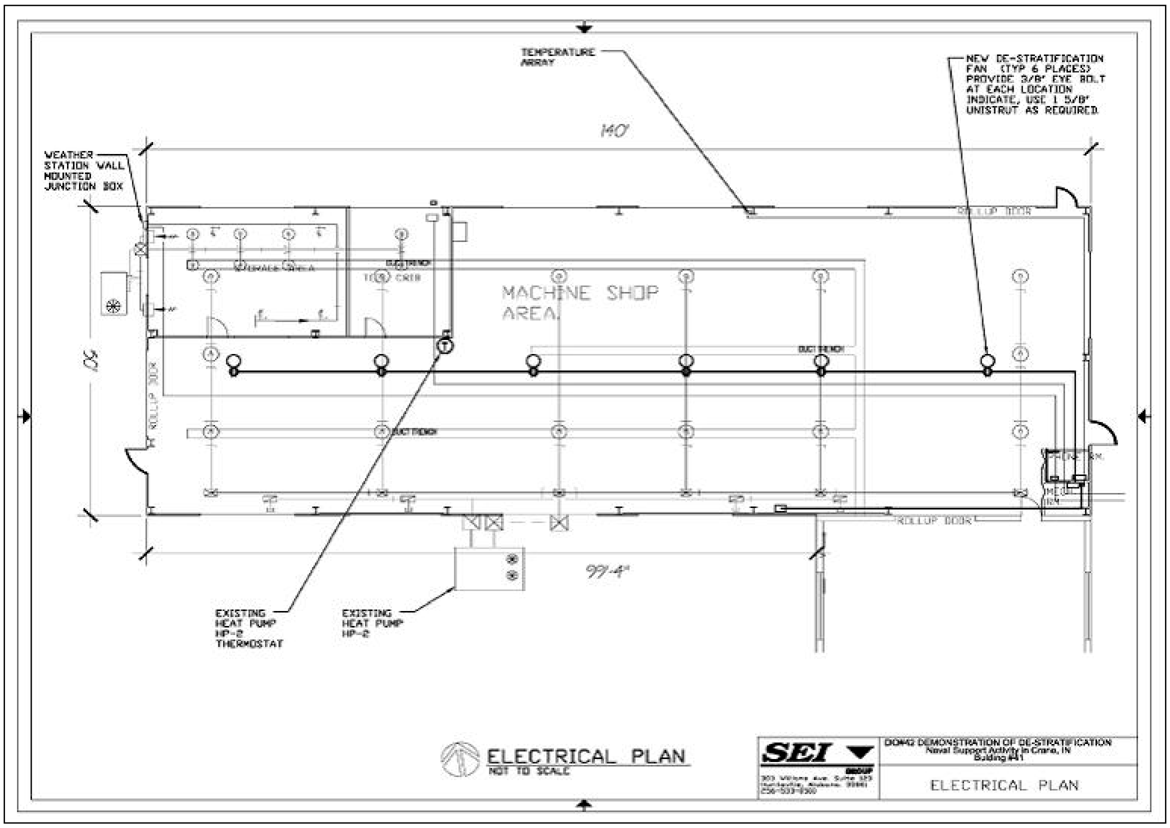

Figure 7.44. Drawing of the West Bethesda site.

A side room exists, which has a mezzanine on its roof. It has its own heat pump and thermostat. There are rollup and regular doors to the serviced space that are open at all times. This is expected to affect the measured heat consumption of the serviced space. The extent of this effect is not quantified. The temperature sensor array is at the corner of the northeast corner of the side room.

The serviced space is a machine shop with about 25 lathes and milling machines. As many as eight machinists can work in the room at any given time. All personnel work at the floor level. The building is used to manufacture ship models.

An overhead crane runs the length and the breadth of the room at an elevation of 21 ft. The fans were required to be mounted above the crane.

There is a rollup door to the outside. This door is not used often, and thus is not expected to have much of an effect.

A programmable thermostat controls the space with four periods for each of the 7 days with both cooling and heating set points. It is not behind a lock box and thus the occupants can, and do, alter the set points. The room is sometimes occupied 24/7, and its heating is set back at night.

Previous Heating, Ventilation, Cooling and Lighting Systems

Data is not applicable to this project.

Retrofit Energy Savings Features

When air is heated, it rises. This causes air to be layered by temperature, which is called thermal stratification. In facilities with high ceilings, this often results in air at the ceiling being much warmer than the air at the floor level. Locating heaters near the ceiling increases the stratification effect. Generally, temperatures increase from 0.5ºF to 1.0ºF per foot in height. If the air is stratified, the average building temperature will be higher than the thermostat setpoint, resulting in higher heating costs.

Manufacturers' literature states thermal destratification fans reduce the floor-to-ceiling air temperature differential by over 80%. This is the result of bringing hot air down to where the personnel are, and more importantly from an energy savings standpoint, to where the thermostat is located. This results in fewer and shorter heating equipment run cycles and subsequently less energy used for heating. The amount of heat lost to ventilation and infiltration is reduced due to the overall reduction of energy being generated, and heating equipment can last longer.

At the beginning of this project, there were two manufacturers of destratification fans: Air Strata who makes the 'StratoJet' and Avedon Engineering, Inc. who makes the "Airius." The Airius Model 40 destratification fan was used in this program. Although at last report Air Strata was not officially out of business, their product was not available when this demonstration was performed or when this report was written. In addition, Air Strata has not been responding to Techval's correspondence.

Thermal destratification fans are small, quiet units typically suspended from the ceiling. A fan takes in air from above and discharges it through a nozzle, forcing a stream of air toward the floor. The area covered by a fan depends on many factors such as ceiling height and building shape. Looking at ceiling height alone, the recommended coverage area for the evaluated fan is up to 1,000 sq ft, which is for up to 40-ft ceiling heights. Sleeves can be purchased to carry more air to the lower heights, increasing the amount of area that can be covered by a fan.

Manufacturers state the fans are easy to install, and require minimal maintenance consisting of a periodic exterior cleaning. Manufacturers state the energy usage for destratification fans is low (as low as 13W for some Airius models). Laboratory and field tests were completed on the power usage of the fans evaluated in this project. These project findings regarding these claims will be presented in a later section of this report.

Manufacturers state destratification fans can provide special assistance in the following situations:

- Manufacturing environments requiring close manufacturing tolerances as the fans increase uniformity of temperature in machinery and equipment.
- Buildings requiring opening large doors allowing heat to escape (such as aircraft hangars, freight facilities, and equipment maintenance facilities) where the fans

can reduce energy costs and improve personal comfort by reducing the time required to reheat the building.
- Buildings requiring a clean environment including food processing and high tech manufacturing, which can benefit from the subtle air movement provided by the fans.
- Buildings where the continuous air circulation can reduce window fogging and frosting; cause damp floors to dry quicker; and help smoke, fumes, vapors, and odors disburse more quickly.
- Buildings where the balancing of temperature and improved circulation can improve drying time and evenness in paint shops, varnish, adhesives, print shops, andc.
- Buildings with condensation problems such as indoor swimming pools, tennis courts, and gymnasiums.

The Techval program has or currently is evaluating some, but not all, of these stated application opportunities.

Thermal stratification during the cooling season causes similar problems as during the heating season. The areas near the cooling equipment may be very cool while much of the occupied zone is still overly warm. In this case, some areas must be overcooled in order to maintain comfortably cool areas in the rest of the occupied zone. This results in increased energy consumption. This is especially critical in cold storage areas and areas with occupied mezzanines. The following are specialized cooling applications:
- Temperature-controlled warehouse applications to reduce spoilage of temperature-sensitive products.
- Buildings with products that can dry out from air drafts, including refrigerated sections of grocery stores, florists, plant nurseries, and greenhouses.

Thermal stratification is particularly a problem where heating and cooling systems are not properly designed and do not distribute the heating or cooling evenly throughout the occupied zone. And, a well-designed heating system often allows thermal stratification to develop during cooling and vice versa. Destratification fans can help remedy these situations. But the destratification created by the fans will be best achieved when the HVAC system is also designed with proper air distribution in mind (e.g., having the heat diffusers close to the floor).

Destratification fans have benefits for both heating and cooling, and industry specialists recommend operating the fans continuously in heated and cooled spaces. If a space is not conditioned, then the fans are not recommended for use as an energy-saving device.

SEI selected the Airius Model 40 for the project. The manufacturer is Avedon Development, LLC in Longmont, CO. Table 7.11 lists the published specifications for Airius fans.

Table 7.11. Airius model comparison.

Airius Thermal Equalizer Model	**Power (Watts)**	**Coverage (sq ft)**	**Maximum Ceiling Height (ft)**
Model 25	35	1,000-1,500	25
Model 40	72	900-1,200	40
Model 40 Plus	72	800-1,000	60

They all operate on 110 V and are 16 in. in height, 12 in. in diameter and weigh 10 lb.

Each has an electric turbine fan and blade design to meet the specified air movement and building requirements for that model. The Model 40 Plus is the Model 40 fan with a flexible duct, of varying lengths.

The fans at either site do not have automatic shutoffs when the fire alarm goes off. This is a viable option as air movement aids fires, but it was not installed. Requirements regarding installing shutoffs should be checked for with a site's fire department, before installation.

For the Avedon fans, there is a full warranty for 1 year from the date of purchase on parts and workmanship. If defective while under warranty, a new unit will be sent at no charge in exchange for the defective unit to be returned United Parcel Service (UPS) Collect. The manufacturer also offers a refurbish program on units that are no longer under warranty. Units are returned to Avedon and will be refurbished, or replaced, for one-half the current price of the model. The refurbish program does not cover units that are damaged beyond the normal expected usage of the product. At the Bethesda site, fan blade failures occurred early in the demonstration project, and the fans were replaced.

Techval completed power measurements on the standard Model 40 fans evaluated in this project. The voltage to the fans was varied and the current and power consumed was measured. Based on these values, the power factor was calculated. Table 7.12 lists the results.

Table 7.12. Model 40 power measurement results.

Voltage (Vac)	Current (Iac)	Power (Watts)	Power Factor
100.63	0.586	57.7	0.98
105.1	0.605	62.3	0.98
110.4	0.63	68.3	0.98
115.9	0.651	74.5	0.99
120.3	0.667	79.5	0.99
125.7	0.687	85.6	0.99
130.3	0.703	91.2	1.00

These results show how the power drawn varies with the voltage. It is standard for voltage in lines to vary by +/- 10% from their nominal values. A curve was fit to the power versus current data, whose equation is: Power = 5.8264e(3.9134 x Current).

Techval also completed field tests on the fans. The power usage of the fans at the Bethesda site were measured to be an average of 54W each, or 323W for the fan system. This does not include the power lost in the wiring leading to the fans, which was not measured at Bethesda.

Resulting Energy Savings

To measure the performance of the destratification system, Techval specified instrumentation, and SEI incorporated the instruments into the overall design, and then installed the equipment in each test facility. The instruments measure the room temperature at 2-ft increments from floor to ceiling, the energy required to heat the room, and the outdoor weather conditions. All of the instruments were connected to Techval data logging equipment. Techval monitors the data logger via a dialup telephone line at each location. Table 7.13 lists the monitoring equipment used at each site.

To determine destratification fan system effects, there must be a way to compare the test parameters, both with and without the fans running. To accomplish this, SEI designed and installed a control circuit to allow a signal from the data collection units to turn the fan systems on and off. As needed, Techval can remotely control when the fans are running. The design also included a “Hand-Off-Auto” switch to allow local control of the fans. In “Hand,” the fans are on. In “Off,” the fans are off. In “Auto,” the fans are controlled remotely by the signal from the data collection unit. SEI designed the fan circuit to include a current transformer on the power feed to the fans. This allows Techval to remotely verify that the fans are running.

Table 7.13. Monitoring equipment and instruments.

		Quantity	
Description	**Model Number**	**Crane, IN**	**Carderock, MD**
Temperature Sensor	BAPI Model BA/1K-AP-631	22	10
Steam Flow Meter	EMCO Model TMP-60S-V03-G5-LOC-TOT-XX-RTD	1	—
Steam Flow Meter optional temperature sensor	EMCO Model TEM-30-RTD-2-T	1	—
Steam Meter Flow Processor (computer)	EMCO Model FP-93-N-1-S-F	1	—
Power Meter	Electro Industries Model PCU-1000-3E-V-A-kW-G-115A-X-X-L200-KYZ-20MAO	—	1
Power Meter Display	Electro Industries Model P34	—	1

Techval selected a multi-function power meter to monitor the voltage and current to the heat pump. The meter calculates the total kilowatts consumed by the heat pump. The meter provides both analog and KYZ outputs to the data collection unit.

The temperature sensors are each in slotted boxes that allow ambient air to infiltrate, but insulate it from the wall it is attached to. There is one temperature array with 13 sensors at Bethesda. The sensors are accurate to +/- ½ °F.

SEI provided the connection from the weather stations to data collection units. Techval selected the weather station hardware that monitors climatic data at each site. The hardware is the Novalynx Model 110-ws-18 Portable Weather Station. More can be found at www.novalynx.com/110-ws-18.html

The data collection system sampled data for 3 months, beginning in November 2004 at each site. As most of the energy savings benefit is to occur in the monitored spaces during heating, it was desired to capture the heating season.

Figures 7.45 and 7.46 show site parameters with and without the destratification fans. Figure 7.45 shows that the expected stratification is seen, where the temperature increases with height. The “average temperature” at each height for the duration of the test is plotted. This figure also shows that with the fans on, less heat is stored at the higher heights. The heat diffusers and the fans are both at the ceiling at Bethesda. The heat from the diffusers is pushed to the floor by the fans. The resulting destratification provides energy savings as will be discussed.

Large difference in temperature near the floor was not anticipated. Thus sensors were not placed there. The dashed line is believed to be the profile existing there. This profile is supported by the energy savings seen at Bethesda, along with personnel reporting they are warmer when the fans are on.

The large effects of the fans at the Bethesda site produce substantial heating system energy savings (Figure 7.46). For each day's average outdoor temperature, substantial heating system energy savings are achieved.

Figure 7.47 shows how the energy savings at a given average outdoor air temperature (OAT) equates into energy cost savings. For cost savings to be seen, more had to be saved on the heating system energy than was spent to operate the fans on a given day. Bethesda has positive savings for all OATs. In Crane, a positive savings is only seen below 20ºF, a temperature not often obtained.

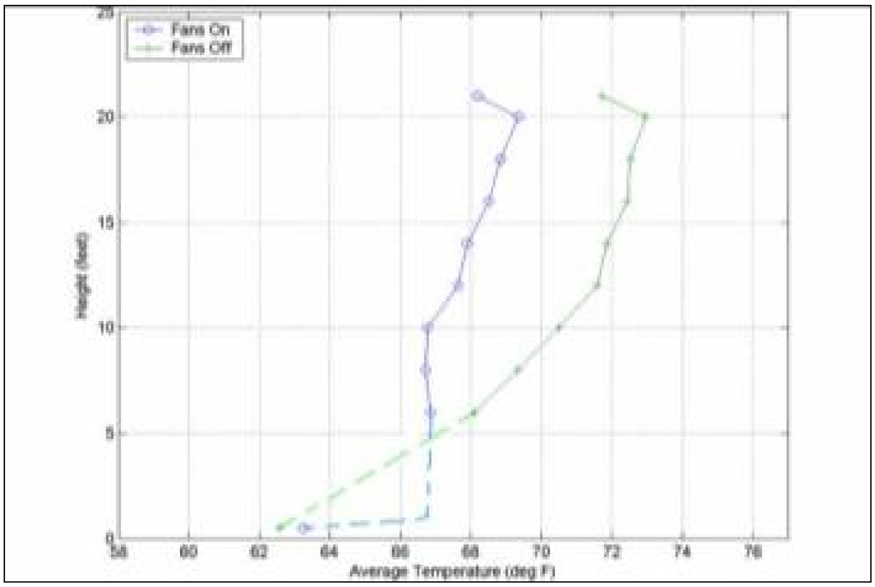

Figure 7.45. Average temperature over test duration versus height for Bethesda.

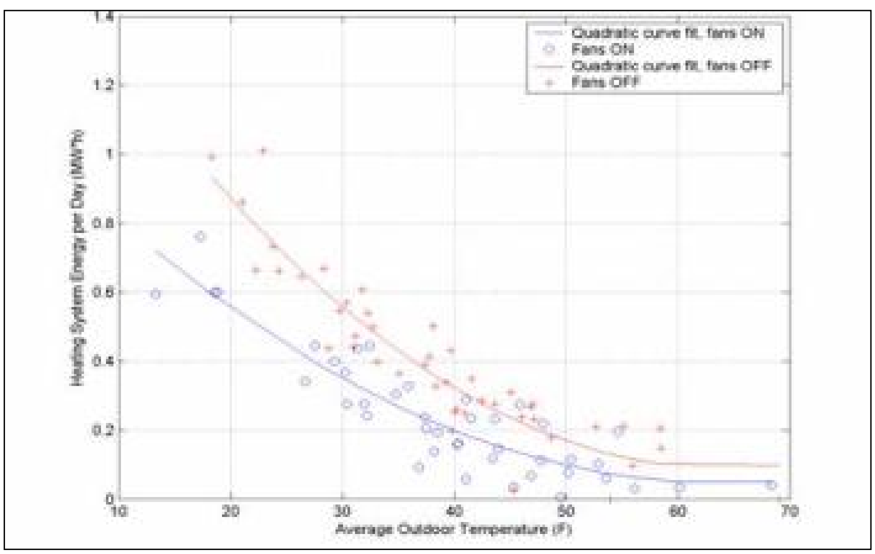

Figure 7.46. Heating system energy usage per average outdoor temperature for Bethesda.

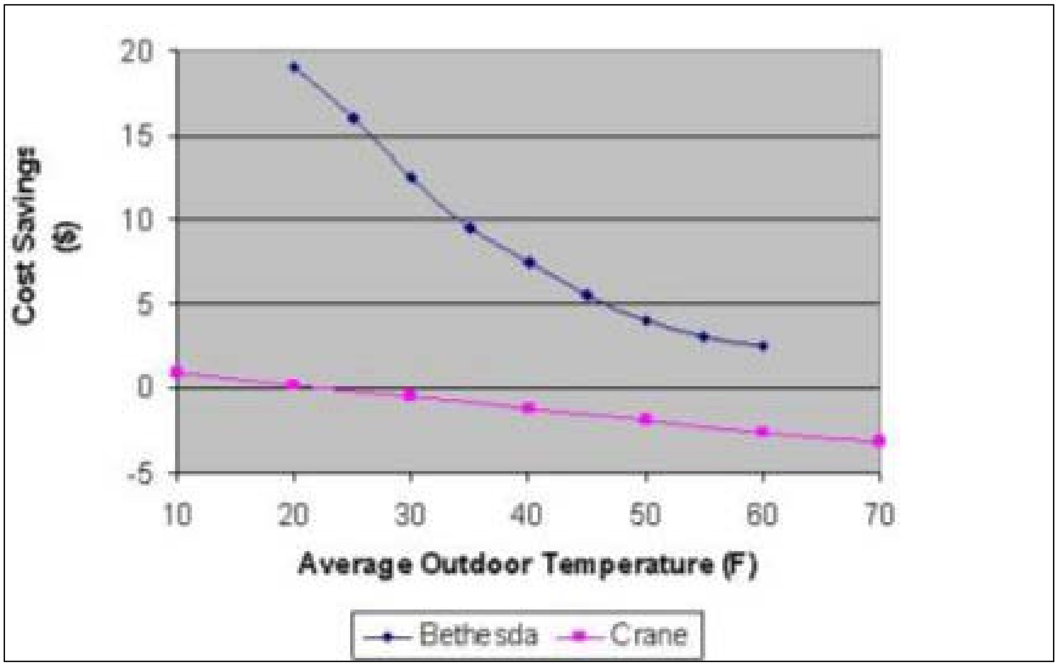

Figure 7.47. Energy cost savings as a function of daily average OAT for Bethesda and Crane.

Finally, power usage evaluations were completed for the fans used in this project. Evaluations prior to installation showed power usage for the standard fan is greatly affected by current, with 58 W used at 0.585 A and 90 W used at 0.7 A. After installation, the power usage of the fans at the Bethesda site was measured to be an average of 54 W each, or 323 W for the fan system. This does not include the power lost in the lines leading to the fans, which was not measured at Bethesda.

The retail price for each fan was $395. After adding in shipping and handling, the total cost of each unit was $410. The manufacturer indicated that the fan would be available in the near future on a General Services Administration (GSA) schedule (Table 7.14) at a $45 discount. This is approximately a 12% discount from the Retail Price Schedule.

Table 7.14. Airius thermal equalizer GSA price schedule.

Model	GSA Price	S&H	Total Cost
Model 25	$299.00	$15.00	$314.00
Model 40	$350.00	$15.00	$365.00
Model 40 Plus	$388.00	$18.00	$406.00

The project conducted was performed by SEI, who subbed out work to local contractors. The costs of the projects to be reported in this section are geared toward the costs that would be experienced if a site went to a local contractor for the work, and not through a lead contractor. It is assumed the site would do the design and project management themselves, and would have a lift (most sites do have a lift for maintenance).

In Bethesda, electricity costs $0.056/kWh and there are 4,240 HDD.

For the Bethesda site, the fans cost $80 to operate per year. Without the fans, the heat pump cost $4,149 to operate in a heat year. The operation of the fans saved an estimated $1,648 per year in heat pump heating. This resulted in a net savings of $1,568 per year (~95 Mbtu/year). This is an overall 38% cost and energy savings.

At Bethesda, the installation ($5,917) and destratification fan ($2,188) costs for the six fans total $8,105 or $1,351 per fan. This, in combination with the $1,568 per year savings results in a 5.2-year simple payback.

Note that the cost per fan is greatly affected by the number of fans installed. Also, per-fan installation costs are to vary on many factors such as location, contracting methods andc. The energy costs also have a dramatic effect on the economics of this technology. This analysis also shows the huge affect building parameters such as envelope-quality have on the viability of such projects.

User Evaluation

The building occupants at Bethesda like the fans. They like the heat coming down from them. At the start of their workday, as the building heats up, the occupants stand under the fans to keep warm. Overall, they feel conditions are better this year with the fans.

There is one concern at Bethesda. An occupant has a fan directly over his workspace. He often does not enjoy the draft. He requests that the fans are kept, but that the fan over his space is moved so it is not blowing directly upon him.

Renovation Costs

$8,105

Experiences/Lessons Learned

<u>Energy Use Saved</u>

95 Mbtu/year

<u>Environmental Impact</u>

None.

<u>Economics</u>

Originally 6.0 year simple payback, but due to utility rate increase, now down to 3.7 years.

<u>Practical Experiences of Interest to a Broader Audience</u>

Where To Install Thermal Destratifiers:

- Facilities with a solid envelope.
- Facilities where the cost of the fuel to heat the building is high and the cost of electricity is low.
- Where a facility is heated with electricity, high electric rates are better.
- Buildings that have been identified as having thermal stratification.
- Larger buildings have better economies of scale.
- Where personnel comfort is a concern.

Resulting Design Guidance

Working.

General Data

Address of Project

Bethesda, MD

Existing or New Case Study

New Case Study

Date of Report

8 December 2008

Acknowledgements

Project Sponsor: US Department of Defense, Navy Techval Program
Designer: SEI Group, Inc.
General Contractor: SEI Group, Inc.
Case Study Author: NAVFAC Engineering Service Center (Mr. Joel Hughes)

References

Additional information concerning this project can be obtained by contacting:

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Application of DOAS to Control Humidity in Bldg. 630, a Military Barracks Facility at Fort Stewart, GA, USA

Photo

Figure 7.48. Typical three-story, six-module barracks facility, Fort Stewart, GA.

Project Summary

Bldg. 630 is a three-story, six-module barracks facility (Figure 7.48) originally constructed in 1977. A typical module consists of four occupant rooms per floor (Figure 7.49). The first floor of one module (Module D) is used as a common area, a laundry room, and a mechanical room. Bldg. 630 is typical of 30 other similar barracks facilities and has a total of 68 occupant rooms with two soldiers occupying each room (Figure 7.50). Fort Stewart is located in a very hot and humid climate and these modular barracks facilities have experienced many problems with mold and mildew in the occupant rooms. Bldg. 630 was selected along with Bldgs. 631 and 637 to demonstrate dehumidification of barracks facilities using three different innovative DOAS. Figure 2 is a floor plan of Bldg. 630 and Figure 3 shows the layout of a typical pair of occupant rooms in Bldg. 630. The floor plans and occupant room layouts in Bldgs. 630, 631, and 637 are identical.

Bldg. 630's three existing makeup air units (MAUs) in the attic and the four-pipe FCU in each of the occupant rooms were left in place. Each of the existing MAUs was augmented with a DX dehumidifier installed in the downstream ductwork. Each DX dehumidifier consists of a DX evaporator cooling coil, a DX compressor, a water-cooled condenser, and a hot water reheat coil.

Site

Bldg. 630 is located within a troop housing complex of 31 similar barracks facilities at Fort Stewart near the city of Hinesville in Liberty County, GA, at 31.87 N latitude, 81.6 W longitude. This location falls within ASHRAE 90.1-2004 Climate Zone 2A (Hot-Humid). Design weather data at this location is characterized by:

- CDD (based on 65 °F) – 2539
- HDD (based on 65 °F) – 1551

- Cooling Design Temperature – 0.4% occurrence*
- Dry Bulb Temp: 95.7 °F
- Mean Coincident Wet Bulb Temp: 78 °F
- Dew Point Temp 71.1 °F
- Heating Design Temperature – 99.6% occurrence
- Dry Bulb Temp 26 °F
- Mean Coincident Wet Bulb Temp 23 °F

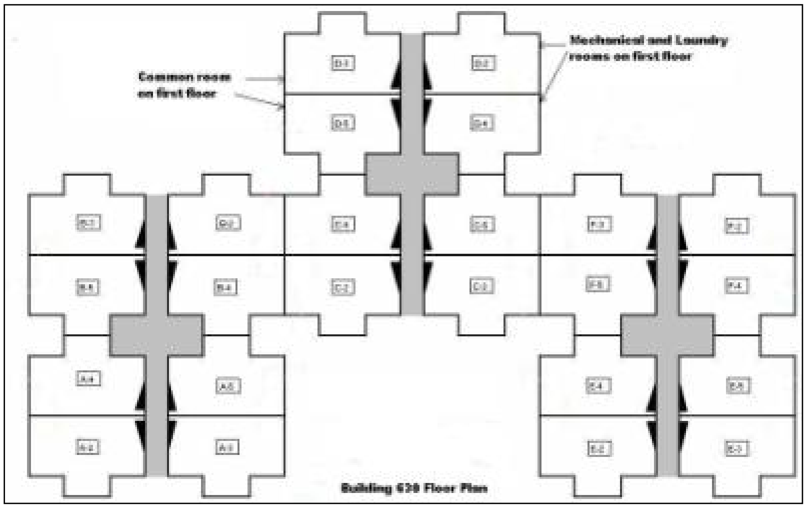


Figure 7.49. Bldg. 630 floor plan.

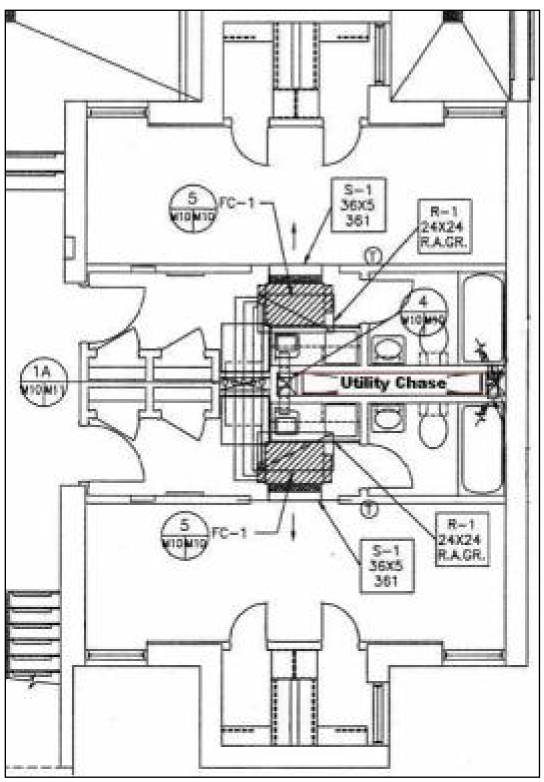


Figure 7.50. Floor plan of occupant rooms (two rooms shown).

* based on *2005 ASHRAE Handbook of Fundamentals* for Hunter Army Airfield, 32.02 N latitude, 81.15 W longitude

Building Description/Typology

Typology/Age

Bldg. 630 is built of concrete masonry unit (CMU) type construction with brick exterior. The building originally was constructed with a flat built up roof. A renovation project in 2000 installed a pitched standing seam metal roof over the top of the original flat roof. This renovation project also upgraded the HVAC system, including installing new hot water and chilled water piping in the attic and in the utility chases, installing makeup air systems and common exhaust systems in the attic, with ductwork installed in the utility chases. Architectural changes included removing end walls in the stairwells in each module to create open landings at each floor level.

General Information

Year of construction	1977
Year of initial renovation:	2000
Year of subject renovation:	2007
Total floor area (m^2):	2440
Total occupant rooms area (m^2):	2370
Occupant capacity:	136
Number of occupant rooms:	68
Typical occupant room:	
Size (m^2):	35
Windows/glass area (m^2):	2.8
Occupants per room:	2
Occupied hours:	12 hrs per weekday; 24 hrs per weekend day

Architectural Drawings

Not available.

Previous Heating, Ventilation, Cooling and Lighting Systems

Prior to this renovation project, the HVAC system consisted of 4-pipe FCUs in each occupant room. Ventilation air was provided to each FCU from three attic-mounted MAUs which incorporated filtration, a preheat coil and a cooling coil. Hot water and chilled water were provided from a central plant. Each occupant room also had an exhaust air grille in the bathroom. Ventilation air and exhaust air stacks were installed in a utility chase which served six rooms (2 on each of three floors) as shown in Figure 7.51.

Prior to this retrofit project, each of Bldg. 630's three original MAUs were designed to deliver 1200 CFM of ventilation air, for a total of about 50 CFM delivered to each occupant room. When the buildings were in use, the MAUs operated continuously. The exhaust fans also normally operated 24/7/365. Each of the 12 exhaust fans removed about 210 CFM, about 35 CFM per occupant room. As a result, the occupant rooms were (theoretically) slightly positively pressurized. Nevertheless, although the building envelope is relatively "tight," the volume of ventilation air delivered by the original MAUs was not sufficient to maintain sufficient positive pressurization to exclude infiltration of hot, humid outdoor air.

To reduce the humidity and minimize mold/mildew problems in the occupant rooms, the Directorate of Public Works (DPW), the authority responsible for operating and maintaining these facilities, installed electric dehumidifiers in each of the rooms. When the building is unoccupied for extended periods, these dehumidifier units are operated continuously. The rated power requirement for these units is 5 amps at 120 volts (600 watts).

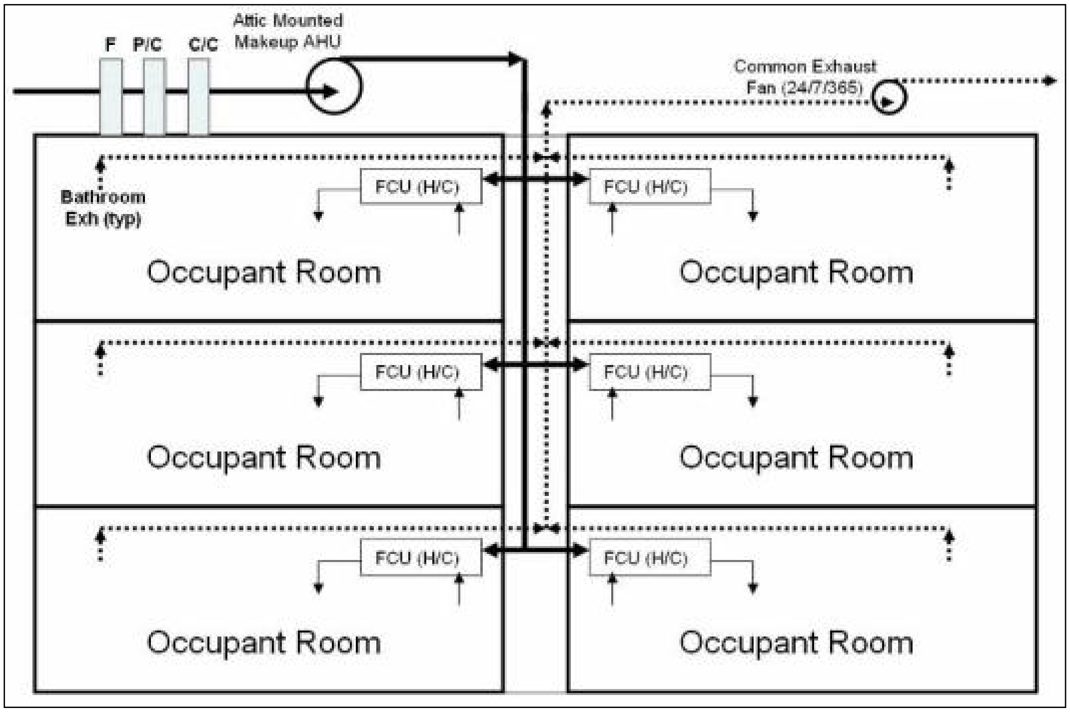


Figure 7.51. Original system configuration (elevation view).

The lighting system in the occupant rooms consists of 2-lamp ceiling-mounted fluorescent fixtures. The lighting system was not altered by this project.

Retrofit Energy Savings Features

<u>Retrofit System Description</u>

This retrofit project retained each of the three original attic-mounted MAUs, augmenting each of them with a DX dehumidifier installed in the downstream ductwork. Each DX dehumidifier consists of a DX evaporator cooling coil, a DX compressor, a water-cooled condenser and a hot water reheat coil. Return water from the MAU's chilled water coil flows through the water-cooled condenser, then through the reheat coil and finally returned to the central chilled water plant. A three-way diverting valve in the condenser water circuit is automatically controlled to maintain a desired ventilation air supply temperature. An airflow measurement array installed in the DX dehumidifier unit in combination with a motorized damper allows accurate regulation of dehumidified air volumes delivered to the building.

Figure 7.52 shows a detailed schematic of one of Bldg. 630's augmented MAU's. In the figure, the leaving dry bulb temperature (DBT) from the chilled water coil is shown to be 60 °F (15.6 C). The downstream DX coil further cools and dehumidifies the air stream down to a DBT of 38 °F (3.3 C). At this point, the air stream can be assumed to be saturated. Therefore, the DBT and dew point temperature (DPT) should be equal. This dry, cold air stream is then reheated to 52 °F (11.1 C) DBT by heat rejected from the DX process. Of course, the DPT remains unchanged so that the system delivers air to the occupant rooms via the existing attic-mounted ventilation air distribution ductwork at 52 °F DBT and 38 °F DPT. Each of the three attic-mounted augmented MAUs delivers 1500 CFM, about 25% more ventilation air than the original system in an effort to maintain positive pressurization of the occupant rooms and prevent infiltration of hot, humid outdoor air.

Figure 7.53 shows a schematic of the installed system. Conditioned air from the DOAS system is ducted to the occupant rooms through the existing makeup air distribution ductwork. Figures 7.54, 7.55, and 7.56 show components of one of the new DX dehumidifiers installed in Bldg. 630. The original four-pipe FCU in each of the occupant rooms were retained to handle the space heating and (sensible) cooling loads. If working as intended, the sensible and latent cooling loads should be decoupled so that all (or nearly all) latent cooling occurs in the DOAS system with little or no condensation occurring in the FCUs.

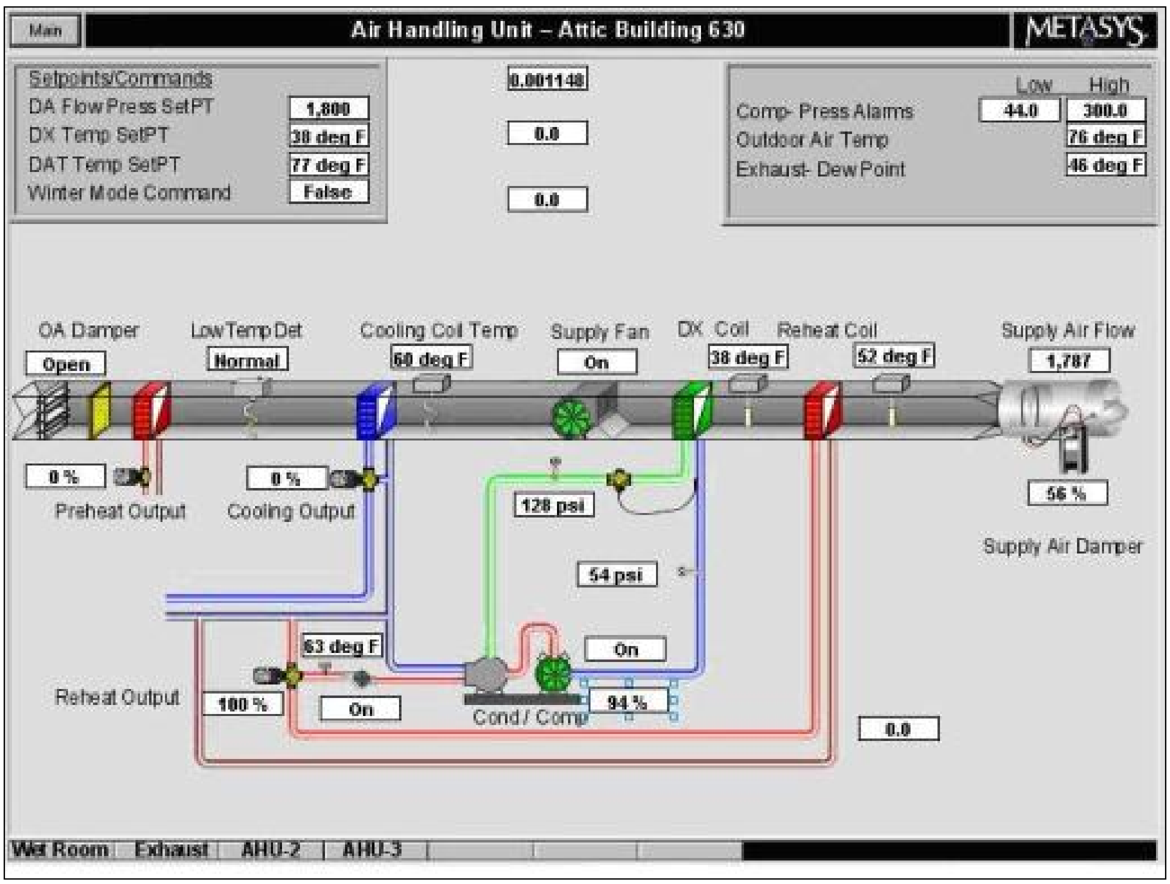


Figure 7.52. Screen capture of Bldg. 630 augmented DOAS makeup air unit schematic. Typical of three units installed in the attic of Bldg. 630.

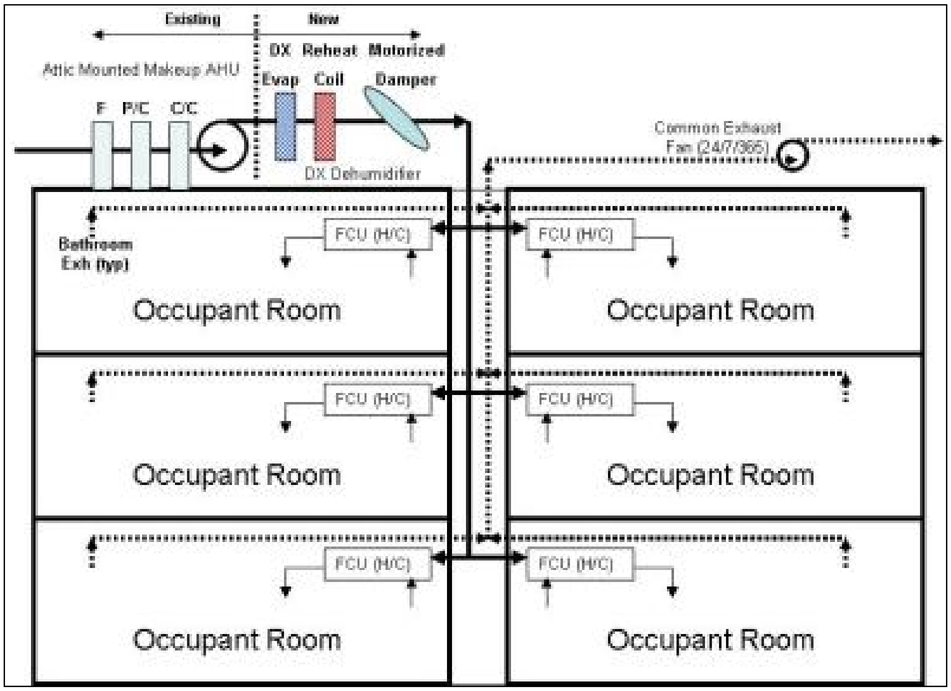


Figure 7.53. New Bldg. 630 DOAS system configuration (elevation view).

Figure 7.54. DX cooling coil located to the left. Hot water reheat coil shown in the center. The motorized damper actuator is barely visible behind the steel framing member to the right.

Figure 7.55. DX compressor and water-cooled condenser.

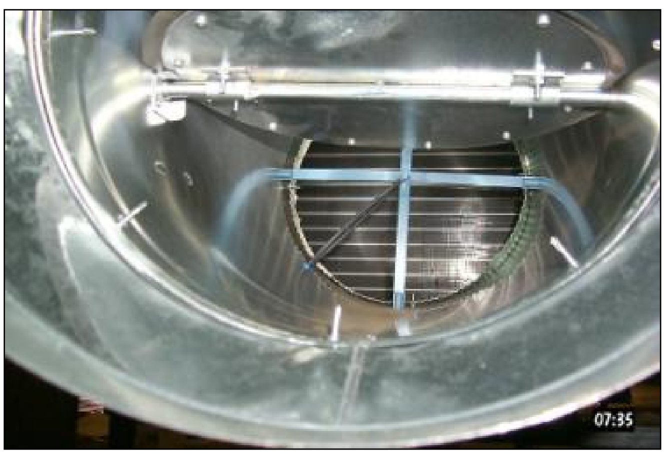


Figure 7.56. Airflow measurement sensor and motorized damper downstream of reheat coil.

Retrofit of Bldg. 630 was completed in September 2007. September weather conditions at Fort Stewart are hot and humid. Although Bldg. 630 was unoccupied when the retrofit project was complete, we installed temperature and relative humidity dataloggers in a number of typical occupant rooms and operated the DOAS system and FCUs through the months of September and October. A follow on project is planned to collect performance data on this building during the summer of 2008 when the building is expected to be occupied.

Energy-Saving Concept

This was primarily a project to demonstrate three approaches to dehumidify and minimize or eliminate mold/mildew problems in barracks facilities using three different DOAS approaches. Although energy performance was not our primary concern, we have initiated a follow on project to measure and analyze the relative energy performance of the three DOAS systems (Bldgs. 630, 631, and 637) and compare to a baseline barracks facility. We believe that we may realize energy savings in the following ways:

- Reduced or discontinued use of dehumidifiers in occupant rooms. Currently, the DPW provides standalone dehumidifiers for each occupant room. These units operate 24/7in an attempt to reduce humidity levels in the occupant rooms to minimize or eliminate growth of mold and mildew in the occupant rooms. The dehumidifiers are noisy, require frequent maintenance and consume significant energy. We believe that the DOAS system will eliminate the need for the standalone dehumidifiers while removing moisture in a more energy efficient manner than these standalone units.
- Ability to keep occupants comfortable at higher room temperature setpoints. Soldiers will often lower their thermostats as low as the system allows, for comfort. We believe that the drier conditions in the occupant rooms will allow the soldiers to be comfortable at higher room temperature setpoints.
- Reduced energy usage during extended unoccupied periods. Barracks facilities often experience extended unoccupied periods as troops are absent for training and other activities. During these extended unoccupied periods, the DPW continues to keep these buildings conditioned to discourage growth of mold and mildew. We believe that the DOAS system should allow the DPW to maintain interior conditions which will discourage mold and mildew development at much warmer interior DBTs.

Heating

This project did not alter the existing heating system.

Resulting Energy Savings

We have not yet evaluated the energy performance of this renovated facility. Unfortunately, no baseline energy performance data is available for this facility and the newly installed system does not include sufficient energy metering capabilities to accurately measure current energy performance. In addition, this facility has not been occupied since the renovation project was completed in September 2007. To address this shortcoming, a follow on project during the summer of 2008 has been initiated to install the instrumentation necessary to measure energy performance in Bldg. 630 (as well as Bldgs. 631 and 637) and a similar baseline facility. All four buildings will be similarly instrumented with temperature/relative humidity dataloggers in several occupant rooms, electrical power usage metering, and chilled/hot water usage metering. This is the most credible approach to allow us to determine the relative energy performance of these facilities during the summer cooling season while the facility is fully occupied.

User Evaluation

As noted above, this facility has not been occupied since the renovation project was completed. As a result, user input is not yet available. Nevertheless, during our brief testing period during September 2007, we noted that the low humidity interior environment caused the occupant rooms to be quite comfortable even at relatively higher interior DBTs. The follow on project referenced above will allow us an opportunity to evaluate the ability of this retrofitted system to control the humidity levels within the facility. This project will compare the performance of this system to Bldgs. 631 and 637 and to the baseline building and will include qualitative inputs from the building occupants.

Renovation Cost

Note that the Bldg. 630 renovation work was a part of a demonstration project that also renovated Bldgs. 631 and 637 (using different technologies). As a result, it is somewhat difficult to accurately assign costs to the three buildings. In addition, because this was a research project, these buildings were extensively instrumented, more than would be expected for a typical project. As a result, the estimated costs (Table 7.15) are considered to be somewhat high.

Table 7.15. Bldg. 630 – DX Dehumidifiers.

Item	Cost
Mechanical & Electrical Work	$65,000
Equipment	$23,000
Controls	$17,000
Design & Construction Management	$15,000
Total	$120,000

Experiences/Lessons Learned

Energy Use

Not yet evaluated.

Impact on Indoor Climate

This project was primarily motivated by a desire to demonstrate a method of eliminating mold/mildew growth in barracks facilities. Most molds reproduce by producing spores, which are microscopic cells, usually between 2-20μm and oblong shaped, and can become airborne very easily. These spores then can attach to surfaces that are wet and new growths called colonies may then form if the right conditions are present. These ideal conditions include high humidity (usually over 65% relative humidity) or moisture content. Ideal temperature range for mold growth is between 50 and 90 °F. No mold is able to grow in the absence of moisture. When the spores settle on a surface and begin to germinate they produce a branching network called hyphae. The mold then begins digesting the surface that they are growing on to survive.

Unfortunately, mold thrives across the full range of desirable indoor space temperature. As a result, the only practical way to control mold/mildew formation and growth is to control the moisture available to the mold spores. Moisture can be removed from an indoor space by supplying ventilation air that is drier than the bulk air within the space and/or by directly removing moisture from the air within the space, typically by condensing moisture on the cooling coil of a FCU or a standalone dehumidifier. If a DOAS system can deliver sufficient quantities of sufficiently dry ventilation air, the need to remove moisture within the space can be reduced or eliminated.

One can reasonably assume that the air leaving a wet cooling coil is saturated (i.e., 100% RH). At this condition, the leaving air DBT and dewpoint temperatures coincide. The cooling coil of a typical AHU has a leaving air temperature (LAT) of about 55 °F. However, if the quality of the chilled water supplied to the coil is low (i.e., not sufficiently cold), the LAT might approach 60 °F. Table 7.16 lists the relative moisture content of air supplied at various DPTs.

Table 7.16. Relative moisture content of air supplied at various DPTs.

Leaving Air DPT	Leaving Air Moisture Content (gr/cu ft)	Moisture Content (lb/hr) @ 1500CFM
40	2.87	36.9
45	3.44	44.3
50	4.12	53.0
55	4.9	63.0
60	5.81	74.8

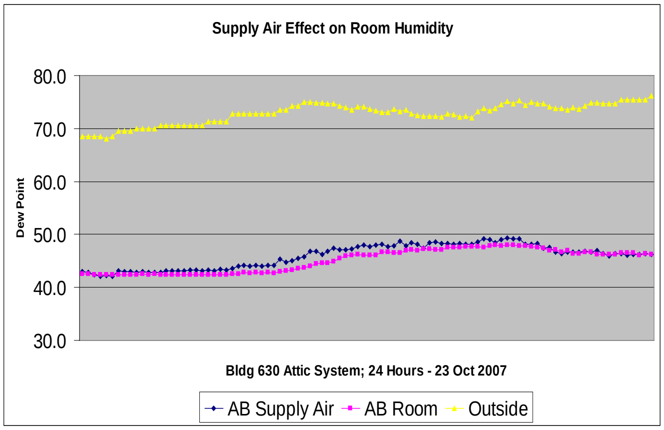
Assuming that the original systems were able to deliver 1200 CFM of makeup air at 55 °F DPT, the moisture content of the air delivered by the original makeup air system would be 50.4 lb/hr. More realistically, due to poor chilled water quality, the makeup air supplied by the original system was probably closer to 60 °F. If so, then the moisture content of 1200 CFM of makeup air at 60 °F DPT would be 59.8 lb/hr.

This DOAS system demonstrated an ability to profoundly impact Bldg. 630’s interior climate. Figures 10a, 10b,and 10c show the systems’ ability to deliver deeply dehumidified outdoor air; outdoor air ranging from 69 to 76 °F DPT is delivered to the occupant rooms at average dew point temperatures of approximately 45 °F (Modules A/B), 42 °F (Modules C/D) and 47 °F (Modules E/ °F).

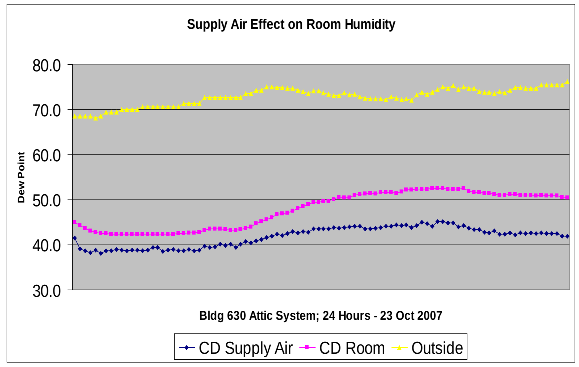
Based on the retrofitted MAU’s ability to deliver ventilation air at approximately 45 °F DPT, each unit would deliver approximately 44.3 lb/hr of moisture to the occupied rooms. Since each of the MAUs serves 48 occupants (2 persons per room times 24 rooms each), the occupant humidity load (assuming moderate occupant activity) can be estimated at about 17.2 lb/hr per makeup air unit. Thus, the retrofitted MAUs (at 1500 CFM and 45 °F DPT) would deliver 15.5 lb/hr less moisture to the space than the original MAUs at 1200 CFM and 60 °F DPT. Thus, the drier air delivered by the retrofitted MAUs is able to offset most of the occupant humidity load when the building is fully occupied. When the building is unoccupied or lightly occupied, the increased flow rate (1500 CFM vs. 1200 CFM) and improved drying capacity will help to reduce and offset the infiltration of humid outdoor air.

Notice that all three DOAS systems show a trend of rising supply air DPT as the outdoor dew point (and presumably, DBT) rises. This trend probably indicates a lack of cooling capacity in the chilled water coils and possibly in the DX cooling coil as well.

For Modules A and B (Figure 7.57), note that the trend of the average DPT in the occupant rooms is below that of the Supply-Air DPT (taken at the outlet of the DOAS AHU). This counterintuitive result may be an inaccuracy in the Temp/RH datalogger in the outlet of the DOAS AHU. Nevertheless, the figure clearly shows that introducing very dry ventilation air creates very dry conditions in the occupant rooms.



Modules A and B



Modules C and D

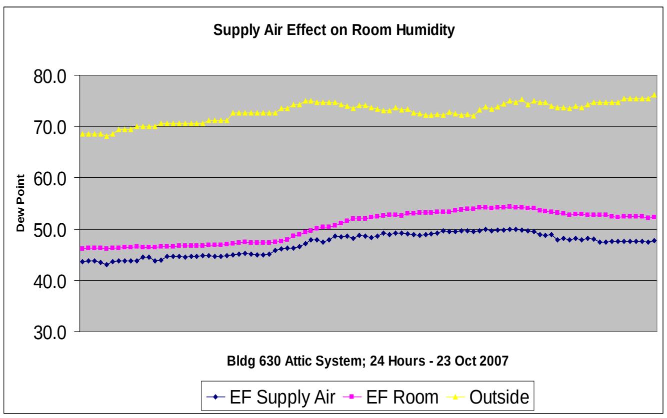


Figure 7.57. Modules A and B - effect of dry outdoor air on occupant room DPTs.

Modules E and F

Economics

Not yet evaluated.

Practical Experiences of Interest to a Broader Audience

There are a number of attractive features associated with this DOAS system:

- Quiet operation. Since this unit is located in the attic, its quiet operation is appreciated.
- Ability to take advantage of “warm” chilled water. Bldg. 630 receives chilled water from a central plant system. The chilled water supply temperature as delivered to Bldg. 630 is somewhat high (from 48 to 52 °F). Nevertheless, this system is relatively insensitive to somewhat higher chilled water supply temperature because the DX coil has the capacity to compensate for the chilled water coil’s lost capacity due to higher than desired chilled water supply temperature. In addition, because the DOAS AHU handles most, if not all, of the latent cooling load, the FCUs in the occupant rooms retain sufficient sensible cooling capacity even at higher chilled water supply temperatures.

- Reduced maintenance of FCUs. By handling most, if not all, of the latent cooling load, the condensate generated by the FCUs should be reduced or eliminated, reducing the need to maintain condensate drains and drain pans.
- Reduced potential for mold and mildew. Drier interior environments and reduced generation of condensate will reduce the potential for generating mold and mildew.

There are also a number of attractive features associated with this DOAS system:

- *Custom built up system.* Unlike the packaged units installed in Bldgs. 631 and 637, the systems installed in Bldg. 630 were prototypes requiring extensive design and field construction effort. Also, the fact that these units were installed in a very cramped and cluttered attic space made the installation work somewhat challenging.
- *Ease of maintenance*. Being located in the attic makes these units somewhat difficult to access for maintenance. Fortunately, the DX technologies incorporated in these systems are relatively simple and easily serviced by installation maintenance personnel.

Some possible unresolved issues include:

- Ensuring uniform distribution of conditioned ventilation air to 68 occupant rooms is challenging. Each DOAS system serves two modules and incorporates an ability to control the volume of dehumidified ventilation air it delivers. The ability to evenly distribute the ventilation air among the rooms within the two modules is not assured.
- Impact of wind on the building exterior may affect our ability to keep occupant rooms pressurized with dry outdoor air. Although a blower door test on a similar building showed that these buildings have “tight” envelopes, preliminary test results indicate that even mild breezes can have an undesired effect.
- Possible opportunities to modify building exhaust strategy. Currently, the common exhaust fans operate 24/7/365, exhausting conditioned air even when the rooms are unoccupied. This reduces the differential pressurization of the occupant rooms and encouraging infiltration of unconditioned outdoor air.
- Sensitivity to “real world” occupied conditions. Troops are known to put any system to the ultimate test. How well will the system respond to troop activities such as cooking, showering, leaving doors and windows open, andc.?
- Residual opportunities for mold and mildew formation. Although the DOAS system appears to be able to produce favorably dry air conditions in the occupant rooms, the presence of chilled water piping in the ceiling space and cold supply air from the FCUs impinging on surfaces will create “local high humidity” regions which could still be subject to mold and mildew growth.

<u>Resulting Design Guidance</u>

Not yet available.

General Data

Address of Project:	1377 Gulick Avenue, Fort Stewart, GA 31314
Existing or New Case Study:	New
Date of Report/Revision No.	9 May 2008

Acknowledgements

Project Sponsor: US Army Assistant Chief of Staff for Installation Management

Designer: Mr. Jerry Weber, Johnson Controls, Inc.
General Contractor: Johnson Controls, Inc.
Case Study Authors: Mr. James Miller, US Army ERDC/CERL
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References

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Application of DOAS To Control Humidity in Bldg. 631, a Military Barracks Facility at Fort Stewart, GA, USA

Photo

Figure 7.58. Typical three-story, six-module barracks facility, Fort Stewart, GA.

Project Summary

Bldg. 631 is a three-story, six-module barracks facility (Figure 7.58) originally constructed in 1977. A typical module consists of four occupant rooms per floor. The first floor of one module (Module D) is used as a common area, a laundry room and a mechanical room. Bldg. 631 is typical of 30 other similar barracks facilities and has a total of 68 occupant rooms (Figure 7.59) with two soldiers occupying each room (Figure 7.60). Fort Stewart is a very hot and humid climate and these modular barracks facilities have experienced many problems with mold and mildew in the occupant rooms. Bldg. 631 was selected along with Bldgs. 630 and 637 to demonstrate dehumidification of barracks facilities using three different innovative DOAS. The Bldg. 631 DOAS system consisted of replacing existing attic-mounted MAUs with a new custom AHU which provided deep dehumidification of outdoor air with a DX evaporator coil downstream of a chilled water coil. The deeply dehumidified air is then reheated by heat rejected from the DX condenser coil before being delivered to the occupant rooms. The four-pipe FCU in each of the occupant rooms have been retained and will continue to handle heating and sensible cooling in the occupant rooms. Figure 2 is a floor plan of Bldg. 631.

Site

Bldg. 631 is located within a troop housing complex of 31 similar barracks facilities at Fort Stewart near the city of Hinesville in Liberty County, GA, at 31.87 N latitude, 81.6 W longitude. This location falls within ASHRAE 90.1-2004 Climate Zone 2A (Hot-Humid). Design weather data at this location is characterized by the following:

- CDD (based on 65 °F) – 2539
- HDD (based on 65 °F) – 1551
- Cooling Design Temperature – 0.4% occurrence*
- Dry Bulb Temp: 95.7 °F

* Based on 2005 ASHRAE Handbook of Fundamentals for Hunter Army Airfield, 32.02 N latitude, 81.15 W longitude

- Mean Coincident Wet Bulb Temp 78 °F
- Dew Point Temp 71.1 °F
- Heating Design Temperature – 99.6% occurrence
- Dry Bulb Temp 26 °F)
- Mean Coincident Wet Bulb Temp 23 °F)

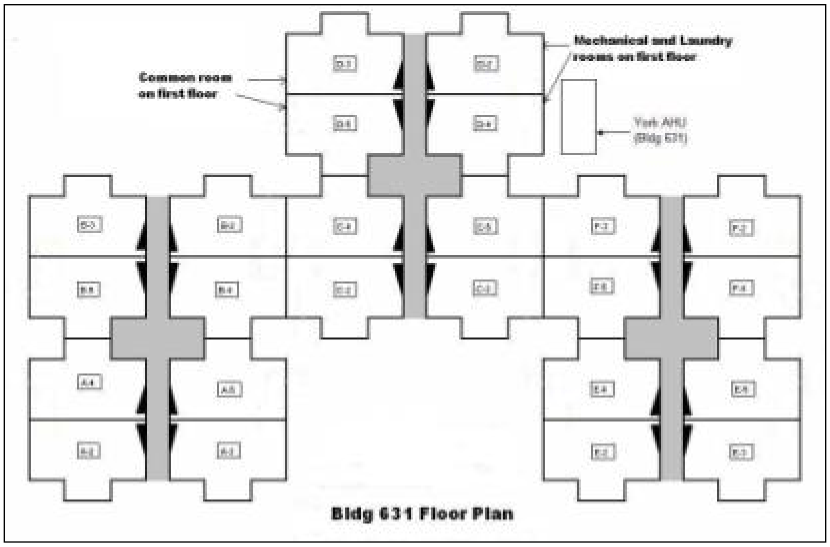

Figure 7.59. Bldg. 631 floor plan.

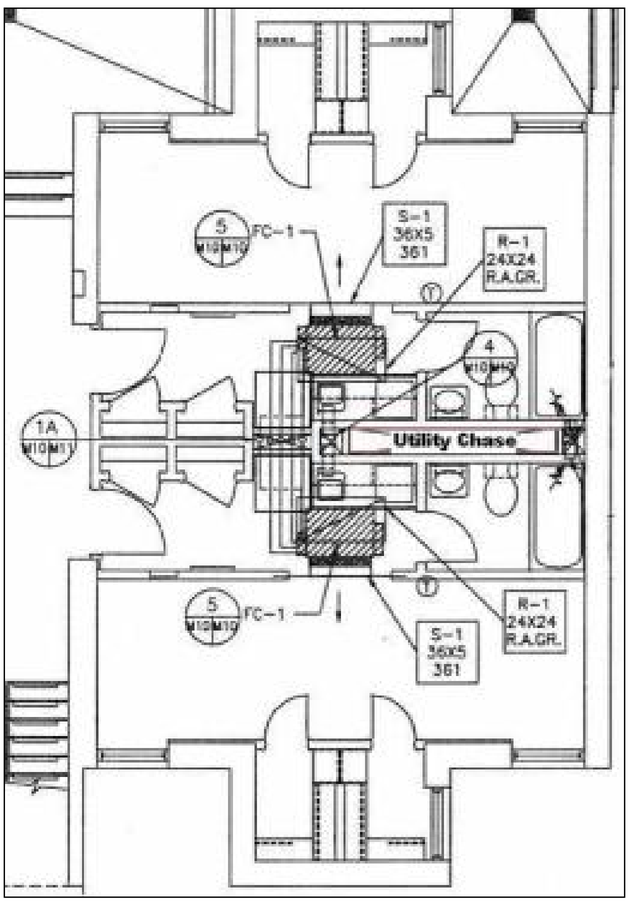

Figure 7.60. Floor plan of occupant rooms (two rooms shown).

Building Description/Typology

Typology/Age

Bldg. 631 is built of CMU type construction with brick exterior. The building originally was constructed with a flat built up roof. A renovation project in 2000 installed a pitched standing seam metal roof over the top of the original flat roof. This renovation project also upgraded the HVAC system, including installing new hot water and chilled water piping in the attic and in the utility chases, installing DOASs and common exhaust systems in the attic, with ductwork installed in the utility chases. Architectural changes included removing end walls in the stairwells in each module to create open landings at each floor level.

General Information

Year of construction:	1977
Year of initial renovation:	2000
Year of subject renovation:	2007
Total floor area (m^2):	2440
Total occupant rooms area (m^2):	2370
Occupant capacity:	136
Number of occupant rooms:	68
Typical occupant room:	
Size (m^2):	35
Windows/glass area (m^2):	2.8
Occupants per room:	2
Occupied hours:	12 hours per weekday; 24 hours per weekend day

Architectural Drawings

Not available.

Previous Heating, Ventilation, Cooling and Lighting Systems

Prior to this renovation project, the HVAC system consisted of 4-pipe FCUs in each occupant room. Ventilation air was provided to each FCU from three attic-mounted makeup AHU which incorporated filtration, a preheat coil and a cooling coil. Hot water and chilled water were provided from a central plant. Each occupant room also had an exhaust air grille in the bathroom. Ventilation air and exhaust air stacks were installed in a utility chase which served six rooms (two on each of three floors) as shown in Figure 7.61.

Each of Bldg. 631's three original makeup AHUs were designed to deliver 1200 CFM of ventilation air, for a total of about 50 CFM delivered to each occupant room. When the buildings are in use, the makeup AHUs operated continuously. The exhaust fans also normally operated 24/7/365 when the buildings were in use. Each of the 12 exhaust fans remove about 210 CFM, about 35 CFM per occupant room. As a result, the occupant rooms were (theoretically) slightly positively pressurized. Nevertheless, although the building envelope is relatively “tight”, the volume of ventilation air delivered by the original MAUs was not sufficient to maintain positive pressurization and exclude infiltration of hot, humid outdoor air.

To reduce the humidity and minimize mold/mildew problems in the occupant rooms, the DPW, the authority responsible for operating and maintaining these facilities, installed electric dehumidifiers in each of the rooms. When the building is unoccupied for extended periods, these dehumidifier units are operated continuously. The rated power requirement for these units is 5 amps at 120 volts (600 watts).

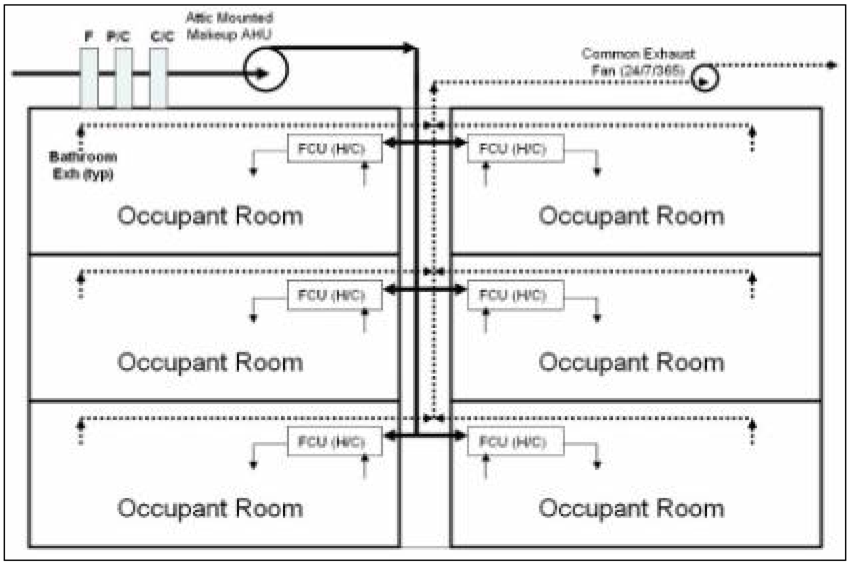

Figure 7.61. Original system configuration (elevation view).

The lighting system in the occupant rooms consists of two-lamp ceiling-mounted fluorescent fixtures. The lighting system was not altered by this project.

Retrofit Energy Savings Features

Retrofit System Description

The retrofit project abandoned the original MAUs, replacing them with a single exterior mounted DOAS system which delivers very dry makeup air to the occupant rooms. The new DOAS system consists of a custom York Solutions exterior AHU mounted on a concrete pad adjacent to the building. Downstream of air filters, a preheat coil and a chilled water cooling coil, the AHU includes a DX cooling coil and an air-cooled condenser. The leaving DPT from the chilled water cooling coil is about 58 °F (14.4 C). The DX cooling coil further dehumidifies the air, with a leaving DPT of approximately 40 °F (4.4 C). This dry air is then reheated by the air-cooled condenser coil before being delivered to the occupant rooms at approximately 62 °F (16.7 C) DBT and 40 °F (4.4 C) DPT. This system delivers 4500 CFM, about 25% more ventilation air than the original system in an effort to maintain positive pressurization of the occupant rooms and prevent infiltration of hot, humid outdoor air. Figure 7.62 shows a detailed schematic of Bldg. 631's new DOAS AHU.

Figure 7.63 shows a schematic of the installed system. Conditioned air from the DOAS system is ducted to the occupant rooms through the existing makeup air distribution ductwork. Figure 7.64 shows the new DOAS AHU and the supply duct from the DOAS AHU to the building attic. The original four-pipe FCU in each of the occupant rooms were retained to handle the space heating and (sensible) cooling loads. If working as intended, the sensible and latent cooling loads should be decoupled so that all (or nearly all) latent cooling occurs in the DOAS system with little or no condensation occurring in the FCUs.

Retrofit of Bldg. 631 was completed in September 2007. September weather conditions at Fort Stewart are hot and humid. Although Bldg. 631 was unoccupied when the retrofit project was complete, we installed temperature and relative humidity dataloggers in a number of typical occupant rooms and operated the DOAS system and FCUs through the months of September and October. A follow on project is planned to collect performance data on this building during the summer of 2008 when the building is expected to be occupied.

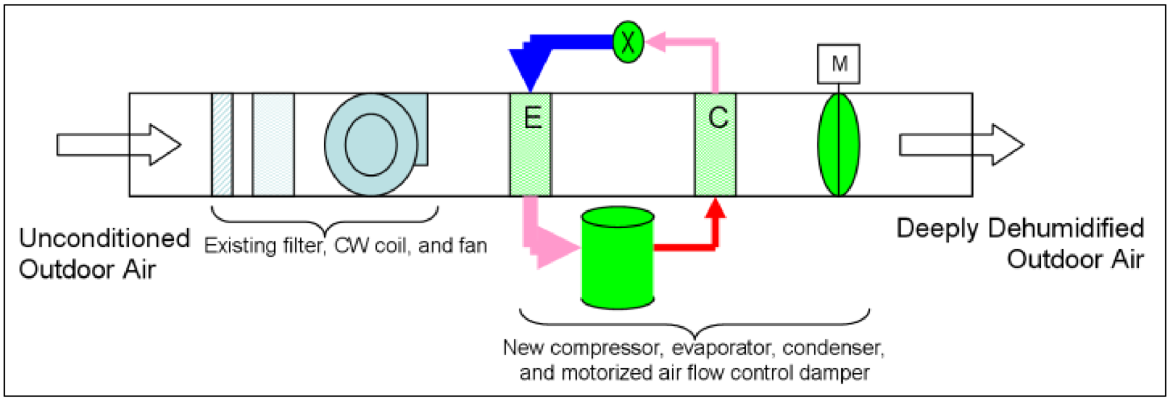

Figure 7.62. DOAS system schematic.

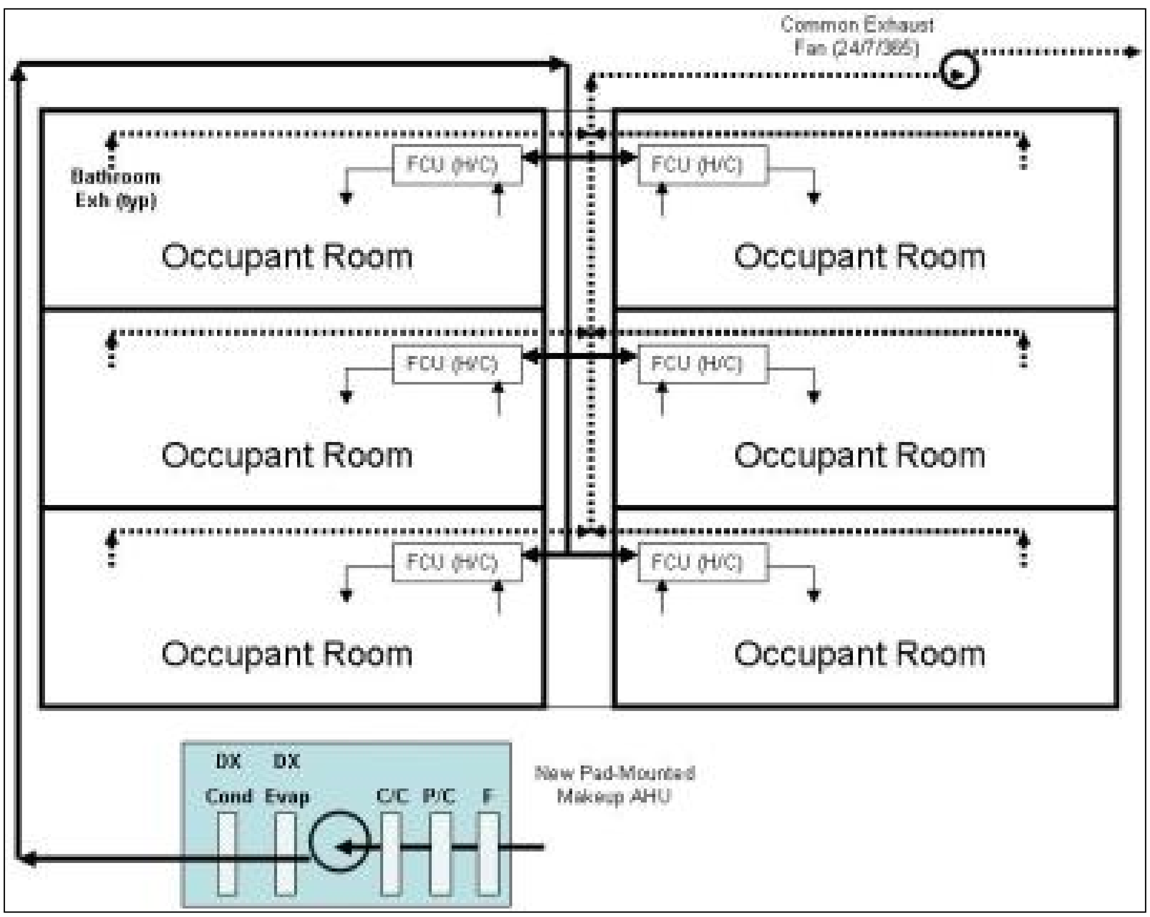

Figure 7.63. New DOAS system configuration (elevation view).

Figure 7.64. Conditioned outdoor air is ducted from the DOAS AHU up the side of the building to the attic.

Energy Saving Concept

This was primarily a project to demonstrate three approaches to dehumidify and minimize or eliminate mold/mildew problems in barracks facilities using three different DOAS approaches. Although energy performance was not our primary concern, we have initiated a follow on project to measure and analyze the relative energy performance of the three DOAS systems (Bldgs. 631, 630 and 637) and compare to a baseline barracks facility. We believe that we may realize energy savings in the following ways:

- *Reduced or discontinued use of dehumidifiers in occupant rooms*. Currently, the DPW provides standalone dehumidifiers for each occupant room. These units operate 24/7in an attempt to reduce humidity levels in the occupant rooms in order to minimize or eliminate growth of mold and mildew in the occupant rooms. The dehumidifiers are noisy, require frequent maintenance and consume significant energy. We believe that the DOAS system will eliminate the need for the standalone dehumidifiers while removing moisture in a more energy efficient manner than these standalone units.
- *Ability to keep occupants comfortable at higher room temperature setpoints*. Soldiers will often lower their thermostats as low as the system allows in order to be comfortable. We believe that the drier conditions in the occupant rooms will allow the soldiers to be comfortable at higher room temperature setpoints.
- *Reduced energy usage during extended unoccupied periods*. Barracks facilities often experience extended unoccupied periods as troops are absent for training and other activities. During these extended unoccupied periods, the DPW continues to keep these buildings conditioned in order to discourage growth of mold and mildew. We believe that the DOAS system should allow the DPW to maintain interior conditions which will discourage mold and mildew development at much warmer interior DBTs.

Heating

This project did not alter the existing heating system.

Resulting Energy Savings

We have not yet evaluated the energy performance of this renovated facility. Unfortunately, no baseline energy performance data is available for this facility and the newly installed system does not include sufficient energy metering capabilities to accurately measure current energy performance. In addition, this facility has not been occupied since the renovation project was completed in September 2007. To address this shortcoming, a follow on project during the summer of 2008 has been initiated to install the instrumentation necessary to measure energy performance in Bldg. 631 (as well as Bldgs. 630 and 637) and a similar baseline facility. All four buildings will be similarly instrumented with temperature/relative humidity dataloggers in several occupant rooms, electrical power usage metering and chilled/hot water usage metering. This is the most credible approach to allow us to determine the relative energy performance of these facilities during the summer cooling season while the facility is fully occupied.

User Evaluation

As noted above, this facility has not been occupied since the renovation project was completed. As a result, user input is not yet available. Nevertheless, during our brief testing period during September 2007, we noted that the low humidity interior environment caused the occupant rooms to be quite comfortable even at relatively higher interior DBTs. The follow on project referenced above will allow us an opportunity to evaluate the ability of this retrofitted system to control the humidity levels within the facility. This project will compare the performance of this system to Bldgs. 631 and 637 and to the baseline building and will include qualitative inputs from the building occupants.

Renovation Cost

Note that the Bldg. 631 renovation work was a part of a demonstration project which also renovated Bldgs. 630 and 637 (using different technologies). As a result, it is somewhat difficult to accurately assign costs to the three buildings. In addition, because this was a research project, these buildings were extensively instrumented, more than would be expected for a typical project. As a result, the estimated costs listed in Table 7.17 are considered to be somewhat high.

Table 7.17. Estimated renovation cost for Bldg. 631 – York AHU.

Item	Cost
Mechanical & Electrical Work	$65,000
Equipment	$23,000
Controls	$17,000
Design & Construction Management	$15,000
Total	$120,000

Experiences/Lessons Learned

Energy Use

Not yet evaluated.

Impact on Indoor Climate

This project was primarily motivated by a desire to demonstrate a method of eliminating mold/mildew growth in barracks facilities. Most molds reproduce by producing spores, which are microscopic cells, usually between 2-20μm and oblong shaped, and can become airborne very easily. These spores then can attach to surfaces that are wet and new growths called colonies may then form if the right conditions are present. These ideal conditions include high humidity (usually over 65% relative humidity) or moisture content. Ideal temperature range for mold growth is between 50 and 90 °F. No mold is able to grow in the absence of moisture. When the spores settle on a surface and begin to germinate they produce a branching network called hyphae. The mold then begins digesting the surface that they are growing on in order to survive.

Unfortunately, mold thrives across the full range of desirable indoor space temperature. As a result, the only practical way to control mold/mildew formation and growth is to control the moisture available to the mold spores. Moisture can be removed from an indoor space by supplying ventilation air that is drier than the bulk air within the space and/or by directly removing moisture from the air within the space, typically by condensing moisture on the cooling coil of a FCU or a standalone dehumidifier. If a DOAS system can deliver sufficient quantities of sufficiently dry ventilation air, the need to remove moisture within the space can be reduced or eliminated.

One can reasonably assume that the air leaving a wet cooling coil is saturated (i.e., 100% RH). At this condition, the leaving air DBT and dewpoint temperatures coincide. The cooling coil of a typical AHU has an LAT of about 55 °F. However, if the quality of the chilled water supplied to the coil is low (i.e., not sufficiently cold), the LAT might approach 60 °F. Table 7.18 shows the relative moisture content of air supplied at various DPTs.

Assuming that the original systems were able to deliver a total of 3600 CFM of makeup air at 55 °F DPT, the moisture content of the air delivered by the original makeup air system would be 151.2 lb/hr. More realistically, due to poor chilled water quality, the makeup air supplied by the original system was probably closer to 60 °F. If so, then the moisture content of 3600 CFM of makeup air at 60 °F DPT would be 179.6 lb/hr.

Table 7.18. Relative moisture content of air supplied at various DPTs.

Leaving Air DPT	**Leaving Air Moisture Content (gr/cu ft)**	**Moisture Content (lb/hr) @ 4500CFM**
40	2.87	110.7
45	3.44	132.9
50	4.12	159
55	4.9	189
60	5.81	224.4

This DOAS system demonstrated an ability to profoundly impact Bldg. 631's interior climate. Figure 7.65 shows the system's ability to deliver deeply dehumidified outdoor air. The figure shows that outdoor air ranging from 70 to 75 °F DPT is delivered to the occupant rooms at approximately 40 °F DPT. We note that the trend of the Room Avg (average DPT in six occupant rooms) is below that of the Supply-Air DPT (taken at the outlet of the DOAS AHU). This counterintuitive result may be an inaccuracy of the Temp/RH datalogger in the outlet of the DOAS AHU. Nevertheless, the figure clearly illustrates that introducing very dry ventilation air creates very dry conditions in the occupant rooms.

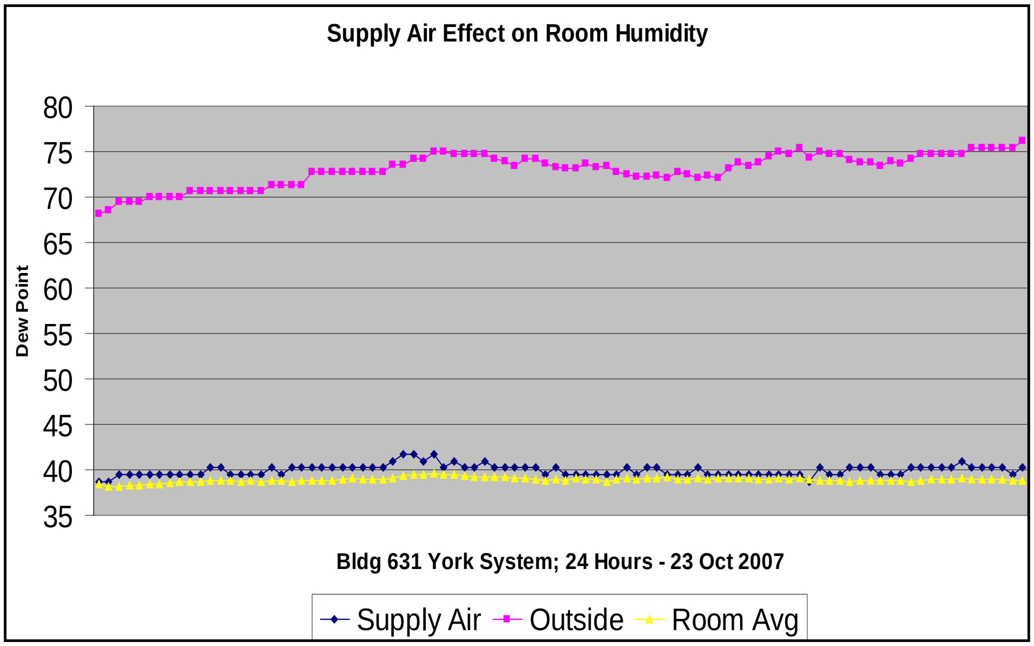

Figure 7.65. Effect of dry outdoor air on occupant room relative humidity.

Based on the retrofitted MAUs' ability to deliver ventilation air at approximately 40 °F DPT, this unit would deliver approximately 110.7 lb/hr of moisture to the occupied rooms. Since this makeup air unit serves 136 occupants (2 persons per room times 68 rooms), the occupant humidity load (assuming moderate occupant activity) can be estimated at about 48.7 lb/hr. Thus, the retrofitted makeup air unit (at 4500 CFM and 40F DPT) would deliver 68.8 lb/hr less moisture to the space than the original MAUs at 3600 CFM and 60 °F DPT. Thus, the drier air delivered by the retrofitted MAUs is able to more than offset all of the occupant humidity load when the building is fully occupied. When the building is unoccupied or lightly occupied, the increased flow rate (4500 CFM vs. 3600 CFM) and improved drying capacity will help to reduce and offset the infiltration of humid outdoor air.

Economics

Not yet evaluated.

Practical Experiences of Interest for a Broader Audience

A number of attractive features are associated with this DOAS system:

- *Use of a commercial off-the-shelf AHU*. Although we customized the unit with the addition of the DX system, the basic unit was a high quality production unit which made project execution relatively easy with minimal risk.
- *Quiet operation*. Since this unit is located in close proximity to an occupied building, its quiet operation is appreciated.
- *Ease of maintenance*. Being located on the ground makes the AHU much easier to maintain than the attic-mounted units that it replaces. Also, the technologies incorporated in the unit (chilled water coil and DX system) are simple and easily serviced by installation maintenance personnel.
- *Ability to take advantage of "warm" chilled water*. Bldg. 631 receives chilled water from a central plant system. The chilled water supply temperature as delivered to Bldg. 631 is somewhat high (from 48 to 52 °F). Nevertheless, this system is relatively insensitive to somewhat higher chilled water supply temperature

because the DX coil has the capacity to compensate for the chilled water coil's lost capacity due to higher than desired chilled water supply temperature. In addition, because the DOAS AHU handles most, if not all, of the latent cooling load, the FCUs in the occupant rooms retain sufficient sensible cooling capacity even at higher chilled water supply temperatures.

- *Reduced maintenance of FCUs*. By handling most, if not all, of the latent cooling load, the condensate generated by the fan coils should be reduced or eliminated, reducing the need to maintain condensate drains and drain pans.
- *Reduced potential for mold and mildew*. Drier interior environments and reduced generation of condensate will reduce the potential for generating mold and mildew.

Some possible unresolved issues include:

- Ensuring uniform distribution of conditioned ventilation air to 68 occupant rooms is challenging.
- Impact of wind on the building exterior may affect our ability to keep occupant rooms pressurized with dry outdoor air. Although a blower door test on a similar building showed that these buildings have "tight" envelopes, preliminary test results seemed to indicate that even mild breezes can have an undesired effect.
- Possible opportunities to modify building exhaust strategy. Currently, the common exhaust fans operate 24/7/365, exhausting conditioned air even when the rooms are unoccupied, which reduces the differential pressurization of the occupant rooms and encouraging infiltration of unconditioned outdoor air.
- Sensitivity to "real world" occupied conditions. Troops are known to put any system to the ultimate test. How well will the system respond to troop activities such as cooking, showering, leaving doors and windows open, andc.?
- Residual opportunities for mold and mildew formation. Although the DOAS system appears to be able to produce favorably dry air conditions in the occupant rooms, the presence of chilled water piping in the ceiling space and cold supply air from the FCUs impinging on surfaces will create "local high humidity" regions which could still be subject to mold and mildew growth.

Resulting Design Guidance

Not yet available.

General Data

Address of Project:	1515 Gulick Avenue, Fort Stewart, GA 31314
Existing or New Case Study:	New
Date of Report/Revision No.:	9 May 2008

Acknowledgements

Project Sponsor:	US Army Assistant Chief of Staff for Installation Management
Designer:	Mr. Jerry Weber, Johnson Controls, Inc.
General Contractor:	Johnson Controls, Inc.
Case Study Authors:	Mr. James Miller, US Army ERDC/CERL
	Mr. Jerry Weber, Johnson Controls, Inc.

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- Mr. Jerry Weber at (256) 217-2718, e-mail: Gerald.E.Weber@jci.com

Application of DOAS To Control Humidity in Bldg. 637, Fort Stewart, GA, USA

Photo

Figure 7.66. Typical three-story, six-module barracks facility, Fort Stewart, GA.

Project Summary

Bldg. 637 is a three-story, six-module barracks facility (Figure 7.66) originally constructed in 1977. A typical module consists of four occupant rooms per floor. The first floor of one module (Module D) is used as a common area, a laundry room and a mechanical room. Bldg. 637 is typical of 30 other similar barracks facilities and has a total of 68 occupant rooms with two soldiers occupying each room. Fort Stewart is located in a very hot and humid climate and these modular barracks facilities have experienced many problems with mold and mildew in the occupant rooms. Bldg. 637 was selected along with Bldgs. 630 and 631 to demonstrate dehumidification of barracks facilities using three different innovative DOAS. Figure 7.67 shows a floor plan of Bldg. 637 and Figure 7.68 shows the layout of a typical pair of occupant rooms in Bldg. 637. The floor plans and occupant room layouts in Bldgs. 630, 631, and 637 are identical.

Bldg. 637's three existing MAUs in the attic were abandoned in place. An all-electric packaged DOAS system incorporating two stages of DX cooling followed by a desiccant wheel was pad mounted adjacent to the building exterior and dehumidified ventilation air was ducted up the side of the building and into the attic where it was connected to the existing outdoor air distribution ductwork. The four-pipe FCU in each of the occupant rooms have been retained and will continue to handle heating and sensible cooling in the occupant rooms.

Site

Bldg. 637 is located within a troop housing complex of 31 similar barracks facilities at Fort Stewart near the city of Hinesville in Liberty County, GA, at 31.87 N latitude, 81.6 W longitude. This location falls within ASHRAE 90.1-2004 Climate Zone 2A (Hot-Humid). Design weather data at this location is characterized by:

- CDD (based on 65 °F) – 2539
- HDD (based on 65 °F) – 1551

- Cooling Design Temperature – 0.4% occurrence*
- Dry Bulb Temp 95.7 °F
- Mean Coincident Wet Bulb Temp 78 °F
- Dew Point Temp 71.1 °F
- Heating Design Temperature – 99.6% occurrence
- Dry Bulb Temp 26 °F
- Mean Coincident Wet Bulb Temp 23 °F.

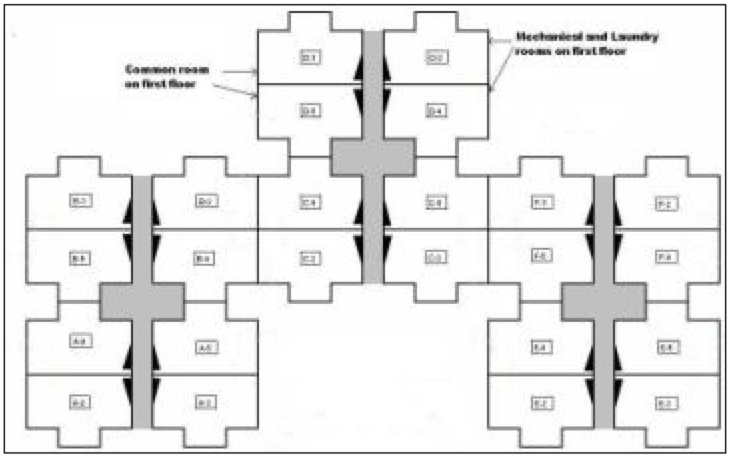

Figure 7.67. Bldg. 637 floor plan.

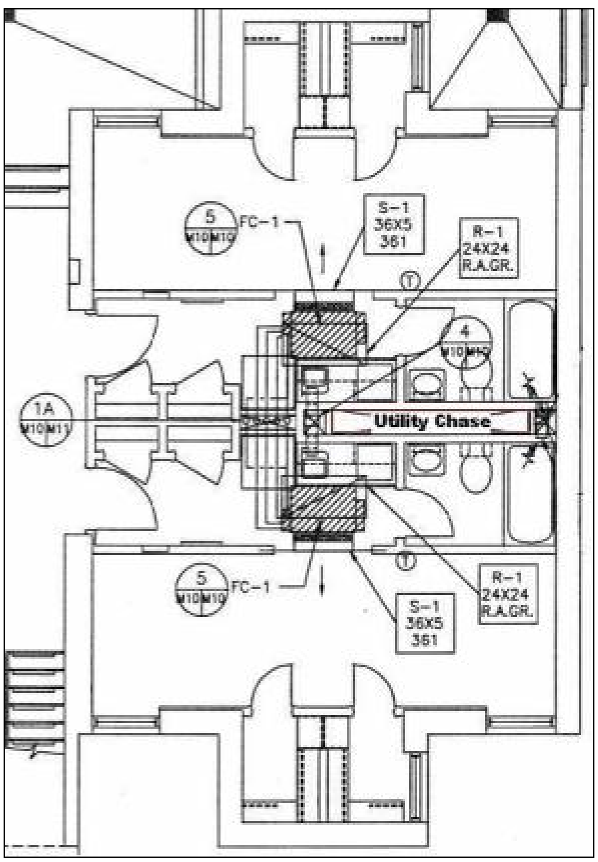

Figure 7.68. Floor plan of occupant rooms (two rooms shown).

* Based on *2005 ASHRAE Handbook of Fundamentals* for Hunter Army Airfield, 32.02 N latitude, 81.15 W longitude.

Building Description/Typology

Typology/Age

Bldg. 637 is built of CMU type construction with brick exterior. The building originally was constructed with a flat built up roof. A renovation project in 2000 installed a pitched standing seam metal roof over the top of the original flat roof. This renovation project also upgraded the HVAC system, including installing new hot water and chilled water piping in the attic and in the utility chases, installing makeup air systems and common exhaust systems in the attic, with ductwork installed in the utility chases. Architectural changes included removing end walls in the stairwells in each module to create open landings at each floor level.

General Information

Year of construction:	1977
Year of initial renovation:	2000
Year of subject renovation:	2007
Total floor area (m^2):	2440
Total occupant rooms area (m^2):	2370
Occupant capacity:	136
Number of occupant rooms:	68
Typical occupant room:	
Size (m^2):	35
Windows/glass area (m^2):	2.8
Occupants per room:	2
Occupied hours:	12 hours per weekday; 24 hours per weekend day

Architectural Drawings

Not available.

Previous Heating, Ventilation, Cooling and Lighting Systems

Before this renovation project, the HVAC system consisted of 4-pipe FCUs in each occupant room. Ventilation air was provided to each FCU from three attic-mounted MAUs, which incorporated filtration, a preheat coil and a cooling coil. Hot water and chilled water were provided from a central plant. Each occupant room also had an exhaust air grille in the bathroom. Ventilation air and exhaust air stacks were installed in a utility chase that served six rooms (two on each of three floors; see Figure 7.69)

Before this retrofit project, each of Bldg. 637's three original MAUs were designed to deliver 1200 CFM of ventilation air, for a total of about 50 CFM delivered to each occupant room. When the buildings were in use, the MAUs operated continuously. The exhaust fans also normally operated 24/7/365. Each of the 12 exhaust fans removed about 210 CFM, about 35 CFM per occupant room. As a result, the occupant rooms were (theoretically) slightly positively pressurized. Nevertheless, although the building envelope is relatively "tight," the volume of ventilation air delivered by the original MAUs was not sufficient to maintain sufficient positive pressurization to exclude infiltration of hot, humid outdoor air.

To reduce the humidity and minimize mold/mildew problems in the occupant rooms, the DPW, the authority responsible for operating and maintaining these facilities, installed electric dehumidifiers in each of the rooms. When the building is unoccupied for extended periods, these dehumidifier units are operated continuously. The rated power requirement for these units is 5 amps at 120 volts (600 watts).

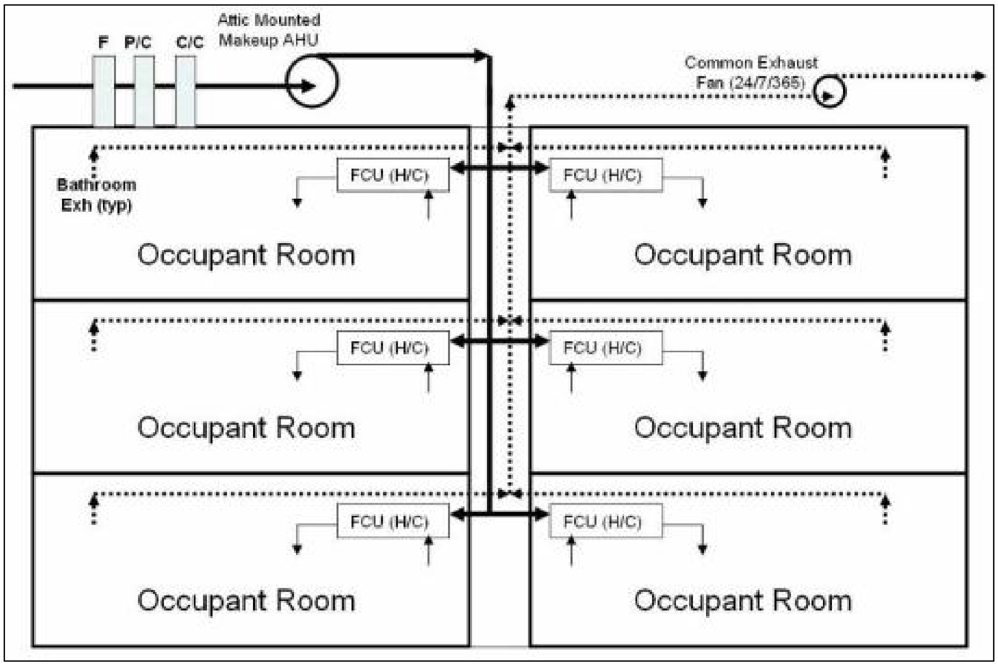

Figure 7.69. Original system configuration (elevation view).

The lighting system in the occupant rooms consists of two-lamp ceiling-mounted fluorescent fixtures. The lighting system was not altered by this project.

Retrofit Energy Savings Features

Retrofit System Description

This retrofit project abandoned each of the three original attic-mounted MAUs, replacing them with an all electric packaged DOAS system incorporating two stages of DX cooling followed by a desiccant wheel, which further dehumidifies and reheats the air stream. This unit was pad mounted adjacent to the building exterior and dehumidified ventilation air was ducted up the side of the building and into the attic where it was connected to the existing outdoor air distribution ductwork.

Figure 7.70 shows a detailed schematic of Bldg. 637's all-electric DX/desiccant DOAS unit. In the figure, the leaving DPT from the DX coils is shown to be 50 °F (10.0 °C). This assumes that the air leaving the DX coils is saturated. The desiccant wheel further dehumidifies and reheats the air, resulting in a supply-air DBT of 64.9 °F (18.3 °C) and a supply-air relative humidity of 39.8% (which is equivalent to a supply-air dewpoint temperature of 39.9 °F [4.4 °C]). This dry air is then delivered to the occupant rooms via the existing attic-mounted ventilation air distribution ductwork. This system delivers 4500 CFM, about 25% more ventilation air than the original system in an effort to maintain positive pressurization of the occupant rooms and prevent infiltration of hot, humid outdoor air.

Figure 7.71 shows a schematic of the installed system. Conditioned air from the DOAS system is ducted to the occupant rooms through the existing makeup air distribution ductwork. The original four-pipe FCUs in each of the occupant rooms were retained to handle the space heating and (sensible) cooling loads. If working as intended, the sensible and latent cooling loads should be decoupled so that all (or nearly all) latent cooling occurs in the DOAS system with little or no condensation occurring in the FCUs. Figures 7.72 and 7.73 show three views of the new DOAS unit.

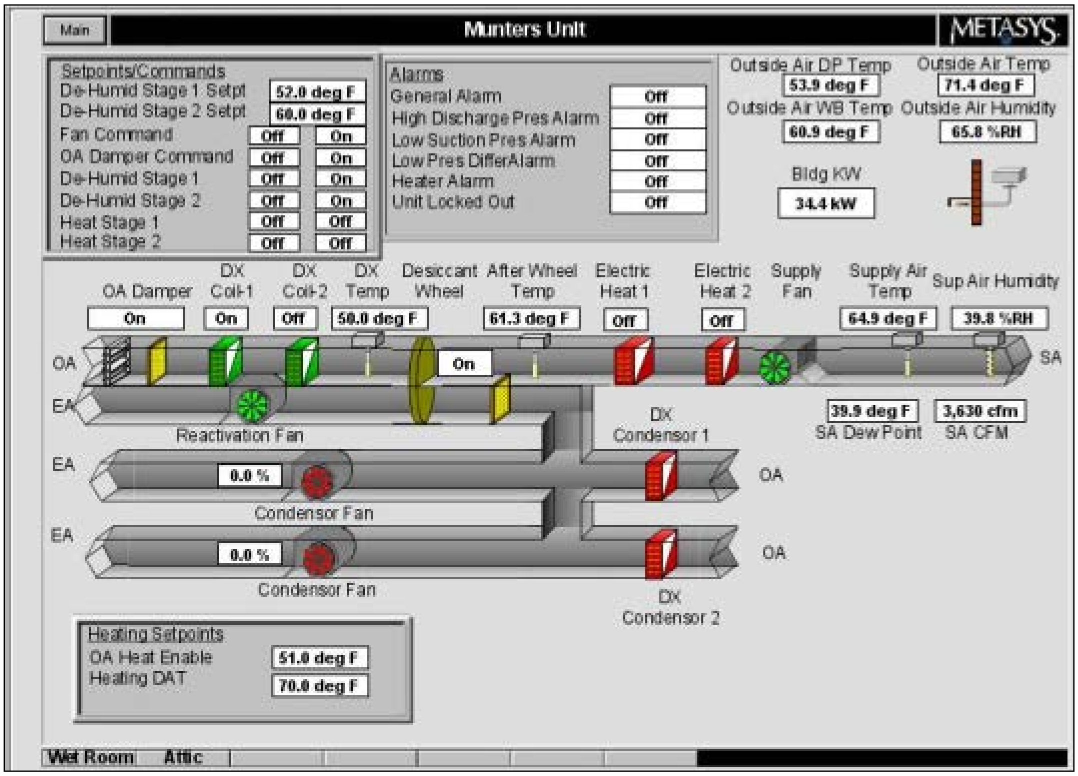

Figure 7.70. Screen capture of Bldg. 637 DX/desiccant DOAS unit schematic.

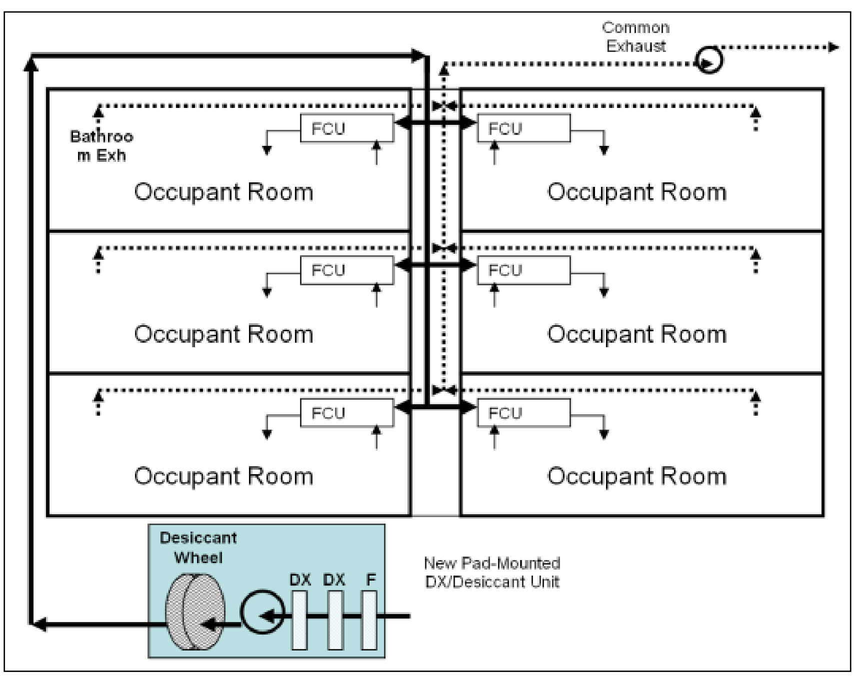

Figure 7.71. New Bldg. 637 DOAS system configuration (elevation view).

Figure 7.72. All-electric DX/desiccant DOAS unit.

Figure 7.73. Blue rectangular opening is the location of (future) supply duct connection. Completed system is shown at the right.

Retrofit of Bldg. 637 was completed in September 2007. September weather conditions at Fort Stewart are hot and humid. Although Bldg. 637 was unoccupied when the retrofit project was completed, we installed temperature and relative humidity dataloggers in a number of typical occupant rooms and operated the DOAS system and FCUs through the months of September and October. A follow on project is planned to collect performance data on this building during the summer of 2008 when the building is expected to be occupied.

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- *Reduced or discontinued use of dehumidifiers in occupant rooms*. Currently, the DPW provides standalone dehumidifiers for each occupant room. These units operate 24/7in an attempt to reduce humidity levels in the occupant rooms to minimize or eliminate growth of mold and mildew in the occupant rooms. The dehumidifiers are noisy, require frequent maintenance and consume significant energy. We believe that the DOAS system will eliminate the need for the standalone dehumidifiers while removing moisture in a more energy efficient manner than these standalone units.

- *Ability to keep occupants comfortable at higher room temperature setpoints*. Soldiers will often lower their thermostats as low as the system allows to be comfortable. We believe that the drier conditions in the occupant rooms will allow the soldiers to be comfortable at higher room temperature setpoints.
- *Reduced energy usage during extended unoccupied periods.* Barracks facilities often experience extended unoccupied periods as troops are absent for training and other activities. During these extended unoccupied periods, the DPW continues to keep these buildings conditioned to discourage growth of mold and mildew. The DOAS system should allow the DPW to maintain interior conditions that will discourage mold and mildew development at much warmer interior DBTs.

Heating

This project did not alter the existing heating system.

Resulting Energy Savings

We have not yet evaluated the energy performance of this renovated facility. Unfortunately, no baseline energy performance data is available for this facility and the newly installed system does not include sufficient energy metering capabilities to accurately measure current energy performance. In addition, this facility has not been occupied since the renovation project was completed in September 2007. To address this shortcoming, a follow on project during the summer of 2008 has been initiated to install the instrumentation necessary to measure energy performance in Bldg. 637 (as well as Bldgs. 630 and 631) and a similar baseline facility. All four buildings will be similarly instrumented with temperature/relative humidity dataloggers in several occupant rooms, electrical power usage metering and chilled/hot water usage metering. This is the most credible approach to allow us to determine the relative energy performance of these facilities during the summer cooling season while the facility is fully occupied.

User Evaluation

As noted above, this facility has not been occupied since the renovation project was completed. As a result, user input is not yet available. Nevertheless, during our brief testing period during September 2007, we noted that the low humidity interior environment caused the occupant rooms to be quite comfortable even at relatively higher interior DBTs. The follow on project referenced above will allow us an opportunity to evaluate the ability of this retrofitted system to control the humidity levels within the facility. This project will compare the performance of this system to Bldgs. 631 and 637 and to the baseline building and will include qualitative inputs from the building occupants.

Renovation Cost

Note that the Bldg. 637 renovation work was a part of a demonstration project that also renovated Bldgs. 630 and 631 (using different technologies). As a result, it is somewhat difficult to accurately assign costs to the three buildings. In addition, because this was a research project, these buildings were extensively instrumented, more than would be expected for a typical project. As a result, the estimated costs listed in Table 7.19 are considered to be somewhat high.

Table 7.19. Estimated costs of Bldg. 637 renovation work.

Cost Item	Bldg. 637 – DX Dehumidifiers
Mechanical & Electrical Work	$65,000
Equipment	$23,000
Controls	$17,000
Design & Construction Management	$15,000
Total	$120,000

Experiences/Lessons Learned

Energy Use

Not yet evaluated.

Impact on Indoor Climate

This project was primarily motivated by a desire to demonstrate a method of eliminating mold/mildew growth in barracks facilities. Most molds reproduce by producing spores, which are microscopic cells, usually between 2-20μm and oblong shaped, and can become airborne very easily. These spores then can attach to surfaces that are wet and new growths called colonies may then form if the right conditions are present. These ideal conditions include high humidity (usually over 65% relative humidity) or moisture content. Ideal temperature range for mold growth is between 50 and 90 °F. No mold can grow in the absence of moisture. When the spores settle on a surface and begin to germinate, they produce a branching network called "hyphae." The mold then begins digesting the surface that they are growing on to survive.

Unfortunately, mold thrives across the full range of desirable indoor space temperature. As a result, the only practical way to control mold/mildew formation and growth is to control the moisture available to the mold spores. Moisture can be removed from an indoor space by supplying ventilation air that is drier than the bulk air within the space and/or by directly removing moisture from the air within the space, typically by condensing moisture on the cooling coil of a FCU or a standalone dehumidifier. If a DOAS system can deliver sufficient quantities of sufficiently dry ventilation air, the need to remove moisture within the space can be reduced or eliminated.

One can reasonably assume that the air leaving a wet cooling coil is saturated (i.e., 100% RH). At this condition, the leaving air DBT and dewpoint temperatures coincide. The cooling coil of a typical AHU has an LAT of about 55 °F. However, if the quality of the chilled water supplied to the coil is low (i.e., not sufficiently cold), the LAT might approach 60 °F. Table 7.20 lists the relative moisture content of air supplied at various DPTs.

Table 7.20. Relative moisture content of air supplied at various DPTs.

Leaving Air DPT	Leaving Air Moisture Content (gr/cu ft)	Moisture Content (lb/hr) @ 4500CFM
40	2.87	110.7
45	3.44	132.9
50	4.12	159
55	4.9	189

Leaving Air DPT	Leaving Air Moisture Content (gr/cu ft)	Moisture Content (lb/hr) @ 4500CFM
60	5.81	224.4

Assuming that the original systems were able to deliver a total of 3600 CFM of makeup air at 55 °F DPT, the moisture content of the air delivered by the original makeup air system would be 151.2 lb/hr. More realistically, due to poor chilled water quality, the makeup air supplied by the original system was probably closer to 60 °F. If so, then the moisture content of 3600 CFM of makeup air at 60 °F DPT would be 179.6 lb/hr.

This DOAS system demonstrated an ability to profoundly impact Bldg. 637's interior climate. Figure 7.74 shows the systems' ability to deliver deeply dehumidified outdoor air.

Notice that this DOAS system shows a trend of rising supply-air dewpoint temperature as the outdoor dewpoint (and presumably, outdoor DBT) rises. This trend possibly indicates a lack of cooling capacity in the two-stage DX cooling coils. In addition, the desiccant wheel loses dehumidification capacity as the ambient dewpoint temperature rises because the desiccant regeneration process is less efficient at high ambient dewpoint conditions. Also, the regenerated section of the desiccant wheel is warmer at higher ambient DBT conditions, further reducing the desiccant wheel's dehumidification capacity.

Note that the chart below shows instances where the DPT in the occupant rooms is below that of the Supply-Air DPT (taken at the outlet of the DOAS AHU). This counterintuitive result may be an inaccuracy in the Temp/RH datalogger in the outlet of the DOAS AHU. Nevertheless, the figure clearly shows that introducing very dry ventilation air creates very dry conditions in the occupant rooms.

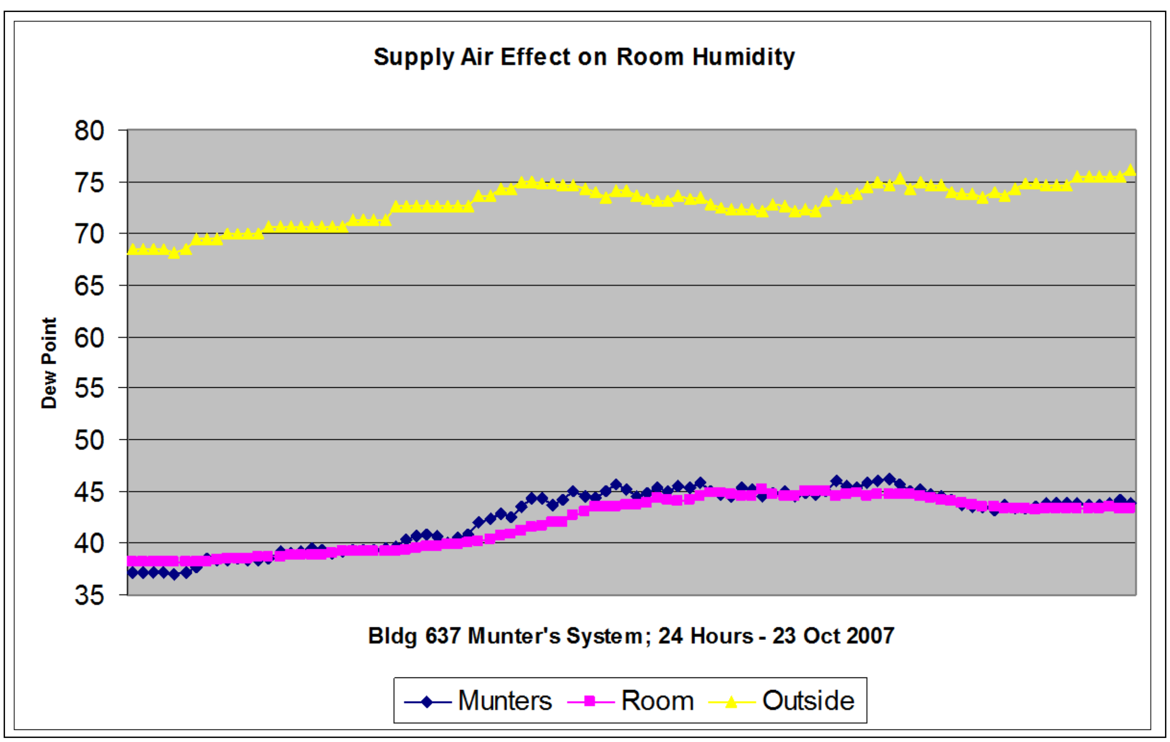

Figure 7.74. Modules A and B; effect of dry outdoor air on occupant room DPTs.

Based on the retrofitted MAUs' ability to deliver ventilation air at approximately 45 °F DPT, this unit would deliver approximately 132.9 lb/hr of moisture to the occupied rooms. Since this makeup air unit serves 136 occupants (two persons per room times 68 rooms), the occupant humidity load (assuming moderate occupant activity) can be estimated at about 48.7 lb/hr. Thus, the retrofitted makeup air unit (at 4500 CFM and 45 °F DPT) would deliver 46.7 lb/hr less moisture to the space than the original MAUs at 3600 CFM and 60 °F DPT. Thus, the drier air delivered by the retrofitted makeup air unit is able to offset most of the occupant humidity load when the building is fully occupied. When the building is unoccupied or lightly occupied, the increased flow rate (4500 CFM vs. 3600 CFM) and improved drying capacity will help to reduce and offset the infiltration of humid outdoor air.

Economics

Not yet evaluated.

Practical Experiences of Interest for a Broader Audience

There are a number of attractive features associated with this DOAS system.

- *Packaged system*. Installation is greatly simplified.
- *All-electric*. No piping connections required, no chilled water required.
- *Ease of maintenance*. Being located on the ground makes the unit accessible for maintenance work.
- *Reduced maintenance of FCUs*. By handling most, if not all, of the latent cooling load, the condensate generated by the FCUs should be reduced or eliminated, reducing the need to maintain condensate drains and drain pans.
- *Reduced potential for mold and mildew*. Drier interior environments and reduced generation of condensate will reduce the potential for generating mold and mildew.

A number of less desirable features associated with this DOAS system are.

- *Noisy operation*. This unit moves a lot of air and generates lots of noise.
- *Unfamiliar technology*. While not terribly complex, this system is less familiar to the installation maintenance personnel than conventional chillers and DX-AC units.

Some possible unresolved issues include the following:

- *Ensuring uniform distribution of conditioned ventilation air to 68 occupant rooms is challenging*. This DOAS system serves six modules and incorporates an ability to control the volume of dehumidified ventilation air it delivers. However, the ability to evenly distribute the ventilation air among the rooms within the six modules is not assured.
- *Impact of wind on the building exterior may affect our ability to keep occupant rooms pressurized with dry outdoor air*. Although a blower door test on this building showed that it has a "tight" envelope, our preliminary test results seemed to indicate that even mild breezes can have an undesired effect.
- *Possible opportunities to modify building exhaust strategy*. Currently, the common exhaust fans operate 24/7/365, exhausting conditioned air even when the rooms are unoccupied, and reducing the differential pressurization of the occupant rooms and encouraging infiltration of unconditioned outdoor air.

- *Sensitivity to "real world" occupied conditions*. Troops are known to put any system to the ultimate test. How well will the system respond to troop activities such as cooking, showering, leaving doors and windows open, andc.?
- *Residual opportunities for mold and mildew formation*. Although the DOAS system appears to be able to produce favorably dry air conditions in the occupant rooms, the presence of chilled water piping in the ceiling space and cold supply air from the FCUs impinging on surfaces will create "local high humidity" regions that could still be subject to mold and mildew growth.

Resulting Design Guidance

Not yet available.

General Data

Address of Project:	1178 William H. Wilson Avenue, Fort Stewart, GA 31314
Existing or New Case Study:	New
Report/Revision:	9 May 2008

Acknowledgements

Project Sponsor:	US Army Assistant Chief of Staff for Installation Management
Designer:	Mr. Jerry Weber, Johnson Controls, Inc.
General Contractor:	Johnson Controls, Inc.
Case Study Authors:	Mr. James Miller, US Army ERDC/CERL
	Mr. Jerry Weber, Johnson Controls, Inc.

Contacts

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Retrofitting of an Administrative Building, Direction Régionale Des Affaires Culturelles (DRAC), Lyon, France

Photo

Figure 7.75. View of the ouest facade

Project Summary

The building (Figures 7.75 – 7.80), also known as Grenier d'Abondance, was built between 1722 and 1728 by the architect Bertrand de la Vaure. At the end of the 1980's, the Ministry of Culture set up the Regional Department of Cultural Affairs of Rhône-Alpes (DRAC) and the dance studios of the Conservatoire National Supérieur Musique and Danse de Lyon (CNSMD) on the premises.

From September 1991 to March 1993, the whole building was the subject of a retrofitting. The staircase and the facade, listed as historic monuments, have been retrofitted by the architect Jean Gabriel Mortamet. The aim was to "retrofit the building to its initial aspect, withdrawing it of all the additions, then to keep out the contemporary elements essential to the program's work: circulation, toilets, electricity, and technical networks by placing them on the courtyard side, finally to respect the triple line of cross vaults by dividing up what was necessary according to a weft coordinated in the structure, never meeting columns and falling systematically in the center of openings to assure a natural lighting to all the premises." In 2004, the ground floor and extreme parts, north and south, floors R+1 and R+2, were retrofitted to adapt the building to the development of services, facilities, and waiting areas for the public and to make a friendlier reception hall.

Site

The building is located at the foot of the Croix Rousse hill, on the left bank of the Saône river, in the center of Lyon (latitude: 45.8 ° N, longitude 5 ° E). The main facade is oriented to the west and onto the quai St Vincent and the Saône River. The building is bordered on the east by a steep cliff at the feet of Fort St John.

The elevation of the city is between 150m and 300m

The climatic characteristics of site are the following:

Year average temperatures:	11.4 °C
Minimum average temperature:	7 °C
Maximum average temperature:	15.9 °C
DJU:	2531 (base 18 °C)

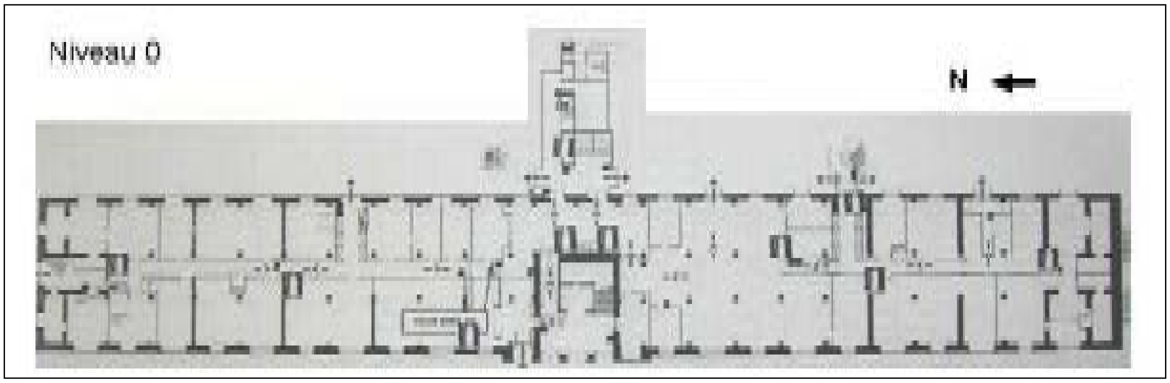

Figure 7.76. First floor.

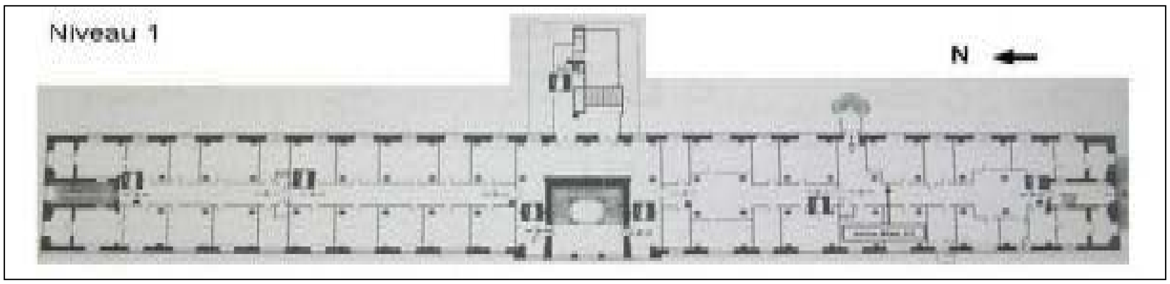

Figure 7.77. Second floor (R+1).

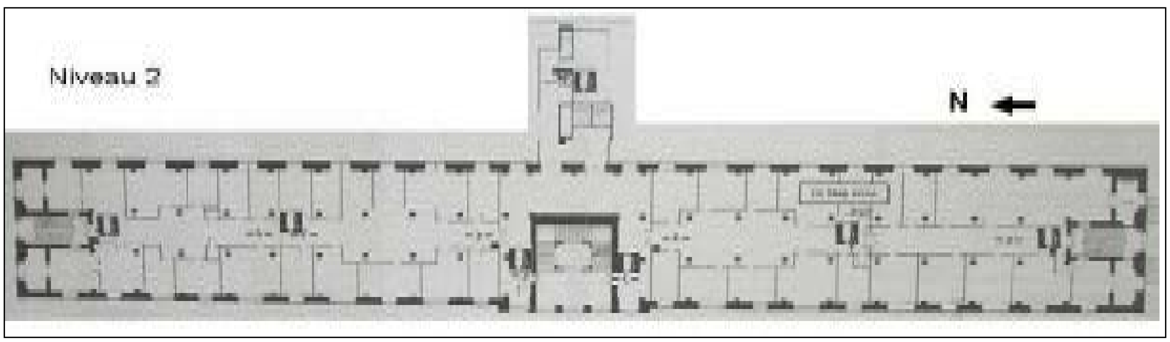

Figure 7.78. Third floor (R+2).

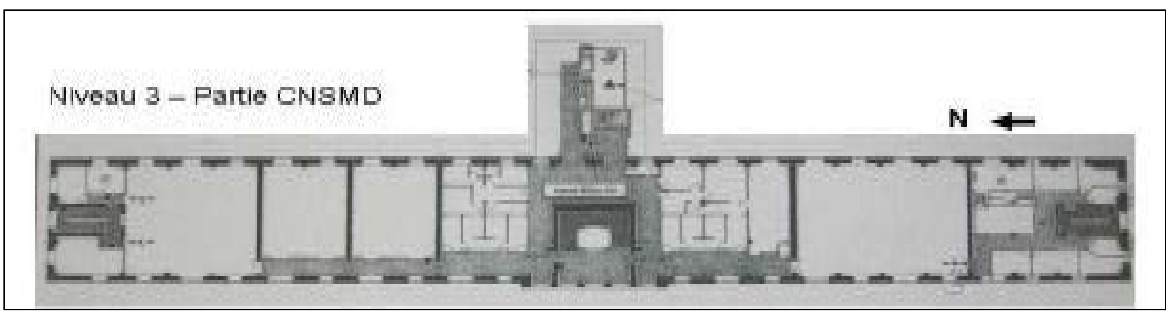

Figure 7.79. Fourth floor with CNSMD.

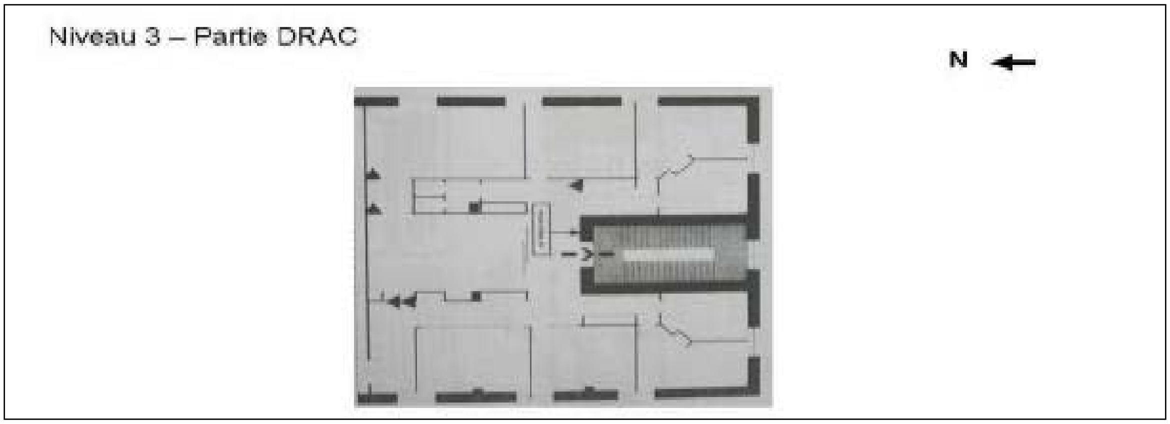

Figure 7.80. Fourth floor with DRAC.

Building Description

Typology/Age

The building features three rows of arches falling edge on two sets of stone pillars and two rows of pillars (Figure 7.81). At the center of this rectangular building (130 m long, 18 m wide), a prominent volume, with a triangular pediment soberly decorated, introduced to a staircase giving access to the floors (Figure 7.82).

The building has four floors. The width of a floor is three vaults. The central vault houses the corridor and side vaults cover rooms and offices. This is true for the ground floor of north building and two floors. The southern ground floor houses the Center for Documentation and Information with a slightly different distribution. The 3rd floor, containing mainly dance studios (CNSMD), is a particular case.

Figure 7.81. View of corridor with arches and pillars of stone.

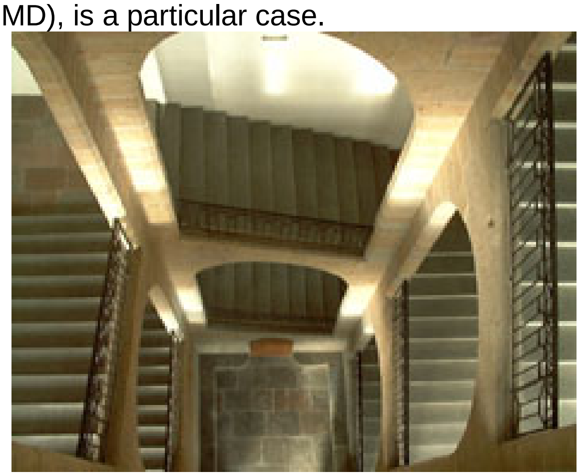

Figure 7.82. View of the staircase (XVIIIth century).

The building was built between 1722 and 1728 by architect Bertrand de la Vaure to store wheat for feeding 120,000 people annually in Lyon. At the end of the XVIIIth century, the building was assigned to military uses: artillery store, arsenal, barracks (until 1987). The departure of the National Gendarmerie allows the Ministry of Culture to set up the Regional Direction of Cultural Affairs of the Rhône-Alpes (DRAC) and the dance studios of the CNSMD on the premises.

The building is included in the supplementary inventory of historical monuments (1987), with the exception of the western façade and the main staircase that had been classified as historical monuments (1990).

General information

Year of construction:	1728
Year of initial rehabilitation:	1993
Year of 2nd rehabilitation:	2004
Total floor area (m^2):	9360
Total heated area (m^2):	Floor Heated area (m^2)
Level 0	2064
Level 1	2171
Level 2	2164
Level 3	2135
Total	8534
Occupied hours:	10 hours every day (8h - 18h/21h), 5 days per week.

Previous Heating, Ventilation, Cooling and Lighting Systems

During the renovation in 1993, six boilers of 140kW each were installed.

Today, there are only four old boilers of 140kW left and just one new boiler of 300kW to replace the two boilers which were out of order. One of the four old boilers, still in place, does not work.

A ventilation system was installed on the 1st floor in 2004. On the other floors, there is a natural ventilation.

The lighting was redone in 1993, except on the 1st floor and at the extremities of the levels 1 and 2 where all lighting was redone in 2004.

Retrofit Energy Savings Features

The purpose of the 1993 renovation was to modify the interior distribution and create an administrative building. It was also to protect the architecture of the ancient building and to build “a box in the box.” Thus, corridors were fitted out with glazed walls to make columns visible from the offices.

In 2004, a new renovation was to create interior spaces to reflect the evolution of services and improve the reception of the public.

Envelope of Building

The building is rectangular with four floors. The walls consist of a masonry rubble limestone 60 cm thick, and covered with a coating of lime. The walls are not insulated. The choice was made to preserve the original and ancient building. There is an insulation on the roof and under the windows.

The windows are made of wood and equipped with double glazing. The roof consists of a structure isolated by 12 cm of mineral wool covered with tiles.

Heating

The building is heated and cooled by FCUs located in the offices, dance studios, and scenic places on the 3rd floor. The common parts, the stairwells, and the toilets are heated by radiators.

The distribution network feeds FCUs situated in offices and the radiators in the common parts. It is a “changeover” system, i.e., the network serves for both heating and air-conditioning. The production of warm water is assured by 5 boilers (4 of 140 kW [Figure 7.83] and 1 of 300 kW [Figure 7.84]). The production of ice-cold water is assured by two cooling units: 1 big unit of 124kW and 1 small of 70 kW.

Figure 7.83. Old generation boiler (140 kW).

Figure 7.84. New-generation boiler (300 kW).

The domestic hot water is produced by independent hot water tanks.

In 1993, a regulation was installed at the level of the primary system. Today, it is out of order.

Three years ago, a regulation on the primary system was added to compensate this breakdown.

Ventilation

The ventilation system of the building is assured by air inlets millwork, except on the 3rd floor where the extraction of the DRAC air volume is assured by air extraction systems in toilets. In 2004, a network of mechanical ventilation was installed on the first floor (Figures 7.85 and 7.86).

The ventilation flow rates allow the extraction of large air volumes and extraction of air from computer premises (server).

Lighting

Artificial lighting consisted in fluorescent lamps of various powers in corridors and rooms. Spotlights serve for lightening the staircases.

Lighting of rooms (offices and meeting rooms) are 2 x 54 W on the first floor, 2 x 36W on the other floors and some 2 x 54W and 2 x 40W.

Lighting of circulations:

- 1 x 54 W at level 0
- 2 x 58 W at level 1
- 2 x 36 W at level 2
- + special lightings in the wide spaces of the corridors
- Lighting of staircases: spotlights of 150 W.

<u>Indoor Climate</u>

Questionnaires and monitoring of indoor climate parameters have been made during the month of may 2007 in the offices.

The inside temperature was between 21 and 25 °C, with a strong thermal inertia of the building. When the amplitude of day-night temperature is 12 °C, the resultant variation inside the building is only 2.5 °C.

The relative humidity was between 35 and 50%.

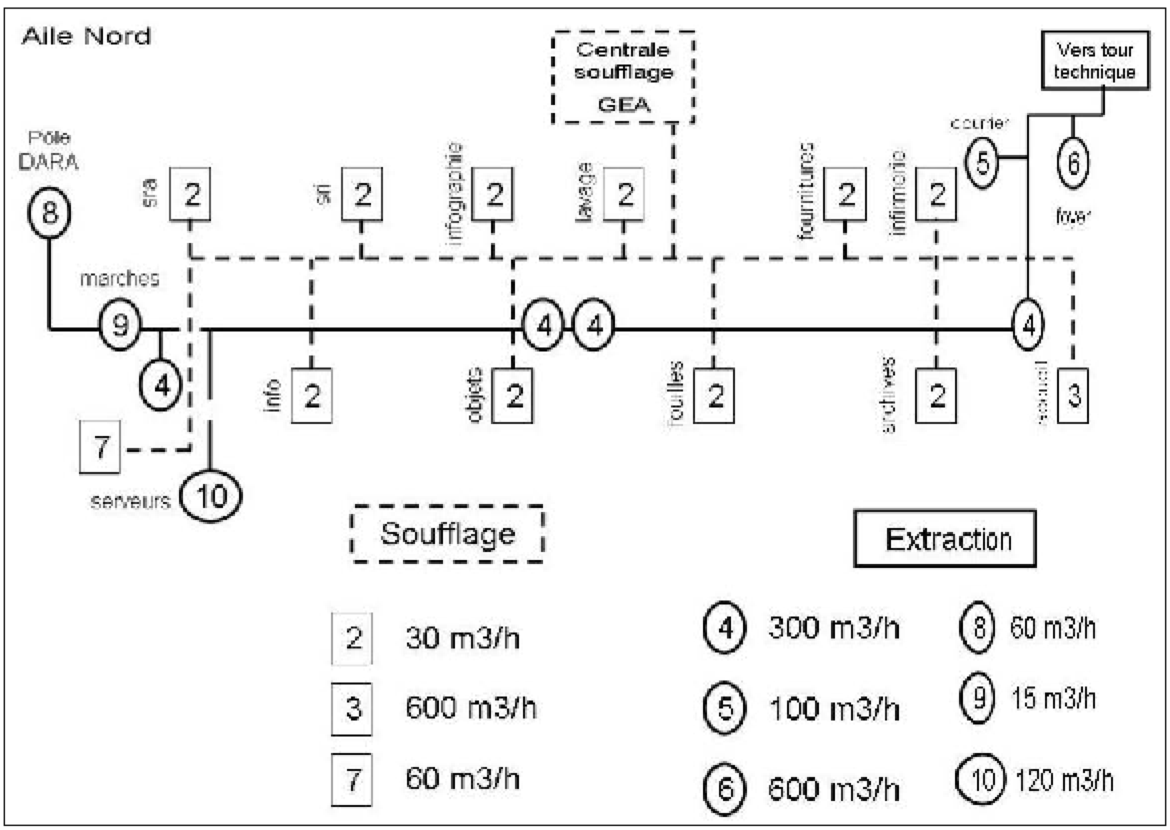

Figure 7.85. Ventilation system configuration (first floor north).

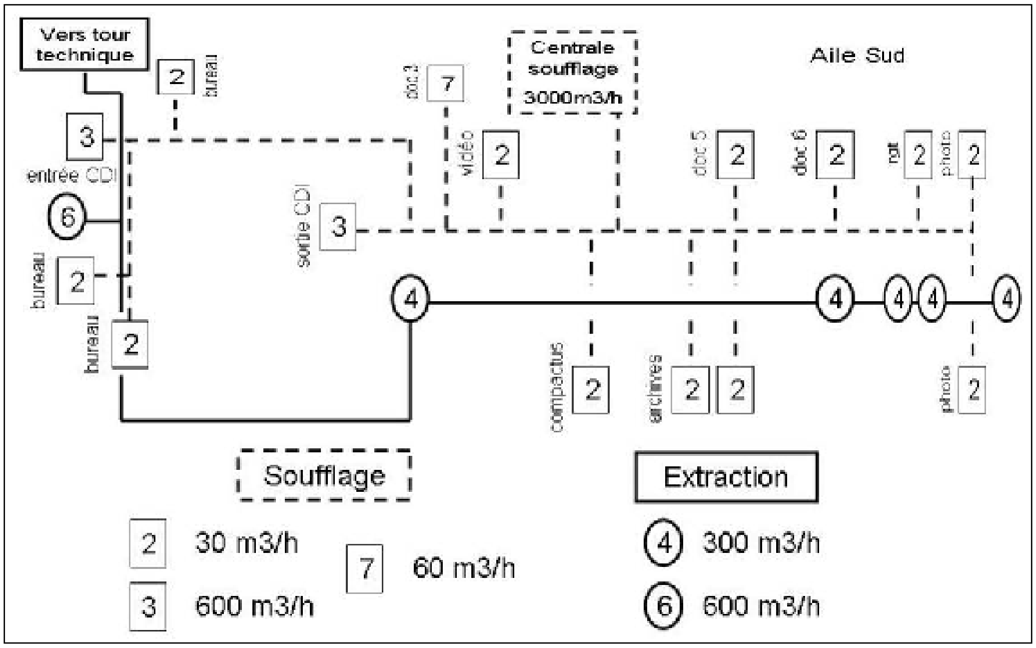

Figure 7.86. Ventilation system configuration (first floor south).

Unpleasant smells were perceived before the renovation in 2004. With the mechanical ventilation system, those unpleasant smells are perceived only in very rare occasions.

The CO_2 concentration on the premises was about 250 ppm.

The power of lighting in the building was about 8 W/m^2.

These measurements showed that the thermal comfort conditions were satisfactory in offices.

Resulting Energy Savings

Data about energy consumption are provided by bills from 2003 to 2006.

Gas

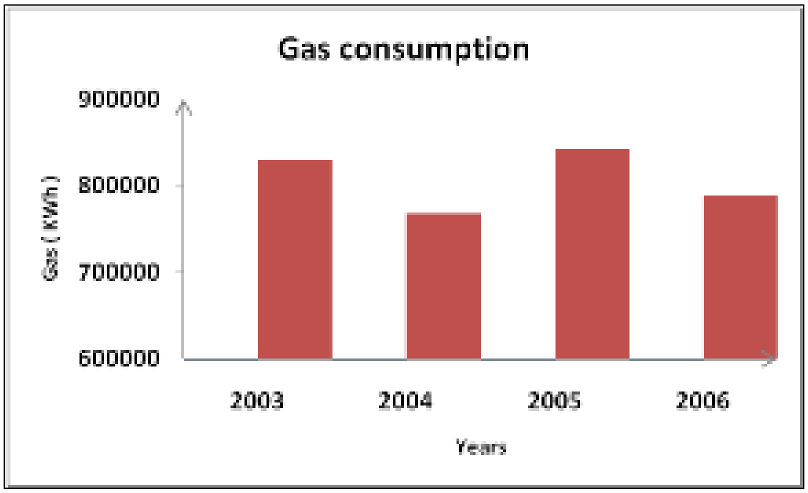

Figure 7.87. Gas consumption.

The reduction of the gas consumption in 2004 (Figure 7.87) is partly explained by climatic conditions reducing the need for heating (outside temperatures higher than usual).

Electricity

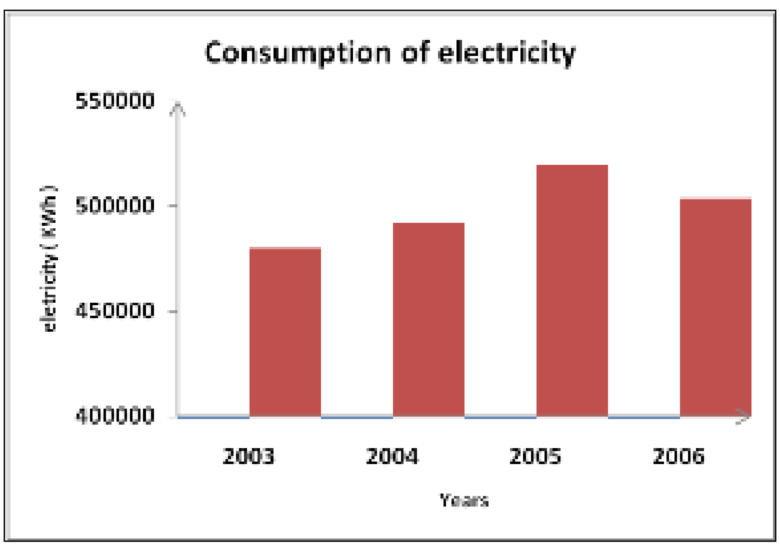

Figure 7.88. Electricity consumption.

The reduction of electricity consumption in 2006 (3%, Figure 7.88) is not followed by the same reduction of bill because of increased costs of kwh.

Water

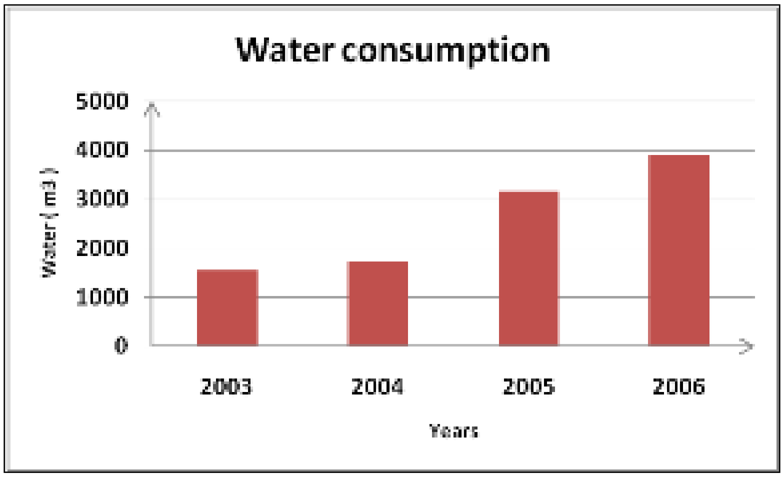

Figure 7.89. Water consumption.

The water bill has decreased in 2006, and the water consumption has increased (Figure 7.89). This increase is partly explained by the installation of air-conditioning system in laboratories at the DRAC, but a water diagnosis of water distribution network is necessary.

User Evaluation

Some questionnaire and surveys are complementary for user evaluation.

In summer, there is no particular discomfort and there is no overheating in the offices.

In winter, the air temperature in offices is satisfactory, but the IAQ is considered poor.

The natural lighting environment is generally considered too dark and not uniform. It is considered to be particularly inadequate for the premises located on the east side, facing the cliff, and satisfying for the premises located on the west side, along the Saône.

The noise of equipments is sometimes perceived as well as conversations in the local neighborhood. The outside noise is perceived on the west side where there are traffic lanes along the Saône.

Costs

Started on September 1991, the renovation was completed on March 1993 for a total of 65,000,000 francs (10,000,000€). Figure 7.90 shows the distribution of the costs of energy consumed during the year 2006.

In 2006, the electricity bill is higher than the gas bill, but the electricity consumption is lower than the gas consumption (Figure 7.91).

Costs (estimated from the bills) are 2006:

Gas	783861 kWh	61%
Electricity	503535 kWh	39%

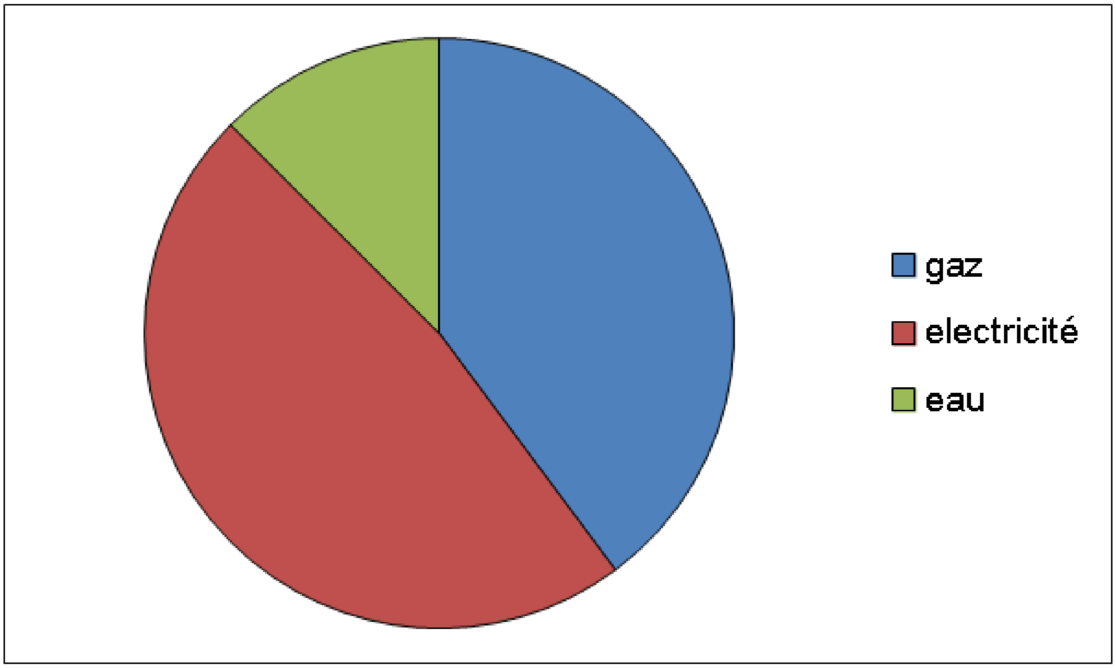

Figure 7.90. Cost repartition (year 2006).

Costs (estimated from the bills) are 2006:

Gas	31897 €	40%
Electricity	38203 €	47%
Water	10029 €	13%

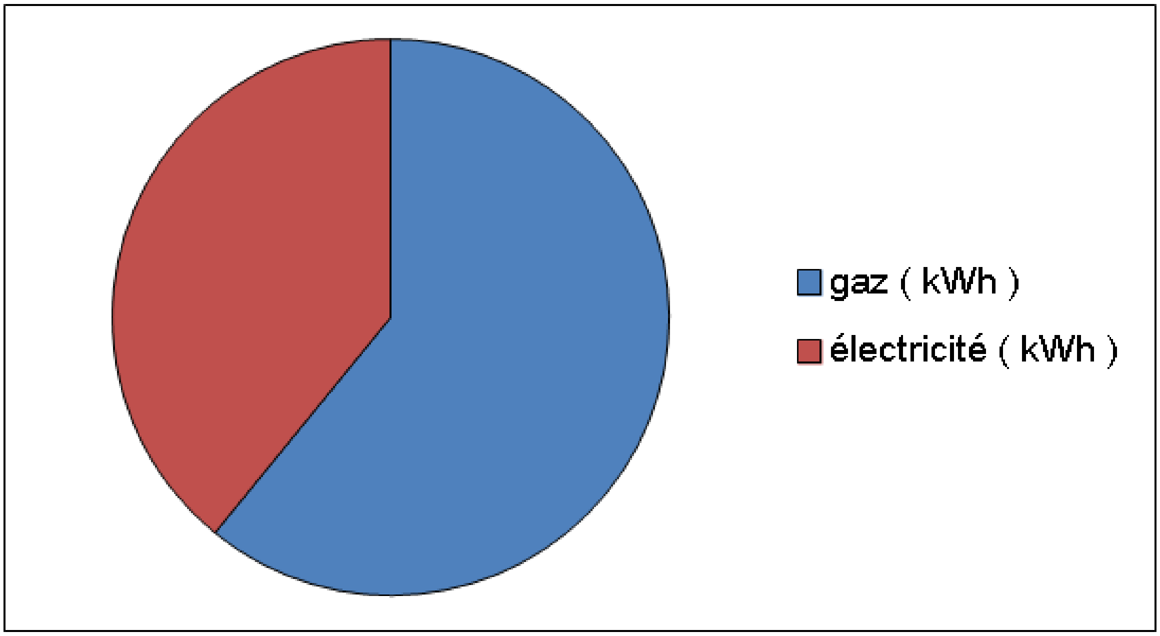

Figure 7.91. Energy consumption repartition (year 2006).

Practical Experiences of Interest for a Broader Audience

This building is an example of many ancient buildings that have a major social and cultural challenge. The wide variety of building techniques used in their construction make the thermal behavior of such buildings complex: heterogeneity of components, variable hygrothermal properties, bioclimatic architecture, andc. The thermal behavior of these ancient buildings makes the use of current technical solutions for newer buildings (built during the industrial period of the last century) risky, because:

- There is a risk of deterioration of the buildings associated with the use of materials or techniques incompatible with existing (sealants, andc.).
- There are some inefficiencies associated with some possible industrialized retrofit solutions (e.g., loss of hygrothermal intrinsic qualities, especially for summer conditions).
- Building life expectancy could be reduced.

The rehabilitation of old buildings requires detailed diagnoses and the development of specific solutions.

This case study shows that rehabilitation aimed at creating “a box in a box” is an architectural solution that will preserve the important components of a historic building (facades, pillars, arches, andc.). It allows, with a reorganization procedure, better control of heat exchange air ventilation in the built volume.

The conservation of thick walls provides a strong thermal inertia of the building envelope. It helps maintain a level of thermal comfort in summer satisfactory limiting the use of cooling systems or air-conditioning.

Strategies for hybrid ventilation at night for these premises would be to consider, such as the installation of energy meters as to improve monitoring of consumption and energy management of the building.

General data

Project Address: Direction Régionale des Affaires Culturelles de Rhône-Alpes, 6, quai St Vincent, 69283 Lyon cedex 01 – France, http://www.culture.gouv.fr/rhone-alpes

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Y. Belmont, C. Baillet, J.L. Collin and people who answered to the questionnaire.

Aerosol Duct Sealant at US Navy Naval Air Systems Command (NAVAIR) in Naval Base Kitsap in Bremerton, WA, USA

Photos

Figure 7.92. Bldg. 865 at Bremerton WA viewed from the northeast.

Project Summary

The aerosol duct sealant technology was demonstrated on four buildings at four different Navy facilities around the country, including Bldg. 865 at the Naval Base Kitsap in Bremerton, WA (Figure 7.92). Data on thermal energy and fan power was collected before and after the duct sealant material was applied. Annual energy and cost savings were predicted based on a typical weather year for each site.

The installation of the duct sealant product was supervised by SEI Group, Inc. The data in Table 7.21 summarize the impact of the duct sealant on thermal energy and fan power. Table 7.22 lists energy cost savings, installation costs, and simple payback period.

Bldg. 865 at Naval Base Kitsap, Bremerton does not have cooling equipment because of the relatively mild summer weather. Heating in the building is predominately from individual room fin tube radiators, and only minor heating to temper makeup air occurs at the AHU coil. The only opportunity for energy savings in this building is from a reduction in the fan energy consumption. The annual fan energy savings are predicted to be 43,975 kWh, a reduction of approximately 60% compared to the baseline fan motor energy use. The site has relatively low electric rates (average $0.04563/kWh), thus the annual energy cost saving are $2,007 and the payback period is 12 years.

The following section provided by outlines a very simple decision tool that identifies buildings/systems for which the decision to seal can be made without significant analysis. To use this tool, the duct systems on a Navy base have been divided into five categories, as summarized in Table 7.23.

Table 7.21. Summary of annual energy and cost savings at the demonstration sites.

Location/Status		Chiller Energy (kWh)	Chiller Energy Cost (2006$)(1)	Heating Energy (kBtu)	Heating Energy Cost (2006$)(1)	Fan Energy (kWh)	Fan Energy Cost (2006$)(1)	Total Energy Cost (2006$)
Bldg. 865, NB Kitsap	Pre-sealant	Building does not have cooling.		0	$0	72,270	$3,298	$3,298
	Post-sealant			0	$0	28,295	$1,291	$1,291
	Savings			0	$0	43,975	$2,007	$2,007
(1) Annual energy cost savings are based on local unit energy prices for each Navy installation.								

Table 7.22. Annual energy cost savings and simple payback estimate.

	Bldg. 865 Bremerton
Annual Energy Cost Savings(1) ($/yr)	$2,007
Installation Costs(2) ($)	$24,155(3)
Simple Payback (yr)	12.0
Cooling Degree Day Based on 65 °F (CDD65)	105
(1) Annual energy cost savings are based on local unit energy prices for each Navy installation. (2) Installation costs provided by SEI Group, Inc. Costs include design engineering, materials and installation. Costs associated with the site selection, research investigation and demonstration aspects of the project are excluded to the extent practicable. Because the duct sealant process was demonstrated in limited areas, rather than the whole building, fixed set up costs per site may be greater than normal as a percentage of total costs. Total installation costs of $21,270 were divided between the two areas based on gross square footage by PNNL. (3) Installation costs in Bldg. 865 at Bremerton includes $8,453 for the duct sealing installation, $8,512 for the replacement of new fan motor, $4,510 for the variable-frequency drive, and $2,680 for the test, adjust and balance.	

Table 7.23. Applicability of duct sealant on Navy bases – decision advice.

System:	Laboratory supply	Laboratory exhaust	Toilet/shower exhaust, ventilation supply or exhaust	Large office supply	Constant volume packaged system
Key Feature:	100% outside air	Type of construction – welded seams (tight) vs. slip and drive (leaky)	Generally poorly sealed	Leakage downstream vs. upstream of terminal boxes	Existence of insulation above ceiling
General Leakage Indicators	Test and Balance reports; Visible dust streaks on duct work, ceilings near supply diffusers, or electrical boxes; Comfort complaints				
Specific Leakage Indicator	Pressure control problems	Pressure control problems	Spot measurements of flows	Duct Blaster test of downstream leakage	Duct Blaster test of leakage
Approximate Sealing Price: [$/sq ft building space]	$0.30-$0.70	$0.20-$0.50	$0.10-$0.40	$0.30-$0.80	$0.40-$1.00
Leakage Range [% Fan Flow]	5-40%	5-40%	10-80%	5-30%	10-50%

SiteBuilding 865 at Naval Base Kitsap in Bremerton, WA, at 47.56 N Latitude, 122.63 W Longitude.

- CDD (based on 65 °F) – 190 (Seattle WA, SEA-TAC)
- HDD (based on 65 F) – 4908 (Seattle WA, SEA-TAC)

Building Description/Typology

Bremerton, WA. Bldg. 865 is an approximately 72,400 sq ft, 10-story Bachelor Enlisted Quarters (BEQ) located at the Naval Base Kitsap in Bremerton, WA. The building was constructed in 1975.The first floor of the facility houses the main lobby and the dormitory style sleeping rooms are on floors 2 through 10.There are 16 rooms per floor, for a total of 144 rooms.

Previous Heating, Ventilation, Cooling and Lighting Systems

Bremerton, WA. Bldg. 865 is located at the Naval Base Kitsap in Bremerton, WA. The building has two AHUs. A small 2100 cfm unit serves the first floor lobby area and the second unit in the attic of the building provides conditioned ventilation air to the individual rooms on floors 2 through 10. Because of the relatively mild climate, there is no air-conditioning in the building.

The attic AHU consists of a supply-air fan (F-2), an exhaust air fan (F-1), and a rotary air-to-air energy recovery wheel (HE-1). The energy recovery effectiveness is rated at 80% sensible and 65% total. Supplemental heat for the supply air is from a hot water heating coil located downstream from the energy recovery wheel and before the supply fan. The heating coil was added to the system after the original construction and is not shown in the “as-built” plans. This is a CAV system that operates continuously (24 hours per day, 7 days per week, 365 days per year). Figure 7.93 shows the layout of the AHU, and Figure 7.94 shows the attic supply and return ducts.

The duct sealing was done on the supply-air ducts only. The return-air system uses an open chase between floors making in impractical to seal. Therefore, the return-air duct system was not sealed.

Primary heat for the individual rooms is from perimeter hot water fin tube convectors. Hot water for the room convectors and the AHU heating coil is from a steam-to-hot water heat exchanger. The steam is from a natural gas central energy plant. Table 7.24 lists the ventilation supply and exhaust fan schedules.

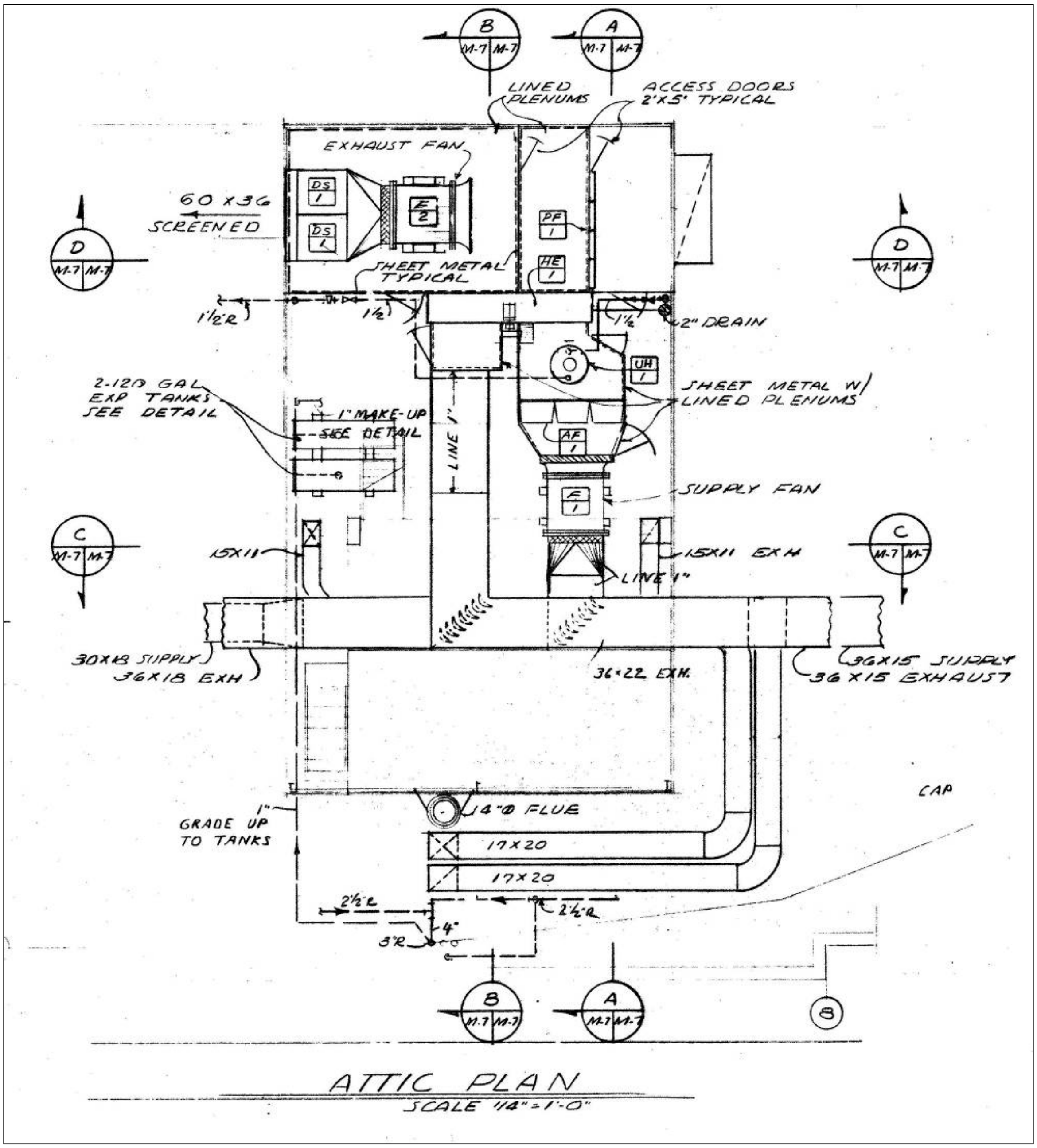

Figure 7.93. Layout of AHU in attic of Bldg. 865.

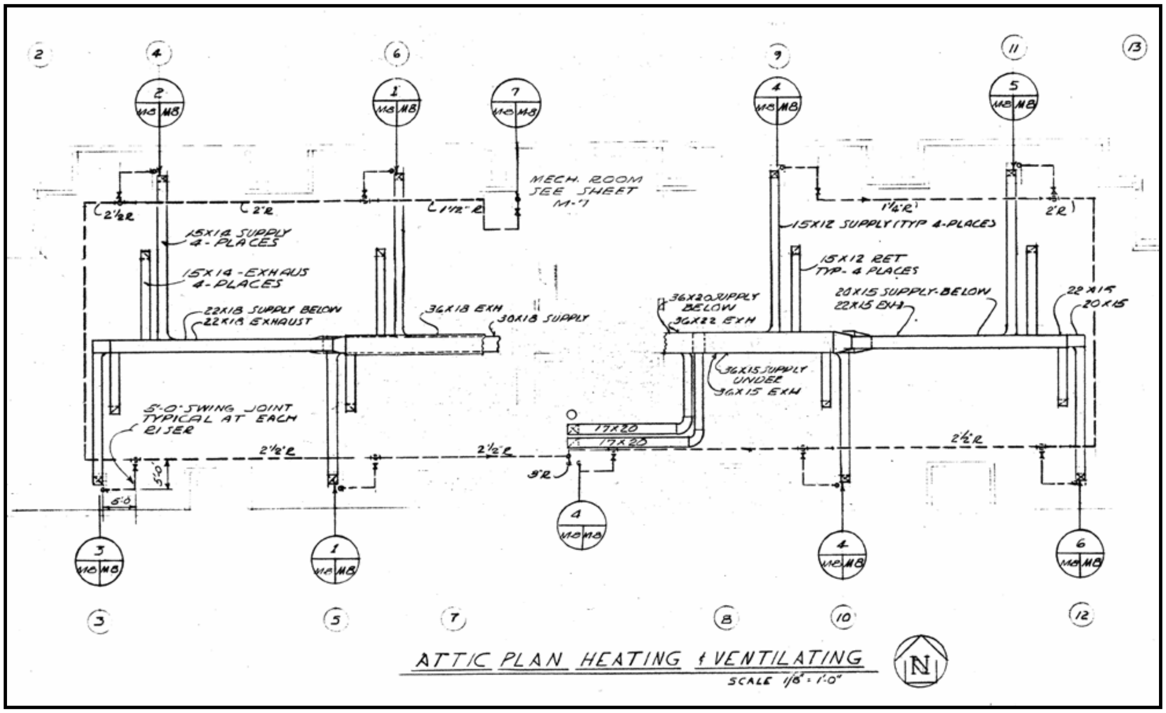

Figure 7.94. Bldg. 865 attic plan for ventilation ducts and hot water heating distribution loop.

Table 7.24. Bldg. 865 ventilation system supply and return fans schedule.

Unit No.	Service	Designed Air Flow (cfm)	External Static Pressure (in. w.c.)	Fan RPM	Motor HP	Minimum Outside Air (%)
Supply F-2	Floor 2-10	13,700	2.2	1170	7.5	100%
Exhaust F-1	Floor 2-10	14,330	1.7	870	7.5	NA

Retrofit Energy Savings Features

Energy reduction is accomplished through sealing air leaks in the duct work, which will result in less air required to be moved by the fans through the air distribution systems. This will, in turn, result in fan motor power reduction. In addition, the reduction of air leaks in the duct work can reduce the thermal energy lost in the space heating and cooling systems. The purpose of this technology demonstration is to document sample leakage rates and the extent to which the leakage rate can be reduced. This demonstration also seeks to document the extent to which reducing leaks in the duct work will also result in a potential reduction in space heating and cooling energy in commercial building applications, where the duct work is frequently located within the building shell and, in many designs, within the partially conditioned space (i.e., the ceiling plenum). The extent to which fan motor, space cooling, and space heating energy can be reduced is the objective of this series of demonstrations.

If it is necessary to make quick decisions on whether duct sealing is appropriate, the following rules of thumb can be used:

1. Laboratory Supply and Laboratory Exhaust systems are worth sealing whenever it can be confirmed that they leak, as the impacts of leakage in these systems are larger than in any other duct system because of the large flowrates, the high fan power, and the heating/cooling loads associated with 100% outside air. Two ways to

know that they leak are Test and Balance reports or problems with being able to control pressures. Note that hospitals are usually 100% outside air as well, but that scheduling sealing in hospitals tends to be difficult.

2. Toilet/Shower Exhaust, Ventilation Supply or Exhaust systems are usually worth sealing. These systems are typically not very well sealed at initial construction. There are some exceptions to this observation, but unfortunately not very many. As most of the cost is in mobilization, the cost effectiveness is highest when there are multiple vertical shafts to be sealed from the same roof or penthouse. If there is some question about whether or not a particular system is leaking, a significant difference in the measured flows at grilles on the bottom and top floors is usually a good indicator of leakage.

3. Large Office Supply systems often benefit from sealing, particularly downstream of terminal boxes, as leakage in these duct sections is often not sealed very well at initial construction. It is also relatively cost-efficient to measure the leakage in a sample of downstream duct sections to determine whether sealing the entire building makes sense.

4. Constant Volume Packaged Systems are usually worth sealing as long as the ducts are located above a ceiling, and there is insulation on the ceiling. A lack of additional insulation on the roof, or the existence of vents on the roof make these applications even more cost effective. If there are questions about the amount of leakage in these systems, a Duct Blaster test (that takes approximately 1 hour), or the sealing results from the first system sealed, can be used to estimate leakage in systems that have not yet been sealed.

Resulting Energy Savings

Bremerton, WA. Bldg. 865, located at Naval Base Kitsap in Bremerton, WA.

The ventilation system in Bldg. 865 is a CAV system that operates 24 hours per day, 7 days per week without any operating schedule. With a CAV system, sealing the supply ducts will increase the amount of supply air reaching the conditioned space. To realize energy savings from the duct sealing process, the air flow to the supply registers needs to be reduced to pre-sealing conditions (delivered $cfm_{post\text{-}sealant} \approx$ delivered $cfm_{baseline}$). To accomplish this, the Navy chose to use VFD control on the existing inline, axial fan to reduce fan speed. Unfortunately, the older fan motor was not compatible with VFD control, necessitating the installation of a new motor in addition to the VFD.

The supply fan motor power reduction and energy savings are determined as the difference between the daily average power measured during the pre-sealing period and the fan motor power after the sealing and air flow adjustment. Table 7.25 lists the incremental changes in fan system performance as modifications were made to the system. The slight increase in average fan motor power (from 8.25 kW to 8.29 kW, approximately 0.5%) immediately after the duct sealing is within the variance of measurement accuracy and therefore, not considered significant. The data in Table 7.25 show that with the installation of the energy efficient motor, fan motor power was reduced by approximately 26% (from 8.25 kW to 6.13 kW). After installation of the VFD, the VFD was used to slow the fan motor (thus reducing the supply-air volume) for the purpose of matching the baseline measurements of supply air to a sampling of apartments. The last row in Table 7.25 shows the fan motor power was reduced to 3.23 kW after the supply-air flow was rebalanced. While the spot air flow velocities and pressure differentials across the fan are not directly comparable, the fan motor power data allows us to roughly estimate that the reduction in fan motor power attributed to the duct sealant process is approximately 35% with an additional 26% attributed to the energy efficient motor (26% + 35% = 61%).

Table 7.25. Bldg. 865 measured supply-air flow rates and supply fan power.

Status	Period	Average Flow Rate at Supply Fan (fpm)	Average Pressure Rise at Supply Fan (in. w.c.)	Motor/ VFD Frequency (Hz)	Average Fan Motor Power (kW)	Percent Power Change from Baseline
Before Sealing	16 Sept 2005 – 10 Jan 2006	571	2.35	60	8.25	-
After Sealing	16 Jan 2006 –10 Mar 2006	562	2.39	60	8.29	-0.5%
After Motor Replacement	28 July 2006 – 6 Aug 2006	753	2.08	49	6.13	26%
After VFD Adjustment	8 Aug 2006 –7 Sept 2006	603	1.33	43	3.23	61%

Table 7.26 summarizes the daily average fan energy consumption for the new motor before and after the VFD adjustment. The annual energy consumption (obtained by multiplying the daily average by 365 days) is 72,270 kWh and 28,295 kWh for the before and after periods, respectively. The annual fan energy savings is estimated at 43,975 kWh. The total energy savings is a combination of the installation of a more efficient motor and the VFD adjustment of the motor.

Table 7.26. Bldg. 865 supply and return fan energy consumption.

	Pre-Seal Fan Energy (kWh)	Post-Seal Fan Energy (kWh)	Fan Energy Savings[1] (kWh)
Daily average (supply fan)	198	78	120
Daily average (return fan)	86	86	0
Annual total (supply fan)	72,270	28,295	43,975
Annual total (return fan)	31,390	31,390	0
Note: 1. The total fan energy savings is a combination of the installation of a more efficient motor and the duct sealant.			

A determination of the heating energy savings was not possible because of the delay in completing the installation of the VFD drive until after the 2005/2006 heating season. However, the primary heating for the building is from hot water fin and tube radiators in each of the rooms and heating of the supply air at the AHU heating coil was expected to be small.

The electric rates used by the site for energy projects are \$0.04711/kWh for the months of February through September and \$0.04268/kWh for October through January. Applying these rates to the estimated savings of 43,975 kWh, the estimated annual energy cost savings is \$2,007. The estimated cost for the duct sealing (including fan motor replacement) in this building was \$24,155. This results in a 12.0 year payback for the technology at this site. If just the cost of the duct sealing is used (\$8453) and the estimated savings just due to the duct sealing (\$1154), the simple payback is 7.3 years.

The level of savings achieved for this building from the duct sealing is encouraging, given it was based solely on fan energy savings, and the relatively low cost of energy. Using the national average electric rate of approximately \$0.08/kWh, the annual fan energy savings would be \$3,518, and the simple payback period, 6.9 years. In addition, the savings would likely have been more and the payback period even more attractive, if the building was in an area with significant heating and/or cooling.

Air flow measurements using a flow hood were also taken in a sample of rooms on each floor before and after the duct sealing process. Each floor, floors 2 through 10, consisted of 16 individual apartments, a lounge, laundry room and a housekeeping storage room. Supply-air flow measurements were taken in several (but not all) rooms. Some of the rooms were not accessible to the study team and in some of the rooms the supply diffuser was partially blocked or otherwise not suitable for flow measurement. In addition, some flow measurements were below the detectable limit of the flow hood (approximately 20 cfm). Table 7.27 shows the change in the supply-air flow rate ($cfm_{post\text{-}sealant}$ - $cfm_{baseline}$) = cfm_{change}) in each of the rooms where valid data was collected. Negative values mean the measured supply-air flow rate after the sealing and adjustment process was less than the initial baseline air flow measurement. In Table 7.27, a blank cell indicates no valid air flow measurement was obtained.

During the baseline process (before the sealing process), the supply-air flow in the individual apartments ranged from less than 20 cfm to 100 cfm. The housekeeping storage room, laundry, and lounge spaces averaged 61, 157, and 78 cfm, respectively. The supply air flow rate delivered to the individual rooms in the post-installation condition (after duct sealing and fan speed reduction) is approximately 4 cfm/room less than the baseline supply-air flow rate (difference averaged across all measured rooms), or approximately 6% less. This difference is considered within acceptable measurement variance.

Table 7.27. Change in air flow rate measured at the supply register in each room of Bldg. 865 (units = cfm).

	Floor								
Room	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
01									
02	-18	-10	19		-2	-26	-23	-37	
03	-38	4	13	7	4	-2	-31	-17	
04									
05									
06		0	18	14	-20	6	-68	-20	
07	-24	9	5	6	9	8	-58	-26	
08									
09									
10	-34	2		10	-2	13	-21		
11	7		4	9	4	10		-21	
12									
13									
14	-16		1	9	13	21	-23		
15	-7	7				12	-12	-17	
16									
Housekeeping	-24	-17	-27	0	-18	-11	2	-58	
Laundry	8	-2	0	-23	16	-1	-36	82	
Lounge	29		47	6		60	6		
Note: Blank cell indicates no data collected or the flow was below detectable limit of the flow hood.									

User Evaluation

Not applicable.

Renovation Costs

Aeroseal™	$8,453
New fan motor	$8,512
Variable-frequency drive	$4,510
Test, adjust and balance	$2,680
Total	$24,155

Experiences/Lessons Learned

Energy Use Saved

96,726 kWh/year

Environmental Impact

None

Economics

12.0 year simple payback

Practical Experiences of Interest to a Broader Audience

Easiest if HVAC system is VAV

Resulting Design Guidance

Working

General Data

Address of Project:	Bremerton, WA
Existing or New Case Study:	New Case Study
Date of Report:	September 2007

Acknowledgements

Project Sponsor:	Commander, Naval Installations Command (CNIC)
Designer:	SEI Group, Inc.
General Contractor:	PNNL
Case Study Author:	NAVFAC Engineering Service Center (Mr. Ben Wilcox)

Contact

Additional information concerning this project can be obtained by contacting:

Techval Program Manager
NAVFAC Engineering Service Center
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Phone: (805) 982-1387

Retrofitting of Office Buildings in the Administrative Area of Gaujot, Strasbourg, France

Photo

Figure 7.95. North view of office Bldgs. F3, J and J'.

Project Summary

The Gaujot administrative area comprises a group of 15 buildings, two-thirds of which were first built at the end of the 17th century to house the garrison troops based in Strasbourg. During the 18th century, the area was used as a military hospital and later as a sanitary centre. Since the end of World War II, the area has been used for administrative purposes.

The different buildings have been retrofitted one after another since 1973. Bldgs. F3, J and J' (Figure 7.95), which are the subjects of this study, are the three most recently retrofitted buildings in the area. The project mainly aimed to rearrange the premises to house administrative services and to comply with the regulation standards (safety, fire, accessibility, asbestos). Thus lighting retrofits were the principal upgrades done to the buildings.

Site

The Gaujot administrative area is located close to the downtown of Strasbourg, a town in the east of France near the Rhine River. The weather is seldom windy and the wind is usually weak. Rainfall is irregular and rarely heavy. Violent storms usually occur at the beginning and the end of summer.

Latitude	48°34' N
Longitude	7°45' E
Altitude	143 m
Year average temperature	10.3 °C
Winter average temperature	2.0 °C
Climate:	Temperate continental, high variations in temperature, severe winters with snow, hot and stifling summers

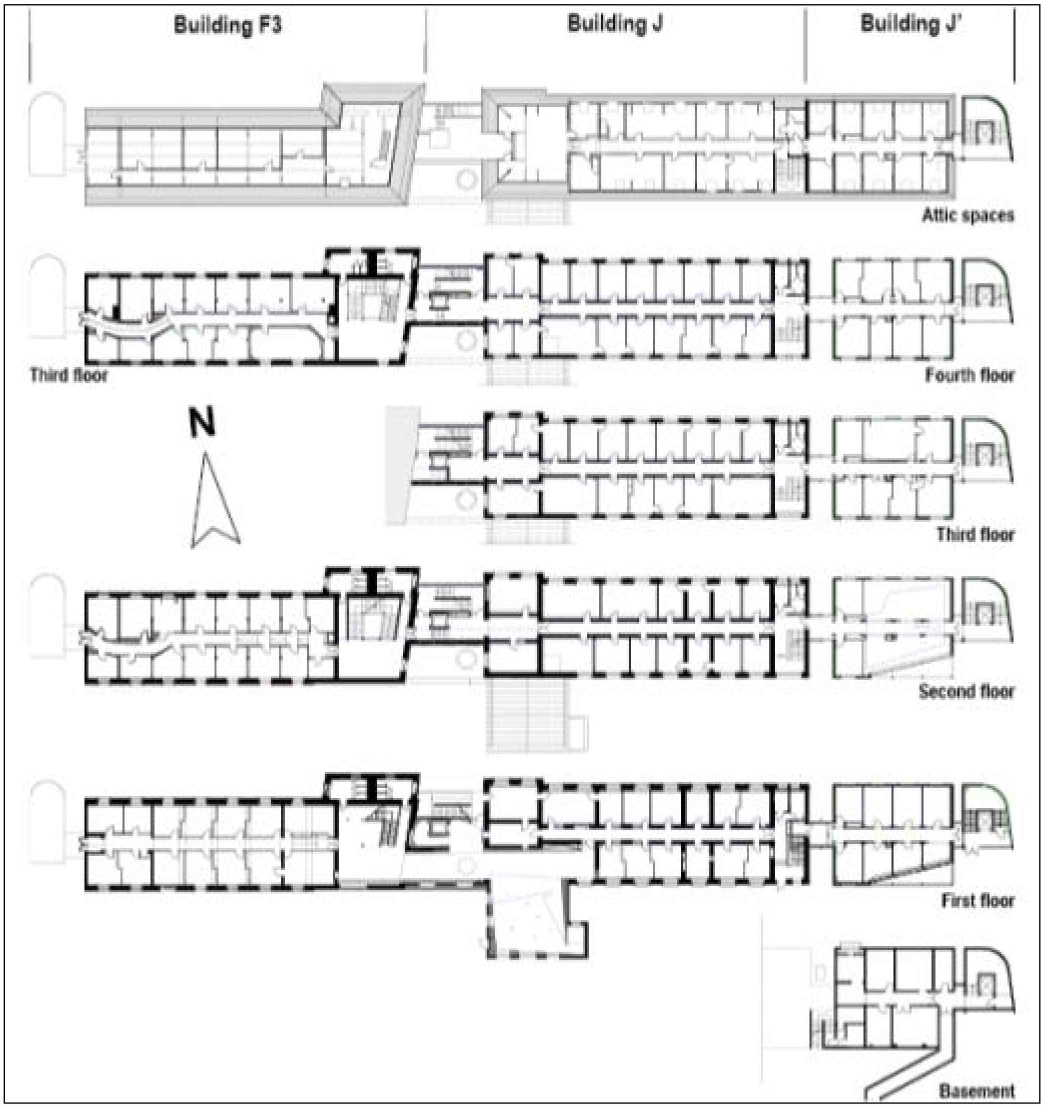

Figure 7.96. Floor plans of different studied buildings.

Building Description

Typology/Age

The group of the studied buildings consists of three adjoining parts built during three different periods. Bldg. F3 was built in 1693, then Bldg. J in 1949 and Bldg. J' in 1992. These buildings are part of the administrative area of Gaujot, which houses several civil services. These buildings are multi-storey central corridor office buildings.

General Information

Bldgs. J (1949) and J' (1992) had been previously occupied until 2002. The present employees have occupied the premises since 2007 after a 2006 refurbishment. Bldg. F3 (1693) was emptied in 2007, and was refurbished in 2007.

The floor area of 4310 m² (Figure 7.96) includes offices, halls, corridors, stairs and washroom facilities (Bldg. F3: 1190 m²; Bldg. J: 2210 m²; Bldg. J': 1010 m²). A typical office is 11 to 18 m² for 1 or 2 persons.

The window area is between 20 and 30% of total area of north and south facades.

Previous Heating, Ventilation, Cooling and Lighting Systems

Building Construction

The framed structure of Bldgs. J (1949) and F3 (1693) is of wood and masonry: sandstone and limestone sealed with mortar at a thickness of 65 cm for F3, and brick with a thickness of 50 cm. Their roofs are of solid timber and tiles. Both buildings were not insulated and had single glazing windows.

The framed structure of Bldg. J' (1992) is of reinforced concrete; its roof is of solid timber and tiles. The windows are double glazed and the building is probably insulated. Infrared photos seemed to show thermal bridges at the contact between the floors and the façades.

The façades of the three buildings are covered with a coating.

The Bldg. F3 is a three-storey building with an unconverted attic; J and J' are five-storey buildings including the converted attics. There is also a basement in Bldg. J'.

Energy Systems

The two energy sources used in the Gaujot administrative area are district heating (for heating) and electricity for the rest of the energy needs. The energy meters are shared by the whole administrative area (except the administrative restaurant as far as electricity is concerned), which does not enable to know precisely the energy consumption of each building.

Heating system

The administrative area is heated with the district heating. The temperature is regulated according to a temperature curve based on the outdoor temperature and an hourly programming. The hot water heaters are of different types: column radiators in Bldgs. F3 and J, as well as lamellar radiators and floor radiators in J, and vertical flat radiators in J'.

Water heating system

The water is heated electrically.

Ventilation system

The ventilation system is natural.

Retrofit Energy Savings Features

Energy-Saving Concept

The architects tried to work on the spatial organization, especially the entrance hall and the vertical openings. The premises were partly reorganized to house the new staff. The renovation was undertaken mainly to comply with the functional needs and current regulations.

Although energy savings were not the main aim of this project, the insulation of the floor of the (unconverted) attic in Bldg. F3, and the double glazing windows in Bldgs. F3 and J should achieve energy conservation as far as heating is concerned. By contrast, Bldg. J' was unchanged.

Building Construction

The structure was not changed. Bldgs. F3 and J were equipped with double glazing windows presenting similar openings as before.

The partition walls were lined with an acoustic insulating material and gypsum boards. Suspended ceilings made of gypsum boards and acoustically insulated were installed, mainly to accommodate the ducts. The floor of the attic in Bldg. F3 was insulated. The floor coverings were changed and the wall coverings were restored. The facades were also refaced.

Energy Systems

Heating system

The heating system remained nearly unchanged. A floor heating system was installed in the hall of Bldg. J, as was an air curtain.

Ventilation system

A mechanical ventilation system was installed in the Bldg. J washrooms. Each new window has self-adjusting air inlet openings (30 m^3/h). Airtightness was improved, especially in the Bldg. J roof.

Cooling system

Only the converted attics were equipped with an outdoor reversible cooling unit (Bldgs. J and J').

Resulting Energy Savings

Energy savings resulting from the retrofitting were assessed using the dynamic simulation software TRNSYS. While the real energy consumption of Bldgs. F3, J and J' is not precisely known (data are available only for the whole administrative area),but since the retrofitting has just been made, therefore there is no feedback yet.

The buildings were modeled with an infiltration rate equal to 0.5 ACH and internal gains equal to 290 W in each office (one person, seated and lightly working, producing 150 W, and one computer producing 140 W). Set temperatures were 19 °C minimum during the working hours and 16 °C the rest of the winter time, and 26 °C maximum during the working hours and 30 °C the rest of the summer time. The working hours were supposed to last from 8.30 to 17.30 during 5 days a week, with the lighting working from 6.30 to 20.30 during these days. The ceiling height for Bldgs. J and J' was assumed to be equal to 2.9 m and 4 m for Bldg. F3. All of these values were assumed to be the same in both cases, before and after retrofitting.

It was assumed that the heat loss coefficients of the windows for Bldgs. J and F3 (single to double glazing windows) and of the attic floor in Bldg. F3 (addition of 20 cm of glass wool) have improved. Table 7.28 lists the U-values used in the model.

Table 7.28. Heat loss coefficients through the envelope of buildings.

Bldgs	Wall/Window	Heat loss coefficient U-value (W/m²K) Before retrofitting	After retrofitting
F3 (1693)	External wall Ground floor Attic floor Window	1.31 2.08 2.29 5.74	1.31 2.08 0.17 1.40
J (1949)	External wall Ground floor Roof Window	1.48 1.96 0.18 5.74	1.48 1.96 0.18 1.40
J' (1992)	External wall Ground floor Roof Window	0.40 1.82 0.18 1.40	0.40 1.82 0.18 1.40

The simulations aimed at estimating the impact of the retrofitting as far as the heating and cooling demands were concerned. Thus the other energy uses were not studied. Figure 7.97 shows the results. Overall, modeling showed that the energy demand for heating and cooling was cut by 32% (and 36% for Bldgs. J and F3).

Figure 7.97. Calculated heating and cooling demand before and after retrofitting.

User Evaluation

No detailed study about the user evaluation was done. However some occupants have observed that it can be too hot in the attic offices.

Costs

Costs were valued at the stage of the preliminary design in August 2004 at €6.1 million, taxes included (Figure 7.98). This budget takes the retrofitting of Bldgs. C, F3, J, J' into account, which is more than the buildings concerned with this case study: F3, J, J'.

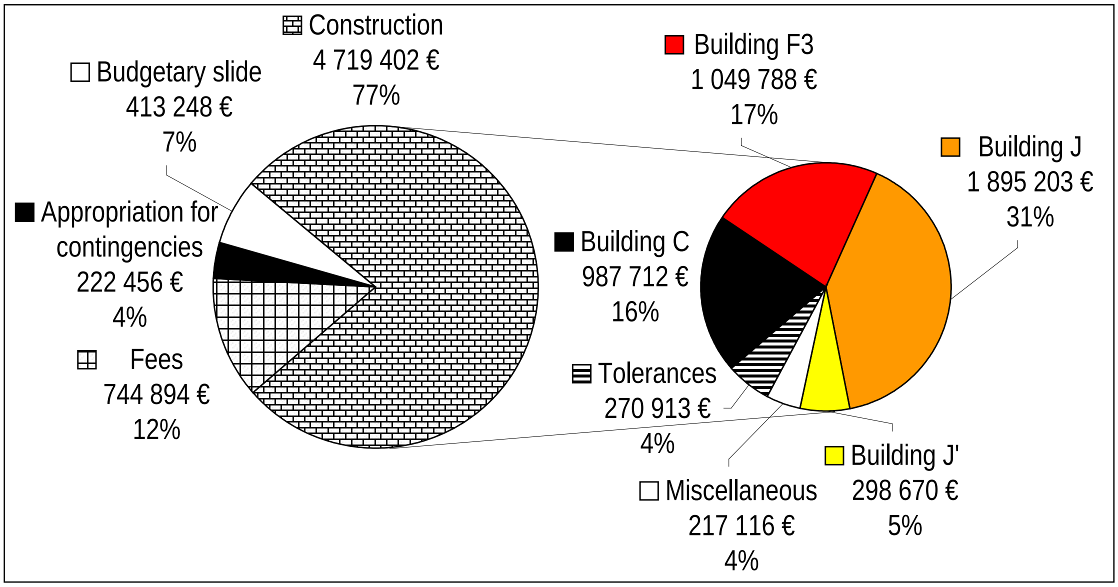

Figure 7.98. Projected cost distribution for the retrofitting of Bldgs. C, F3, J and J'.

Practical Experiences of Interest for a Broader Audience

Thanks to the double glazing in Bldgs. F3 and J, and to the insulation of the attic in Bldg. F3, the heating demand was cut by more than 30%.

The thermal expertise of an ancient building involves some difficulties. For the one hand, the existing building stock, at least in France, is characterized by a great variety, as much to the materials, the constructive techniques, the servicing, the aging of the buildings, as to the operations on the building over the years. On the other hand, the documents relating to these buildings, because of their age, have been lost or have even never existed. Eventually, the management of such buildings is often inaccurate as far as energy is concerned when one is interested in their thermal behavior: manager not much trained about this issue, energy monitoring for a group of buildings and for different types of use at the same time, andc. All these reasons make the thermal expertise of an old building more difficult and one must put forward some hypotheses conditioning the accuracy of the obtained results, in particular when the absence of measurements in situ leads to model the building so as to assess the impact of ECMs.

Different experimental approaches were carried out for this case study: the measurement campaign of temperature and relative humidity in situ and the infrared thermograph enabled to give complementary pieces of information to the factual analysis of the buildings and to the existing documents.

It seems much important to integrate the energy issue from the design stage, among the other issues that are at stake when a building is retrofitted, so that the building should be improved in each of these subjects.

A detailed engineering analysis with implementation, performance measurement and verification assessment and fully instrumented diagnostic measurements (long-term measurements) is necessary for optimizing the retrofitting strategy of old buildings.

Moreover, a monitoring approach (energy meters, andc.) should be carried out to verify and quantify the efficiency of the ECMs, before and after retrofitting, for each building, each energy source and each use of energy.

General Data

Address of project Cité administrative Gaujot
2 rue de l'Hôpital Militaire
67000 Strasbourg – France
Builder: DDE Bas-Rhin, construction department
Architect: D. Coulon
Structure engineer: BATISERF – INGÉNIERIE
HVAC engineer: G. Jost
Economist: E3 ÉCONOMIE.
Authors of this report: R. Cantin, E. Mordacque
ENTPE, rue Maurice Audin, 69518 Vaulx-en-Velin cedex - FRANCE

Acknowledgements

DDE Bas-Rhin, Construction Department

A Retrofit for Energy Conservation Using calorSchwank Tube Heater Technology

Photo

Due to sensitivity, photography in both cases were prohibited.

Project Summary

In 2000, the first inquiry came from Siemens Building Technologies for the modernization of the building technologies for the US Air Base in Ramstein, Germany. The main requirement was to retrofit the 50 year-old buildings and hangars with energy efficient heating systems.

After visiting and inspecting the facilities, Schwank proposed a high-performance and energy efficient infrared heating system, including an energy consumption forecast. Together with Siemens Building Technologies, a whole system (including Siemens control system) was quoted to the US Air Force.

Site

Warehouse US Air Base, Kaiserslautern, Germany: Schwank has equipped the warehouse with high-performance, energy-saving tube heaters. Installed power is 430kW/1.5 MMBtu.

Hangars US Air Base, Ramstein, Germany: Schwank has equipped the hangars (2210, 2291, 2472 and 2310) with high-performance and high-efficiency Schwank tube heaters; installation consists of total installed power of 2000kW/6.8 MMBtu.

Building Description/Typology

Typology/Age

Old and poorly insulated buildings (approximately 50 years old)

General Information

	Warehouse	**Hangars**
Year of construction:	Approximately 50 years ago	
Year of renovation:	2004	2007

Architectural Drawing:

Previous Heating, Ventilation, Cooling and Lighting Systems

The old heating system was warm air unit heaters (warm water) supplied by distant heat, which was uncomfortable and characterized by very high-energy consumption/costs.

Retrofit Energy Savings Features

Retrofit System Description

The newly installed tube heaters (Figure 7.99) are highly energy efficient, save on energy costs, have a high radiant factor with low convective heat output and are fully insulated.

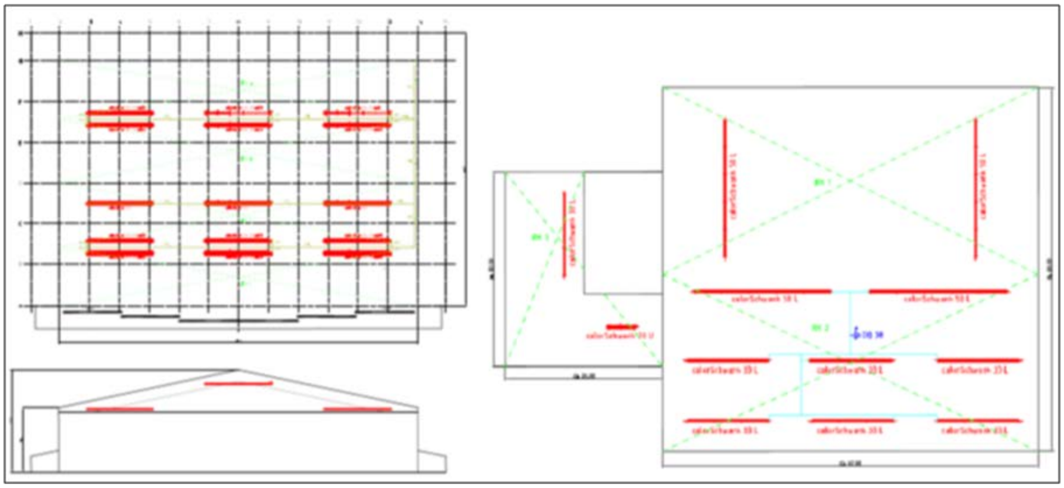

Figure 7.99. Layout of heater placement in Hangar 2310 and warehouse in Kaiserslautern.

Energy-Saving Concept

Use of radiant heat to provide comfort for occupants while not having to increase the indoor air temperature.

Building

Warehouse and hangar

Heating

The heating system consists of an insulated radiant tube heater with an indoor temperature control system

Resulting Energy Savings

The new system saves between 40 and 50% of energy cost as compared to the previous system.

User Evaluation

The building administrators and occupants are very satisfied, especially with energy savings and room temperature comfort.

Renovation Cost

1. Warehouse: approximately $78,000
2. Hangars: approximately $430,000.

Experiences/Lessons Learned

Energy Use

40 to 50% energy savings

Impact on IAQ

The impact on IAQ was met with a positive response from the staff as being a warmer and more comfortable indoor temperature. The facilities are getting warm also on very cold winter days, with no air movement ("drafts") anymore, resulting in the elimination of swirling dust particles, and low, convenient acoustic/noise level.

Economics

The 40–50% reduction in energy consumption also results in considerable energy cost savings.

Practical Experiences of Interest to a Broader Audience

Cooperation between energy-saving radiant heaters and contracting is very profitable for both the end user and the property owner, with quick payback periods.

General Data

Address of Project:	Ramstein US Air Force Base, Germany and US Army Kaiserslautern
Existing or New Case Study:	New
Date of Report/Revision No.:	14 March 2009

Acknowledgement

Case Study Authors: Mr. Uwe Bornflet and Mr. Adreas Bodemma, Siemens Building Technologies

Contacts

Additional information concerning this project can be obtained by contacting:

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- Mr. Adreas Bodemma at +49 (0) 173/3218620

A Retrofit for Energy Conservation Using GSHPs at Fort Polk, LA

Photo

Figure 7.100. Fort Polk, LA family housing (1).

Project Summary

In January 1994, the Army awarded a 20-year shared-energy-savings contracts to Co-Energy Group (CEG), a Santa Monica, CA based performance contracting energy service contractor (PC/ESCO). In 1996, the world's largest installation of geothermal heat pumps was completed, replacing 3,243 air-source heat pumps and 760 central air-conditioning/ natural gas forced-air furnace systems for 4,003 housing units [2]. Other conservation measures were taken, such as installing CFLs, low-flow showerheads, desuperheaters (for water heating), and attic insulation where needed. This increase in efficiency and reduction in energy cost was necessary to meet the mandated reduction in Federal building energy use [1].

Site

The project was located at the US Army's Fort Polk military base, in West-Central Louisiana just outside of Leesville. The GSHP served family housing units at Fort Polk (Figure 7.100).

Building Description/Typology

Typology/Age

The housing units were apartments, townhouses, and duplexes built between 1972 and 1988. Unit floor space ranged from 900 to 1,400 sq ft [2].

General Information

Year of construction:	1972 - 1988
Year of subject renovation:	1995 - 1996
Number of buildings:	4003 apartments

Architectural Drawing:

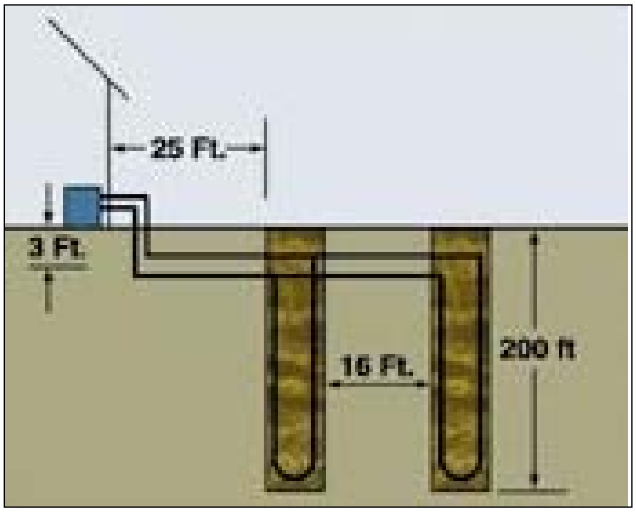

Figure 7.101. Each heat pump is linked to two U-shaped ground heat exchangers that are in 4-1/8-in. vertical bores.

Previous Heating, Ventilation, Cooling and Lighting Systems

The HVAC systems that were replaced consisted of a hodge-podge of minimum-efficiency central system and packaged heat pump units that presented a large logistical maintenance problem. It is assumed that the lighting replaced by CFLs was traditional incandescent lighting.

The Army had outsourced housing maintenance to the lowest-bidding contractors to deal with the increasing number of service requests to the HVAC equipment. These maintenance requests were acute and worsening, averaging 90 calls per day. The number of different types of units made it difficult for the maintenance contractors to keep parts stocked and technicians trained for all of them.

Retrofit Energy Savings Features

Retrofit System Description

The solution was to replace the inefficient heating and cooling systems (with energy efficiency ratings (EER) of between 7 and 8) with GSHPs that have an EER of 15.4 [2] (Figure 7.101). This is in addition to the other energy efficiency measures such as replacing all light bulbs with CFLs, installing low-flow showerheads, and desuperheaters. About 75% of the GSHPs used desuperheaters, which recover waste heat and transfer it to the water heater. They were not used in the other homes because the heat pumps and water heaters were too far apart to make their use practical.

The GSHP configuration is a closed-loop, vertical-borehole ground heat-exchanger system. Each heat pump has its own ground heat exchanger of the vertical U-tube type of polyethylene pipe. Over 8,000 borehole heat exchangers were drilled. Each borehole has a 4-in. diameter and a 100 to 450 ft depth. The heat exchanger, heat pump, and other system components were designed for easy installation, compact size, maximum efficiency, long life, low maintenance cost, and adequate capacity to provide a more comfortable environment for residents [1]. A TRNSYS model was used to size the

GSHPs.

Energy-Saving Concept

GSHPs most often exchange heat with the ground by means of a ground heat exchanger. The heat exchanger consists mainly of long pipes, either drilled vertically into the ground or buried in trenches, that use the tempering effect of the earth to heat cold water or cool warm water. When the system operates, a pump circulates the water through the heat exchanger and the heat pump, and the heat pump moves energy between the conditioned space and the water. Because it relies on the earth (instead of outdoor air) as the heating or cooling source, it is substantially cheaper to run than a conventional heating and air-conditioning system [3].

GSHPs are more efficient than conventional heating and cooling systems because, with ground source units, air needs to be moved on only one side of the unit. On the other side, it moves water, and it takes less electricity to move 2.5 gpm/ton of water (or anti-freeze, in northern climates) than it would take to move the 900 CFM/ton of air required in air-source heat pumps across the outdoor unit. Unlike air-source heat pumps, ground source systems do not need to defrost. Because there is no outdoor unit, there are no defrost controls to maintain and no performance deterioration from corrosion, vandalism, or clogging with debris.

Air-source units must engage backup electric-resistance heat at low OATs in all locations, but GSHPs require backup only in extreme heating-dominated climates. Also, since ground temperatures remain relatively constant, GSHPs do not have to contend with the capacity-limiting and efficiency-reducing operating conditions caused by extreme outdoor temperatures.

GSHPs also generally require less maintenance, as the heat pump is a packaged water-to-air unit that is factory charged with refrigerant, avoiding the problems associated with field-charged split systems. Also, the underground piping is high-density polyethylene, which is usually guaranteed for 50 years. ASHRAE gives the median service life of a water source heat pump as 4 years longer than that of an air-source pump. Such longevity factors tend to lower the charges for maintenance contracts for the equipment by as much as 25% [3].

Resulting Energy Savings

ORNL's evaluation of energy savings was based on pre- and post-retrofit monitoring of energy flows, with data taken at 15-minute intervals from August 1994 through February 1997. The retrofit construction period extended from March 1995 through August 1996 [1]. The overall project reduced the annual family housing electrical consumption by 33% (26 million kWh), summer peak electrical demand by 43% (7.5 MW), eliminated natural gas consumption for space and water heating, and improved load factor from 52 to 62%. This efficiency improvement also reduces CO_2 emissions by 22,400 tons annually. A TRNSYS simulation model showed that 66% of the savings could be attributed to the new heat pumps, 29% to the lighting retrofit, and 5% to installation of the low-flow showerheads [3]. In accordance with CEG's agreement, the Department of Defense's 22.5% share of the energy savings equates to $345,000/year during the 20-year contract and over $2 million annually afterwards, as long as the GSHPs last [1].

User Evaluation

While no housing occupant was interviewed in this report, it was documented that maintenance requests were reduced to virtually none on installation of the GSHPs.

Renovation Costs

CEG bore all the upfront costs of the project and assumed responsibility for maintenance in exchange for a 77.5% share of the energy savings and a fixed price for maintenance equal to 77.5% of the Army's projected cost for maintenance without the energy retrofit [1]. The company spent $19 million on GSHPs, which averages to a cost of about $4,700 per housing unit. This arrangement allowed them to recover their capital investment, cover the cost of financing the investment, system operation and maintenance expenses, and earn a profit [2].

Experiences/Lessons Learned

The engineers and project managers supervising this massive undertaking had three main tasks before installing the system: to develop models of energy consumption and perform design calculations to size heat pumps and ground heat exchangers for the 4,003 apartments; to engineer the other retrofits for each apartment; and to estimate the overall energy savings [1].

At the time of the request for proposal (RFP), the only company that bid was CEG, as GSHPs were not a well known or used technology. Once they received the bid and began development of the project, CEG found it more feasible to redesign some smaller existing units to meet project specifications. Previously, none of the 1.5 to 2-ton GSHPs on the market was efficient enough with a low enough installation cost to make the project cost effective.

During the installation, about 680 miles of 1-in plastic tubing were used. When burying the tubing, the contractors had to be careful to avoid other buried pipes, such as sewer lines and water supply pipes. Where the tubing comes out of the ground, cement was used to seal the borehole and prevent surface water runoff and its contaminants from flowing down into the water table [3].

Part of the motivation for the project was that the Clinton Administration had passed Executive Order 12902 as part of The Energy Policy Act of 1992 mandating that the government become more energy efficient. This directive was to reduce the energy consumption of Federal agencies by 30% by 2005, as compared to a 1985 baseline. The deficit-reduction policies of Congress suggested that any increase in energy use would have to be funded from the training or salary budget, because the $13 million annual energy budget was not going to be increased [1].

The Fort Polk project received Vice President Al Gore's "Hammer Award" in 1997 for "hammering away at building a better government"-one that works better and costs less [1].

General Data

Address of Project: 7784 Colorado Ave #840 Fort Polk, LA 71459
Existing or New Case Study: Existing
Date of Report: March 1988

Acknowledgements

Designer and General Contractor: CEG, Santa Monica, CA
Case Study Authors: Patrick Hughes and John Shonder, of USDOE's ORNL, led the USDOE evaluation of the project.

References

P.J. Hughes and J.A. Shonder. Oak Ridge National Laboratory (1998). The Evaluation of a 4000-Home Geothermal Heat Pump Retrofit at Fort Polk, LA: Final Report.

Holihan, P. Energy Information Administration/ Renewable Energy 1998: Issues and Trends. Analysis of Geothermal Heat Pump Manufacturers Survey Data, http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/99/990913.html

Contact

Building Owner and Project Implementer Greg Prudamme, Environmental Engineer, (318) 531-6029

High-Efficiency Radiant Heating Panels in U.S. Army Garrison (USAG) Katterbach Hangar 5807-1/2

Photos

Figure 7.102. Interior of Hangar 5807-1/2.

Project Summary

Plans for a retrofit of several hangars in Ansbach and Katterbach, Germany first began 3 years ago. Four hangars were initially selected, one of which was Katterbach Hangar 5807-1/2 (Figure 7.102).

Onsite surveys were carried out by Deiter Neth of Senergy (an energy consultant). The surveys concluded that there was one sensible energy efficient heating option with a unique radiant output of 81%: the FRENGER SYSTEMEN radiant panels. These panels could heat the hangar more efficiently by using less energy than other heating alternatives and featuring lower maintenance costs.

The innovative design of the radiant panels optimizes energy efficiency and increases performance. Using radiant panels as the heating system means comfort is maintained and the temperature remains relatively constant even on the coldest days—even when the large hangar doors are frequently opened and closed.

Due to the very lightweight nature of the product, the ECO EVO PLUS radiant panels could be installed easily without any structural difficulties. Furthermore, due to the flexibility of the panels, it was easy to combine with the installation of light fittings, sprinkler system, and a crane.

Site

The Katterbach Hangar 5807-1/2 is located in Katterbach, Germany (Figure 7.103).

Figure 7.103. Google map showing the location of Katterbach, Germany.

Building Description/Typology

Hangar 5807-1/2 is located in Katterbach, Germany. It is 21,285 sq ft with a ceiling height of 51 ft.

Previous Heating, Ventilation, Cooling and Lighting Systems

Before the retrofit, the hangar was heated by forced air. This was very expensive, ineffective, noisy, and uncomfortably drafty. Figure 7.104 shows an ineffective forced-air heat system, which caused a wide variation between floor and ceiling temperature.

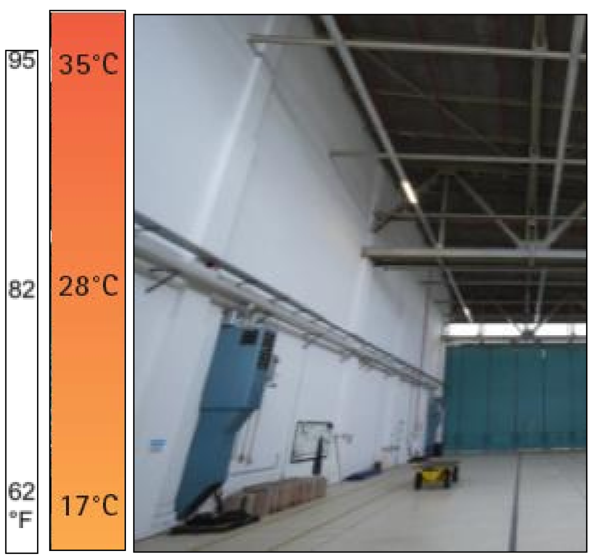

Figure 7.104. A forced-air system was used to heat the hangar.

Retrofit Energy Savings Features

The retrofit heating system consists of a FRENGER SYSTEMEN BV high-efficiency ceiling-mounted radiant panel system for the ultimate in energy efficiency. Fuel savings of 50% have been officially confirmed in many buildings very similar to Hangar 5807-1/2, when compared with forced-air systems.

Figures 7.105 and 7.106 show that the temperature variance from floor to ceiling has been greatly reduced as a result of the radiant panels. Additionally, Hangar 5807-1/2 can be heated up very quickly due to the low mass of the FRENGER SYSTEMEN BV radiant panels.

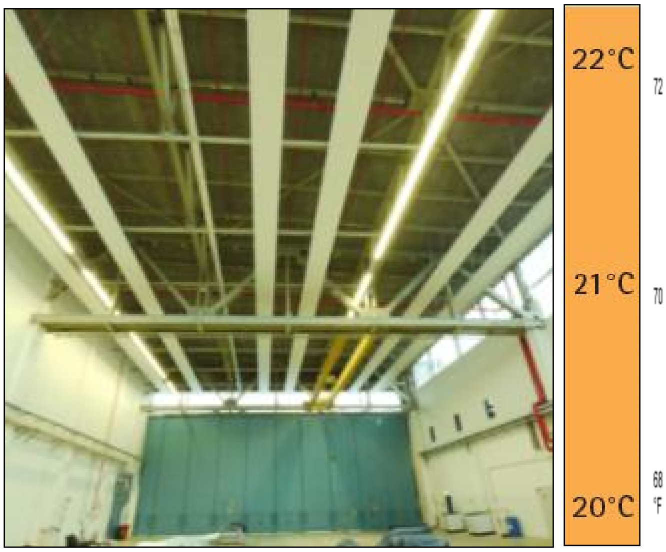

Figure 7.105. The new radiant power heating keeps the temperature more constant between the floor and ceiling.

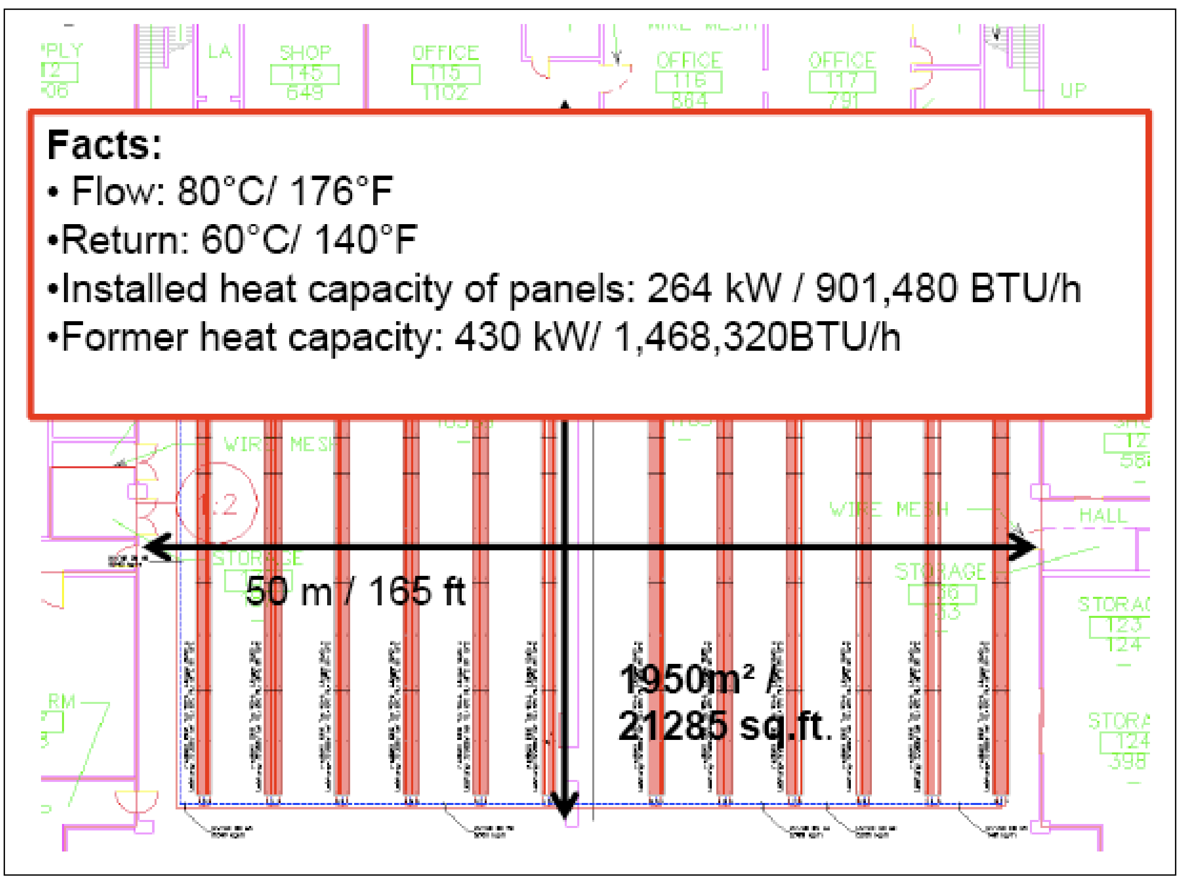

Figure 7.106. Schematic of Hangar 5807-1/2.

Resulting Energy Savings

After installing the ECO EVO PLUS radiant panels, the Garrison saves tens of thousands of dollars every year combined with a 50% smaller carbon dioxide footprint. Relative to the previous heating system, the radiant panels reduce heat capacity by 264 kW and 1,468,320 Btu/h. The resulting energy consumption reduction is 525,315 kWh and 1,792 mBtu. In addition, in this particular retrofit, the average carbon dioxide reduction is expected to be 105,063 kg each year.

These energy reductions result in the following monetary savings:

- Heating: $34,809/year
- Electricity: $11,174/year
- Maintenance: $750/year
- Estimated Payback: 5.1 years.

User Evaluation

Because the floor-to-ceiling temperature is almost constant, the hangar is a very comfortable environment. The heat emitted by the radiant panels reaches the walls, floors, and ceiling—resulting in utterly unsurpassed energy efficiency combined with high indoor thermal comfort.

According to Regine Krantz of DPW Ansbach, “I am fully convinced of the FRENGER radiant panel heating—it works great. We will definitely install it in other buildings too!”

Renovation Costs

€190,000 ($239,600)

General Data

<u>Address of Project</u>

Katterbach, Germany

<u>Existing or New Case Study</u>

Existing case study

<u>Date of Report</u>

January 2010

Acknowledgements

FRENGER SYSTEMEN BV
USAG Katterbach

References

FRENGER SYSTEMEN BV, “Case Study – USAG Katterbach – Hangar 5807-1/2 Installation of Radiant Panals.”

Menge, Dr.-Ing. Klaus, “High-efficiency Radiant Heating Panels: Energy Savings (up to 50%),” FRENGER SYSTEMEN BV.

First Laboratory Building in Colorado To Obtain LEED Silver Certification

Photos

Figure 7.107. The Colorado Springs Utilities Laboratory.

General

Address of Project

Colorado Springs Utilities Laboratory
703 Las Vegas Street
Colorado Springs, CO 80903

Existing or New Case Study

NA

Date of Report

October 2009

Project Summary

Although laboratory buildings are usually very large energy consumers, the Colorado

Springs Utilities Environmental Services Laboratory (Figure 7.107) has implemented evaporative cooling, daylighting, and water conservation to become one of the few energy efficient laboratories. When the Colorado Springs Utilities set out to create a new workspace and laboratory, its goal was to provide a space with a sustainable design that reflected the utility's mission to provide healthy and reliable water. [1] The building's general (and interior) design—from energy efficient heating and cooling, to daylighting, to recycling and using renewable materials—reflects that.

In building the new laboratory, the content an source of materials were considered in the construction plans. Sixty-three percent of materials used in the construction were shipped from within 500 miles of the location. [2] Of the materials used in the building, 27% were recycled materials. [3] In addition, 58% of construction waste that would have been sent to landfills was recycled instead. [2, 3, 4]

Retrofit Features

The building construction focused on energy efficiency. All windows are of low-e glass with a low shading coefficient. The roof has an insulation value of R-30, and the walls of the exterior have an insulation value of R-20. [2]

The laboratory uses an evaporative cooler, which, during moderate weather, can altogether eliminate the need to operate the chiller. [2] Using evaporative cooling technology not only saves the laboratory in energy consumption, but also in reduced utility bills—even after the additional cost of the direct evaporative cooling modules. The total additional equipment and hookup costs came to $20,000 ($12,000 for the laboratory and $8,000 for the offices). According to a lifecycle cost analysis, adding the evaporative cooling technology will save the utility $12,000 annually and result in simple payback period of 1.67-year. [5]

In addition to employing evaporative cooling, the laboratory portion of the new building was built with a passive solar design. With light shelves located above the building's south-facing windows, heat from the sun will be reduced during the warm months of summer. [2] Daylighting is also a key element in the design. Windows along a 300-ft long axis that runs down the length of the building pour natural light into the interior offices and laboratories. [1] Photo sensors were placed in these rooms to control the amount of electrical lighting used during daylight. The sensor system, combined with efficient lighting fixtures (high-efficiency T5 fluorescent fixture and CFL) brings new building's total lighting load to just around 55 kW (1.14W/sq ft). [2]

Overall, with all of these efficiency measures—building materials, evaporative cooling technology, passive solar design, daylighting and efficient lighting and sensors—Colorado Springs Utilities' new laboratory will cost the utility $50,000 less to operate each year compared with its past facility. [2, 3, 4] Energy savings were noted as being 50%, when compared to a base case. [5] When compared to a comparable building built to local energy codes and standards, the new laboratory will consume 26% less energy and save 55% on non-potable water bills for exterior landscaping. [2, 4] According to RMH Group, who performed the mechanical and engineering aspects of the project, the energy efficiency measures employed in this project reduced energy bills by 30% and plumbing-related water bills by 44%. [6]

Site

The Colorado Springs Utilities Laboratory is located in Colorado Springs, CO. The average warmest month is July with an average high temperature of 84°F; the average coldest month is January with an average low temperature of -14°F.

Location

Latitude	Longitude
39°49'N	104°49'W

Typology/Age

Laboratory and Offices

Project timeline: April 2005 (completed); May 2005 (opened)
Year of subject renovation: n/a; the laboratory was a new construction
Total floor area (sq ft): 48,500 sq ft (2/3 laboratory space; 1/3 office space)

Before

Building Construction

The Colorado Springs Utilities Laboratory is an entirely new construction.

Concept

Retrofit Concept

One concept employed in the laboratory building is the use of direct evaporative cooling. The concept behind evaporative cooling is that during warm months it pre-cools the outside air. This reduces the load on the chiller during these months. Additionally, during the more moderate months of fall and spring, evaporative cooling often even eliminates the need for the chiller to run at all. [2]

Building Construction

A prominent aspect of the new laboratory building's energy savings features is its use of evaporative cooling technology. The building has two separate heating and cooling systems, one for laboratory space and one for office space. Each system has a direct evaporative cooling module. The space of the laboratory portion is about two-thirds of the building while the office portion is about one-third. [5]

Heating/Ventilation/Cooling and Lighting Systems

In addition to energy savings, implementing daylighting also results in a healthy, more pleasant workspace for employees. [3]

Results

The energy savings measures taken in building the new laboratory will save the utility 26% in terms of energy consumption and 30% on energy bills. The utility will save 44% on water bills due to high-efficiency fixtures and 55% on non-potable water bills due from landscaping with native plants.

User Evaluation

Significant cost savings will be demonstrated though utility bills. The Colorado Springs Utilities Laboratory building will serve as an example for other laboratory building and renovation projects, showing that laboratories do not have to be the high-energy consumers they are often thought of. [2]

Renovation Costs

Total project cost:	$11.5M
Laboratory AHU:	$12,000
Office AHU:	$8,000
Cost per square foot:	$237.11

Lessons Learned

<u>Energy Use</u>

The evaporative cooling technology, combined with passive solar design and daylighting, saves the utility 26% of its annual energy consumption. [2, 4] The evaporative cooling will save the utility about $12,000 each year in energy bills. The daylighting has reduced the building’s lighting load to just 1.14 watts per square foot.

<u>Environmental Impact</u>

Through the energy savings measures taken in this laboratory will result in a reduction in greenhouse gases: 964,700 lb of carbon dioxide emissions will be avoided each year. [2]

<u>Economics</u>

Through the energy savings measure taken the utility will see monetary savings through lower utility costs and lower maintenance, repair, and replacement costs. The annual operating costs for a chiller with only chilled water is about $17,900. The same costs for a chiller with chilled water and evaporative cooling is $5,900, thus saving the utility $12,000 annually. With the evaporative cooling technology costing $20,000 (including equipment and hookup costs), the utility will begin to see returns on its investment in less than 2 years. [5]

<u>Practical Experiences of Interest to a Broader Audience</u>

What is important about this project—beyond the energy savings measures—is that this new laboratory building goes against traditional ideas that laboratories have to be high-energy consuming structures. Laboratories are often designed keeping worker safety and air circulation in mind. Energy efficiency is often not incorporated. The significance of this project—what makes it stand out from others—is that it is a laboratory building that combines all of these aspects. Additionally, as a result, the Colorado Springs Utilities Laboratory and those involved in its design and construction have received a number of awards and recognitions: [6]

- LEED-New Construction (LEED-NC) Silver Certification
- Compliance with Labs 21 Criteria
- Engineering Excellence Award, Building/Technology Systems Category, American Council of Engineering Companies of Colorado (2006)

- Exemplary Building Award, Colorado Renewable Energy Society (2006)
- Gold Hard Hat Award, Outstanding Office Project (2005)

Info

References

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3. Zubeck, Pam. "Utilities Lab Wins 'Green' Award." The Gazette. Colorado Springs, CO. 22 May 2006.
4. Ambient Energy. "Colorado Springs Utility Laboratory LEED Project Case Study." http://www.ambient-e.com/images/case%20study%20LEED%20energy%20csu%20lab%20case.pdf
5. "Evaporative Cooling." Rocky Mountain Chapter of ASHRAE 16th Annual Technical Conference. 11 April 2008, http://www.rockymtnashrae.com/wp-content/uploads/2009/03/evaporativecooling.pdf
6. RMH Group. "Colorado Springs Utilities Lab," http://www.rmhgroup.com/index.php?method=show_node&params=179

Acknowledgements

Building owners:	Colorado Springs Utilities, Colorado Springs
Architect:	RNL Design, Denver
General contractor:	Gerald H. Phipps
Mechanical and electrical engineers:	RMH Group
Energy and sustainability consultant:	Ambient Energy
Case study author:	SENTECH, Inc. (Ashley R. Smith)

Municipal Youth Centre, Naples, Italy

General Data

Figure 7.108. View of the building main entrance.

Address of project	**Piazza Carlo III, Naples, Italy**
Year of construction	1751
Year of renovation	2004
Total floor area	10,000 m^2
Number of occupants	
Number of rooms	
Typical rooms	

Project Summary

The Real Albergo dei Poveri (Figure 7.108) is an important historical building, which has become property of the municipality in 1981, after the earthquake of 1980, which severely damaged it.

First of all the consolidation works had to be done, to make the structure stable still giving importance to the artistic value of the building. This importance was also underlined by the attention that the project received by the academic world.

After long consideration, at the beginning of the 2000s the new destination of the building was decided, and it was transformed in a Youth Center, including university activities, research activities, exhibitions, cinema, music, theater, information points, meeting rooms, offices, classrooms, a library, a cafeteria, restaurants, and so on.

Part of the project has been funded by the EU VI Framework Program, through the Eco-Buildings SARA Project (Sustainable Architecture applied to Replicable public access buildings).

Site, Typology

Site

Figure 7.109. Localization of the city Naples and of the building.

The building is located in downtown Naples, one of the most important cities of Southern Italy, exposed to the seaside (Figure 7.109).

Parameter	Measure
Latitude	40°51' N
Longitude	14°16' E
Altitude	17 m
Mean annual temperature	18.2 °C
Mean winter temperature	12.4 °C
Climate description	1034 HDD

Typology/Age

The Real Albergo dei Poveri is an important historical monument; is very large (100,000 m^2 surface, of which 7,500 m^2 participates in the SARA project) and has a total volume of 830,000 m^3. It is a public building. Construction began in 1751 by King Carlo III, but it was never finished. Over the past 250 years, it has served many different purposes, including hospitality, learning, and public assistance.

Retrofit Features

It was a priority of this work to respect the legislation for heritage building, all the efforts have been made to propose an eco-building that is responsive to external climate factors such as solar energy, both used as source of natural light and of free heat. To this end, the design integration has become very early part of the process, even if most performing and successful results must match with Italian heritage building regulation and observations. All the drawings have been verified, accepted and adopted by the Municipality. Various worksites are still in progress (Figures 7.110 – 7.113).

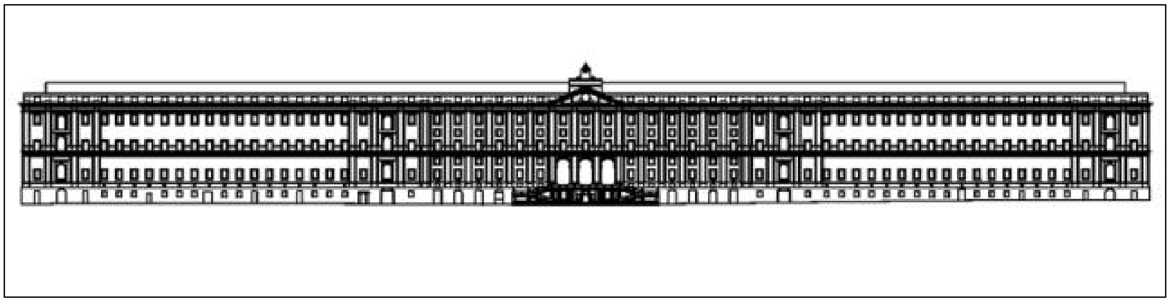

Figure 7.110. Southeastern facade of the building after retrofit.

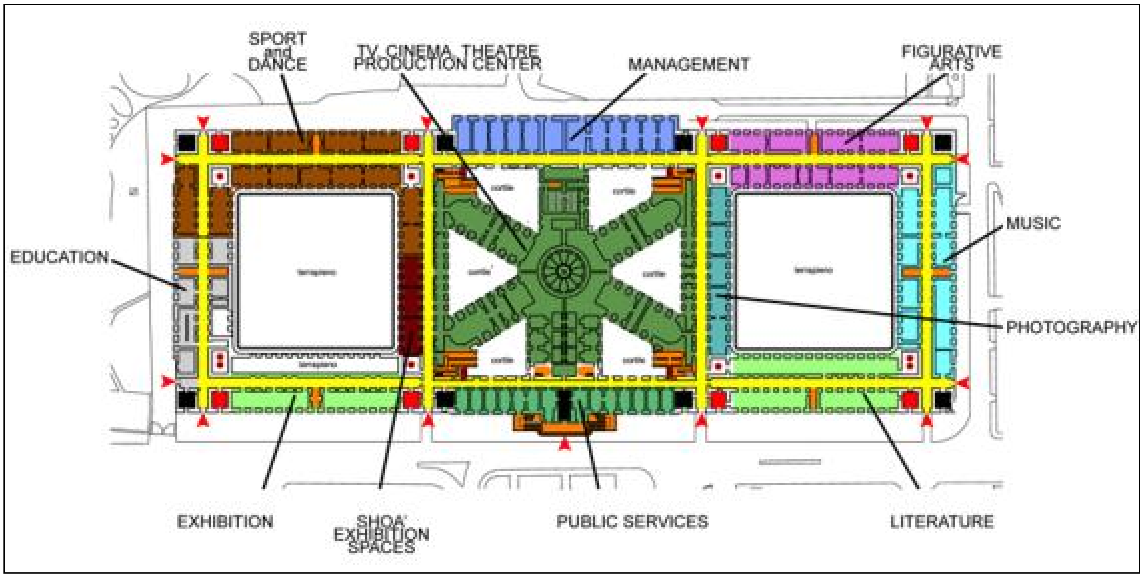

Figure 7.111. Plan of the ground floor after retrofit.

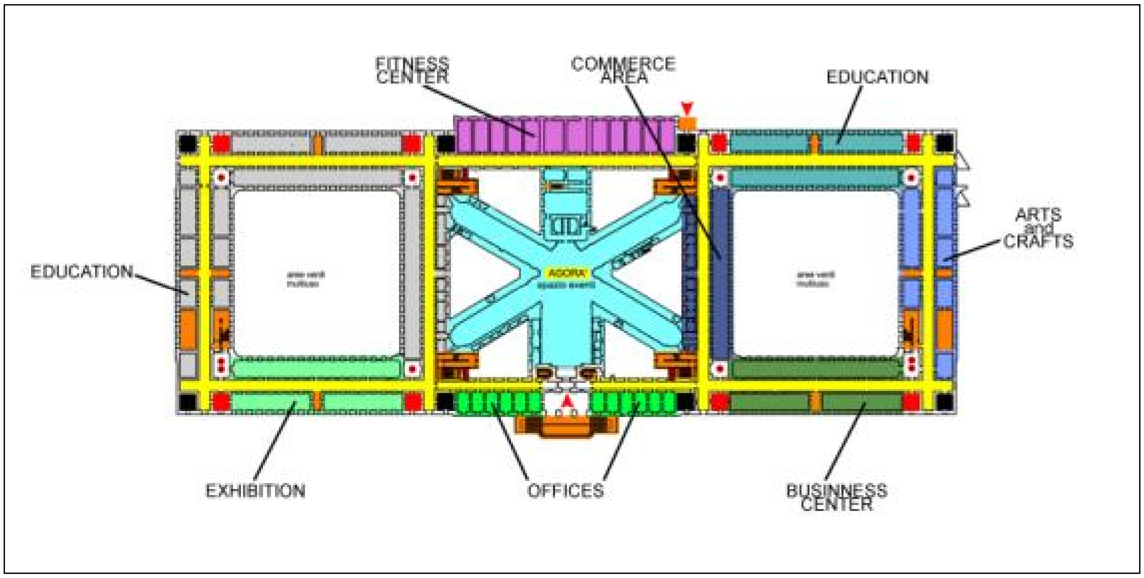

Figure 7.112. Plan of the first floor after retrofit.

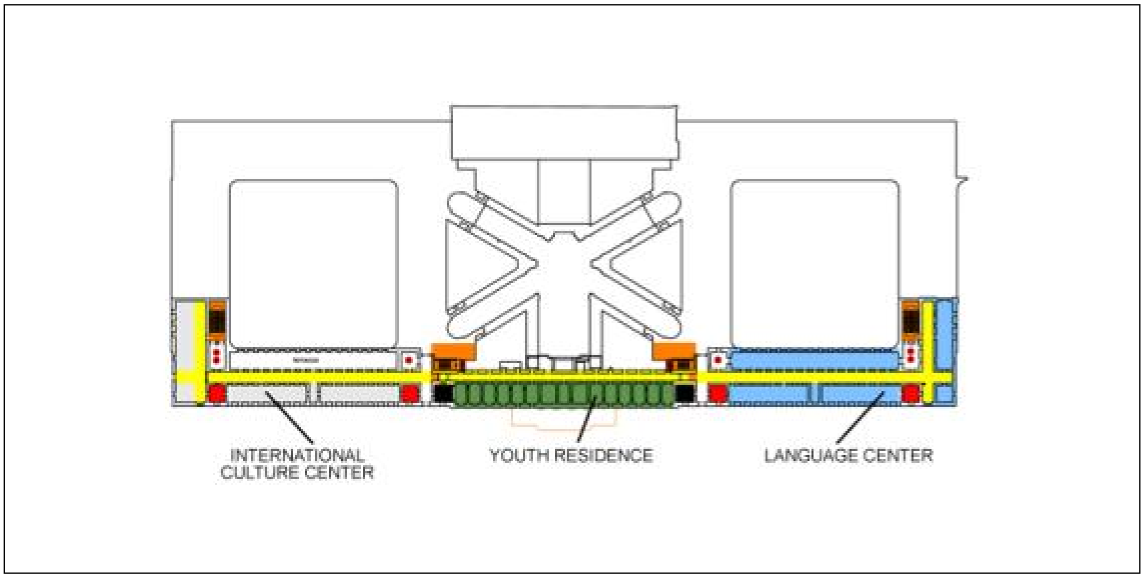

Figure 7.113. Plan of the fourth floor after retrofit.

Before Retrofit

Building Construction

The historical building has a massive stone and masonry construction, which during the centuries had been adjusted through the various current materials, such as the concrete used on the upper floors.

Heating/Ventilation/Cooling and Lighting Systems

No information available.

Problems/Damages

The building is historical and survived an important earthquake; it therefore needs consolidation and reconfiguration of damaged and unused portions of the building. Specifically, some later built concrete walls on the upper floors present a structural danger since they unbalance the whole building.

Retrofit Concept

The most relevant criteria taken into account are:

- respect for the ancient building, its history, its already existing historical materials and its shape
- use of traditional techniques for the reconstruction
- use of local, natural and ecological materials in the restoration.

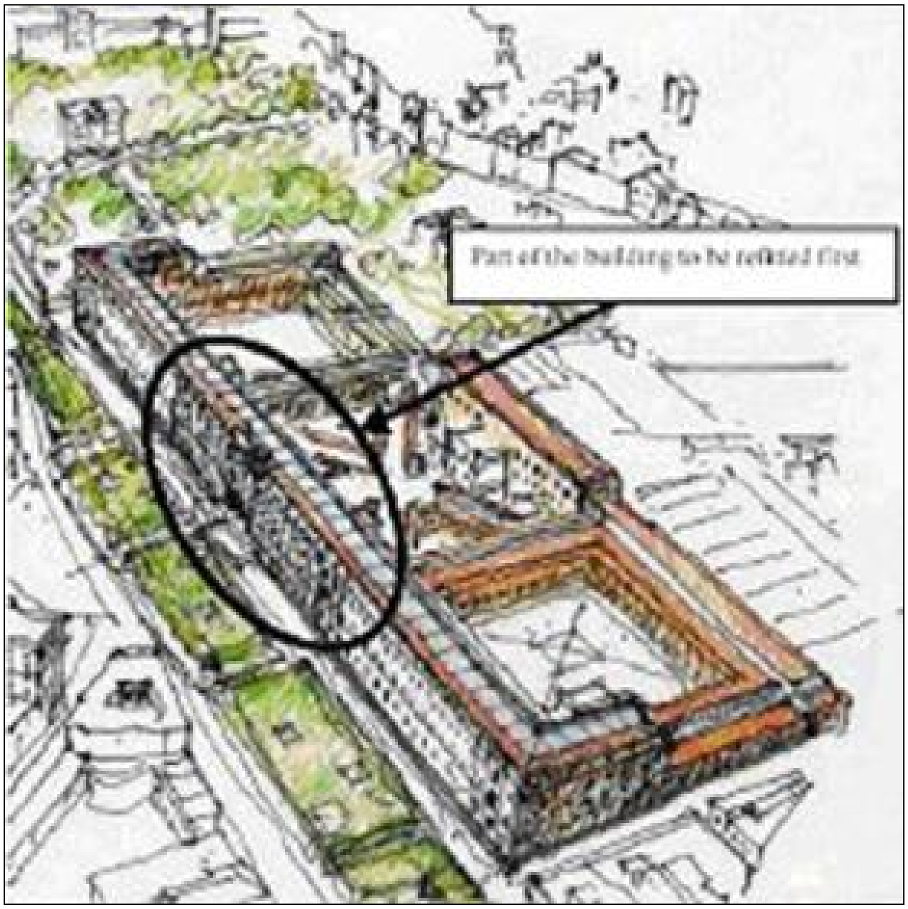

Figure 7.114. Sketch of the building underlying the main intervention areas.

<u>Building Construction</u>

The renovation project dealt first of all with the demolition of the later added concrete walls of the upper floors, which structurally unbalance the building, and then with its reconstruction using the materials already used in the building, which are sustainable and provide excellent insulation (Figure 7.114). These materials are traditional and locally sourced, in a framework of large scale sustainability concept.

Since the original construction is massive, and its ability to provide a comfortable indoor environment is very good, the whole energy strategy and the project involving newly built parts must consider the original design. As part of this overall strategy, there is also a careful passive solar design, which aims to take advantage of natural lighting, to reduce the energy demand for artificial lighting, and to still provide enough control to avoid summer overheating.

After a long and detailed architectural research, the architectural team found that the roof of the building would not necessarily have to be rebuilt with traditional materials such as fired clay tiles, but could use a more innovative concept: photovoltaic materials were chosen for their double quality of allowing natural light to enter when used directly as roofing material, and for their ability to generate energy (Figure 7.115).

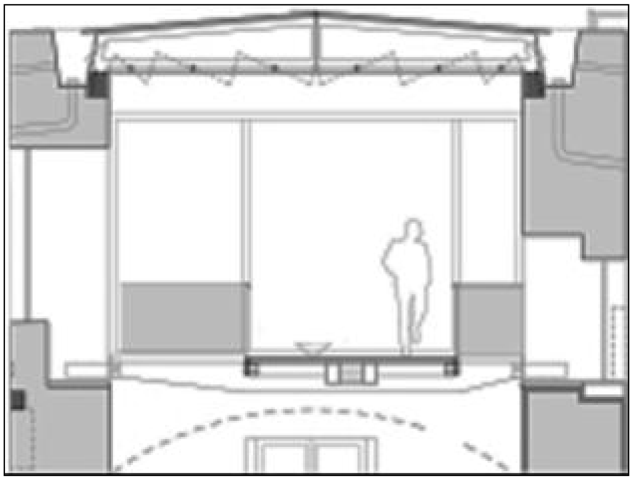

Figure 7.115. Section of the fourth floor, with the glazed roof.

Heating/Ventilation/Cooling and Lighting Systems

Since an air-conditioning system is not compatible with such a large building, ventilation is naturally provided through manually operable air exchangers. The low U-value of the envelope allows the installation of low-temperature floor heating system, with a high-performance gas boiler as generator.

A rainwater recovery system has been provided through the creation of large storage tanks in the underground floor: the water collected will be used for toilet flushing.

To implement renewable energy, a roof of integrated PV cells for a total power of 72 kWp is planned (already approved by the ministries) for the first portion of the building. The total roof surface is about 30,000 m^2 and about 3,700 m^2 can be covered by PV. Only about 520 m^2 (Lot AB, participating to SARA Project) and 430 m^2 (Lot C) of PV are already concluded, allowing the internal replicability of the project. To be in accordance with the original building pattern, custom designed semi-transparent PV modules (Figure 7.116) will be installed to produce around 88,125 kWh/y of electricity.

Figure 7.116. Structure for the glazed roof and semi-transparent PV cells.

A general monitoring system has been installed to measure the efficiency and energy production of the PV system and to control the thermal and natural illumination of the three newly built upper floors. The indoor corridor has been equipped with irradiation and temperature sensors, while the PV system will be monitored according to international standard CEI/IEC 61724 (*Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange and Analysis*), to measure:

- incident irradiation Gi in W/m^2
- ambient and module temperature in °C
- energy produced by the PV system andu in kWh
- energy from Utility Efu in kWh.

Energy Savings

Expected energy savings have been calculated, comparing the estimated energy consumption connected with a traditional renovation of the building with the consumption connected with the actual renovation strategy, resulting in a comparison of total yearly energy demand in kWh/m^{2}y of:

- standard building: 250 kWh/m^{2}y
- actual building: 175 kWh/m^{2}y.

The calculated energy savings are around 30% of the total yearly energy demand.

User Evaluation

No information available.

Renovation Costs

The whole project of consolidation, restoring and re-using of the building will cost 25,000,000 Euro. The SARA Project amounts to 5% of the costs of the Lot AB (21,000,000 Euro).

Lessons Learned

"Naples Municipality considers its participation to SARA project a successful achievement; it rewards the commitment into design and realize activities of Real Albergo dei Poveri's refurbishment: designed works have been approved, thanks to high design quality, by cultural heritage ministry and by the European Commission thanks to sustainability of choices over both materials and reconstruction techniques. The Real Albergo dei Poveri is located in the historical centre of Naples and this work can be considered a pilot experience. Indeed it will be replicated both in different sections of the same building and in different monumental buildings nearby."

Rocco Papa, Professor and Engineer (Statement as Vice Mayor of Naples, press conference, 12th June 2003).

Additional Information

Promoter:	Comune di Napoli
Group leaders:	Giorgio Croci, Italy Didier Repellin, France
Architects:	Mario Biritognolo, Italy Francesca Brancaccio, Italy Giuseppe Carluccio, Italy Nicolas Detry, France Laurence Lobry, France Pascal Prunet, France Paolo Rocchi, Italy
Links	www.comune.napoli.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1453 www.ecobuildings.info/pop_up_template/pop_up_SARA_MunicipalYouthCentreNapoliItaly.html www.sara-project.net/article.php3?id_article=14

Promoting Sustainability through High School Campus Redesign

Photos

New School Entrance

New School Lobby

Old School Lobby

New Library

New Science Lab

Old Science Lab

New School Exterior

New Commons

Old Cafeteria

Figure 7.117. Photos of Oak Ridge High School before and after the project.

Project Summary

While Oak Ridge High School (ORHS, Oak Ridge, TN) had been long known for its success in academic excellence, its 1950s-built campus did not reflect the success of its students—that is, until August 2008 (Figure 7.117). After 5 years of planning, design, and construction, students were welcomed to a new school year with a new campus where sustainability was a central focus. The goals for this project were to “create an inspiring, state-of-the-art learning environment that supports the school’s educational vision, fosters strong community connections, increases the school’s visibility, and promotes sustainability with pursuit of LEED Silver certification.” [1] The project was primarily funded by a bond. Supplemental funding came from resident and business contributions (totaling $8M), and from supporters who donated funding for specific school areas.

This project marks the largest school renovation in Tennessee history. Two of the school's seven buildings were completely replaced, and a third was partially replaced. The school was renovated on the existing 58.5-acre campus rather than constructing a new building on an undeveloped property. Many high schools of comparable size (1,700 student capacity; 346,400 sq ft) use between 70 and 80 acres of land. To reduce the building's footprint, architects designed the campus with multi-story buildings.

Sustainability was considered in the construction and use of building materials. Seventy-five percent of the school's original walls, floors, and roofs were reused. Twenty percent of the new building materials used contained recycled content. In addition, over 20% of the materials used were harvested and manufactured in the region.

Almost 200 geothermal wells were installed over 300 ft below the ground and a hybrid geothermal mechanical system and water source heat pump was installed. The system is expected to save 26% more energy than a comparable conventional chiller and gas-fired boiler system. The use of high-performance and low-flow fixtures is expected to reduce water usage by 22%, and vegetation was planted on the school campus that requires little maintenance and no irrigation.

Finally, a new lighting design was implemented to further save energy. Occupancy sensors were placed in each classroom, as well as a light system that can be set to one of three light levels (each in 1/3 increments). Two-thirds of all corridor lighting automatically shuts off while classes are in session, saving about 7 hours worth energy from these lights each school day.

Site

ORHS is located in Oak Ridge, TN (Anderson County, Figure 7.118). Latitude: 36°06'N; Longitude: 84°11'W; Elevation: 275m (910'). The warmest month is July with an average high temperature of 30.4°C (86.7°F); the coldest month is January with an average low temperature of -3.8°C (25.2°F).

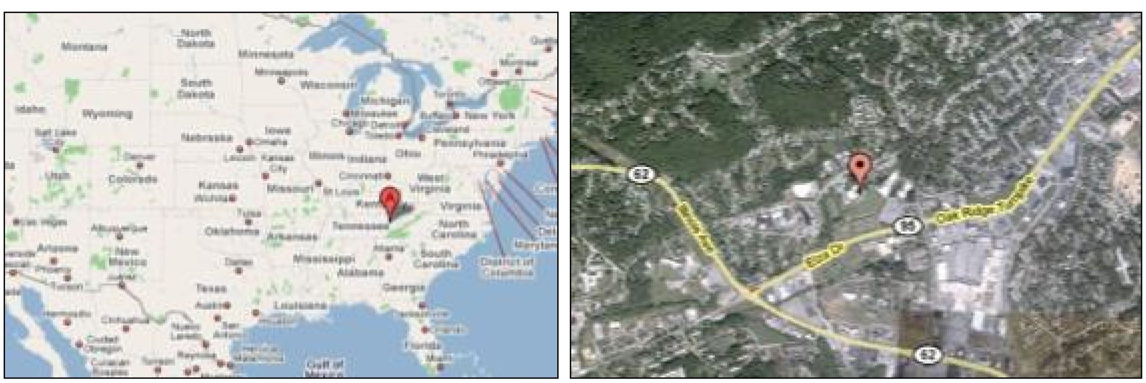

Figure 7.118. Google maps showing the Location of ORHS.

Building Description/Typology

Typology

MidSouth Geothermal installed the geothermal system. A total of 198 geothermal wells were drilled beneath the ground of the ORHS campus. In these wells is a series of closed-loop polyethylene pipes, or the earth coil or loop field. The geothermal heat pump acts as a high-efficiency heat exchanger, transferring heat to and from the earth coil to supply heat during cold months. During warm months, the process is reversed as to provide cooling during warm months. [4]

General Information

Project Timeline:	Sept. 2004 (Contract Date) – Aug. 2008 (Completion Date)
Year of subject renovation:	Original ORHS was built in 1950s
Total floor area (sq ft):	346,400 sq ft (180,000 renovation/166,400 new)
Occupied hours:	10 hours per school day.

Previous Heating, Ventilation, Cooling and Lighting Systems

Prior to the hybrid geothermal system, ORHS had a conventional HVAC system. [5]

Retrofit Energy Savings Features

Retrofit System Description

The primary source of energy savings resulting from the ORHS renovation will come from the geothermal hybrid heating and cooling system. The geothermal portion of this system employs GSHPs with the earth providing the heat source (in the heating mode) and the heat sink (in cooling mode).

Energy-Saving Concept

Because the underground temperature does not fluctuate as much as that above ground, the geothermal system can heat and cool a building much more efficiently than conventional HVAC systems.

Building Improvement

In addition to energy savings and lower emissions, the geothermal hybrid system will have lower maintenance needs. Because much of the systems elements are underground, they are not exposed to the elements that a conventional system would be. Therefore the geothermal system elements will be slower to need maintenance, repair, and replacement.

Resulting Energy Savings

The hybrid geothermal mechanical system and water source heat pump uses approximately 26% less energy when compared with a conventional chiller and gas-fired boiler system. High-performance and low-flow fixtures will reduce campus water usage by 22%.

User Evaluation

Significant cost savings will be demonstrated though utility bills. This cost savings could be used to support other educational needs.

Renovation Costs

Total Project Cost: $61M
Building Construction Cost: $50.4M
Site Development Cost: $1.6M
Furniture & Equipment Cost: $1.3M
Fees & Other Cost: $7M
Cost per Square Foot: $176.00

Experiences/Lessons Learned

Energy Use

The hybrid geothermal system saves ORHS about 26% of its annual energy consumption. [1]

According to MidSouth Geothermal, who installed the geothermal system, end users typically realize between 20 and 50% in energy savings over conventional systems. [4]

Environmental Impact

The hybrid geothermal system combines renewable energy with increased efficiency to reduce energy consumption. This reduction will result in a reduction in greenhouse gases. [4]

Economics

Because of the energy saved using the hybrid geothermal system (when compared with a conventional gas, oil, or heat pump system), the end user will see monetary savings through lower utility costs and lower maintenance, repair, and replacement costs. [4]

Practical Experiences of Interest to a Broader Audience

The geothermal portion of the hybrid system uses heat from within the earth's outer crust. While this type of system can be used and save energy in almost any geographical location, in the mid-South this earth layer has an average temperature of 58°F and only a small temperature differential—allowing the system to be more energy efficient. Additionally, the geothermal portion of the hybrid system burns no fossil fuels. According to MidSouth Geothermal, for each hour of use, the geothermal system produces one pound less CO_2 than a conventional HVAC system. [4]

Installing a geothermal heating and cooling system can help a building qualify for LEED® certification. A building can earn 20 LEED points with such a system. A building needs 26 to 32 points for certification, 33 to 38 points for silver certification, 39 to 51 points for gold certification, and 52 to 69 points for platinum certification. The Oak Ridge High School has applied for Silver LEED Certification. [4]

General Data

Address of Project

Oak Ridge High School
1450 Oak Ridge Turnpike

Oak Ridge, TN 37830

Existing or New Case Study

New

Date of Report

September 2009

Acknowledgements

Funding Sources: Revenue Bonds (primary); Grants and Donations (secondary)

Interior Design, Landscape Architecture, and Structural and Mechanical Engineering: DLR Group (Overland Park, KS)

Civil Engineering: Adams Craft Herz Walker, Inc. (ACHW) (Oak Ridge, TN)

Construction/Project Management: Heery International (Greg Peirce)

General Contractor: Messer Construction (Andy Lorenz)

Acoustical Consultant: Coffeen Fricke (Jill Elmers)

Theater Consultant: A to Z Theatrical Supply & Service (Brad Schmitz)

Laboratory Consultant: Earl Walls Associates

Food Service/Kitchen Consultant: Strategic Equipment (Ann Delap)

Other: Commissioning & Green Building Services – LEED/Commissioning (Jay Enck)

Case Study Author: SENTECH, Inc. (Ashley R. Smith)

References

1. Peter Li Education Group. 2008. "Oak Ridge High School: Green Project of Distinction Winner 2008 Green Education Design Showcase." Education Design Showcase. http://www.education designshowcase.com/view.esiml?pid-22.

2. Learning by Design 2009. "Oak Ridge High School." Citation of Excellence 2009. http://www.learningbydesign.biz.

3. DLR Group. "DLR Group Renovates Historic Oak Ridge H.S." http://www.dlrgroup.com/?p=4.1.12.

4. MidSouth Geothermal. Website. http://www.midsouthgeothermal.com.

5. Oak Ridge Public Schools Education Foundation. http://www.orpsef.org/progress.htm.

High-Efficiency Radiant Heating Panels in Weisbaden Army Airfield Hangar 1035

Photos

Figure 7.119. Interior of Hangar 1035.

Project Summary

When the decision was made to carry out a retrofit of Hangar 1035 (Figure 7.119), finding an energy efficient way to heat the 11,000-sq ft facility was a high priority. Ernst P. Kusiak of US Garrison Weisbaden had concluded that FRENGER SYSTEMEN radiant panels would heat the hangar more efficiently than the current heating system. The panels would use less energy than other heating alternatives and would lower maintenance costs.

FRENGER SYSTEMEN BV carried out an onsite survey that concluded the installation of highly efficient ECO EVO PLUS radiant panels would dramatically reduce energy consumption. This is a result of the panels' unique radiant output of 81%. Because they are lightweight, the ECO EVO PLUS panels could be installed easily and without any structural difficulties. Furthermore, the flexibility of FRENGER radiant panels allows an easy combined installation of light fittings and a sprinkler system.

Site

Hangar 1035 is located in Wiesbaden, Germany (Figure 7.120).

Figure 7.120. Google map showing the location of Wiesbaden, Germany.

Building Description/Typology

Hangar 1035 is located in Wiesbaden, Germany. It is 11,329 sq ft with a ceiling height of 33 ft.

Previous Heating, Ventilation, Cooling and Lighting Systems

Prior to the retrofit, the hangar was heated by forced air. This was very expensive, ineffective, noisy, and uncomfortably drafty. Figure 7.121 shows the ineffectiveness of the forced-air heat system. There was a wide variation between floor and ceiling temperature.

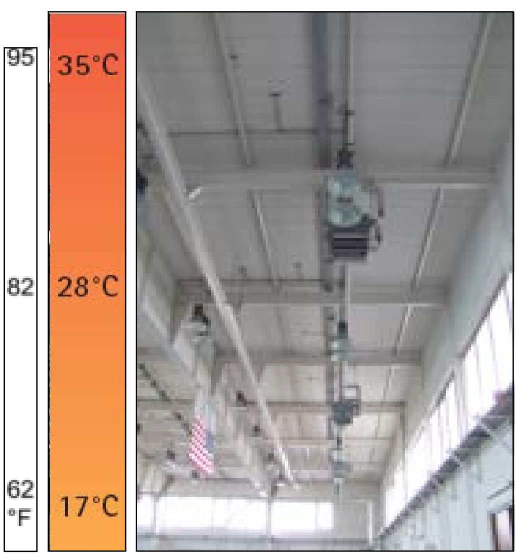

Figure 7.121. A forced-air system was used to heat the hangar.

Retrofit Energy Savings Features

The retrofit heating system consists of a FRENGER SYSTEMEN BV high-efficiency ceiling-mounted radiant panel system for the ultimate in energy efficiency. Fuel savings of 50% have been officially confirmed in many buildings very similar to Hangar 1035, when compared with forced-air systems.

Figures 7.122 and 7.123 show that the temperature variance from floor to ceiling has been greatly reduced as a result of the radiant panels. Additionally, Hangar 1035 can be heated up very quickly due to the low mass of the FRENGER SYSTEMEN BV radiant panels.

Figure 7.122. The new radiant power heating keeps the temperature more constant between the floor and ceiling.

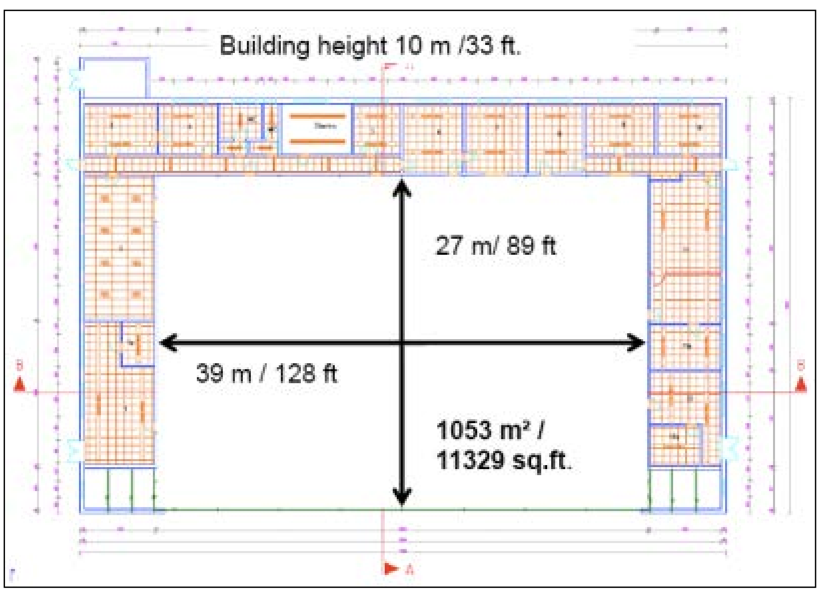

Figure 7.123. Schematic of Hangar 1035.

Resulting Energy Savings

After installing the ECO EVO PLUS radiant panels, the Garrison saves tens of thousands of dollars every year combined with a 50% smaller carbon dioxide footprint. Relative to the previous heating system, the radiant panels reduce heat capacity by 79 kW and 270,000 Btu/h. The resulting energy consumption reduction is 853 mBtu. In addition, in this particular retrofit, the average carbon dioxide reduction is expected to be 50,000 kg each year. Resulting monetary savings are:

- Heating: $21,122.49/year
- Electricity: $6,148.80/year
- Maintenance: $490.00/year
- Estimated payback period: 4.1 years.

Fuel savings of 50% have also been officially confirmed in many buildings of this type and height when compared to forced-air systems.

User Evaluation

Comfort levels within the hangar are no longer compromised when the large doors are opened and closed. Because the radiant panels act as a heating system, the temperature is able to stay relatively constant even on the coldest days. According to Ernst P. Kusiak, "The FRENGER radiant panel heating system was ideal for an application like [Hanger 1035]."

Renovation Costs

€ 90,000 ($114,000)

General Data

Address of Project

Wiesbaden, Germany

Existing or New Case Study

Existing case study

Date of Report

January 2010

Acknowledgements

FRENGER SYSTEMEN BV

Wiesbaden Army Airfield

References

FRENGER SYSTEMEN BV, "Case Study – Wiesbaden Army Airfield – Hangar 1035 Installation of Radiant Panels."

Menge, Dr.-Ing. Klaus, "High-efficiency Radiant Heating Panels: Energy Savings (up to 50%)," FRENGER SYSTEMEN BV.

High-Efficiency Radiant Heating Panels in Schweinfurt Conn Barracks, Bldg. 35

Photos

Figure 7.124. Photo of the interior of Bldg. 35.

Project Summary

Bldg. 35 at the Schweinfurt Conn Barracks (Figure 7.124) was always a building where people did not like to work because of the poor thermal conditions. Radiators were used as a heating system. However, due to the high air exchange rate, this system never managed to adequately heat the building. Strong worker complaints about the indoor climate influenced the decision to replace the heating system of Bldg. 35 at Conn Barracks; increasing the thermal comfort was a high priority.

FRENGER SYSTEMEN BV carried out an onsite survey to evaluate whether installing high-efficiency ECO EVO PLUS radiant panels would significantly increase the thermal comfort. Peter Bonnet of US Garrison Schweinfurt (DPW) concluded that the FRENGER SYSTEMEN radiant panels would increase the comfort level inside the building. Furthermore, he concluded that the panels would heat the hangar more efficiently and use less energy than other heating alternatives.

A FRENGER SYSTEMEN BV high-efficiency ceiling-mounted radiant panel system was installed. Radiation is emitted by radiant panels and reaches the walls, floor, furniture, and people in the room. The walls and floors are large areas that absorb the radiant heat, thus becoming warmer. Once the radiant panels were installed, the comfort level increased dramatically. Those who work in Bldg. 35 are much more comfortable.

Site

The Schweinfurt Conn Barracks is situated just outside the city limits of Schweinfurt, Germany (Figure 7.125).

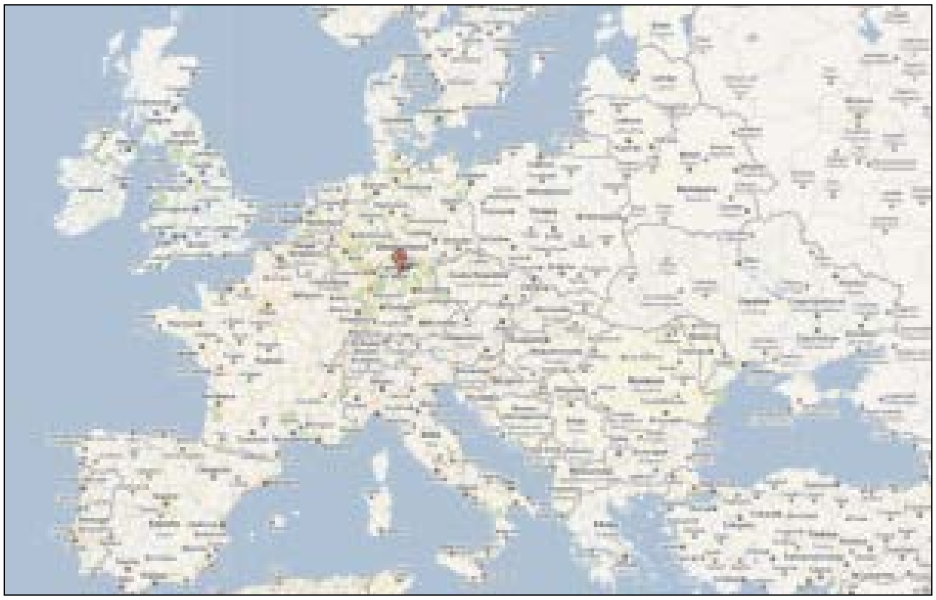

Figure 7.125. Google map showing the location of Schweinfurt, Germany.

Building Description/Typology`

Bldg. 35 is a hanger in the Conn Barracks. It is used for maintenance on cars, has high ceilings, and large doors. The building is 1,750 sq ft with a ceiling height of 18 ft.

Previous Heating, Ventilation, Cooling and Lighting Systems

Previously, the building was heated by a radiator system that was mainly based on convection. Because Bldg. 35 is a maintenance and service building for cars, the doors are frequently opened. Thus, the warm air was always lost—even when the large doors were opened for just 30 seconds.

Figure 7.126 shows the old, very inefficient radiators, which did not provide effective thermal comfort. There was a wide variation between floor and ceiling temperature.

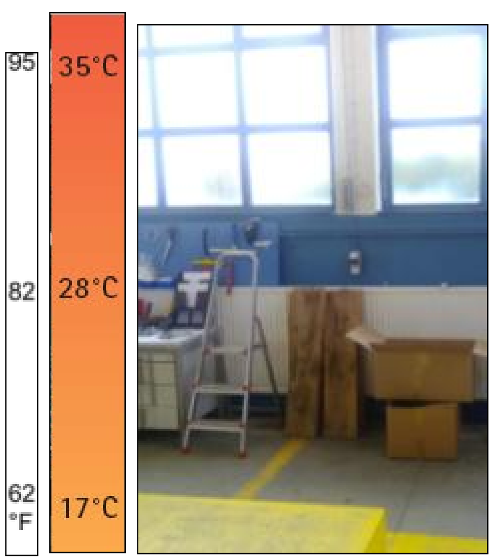

Figure 7.126. Radiators were used for heating prior to the retrofit; as a result, temperature varied greatly between the floor and ceiling.

Retrofit Energy Savings Features

The FRENGER radiant panel heating was developed by Gunnar Frenger. The FRENGER ceiling panels offer both energy and cost savings of up to 50%, and they provide the most efficient heating system for hangars, motor pools, and large warehouse-type spaces. These panels warm up quickly. They are essentially maintenance free because they have no moving parts, and they do not produce noise because the panels contain no fans. In addition, they are easy to install and their life expectancy is greater than 30 years.

Figures 7.127 and 7.128 show that the temperature variance from floor to ceiling has been greatly reduced as a result of the radiant panels. Additionally, Bldg. 35 can be heated up very quickly due to the low mass of the FRENGER SYSTEMEN BV radiant panels.

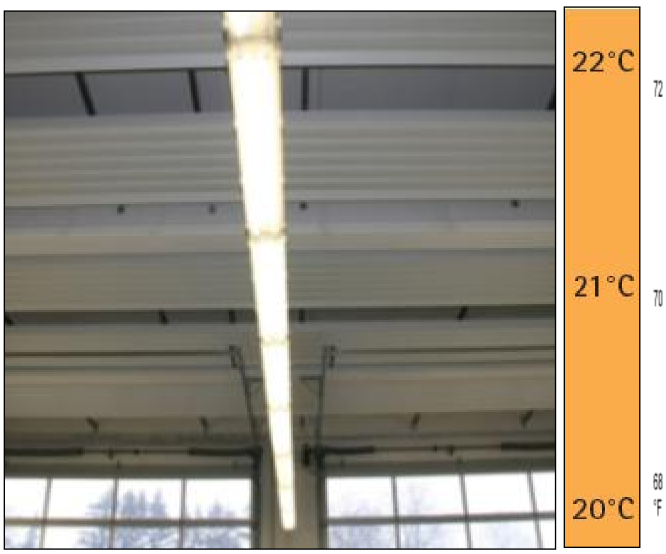

Figure 7.127. The new radiant power heating keeps the temperature more constant between the floor and ceiling.

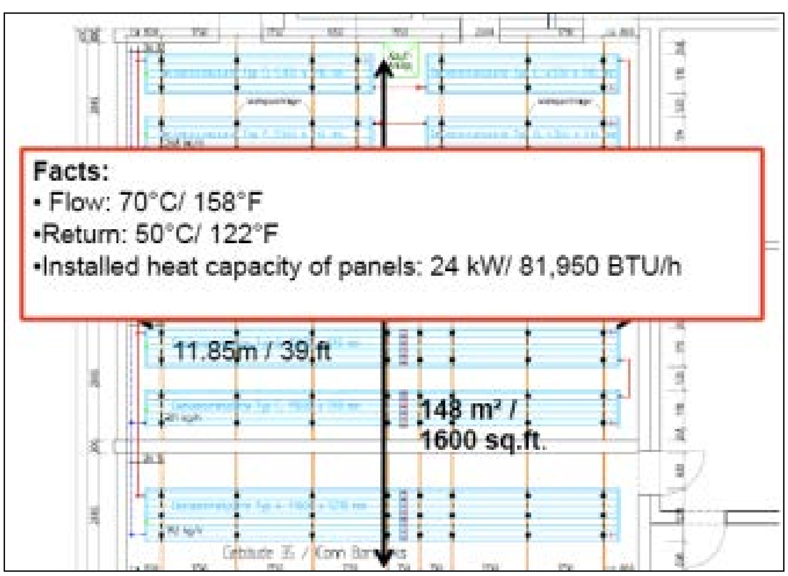

Figure 7.128. Schematic of the Conn Barracks Bldg. 35.

Resulting Energy Savings

After installing the ECO EVO PLUS radiant panels, the building has reduced the usage of heating energy by approximately 50%. The heat capacity of the ECO EVO PLUS radiant panels is 27 kW and 92,200 Btu/h. The calculated energy savings resulting from the retrofit is 26,161 kWh and 178 mBtu. In addition, a 5,232-kg reduction of carbon dioxide is expected annually.

User Evaluation

The radiant panels act as a heating system that allows temperature to stay relatively constant even on the coldest days. As a result, workers in Bldg. 35 are much more comfortable since the installation of the radiant panels.

Chief mechanical engineer DPW Peter Bonnet stated, “I am fully convinced of the FRENGER radiant panel heating—it works great. We will definitely install it in other buildings too!”

Renovation Costs

€20,000 ($25,200)

General Data

Address of Project

Schweinfurt, Germany

Existing or New Case Study

Existing case study

Date of Report

January 2010

Acknowledgements

FRENGER SYSTEMEN BV
Schweinfurt Conn Barracks

References

FRENGER SYSTEMEN BV, “Case Study – Schweinfurt Conn Barracks – Bldg. 35 Installation of Radiant Panals.”

Menge, Dr.-Ing. Klaus, “High-efficiency Radiant Heating Panels: Energy Savins (up to 50%),” FRENGER SYSTEMEN BV.

Large Scale Application of SolarWall Solar Air Heating Systems to Preheat Ventilation Air at Fort Drum, NY

Photo

Figure 7.129. Unglazed SolarWall panels installed above rollup doors of a maintenance shop, Fort Drum, NY.

Project Summary

One of the largest and most extensive solar air heating projects in the world has been completed at the US Army Garrison, Fort Drum, in upstate New York. The project is extremely significant in terms of the sheer magnitude of solar energy captured and avoided CO_2 emissions. It shows the tremendous potential for solar thermal energy technologies when appropriately deployed on a large scale.

In the fall of 2005, the US Army Corps of Engineers executed a multimillion dollar retrofit project to upgrade 27 of Fort Drum's vehicle maintenance buildings. The US Department of Defense ECIP provided project funding. Conserval Engineering and Conserval Systems worked closely with Fort Drum over the 2-year contract to design and install the SolarWall air collector systems (aka, a "transpired or unglazed perforated collector"). SolarWall systems had previously been installed at six other US military bases. This project was one of the reasons why the US Army Corps of Engineers, in 2006, identified the SolarWall collector (Figure 7.129) as one of two cost effective technologies ideally suited for military buildings such as vehicle maintenance facilities.

Site

Fort Drum is located in upper New York state, approximately 300 miles NNW of New York City near the city of Watertown, NY, at 44.04 N latitude, 75.749 W longitude. This location falls within ASHRAE 90.1-2004 Climate Zone 6. Design weather data at this location is characterized by the following:

- CDD (based on 65 F) – 301 (Watertown, NY airport)
- HDD (based on 65 F) – 7601 (Fort Drum, from US Army Technical Manual TM 5-785)
- Cooling Design Temperature – 0.4% occurrence[*]
- Dry Bulb Temp 86.2 °F

[*] Based on 2005 ASHRAE Handbook of Fundamentals for Fort Drum/Wheeler Sack Army Airfield, 44.05N latitude, 75.73W longitude

- Mean Coincident Wet Bulb Temp 70.6 °F
- Heating Design Temperature – 99.6% occurrence[*]
- Dry Bulb Temp -14 °F

Building Description/Typology

Typology/Age

Typical military buildings, such as vehicle maintenance garages, hangars, and warehouses (Figure 7.130) were chosen for this project. These types of buildings are ideal candidates for solar air heating because they have a high ventilation load, which represents an enormous energy expenditure given the tremendous volume of air that has to be continuously brought in and preheated over the entire heating season. In addition, these buildings have large existing exterior wall surfaces, making it easy to integrate a SolarWall system into the exterior façade.

Figure 7.130. Large buildings such as maintenance garages, hangars, and warehouses are the best candidates for this technology.

The SolarWall panels were mounted 6 to 10 in. from the existing exterior wall to create an air cavity (Figure 7.131). The heated boundary layer is drawn off the panels through the perforations into the air cavity, from where it is either directed into the HVAC units or into the building through a fan and ducting system.

Figure 7.131. Left, the completed SolarWall system at Fort Drum's Bldg. 207; right, Bldg. 1750.

Conserval Engineering customized the interior heat distribution for optimal performance in each building. In total, 99 fans are being used to deliver 300,000 cfm of ventilation air. Also, new makeup air fans and distribution ducts were installed to improve the ventilation air in some of the older facilities (Figures 7.132 and 7.133). In some cases the air was brought in through wall fans, in other cases through roof mounted fans or HVAC units.

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[*] Based on US Army Technical Manual TM 5-785 for Fort Drum.

The issue of destratification was present in many of the buildings; the temperature at the ceiling of tall hangars was as much as 20 °F (12 °C) warmer than floor temperature prior to the installations. The SolarWall ducting systems were designed to minimize the stratified ceiling heat, resulting in additional energy savings.

Figure 7.132. Ventilation air distribution ducting.

Figure 7.133. Ventilation air distribution ducting.

A variety of colors were selected for the 50 SolarWall systems; including: black, brown and blue-grey. The objective was to complement the existing color schemes of the buildings (Figure 7.134 and 7.135).

Figure 7.134. SolarWall panel colors were selected to enhance building appearance.

Figure 7.135. Typical retrofitted buildings.

General Project Information

- Year of construction: various
- Year of initial renovation: various
- Year of subject renovation: 2005
- 50 SolarWall® heating systems installed on 27 buildings
- 110,000 sq ft (10,220 m^2) of solar panels
- 300,000 cfm (510,000 m^3/h) of air heated with 99 fans
- Projected fuel savings of 44 million MBtu (46,000 GJ) per year
- 13,640 MBtu/hr (4 MW) of thermal energy capacity
- 2,000 tons of CO_2 displacement per year.

Architectural Drawings

Not available.

Previous Heating, Ventilation, Cooling and Lighting Systems

Prior to this renovation project, ventilation air was heated by a variety of preheat systems (e.g., steam, hot water, gas-fired). Due to the volume of ventilation air required, this required a significant quantity of energy to preheat the outdoor air, especially at the cold temperatures prevalent during Fort Drum's heating seasons. Also, some of the buildings involved in this project were not ventilated prior to this project, so this project added ventilation systems to those buildings. Note that this project did not involve changes to existing cooling or lighting systems.

Retrofit Energy Savings Features

Retrofit System Description

This retrofit project demonstrated that an unglazed SolarWall solar air heating system is a practical means of preheating ventilation air in large buildings with high ventilation air requirements (Figure 7.136). The project involved the installation of large scale SolarWall systems on the existing exterior walls of the buildings. SolarWall panels consist of heat absorbing metal sheets whose surface is punched with thousands of closely spaced, small holes through which outdoor air is drawn into the building by a ventilation fan. When sunlight is incident upon the surface of the SolarWall system, the all-metal panel absorbs the solar radiation and the boundary layer is heated. Simultaneously, cold outdoor air is heated as it is drawn through these tiny holes. This warmed outdoor air is distributed throughout the large open bay areas of the building and discharged as close to the ceiling as possible. Because the warmed outdoor air is typically cooler than the desired space temperature, it mixes with the warm stratified air near the ceiling, cooling it and causing it to migrate down to the work zone. The net result is that room temperatures are more uniform, comfort in the work zone is improved and less heat is lost through the roof.

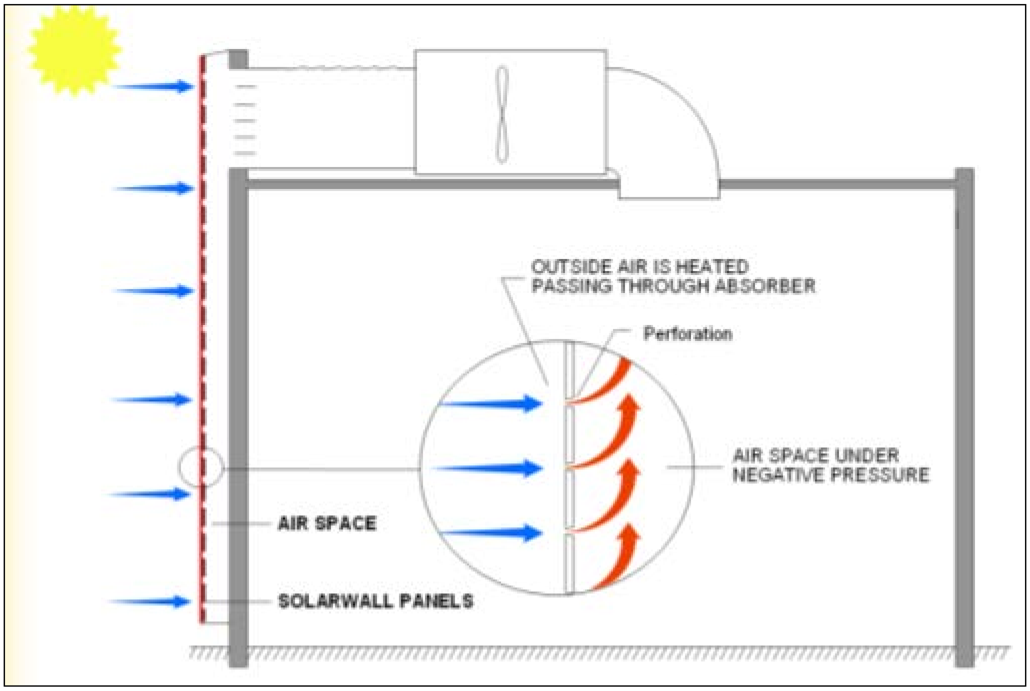

Figure 7.136. How a SolarWall system preheats ventilation air.

Large buildings with open bays and high ceilings, such as vehicle maintenance garages, hangars, and warehouses are ideal candidates for solar air heating. They have a high ventilation load, which represents an enormous energy expenditure given the tremendous volume of air that has to be continuously brought in and then heated over the entire heating season. In addition, these buildings have large wall surfaces available, making it easy to integrate a SolarWall thermal energy collection system into the exterior façade.

Energy-Saving Concept

This project demonstrated the feasibility of installing large scale SolarWall heaters to capture solar thermal energy and use it to preheat ventilation air in large buildings with high ventilation loads. Energy is saved in several ways:

- Ventilation air is preheated as it comes into contact with the warmed surface of the SolarWall system.
- Cool ventilation air introduced near the roof level mixes with stratified warm air, causing it to cool and migrate downward to the occupied zones, making the space more comfortable while requiring less heating energy.
- By reducing the temperature of air immediately below the roof, heat losses through the roof are reduced.
- The flow of ventilation air in the cavity formed by the SolarWall system and the existing exterior wall has the effect of recapturing heat lost through that part of the existing exterior wall, thereby reducing heat losses through that portion of the existing wall to zero (Figure 7.137).

Heating

This project reduced the load on the existing ventilation air heating systems.

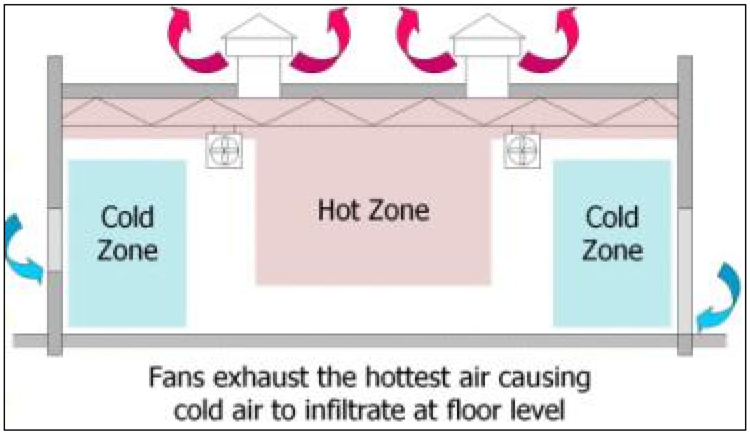

Figure 7.137. Destratification improves comfort while reducing heat losses.

Resulting Energy Savings

It is estimated that this project will allow Fort Drum to produce a minimum of 13,640 MBtu/hr (4MW) of solar thermal energy. This will avoid production of 2,000 tons of CO_2 annually by reducing the natural gas heating load by 44 million MBtu/h (46,000 GJ) each year.

User Evaluation

The USDOE's NREL has been evaluating the systems since they were commissioned. A final report from NREL is pending. Mr. Steve Rowley, Fort Drum's Energy Manager, believes that the systems can meet theoretical performance predictions. However, theoretical performance is often not achieved because occupants in some buildings turn the systems off because of complaints of fan noise or of cold air "dumping" on them from unducted systems. Attention to fan noise and ventilation air distribution system design is crucial to the success of the project.

Renovation Cost

$3 million was allocated to this turnkey project which retrofitted 27 buildings. Final costs were $3.4 million because additional costs were incurred for control systems.

Experiences/Lessons Learned

Energy Use

One of the SolarWall systems (4,100 sq ft) on Bldg. 91 is currently monitored by NREL. The preliminary results from 3 days of monitoring the system during February 2007 (with results extrapolated to the entire month) were calculated as follows:

- Assumptions:
- Natural gas cost @ $0.90 /therm
- Boiler efficiency 70%
- Results:

- Solar energy gain - $36/day
- Natural gas savings for the one SolarWall system for 1 month were approximately $1000.

Additional testing was conducted in November and December 2007 (61 days). The preliminary results from this testing were calculated as follows:

- Assumptions:
- Natural gas cost @ $0.924 /therm
- Boiler efficiency 70%
- Results:
- Total energy gained – 107 MBtu
- Total energy cost savings were $1,259.

Impact on Indoor Climate

This project improved the indoor climate by causing more uniform temperature distribution. The result was that temperatures at the floor level and at loft levels were nearly uniform. Also, buildings that were inadequately ventilated previously were modified to deliver proper amounts of ventilation air to the working areas, improving comfort and creating more healthful working conditions.

In some buildings, fan noise and/or cold air “dumping” onto building occupants generated complaints. These problems are correctable through improved designs of the distribution system. This is discussed more fully below.

Economics

The economics of this project were evaluated based on October 2008 fuel costs and discount rates (Table 7.29).

Table 7.29. October 2008 fuel costs and discount rates

Energy Source	Cost $/MBtu	Savings MBtu/Year	Annual Savings ($)	Discount Factor	Discounted Savings
Natural Gas	$11.83	44,317	$524,381	13.28	$6,963,778
Electrical Demand	NA	NA	5	11.75	$64
TOTAL		44,317	$524,386		$6,963,843

Based on these savings figures, a simple payback of 6.58 years was calculated. The savings to investment ration (SIR) was found to be 2.02 and the adjusted internal rate of return (AIRR) was 7.72%.

Practical Experiences of Interest for a Broader Audience

A number of attractive features are associated with this DOAS system:

- Attractive appearance. The SolarWall systems are designed and installed to enhance the appearance of the existing building. A variety of colors are available.
- Ease of maintenance. These systems are very simple and contain few moving parts (fan, belt, outdoor air dampers, preheat coil valve). Otherwise, no other parts require routine maintenance.

Some design-related Lessons Learned include:

- Fan noise. Fans and ducted distribution systems in some buildings are somewhat noisy. The User has had to slow the fans down to minimize noise. The effect of this is to reduce the system's heat collection capacity. Silencers on fan discharges and variable-speed drives on fans to allow adjustment are recommended. Unducted wall fans can be noisy and should be avoided.
- Avoid gravity outdoor air dampers. Gravity dampers open when the fans start and tend to blow cold air downward, causing complaints from occupants. A better approach would be to use a motorized damper interlocked to the fan. Set the louvers to open out and blow air toward the ceiling.
- Provide distribution ductwork for ventilation air. This improves distribution of ventilation air and reduces noise and complaints of cold air being dumped on the occupants.
- Tie controls into a DDC building control system. Controlling the SolarWall with a 7-day time clock and a thermostat is not ideal. For Army Installations better control is achieved with a DDC system. Also, the SolarWall system should be interlocked through the DDC system to shut down in the event of a fire alarm activation.
- The SolarWall system needs to be properly oriented and carefully sized for the ventilation load. Select a south or southwest /south east facing wall.
- New construction projects are ideal for installation of SolarWall systems. On new construction, the additional cost of a SolarWall system would be negligible. Also, the building could be oriented to optimize performance of the system.

Resulting Design Guidance

Not yet available.

General Data

Address of Project: Fort Drum, NY
Existing or New Case Study: New
Date of Report/Revision No.: 16 October 2008

US Department of Defense, ECIP

Designer: Conserval Systems, Inc
General Contractor: Conserval Systems, Inc.
Case Study Authors: Ms. Victoria Hollick, Conserval Engineering, Inc.
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Oil-Free Magnetic Bearing Chiller Compressor at the Fleet Industrial Supply Center in San Diego, CA

Photos

Figure 7.138. New compressor retrofitted to existing frame in San Diego, CA.

Project Summary

This Case Study presents a preliminary analysis of the data collected as a part of the technology validation of an Oil-Free Magnetic Bearing Chiller Compressor (Figure 7.138) performed by the Navy's Energy Technology Validation (Techval) Program. The compressor is rated at 60–90 tons and has an integral VFD, variable inlet vanes and is controlled by an internal microprocessor. The compressor is advertised as being up to 10% more efficient than existing chillers at full load and 30% more efficient at part load. The objective of this project is to demonstrate the cost effectiveness of this chiller compressor technology and to determine if can help the Navy meet their energy reduction goals. This chiller compressor should reduce energy use without any maintenance issues and with a simple payback of less than 10 years.

This oil-free compressor has been installed at three Navy sites, one of which is the FISC in San Diego, CA. The San Diego site was a compressor retrofit, in that the condenser and evaporator of the original chiller were reused. Based on a preliminary analysis of the data, this chiller compressor achieved a simple payback of 8.4 years in San Diego, with the chiller saving $21,206/yr. Energy savings are 176,717 kWh/yr. Techval recommends that the oil-free compressors tested be considered in the following situations:

- where energy costs are relatively high (> $0.07/Kwh)
- where the chiller is runs long hours at part load
- where the compressor is in need of replacement.

The above list is not exclusive; other applications may be equally viable.

Table 7.30 lists a synopsis of the data collected for the center in San Diego.

Table 7.30. Synopsis of collected data.

Project Site	Project Type	$/kWh	Tons	Annual kWh savings	Annual Energy $ Savings	% Savings	Cost	$/Ton	Payback (years)
San Diego 2006	Add 3rd compressor	$0.121	240	176,717	$21,206	40%	$178,787	$744	8.4

Site

San Diego, California. Fleet Industrial Supply Center, at 32.72 N latitude, 117.16 W longitude.

- CDD (based on 65 °F) – 984 (San Diego, CA)
- HDD (based on 65 °F) – 1256 (San Diego, CA)

Building Description/Typology

FISC in San Diego, CA.

Previous Heating, Ventilation, Cooling and Lighting Systems

At San Diego, there were two existing 360 ton screw compressors on 275 ton frames. These chillers were determined to be grossly oversized for the current cooling load on the building. In addition, due to critical electrical loads in the building, the entire cooling system had 100% redundancy, i.e., two chillers and two cooling towers. Here it was decided to do a retrofit on one of the chillers and reuse the existing evaporator and condenser. The old compressor was removed and two new 90 ton oil-free compressors were installed on the existing frame to give approximately 180 tons of cooling.

Originally the two new 90 ton chillers were able to replace the 360 ton chiller and meet the cooling load on the building. Several months after the two new chillers were installed, the site added additional electrical equipment to the building that increased the cooling load to the point that the new chillers were no longer able to completely meet the cooling load. This resulted in the unwanted necessity of occasionally running the remaining original inefficient screw chiller on the hottest days of the summer. In addition, in January 2005, one of the two cooling towers failed due to a seized bearing. Each of these events resulted in the loss of 100% redundancy to the building. The decision was made to replace both cooling towers and add a third compressor to the existing 275 ton frame. It was also decided to further increase the efficiency of the system by changing the control sequence of the compressors. Originally the two new compressors ramped up and down together so that each of them always had 50% of the load. It was determined that it would be more efficient to operate each of the three compressors at different loads and a control sequence was written by the manufacturer to operate the compressors most efficiently over the entire load range. The change out of the cooling towers and installation of the new compressor were completed in mid-June 2005.

Retrofit Energy Savings Features

The Oil-Free Magnetic Bearing Chiller Compressor evaluated by the Navy's Energy Technology Validation (Techval) Program is rated at 60–90 tons and has an integral VFD, variable inlet vanes and is controlled by an internal microprocessor. The compressor is advertised as being up to 10% more efficient than existing chillers at full load and 30% more efficient at part load.

Resulting Energy Savings

After Techval installed the third oil-free magnetic bearing compressor in San Diego, Techval collected data in January, April, and August 2006. Tables 7.31, 7.32, and 7.33 list the results from these three data monitoring periods.

Table 7.31. San Diego, January 2006.

Existing Chiller								
	Chilled Water Flow Rate (gpm)	**Chilled Water Temp. in (°F)**	**Chilled Water Temp. out (°F)**	**Chilled Water Temp. Delta**	**Load (tons)**	**Condensing Water Temp. (°F)**	**Electrical Demand (kW)**	**Efficiency (kW/ton)**
Minimum	427	46	44	0.0	0	68	0	0.32
Maximum	512	59	54	14.7	290	75	94	2.53
Average	485	47	45	2.4	48	71	47	1.11
New Compressors								
Minimum	421	45	41	0.5	0	65	0	0.31
Maximum	484	52	48	7.8	153	76	86	2.69
Average	462	47	45	2.5	44	69	25	0.59

Table 7.32. San Diego, April 2006.

Existing Chiller								
	Chilled Water Flow Rate (gpm)	**Chilled Water Temp. in (°F)**	**Chilled Water Temp. out (°F)**	**Chilled Water Temp. Delta**	**Load (tons)**	**Condensing Water Temp. (°F)**	**Electrical Demand (kW)**	**Efficiency (kW/ton)**
Minimum	440	44	44	0.0	0	68	0	0.54
Maximum	509	53	53	5.8	120	75	73	1.67
Average	485	44	44	2.6	52	72	51	1.04
New Compressors								
Minimum	429	45	41	0.0	0	65	0	0.00
Maximum	492	51	49	6.1	117	75	78	2.32
Average	460	47	45	2.6	49	69	26	0.55

Table 7.33. San Diego, August 2006.

Existing Chiller								
	Chilled Water Flow Rate (gpm)	**Chilled Water Temp. In (°F)**	**Chilled Water Temp. out (°F)**	**Chilled Water Temp. Delta**	**Load (tons)**	**Condensing Water Temp. (°F)**	**Electrical Demand (kW)**	**Efficacy (kW/ton)**
Minimum	435	46	44	1.9	39	69	42	0.47
Maximum	520	57	46	11.0	230	82	136	1.26
Average	491	49	44	4.9	101	75	66	0.73
New Compressors								
Minimum	438	44	39	1.2	23	67	16	0.36
Maximum	494	59	52	11.3	224	86	166	0.77
Average	469	50	45	5.5	108	72	56	0.49

User Evaluation

Not applicable.

Renovation Costs

$178,787

Experiences/Lessons Learned

Energy Use Saved

176,717 kWh/year

Environmental Impact

None

Economics

Simple payback: 8.4 years

Practical Experiences of Interest to a Broader Audience

- Quiet – In San Diego the chilled water pumps make more noise than the chiller. Could be a plus if installation is in an area where noise is an issue.
- Light weight – If compressor needs to be changed out, can be accomplished manually by two persons.
- Low startup draw – about 2 amps. Could be a plus if you are replacing or installing a backup generator since generator can be downsized to handle full load draw, not startup. Smaller generator may pay for incremental cost of compressor.

Resulting Design Guidance

Working.

General Data

Address of Project

San Diego, CA

Existing or New Case Study

New Case Study

Date of Report

January 2009

Acknowledgements

Project Sponsor: Commander, Naval Installations Command (CNIC)
Designer: SEI Group, Inc.
General Contractor: SEI Group, Inc.
Case Study Author: NAVFAC Engineering Service Center (Mr. Ben Wilcox)

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Oil-free Magnetic Bearing Chiller Compressor at the Naval Air Station in Jacksonville, FL

Photos

Figure 7.139. Oil-free magnetic bearing chiller compressor.

Project Summary

This Case Study presents a preliminary analysis of the data collected as a part of the technology validation of an Oil-Free Magnetic Bearing Chiller Compressor (Figure 7.139) performed by the Navy's Energy Technology Validation (Techval) Program. The compressor is rated at 60–90 tons and has an integral VFD, variable inlet vanes and is controlled by an internal microprocessor. The compressor is advertised as being up to 10% more efficient than existing chillers at full load and 30% more efficient at part load.

The objective of this project is to prove that this chiller compressor is a cost effective technology that if installed in Navy facilities will help the Navy meet its energy reduction goals. This chiller compressor should reduce energy use without maintenance issues and with a simple payback of less than 10 years.

This oil-free compressor has been installed at three Navy sites, one of which is the Naval Air Station Jacksonville, FL. The Jacksonville site was a compressor retrofit, in that the condenser and evaporator of the original chiller were reused. Based on a preliminary analysis of the data, this chiller compressor achieved a simple payback of 7.0 years in Jacksonville, with the chiller saving $15,358 and 284,407 kWh/yr. Techval recommends that the oil-free compressors tested be considered in the following situations:

- Where energy costs are relatively high (> $0.07/Kwh)
- Where the chiller is runs long hours at part load
- Where the compressor is in need of replacement.

The above list is not exclusive, other applications may be equally viable.

Table 7.34 lists a synopsis of the data collected for the Naval Air Station in Jacksonville.

Table 7.34. Synopsis of collected data.

Project Site	Project Type	$/kWh	Tons	Annual kWh savings	Annual Energy $ Savings	% Savings	Cost	$/Ton	Payback (years)
JAX Dec/Apr 2006/2007	Compressor Retrofit with Cond. Water reset	$0.054	120	284,407	$15,358	41%	$107,592	$897	7.0

Site

Jacksonville, Florida, Naval Air Station (NAS), at 30.50 N latitude, 81.70 W longitude:

- CDD (based on 65 F) – 2694 (Jacksonville, FL)
- HDD (based on 65 F) – 1434 (Jacksonville, FL)

Building Description/Typology

Jacksonville, Florida. NAS in Jacksonville.

Previous Heating, Ventilation, Cooling and Lighting Systems

Building 926, which serves as the Helicopter Training Facility, was selected as the candidate building. It was constructed about 15 years ago and there have been no apparent major renovations of the building since initial construction. It is not listed on any historical register. The building is approximately 85,000 sq ft in size. The facility can be occupied during normal business hours and up to 10 p.m. It is normally shut down on the weekends although some cooling loads from computer systems are required during unoccupied periods.

The HVAC system consisted of a primary-secondary, constant flow, chilled water loop system. The primary loops consists of: two 120 ton chillers (each with two 60 ton compressors) and one (1) dedicated chilled water pump, a condenser water pump, and one (1) cooling tower cell per chiller. Due to the piping and valves at the cooling towers, it is possible to manually switch one (1) cell to run with any one (1) chiller at a time. However, it is not possible to run both cells for one (1) chiller.

The project removed two existing compressors from one of the chillers and replaced them with two 60 ton oil-free magnetic bearing compressors. In addition, at this site condensing water reset was used to further improve the efficiency. The compressor already has the software installed that essentially makes this feature a “plug and play” if the cooling tower fan two speed or a VFD.

The chillers then automatically switched back and forth between the existing and the retrofitted chiller every week for a year while data was taken in 15 minute intervals.

Retrofit Energy Savings Features

The Oil-Free Magnetic Bearing Chiller Compressor evaluated by the Navy’s Energy Technology Validation (Techval) Program is rated at 60–90 tons and has an integral VFD, variable inlet vanes and is controlled by an internal microprocessor. The compressor is advertised as being up to 10% more efficient than existing chillers at full load and 30% more efficient at part load.

Resulting Energy Savings

Once the two new compressors were installed, Navy Techval took data from December 2006 until January 2008. See data in Table 7.35.

Table 7.35. Jacksonville data (2007).

	Compressor Efficacy	Plant Efficacy	Average Load	Average Compressor Power	Cooling Tower Power	Plant Power
New Compressors	0.57 kW/ton	0.61 kW/ton	75.4 ton	45.9kW	2.44kW	48.3 kW
Existing	1.02 kW/ton	1.04 kW/ton	76.7 ton	78.5kW	1.55kW	80.1 kW

User Evaluation

Not applicable.

Renovation Costs

$107,592

Experiences/Lessons Learned

Energy Use Saved

284,407 kWh/year

Environmental Impact

None

Economics

7.0 years simple payback

Practical Experiences of Interest to a Broader Audience

- Quiet – In San Diego, the chilled water pumps make more noise than the chiller, which could be an advantage if installation is in an area where noise is an issue.
- Light weight – If compressor needs to be changed out, two persons can do the job manually.
- Low startup draw – about 2 amps, which could be an advantage when replacing or installing a backup generator since the generator can be downsized to handle full load draw, not startup; the smaller generator may pay for incremental cost of compressor.

Resulting Design Guidance

Working.`

General Data

Address of Project: Jacksonville, FL
Existing or New Case Study: New Case Study
Date of Report: January 2009

Acknowledgements

Project Sponsor:	Commander, Naval Installations Command (CNIC)
Designer:	SEI Group, Inc.
General Contractor:	SEI Group, Inc.
Case Study Author:	NAVFAC Engineering Service Center (Mr. Ben Wilcox)

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Oil-free Magnetic Bearing Chiller Compressor at the Naval Undersea Warfare Center in Newport, RI and the Fleet Industrial Supply Center in San Diego, CA

Photo

Figure 7.140. New chiller before installation at Newport RI.

Project Summary

This Case Study presents a preliminary analysis of the data collected as a part of the technology validation of an Oil-Free Magnetic Bearing Chiller Compressor (Figure 7.140) performed by the Navy's Energy Technology Validation (Techval) Program. The compressor is rated at 60–90 tons and has an integral VFD, variable inlet vanes and is controlled by an internal microprocessor. The compressor is advertised as being up to 10% more efficient than existing chillers at full load and 30% more efficient at part load. The objective of this project is to prove that this chiller compressor is a cost effective technology that if installed in Navy facilities will help the Navy meet its energy reduction goals. This chiller compressor should reduce energy use without maintenance issues and with a simple payback of less than 10 years.

This oil-free compressor has been installed at three Navy sites, one of which is the Naval Undersea Warfare Center (NUWC) in Newport, RI. An entirely new chiller consisting of an oil-free magnetic bearing compressor and a plate-and-frame condenser and evaporator were installed. Based on a preliminary analysis of the data, this chiller compressor achieved a simple payback of 3.8 years in Newport, with savings from the chiller approximately $26,192 and 227,760 kWh/yr. Techval recommends that the oil-free compressors tested at least be considered in the following situations:

- where energy costs are relatively high (> $0.07/Kwh)
- where the chiller is runs long hours at part load
- where the compressor is in need of replacement.

The above list is not exclusive, other applications may be equally viable. Table 7.36 lists a synopsis of the data collected for the center in Newport.

Table 7.36. Synopsis of collected data.

Project Site	Project Type	$/kWh	Tons	Annual savings kWh	Annual Energy Savings ($)	Savings (%)	Cost	$/Ton	Payback (years)
Newport, Sep/Nov 2005	New Chiller	$0.115	80	227,760	$26,192	65%	$100,783	$1260	3.8

Site

Newport, RI. NUWC at 41.48 N latitude, 71.34 W longitude:

- CDD (based on 65 F) – 606 (Providence, RI)
- HDD (based on 65 F) – 5884 (Providence, RI)

Building Description/Typology

NUWC at Naval Station Newport, Newport RI.

Previous Heating, Ventilation, Cooling and Lighting Systems

At Newport, there were two existing 100-ton reciprocating chillers for both comfort cooling and year round cooling of some electronic equipment located in the building. There was some concern that if the new 90 ton chiller were to replace one of the existing 100 ton chillers, there would not be enough capacity with the new chiller and so the decision was made to leave the existing chillers and add the new oil-free chiller. The test plan then called for the chillers to switch between the one that was the lead and the one that was the lag every 24 hours. The replacement chiller at Newport was a new chiller that included an oil-free magnetic bearing compressor. The evaporator and condensers were modular so if additional cooling capacity was needed in the future, another chiller could be brought in and stacked on top of the existing chiller. The chiller used a plate-and-frame heat exchanger. The chiller was small enough so it could be brought in through a standard sized doorway.

Retrofit Energy Savings Features

The Oil-Free Magnetic Bearing Chiller Compressor evaluated by the Navy's Energy Technology Validation (Techval) Program is rated at 60–90 tons, has an integral VFD and variable inlet vanes, and is controlled by an internal microprocessor. The compressor is advertised as being up to 10% more efficient than existing chillers at full load and 30% more efficient at part load.

Resulting Energy Savings

Due to many problems not related to the oil-free magnetic bearing compressor itself, the only data collected from Newport has been from the fall of 2005. The new chiller has been shut down due to clogged condensing water filters. Abrupt changes in the condensing water temperature have occurred (probably caused by site personnel), as well as abrupt changes in chilled water flow rate (most likely caused by the site personnel). Changes in condensing water temperature and chilled water flow rate alter the efficiency of the chiller and thus introduce additional variables into the data analysis. In addition, the existing monitoring system installed on the original chiller by the site had numerous failures. Techval was able to collect data from 25 Sep 2005 until 14 Nov 2005. The data shows that at nearly identical conditions the new chiller was an average of 65% more efficient for the entire monitoring period (Table 7.37).

If one assumes that late September through early November are average cooling months in Newport, then the average load for the year would be approximately 36 tons. With an average of 1.11 kW/ton, the average demand for the existing chiller would be 40 kW. This would be 28,800 kWh for the month. The cost of electricity is $0.115/kWh in Newport, which translates into $3312/mo to operate the existing chiller. The new chiller at 0.38 kW/ton would use 10,080 kWh/mo or $1159/mo. The savings between the old chiller and the new chiller would be 18720 kWh and $2153/mo. This would equal 227,760 kWh/yr and $26192/yr. The installed cost of the new chiller in Newport was $100,783 for a simple payback of 3.8 years.

Table 7.37. Newport data (2005).

Existing Chiller								
	Chilled Water Flow Rate (gpm)	**Chilled Water Temp. in (°F)**	**Chilled Water Temp. out (°F)**	**Chilled Water Temp. Delta**	**Load (tons)**	**Condensing Water Temp. (°F)**	**Electrical Demand (kW)**	**Efficiency (kW/ton)**
Minimum	187	52	48	2.5	24	48	33	0.76
Maximum	250	56	52	6.6	66	70	58	1.77
Average	231	54	50	3.7	36	60	40	1.13
New Chiller								
Minimum	180	45	41	3.2	25	48	5	0.12
Maximum	206	53	47	7.3	57	78	32	0.65
Average	192	50	45	4.7	37	59	14	0.37

User Evaluation

Not applicable.

Renovation Costs

$100,783

Experiences/Lessons Learned

Energy Use Saved

227,760 kWh/year

Environmental Impact

None

Economics

3.8 year simple payback

Practical Experiences of Interest to a Broader Audience

- Quiet – In San Diego, the chilled water pumps make more noise than the chiller, which could be an advantage if installation is in an area where noise is an issue.
- Light weight – If compressor needs to be changed out, two persons can do the job manually.

- Low startup draw – about 2 amps, which could be an advantage when replacing or installing a backup generator since the generator can be downsized to handle full load draw, not startup; the smaller generator may pay for incremental cost of compressor.

Resulting Design Guidance

Working.

General Data

Address of Project:	Newport, RI
Existing or New Case Study:	New Case Study
Date of Report:	January 2009

Acknowledgements

Project Sponsor:	Commander, Naval Installations Command (CNIC)
Designer:	SEI Group, Inc.
General Contractor:	SEI Group, Inc.
Case Study Author:	NAVFAC Engineering Service Center (Mr. Ben Wilcox)

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Retrofitting of University Dormitories
City Vert-Bois, Montpellier, France

Photo

Figure 7.141. South view of the building after retrofitting.

Project Summary

The University City Vert-Bois was built in 1968 in Montpellier. It features six buildings in a green park, close to the university Paul Valery. The six buildings have the same structure (Figure 7.141). Oriented north-south, they were featuring of 166 rooms and collective toilets before retrofitting.

Since 2003, all operations of retrofitting systematically bring elements of sanitary comfort in rooms (washbasin, toilet, and shower, Figures 7.142-7.144). From this date, all the technical installations were also renovated (e.g., the swallowed facades, the waterproof nesses of roofs). These facades will not require heavy maintenance for several years, except for paint. This case study concerns Bldg. D of the University City, where rooms were transformed into studios in 2003.

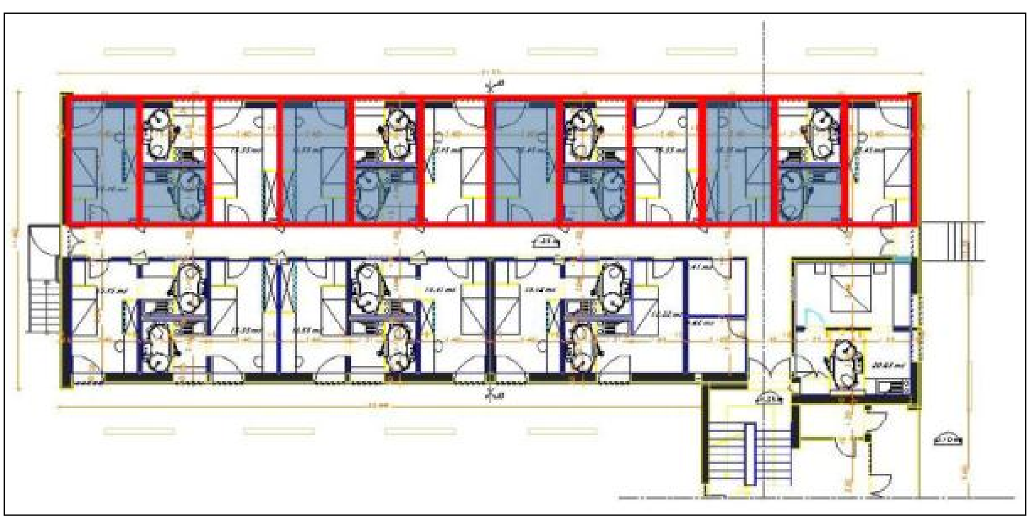

Figure 7.142. First floor (2 blocks).

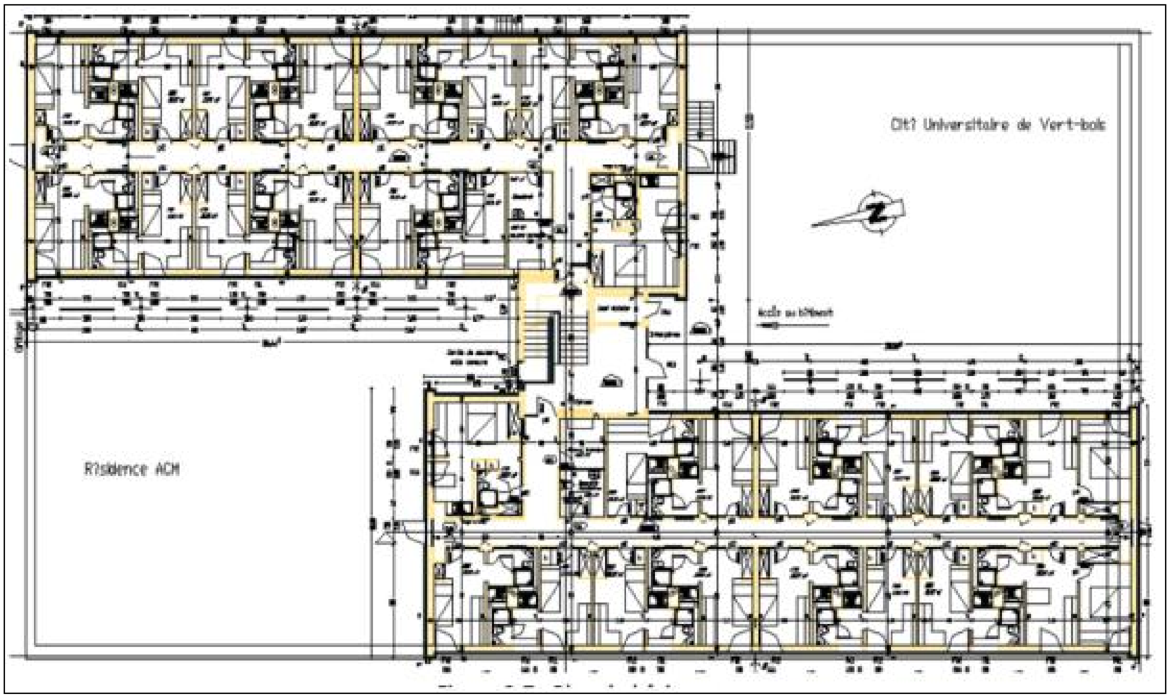

Figure 7.143. Indoor distribution in a floor (east block).

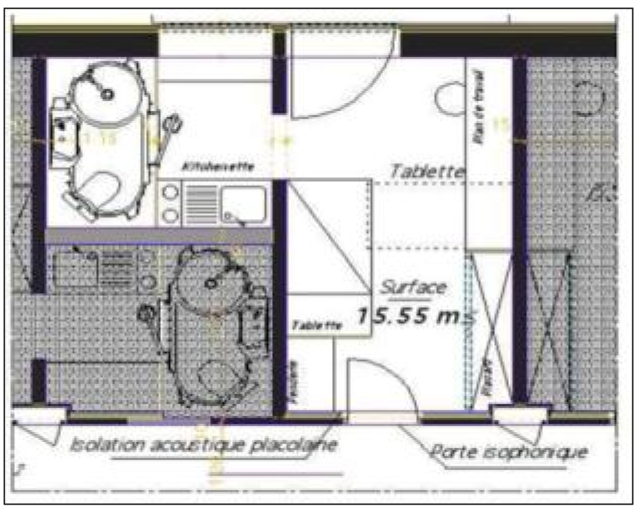

Figure 7.144. One housing plan.

Site

The university dormitory Vert-Bois is located in the north of Montpellier, in the southeast of France:

(Latitude : 43,4°N, longitude : 3,5°E). The elevation of the city is about 70 meters above sea level.

The climatic characteristics of site are:

- Year average temperature : 14.2 °C
- Minimum average temperature : 9.3 °C
- Maximum average temperature: 19.1 °C
- DJU : 1841 (base 18 °C)

Building Description

Typology/Age

The building functions primarily as a student dormitory. The four-floor building consists of two blocks (east and west) with a common stairwell (Figure 7.145). The western block is a a half-floor higher than the east. Initially, the building had 166 rooms of approximately 10 m², and collective toilets.

Figure 7.145. View of dormitories before retrofitting.

In 2001, the decision was made to retrofit the building. The initial project aimed at redistributing the internal premises of the building to increase the size of the quarters; 166 rooms of 10 m² were to be transformed into 120 studios of 15m², with a kitchen area and a toilet block (shower, washbasin, and toilets) in each studio. This retrofitting was realized using a High Environmental Quality approach (green approach in France) and according to two main objectives:

- to improve the indoor comfort of the occupants: thermal (summer and winter), visual, and acoustic
- to minimize the impact of the building on the environment, by energy and water savings.

General Information

- Year of construction : 1968
- Year of retrofitting : 2003
- Total floor area (m^2) : 2485
- Total heated floor (m^2) : 2289
- Number of housings: 166 before retrofitting and 120 (studios) after retrofitting
- Area of each housing: 10 m² before retrofitting and 15 m² after retrofitting
- Occupied hours: 12 to 13 hours every day (18h – 8/9h).

Previous Heating, Ventilation, Cooling and Lighting Systems

Before 2003, the two sources of energy were electricity and gas. Heating and domestic hot water were provided by two gas boilers (337 kW each). The central control depends on the outside temperature, and the local control was regulated by thermostatic valves on the radiators. In winter, the heat was set to 20 °C. Air ventilation is a simple ventilation flow with a renewal rate of 0.6 vol./hour.

Thermal insulation was poor due to the simple glazing as well as the non-insulated walls

(Plaster + 30 cm of raw concrete + coating). The east-west orientation of the building is unfavorable for the summer comfort; it receives the morning and evening sun (the west orientation is source of overheating late in the afternoon).

Retrofit Energy Savings Features

An outside insulation of 10 cm with a metallic cladding cover the envelop of the building (Figure 7.146). A low- emissivity double glazing is installed.

Figure 7.146. Outside insulated envelope.

Different solutions were carried out to reduce overheating:

- outside terraces with vegetation
- solar protections
- simple thermo-mechanical ventilation.

In each housing unit, artificial lighting is provided by three wall luminaries equipped with energy-saving lamps of 13 W, placed on the front door, at the entrance of the kitchen, and at the head of the bed, and by three fluorescent tubes for the desk, and two of 18 W in the bathroom and on the kitchen washbasin. The lighting power ratio is 7.5 W/m^2.

The glazed surfaces were enlarged to take advantage of natural lighting, and the inside walls in each housing were painted in white.

The acoustical insulation has been improved on circulations by means of double walls and soundproofing doors (acoustical decrease of 30 dB).

The following low energy consumption devices have been installed:

- fluorescent compact low energy consumption lamps
- lighting timer in circulations
- refrigerator with low energy consumption
- new gas boiler.

Different low-water consumption equipments have been installed:

- thermostatic mixer taps (washbasins, showers)
- ventilator system of water for washbasins

- shower heads with turbulence in showers
- toilets with a double capacity flush (3/6 liters).

This retrofit project has been the opportunity to install renewable energy techniques. Solar collectors provide energy for domestic hot water (Figure 7.147). It is an indirect type with forced circulation and external heat exchanger. There are four hot water tanks: three with 1000 liters of storage plus one with 2000 liters. Photovoltaic panels (48 modules) have been installed (Figure 7.148). The supplied electricity is directly used in the different dormitories on the university campus.

Figure 7.147. Solar collectors on the roof.

Figure 7.148. Photovoltaic panels.

Resulting energy savings

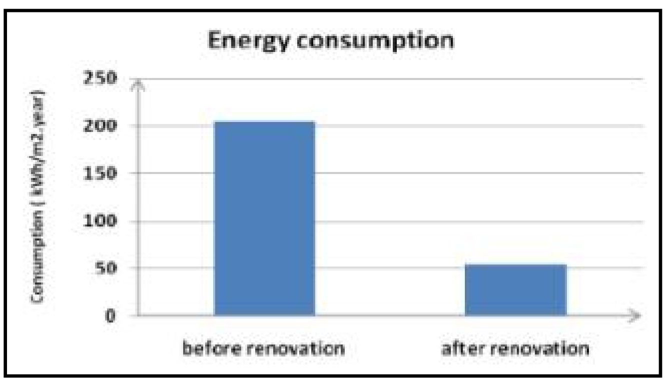

Figure 7.149. Evaluation of energy consumption.

Gas is the only source of energy for heating and production of domestic hot water. The energy consumption meters are common with all the buildings of the university campus. However, the invoices and the energy optimization of consultancy society provide consumption information. Before rehabilitation, the energy consumption of the building (for heating, hot domestic water and cooling) is estimated at 200 kWhep/m².year (where “ep” = energy primary), and after rehabilitation, 55 kWhep/m²/year (Figure 7.149). An accurate assessment of energy consumption of the building requires the implementation of metering.

User Evaluation

Some questionnaire and surveys were made in May 2008.

IAQ is qualified as “medium.” Measurements of CO_2 recorded in different studios, between 300 and 500 ppm, are satisfactory. The indoor air is never perceived as very fresh and some students noted a significant moisture in their homes. The temperature in summer is perceived by students as too warm in the building.

Students are slightly disturbed by ambient noise, especially the conversations in the neighborhood and the outside noise. The sound pressure levels was measured, inside the studio apartment, with closed windows and doors, at between 25 and 30 dB, which is satisfactory.

The light environment is often considered too dark, but fairly stable, uniform and non-glare. Lighting is generally considered average.

The indoor illumination, whether in natural or artificial light, corresponds to an average illumination. Some studios are poorly exposed, which reduces the natural lighting. Balconies and walls to be vegetated are also an obstacle to natural lighting. Students on the ground floor appear to be most bothered by the lack of lighting in their studio apartment.

Costs

Total cost :2 027 877.00 €
Total cost per studio apartment: 16 898.98 €
Financing :

- State and Region dotation: 1 640 994.00 €
- Loan (4.13%, 15 ans) : 213 000.00 €
- Subsidies (ENR, andc.): 133 466.00 €
- CROUS: 40 417 00 €

Practical Experiences of Interest for a Broader Audience

The total insulation of the envelope of the building, including outside insulation, as well as insulation of roofs and floors, significantly reduces heating needs. This architectural modifications also improves the integration of the building in its environment. This heavy renovation provides an opportunity to develop solutions using renewable energy on site: solar collectors for heating domestic water and photovoltaic panels for generating electricity.

However, the total insulation of the building without a thermal regulation strategy of the envelope (hybrid or natural ventilation, external solar protection, bioclimatic techniques) generates a risk of overheating during summer.

The vegetation of the facades and balconies helps protect the building from sunlight by the shade. It can improve the comfort of summer in the areas inhabited, but requires continuous maintenance.

The east-west building orientation makes sunscreens necessary, which will increase the need for artificial lighting in the morning and in the evening. The enlargement of windows allows a gain of natural light and heating during the winter and reduces the need for artificial lighting and heating.

The retrofitting into larger studios offers better living and working conditions for students.

The renewable energy use is presented on a bulletin board in the hall of residence. This board shows the solar energy productions and external climatic parameters. A charter of eco-living, introducing the green building approach and gestures, is also distributed to students.

The introduction of solar equipment requires a revision of energy policy and equipment maintenance, and the installation of energy sub-meters should improve the energy management of the building.

General Data

Address of project:
Cité universitaire Vert-Bois
192, rue de la Chênaie
34096 MONTPELLIER CEDEX 5

Owner: CROUS Montpellier

Contact: Laurent Larrieu

Architects: ARCHIVOLT Architecture - Véronique Bofferding & Christian Combes

Office Performing the Study: IZUBA Energies - Thierry Salomon & Stéphane Bedel

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A Retrofit for Water Conservation Using a Membrane Bioreactor

Photo

Figure 7.150. Schofield Barracks Wastewater Treatment Plant.

Project Summary

In 2004, Aqua Engineers, Hawaii's leading water and wastewater management company, entered a 50-year privatization agreement with the US Army to own, operate, and upgrade the Schofield Barracks Wastewater Treatment Plant (Figure 7.150). According to Eassie Miller, the president and Corporate Executive Officer (CEO) of Aqua Engineers, Aqua Engineers, Inc. is an employee-owned company that prides itself in protecting and preserving Hawaii's precious water resources. "The partnership with the US Army and Aqua's ownership of the Schofield Barracks wastewater system has provided our team with an opportunity to continue to meet our mission of providing excellence in water and wastewater services to meet client and community needs," Miller said.

The 3.2 MGD (12,112 m^3/d) facility's treatment processes needed to be upgraded to R-1 quality effluent for reuse while increasing plant capacity to 4.2 MGD (15,900 m^3/d) ensuring that it could cost-effectively meet ongoing regulatory demands. Aqua Engineers worked with the US Army to upgrade and expand the Schofield Barracks Wastewater Treatment facility with environmentally sustainable solutions.

Although surrounded by ocean, Hawaii suffers extreme droughts. Currently, stream flow and groundwater levels are below normal. Hawaii residents depend on aquifers and surface water for potable water supply; however, more than 70% of this water is used to irrigate farm crops, golf courses, and residential and commercial landscaping. For this reason, it is important that technologies be used to recycle water for irrigation purposes to preserve Hawaii's natural supply of drinking water.

Site

The treatment plant was located on the island of Oahu, HI and provides clean water for 28,000 military personnel and their families.

Facility Description/Typology

Typology/Age

The age of the existing treatment facility was not specified. The project was commissioned in October 2006 and took 8 months to complete.

General Information

Year of construction: not specified
Year of subject renovation: 1996–1997

Architectural Drawing:

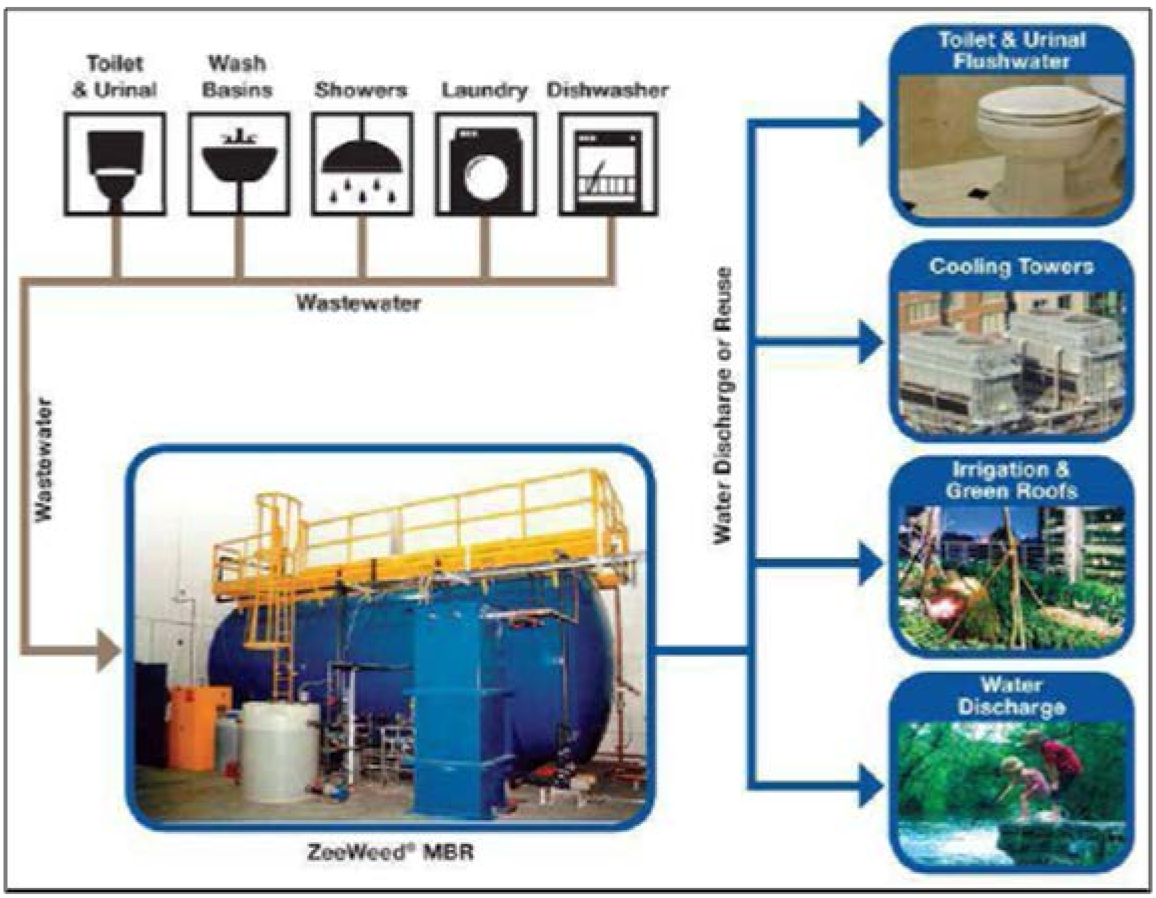

Figure 7.151. ZeeWeed membrane bioreactors (MBRs) treat all grey and black water.

Retrofit Water Savings Features

Retrofit System Description

Raw sewage, after fine screening, flows to equalization and primary clarification, then to one of four anoxic zones for denitrification, and then to the corresponding aerobic zones for nitrification. Pretreated water is distributed among four ZeeWeed immersed membrane trains, where permeate pumps draw the settled water through the membrane fiber (Figure 7.151). With a nominal pore size of 0.04 Jm, the ZeeWeed membrane acts as a physical barrier to turbidity producing an effluent with less than 0.2 Nephelometric Turbidity Units (NTU) for 95% of the time and less than 0.5 NTU 100% of the time. This meets Hawaiian R-1 water reuse requirements. Membrane fibers are automatically cleaned with a clean-in-place backpulsing process that forces permeate water back through the membranes. This dislodges any particles that may adhere to the membranes.

Aeration of the membranes is also used to scour debris from the fibers, to provide mixing within the process tank, and provide oxygen for the micro-organisms. Treated effluent is further treated with ultraviolet (UV) disinfection and will then be either discharged or reused on base. The MBR is configured to use four of the six existing aeration basins. When future expansion is required, the remaining two aeration basins can be used to provide an additional 50% capacity, increasing the plant capacity to 6.3 MGD (23,850 m3/d) within the existing space.

Water-Saving Concept

The Aqua Engineers and US Army team worked with their design engineers and General Electric (GE) Water & Process Technologies to determine the optimal method for doubling the treatment capacity of the facility while maximizing the use of the existing facility. The team recommended that the plant be retrofitted with a ZeeWeed MBR to replace the existing secondary treatment process and to produce R-1 reuse water. A ZeeWeed MBR is a biological and physical process that combines the biological treatment of wastewater contaminants in aeration basins with physical solid-liquid separation using ZeeWeed ultrafiltration membranes.

The MBR system allowed for an easy expansion of the treatment plant and provided premium recycled water to irrigate lawns, golf courses, parks, and other sites on base, positively affecting the nearly 28,000 military personnel and their families and ensuring the Army’s ability to expand their family housing and support facilities. The MBR system was commissioned in the Schofield Barracks Wastewater Treatment Plant after only 8 months of construction, on-time and on-budget, and will allow the military base to significantly reduce the consumption of municipal drinking water.

Resulting Energy Savings

GE awarded the Aqua Engineers and US Army Partnership with a 2007 Ecomagination award for outstanding environmental leadership. The award honors the partnership for its use of an innovative wastewater treatment and reuse system to reduce demand on potable water supplies and preserve the environment. By converting to an MBR system, the military base is able to save 4.2 million gallons (15,900 m^3) of municipal water per day while eliminating the excessive discharge concentrations in the effluent.

A Retrofit for Energy Conservation Using Whole Building Diagnosticians on Outside Air/Economizers at the Federal Aviation Administration (FAA) Denver Airport

Photo

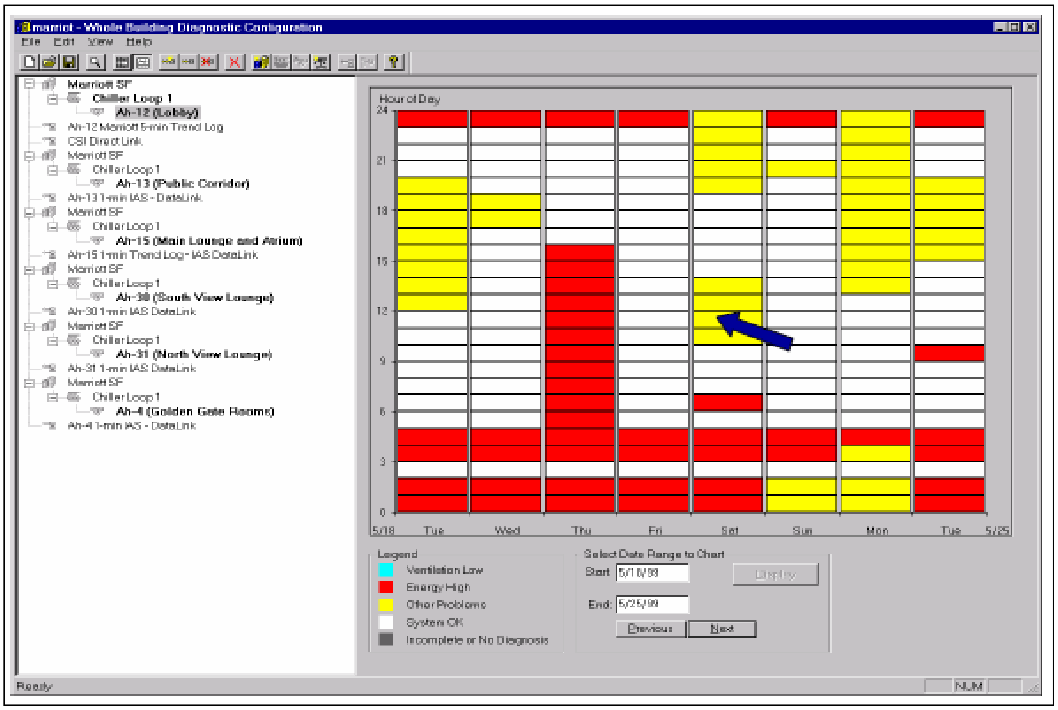

Figure 7.152. Diagnostic results color-coded to show system functioning status.

Project Summary

This project aimed to quantify the effectiveness of Whole Building Diagnosticians (WBD) at identifying operational problems in a buildings's AHU. The FAA's Denver airport was chosen to be a test location for the FEMP's New Technology Demonstration Program due to the building operator's interest and the compatibility with the building control system. The project commenced in October 1999 and the software was installed in two buildings on site. Data collection began in mid-May of 2000 on the three out of nine AHU the researchers were permitted access to.

The WBD is a modular diagnostic software system that specifically provides monitoring, detection, and diagnosis of common problems occurring in HVAC systems and equipment in buildings (Figure 7.152). It tracks and records a building's overall use, monitors the performance of AHU, as well as detects problems with the Outdoor Air/Economizer module (OA/E).

Inefficient operations were identified with all three AHU that should have been identified during the normal commissioning of the building. However, merely identifying that a problem exists does not guarantee that it will be fixed. There must be a concerted effort on the part of the building operators to be educated in using the control systems or to communicate with contractors to remedy the problems that are identified.

Site

Denver, Colorado, Denver International Airport, at 39.81N latitude, -104.67W longitude

- CDD (based on 65 F) – 984 (Denver, CO)
- HDD (based on 65 F) – 1256 (Denver, CO)

Building Description/Typology

Typology/Age

WBD equipment was installed in two buildings: the air traffic control tower (ATCT Base) and the traffic control (TRACON) building. Security concerns limited the researchers to only installing the devices to the AHU that serve general office space.

General Information

	ATCT	TRACON
Year of construction:	Not provided	Not provided
Year of renovation:	1999-2000	1999-2000
Total floor area (sq ft):	26,000	67,000
Occupant capacity:	Not provided	Not provided
Occupied hours:	Not provided	Not provided

Architectural Drawing:

Heating, Ventilation, Cooling and Lighting Systems

The OA/E module in place was manufactured by Johnson Controls Metasys. It is designed to measure seven variables at hourly increments. Figure 7.153 shows the process.

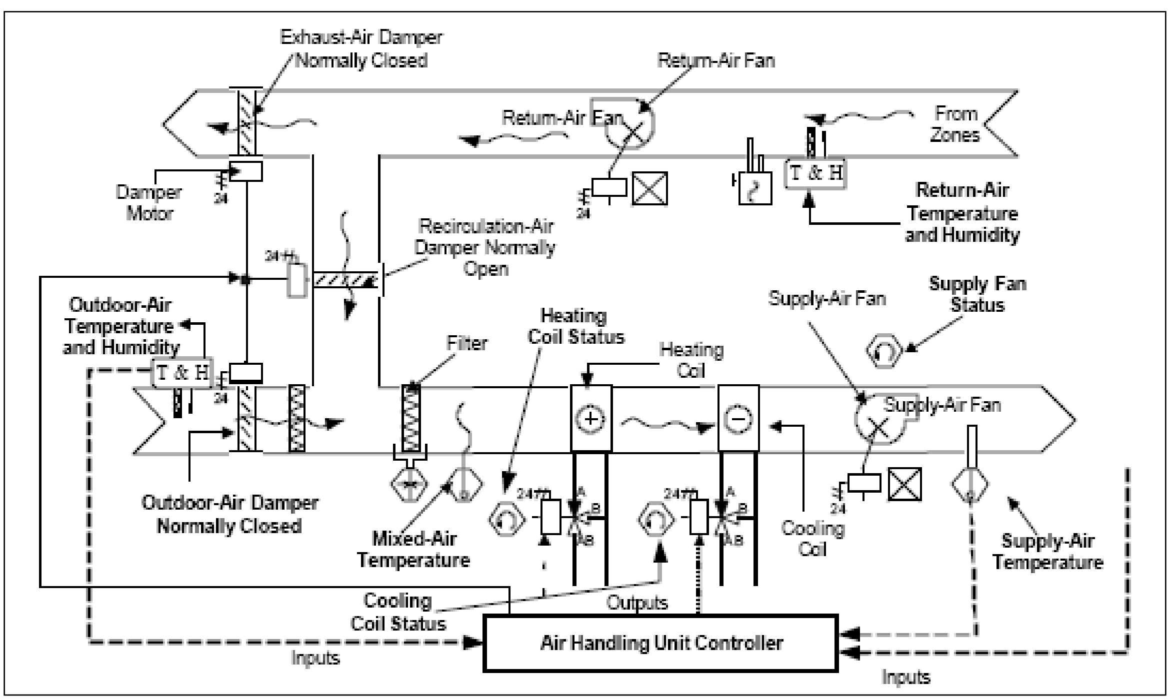

Figure 7.153. Air handler showing the sensor locations.

The heating/cooling system in ATCT Base is a 60-ton reciprocating chiller chilled water distribution VAV system with terminal gas heat from natural gas. The system in TRACON is a 200-ton centrifugal chiller chilled water distribution VAV system with terminal heat from natural gas. The lighting system did not change.

Retrofit Energy Savings Features

Retrofit System Description

The WBD was developed by the USDOE's PNNL, in conjunction with subcontractors Honeywell, Inc. and the University of Colorado. It was installed on the primary workstations using Windows 95 to monitor the ventilation system's efficiency. The OA/E module supplies the right amount of outdoor air based on day and time and provides free cool air from outside when appropriate, while not supplying excess air. The OA/E also "pre-conditions" incoming air using already conditioned and otherwise outgoing air via a heat-exchanger.

Key features of WBD technology are that it:

- provides automated detection and diagnosis of energy performance problems in commercial buildings
- includes two diagnostic modules: the Whole Building Energy (WBE) module and the Outdoor Air Economizer (OAE) diagnostic module
- uses mostly data commonly collected by Building Management Systems (BMSs)
- stores all data in a database for easy use of data from a number of sources—BMSs, analysis tools, and other databases
- presents results graphically
- allows users to hierarchically explore causes of problems and provides advice on how to fix them
- is expandable by adding new modules.

Energy-Saving Concept

The energy-saving concept demonstrated in this case study is to reduce a building's energy consumption using software known as *Whole Building Diagnosticians*. This program monitors OA/Es, which reduce energy consumption by reducing the workload on the heat pump in increasing or decreasing the temperature of the incoming air to the desired level.

Resulting Energy Savings

- TRACON AHU-1: 9,898 kWh
- TRACON AHU-2: 14,279 kWh

User Evaluation

In an exit interview with the Systems Coordinator and FAA's Energy Coordinator for the Denver International Airport facilities, he indicated that he had been the only operator to use the tool. He had checked the user interface about once a month, and correctly diagnosed the system as allowing too much outside air. This problem had not been corrected yet, which possibly indicates a lack of confidence of the FAA employees in manipulating the control strategy, or simply that they relied on the FEMP Shared Savings Energy Performance contractors to make the repairs.

Renovation Cost

Approximately $20,000

Experiences/Lessons Learned

Energy Use

To calculate savings in energy consumption, the researchers could only estimate savings for the TRACON building's two handlers, and not the ATCT handler. This was due to problems with faulty air temperature sensors being identified, but not corrected. Without the sensors being fixed in the ATCT building, it was impossible to determine what other problems would have been identified later. Due to this, the researchers had to estimate the savings potential based on hypothetical identification and correction of inefficiencies with the AHU.

In comparisons of baseline vs. ideal operations, for TRACON AHU-1 a savings of $756 could be realized, or 27%. In TRACON AHU-2, a savings of $1,755, or 36%, could be realized. These calculations are for total cooling and zone reheat combined.

Impact on IAQ

Automated commissioning and diagnostic technology improves the comfort level of building occupants by monitoring the condition of the air within (specifically) CO_2 levels, and triggering it to circulate more fresh air from outside.

Economics

The researchers estimated the annual savings to be between $750 and $1,750. For all three AHU combined, this totaled roughly $3,750/year. At this rate, the simple payback period would be 2 to 3 years if no additional capital costs are assumed. Costs for a production-mode WBD tool were estimated at around $20,000, with a resulting timeframe of payback just over 5 years.

Practical Experiences of Interest to a Broader Audience

By partnering with industry, USDOE will expedite the commercialization of this technology and put building diagnostic technology into use earlier. The WBD demonstrates that automated diagnostic technology has much potential to reduce buildings' energy consumption. It can also be deployed in several ways to ensure buildings are operated and maintained more efficiently:

- **Commissioning:** During the commissioning process, the OAE module is used to diagnose problems by processing data that is collected from AHU once they are installed and operational.
- **Operation:** The WBD could be deployed by installers or manufacturers as an embedded part of a control system, to ensure that operations staff has this tool to diagnose problems continuously and in real time.
- **On-board equipment diagnostics:** The OAE could be integrated into the control system of HVAC units. The information collected could be provided in real time, or stored for later viewing by operations staff.
- **Centralized diagnostic services and facility management:** This technology could be used at a central location by a manager of several properties to process

data from multiple buildings. This would streamline the maintenance process by reducing site visits and lowering operating costs.

Resulting Design Guidance

Solving the identified problems should be an inherent part of the project, rather than anticipating that the staff will correct them.

General Data

Address of Project:	Denver International Airport 7698 Pena Blvd. Denver, CO 80249
Existing or New Case Study:	New
Date of Report/Revision No.:	December 2002
Project Sponsor:	The USDOE's Office of Energy Efficiency and Renewable Energy (EERE) FEMP
Designer:	Honeywell Technology Center and the University of Colorado Joint Center for Energy Management
Case Study Authors:	R.G. Pratt, N. Bauman, and S. Katipamula

References

1. Pacific Northwest National Laboratory. Retrieved 19 August 2009 from the World Wide Web: http://www.buildingsystemsprogram.pnl.gov/fdd/wbd/index.stm
2. Bauman, N., Katipamula, S., & Pratt, R. 2003. "New Technology Demonstration of the Whole Building Diagnostician at the Federal Aviation Administration-Denver Airport." Pacific Northwest National Laboratory, Richland, WA.

Contact

Srinivas Katipamula, PNNL, Telephone: (509) 372-4281

Banff National Park of Canada: Reducing Energy Consumption—Helping the Environment

Background

Established in 1885, Banff National Park (Figure 7.154) is the birthplace of Canada's parks system and part of the Canadian Rocky Mountain Parks World Heritage Site. The park spans 6641 km^2 of valleys, mountains, glaciers, forests, meadows and rivers in southwest Alberta. This part of a complex chain of national, provincial and territorial parks and wilderness areas, which totals 5 million acres, has been set aside for posterity. The site is one of the world's largest protected domains.

In July 2002, Banff became the first national park in Canada to sign an energy performance contract (EPC) with an ESCO aimed at improving the energy efficiency of 88 of its buildings over 10 years. The process began in December 2000 when the Parks Canada Agency issued a RFP to improve the energy efficiency of its buildings at Banff. The Federal Buildings Initiative (FBI), a program within Natural Resources Canada's Office of Energy Efficiency, worked with Parks Canada to assess possible energy efficiency opportunities and any preliminary work required to deliver the improvements. Both parties determined that an EPC could help update Banff National Park's infrastructure and enhance the energy management practices of its operations, thereby reducing its energy and water consumption and greenhouse gas (GHG) emissions.

Figure 7.154. Banff National Park Welcome Center.

Project Highlights

Banff National Park awarded a 10-year, $506,426 comprehensive energy efficiency project to MCW Custom Energy Solutions Ltd. in 2001, and signed the EPC the following year. The construction phase of the project was completed in 2003. MCW is currently monitoring the project.

The project focused on updating 88 of the 200 buildings at the park. Each spans about 65 to 135 m^2, totaling 20 119 m^2 in floor space. Several types of buildings were retrofitted, including garages, offices, and campground washrooms.

The EPC currently generates over $72,362 in annual energy and water savings and has reduced GHG emissions by 370 tons per year (Figure 7.155). MCW has already implemented the following energy efficiency measures:

- **Lighting retrofits**. T-8 fluorescent lamps replaced inefficient T-12 fixtures. Other lighting features include LED exit signs, screw-in compact fluorescents, de-lamping, and the use of reflectors.
- **Installation of new high-efficiency refrigerators**. New refrigerators in the staff residences and garage typically operate at less than half the consumption of the old units.
- **Improvements to building envelope**. Re-caulked windows and the installation of door seals reduce air and moisture infiltration. A door interlock in the holding area in the main garage reduces uncontrolled heat loss.
- **Installation of new high-efficiency front-loading washing machines and gas dryers**. The new washing machines yield significant water and gas savings. The use of a gas dryer instead of a conventional electric dryer helps lower fuel costs.
- **Replacement of natural draft boilers with new high-efficiency condensing boilers**. The new boilers in the warden's office and the general works and trades area allow considerably lower flue gas temperatures, due to the stainless steel construction of the boiler and flue.
- **Revamping of HVAC controls**. Heating controls in the main garage now improve IAQ with the replacement of carbon dioxide sensors. Interlocking MAUs and exhaust fans, as well as programmable thermostats for all unit heaters, provide damper control to ensure summer free cooling and a controlled air supply.
- **Solar hot water collector**. A solar hot water collector on the roof of the campground shower facility helps reduce the amount of fuel needed to heat water.

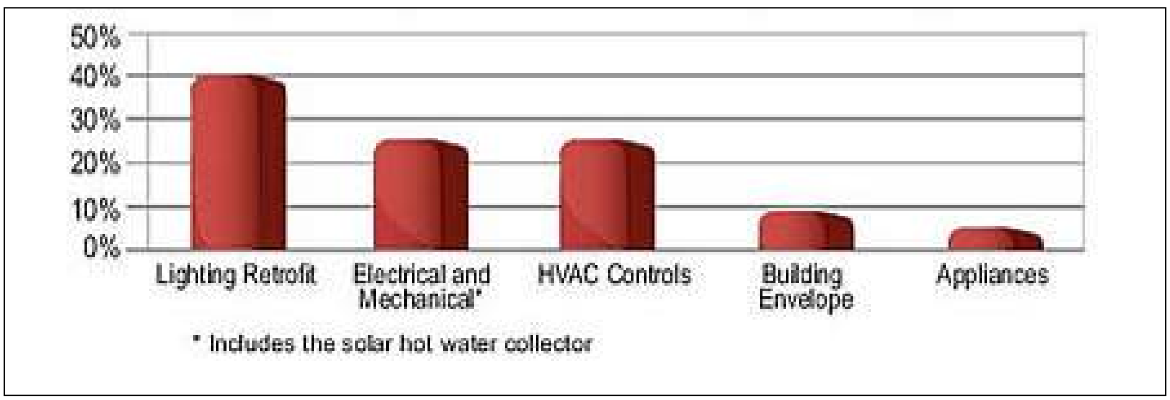

Figure 7.155. Energy efficiency measures and their projected savings.

Employee and Public Awareness

Employee Awareness

An employee awareness program helps educate and motivate building occupants. When employees know how their actions can affect energy consumption, they can directly contribute to the savings already achieved through the technical retrofits.

As part of Banff National Park's employee awareness campaign, the MCW team held a “Celebrate Success Day” in all the major buildings in the park.

MCW set up booths and invited building occupants to information sessions that explained the energy efficiency project and its measures. The sessions promoted the positive impact of the project on building operations and costs, as well as the environment.

Public Awareness

As one of the world's premier destination spots, the park boasts more than 3 million visitors a year, not including an additional 4.6 million people who travel through the park on the Trans-Canada Highway. Visitors want a chance to experience and enjoy the beauty and wildlife of the national parks, and they look to Parks Canada to demonstrate best practices in energy conservation and energy alternatives.

The high volume of visitors and their interest in environmental issues create a unique opportunity for Parks Canada to showcase new technology, promote energy conservation and highlight efforts to reduce GHG emissions and air pollution.

Banff National Park and MCW mounted information displays at major centres throughout the park to inform visitors of the importance of energy and water conservation. The displays include materials detailing the project, its conservation measures and the efforts of Banff National Park to reduce GHG emissions and help the environment.

For example, the new solar hot water collector at the campground shower facility attracts a great deal of attention and offers an opportunity to showcase a visible and low-cost renewable energy measure. Step-by-step graphics make it easy to understand how solar energy works. The display also reminds visitors that the amount of hot water is finite and their personal conservation plays a part.

Project Highlights

Now that its EPC project is complete, Banff National Park is continuing to curb energy consumption and control costs by implementing further savings opportunities, including:

- Installation of high-efficiency furnaces in all staff homes within the park. This has significantly lowered natural gas consumption
- Continued upgrades to lighting and thermostat applications with new technology, as it becomes available
- Project managers at the park are constructing a new “off-grid” washroom facility. It will use solar panels to generate all its energy for light and heat.

The Banff National Park EPC project continues to deliver environmental, financial and operational benefits. Its experience is serving as a model for the entire national parks system, which is helping Parks Canada develop a long-term plan to manage the energy efficiency and environmental impact of its buildings.

Communications Research Centre Canada – Reducing Operating Costs While Responding to Environmental Challenges

Introduction

Between 1993–94 and 1998–99, Communications Research Centre Canada (CRC) at Shirley's Bay, west of Ottawa, Ontario, reduced its energy costs by 41% and its water costs by 59%. Although the amount of serviced floor space in use and the patterns of water use varied over time, most of the savings can be attributed to a coordinated long-term plan to improve the efficiency of energy and water use through a series of well-conceived conservation measures. The step-by-step approach used by CRC to initiate and carry out its long-term plan can serve as a practical model for other organizations facing environmental challenges.

Background

It was clear by the early 1990s that the facilities at the 350-hectare CRC complex needed a mid-life retrofit. Energy and water costs were high and rising, chlorofluorocarbon (CFC) coolant had to be safely eliminated to comply with new environmental regulations, the newer buildings required extra insulation, and an aging chiller in the central heating and cooling plant was due for replacement.

Action was needed, but economic pressures had squeezed capital and maintenance budgets to a point where major building systems upgrades became difficult to finance and implement on an in-house basis. Jean-Maurice Charron, CRC's Manager of Plant Engineering Services, contacted the FBI in early 1993 for information and advice on how he could move forward. He learned that the FBI's savings-financing approach to energy and water efficiency upgrades could help him control the centre's utility bills, replace aging equipment, and improve environmental performance and energy use to reduce greenhouse gas emissions that contribute to climate change.

The Energy Performance Contract

The FBI of Natural Resources Canada's Office of Energy Efficiency advocates the use of EPCs with private sector ESCOs as a cost effective way for federal departments and agencies to reduce energy and water consumption in their facilities. Through these contracts, ESCos are retained as long-term partners who work closely with their client organizations to design and implement their projects. Typically, ESCos will:

- work with representatives of client organizations to define the goals and objectives of their projects
- gather data on current patterns of energy and water consumption
- identify savings opportunities
- draw up comprehensive project designs to take advantage of the identified savings opportunities
- arrange private sector financing for the projects
- procure and install new equipment
- train staff in operating and maintaining equipment
- monitor the resulting changes in utility use and report them back to their clients

The revenue streams generated by these projects are typically forwarded to the ESCos in payment for their work, as well as to cover the capital cost of new equipment and financing charges. Future savings are retained by the contracting federal organizations once the pre-determined values of their contracts are paid out or the terms of the contracts have expired.

A Flexible Approach to Meet Specific Needs

Mr. Charron saw that the inherent flexibility of the FBI's savings-financing option was well-suited to the CRC's needs. He formed a project team that included Nyle Belkov, Chief Operating Engineer; Ben Stach, then Head of Mechanical Engineering, and Brian Carleton, Energy Contracts Officer. He also made sure that Industry Canada – CRC's custodial department – as well as other tenant organizations were consulted.

The team invited FBI officials to visit the Shirley's Bay site and present an overview of the savings-financing approach and how it might be adapted to address CRC's specific needs. Once the team accepted that savings-financing was an approach worth pursuing, its members collaborated to identify the goals for the project and compile the goals into a briefing submission. A prerequisite for proceeding was to obtain top-level support for the project's objectives. The President of the CRC was favorably impressed by the team's preliminary proposal and informed the Minister of Industry – the federal Minister responsible for the centre – who readily supported approval to proceed.

A Key Decision: Selecting the Right ESCO

Strong top-level support for the project gave the team the mandate it needed to move forward. It used the FBI's implementation document templates to select the most suitable ESCos from the program's list of qualified bidders. By using time-tested documentation to solicit proposals from companies of proven ability, the team could direct its attention toward evaluating project-specific proposals, rather than assessing the claims and project-readiness of unknown firms.

Four firms from the FBI's qualified bidders list of ESCos were invited to perform “walkthrough” energy and water audits of CRC's facilities. Two of these firms went on to submit preliminary concept reports to the team, both emphasizing that CRC could save significant amounts of energy and water.

Staff from PWGSC and a private consultant helped develop a set of criteria to evaluate the proposals. Each member of the project team reviewed the proposals. The scores that each team member assigned to the proposals were tallied to yield composite values and final ratings.

Next, both ESCos made oral presentations on their proposals. Brian Carleton, Energy Contracts Officer, recalls the oral presentations as a useful exercise. “They were sales pitches, of course, but they provided us with a good idea of what the individuals we would be working with were like,” he says.

Honeywell Limited was selected for the contract, primarily because it was willing to invest more in the project than the other firm. On this basis, Honeywell was invited to conduct detailed baseline audits of energy and water consumption throughout CRC and facilities owned by others and to draw up a detailed energy feasibility study and concept report.

The Project

Honeywell worked with the team members to design a plan for 35 of the 70 buildings at the Shirley's Bay campus. The final plan included all of the site's major buildings, but none of the small, little-used facilities, some of which were slated for demolition.

A $3.5-million, 6.5-year-term EPC was negotiated. It was customized to include a performance guarantee premium of $249,000, as well as $224,000 in third-party finance interest charges and $330,000 in non-guaranteed extras. Honeywell guaranteed post-construction cost savings of $530,000 per year and projected that total energy consumption would decline by about 40% and water consumption by 30% once the proposed measures were fully implemented. In year three of the contract, CRC exercised its option for accelerated paydown, thereby reducing interest paid to $48,000 instead of the forecasted $224,000.

The design for the project included the following measures:

- **replacing an aging chiller in the central heating and cooling plant** (Figure 7.156) to safely eliminate environmentally harmful CFCs from the facility while sparing the centre's capital budget an upfront expense of over $100,000;
- **replacing high-pressure boilers with low-pressure boilers** to reduce nitrogen oxide (NO_x) emissions – in particular nitrogen dioxide (NO_2) and nitric oxide (NO) – in anticipation of future environmental regulations. With advanced controls automation, this measure allowed for further operational cost reductions of $245,000 annually;
- **reviewing and recalibrating cooling distribution patterns** to improve efficiency and indoor comfort;
- **upgrading chilled water line drainage** to reduce maintenance costs for the system piping and rust build-up and eliminate standing water;
- **adjusting the building system on-off scheduling** to follow patterns of actual use by employees;
- **installing energy efficient lighting**, adjusting lighting levels where appropriate and replacing outdated fluorescent fixtures with T-8 bulbs and electronic ballasts;
- **focusing on water-saving measures** by installing new water meters; Honeywell is also working with major tenants to minimize waste;
- **installing small package boiler units** in several locations to make it possible to shut down the central heating and cooling plant during the summer when heating requirements are minimal; and
- **replacing electric heaters with oil furnaces** in several small outlying buildings to reduce heating costs.

In addition, the CRC-Honeywell EPC included the following non-guaranteed extras: steam metering (Figure 7.157), cooling tower and chill water portion of the contract.

Employee Education

Formal instruction in the field of environmental systems was delivered by Seneca College of Applied Arts and Technology. In addition, Natural Resources Canada's “Dollars to $ense” energy efficiency workshops gave operations staff an opportunity to learn more about energy efficiency, specifically identifying energy savings opportunities, designing and implementing energy management plans, and monitoring and tracking.

Figure 7.156. Cooling unit at the CRC.

Figure 7.157. Steam metering at the CRC.

Training for building systems operations staff has had a positive impact on overall performance. It has also established training standards by which to upgrade capabilities and qualifications of building operators.

Project Results

From the beginning, the project has generated solid savings. Utility costs began to drop almost immediately. During the 27-month construction phase, for example, cumulative savings totaled $1.1 million. By 1998–99, the unadjusted value of energy savings was over $500,000 per year. Although the total amount of serviced floor space varied somewhat from year to year between 1993–94 and 1998–99, total annual energy consumption fell from 3.243 gigajoules per square meter (at a cost of $30.57) in 1993–94 to 1.766 gigajoules per square meter ($18.03) in 1998–99. This corresponded to a net energy savings of 46% and a dollar savings of 41%.

The impact of the water conservation component of the project was even more dramatic. Measured water consumption fell from 133 730 cubic meters (costing $200,918) in 1993–94 to 59 138 cubic meters ($81,667) in 1998–99, a volume reduction of 56% and a dollar savings of 59%. It is important to note that conservation measures alone did not fully account for the savings. By 1993–94 senior operations staff had begun to suspect that the water consumption meters were not recording actual water consumption accurately. Their suspicions were confirmed as soon as the meters were replaced; recorded consumption in 1994–95 dropped to 87 380 cubic meters ($130,118), a savings of 35%. The additional water savings that were realized through to 1998–99 are due to a range of other standard EPC-related water conservation measures, as well as complementary in-house efforts to reduce consumption.

The CRC's EPC has reduced energy and water costs dramatically and will continue to deliver lower operating costs. Several factors have contributed to the overall success of the project:

- The Manager of Plant Engineering decided at the outset to form a project team of qualified operations staff. Team members cooperated to define their energy, water and environment-related needs and expectations for the project. They also considered how the FBI's savings-financing option could be tailored to address the needs of CRC.
- Support from the federal Minister of Industry, the President of the CRC and the union gave the project team members the authority and momentum they needed to act decisively.
- Team members had developed firm ideas concerning their priorities, before qualified ESCos appeared on the scene to conduct preliminary audits and prepare initial project proposals.
- CRC recognized the importance of choosing the right ESCos. Project proposals were evaluated systematically using clear selection criteria, and onsite presentations gave the committee members an opportunity to become acquainted with the individuals who would be at the centre of their negotiated partnership.
- Tenant organization buy-in for the project has boosted its overall success. Several tenants have implemented savings measures of their own, in tandem with those put in place as part of the centre-wide project.

Improved Efficiency Can Help the Environment

The environmental benefits of the Honeywell Limited EPC have been significant. The safe elimination and ability to capture CFCs in accordance with federal policy guidelines is an important issue that was addressed by installing a new chiller, R134-A, which does not deplete the ozone layer.

As planning for the project progressed, measures to control NO_x emissions also emerged as an important environmental issue. The replacement of high-pressure boilers with low-water content units and low NO_x emissions, was an important element of the final design of the project. This measure was specifically intended to meet anticipated NO_x emissions performance guidelines.

More recently, the Government of Canada has announced ambitious greenhouse gas emissions targets from its own operations; a reduction to 31% below 1990 emissions levels will be required by 2010. Communications Research Centre compliance with the new emissions targets will be facilitated by the 46% reduction in annual energy consumption that had already been achieved between 1993–94 and 1998–99.

The building systems team of CRC has accepted the challenge of integrating evolving environmental performance guidelines into the multi-year energy and water efficiency management plans. A more proactive approach is now taken. As Brian Carleton notes, “Within the building systems group, we're now much more aware of energy-related issues and especially government decisions that might affect us down the road.”

Consolidating Savings Through Residual Opportunities

The building systems team is currently focused on taking advantage of residual opportunities; in particular, small-scale “soft” measures, which cost very little to implement, but offer significant potential for increasing savings over the long term. Soft energy efficiency measures now being put into place include installing motion sensors and Employee Awareness campaign to use computer power management features.

Community Towers Complex Case Study

Background

Located in downtown San Jose, CA, the Community Towers Complex (Figure 7.158) consists of the 10-story Great Western Bank Building and the 12-story California Commerce Bank Building, which together encompass a total of 350,000 sq ft (33,000 m^2). Both were constructed in the 1960s. In the early 1990s, while preparing to sell the complex, the owners set out to reduce their operating and maintenance costs compared to other office buildings in the downtown area to enhance the property's profitability and its attractiveness to prospective buyers. While searching for a contractor to replace a set of aging chillers, the owners heard about performance contracting and learned that they could reduce energy and maintenance costs even further through a comprehensive energy conservation retrofit. They also learned that a healthier work environment for their building tenants — including better lighting and improved IAQ — could further enhance the marketability of their building.

The owners sent out a RFPs for an energy efficiency retrofit and received three bids. Within a month of receiving the bids, the owners selected Viron Energy Service and signed a contract for the job. The contract called for Viron to provide an audit of energy use in the building, systems engineering design and construction management for the energy improvements, training of building operations staff, post-installation maintenance, and performance monitoring of the new systems.

Figure 7.158. Community Towers Complex.

The Project

Viron estimated that the buildings were using an average of 4.4 million kWh of electricity and 104,000 therms (11 TJ) of natural gas per year. Based on an assessment of the buildings' equipment, Viron recommended improvements including high-efficiency lighting, electronic controls, and conversion of air distribution systems to variable volume with digital zone control. A high-efficiency domestic water heater was also installed. Two 30-year-old, 500-ton (1800 kW) capacity centrifugal chillers were replaced with two high-efficiency, 275-ton (970 kW) capacity, CFC-free, rotary screw chillers.

While most ESPCs are based on ESCO or third-party financing, with repayment out of the customer's savings stream, in this case the building owners were able to finance the entire $1.4 million project themselves. The local gas and electric utility, through its demand side management program, provided utility rebates totaling $260,000, reducing the net cost of the project by 19%. The owners financed the project over a 7-year period with a positive cash flow.

Under its contract with Community Towers, Viron guaranteed an annual energy cost savings of $175,000, and the project resulted in $20,000 per year in maintenance savings, for a total annual savings of $195,000. To support its energy savings guarantee, Viron provides electronic monitoring through the EMS. A monthly report is sent to Community Towers indicating the actual energy cost savings relative to the guaranteed savings. As in most other contracts of this nature, if savings guarantees are not met, Viron pays the building owners the amount of the shortfall.

Results/Lessons Learned

Community Towers' owners say that they consider the contract a success. Taylor Clayton, Vice President of Boccardo Properties, enthusiastically describes the benefits of the comprehensive energy efficiency retrofit from a building owner's perspective. "I consider the energy savings as fuel for improvements to our business. The new systems, including chillers, have greatly benefited our customers. In the long and short haul this investment will help us to renew our leases and bring new customers to our buildings."

A Retrofit for Energy Conservation Using Two-Wheel Desiccant System Technology in Maryland

Photo

Figure 7.159. Engelhard/ICC TWDS rooftop unit.

Project Summary

TWDSs, Figure 7.159) are desirable because they remove moisture from the air before it enters a conditioned space, thus lowering overall humidity. The objective of this case study was to evaluate the cost effectiveness and energy conservation potential of the TWDS as it conditions the air to the appropriate comfort levels for the dining area occupants.

The desiccant system installed was manufactured by Engelhard/ICC and has a 1,600 cfm generating capacity. It was installed in 1994 as a collaboration between Engelhard/ICC, APG, and ERDC-CERL to demonstrate desiccant technology under the Army's FEAP Program. While several rooftop air-conditioning units serve the entire building, CERL elected to evaluate just the dining facility because it exhibits higher occupant density.

The performance monitoring at this site is only partial, as no historical utility billing information is available. Several variables were recorded at 15-minute data intervals from August 1994 through January 1995, including: outdoor DBT and relative humidity, process DBT and relative humidity (supply), process air flow rate, run time of the unit, regeneration air temperature, electricity consumption, and regeneration gas consumption.

Site

Aberdeen Proving Ground is located approximately 40 miles northeast of Baltimore, in the upper corner of Maryland, at 39°28'24"N latitude, 76°8'27"W longitude. this location falls within ASHRAE 90.1-2004 Climate Zone 4. Design weather data at this location is characterized by the following:

- CDD – 1403
- HDD – 4654.

Cooling Design Temperature –	
Dry Bulb Temp (°F)	Mean Coincident Wet Bulb Temp (°F)
94°	75°
Heating Design Temperature –	
Dry Bulb Temp (°F)	
10°	

Building Description/Typology

Typology/Age

The building is an Army-owned Burger King franchise that is representative of a typical fast food restaurant.

General Information

Year of construction:	Not provided
Year of renovation:	1994
Total floor area (m^2):	Not provided
Total occupant rooms area (m^2):	Not provided
Occupant capacity:	Exact number unknown, but dining room chosen for study because of highest occupant density
Number of occupant rooms:	One
Size (m^2):	Not provided
Windows/glass area (m^2):	Not provided
Occupants per room:	Not provided
Occupied hours:	24 hours every day of the week

Architectural Drawings

Previous Heating, Ventilation, Cooling and Lighting Systems

For the purposes of this case study, the only relevant systems are ventilation and AC. Initially, the dining area had two packaged rooftop units (5-ton and 7.5-ton) supplying 700 cfm of ventilation out of a total supply flow rate of 5,000 cfm. Although the peak design load matched the equipment's nominal capacity (12.5-ton) for the dining area, the components of the load (sensible and latent) did not match the equipment capacities. At the design conditions, the nominal capacity of the two units was reduced from 12.5 tons to 10.5 tons, approximately 13% below the design load, because of supply fan reheat and other losses. The total latent capacity of the units at the design conditions was also less than the required design latent capacity. This shortage was exacerbated by off-design conditions, in which the latent component of the total load did not drop off nearly as quickly as the sensible component. Because of these problems, the two packaged units were unable to dehumidify and cool the air simultaneously, frequently resulting in hot and humid conditions in the dining area. Installation of the TWDS has resulted in the latent load from ventilation and internal gains being handled efficiently. The TWDS has operated reliably as designed.

Retrofit Energy Savings Features

Retrofit System Description

The design concept was to separate the sensible (internal gains) and latent (ventilation and internal latent) cooling functions. The sensible cooling was handled by the existing rooftop unit and the latent cooling was accomplished by installing a new TWDS, which replaced an existing 5-ton rooftop unit. By separating the cooling functions, the effectiveness of the conventional vapor compression system and the desiccant-based system was maximized.

The TWDS combines a rotary desiccant wheel with a high-effectiveness rotary heat-exchanger wheel. This combination transfers some of the “sensible penalty” associated with the desiccant wheel over to the regeneration air stream. The unit uses a propane-fired steam boiler for the remainder of the regeneration heat, which is housed within the desiccant unit.

There are four possible operating modes for desiccant systems: recirculation, pure ventilation, makeup, and mixed. However, for this study, the TWDS was operated in makeup mode (Figure 7.160), which means that the source of both process and regeneration air is outdoors. The outside air is passed through the desiccant wheel where it is dehumidified and then cooled as it passes through the sensible heat-wheel (Figure 7.161). The warm dry air is directed to the conditioned space by its own concentric diffuser at ceiling level, and the return air is cooled by the existing 7.5-ton packaged rooftop unit. Dry air from the TWDS and the cool air streams only mix inside the dining area.

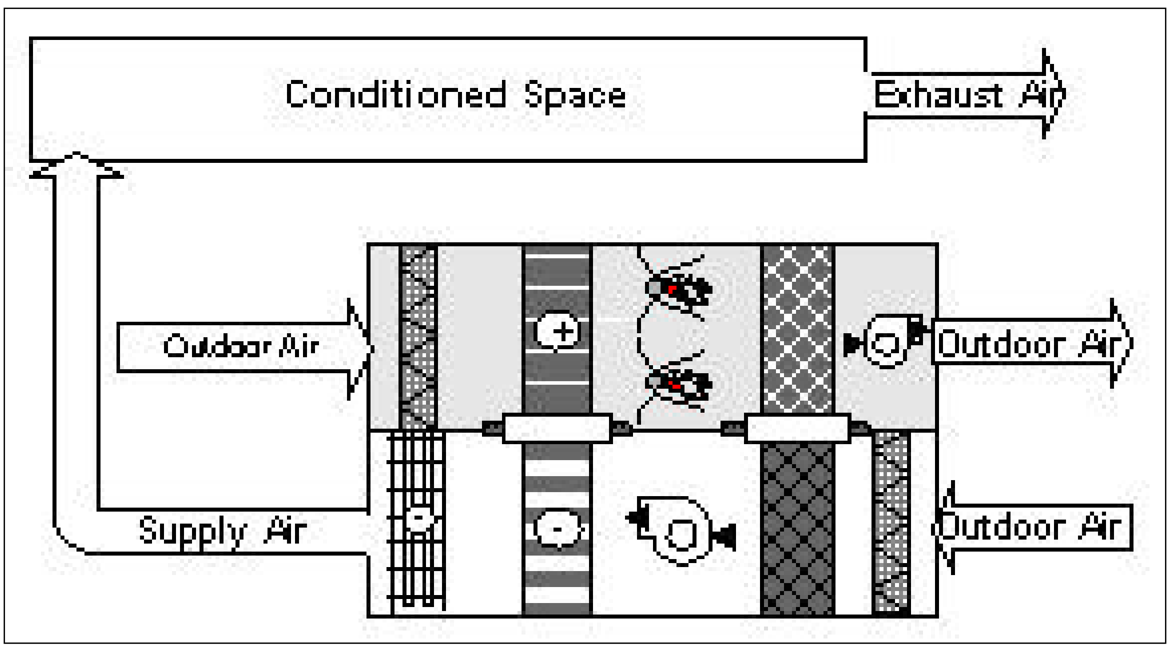

Figure 7.160. Makeup operating mode.

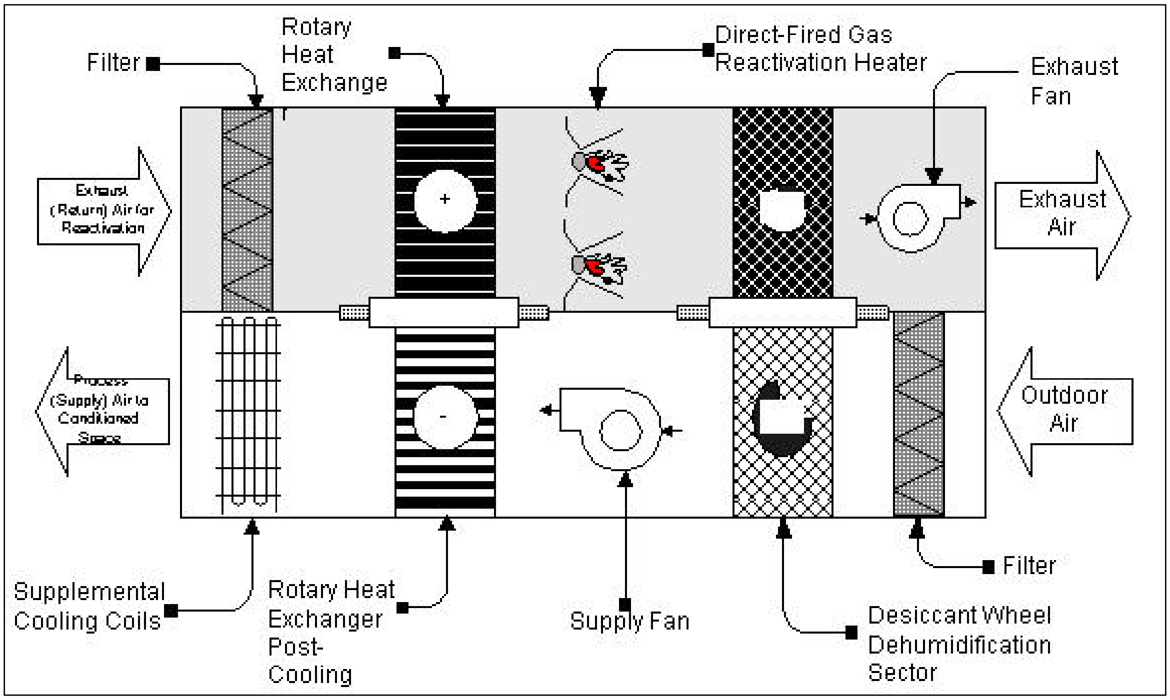

Figure 7.161. Schematic of the two-wheel desiccant system.

<u>Energy Saving Concept</u>

A small increase in local emissions will occur, because of the use of a fossil fuel- (gas or propane) fired heater for regeneration. However, there will also be a decrease in utility emissions, because of reduced electric energy use. Desiccant systems reduce the cooling load on the conventional system; therefore, smaller conventional systems can be used, reducing the use of ozone-depleting chlorofluorocarbons (CFCs).

<u>Building</u>

The primary improvement is better management of humidity and a more comfortable environment.

<u>Heating</u>

The existing 5-ton rooftop unit was replaced with a new 1600 cfm TWDS to work in tandem as a hybrid system with an existing 7.5-ton air-conditioning unit.

Resulting Energy Savings

Energy savings could not be measured, as there was no historical data. Simulation models, such as DOE2, must be used to compare TWDS with conventional systems.

User Evaluation

Improvements in operating conditions were immediately noticed by the restaurant employees and customers.

Renovation Cost

The first cost of a desiccant system is higher than that of a conventional system. To offset this disadvantage, innovative designs using hybrid systems are often required. The 1,600-cfm TWDS (without additional vapor compression cooling) was installed at a cost of between $5/cfm and $8/cfm.

Experiences/Lessons Learned

Energy Use

The daily average electric demand was around 4 kW, and the daily average gas consumption was around 30 cu ft/h. The gas consumption in winter reflects the nighttime heating energy consumption.

Impact on Indoor Climate

Air quality is greatly improved, in addition to reducing operating costs, as it is less humid and thus more comfortable.

Economics

Desiccant systems are sized based on airflow rate, or cfm, and so costs are usually given in $/cfm. For large projects, the typical cost can be estimated at $5/cfm, while on smaller projects (less than 1,000 cfm) it can cost up to $8/cfm. The installation costs can vary based on differing site requirements; for example, if installing a hybrid system, the vapor compression system is an additional cost.

Although the desiccant technology has been employed for several decades, its use was limited to industrial and military sectors. The market potential in those sectors was estimated to be between $50 and $60 million in the early 1990s (Mei and al. 1992). No concrete estimates are available either for the commercial buildings sector or for the Federal sector because wider applications of the technology are only now being investigated.

Practical Experiences of Interest to a Broader Audience

TWDS technology has much potential in the Federal sector to reduce operating cost, while simultaneously improving IAQ, but the main impediments to use of these systems are lack of familiarity, assurance, and education about these benefits. The technology is especially useful for conditioning storage spaces, ice arenas that operate in summer, hospital operating rooms and most supermarkets. In a situation where the existing conventional system is unable to provide sufficient latent cooling capacity, a TWDS can be integrated with the existing system. In such a situation, the first cost usually favors a TWDS over a conventional system. It is usually not economical to install a desiccant system in situations where the design space dew point requirement is higher than 50 °F, or where the latent to total capacity ratio is less than 25%.

Resulting Design Guidance

The desiccant systems are generally designed for outdoor installation. Most commercial desiccant systems are mounted on rooftops. The units are installed on concrete pads located as close as possible to the gas and electrical interfaces. If the desiccant unit is equipped with an evaporative cooler, it will need water supply. In some large systems, a communication point may be needed to remotely monitor the unit's operation. Clearance may not be an issue for rooftop-mounted units; units installed in enclosed spaces must have sufficient side access clearance for maintenance.

General Data

Address of Project

Aberdeen Proving Ground, MD

Existing or New Case Study

New

Date of Report/Revision No.

April 1997

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The Army's FEAP Program

Designer

The TWDS was manufactured by Engelhard/ICC

General Contractor

Aberdeen Proving Ground and USACERL

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USDOE–FEMP Super ESPC Program

Background

The USDOE's FEMP Program created the Super ESPC program to reduce the time and effort required for Federal agencies to award ESPC contracts at Federal agency facilities. FEMP awarded indefinite-delivery, indefinite-quantity (IDIQ) contracts to selected ESCOs using a process that fulfilled the competition requirements of the Federal Acquisition Regulations (FAR). To set up ESPC projects for their facilities, agencies award delivery orders to the pre-selected Super ESPC ESCOs.

Super ESPC project development is carried out in four phases. In Phase 1, an ESCO and an agency explore opportunities for energy savings through informal communications, meetings, and exchange of information. If the potential for a project exists, the ESCO develops an initial proposal, which is the goal of Phase 2. The initial proposal is based on a preliminary survey of the site and includes a description of proposed ECMs and estimates of energy and cost savings. The agency reviews the initial proposal and decides whether or not to proceed.

If the initial proposal is acceptable, development proceeds to Phase 3. The agency transmits a letter confirming its intention to award the delivery order to the ESCO and issues a delivery order RFP. In response, the contractor performs a detailed energy survey and submits a report that describes the basis for the project's contractually guaranteed savings. The detailed energy survey is the ESCO's comprehensive audit of facilities and energy systems at the project site. The detailed energy survey augments, refines, and updates the preliminary site survey data and provides the information needed to update the feasibility analyses of the ECMs under consideration for the project. The agency's project team reviews the proposal and submits its comments to the ESCO. Based on these comments and further negotiation, the ESCO develops a final proposal. This is a fixed-price proposal for installation of the ECMs, and usually includes performance of ongoing services such as measurement and verification (M&V) and operations and maintenance. Phase 4 of the development process entails construction, commissioning, and agency acceptance of the ECMs.

The performance period begins after the agency formally accepts the completed project. In the United States, most agencies of the Federal government are funded by the US Congress through the budget process and are prohibited from issuing their own debt. For this reason, the ESCO obtains the financing required to fund project construction. During the performance period, the agency pays the ESCO from the savings that are generated by the ECMs. The ESCO uses this payment to repay the lender and to fund the performance-period services called for by the contract.

Federal regulations require that the savings from Super ESPCs exceed their costs in each year of the contract, and the ESCO must guarantee a level of annual cost savings that is sufficient to pay for the debt service and any performance-period services under the contract. M&V is also required, and at least once a year, the ESCO produces an M&V report detailing the results of a program of measurements, inspections, engineering calculations, and comparisons with energy baselines, carried out to estimate the level of savings being delivered by the installed equipment. If the savings do not meet the guarantees, the agency can withhold payments to the ESCO up to the level of the shortfall.

A key element of the Super ESPC program is the use of project facilitators, who assist the agency in the contract development process. FEMP project facilitators are objective, expert consultants for technical, financial, and contractual issues who help to optimize the financial value of ESPC projects. Use of a project facilitator is mandatory for those who use USDOE's Super ESPCs. Up to the notice of intent to award (end of Phase 2) FEMP provides project facilitation free of charge; further services through the first year of the performance period are available on a reimbursable basis.

Since the program began in 1998, more than $700 million in conservation projects have been funded through the use of Super ESPCs, saving the Federal government an estimated $1.6 billion in energy and energy-related costs.

A Typical Project

An example of a recent Super ESPC project is the one being implemented by Johnson Controls, Inc. for the National Archives and Records Administration (NARA). The project involves the Lyndon B. Johnson Library in College Station, TX, and the Gerald R. Ford Library in Ann Arbor, MI. The ECMs in this project are:

- Gerald R. Ford Library
  - Boiler replacement
  - EMCS upgrade
  - VAV conversion
  - Energy efficient lighting upgrade
  - Variable-frequency-drive electric motors
- Lyndon B. Johnson Library:
  - Chilled water and hot water systems improvements
  - Energy mangement control system upgrade
  - Airflow improvements
  - HVAC system upgrades
  - Energy efficient lighting upgrade.

The total implementation price of $4.3 million dollars (which is very nearly equal to the program average of $4.7 million) is financed for 20 years at 6.2% interest. The project is expected to save 1.4 million kWh of electricity, 3300 MBtu of natural gas and 23,000 MBtu of steam each year. The total estimated cost savings in the first year of the performance period is $498,000. Based on analysis of previous years' utility bills, it was agreed to escalate this amount by 2.9% per year. Of the estimated savings, the ESCO guarantees 75%, and each year NARA pays the ESCO one dollar less than the guaranteed savings.

In addition to debt service, payments to the ESCO fund performance-period services costing $65,000 per year (escalating at the same rate as the guaranteed savings) of which about 40% is for M&V, 43% is for operations and maintenance, and 17% is for management and administration.

Measurement & Verification

M&V for the project is mostly based on FEMP's Option D, which is calibrated simulation. During project development, Johnson Controls used building energy analysis software to develop pre-retrofit models of the libraries' energy use as a function of weather, occupancy, and other parameters. The models were calibrated using utility bills from the two sites. The retrofit technologies were then implemented in software and used to predict post-retrofit energy use and the energy savings. Each year, Johnson Controls performs a series of measurements on the installed equipment (for example, flue gas analyzers are used to measure boiler efficiency, and power meters are used to measure the draw of motors installed on fans and pumps). A report is prepared to show that the efficiency and power use of the installed equipment is the same (within measurement error) as the values used to estimate post-retrofit energy use.

NARA is just one of the 18 agencies of the US Federal government that have used the Super ESPC contract to implement energy conservation projects at their facilities. Since 1998, more than 130 Super ESPC contracts have been awarded.

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Employee Awareness and the FBI

Background

The FBI, a voluntary program developed and administered by Natural Resources Canada's Office of Energy Efficiency, offers a model framework for updating Federal facilities with energy-saving technologies and practices. The goal of the FBI is to help Federal government departments and agencies improve the energy efficiency of their facilities and to reduce greenhouse gas emissions in response to the challenge of climate change.

The main feature of the FBI model is an innovative contractual arrangement – the EPC – between a pre-qualified energy management services company and a Federal government department or organization. Through this arrangement, the full cost of energy efficiency improvements can be financed by the guaranteed energy savings resulting from the improvements rather than by using capital budgets.

The lower energy bills that result from the improvements are paid to the utility, and an amount equivalent to the energy savings is paid to the energy management services company until the cost of the energy efficiency improvements is recovered. From then on, the Federal department or organization will benefit from the full amount of the savings.

Under an EPC, an energy management services company provides technical and non-technical assistance to the client organization. This may include project design and engineering, supplying and installing new equipment, providing savings guarantees, organizing project financing (if required), training for building operators, and designing an awareness program for employees or building occupants. Ideally, all measures are implemented to deliver the greatest energy savings in the least amount of time.

Although technical components such as lighting and EMCSs generate the largest portion of the energy savings, employee awareness initiatives can yield substantial additional savings. The greater the energy savings from all sources, the sooner project costs will be paid back.

Employee Awareness

An employee awareness program provides employees and/or building occupants with prompt and precise information on how energy resources are used in the workplace and how employees' actions can directly affect energy consumption. By changing employees' attitudes and behavior, it is possible to significantly reduce energy use and contribute to the savings achieved through technical measures.

Simple actions — such as turning off lights, computers and printers, installing insulation and weatherstripping, keeping the pressures of compressed air systems at their correct settings, ensuring that filters on heating and cooling coils are clean and dust-free, and maintaining expensive equipment at peak efficiency — all contribute to reduced energy use and energy costs in the workplace.

A FBI employee awareness program should aim to:

- promote the FBI energy efficiency project within the workplace
- encourage employee commitment and participation in the project

- promote the benefits of energy-saving technologies and practices in the workplace, at home and on the road.

Successful employee awareness initiatives are implemented over a period of time. The following have proven effective in generating interest and enthusiasm for improved energy efficiency and additional savings:
- newsletters
- fact sheets
- e-mail messages
- electronic signs
- energy awareness days or weeks
- stickers and buttons
- videos and screen savers
- logos.

Experience has shown that even a standalone employee awareness program has the potential to generate significant savings at low cost, provided it is well run. The employee awareness program at Canadian Forces Base Halifax, for example, initially cost $20,000 per year and was expected to generate savings of $50,000 per year. In fact, savings due to EPC retrofits and the base's energy awareness program have exceeded original estimates by 20%. The current annual savings from all energy efficiency measures at Canadian Forces Base Halifax is now $1.9 million.

Employee Awareness in Action—Success Stories

Many Federal government departments have implemented extensive and successful employee awareness programs as part of their energy efficiency projects.

Industry Canada's Communications Research Centre, Ottawa

Industry Canada's EPC for the Shirleys Bay Communications Research Centre has resulted in estimated savings of $600,000 per year, at least a part of which can be attributed to the Centre's employee awareness program. Organizers focused on five strategies to deliver the message: (1) advertising, (2) education, (3) information, (4) employee involvement, and (5) response to employee feedback. The program's main objective was to keep employees constantly updated and informed on the progress of the Centre's energy efficiency improvement project.

One of the more innovative aspects of the Centre's employee awareness program was the presentation of an onsite workshop that allowed staff members to see for themselves how energy savings were being achieved. Energy experts demonstrated how new technologies such as energy efficient light fixtures and ballasts save energy in comparison to old technologies, such as conventional fluorescent light fixtures.

Other elements of the employee awareness program included posters, energy information and awareness days (as well as newsletters and employee e-mail), al of which were particularly instrumental in keeping employees up to date on the progress of the energy efficiency improvements.

Employee input, an essential component of the program and the FBI project, was promoted through open-line communications, a survey, and a contest, to solicit staff suggestions.

Employee participation and response to employee feedback are both required to make an employee awareness program work. According to site project director Jean-Maurice Charron, “Both the savings and awards that were received as a result of their hard work generated much-needed publicity and put the project on the map.”

Canadian Forces Base Halifax, Nova Scotia

One of the most successful employee awareness programs was developed and implemented by Canadian Forces Base Halifax. The information tools used included a travelling project-information booth, fact sheets, project-savings charts, a logo to promote saving energy, refrigerator magnets, posters, newsletters, Base newspaper articles, a video, lunchtime information sessions, an “Energy Ideas” contest, and a telephone hotline to answer employees' questions concerning the energy performance project.

During the construction phase of the retrofit project, employees were constantly updated on changes being made to their buildings. According to Rose Collicott, the Formation Construction Engineering Environmental Officer who managed the awareness program, “you have to bombard employees with information from numerous sources to get the message across.”

At Canadian Forces Base Halifax annual events are held to provide everyone an opportunity to learn what individuals can do to help reduce energy and water consumption. For example, each year several events are held during Environment Week to generate awareness of energy- and water conservation opportunities, including a kickoff luncheon and family-day celebrations, a newsletter that outlines ways to save water at work and at home, and a “Wise Use of Water” contest that awards prizes to individuals who submit the best water conservation tips.

Canadian Forces Base Halifax's annual Energy Awareness Week is held in November and features several activities to promote saving energy, including information luncheons, energy-saving ideas contests, posters, and a travelling information booth.

Environment Canada's Canada Centre for Inland Waters, Burlington, Ontario

The Canada Centre for Inland Waters is a research complex run by Environment Canada's National Water Research Institute. Environment Canada's Wastewater Technology Centre and the Department of Fisheries and Oceans also operate out of the complex.

An EPC was used to refit and revamp the HVAC systems and to install energy efficient lights and water-saving measures throughout the facility.

One of the most interesting aspects of this project was the interest generated by employees of the three organizations. In fact, when the first general orientation meeting was held to review the project with Canadian Centre for Inland Waters employees, more than three-quarters of the employees showed up, many of them asking questions and making suggestions for increasing energy efficiency in the buildings.

Although the Canadian Centre for Inland Waters coordinated its energy awareness program with an existing “go green” initiative already in place, the employee awareness program developed at Canadian Centre for Inland Waters was at least partly based on Natural Resources Canada's energy awareness publication, *A Manager's Guide to*

Creating Awareness in Energy Efficiency. Over the course of several months, the Canadian Centre for Inland Waters used many of the ideas outlined in this publication, including posters, tent cards and calendars.

One of the most innovative ideas of the employee awareness program came from Canadian Centre for Inland Waters itself. To attract attention to the project, a computer was set up in the main lobby area to show employees the current monthly energy savings compared to the energy costs before the EPC and employee awareness program were initiated. The computer was set up to get people to believe in the EPC and back it up. With savings of more than $900,000 per year, it is clear that this has been achieved with a great deal of success.

Canadian Forces Base Gagetown, Oromocto, New Brunswick

Canadian Forces Base Gagetown is another base that has successfully implemented an employee awareness program as part of an EPC. Using the slogan “Aiming at Energy Efficiency – Be Part of It!” the program aims to educate all base personnel on the importance of energy efficiency and what they can do to help reduce energy consumption.

Canadian Forces Base Gagetown used a variety of tools, including a billboard announcing the energy efficiency program to all visitors, a calendar with energy tips, and dates for energy awareness activities, and regular e-mail messages to employees. An Energy Awareness Week was also held.

ESPC Implementation at Fort Polk, LA

Background

Fort Polk is a 200,000-acre (81,000-ha) US Army base in West-Central Louisiana near the town of Leesville (Figure 7.162). As of the early 1990s, the base contained 4003 permanent family housing units in 1290 separate buildings. Constructed in nine phases between 1972 and 1988, most buildings were townhouses comprising two to six attached units. The majority were heated and cooled by minimum-efficiency electric heat pumps, while about 20% used minimum-efficiency electric central air-conditioning and natural-gas-fired furnaces. The base had outsourced the maintenance of this equipment, much of which was nearing the end of its useful life, to a series of private contractors, but by 1993 the high numbers of service calls had overwhelmed several contractors' budgets and their capabilities to provide acceptable service to the tenants.

Faced with the requirements of Executive Order 12902, which called for a 30% reduction in energy use by 2005 relative to 1985 consumption in, and with much of its space conditioning equipment nearing the end of its useful life, Fort Polk's family housing was in need of major renovation. With no prospect for the large appropriation needed to install new equipment, Fort Polk chose to implement an ESPC. With the assistance of the Army's Center of Excellence for Performance Contracting (US Army Engineering and Support Center in Huntsville, AL), a feasibility study was performed and a RFPs developed. The RFP conveyed a preference for the use of GSHPs. An agreement was negotiated based on the one bid received from CEG.

Figure 7.162. Entry to Folk Polk, LA.

The Contract

The contract between the Army and the ESCO was a *shared-savings* type of performance contract. It called for CEG to replace the heating and air-conditioning in all 4003 of the family housing units with GSHPs and other ECMs in return for a share of the resulting energy and maintenance cost savings over a 20-year period. CEG would install $18.9 million worth of equipment in the residences and would also be responsible for maintenance, repair, and replacement of the installed equipment over the life of the contract.

Co-Energy began installing GSHPs with a total capacity of about 6600 tons, or 23,200 kW, and corresponding vertical bore heat exchangers in 1995. In most units, a hot gas desuperheater was installed on the heat pumps to supplement hot water heating. Indoor and outdoor light fixtures were converted to use CFLs, and some fixtures were delamped altogether. Low-flow shower heads were installed in each residence, and ceiling insulation was added in some upstairs units.

Site

Fort Polk is a 200,000-acre (81,000-ha) US Army base in West-Central Louisiana near the town of Leesville. As of the early 1990s, the base contained 4003 permanent family housing units in 1290 separate buildings. Constructed in nine phases between 1972 and 1988, most buildings were townhouses comprising two to six attached units.

Measurement and Verification

As originally awarded, the contract called for using M&V Option C, which is utility meter billing analysis (IPMVP 1999). The objective was to determine savings by comparing actual monthly energy use with historical use, with savings valued at the actual blended rate charged by the utility.

The contract contained a formula for the baseline monthly electricity consumption in kWh as a function of total degree days (defined as the sum of monthly base-65 °F heating and base-65 °F CDD). Based on regression of about 5 years of historical billing data for all areas of Fort Polk (including non-residential areas) with total degree days, this formula was used to predict the monthly electricity consumption that would have occurred if the retrofits had not been installed. In each month, the ESCO's payment for electricity savings was determined as follows:

- The number of base-65 °F heating and CDD in the previous month (as measured at the weather station at Fort Polk's airfield) was summed to determine the number of total degree days.
- The number of total degree days was substituted into the regression formula to determine the baseline electricity consumption.
- The actual electricity consumption (as determined from that month's utility bill) was subtracted from the baseline electricity consumption to determine the number of kWh saved for the month.
- The number of kWh saved was multiplied by the blended electricity rate (total electricity cost divided by total kWh consumed, according to that month's utility bill) to determine the electricity cost savings.
- The electricity cost savings was multiplied by a percentage to determine the ESCO's share of the monthly electricity cost savings. The schedule for the ESCO's share began at 80% in the first year of the contract, rose to 90% by year three, and declined thereafter to 65% by year 20. Overall, the ESCO was to have received 77.5% of the electricity cost savings.

A similar procedure was used to determine gas savings.

Since the ESCO was assuming responsibility for maintenance and repair of the installed equipment, Fort Polk would no longer have to pay a private maintenance contractor. This maintenance savings was shared with the ESCO as well. Based on what it had been paying the maintenance contractor, Fort Polk calculated its per-residence maintenance cost. This cost was inflated each year along with the consumer price index to calculate the maintenance cost savings. Similar to the schedule for energy savings, the ESCO received a share of the maintenance savings that began at 80% in the first year of the contract, rose to 90% by year three, and declined thereafter to 65% by year 20. Overall, the ESCO was to receive 77.5% of the maintenance cost savings.

The contract included no provision for savings shortfalls. The ESCO was to be paid according to actual energy savings as determined from the regression formula and the monthly bills using current-month energy rates.

Project Results

The Fort Polk ESPC was the subject of an extensive evaluation performed by Oak Ridge National Laboratory (Hughes and Shonder 1998). The conservation measures were shown to reduce electrical energy use by 25.8 million kWh per year, which is 32.5% of the electrical energy previously used in family housing. Peak electricity demand in a typical year was reduced by 7.55 MW, which is 43.5% of the pre-retrofit peak demand. In addition, the project reduced natural gas consumption by 260,000 therms (27 TJ). All savings figures are normalized to a Typical Meteorological Year (TMY) at the site.

Although the conservation measures performed as expected, as time went on the contract itself was found to have a number of limitations. One problem discovered during initial stages of construction was the requirement for a summer indoor design temperature of 78 °F (26 °C) and a winter indoor design temperature of 68 °F (20 °C). While not too far outside the norm, many Americans would find such setpoints to be uncomfortable. However, in accordance with this requirement, the ESCO installed thermostats that did not allow these setpoints to be exceeded. When tenants began complaining that their residences were too cold in the winter and too warm in the summer, base personnel installed ceiling fans in some of the residences. These of course used additional electrical energy and reduced the savings from the retrofits. Eventually, Fort Polk requested that the ESCO replace the non-adjustable thermostats with conventional adjustable ones. This decision also reduced the electricity savings from the project.

The M&V plan for the Fort Polk project was designed to estimate the actual gas and electricity savings as accurately as possible by comparing actual monthly energy use against pre-retrofit energy use as calculated, per calendar month, by regression analysis of 5 years' pre-retrofit energy use data. The savings were then to be valued at the actual prices paid for gas and electricity. While such attention to accuracy may seem like a good idea, there are drawbacks to this approach. In an ESPC of this type, the ESCO obtains private financing to purchase and install the conservation measures. The payments from the site to the ESCO are based on actual monthly energy savings, which depends on the weather. Because the GSHPs are more efficient than the equipment that was replaced, the longer the GSHPs operate (to heat or cool the residences) the more energy is saved. Conversely, in relatively mild weather when less heating and cooling is required, energy savings are reduced. In their shared-savings agreement with Fort Polk, the ESCO assumed the risk that mild weather would reduce energy savings and the site's payments, and therefore increased the risk that the contract would not yield sufficient income to make the loan payments to the financier.

Another drawback of the Fort Polk contract was the use of the current blended electricity rate to value the savings and determine the payments to the ESCO. Under this arrangement, the ESCO assumed the risk that payments from the site would be reduced if electricity prices fell.

Today, shared-energy-savings contracts are rare because of the effort required to determine energy and cost savings monthly, and also because these contracts represent a high degree of uncertainty and risk to the ESCO. ESCOs and ESPC customers have generally agreed since then that sharing the weather and energy price risks is a better deal for both parties than forcing the ESCO to take those risks and price them into the contract. In most ESPC contracts today, the site assumes the risk for both weather and energy prices, and the ESCO guarantees a level of savings sufficient to pay off the financing for the project in a timeframe that is acceptable to the customer. Energy savings are calculated on the basis of a TMY, and energy prices are assumed to escalate throughout the contract term at a fixed rate that is negotiated by the site and the ESCO. Payments are generally fixed, increasing annually according to the negotiated rate of energy price escalation.

Valuing electricity savings at the blended rate (i.e., the total monthly cost divided by the number of kWh consumed) also tends to underestimate the true value of the savings, because blended rates are always lower than marginal rates — the rates that are effective at the highest level of energy consumption, where the savings actually occur. In the case of Fort Polk, the retrofits significantly lowered peak demand as well as overall usage. Without the usual peak demand charges, the blended monthly electricity rate severely undervalued the cost savings.

As it turned out, a few years after the ESPC was awarded, it was modified to correct these problems. Energy savings were calculated based on a TMY, with constant electricity and gas savings (one-twelfth of the annual amounts) assumed each month. Energy rates for calculating cost savings were adjusted to make them closer to the marginal rates and were escalated at a constant rate through the rest of the contract term.

In 2003, in keeping with privatization efforts being made throughout the US Department of Defense, the Army privatized Fort Polk's family housing. The Fort Polk ESPC was liquidated, and Co-Energy was paid an amount sufficient to pay its creditors.

Reference

Hughes, P. J., and J. A. Shonder.1998. *The Evaluation of a 4000-Home Geothermal Heat Pump Retrofit at Fort Polk, Louisiana: Final Report.* Oak Ridge National Laboratory, Oak Ridge, TN, Report No. ORNL/CON-460, March 1998.

Morgan County, CO, School District Re-3

Background

Fort Morgan is a city of 11,000 in northeast Colorado about 80 miles from Denver. The local school district consists of eight schools that serve a total of 3000 students. In 2001, faced with high operating costs and a growing maintenance backlog, but lacking the funding required to perform needed equipment upgrades, the district chose to implement its first ESPC. The state of Colorado encourages public entities to use performance contracting and provides technical and contracting assistance through its Rebuild Colorado program. Using this assistance, the school district developed a RFPs and sent it out for bid. A proposal submitted by Ennovate, an ESCO in suburban Denver, was selected over two other proposals received.

The Project

Ennovate developed a list of 41 proposed ECMs with final pricing and energy cost savings. The list was placed in a spreadsheet, allowing the school district to select or reject options to customize the financial and technical performance of the project. All pricing was open-book, and the school was able to review equipment, labor, project management, engineering, and overhead costs, as well as other pricing details. The ECMs to be installed were selected based on a combination of the district's facility improvement needs, the overall cost savings, and project cash flow.

Among the conservation measures included in the project were:

- Lighting upgrades, including T-8 lamps, occupancy sensors, and new fixtures in underlit classrooms and gyms
- Variable-speed drives on hot and chilled water pumps
- Replacement of aging boilers with condensing boilers
- Replacement of single-pane, steel-frame windows with double pane, low-emissivity windows
- Instantaneous-demand hot water heaters
- Replacement of electric cooking equipment with natural-gas-fired cooking equipment
- Radiant gas heating systems in gymnasiums and workshops
- A district-wide, internet-accessible HVAC control system.

Construction began in June 2002 and was completed in June 2003. The total cost was $2.5 million, which was financed by the district through a lease-purchase agreement with a term of 12 years. Finance charges will add about $725,000 over that period.

Measurement and Verification

First-year savings from the project were estimated at $360,000 comprising $257,000 in gas and electricity costs, $53,000 in operational savings, and $50,000 in capital cost avoidance. Ennovate verifies the electric and gas savings only.

During project development, calibrated baseline formulas were developed to predict hourly gas and electricity use in each school based on occupancy and outside air temperature. To measure savings, gas and electric meters at each school are read electronically once per hour. Baseline energy use is also calculated in each hour, and energy savings is defined as the difference between the baseline and the meter readings. To calculate cost savings, year-one energy prices are assumed to escalate by 3% per year. Ennovate reports energy and cost savings to the district in monthly e-mails and makes a formal energy savings reconciliation presentation to the school board each year.

In accordance with Colorado statutes that pertain to performance contracting with local governments, if Ennovate falls short of its guaranteed savings for any given year as determined by the M&V process described above, it must pay the school district the amount of its shortfall for that year.

Results and Lessons Learned

According to district officials, the overall experience with the performance contract has been positive. To date, the equipment has performed as advertised, and the guaranteed savings have been delivered. Were the need to arise, the district would definitely consider another performance contract, although some thought that installing all of the equipment in 1 year (the majority during just one summer) caused too much disruption. School district officials stated that in the future they would stage the installation of the ECMs over several years.

References

Colorado Governor's Office of Energy Management and Conservation. *Commercial & Institutional Energy Programs*. Web page, http://www.state.co.us/oemc/programs/commercial/index.htm

Middle Tennessee State University

Background

Located in Murfreesboro about 30 miles southeast of Nashville, Middle Tennessee State University (MTSU, Figure 7.163) serves more than 22,000 students, awarding undergraduate and graduate degrees in a variety of academic areas including Business Administration, Fine Arts, Music, Science, Nursing, and Social Work. The campus consists of 109 buildings on a 466-acre (189-ha) site. As one of the 45 educational institutions governed by the Tennessee Board of Regents, MTSU receives funding for maintenance and capital improvements from the operating budget of the State of Tennessee.

Figure 7.163. Entry to Middle Tennessee State University.

By 1999, rapid growth in enrollment, a growing backlog of deferred maintenance, and the declining availability of state funding led the university to seek alternative methods to upgrade its aging facilities. Recognizing the potential of using energy cost savings to fund improvements to its energy infrastructure, the university established the Center for Energy Efficiency, which worked with the Tennessee Board of Regents to establish a program to allow self-funding of energy conservation projects.

The Project

In December 2001, after evaluating proposals from a number of ESCOs, MTSU awarded Siemens Building Technologies an ESPC with an ordering capacity of $10 million. To date, approximately $8.2 million of that capacity has been exercised. Completed projects include lighting upgrades in 1.5 million sq ft (139,000 m^2) of building space, installation of a 10-MW backup generator (which allowed the university to switch to a lower-priced interruptible electric rate), HVAC retrofits, controls adjustments, and installation of vending misers on campus vending machines. Total savings from the conservation measures installed to date are estimated to be about $900,000. Projects have been financed with Tennessee State School Bond Authority (TSSBA) bonds that have a maturity of 15 years.

Overall, MTSU officials have been satisfied both with the project and the process. The equipment is performing well, and MTSU believes they are receiving the savings that were projected.

Lessons Learned

Given the success of the MTSU program, the Tennessee Board of Regents developed a vehicle to allow other universities in its system to use ESPCs to fund energy conservation projects. In 2003, the Tennessee Board of Regents awarded three blanket ESPCs, one for each of the three main geographical regions of Tennessee (East, Middle, and West). The program is modeled on the USDOE FEMP Super ESPC — an IDIQ contract was awarded to a single ESCO in each region, and institutions implement projects by issuing delivery orders against the IDIQ for their particular regions.

As in the USDOE Super ESPC program, the project implementation process begins with a kickoff meeting between a regional ESCO and an acquisition team for the customer in that region. The institution presents its list of needed improvements and supplies the ESCO with an inventory of energy-related equipment, building areas, descriptions of EMSs and procedures, utility billing records, and other needed information. The ESCO makes a preliminary site survey and uses the information gathered to develop an initial proposal. The initial proposal contains a summary of the potential scope of work, a list of ECMs, preliminary estimates of project costs and annual energy and maintenance savings, a subcontracting plan, and a preliminary project schedule.

After reviewing the initial proposal, the institution negotiates with the ESCO to further refine the scope of the project. When the institution is satisfied with the proposal, the ESCO performs a detailed energy survey. The detailed energy survey entails the collection of detailed information about the facilities and their operation needed to define the final project scope, construction costs, and energy and cost savings.

Information collected for the detailed energy survey is used to develop a final proposal, which provides the detailed project scope and cost proposal. The final proposal also includes detailed calculations of the energy and energy-related cost savings that will result from the project. On award, the final proposal becomes a contract in which the ESCO agrees to provide design and installation of the ECMs for a fixed price. Unlike the ESPCs awarded under the FEMP program, ESCOs in Tennessee Board of Regents contracts usually make no guarantees of performance beyond what is covered under equipment warrantees. According to Joe Whitefield, director of the Center for Energy Efficiency, the Tennessee Board of Regents views the contract primarily as a funding vehicle, with energy conservation as a secondary benefit. For this reason, the program does not place much emphasis on M&V of savings. The institution is expected to assess the validity of the energy savings projections in the final proposal prior to contract award. The Center for Energy Efficiency at MTSU provides assistance to other universities in making these assessments.

Another major difference from FEMP's Super ESPC program is that ESPCs awarded under the Tennessee Board of Regents program are self-funded using bonds issued on behalf of the institutions TSSBA. Aside from warrantees, the ESCO's role in the project essentially ends when the conservation measures are installed and accepted by the institution. ESCOs may also perform operations and maintenance on the installed equipment, but this would be done under a separate contract.

References

Center for Energy Efficiency at Middle Tennessee State University. Web page, http://cee.web.mtsu.edu/

The National Research Council of Canada: Energy Efficiency Pioneer

Background

The National Research Council, Canada's most comprehensive science and engineering research organization, has earned an international reputation for excellence. It has also been honored as a pioneer in the efficient use of energy, winning eight awards over the past 11 years.

The nature of its operations makes the National Research Council a heavy consumer of energy. Wind tunnels, compressors, exhausters, ventilators, environmental chambers, clean rooms, lasers and magnets all use large amounts of electricity. So, in the late 1980s, as hydro rates went up and budget allocations went down, the Council faced an energy crisis. It had to find a way to update its facilities to conserve energy, but could not afford the necessary improvements.

The National Research Council (Figure 7.164) collaborated with Natural Resources Canada and found a way – energy performance contracting. This relatively new method of implementing energy efficiency improvements did not require an upfront investment. Hence, the National Research Council became the first federal organization to enter into an energy management agreement with a private sector firm.

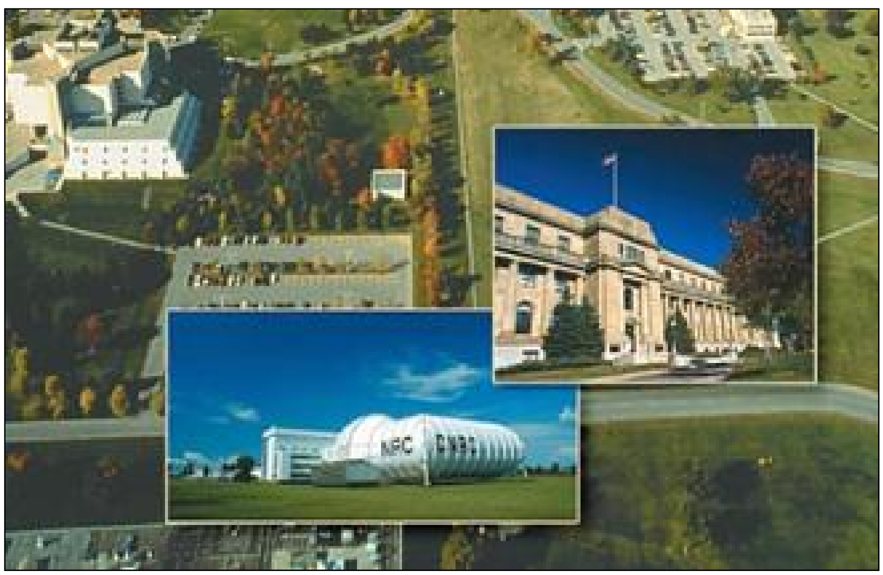

Figure 7.164. Canada's National Research Council.

In 1989 the Council signed a 5-year, $1.6-million contract with Rose Technology Group Limited (RTG) (now Vestar). Under the terms of the contract, the National Research Council did not have to put up any money. Instead, the ESCO would finance the needed improvements and later recoup its investment from the resultant savings in energy.

The project focused on four buildings with a total floor space of 61 000 m^2 (657 000 sq ft). As part of its service, RTG first conducted an energy audit. By reviewing 3 years of utility bills (adjusting for weather and occupancy) before undertaking the retrofit, the company established an energy use baseline for the buildings.

The most important improvements involved installing a centralized EMCS, improving the lighting in buildings and retrofitting AHUs. RTG, in collaboration with project manager

Subash Vohra, specified and commissioned all the new equipment and trained National Research Council staff in its use.

Mr. Vohra, Director General of the Council's Administrative Services and Property Management Branch, says he was intrigued by the concept, but was not sure if the arrangement would work. He now describes it as a “smashing success.” The improvements led to savings of $400,000 a year, and the project had paid for itself even before the contract expired. For his leadership in the initiative, Mr. Vohra received the first Canada's Energy Efficiency Award.

Building on Success

Today, the National Research Council occupies three sites in the National Capital Region: the Montreal Road Campus, the Uplands Campus and 100 Sussex Drive. These locations include 80 buildings with a total floor area that exceeds 232 250 m^2 (2.5 million sq ft). Many of these buildings were constructed 50 to 60 years ago, when energy costs were very low and conservation was not a priority.

“As custodians responsible for these facilities, these days we have to do more with less and less,” explains Mr. Vohra. “Given current fiscal restraints, we must maximize value for money in service delivery by continually reviewing operations and exploring cost effective ways to cool, heat, and ventilate.” When the Council hired a full-time energy management engineer in 1991, Mr. Vohra told him: “Your salary will come from the energy savings.”

Since its first successful project in 1989, the National Research Council has undertaken a dozen other energy efficiency initiatives. These projects have been self-financed, undertaken with financial incentives from utilities, or achieved through EPCs using third-party financing.

The National Research Council has since financed many successful projects through EPCs.

- The Council installed a 4.5-megawatt gas turbine cogeneration unit at the Montreal Road campus for $6.7 million, with a $1-million incentive from Ontario Hydro. The unit's heat-recovery boiler generates steam that is used for heating in winter and, with an absorption chiller, cooling in summer. The $1 million saved in energy costs each year means that the price of the project was paid for in less that 6 years. Mr. Vohra received an award from Treasury Board for this exemplary contribution to the National Research Council and the Federal Real Property Community.
- In response to the rising cost of purchasing steam from an outside supplier, Honeywell converted the heating systems in four buildings at the Uplands Campus from steam to gas-fired hot water boilers. The $286,000 project saved $120,000 in its first year of operation and paid for itself in less than 3 years.
- One innovative project took advantage of pipes that had been installed specifically to supply chilled water for cooling in the summer. Now, in the winter, a new pump recycles water through a cooling loop and harnesses the winter cold, providing condenser water for three five-ton refrigeration units. An added bonus is saving 57 liters (15 gallons) of city water per minute for an annual saving of more than $11,000. The project was paid for in less than 2 years.
- One project made possible through a contract with RTG and an incentive from Ontario Hydro retrofitted 14 000 light fixtures in four Ottawa buildings and

upgraded air-handling systems in one of them. The annual savings of $295,000 cover a payback period of 5.2 years.

The National Research Council has also used energy management service contracts in its regional facilities. For example, Johnson Controls Ltd. upgraded the HVAC systems at the Council's facilities in St. John's, Newfoundland. As well, Siemens Building Technologies, Ltd. completed a HVAC and lighting upgrade project in facilities in Halifax, Nova Scotia. Both projects have 5-year payback periods.

Through these and other energy efficiency improvements, the National Research Council now saves more than $2.25 million a year in energy bills. “Searching for new projects that will save energy and costs is an ongoing business at the National Research Council,” says Mr. Vohra, “and we are confident that, with the help of third-party financing, we can achieve more with no upfront costs. At the same time, this will also help us reduce greenhouse gas emissions.”

Incentive and Inspiration

Mr. Vohra says that energy performance contracting has made a big difference to the National Research Council. “If this incentive had not been there, we wouldn't have even thought of those projects. The biggest advantage is that it is a source of capital that we didn't have before.”

The FBI has also been a source of ideas. “It has actually given me food for thought and made me realize that there are a lot of places where we could save energy,” says Mr. Vohra. He learns from working with private energy service companies. “When their role in a particular project is over, I can apply the same energy-saving principles to other buildings.”

The Canada Centre for Inland Waters—Building on Success

Background

Figure 7.165. Canada's National Water Research Institute.

Environment Canada's National Water Research Institute (NWRI, Figure 7.165) is Canada's pre-eminent freshwater research facility. One of NWRI's two main centers, the Canada Centre for Inland Waters (CCIW), is home to a successful FBI energy efficiency improvement project. Located on the shore of Lake Ontario in Burlington, Ontario, CCIW is one of the world's leading water research centers. The CCIW complex consists of six interconnected buildings, most built in the early 1970s, with a total of almost 50 000 m^2 of floor space.

An energy efficiency retrofit of CCIW was first proposed in 1993, in response to the pressing need to control energy costs, upgrade equipment and installations, and reduce the environmental impact of operations. At that time, about 50% of CCIW's total annual operating and maintenance costs were being spent on electricity, gas and water – totaling $1.5 million a year.

Faced with the challenge of maximizing operational efficiencies, Dave Gamache, NWRI's Manager of Building and Property Technical Services at CCIW, contacted the FBI, a voluntary program of Natural Resources Canada's (NRCan's) Office of Energy Efficiency.

The FBI of NRCan's Office of Energy Efficiency aims at improving energy efficiency, cutting your organization's energy costs and reducing greenhouse gas (GHG) emissions that contribute to climate change. This initiative offers a comprehensive approach for improving the energy and water efficiency of Federally owned buildings. It enables Federal organizations to use savings from energy efficiency measures to finance the capital costs of building upgrades, retrofits and installations. This savings-financing approach for undertaking energy and water efficiency improvements is referred to as energy performance contracting.

The Energy Performance Contract

In 1995, following a competitive tendering process involving five ESCOs pre-qualified by the FBI, CCIW awarded an EPC to Rose Technology (now Cinergy Solutions – Demand Ltd.). The successful ESCO developed its proposal into a detailed feasibility study that outlined the efficiency measures and improvements that would produce the guaranteed energy savings.

Upon acceptance of the feasibility study, the energy savings were put into place. In addition to new equipment and improved technology, CCIW began benefiting immediately from an improved building environment, reduced maintenance, lower emissions from laboratories and access to recapitalization funding. Heightened employee awareness of energy use and efficiency resulted from the creation of a “Go Green” committee and an e-mail exchange forum. Energy management training was provided to upgrade the skills of building operators and improve the technical performance of the project.

Project Results

In May 2003, the energy performance component of the project ended. The project cost of $7.5 million was paid out of realized energy savings, exceeding original projections for the seven-year efficiency retrofit program. With $9.1 million in total savings, the project also reduced greenhouse gas (GHG) emissions by 6700 tons per year.

The following measures helped the project realize significant energy savings and associated benefits:

- An 800-kilowatt cogeneration unit and a waste-heat-fired boiler were installed in the central plant to improve efficiency and permit main boiler shutdown in the summer months.
- A thorough upgrade to the HVAC system resulted in improved monitoring capabilities, upgraded laboratory airflow, improved pressurization standards and temperature control, reduced heat loss, lower maintenance costs and improved occupant comfort.
- Installation of T-8 fluorescent tubes and electronic ballasts, “white light” metal halide units, high-efficiency exit signs, lighting control switches and occupancy sensors were among the many electrical retrofit measures.
- Installation of fume hoods with nighttime setback capabilities reduced emissions and improved the safety of operations.
- In addition to the energy efficiency measures, a waste audit led to the implementation of wet/dry recycling.

Even though research activity has increased at CCIW since the project started, energy consumption has fallen almost 15% from baseline levels, and water consumption has dropped 33% (Figure 7.166).

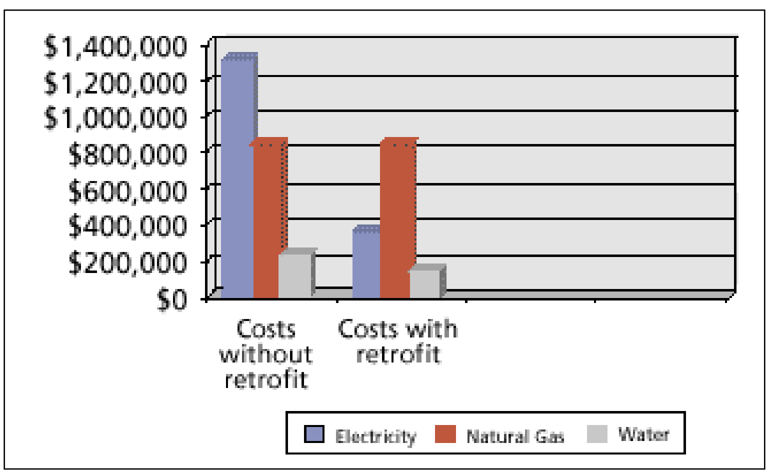

Figure 7.166. Energy retrofits reduce energy costs.

For the year 2000, the actual costs for electricity, natural gas and water at CCIW are shown on the right. Figure 2 shows the estimated costs for energy and water are illustrated on the left without the efficiency measures being implemented.

Looking back over the experience, Dave Gamache says, “This project demonstrates that environmental improvements to building operations can generate substantial economic savings as well.” As each stage of the project was completed, further potential savings emerged. The initial project was just the first step to new and innovative energy efficiencies.

Since project implementation, new measures have included the construction of a “summer steam line,” allowing the facility to shut the boilers off and to run on a waste heat boiler for the summer months. As well, they installed two solar walls to preheat incoming air, a photovoltaics system to generate electricity, and a living wall. (A living wall is an air biofilter that removes and treats airborne contaminants that can contribute to low-level, negative health effects, such as headaches, asthma, drowsiness and malaise.) The living wall also offers a pleasing environment for employees who can now enjoy its beauty and fragrance and the sounds of trickling water.

NWRI intends to build on its success with the CCIW project and is now looking at more ways to save money and improve energy efficiency. Among the possibilities being considered are the naturalization of the grounds and the retrofit of the boiler plant to further increase efficiency and reduce GHG emissions.

The Royal Canadian Mounted Police Training Academy: Partnering for Energy Efficiency Opportunities

Background

The Royal Canadian Mounted Police (RCMP) Depot Division in Regina, Saskatchewan, is the main Training Academy for the RCMP. The primary objective of the Academy is to train cadets and law enforcement professionals. Also located on the site is “F” Division Headquarters, which provides policing services for the province. With historic associations dating back to its legendary frontier days, the Depot Division is truly the “home” of the force.

Following a RFP in May of 2002, the RCMP received and evaluated four Proposals from pre-qualified ESCOs to provide energy and water efficiency improvements at the Training Academy as part of a savings-financing arrangement under the FBI.

In 2003, the RCMP signed an EPC with Vestar (now Optimira Energy Ltd.) to design, manage, construct, finance and guarantee the results of their energy efficiency retrofit. The project was prompted by the success of the RCMP “D” Division Headquarters project in Winnipeg, Manitoba, where $90,000 in annual savings had been realized through energy upgrades and water efficiency measures.

As the RCMP's largest energy consumer, the Training Academy offered a significant opportunity for reducing energy and water consumption and greenhouse gas (GHG) emissions.

The Project

The Training Academy's 10-year, $4.6-million EPC was signed in August 2003. Of the 49 buildings at the site, 35 have been included in the EPC. Several different types of buildings have been refurbished – garage, laboratory, medical, mess, office, pool, residence and recreational. Each one presented a different energy use intensity, pattern and savings opportunity.

Due to the comprehensive nature of the energy efficiency project, savings at the Training Academy have been broad-based. Direct annual energy and water savings have reached an estimated $460,000 and GHG emissions have been reduced by about 7800 tons of CO_2 equivalents per year. Natural gas consumption has been cut by 1.5 million m^3 per year. Purchased electricity has decreased by an annual 4.3 million kWh. Water conservation measures have led to a drop in water consumption of 37 000 m^3 per year. Due to infrastructure renewal and the installation of new technologies, maintenance costs have also decreased considerably.

After an extensive analysis and energy audit of the site, the ESCOs identified several measures applicable to the buildings selected, including:

- Replacing standard efficiency motors used on various mechanical and electrical equipment with new, high-efficiency electric motors
- Installing carbon monoxide sensors to modulate garage exhaust fan systems for optimum control
- Insulating all steam valves with special insulation jackets to reduce heat dissipation and reduce overall gas consumption costs

- Updating the lighting system to T-8 fluorescent lamps and electronic ballasts, which will provide a 35% reduction in energy use while improving light quality and occupant comfort
- Installing an override system for a paint shop ventilation system so occupants can adjust the exhaust system during periods of intensive use, and adjust to low flow during periods when fumes do not accumulate
- Installing a VFD on the swimming pool circulation pump to reduce overall electrical consumption during off hours.

As well as traditional energy and water efficiency measures, the project included a number of emerging technologies.

Solar Walls

Solar walls have been installed for combustion air in the Central Heating Plant and at the Firing Range.

Solar walls can provide heated ventilation air for buildings. They operate by drawing air through a cavity formed by the solar wall. Because the wall is metal, it can absorb a significant amount of heat from the sun. This heat, in turn, is transferred to the cool makeup air passing through the metal chamber, preheating the air prior to introduction to the ventilation unit.

Preheating of outside air provides a savings opportunity in reduced steam consumption and associated gas usage.

Firing Range: Schedule Optimization and Heat Recovery

The Firing Range at the Training Academy is used intensively, with the makeup air unit and exhaust fan running from 12 to 14 hours per day, Monday through Friday. Regardless of occupancy, which varies throughout the week, the makeup air unit and fan exhaust is always operational. The makeup air and fan exhaust is used to ensure that lead vapors in the air do not migrate into the shooting area. Makeup air is provided at the shooting end and exhaust air is drawn from the Range at the target end. This supplies fresh air to the occupants. To save on gas consumption, the ESCO installed a glycol coil in the makeup air unit to allow for heat recovery. Energy from the warm exhaust air is applied to the cold makeup air, preheating the air so that supplemental heat used to raise the air to room temperature is reduced. In addition, air drawn through the solar wall located on the south face of the building is preheated prior to entry to the ventilation system. The installation of an occupancy sensor also ensures that the makeup air unit and the fan system are only operational when the area is occupied. These measures have cut gas consumption at the Firing Range by 50%.

Low Consumption Plumbing

The water conservation measures at the Training Academy include the replacement of water closets in all buildings, except those built in the 1990s, with 6-liter fixtures. All wall-mounted urinals have been replaced with new “waterless” urinals. This fixture functions touch-free, is odorless, uses no water, and has been found to be very acceptable to clients. Floor-mounted urinals with flush valves have been refitted with new 3.7-liter flush valves. Faucets have been equipped with anti-drip, anti-siphon, low-flow aerators. Existing shower heads have been replaced with low-flow units. There has been considerable impact on overall savings as a result of the project's water conservation measures. Water in the City of Regina is an especially valuable resource and as such is very costly. Retrofitting the plumbing fixtures throughout the complex has led to a significant decrease in water consumption. The low consumption plumbing has also helped reduce fuel costs for domestic hot water and has lowered overall maintenance costs.

Project Success

Early Planning

Early planning is a critical component of any effective and successful energy efficiency project. It is paramount to managing change, and it also ensures that challenges or obstacles can be met quickly and efficiently. This requires a regular examination of plans and targets, and an ongoing focus on the measures and opportunities being put in place.

From the outset, the Training Academy's Project Team coordinated their efforts and began outlining some of their goals and objectives. In other words, they detailed what they expected from the energy efficiency project in terms of their energy, water, and environmental needs.

Early planning proved a useful tool for the Project Team when the ESCOs first toured the buildings, at the RFP stage. According to Karen Dupuis, Manager of Sustainable Development at the RCMP, Northwest Region, the ESCOs were “very responsive to our needs. They had an opportunity to consult with knowledgeable staff. This consultation not only helped in initiating an inclusive relationship, but really lent to buy-in from staff who have been directly affected by any proposed changes.”

The preliminary audit allowed the ESCOs to gather needed information and data for their proposal preparation. With help from staff, the ESCOs also identified the energy needs of the organization. This, in turn, reinforced staff support as it gave them the opportunity to become involved in the retrofit project, while exposing them to the ESCO personnel. Early planning and involvement by the Project Team also proved critical once the successful ESCO was selected.

Since the Project Team had a good understanding of their energy management situation, they were able to begin working in a collaborative fashion with the ESCO from the outset. This helped cement a strong relationship between parties during the design and construction phase. With a good understanding of project goals and objectives, the Project Team could easily identify with the measures being implemented by the ESCO.

With open communication and a mutual understanding of the goals and needs of the organization, both parties were better able to share in the responsibilities and tasks of project implementation. As well, they were more responsive when adapting to changes during the life of the project.

Flexibility of the EPC

In the original proposal, the ESCO had planned for the installation of an 800-kW reciprocating cogeneration unit, complete with a high-pressure steam waste heat boiler. The unit would have provided domestic hot water for the Central Training Facility, the Pool Building and the RCMP “F” Division headquartered nearby. Once a detailed analysis of the cogeneration measures was finalized, however, both parties concluded that the expected added value of the unit would not justify the extra costs to the project. Because cogeneration is always a large, complex measure, it may not be economically viable in every situation. Although the cogeneration measure did not proceed, the strength of the ESCO and client relationship allowed the RCMP and the ESCO to adapt to the changing needs of the retrofit project. Both parties are now investigating new energy efficiency opportunities for the facilities at the Training Academy.

A key benefit of an EPC is that, as a service contract, measures can be updated and changed to best suit the client's needs. As prices and technologies evolve, measures that were, at first, not feasible can later be introduced into the project. Throughout project planning and development, and continuing into the contract, the overall viability of measures must be determined.

For the RCMP, the flexibility of the EPC will allow them to select energy measures that will benefit the Training Academy and reduce energy costs. For example, they are currently considering the replacement of steam absorption chillers at the forensics laboratory with high-efficiency electric chillers.

Continued efforts to implement energy efficiency measures throughout the project will further improve the efficiency of facilities at the Training Academy, and will lead to an increased reduction in energy and water costs and GHG emissions.

The Royal Canadian Mint: Improving Energy Performance

Background

The Royal Canadian Mint (Figure 7.169) is the Crown corporation responsible for minting and distributing Canada's circulation coins. It also designs and manufactures collector, commemorative, and gold bullion coins, as well as customized medals and tokens for customers across Canada and around the world.

Figure 7.167. The Royal Canadian Mint.

With headquarters in Ottawa, Ontario, where it designs the coins, and a production facility in Winnipeg, Manitoba, the Mint employs over 450 people in all aspects of coin design, production and marketing.

In the fall of 2003, the Mint recognized an opportunity to improve the energy performance of its historic building on Sussex Drive in Ottawa, which it has occupied since its founding in 1908. It concluded that, by using energy and water more efficiently, it could substantially reduce operating costs and lower greenhouse gas (GHG) emissions that contribute to climate change.

In addition, by introducing energy efficient design elements, including new systems and equipment, the retrofit would improve the building's air quality, creating a healthier and more comfortable work environment for employees.

In January 2004, the Mint issued a RFP for energy efficiency improvements to its facility. By March of that year, representatives of the Mint began to evaluate proposals from four ESCOs, which were pre-qualified under the FBI.

The Project

The project was underway in the fall of 2003 when the Mint began working with the FBI to develop an energy efficiency opportunity assessment. An opportunity assessment considers the age and maintenance characteristics of buildings, provides an overview of their energy systems and reviews energy and water consumption. Like an energy audit, the assessment offers clients technical data and analyses, possible energy savings opportunities and preliminary savings estimates.

A critical first step, the opportunity assessment helped the Mint to determine whether an EPC would be beneficial. It also ensured that the project would be of market value to the pre-qualified ESCO.

Once the Mint was identified as a candidate for an EPC, the project team, which would work closely with the ESCO, began outlining some of the energy efficiency goals and objectives of the retrofit. This early planning allowed the project team to identify the issues facing the Mint, including inefficiencies in water and energy use and high operating costs. It also laid some of the groundwork that would later help in selecting the ESCO for the project.

The project team identified the following goals for the project:

- improve energy efficiency in the facility
- reduce the facility's operating and maintenance costs
- reduce GHG emissions
- create a healthier, more comfortable workenvironment for employees.

Careful planning and preparation before selecting an ESCO can make the difference between choosing a “good” ESCO and the “right” ESCO for the job. As a long-term partner, the ESCO must work closely with the organization to plan the project, implement the recommended measures and monitor the resulting changes in energy and water use. After carefully reviewing proposals from the four ESCOs, the Mint selected Siemens Building Technologies Ltd. to implement the project. Siemens was chosen because its scope of work was innovative and dealt extensively with converting costly maintenance improvements into significant savings. As Dr. Albert Maringer, President and CEO of Siemens Canada Ltd., explained, “It was our goal to provide the most innovative solutions to reduce future energy costs and provide a new infrastructure program that will reduce overall maintenance requirements at the Mint.”

Once the ESCO was selected, the process of preparing a detailed feasibility study and negotiating the final contract was underway. On March 24, 2005, the Mint and Siemens Building Technologies Ltd. finalized and signed the EPC.

Project Scope and Implementation

The proposed total costs of the energy efficiency improvements at the Mint are estimated at $8 million. Potential cost savings are estimated to reach as high as $1 million annually. The project's design integrates a variety of systems, technologies, practices and programs, including the following energy efficiency measures:

- Installation of new chillers and boilers in response to the rising cost of purchasing steam from an outside supplier. The feasibility study conducted by Siemens concluded that the installation of new chillers and boilers in the facility would be the most economical solution for the Mint.

- Replacement of aging air compressors with new energy efficient ones to increase the reliability of operations and lower maintenance costs.
- Installation of two new supply-air units with VAV terminal boxes to replace old fan coils. The VAV system varies the amount of air delivered to ensure workspace conditions are maintained. The system also substantially lowers energy and maintenance costs.
- Modernization of the filtration unit in the Mint's process operation to increase water filtration capacity and reduce energy use.

Work to implement the energy efficiency improvements began in January 2005. During the construction period, the Mint and Siemens worked together to ensure that all project components were implemented seamlessly and that the Mint would benefit from the energy management solutions being integrated. Because of the Mint's manufacturing environment (Figures 7.168 and 7.169), care was taken to avoid shutting down the production process.

Figure 7.168. Coin inspection at the Royal Canadian Mint.

Figure 7.169. Coin stamp operation at the Royal Canadian Mint.

Sullivan County, TN, School District

Background

In 1999, officials from the Sullivan County School District attended a seminar at Middle Tennessee State University and came away with the idea of using an ESPC to fund much-needed improvements in the schools the district operates in East Tennessee (Figure 7.170). The idea was put into practice in August 1999 when the district sent out a request for qualifications to ESCOs. Ten companies responded. Of these, three were selected to perform a walkthrough audit of one of the school buildings to develop a preliminary proposal for the single building. After reviewing the proposals, the district selected Energy Systems Group (ESG), and invited the company to develop a formal proposal for all 28 of the district's schools.

Figure 7.170. Library in Sullivan County, TN, School.

The Project

After performing a detailed energy survey, ESG proposed a comprehensive set of ECMs. The final project, approved in June of 2001, included many of the measures typically applied in schools, such as lighting upgrades (primarily conversion of fluorescent lighting to T8 fixtures with electronic ballasts), HVAC system upgrades, replacement of single-pane windows with high-efficiency double pane windows, and an EMCS. Other measures such as attic insulation, dropped ceilings (to reduce space conditioning requirements in spaces with high ceilings) and replacement of electric stoves and ovens with gas-fired equipment were included as well. Substantial savings in water and sewer costs would also be realized through replacement of lavatory fixtures. The total construction cost was $24.2 million, which the school financed through a bond issue approved by the Sullivan County Commission.

The cost-saving measures included in the project were not limited to energy and water conservation alone. ESG also installed a new telecommunications system, which allowed the district to obtain telephone service at a lower cost. A new point-of-sale system implemented in school cafeterias has increased both sales and use of the low-income lunch program, which has increased revenue to the school district. An automated maintenance management system has reduced operational costs as well. These savings are tracked by ESG and the district, but are not part of the guarantee.

ESG does guarantee utility cost savings for the entire 15-year term of the project. M&V of these savings is based on utility bill analysis, in conformance with IPMVP Option C. As part of the detailed energy survey, ESG developed baseline energy use models for each school by correlating pre-retrofit gas and electricity consumption with heating and CDD, the number of days in the billing period, and the number of occupied and unoccupied days in the billing period. Each school receives a monthly report on its utility use, and the district receives quarterly reports that compare actual utility costs for each school with what utilities would have cost under the baseline conditions. In addition, ESG produces an annual report that provides more detailed information on the savings accrued during the previous year. If the savings fall below the guarantee, ESG must pay the district the amount of the shortfall.

Results/Lessons Learned

According to Maintenance Director Joe Akard, the performance contract is proceeding exceptionally well, with savings ahead of schedule. During the first year of the performance period, ESG guaranteed $753,000 in savings from electricity and gas costs and $132,000 in savings from water and sewer costs. Actual savings, according to the utility bill analysis, were $940,000 in electricity and gas costs and $180,000 in water and sewer costs.

Note that the use of utility bill analysis as the primary method of M&V does have some drawbacks in contracts of this type. Since actual energy use determines the savings, the ESCO must pay close attention to energy use in the treated buildings to ensure, for example, that lights are turned out in the evenings, equipment is not left running over weekends, and temperature setpoints are not overridden. The ESCO must also keep track of any changes in the energy consuming equipment in the buildings (a new copy machine, for example) and adjust the baseline formula accordingly. In this case, ESG monitors energy use continuously via the internet and develops weekly reports that are shared with the district during twice-weekly meetings. ESG also helped the district write its first energy policy to define appropriate operating practices.

US Marine Corps Camp Lejeune, NC

Background

Located on a 156,000-acre site on the coast of North Carolina, Camp Lejeune is the world's largest US Marine Corps base and uses about one-quarter of the total energy consumed by the Marine Corps. On any given day, about 45,000 Marines are on active duty at Camp Lejeune. Base residential areas include a total of 4640 homes that house about 11,000 Marines and family members.

By the mid-1990s, Camp Lejeune's family housing was consuming 91 million kWh of electricity per year on average. At 19,600 kWh per residence, this was about 30% higher than the average residential electricity use for this region of the United States. Part of the problem was that in much of the housing heating and cooling was supplied by minimum-efficiency air-source heat pumps that had been installed in the early 1980s and were nearing the end of their service life. The maintenance and repair costs for this equipment were also a problem. After considering several options, officials at Camp Lejeune decided to replace the air-source heat pumps with GSHPs.

The Project

Camp Lejeune received three proposals for financing and implementing the energy retrofit, two for ESPC projects and the third from a subsidiary of the local utility for a project financed and carried out under an UESC. US Federal agencies are allowed under several authorities to finance energy projects through UESCs offered by their utility providers, which are similar to ESPCs. Both ESPCs and UESCs allow private, third-party capital to be used to purchase and install ECMs, which is repaid over time using the energy cost savings generated by the ECMs. A primary difference between the two financing vehicles is that UESCs are not required by law to include performance or savings guarantees or M&V. Also, Super ESPC terms can be as long as 25 years, whereas UESCs have generally been limited to 10-year terms. Agencies' policy makers and contracting officers commonly set strict upper limits on contract terms to minimize the government's long-term commitments (and financing costs).

Camp Lejeune decided to fund the project through a UESC contract with a subsidiary of the local utility. Camp Lejeune personnel indicated that a primary reason for selecting the UESC over an ESPC was the 10-year contract term offered by the utility. Beginning in May of 2000, air-source heat pumps were replaced with GSHPs in 2054 residences. Altogether the new installed equipment provided 3450 tons (12,130 kW) of heating and cooling capacity at a total construction cost of $12.7. Camp Lejeune paid a portion of this cost to the utility on completion of construction and the utility financed the remainder. Over the 10-year contract term, Camp Lejeune was to pay the utility a total of $15.5 million.

Measurement and Verification

Although UESC contracts do not require savings guarantees or verification, Camp Lejeune insisted on a savings guarantee that would be verified annually through analysis of the previous year's utility bills. Using 5 years of pre-project utility billing data, the baseline electricity consumption in family housing for a TMY was estimated to be 91.1 million kWh, and the total annual demand (defined as the sum of the monthly billing demands for the 12 months of the TMY) was estimated at 734,000 kW. In each year of the post-retrofit period, the utility was to normalize electricity use and billing demand for the previous 12 months to the same typical year. Normalized post-retrofit electricity use and total demand were then subtracted from the baseline electricity use and demand to estimate the annual savings. The guarantee was based on an electricity savings of 20.9 million kWh per year and demand savings of 83,500 MW. Using energy and demand prices from 2002 ($0.033 per kWh and $9.25 per kW of billing demand) the energy cost savings was estimated at $1.5 million. Camp Lejeune was to pay one-twelfth of this amount to the utility each month. If the normalization showed the actual energy cost savings to be less than 90% of this value, the payment to the utility was to be reduced by the amount of the shortfall.

Project Results

It was clear in the first year after installation that the savings targets were not being met. In addition, heat pumps in more than half of the residences were unable to maintain heating setpoints during very cold weather because of undersizing of both the heat pumps themselves and the ground heat exchangers. An analysis of utility bills performed by a third party after the second year of the contract estimated the normalized energy savings at 13.8 million kWh and total demand savings at 40,000 kW. Using the contract energy prices, this translated into a savings of $873,000 — about 60% of the guaranteed cost savings. Over the 10-year contract period, the shortfall in savings would amount to nearly $6 million dollars.

Following the completion of the 2-year billing analysis, Camp Lejeune and the utility began a lengthy period of negotiations. Camp Lejeune's position was that it was the utility's responsibility to repair and/or upgrade the heat pumps that were unable to meet heating setpoints and that its monthly payments to the utility should be reduced for the remainder of the contract to reflect the $6 million shortfall. Utility company representatives presented its own analysis claiming that the majority of the shortfall was due to excess energy use by the residents of Camp Lejeune family housing.

Nevertheless, a simple calculation might have raised concerns that the utility's original savings estimate was too optimistic. Before the retrofits, each residence was using on average 19,600 kWh of electricity per year. The estimated savings of 20.9 million kWh per year amounts to more than 10,000 kWh per residence, which is about 51% of the pre-retrofit electricity use.

However, conventional wisdom in the GSHP industry would predict about 33% savings for a residential retrofit, which agrees with independently verified savings of 33% from a similar retrofit project in military housing at the US Army's Fort Polk. These facts might have led to the conclusion that the Camp Lejeune project was unlikely to reduce electricity use by 51%.

Ultimately, the utility installed backup resistance heating to allow undersized heat pumps to meet peak heating loads. This resolved the problem in these residences, but increased electricity use and demand during the winter months and reduced savings. Camp Lejeune accepted partial responsibility for the savings shortfall, and total payments to the utility were reduced by $3 million rather than the $6 million originally requested.

Lessons Learned

Despite the problems that occurred in this project, Jim Sides, utility manager at Camp Lejeune, remains positive. “We learned a lot, and those lessons have made us smarter consumers of performance contracting services.” The first thing Sides recommends is to make certain the project is well-designed. “Have designs reviewed by a third-party subject matter expert who has no ties to the ESCO and will tell you the hard truth. If necessary design changes render the project unfeasible because of payback, don’t do the project.”

Sides also recommends that savings guarantees be well-written and iron-clad. “One of the benefits of a performance contract is that the ESCO assumes the technical risk. Without a savings guarantee, technical risk shifts to the customer.” Finally, Sides urges potential customers to personalize the project. “Think about it. If this were your money, would you do the project?”

Washington State ESPC Program

Background

The State of Washington encourages all state and local agencies to use performance contracting for energy conservation projects. Since 1986, about $145 million in energy conservation projects have been carried out in Washington using ESPCs. Like many other states, Washington has realized that there are a number of benefits to providing assistance to the agencies that use ESPCs. In this case, assistance is available from the Department of General Administration's "GA Energy Team" on a fee-for-service basis to state agencies, colleges and universities, cities and towns, counties, school districts, port facilities, libraries, hospitals, and health districts. The Energy Team provides an array of services similar to those offered by project facilitators in the USDOE's Super ESPC program — assistance in ESCO selection, proposal evaluation, technical and contracting assistance, evaluation of M&V plans and reports, andc.

In Washington, the project implementation process begins when a government agency issues a request for qualifications (RFQ) that invites ESCOs to submit a detailed statement describing the range of services offered, past experience, management approach, approach to M&V, financial stability, and other pertinent aspects of their business. The agency reviews and evaluates the qualifications of the ESCOs that respond and generally selects three for further interviews. In some cases, each of the three ESCOs may be asked to perform a preliminary survey of the site and prepare a list of conservation measures, which will serve as an initial proposal. Based on the interviews (and evaluation of the preliminary surveys, if required), the agency makes its selection. At this time, the agency also begins the process of securing financing for its project. In Washington, most projects are financed through lease–purchase agreements with the State Treasury.

The winning ESCO performs a detailed energy survey, which is an investment-grade audit that analyzes current building conditions, establishes base-year (pre-project) energy consumption, and identifies and defines the energy efficiency and cost reduction measures that will be implemented, with their associated energy and cost savings. After negotiations with the agency, the ESCO presents a final proposal containing the complete scope of work for the project, energy and cost savings guarantees, and a firm, fixed-price proposal for construction of all ECMs. When all parties are in agreement, the ESCO proceeds with construction.

In general, ESCOs secure their own financing during the construction period. Only when construction is complete and the ECMs have been commissioned and accepted by the agency does the State Treasury release the funding secured through the lease–purchase agreement. The agency then pays the ESCO's expenses for the audit, construction, and construction-period interest.

A Representative Project

Eastern State Hospital (Figure 7.171) is a psychiatric care facility operated by the State of Washington. Located in Medical Lake just outside of Spokane, the facility provides evaluation and inpatient treatment for individuals with serious or long-term mental illness. The entire complex contains about 20 buildings, some of which were constructed in the 1880s.

Figure 7.171. Eastern State Hospital Building.

In 1998, faced with increasing energy and maintenance costs at the hospital, an aging physical plant, and a shortfall in its capital improvement budget, the Washington Department of Social and Health Services (DSHS) decided to investigate performance contracting as a way to implement the many upgrades that were needed at Eastern State. With the assistance of the GA Energy Team, DSHS issued an RFQ, formed an evaluation committee, and selected Abacus Resource Management Company to make a proposal. Abacus performed a detailed energy audit of the hospital and developed an extensive list of ECMs. DSHS ultimately settled on a package of improvements worth $2.5 million, which included installation of T-8 lamps and electronic ballasts, a campus-wide energy management and control system, variable-speed drives on fans, new steam boilers in the central plant, hot water boilers in individual buildings, steam trap replacement, and repairs to the steam and condensate piping systems. The project was financed over a 10-year period using the state's lease–purchase program. Guaranteed savings from reducing use of electricity and natural gas were about $315,000 per year.

State law in Washington requires M&V of guaranteed energy savings. The ESCO is generally required to produce an annual M&V report for one to 3 years after construction, or until it is established that guarantees are being met and the equipment is operating according to specifications. M&V is based on IPMVP and is most often a mixture of Option A (stipulated values) and Option B (retrofit isolation) techniques. If the annual report indicates that savings are less than the guarantees, the ESCO must pay the agency the amount of the shortfall.

The Eastern State Hospital Project was the first use of ESPC by the DSHS. The successful results from the project led to a decision by DSHS to audit all of its facilities in the state. As a result, ESPCs were implemented at a number of other facilities.

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Acronyms and Abbreviations

Term	Definition
A&E	Architect and Engineer
AC	alternating current
ACGIH	American Conference of Governmental Industrial Hygienists
ACH	Air Changes per Hour
ACHW	Adams Craft Herz Walker, Inc.
ACSA	Association of Collegiate Schools of Architecture
AHU	Air Handling Unit
AIRR	Adjusted Internal Rate of Return
AMS	Architectural Metal Systems
ANSI	American National Standards Institute
APG	Aberdeen Proving Ground
ASH	Anti-Sweat Heating
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
ATCT	Air Traffic Control Tower
BEI	Biological Exposure Index
BEQ	Bachelor Enlisted Quarters
BMS	Building Management System
Btu	British Thermal Unit
CAV	Constant Air Volume
CCIW	Canada Centre for Inland Waters
CD	Compact Disk
CDD	Total Cooling Degree Days
CD-ROM	Compact Disk-Read Only Memory
CEC	California Energy Commission
CEG	Co-Energy Group
CEI/IEC	Commission électrotechnique internationale/International Electrotechnical Commission (CEI/IEC)
CEO	Corporate Executive Officer
CERL	Construction Engineering Research Laboratory
CFC	Chlorofluorocarbon
CFL	Compact Fluorescent Lamp
CFM	Cubic Feet per Minute
CGSB	Canadian General Standards Board
CIBSE	The Chartered Institution of Building Services Engineers
CIEE	California Institute for Energy and the Environment
CMHC	Canada Mortgage and Housing Corporation
CMU	Concrete Masonry Unit
CNIC	Commander Naval Installations Command
CNSMD	Conservatoire National Supérieur Musique and Danse de Lyon
COGEN	Cogeneration
COGEN-SIM	The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems
COP	Coefficient of Performance
CRC	Communications Research Centre Canada
CROUS	Centre régional des œuvres universitaires et scolaires

Term	Definition
DBT	Dry Bulb Temperature
DCV	Demand Controlled Ventilation
DDC	Direct Digital Control
DHW	Domestic Hot Water
DJU	Degrés Jours Unifiés (French: Degree Days Unified)
DLA	Defense Logistics Agency
DOAS	Dedicated Outdoor Air Supply
USDOE	US Department of Energy
DPT	Dew Point Temperature
DPW	Directorate of Public Works
DR	Discount Rate
DRAC	Direction Régionale Des Affaires Culturelles
DSHS	Department of Social and Health Services
DX	Direct Expansion
DX-AC	Direct Expansion-Alternating Current
ECBCS	Energy Conservation in Buildings and Community Systems
ECIP	Energy Conservation Investment Program
ECM	Energy Conservation Measure
EEM	Energy Efficiency Measure
EER	Energy-Efficiency Rating
EERE	[US DOE] Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EMCS	Energy Management Control System
EMS	Energy Management System
EPC	Energy Performance Contract
EPS	Expanded Polystyrene
ER	Escalation of Electricity
ERDC	Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ERV	Energy Recovery Ventilator
ES	Electricity Savings
ESCO	Energy Service Company
ESG	Energy Systems Group
ESPC	Energy Savings Performance Contract
EU	European Union
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FBI	Federal Buildings Initiative
FCAW	Flux Cored Arc Welding
FCC	Federal Communications Commission
FCU	Fan Coil Unit
FD	Forced Draft
FEAP	Facilities Engineering Applications Program
FEMP	Federal Energy Management Program
FISC	Fleet Industrial Supply Center
FY	Fiscal Year
GE	General Electric

Term	Definition
GHG	Greenhouse Gas
GJ	Gigajoules
GMAW	Gas Metal Arc Welding
GMAW-P	Pulsed Gas Metal Arc Welding
GR	Gas Rate
GS	Gas Savings
GSA	General Services Administration
GSHP	Ground Source Heat Pump
GTAW	Gas Tungsten Arc Welding
HDD	Heating Degree Days
HID	High Intensity Discharge
HiPTI	High Performance Thermal Insulation
HP	Horsepower
HPAC	Hazard Prediction & Assessment Capability
HVAC	Heating, Ventilating, and Air-Conditioning
HX	Heat Exchanger
IAQ	Indoor Air Quality
IBP	Fraunhofer Institute for Building Physics
IC	Initial Cost
IDEC	Indirect and Direct Evaporative Cooling
IDIQ	Indefinite Delivery/Indefinite Quantity
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IES	Infrastructure and Essential Services
IESNA	Illuminating Engineering Society of North America
IMCOM	US Army Installation Management Command
IP	Inch-Pound (units of measure)
IPMVP	International Performance Measurement and Validation Protocol
IR	Infrared
ISBN	International Standard Book Number
ISO	International Standards Organization
IWEC	International Weather for Energy Calculations
LBNL	Lawrence Berkeley National Laboratory
LCC	Life Cycle Cost
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
LEED-NC	LEED-New Construction
LLC	Limited Liability Company
LPD	Lower lighting Power Density
M&V	Measurement and Verification
MAU	Makeup Air Unit
MBR	Membrane Bioreactor
MBtu	1 million Btus
MC	Maintenance Cost
MCAS	Marine Corps Air Station
MGD	million gal/day
MOIST-EN	Whole Building Heat, Air and Moisture Response
MTSU	Middle Tennessee State University

Term	Definition
MW	Megawatt
NA	Not Applicable
NARA	National Archives and Records Administration
NAS	National Airspace Systems
NAVAIR	US Navy Naval Air Systems Command
NAVFAC	Naval Facilities Engineering Command
NIST	National Institute of Standards and Technology
NLPIP	National Lighting Product Information Program
NO	Nitric Oxide
NREL	National Renewable Energy Laboratory
NSWCCD	Naval Surface Warfare Center Carderock Division
NTU	Nephelometric Turbidity Units
NUWC	Naval Undersea Warfare Center
NWRI	(Environment Canada's) National Water Research Institute
OA	Outside Air
OA/E	Outdoor Air/Economizer (module)
OAE	Outdoor Air Economizer
OAT	Outdoor Air Temperature
OECD	Organization for Economic Cooperation and Development
ORHS	Oak Ridge High School
ORNL	Oak Ridge National Laboratory
OSU	Oklahoma State University
PAW	Plasma Arc Welding
PC/ESCO	Performance Contracting Energy Service Contractor
PH	Productive Hours
PNNL	Pacific Northwest National Laboratory
POC	Point of Contact
PSZ	Packaged Single Zone
PSZ-AC	Packaged Single Zone Systems With Air Conditioning
PV	PhotoVoltaic
PW	Present Worth
PWGSC	Public Works and Government Services Canada
R&D	Research and Development
RAF	Return Air Fan
RAP-RETRO	Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost
RCMP	Royal Canadian Mounted Police
RD&D	Research, Development, and Demonstration
RFP	Request for Proposal
RFQ	Request for Qualifications
RH	Relative Humidity
RO	Reverse Osmosis
ROI	Return on Investment
RPM	Revolutions Per Minute
RTG	Technology Group Limited (now Vestar)
S&H	Shipping and Handling
SARA	Sustainable Architecture applied to Replicable public Access buildings (Project)
SAW	Submerged Arc Welding

Term	Definition
SEA-TAC	Seattle-Tacoma (Airport)
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SHW	Solar Hot Water
SI	Systeme Internationale
SIR	Savings to Investment Ratio
SPB	Simple Payback
SPC	Statistical Process Control
TLV	Threshold Limit Value
TM	Army Technical Manual
TMY	Typical Meteorological Year
TR	Technical Report
TRACON	Traffic Control
TSSBA	Tennessee State School Bond Authority
TWDS	Two Wheel Desiccant System
UESC	Utility Energy Service Contract
UF	Ultrafiltration
UF/RO	Ultrafiltration/Reverse Osmosis
UK	United Kingdom
UPS	United Parcel Service
US	United States
USA	United States of America
USAG	U.S. Army Garrison
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
UV	Ultraviolet
VAV	Variable Air Volume
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
VTT	Finnish National Technical Research Institute
WBD	Whole Building Diagnosticians
WBDG	Whole Building Design Guide
WBE	Whole Building Energy
WBGT	Wet Bulb Globe Temperature
WE	Weekend
WG	Working Group
WSHP	Water Source Heat Pump

APPENDIX A

ECM Performance Data (Barracks)

A-1 Increased Wall Insulation

Table A.1. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline (kBtu/ft^2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	9.35	9.50	9.78	9.83	9.88
Houston, TX	9.09	9.51	10.36	10.71	10.90
Phoenix, AZ	11.23	11.72	12.73	13.15	13.33
Memphis, TN	8.12	8.68	9.99	10.60	10.95
El Paso, TX	9.07	9.61	10.76	11.27	11.53
San Francisco, CA	13.93	14.91	16.86	17.63	18.04
Baltimore, MD	7.89	8.42	9.80	10.52	10.99
Albuquerque, NM	8.67	9.40	11.12	11.90	12.35
Seattle, WA	6.77	7.21	8.44	9.10	9.52
Chicago, IL	9.36	9.96	11.56	12.41	12.96
Boise, ID	9.74	10.50	12.43	13.40	13.97
Burlington, VT	9.40	9.85	11.15	11.92	12.43
Helena, MT	8.86	9.38	10.88	11.73	12.29
Duluth, MN	10.92	11.39	12.80	13.66	14.25
Fairbanks, AK	14.94	15.38	16.79	17.72	18.38

Table A.2. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline (kWh/m^2-y).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	29.48	29.96	30.85	30.99	31.16
Houston, TX	28.67	29.98	32.68	33.77	34.37
Phoenix, AZ	35.40	36.97	40.15	41.47	42.03
Memphis, TN	25.61	27.38	31.49	33.42	34.52
El Paso, TX	28.59	30.32	33.93	35.53	36.36
San Francisco, CA	43.93	47.03	53.18	55.60	56.90
Baltimore, MD	24.89	26.56	30.91	33.17	34.65
Albuquerque, NM	27.35	29.64	35.07	37.53	38.95
Seattle, WA	21.34	22.75	26.62	28.68	30.01
Chicago, IL	29.53	31.40	36.45	39.14	40.86
Boise, ID	30.72	33.12	39.20	42.26	44.06
Burlington, VT	29.65	31.08	35.17	37.59	39.21
Helena, MT	27.93	29.57	34.30	36.98	38.75
Duluth, MN	34.45	35.91	40.35	43.07	44.92
Fairbanks, AK	47.12	48.51	52.96	55.88	57.97

Table A.3. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline ($/ft²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	$2.72	$2.76	$2.83	$2.84	$2.86
Houston, TX	$1.82	$1.88	$1.99	$2.03	$2.05
Phoenix, AZ	$2.32	$2.41	$2.58	$2.66	$2.68
Memphis, TN	$1.35	$1.43	$1.62	$1.70	$1.75
El Paso, TX	$1.64	$1.70	$1.82	$1.88	$1.91
San Francisco, CA	$1.92	$2.01	$2.20	$2.27	$2.31
Baltimore, MD	$1.35	$1.43	$1.62	$1.72	$1.80
Albuquerque, NM	$1.18	$1.26	$1.45	$1.53	$1.58
Seattle, WA	$0.90	$0.96	$1.12	$1.20	$1.25
Chicago, IL	$1.31	$1.39	$1.60	$1.71	$1.78
Boise, ID	$1.16	$1.24	$1.46	$1.57	$1.64
Burlington, VT	$1.59	$1.67	$1.87	$2.00	$2.08
Helena, MT	$1.15	$1.21	$1.40	$1.51	$1.58
Duluth, MN	$1.30	$1.36	$1.52	$1.62	$1.69
Fairbanks, AK	$1.74	$1.79	$1.95	$2.06	$2.14

Table A.4. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline (kBtu/ft²-y).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	9.41	9.56	9.84	9.89	9.94
Houston, TX	14.19	14.72	15.80	16.20	16.29
Phoenix, AZ	15.36	15.93	17.08	17.54	17.60
Memphis, TN	20.25	21.33	23.50	24.34	24.77
El Paso, TX	16.70	17.53	19.02	19.63	19.75
San Francisco, CA	16.11	17.16	19.22	20.01	20.34
Baltimore, MD	27.91	29.52	32.69	33.94	34.77
Albuquerque, NM	23.67	25.11	27.94	29.05	29.54
Seattle, WA	26.55	28.18	31.45	32.76	33.51
Chicago, IL	36.42	38.56	42.84	44.53	45.82
Boise, ID	31.94	33.92	37.83	39.37	40.29
Burlington, VT	41.55	44.02	48.95	50.90	52.63
Helena, MT	40.48	42.99	48.03	50.01	51.66
Duluth, MN	52.91	56.10	62.39	64.88	67.34
Fairbanks, AK	73.13	77.49	86.21	89.67	93.56

Table A.5. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline (kWh/m^2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	16.73	17.53	18.09	18.31	18.41
Houston, TX	33.88	35.35	38.12	39.03	38.74
Phoenix, AZ	36.76	38.24	41.03	42.13	42.66
Memphis, TN	53.37	56.19	61.63	63.79	63.15
El Paso, TX	41.47	43.37	49.05	50.49	47.37
San Francisco, CA	41.21	43.78	47.24	48.65	48.82
Baltimore, MD	75.66	80.48	89.50	92.89	92.79
Albuquerque, NM	67.59	71.58	78.67	81.43	80.92
Seattle, WA	76.74	80.97	88.59	91.49	91.29
Chicago, IL	100.04	106.20	119.03	124.38	125.73
Boise, ID	89.32	95.12	105.95	110.38	110.78
Burlington, VT	115.96	122.88	137.91	143.79	147.04
Helena, MT	122.95	134.05	149.10	155.06	155.06
Duluth, MN	154.76	164.34	183.70	191.69	197.39
Fairbanks, AK	218.50	233.23	262.24	273.73	285.67

Table A.6. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline ($/ft^2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	$2.73	$2.78	$2.85	$2.86	$2.88
Houston, TX	$2.86	$2.93	$3.07	$3.12	$3.12
Phoenix, AZ	$3.19	$3.29	$3.49	$3.57	$3.58
Memphis, TN	$3.39	$3.55	$3.86	$3.98	$4.04
El Paso, TX	$3.12	$3.22	$3.39	$3.46	$3.46
San Francisco, CA	$2.24	$2.34	$2.53	$2.61	$2.63
Baltimore, MD	$5.15	$5.39	$5.85	$6.03	$6.14
Albuquerque, NM	$3.39	$3.56	$3.87	$4.00	$4.04
Seattle, WA	$3.63	$3.84	$4.26	$4.42	$4.51
Chicago, IL	$5.19	$5.47	$6.03	$6.25	$6.42
Boise, ID	$3.82	$4.05	$4.50	$4.68	$4.78
Burlington, VT	$7.16	$7.56	$8.36	$8.66	$8.94
Helena, MT	$5.31	$5.63	$6.26	$6.50	$6.70
Duluth, MN	$6.37	$6.75	$7.49	$7.77	$8.06
Fairbanks, AK	$8.48	$8.97	$9.95	$10.34	$10.77

Table A.7. Annual energy savings for wall insulation and reduced infiltration over the standard baseline - international locations (kWh/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	9.13	9.59	11.00	11.87	12.46
Ottawa	7.88	8.16	9.05	9.64	10.04
Vancouver	6.74	7.25	8.65	9.42	9.90
Stuttgart	10.24	11.20	13.37	14.35	14.90
Copenhagen	5.11	5.43	6.37	6.93	7.30
Helsinki	8.64	9.04	10.19	10.86	11.29
Tampere	9.17	9.59	10.81	11.52	11.99
Lyon	3.72	3.93	4.51	4.85	5.07
Marseille	1.88	1.98	2.25	2.40	2.50
Nantes	2.97	3.13	3.58	3.83	4.00
Paris	4.12	4.35	4.99	5.36	5.60
London	8.89	9.74	11.66	12.52	13.00
Milan	3.47	3.72	4.43	4.84	5.10
Naples	0.90	0.96	1.12	1.20	1.24
Palermo	0.01	0.01	0.02	0.02	0.02
Rome	0.96	1.03	1.21	1.30	1.35

Table A.8. Annual energy cost savings for wall insulation and reduced infiltration over the standard baseline - Canadian locations ($/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	$1.65	$1.73	$1.99	$2.14	$2.25
Ottawa	$1.38	$1.43	$1.58	$1.68	$1.75
Vancouver	$1.13	$1.21	$1.43	$1.55	$1.62

Table A.9. Annual energy cost savings for wall insulation and reduced infiltration over the standard baseline - European locations (euro/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Stuttgart	€ 2.42	€ 2.65	€ 3.16	€ 3.39	€ 3.52
Copenhagen	€ 1.21	€ 1.28	€ 1.51	€ 1.64	€ 1.73
Helsinki	€ 2.04	€ 2.14	€ 2.41	€ 2.57	€ 2.67
Tampere	€ 2.17	€ 2.27	€ 2.56	€ 2.72	€ 2.83
Lyon	€ 0.88	€ 0.93	€ 1.07	€ 1.15	€ 1.20
Marseille	€ 0.45	€ 0.47	€ 0.53	€ 0.57	€ 0.59
Nantes	€ 0.70	€ 0.74	€ 0.85	€ 0.91	€ 0.94
Paris	€ 0.98	€ 1.03	€ 1.18	€ 1.27	€ 1.32
London	€ 1.66	€ 1.82	€ 2.18	€ 2.34	€ 2.43
Milan	€ 0.82	€ 0.88	€ 1.05	€ 1.14	€ 1.21
Naples	€ 0.21	€ 0.23	€ 0.26	€ 0.28	€ 0.29
Palermo	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	€ 0.23	€ 0.24	€ 0.29	€ 0.31	€ 0.32

Table A.10. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline- international locations (kWh/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	156.69	166.75	186.77	194.68	198.92
Ottawa	140.90	149.65	167.03	173.85	177.50
Vancouver	88.48	94.40	106.24	110.94	113.44
Stuttgart	32.29	35.31	42.17	45.24	46.98
Copenhagen	35.45	38.89	46.80	50.36	52.39
Helsinki	143.79	150.69	164.04	169.17	171.89
Tampere	149.33	156.59	170.69	176.13	179.03
Lyon	63.48	66.89	73.54	76.11	77.46
Marseille	40.79	42.69	46.17	47.39	48.00
Nantes	56.87	59.70	65.06	67.05	68.08
Paris	69.55	73.31	80.65	83.46	84.96
London	28.04	30.71	36.77	39.47	41.01
Milan	10.95	11.73	13.97	15.26	16.09
Naples	2.83	3.02	3.52	3.77	3.92
Palermo	0.04	0.04	0.05	0.05	0.06
Rome	3.03	3.24	3.80	4.09	4.26

Table A.11. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline- Canadian locations ($/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	$9.03	$9.60	$10.72	$11.16	$11.40
Ottawa	$8.03	$8.51	$9.45	$9.82	$10.01
Vancouver	$4.88	$5.19	$5.78	$6.02	$6.14

Table A.12. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline- European locations (euro/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Stuttgart	€ 2.42	€ 2.65	€ 3.16	€ 3.39	€ 3.52
Copenhagen	€ 2.66	€ 2.92	€ 3.51	€ 3.78	€ 3.93
Helsinki	€ 10.78	€ 11.30	€ 12.30	€ 12.68	€ 12.89
Tampere	€ 11.19	€ 11.74	€ 12.80	€ 13.20	€ 13.42
Lyon	€ 4.76	€ 5.01	€ 5.51	€ 5.71	€ 5.81
Marseille	€ 3.06	€ 3.20	€ 3.46	€ 3.55	€ 3.60
Nantes	€ 4.26	€ 4.48	€ 4.88	€ 5.03	€ 5.10
Paris	€ 5.21	€ 5.50	€ 6.05	€ 6.26	€ 6.37
London	€ 1.66	€ 1.82	€ 2.18	€ 2.34	€ 2.43
Milan	€ 0.82	€ 0.88	€ 1.05	€ 1.14	€ 1.21
Naples	€ 0.21	€ 0.23	€ 0.26	€ 0.28	€ 0.29
Palermo	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	€ 0.23	€ 0.24	€ 0.29	€ 0.31	€ 0.32

A-2 Increased Roof Insulation

Table A.13. Annual energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline (kBtu/ft^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	12.91	13.93	14.30	14.47	14.58
Houston, TX	13.12	13.93	14.14	14.27	14.40
Phoenix, AZ	15.21	15.49	15.64	15.77	15.90
Memphis, TN	13.65	14.27	14.48	14.64	14.78
El Paso, TX	11.38	11.99	12.15	12.23	12.32
San Francisco, CA	13.71	14.48	14.77	14.86	14.92
Baltimore, MD	15.75	16.37	16.62	16.80	17.00
Albuquerque, NM	14.40	15.06	15.30	15.44	15.55
Seattle, WA	11.63	12.22	12.45	12.65	12.79
Chicago, IL	20.27	20.85	21.12	21.31	21.51
Boise, ID	18.33	18.76	18.99	19.17	19.38
Burlington, VT	22.13	22.57	22.84	23.07	23.22
Helena, MT	20.31	20.81	21.10	21.30	21.47
Duluth, MN	28.39	28.81	29.10	29.30	29.45
Fairbanks, AK	41.00	41.48	41.83	42.08	42.29

Table A.14. Annual energy savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline (kWh/m^2-yr)

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	40.72	43.92	45.10	45.62	45.97
Houston, TX	41.38	43.93	44.60	45.01	45.40
Phoenix, AZ	47.97	48.86	49.32	49.74	50.13
Memphis, TN	43.03	45.01	45.67	46.17	46.61
El Paso, TX	35.89	37.81	38.32	38.56	38.85
San Francisco, CA	43.24	45.66	46.57	46.86	47.06
Baltimore, MD	49.68	51.63	52.42	52.98	53.61
Albuquerque, NM	45.42	47.48	48.26	48.68	49.03
Seattle, WA	36.67	38.52	39.26	39.89	40.32
Chicago, IL	63.94	65.74	66.59	67.21	67.83
Boise, ID	57.79	59.16	59.90	60.44	61.10
Burlington, VT	69.78	71.17	72.03	72.74	73.23
Helena, MT	64.06	65.63	66.55	67.18	67.70
Duluth, MN	89.53	90.87	91.76	92.41	92.88
Fairbanks, AK	129.31	130.82	131.90	132.72	133.36

Table A.15. Annual energy cost savings for increased roof insulation and reduced infiltration over the Standard 90.1-1989 baseline ($/ft²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	$0.29	$0.31	$0.32	$0.32	$0.32
Houston, TX	$0.22	$0.24	$0.24	$0.25	$0.25
Phoenix, AZ	$0.28	$0.29	$0.29	$0.30	$0.30
Memphis, TN	$0.19	$0.20	$0.20	$0.20	$0.21
El Paso, TX	$0.15	$0.16	$0.17	$0.17	$0.17
San Francisco, CA	$0.15	$0.18	$0.19	$0.19	$0.19
Baltimore, MD	$0.18	$0.19	$0.19	$0.20	$0.20
Albuquerque, NM	$0.15	$0.16	$0.17	$0.17	$0.17
Seattle, WA	$0.12	$0.13	$0.13	$0.13	$0.14
Chicago, IL	$0.24	$0.25	$0.25	$0.25	$0.26
Boise, ID	$0.17	$0.18	$0.18	$0.18	$0.19
Burlington, VT	$0.29	$0.30	$0.30	$0.30	$0.31
Helena, MT	$0.25	$0.26	$0.27	$0.27	$0.27
Duluth, MN	$0.29	$0.29	$0.30	$0.30	$0.30
Fairbanks, AK	$0.40	$0.41	$0.41	$0.41	$0.41

Table A.16. Annual energy savings for increased roof insulation and reduced infiltration over the standard baseline – international locations (kWh/m²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	156.69	166.75	186.77	194.68	198.92
Ottawa	140.90	149.65	167.03	173.85	177.50
Vancouver	88.48	94.40	106.24	110.94	113.44
Stuttgart	32.29	35.31	42.17	45.24	46.98
Copenhagen	35.45	38.89	46.80	50.36	52.39
Helsinki	143.79	150.69	164.04	169.17	171.89
Tampere	149.33	156.59	170.69	176.13	179.03
Lyon	63.48	66.89	73.54	76.11	77.46
Marseille	40.79	42.69	46.17	47.39	48.00
Nantes	56.87	59.70	65.06	67.05	68.08
Paris	69.55	73.31	80.65	83.46	84.96
London	28.04	30.71	36.77	39.47	41.01
Milan	10.95	11.73	13.97	15.26	16.09
Naples	2.83	3.02	3.52	3.77	3.92
Palermo	0.04	0.04	0.05	0.05	0.06
Rome	3.03	3.24	3.80	4.09	4.26

Table A.17. Annual energy cost savings for increased roof insulation and reduced infiltration over the standard baseline – Canadian locations ($/m²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	$0.03	$0.05	$0.07	$0.08	$0.09
Ottawa	$0.02	$0.04	$0.05	$0.06	$0.06
Vancouver	$0.04	$0.06	$0.07	$0.07	$0.08

Table A.18. Annual energy cost savings for increased roof insulation and reduced infiltration over the standard baseline – European locations (euro/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Stuttgart	€ 1.25	€ 1.56	€ 1.70	€ 1.78	€ 1.84
Copenhagen	€ 0.13	€ 0.21	€ 0.26	€ 0.29	€ 0.32
Helsinki	€ 2.12	€ 2.66	€ 2.91	€ 3.06	€ 3.15
Tampere	€ 2.25	€ 2.84	€ 3.10	€ 3.25	€ 3.35
Lyon	€ 0.28	€ 0.40	€ 0.47	€ 0.52	€ 0.55
Marseille	€ 0.17	€ 0.24	€ 0.28	€ 0.31	€ 0.33
Nantes	€ 0.24	€ 0.34	€ 0.40	€ 0.44	€ 0.46
Paris	€ 0.31	€ 0.45	€ 0.52	€ 0.57	€ 0.61
London	€ 0.85	€ 1.06	€ 1.16	€ 1.21	€ 1.25
Milan	€ 0.26	€ 0.37	€ 0.44	€ 0.48	€ 0.51
Naples	€ 0.09	€ 0.12	€ 0.14	€ 0.15	€ 0.16
Palermo	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	€ 0.09	€ 0.12	€ 0.14	€ 0.15	€ 0.16

A-3 Attic Insulation

Table A.19. Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline (kBtu/ft^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	3.56	4.34	4.58	4.65	4.72
Houston, TX	5.20	5.99	6.26	6.36	6.43
Phoenix, AZ	3.83	4.26	4.40	4.48	4.55
Memphis, TN	7.48	8.35	8.69	8.88	8.99
El Paso, TX	4.87	5.57	5.76	5.84	5.90
San Francisco, CA	5.35	6.10	6.35	6.43	6.49
Baltimore, MD	11.35	12.47	12.96	13.24	13.42
Albuquerque, NM	8.20	9.17	9.54	9.72	9.84
Seattle, WA	8.72	9.66	10.05	10.26	10.40
Chicago, IL	15.95	17.31	17.93	18.28	18.53
Boise, ID	11.98	13.10	13.59	13.88	14.07
Burlington, VT	19.40	20.85	21.52	21.92	22.18
Helena, MT	17.02	18.38	19.00	19.37	19.61
Duluth, MN	25.93	27.87	28.80	29.34	29.70
Fairbanks, AK	39.34	41.94	43.20	43.94	44.44

Table A.20. Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline (kWh/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	11.23	13.68	14.43	14.68	14.87
Houston, TX	16.40	18.90	19.74	20.05	20.29
Phoenix, AZ	12.07	13.42	13.88	14.13	14.34
Memphis, TN	23.59	26.32	27.42	28.00	28.35
El Paso, TX	15.37	17.56	18.18	18.43	18.61
San Francisco, CA	16.88	19.25	20.02	20.29	20.46
Baltimore, MD	35.80	39.33	40.88	41.75	42.33
Albuquerque, NM	25.86	28.92	30.08	30.65	31.04
Seattle, WA	27.51	30.45	31.69	32.34	32.81
Chicago, IL	50.29	54.58	56.53	57.66	58.43
Boise, ID	37.77	41.31	42.87	43.77	44.39
Burlington, VT	61.17	65.74	67.86	69.12	69.95
Helena, MT	53.68	57.97	59.93	61.08	61.84
Duluth, MN	81.79	87.88	90.81	92.54	93.66
Fairbanks, AK	124.07	132.27	136.22	138.57	140.13

Table A.21. Annual energy savings for increased attic insulation and reduced building infiltration over the Standard 90.1-1989 baseline – International locations (kWh/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	186.76	185.60	185.38	185.24	185.13
Ottawa	183.33	182.34	182.18	182.09	182.01
Vancouver	172.29	173.12	173.31	173.38	173.38
Stuttgart	98.47	91.95	90.58	89.97	89.62
Copenhagen	96.56	94.91	94.56	94.35	94.25
Helsinki	165.81	158.18	157.20	156.71	156.43
Tampere	170.36	161.84	160.48	159.89	159.38
Lyon	122.07	121.60	121.51	121.50	121.49
Marseille	124.62	125.25	125.41	125.50	125.57
Nantes	115.17	115.42	115.50	115.57	115.61
Paris	115.50	114.92	114.82	114.79	114.77
London	84.64	79.33	78.17	77.65	77.36
Milan	137.45	136.03	135.79	135.65	135.56
Naples	141.28	142.21	142.25	142.27	142.25
Palermo	151.31	151.26	151.23	151.21	151.17
Rome	137.30	138.45	138.53	138.57	138.58

A-4 Cool Roofs

Table A.22. Annual energy savings for cool roof (kBtu/ft^2-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	0.36	0.66
Houston, TX	0.23	0.40
Phoenix, AZ	0.18	0.20
Memphis, TN	0.12	0.21
El Paso, TX	0.15	0.14
San Francisco, CA	0.00	0.04
Baltimore, MD	0.03	0.06
Albuquerque, NM	0.05	0.05
Seattle, WA	0.03	0.04
Chicago, IL	-0.06	-0.06
Boise, ID	-0.02	-0.02
Burlington, VT	-0.06	-0.06
Helena, MT	-0.07	-0.07
Duluth, MN	-0.09	-0.09
Fairbanks, AK	-0.04	-0.04

Table A.23. Annual energy savings for cool roof (kWh/m^2-yr)..

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	1.14	2.09
Houston, TX	0.71	1.27
Phoenix, AZ	0.55	0.63
Memphis, TN	0.37	0.67
El Paso, TX	0.49	0.46
San Francisco, CA	0.01	0.13
Baltimore, MD	0.10	0.20
Albuquerque, NM	0.16	0.15
Seattle, WA	0.09	0.11
Chicago, IL	-0.17	-0.17
Boise, ID	-0.07	-0.08
Burlington, VT	-0.20	-0.20
Helena, MT	-0.23	-0.23
Duluth, MN	-0.28	-0.28
Fairbanks, AK	-0.14	-0.14

Table A.24. Annual energy cost savings for cool roof ($/ft²-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	$1.80	$1.79
Houston, TX	$1.65	$1.64
Phoenix, AZ	$1.56	$1.56
Memphis, TN	$1.43	$1.43
El Paso, TX	$1.44	$1.44
San Francisco, CA	$1.73	$1.73
Baltimore, MD	$1.48	$1.48
Albuquerque, NM	$1.35	$1.35
Seattle, WA	$1.08	$1.08
Chicago, IL	$1.61	$1.61
Boise, ID	$1.10	$1.10
Burlington, VT	$2.18	$2.18
Helena, MT	$1.54	$1.54
Duluth, MN	$1.56	$1.56
Fairbanks, AK	$2.26	$2.26

A-5 Building Airtightness

Table A.25. Annual energy savings for improved airtightness (kBtu/ft²-yr).

Location	0.5 cfm/ft²	0.25 cfm/ft²	0.15 cfm/ft²
Miami, FL	3.00	4.60	5.22
Houston, TX	5.64	8.25	9.24
Phoenix, AZ	5.33	7.76	8.67
Memphis, TN	8.98	13.14	14.71
El Paso, TX	6.35	8.86	9.75
San Francisco, CA	8.37	11.91	13.17
Baltimore, MD	12.62	18.56	20.84
Albuquerque, NM	9.64	13.89	15.48
Seattle, WA	11.70	16.89	18.82
Chicago, IL	16.36	24.04	26.98
Boise, ID	13.96	20.39	22.84
Burlington, VT	19.41	28.46	31.96
Helena, MT	17.32	25.19	28.18
Duluth, MN	23.98	35.25	39.60
Fairbanks, AK	35.09	51.79	58.27

Table A.26. Annual energy savings for improved airtightness (kWh/m^2-yr).

Location	0.5 cfm/ft^2	0.25 cfm/ft^2	0.15 cfm/ft^2
Miami, FL	9.46	14.52	16.47
Houston, TX	17.79	26.03	29.15
Phoenix, AZ	16.81	24.47	27.33
Memphis, TN	28.33	41.45	46.38
El Paso, TX	20.01	27.93	30.75
San Francisco, CA	26.38	37.57	41.54
Baltimore, MD	39.79	58.51	65.72
Albuquerque, NM	30.40	43.82	48.80
Seattle, WA	36.88	53.27	59.34
Chicago, IL	51.58	75.81	85.10
Boise, ID	44.03	64.31	72.01
Burlington, VT	61.21	89.74	100.78
Helena, MT	54.62	79.43	88.87
Duluth, MN	75.63	111.17	124.87
Fairbanks, AK	110.67	163.33	183.76

Table A.27. Annual energy cost savings for improved airtightness ($/ft^2-yr).

Location	0.5 cfm/ft^2	0.25 cfm/ft^2	0.15 cfm/ft^2
Miami, FL	$0.08	$0.12	$0.14
Houston, TX	$0.09	$0.13	$0.15
Phoenix, AZ	$0.09	$0.13	$0.15
Memphis, TN	$0.12	$0.18	$0.20
El Paso, TX	$0.08	$0.11	$0.12
San Francisco, CA	$0.08	$0.11	$0.12
Baltimore, MD	$0.17	$0.25	$0.28
Albuquerque, NM	$0.10	$0.14	$0.16
Seattle, WA	$0.14	$0.20	$0.22
Chicago, IL	$0.19	$0.27	$0.30
Boise, ID	$0.15	$0.22	$0.24
Burlington, VT	$0.28	$0.40	$0.45
Helena, MT	$0.20	$0.27	$0.30
Duluth, MN	$0.26	$0.37	$0.41
Fairbanks, AK	$0.37	$0.52	$0.58

Table A.28. Annual energy savings for improved airtightness – international locations (kWh/m2-yr).

Location	0.5 cfm/ft^2	0.25 cfm/ft^2
Edmonton	24.88	36.77
Ottawa	22.87	33.82
Vancouver	15.22	22.36
Stuttgart	15.73	23.17
Copenhagen	12.78	16.94
Helsinki	20.88	30.14
Tampere	22.24	32.20
Lyon	7.89	10.54
Marseille	3.26	3.71
Nantes	5.74	7.04
Paris	8.66	11.35
London	14.44	21.26
Milan	8.41	10.91
Naples	1.39	1.48
Palermo	0.02	0.02
Rome	1.58	1.69

Table A.29. Annual energy cost savings for improved airtightness – Canadian locations ($/m2-yr).

Location	0.5 cfm/ft^2	0.25 cfm/ft^2
Edmonton	$4.37	$6.32
Ottawa	$3.83	$5.60
Vancouver	$2.39	$3.49

Table A.30. Annual energy cost savings for improved airtightness – European locations (euro/m2-yr).

Location	0.5 cfm/ft^2	0.25 cfm/ft^2
Stuttgart	€ 3.72	€ 5.48
Copenhagen	€ 3.02	€ 4.00
Helsinki	€ 4.94	€ 7.12
Tampere	€ 5.26	€ 7.61
Lyon	€ 1.87	€ 2.49
Marseille	€ 0.77	€ 0.88
Nantes	€ 1.36	€ 1.66
Paris	€ 2.05	€ 2.68
London	€ 2.70	€ 3.98
Milan	€ 1.99	€ 2.58
Naples	€ 0.33	€ 0.35
Palermo	€ 0.00	€ 0.00
Rome	€ 0.37	€ 0.40

A-6 Advanced Windows

Table A.31. Annual energy savings for advanced windows (kBtu/ft²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	1.52	1.62	2.04	2.27	1.86	2.36	2.10	1.86
Houston, TX	2.52	2.82	2.97	3.27	3.11	3.44	3.39	3.43
Phoenix, AZ	2.48	2.79	2.97	3.32	3.15	3.51	3.46	3.52
Memphis, TN	2.58	3.10	2.97	3.33	3.44	3.59	3.77	4.13
El Paso, TX	2.77	3.24	3.10	3.35	3.51	3.56	3.74	4.04
San Francisco, CA	2.26	2.69	2.24	2.45	2.88	2.67	3.05	3.59
Baltimore, MD	3.49	4.24	3.95	4.43	4.71	4.82	5.14	5.73
Albuquerque, NM	2.41	3.20	2.75	3.11	3.53	3.43	3.84	4.48
Seattle, WA	3.46	4.02	3.70	4.18	4.47	4.57	4.91	5.47
Chicago, IL	4.51	5.60	5.22	5.87	6.21	6.38	6.79	7.56
Boise, ID	3.73	4.70	4.25	4.80	5.21	5.26	5.71	6.46
Burlington, VT	4.88	6.16	5.70	6.43	6.85	7.01	7.51	8.41
Helena, MT	4.10	5.41	4.88	5.59	6.07	6.17	6.71	7.69
Duluth, MN	5.74	7.47	6.83	7.76	8.34	8.46	9.14	10.36
Fairbanks, AK	8.64	11.18	10.68	11.96	12.41	12.84	13.51	15.00

Table A.32. Annual energy savings for advanced windows (kWh/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	4.79	5.10	6.44	7.17	5.86	7.43	6.61	5.86
Houston, TX	7.94	8.88	9.38	10.32	9.82	10.84	10.68	10.82
Phoenix, AZ	7.81	8.81	9.36	10.48	9.94	11.08	10.91	11.11
Memphis, TN	8.13	9.78	9.36	10.49	10.86	11.32	11.89	13.01
El Paso, TX	8.73	10.22	9.77	10.57	11.06	11.23	11.78	12.74
San Francisco, CA	7.13	8.48	7.05	7.71	9.08	8.43	9.63	11.31
Baltimore, MD	11.00	13.38	12.46	13.98	14.85	15.18	16.22	18.08
Albuquerque, NM	7.60	10.10	8.68	9.80	11.12	10.82	12.11	14.14
Seattle, WA	10.91	12.67	11.66	13.18	14.09	14.41	15.47	17.26
Chicago, IL	14.21	17.66	16.47	18.53	19.58	20.12	21.43	23.83
Boise, ID	11.76	14.82	13.41	15.13	16.42	16.59	18.01	20.37
Burlington, VT	15.40	19.43	17.98	20.28	21.61	22.11	23.68	26.53
Helena, MT	12.94	17.05	15.38	17.62	19.15	19.44	21.17	24.25
Duluth, MN	18.09	23.56	21.54	24.48	26.32	26.69	28.82	32.68
Fairbanks, AK	27.24	35.26	33.66	37.72	39.13	40.48	42.61	47.32

Table A.33. Annual energy cost savings for advanced windows ($/ft^2-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	$0.04	$0.04	$0.06	$0.06	$0.05	$0.06	$0.06	$0.05
Houston, TX	$0.04	$0.05	$0.06	$0.06	$0.05	$0.06	$0.06	$0.06
Phoenix, AZ	$0.05	$0.05	$0.06	$0.06	$0.06	$0.07	$0.06	$0.06
Memphis, TN	$0.04	$0.05	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06
El Paso, TX	$0.04	$0.05	$0.05	$0.06	$0.05	$0.06	$0.06	$0.06
San Francisco, CA	$0.02	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.04
Baltimore, MD	$0.05	$0.06	$0.07	$0.07	$0.07	$0.08	$0.08	$0.09
Albuquerque, NM	$0.03	$0.04	$0.04	$0.04	$0.04	$0.05	$0.05	$0.05
Seattle, WA	$0.04	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06	$0.07
Chicago, IL	$0.06	$0.07	$0.07	$0.08	$0.08	$0.08	$0.09	$0.09
Boise, ID	$0.04	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06	$0.07
Burlington, VT	$0.08	$0.10	$0.09	$0.11	$0.11	$0.11	$0.12	$0.13
Helena, MT	$0.05	$0.07	$0.06	$0.07	$0.07	$0.08	$0.08	$0.09
Duluth, MN	$0.06	$0.08	$0.08	$0.09	$0.09	$0.10	$0.10	$0.11
Fairbanks, AK	$0.09	$0.12	$0.12	$0.13	$0.14	$0.14	$0.15	$0.16

Table A.34. Simple payback relative to window I (years).

Location	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	4.3	1.7	4.5	5.6	8.7	9.9	15.0
Houston, TX	3.9	1.7	4.5	5.2	8.6	9.3	13.0
Phoenix, AZ	3.7	1.6	4.3	4.8	8.2	8.6	11.6
Memphis, TN	4.1	2.0	5.3	5.4	9.8	9.8	12.4
El Paso, TX	3.8	1.8	4.9	5.1	9.3	9.5	12.5
San Francisco, CA	6.7	3.5	9.1	8.9	17.0	16.3	19.8
Baltimore, MD	2.9	1.4	3.8	3.8	7.0	6.9	8.7
Albuquerque, NM	4.8	2.5	6.6	6.4	12.2	11.6	14.0
Seattle, WA	3.8	2.0	5.2	5.0	9.6	9.1	11.1
Chicago, IL	2.6	1.3	3.6	3.5	6.7	6.4	7.9
Boise, ID	3.6	2.0	5.2	4.9	9.6	8.9	10.6
Burlington, VT	1.9	1.0	2.6	2.6	4.9	4.7	5.7
Helena, MT	2.9	1.5	4.0	3.8	7.3	6.8	8.1
Duluth, MN	2.2	1.2	3.2	3.0	5.8	5.5	6.5
Fairbanks, AK	1.5	0.8	2.1	2.1	4.0	3.8	4.6

Table A.35. Annual energy savings for advanced windows – international locations (kWh/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Edmonton	-7.23	-1.72	-4.07	-1.30	0.85	0.96	3.30	7.39
Ottawa	-6.03	-1.35	-3.18	-0.63	1.04	1.40	3.30	6.71
Vancouver	-2.44	-0.22	-1.86	-0.33	1.21	1.08	2.65	5.08
Stuttgart	2.08	14.34	7.14	15.45	22.22	22.90	30.13	41.75
Copenhagen	1.43	5.17	2.87	7.90	9.90	11.49	14.12	18.93
Helsinki	-17.65	-2.14	-7.68	5.34	10.26	15.24	22.09	34.89
Tampere	-18.81	-2.20	-8.01	5.46	10.63	15.79	22.99	36.60
Lyon	-8.40	-4.66	-7.47	-2.65	-0.16	1.11	4.05	8.99
Marseille	-7.42	-5.12	-8.33	-5.76	-2.91	-3.66	-1.06	2.51
Nantes	-8.16	-5.24	-8.39	-4.24	-1.47	-1.08	1.82	6.32
Paris	-9.31	-5.26	-8.32	-2.81	-0.11	1.37	4.62	10.14
London	4.11	13.88	6.73	13.77	20.55	20.26	27.17	37.93
Milan	-6.44	-3.79	-5.98	-3.25	-1.26	-0.85	1.32	4.87
Naples	-2.81	-2.07	-3.34	-2.32	-1.18	-1.42	-0.37	1.03
Palermo	-0.08	-0.07	-0.14	-0.10	-0.05	-0.07	-0.03	0.00
Rome	-3.26	-2.34	-3.78	-2.66	-1.37	-1.73	-0.56	1.01

Table A.36. Annual energy cost savings for advanced windows – Canadian locations ($/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Edmonton	-$0.31	-$0.05	-$0.13	$0.00	$0.06	$0.09	$0.17	$0.34
Ottawa	-$0.25	-$0.04	-$0.09	$0.03	$0.07	$0.11	$0.17	$0.31
Vancouver	-$0.09	$0.01	-$0.04	$0.03	$0.07	$0.08	$0.14	$0.22

Table A.37. Annual energy cost savings for advanced windows – European locations (euro/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Stuttgart	€ 0.12	€ 0.82	€ 0.41	€ 0.88	€ 1.27	€ 1.31	€ 1.73	€ 2.39
Copenhagen	€ 0.08	€ 0.30	€ 0.16	€ 0.45	€ 0.57	€ 0.66	€ 0.81	€ 1.08
Helsinki	-€ 1.01	-€ 0.12	-€ 0.44	€ 0.31	€ 0.59	€ 0.87	€ 1.26	€ 2.00
Tampere	-€ 1.08	-€ 0.13	-€ 0.46	€ 0.31	€ 0.61	€ 0.90	€ 1.32	€ 2.09
Lyon	-€ 0.48	-€ 0.27	-€ 0.43	-€ 0.15	-€ 0.01	€ 0.06	€ 0.23	€ 0.51
Marseille	-€ 0.42	-€ 0.29	-€ 0.48	-€ 0.33	-€ 0.17	-€ 0.21	-€ 0.06	€ 0.14
Nantes	-€ 0.47	-€ 0.30	-€ 0.48	-€ 0.24	-€ 0.08	-€ 0.06	€ 0.10	€ 0.36
Paris	-€ 0.53	-€ 0.30	-€ 0.48	-€ 0.16	-€ 0.01	€ 0.08	€ 0.26	€ 0.58
London	€ 0.19	€ 0.63	€ 0.30	€ 0.62	€ 0.93	€ 0.92	€ 1.23	€ 1.72
Milan	-€ 0.37	-€ 0.22	-€ 0.34	-€ 0.19	-€ 0.07	-€ 0.05	€ 0.08	€ 0.28
Naples	-€ 0.16	-€ 0.12	-€ 0.19	-€ 0.13	-€ 0.07	-€ 0.08	-€ 0.02	€ 0.06
Palermo	€ 0.00	€ 0.00	-€ 0.01	-€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Rome	-€ 0.19	-€ 0.13	-€ 0.22	-€ 0.15	-€ 0.08	-€ 0.10	-€ 0.03	€ 0.06

A-7 External Roller Shades

Table A.38. Annual energy savings for external roller shades (kBtu/ft²-yr).

Location	Actively Controlled Shutters	Schedule Control Shutters
Miami, FL	2.29	1.16
Houston, TX	1.56	1.33
Phoenix, AZ	1.76	1.45
Memphis, TN	1.04	1.04
El Paso, TX	0.38	0.86
San Francisco, CA	-0.21	-0.35
Baltimore, MD	0.57	0.60
Albuquerque, NM	0.32	0.48
Seattle, WA	0.13	-0.13
Chicago, IL	0.40	0.40
Boise, ID	0.21	0.07
Burlington, VT	0.22	0.02
Helena, MT	0.09	-0.19
Duluth, MN	0.07	-0.40
Fairbanks, AK	0.02	-0.60

Table A.39. Annual energy savings for external roller shades (kWh/m²-yr).

Location	Actively Controlled Shutters	Schedule Control Shutters
Miami, FL	7.22	3.66
Houston, TX	4.90	4.18
Phoenix, AZ	5.54	4.56
Memphis, TN	3.27	3.29
El Paso, TX	1.18	2.71
San Francisco, CA	-0.67	-1.09
Baltimore, MD	1.80	1.89
Albuquerque, NM	1.02	1.50
Seattle, WA	0.42	-0.41
Chicago, IL	1.27	1.27
Boise, ID	0.67	0.24
Burlington, VT	0.69	0.07
Helena, MT	0.28	-0.59
Duluth, MN	0.23	-1.25
Fairbanks, AK	0.05	-1.91

Table A.40. Annual energy savings for external roller shades – international locations (kWh/m^2-yr).

Location	Actively Controlled Shutters	Schedule Control Shutters
Edmonton	-0.41	-2.27
Ottawa	0.46	-0.55
Vancouver	-0.27	-1.94
Stuttgart	-2.49	-4.20
Copenhagen	-0.25	1.30
Helsinki	-1.66	-2.33
Tampere	-1.62	-2.62
Lyon	-4.26	0.74
Marseille	-7.09	1.11
Nantes	-5.62	0.68
Paris	-4.16	0.11
London	-2.29	-5.20
Milan	-2.59	0.75
Naples	-2.12	0.50
Palermo	-0.24	0.01
Rome	-3.00	0.52

A-8 Exterior Light Shelves

Table A.41. Annual energy savings for exterior light shelves (kBtu/ft^2-yr).

Location	Exterior Light Shelves
Miami, FL	0.60
Houston, TX	0.27
Phoenix, AZ	0.45
Memphis, TN	-0.11
El Paso, TX	-0.09
San Francisco, CA	-0.62
Baltimore, MD	-0.29
Albuquerque, NM	-0.59
Seattle, WA	-0.22
Chicago, IL	-0.37
Boise, ID	-0.42
Burlington, VT	-0.40
Helena, MT	-0.47
Duluth, MN	-0.62
Fairbanks, AK	-0.33

Table A.42. Annual energy savings for exterior light shelves (kWh/m2-yr).

Location	Exterior Light Shelves
Miami, FL	1.89
Houston, TX	0.86
Phoenix, AZ	1.43
Memphis, TN	-0.33
El Paso, TX	-0.27
San Francisco, CA	-1.96
Baltimore, MD	-0.91
Albuquerque, NM	-1.86
Seattle, WA	-0.68
Chicago, IL	-1.15
Boise, ID	-1.33
Burlington, VT	-1.26
Helena, MT	-1.47
Duluth, MN	-1.96
Fairbanks, AK	-1.04

Table A.43. Annual energy savings for exterior light shelves – international locations (kWh/m2-yr).

Location	Exterior Light Shelves
Edmonton	-0.02
Ottawa	-0.85
Vancouver	-0.98
Stuttgart	-2.25
Copenhagen	-2.34
Helsinki	-2.40
Tampere	-2.12
Lyon	-2.60
Marseille	-5.01
Nantes	-1.43
Paris	-5.01
London	-1.00
Milan	-1.74
Naples	-2.17
Palermo	-2.26
Rome	-1.99

A-9 Exterior Vertical Fins

Table A.44. Annual energy savings for exterior vertical fins (kBtu/ft^2-yr).

Location	Vertical Fins
Miami, FL	0.74
Houston, TX	0.30
Phoenix, AZ	0.50
Memphis, TN	-0.19
El Paso, TX	-0.20
San Francisco, CA	-0.81
Baltimore, MD	-0.40
Albuquerque, NM	-0.80
Seattle, WA	-0.32
Chicago, IL	-0.49
Boise, ID	-0.60
Burlington, VT	-0.54
Helena, MT	-0.65
Duluth, MN	-0.81
Fairbanks, AK	-0.50

Table A.45. Annual energy savings for exterior vertical fins (kWh/m^2-yr).

Location	Vertical Fins
Miami, FL	2.34
Houston, TX	0.93
Phoenix, AZ	1.57
Memphis, TN	-0.59
El Paso, TX	-0.62
San Francisco, CA	-2.56
Baltimore, MD	-1.28
Albuquerque, NM	-2.51
Seattle, WA	-1.01
Chicago, IL	-1.54
Boise, ID	-1.88
Burlington, VT	-1.71
Helena, MT	-2.04
Duluth, MN	-2.57
Fairbanks, AK	-1.58

Table A.46. Annual energy savings for exterior vertical fins – international locations (kWh/m^2-yr).

Location	Vertical Fins
Edmonton	-0.02
Ottawa	-0.86
Vancouver	-1.01
Stuttgart	-2.37
Copenhagen	-2.47
Helsinki	-2.47
Tampere	-2.14
Lyon	-2.69
Marseille	-4.17
Nantes	-1.86
Paris	-4.18
London	-1.03
Milan	-2.29
Naples	-1.85
Palermo	-1.94
Rome	-2.72

A-10 Energy Recovery Ventilator

Table A.47. Annual energy savings for energy recovery ventilator (kBtu/ft^2-yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	1.04	1.22	1.48
Houston, TX	5.50	6.36	7.25
Phoenix, AZ	4.37	4.98	5.63
Memphis, TN	10.23	11.83	13.42
El Paso, TX	7.07	8.13	9.18
San Francisco, CA	11.53	13.27	14.96
Baltimore, MD	15.61	18.08	20.53
Albuquerque, NM	11.56	13.35	15.13
Seattle, WA	15.54	17.94	20.29
Chicago, IL	19.70	22.80	25.88
Boise, ID	17.17	19.86	22.51
Burlington, VT	23.38	27.07	30.71
Helena, MT	20.99	24.22	27.39
Duluth, MN	29.18	33.83	38.41
Fairbanks, AK	42.63	49.43	56.12

Table A.48. Annual energy savings for energy recovery ventilator (kWh/m²-yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	3.27	3.86	4.67
Houston, TX	17.33	20.06	22.85
Phoenix, AZ	13.78	15.72	17.74
Memphis, TN	32.27	37.30	42.32
El Paso, TX	22.31	25.64	28.95
San Francisco, CA	36.37	41.85	47.19
Baltimore, MD	49.22	57.00	64.75
Albuquerque, NM	36.47	42.10	47.70
Seattle, WA	49.00	56.57	63.98
Chicago, IL	62.12	71.91	81.60
Boise, ID	54.16	62.62	70.99
Burlington, VT	73.72	85.38	96.86
Helena, MT	66.19	76.37	86.39
Duluth, MN	92.03	106.69	121.11
Fairbanks, AK	134.44	155.87	176.96

A-11 Indirect Evaporative Cooling

Table A.49. Annual energy savings for indirect evaporative cooling (kBtu/ft²-yr).

Location	IDEC
Miami, FL	0.85
Houston, TX	0.84
Phoenix, AZ	12.97
Memphis, TN	2.20
El Paso, TX	7.86
San Francisco, CA	0.42
Baltimore, MD	2.62
Albuquerque, NM	6.01
Seattle, WA	1.00
Chicago, IL	3.81
Boise, ID	4.02
Burlington, VT	2.59
Helena, MT	2.88
Duluth, MN	1.53
Fairbanks, AK	1.07

Table A.50. Annual energy savings for indirect evaporative cooling (kWh/m^2-yr).

Location	IDEC
Miami, FL	2.67
Houston, TX	2.66
Phoenix, AZ	40.89
Memphis, TN	6.94
El Paso, TX	24.78
San Francisco, CA	1.33
Baltimore, MD	8.27
Albuquerque, NM	18.96
Seattle, WA	3.17
Chicago, IL	12.00
Boise, ID	12.69
Burlington, VT	8.16
Helena, MT	9.08
Duluth, MN	4.83
Fairbanks, AK	3.39

A-12 Hybrid Evaporative Cooling

Table A.51. Annual energy savings for hybrid evaporative cooling (kBtu/ft^2-yr).

Location	IDEC
Miami, FL	5.27
Houston, TX	4.07
Phoenix, AZ	14.76
Memphis, TN	3.35
El Paso, TX	8.75
San Francisco, CA	1.42
Baltimore, MD	3.54
Albuquerque, NM	6.51
Seattle, WA	1.73
Chicago, IL	4.18
Boise, ID	5.95
Burlington, VT	5.04
Helena, MT	3.84
Duluth, MN	4.91
Fairbanks, AK	6.03

Table A.52. Annual energy savings for hybrid evaporative cooling (kWh/m^2-yr).

Location	IDEC
Miami, FL	16.61
Houston, TX	12.82
Phoenix, AZ	46.56
Memphis, TN	10.55
El Paso, TX	27.60
San Francisco, CA	4.48
Baltimore, MD	11.15
Albuquerque, NM	20.54
Seattle, WA	5.45
Chicago, IL	13.17
Boise, ID	18.77
Burlington, VT	15.90
Helena, MT	12.11
Duluth, MN	15.48
Fairbanks, AK	19.01

A-13 DOAS with FCU

Table A.53. Annual energy savings for DOAS with FCU (kBtu/ft^2-yr).

Location	DOAS with Fan-Coil
Miami, FL	6.33
Houston, TX	6.62
Phoenix, AZ	8.42
Memphis, TN	10.03
El Paso, TX	6.27
San Francisco, CA	5.35
Baltimore, MD	15.53
Albuquerque, NM	12.14
Seattle, WA	13.14
Chicago, IL	22.06
Boise, ID	19.25
Burlington, VT	27.11
Helena, MT	25.04
Duluth, MN	35.71
Fairbanks, AK	54.56

Table A.54. Annual energy savings for DOAS with FCU (kWh/m^2-yr).

Location	DOAS with Fan-Coil
Miami, FL	19.96
Houston, TX	20.88
Phoenix, AZ	26.56
Memphis, TN	31.64
El Paso, TX	19.77
San Francisco, CA	16.88
Baltimore, MD	48.97
Albuquerque, NM	38.29
Seattle, WA	41.43
Chicago, IL	69.56
Boise, ID	60.70
Burlington, VT	85.50
Helena, MT	78.96
Duluth, MN	112.60
Fairbanks, AK	172.07

A-14 DOAS with Radiant Heating and Cooling

Table A.55. Annual energy savings for DOAS with radiant heating and cooling ($kBtu/ft^2$-yr).

Location	Radiant System
Miami, FL	25.72
Houston, TX	26.94
Phoenix, AZ	26.56
Memphis, TN	33.76
El Paso, TX	22.33
San Francisco, CA	22.74
Baltimore, MD	44.92
Albuquerque, NM	33.05
Seattle, WA	34.24
Chicago, IL	58.34
Boise, ID	47.95
Burlington, VT	67.85
Helena, MT	57.67
Duluth, MN	84.05
Fairbanks, AK	129.45

Table A.56. Annual energy for DOAS with radiant heating and cooling (kWh/m²-yr).

Location	Radiant System
Miami, FL	81.11
Houston, TX	84.95
Phoenix, AZ	83.77
Memphis, TN	106.47
El Paso, TX	70.43
San Francisco, CA	71.70
Baltimore, MD	141.66
Albuquerque, NM	104.24
Seattle, WA	107.99
Chicago, IL	183.98
Boise, ID	151.22
Burlington, VT	213.97
Helena, MT	181.87
Duluth, MN	265.06
Fairbanks, AK	408.22

Table A.57. Annual energy for DOAS with radiant heating and cooling – international locations (kWh/m²-yr).

Location	Radiant System
Edmonton	0.03
Ottawa	2.16
Vancouver	2.52
Stuttgart	5.53
Copenhagen	11.55
Helsinki	19.95
Tampere	19.18
Lyon	20.23
Marseille	65.85
Nantes	-10.28
Paris	83.95
London	32.79
Milan	42.92
Naples	70.52
Palermo	76.74
Rome	37.19

A-15 Ground Source Heat Pumps

Table A.58. Annual energy saving for GSHPs (kBtu/ft²-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	26.93	26.75	26.59	26.41	26.21	26.01
Houston, TX	30.87	30.83	30.73	30.60	30.45	30.29
Phoenix, AZ	26.49	26.62	26.73	26.78	26.79	26.75
Memphis, TN	37.51	39.94	40.18	40.02	39.81	39.57
El Paso, TX	26.02	26.34	26.47	26.59	26.64	26.61
San Francisco, CA	26.04	29.45	29.35	29.16	28.94	28.70
Baltimore, MD	42.50	50.30	51.59	51.49	51.32	51.10
Albuquerque, NM	32.19	37.57	38.87	38.73	38.52	38.27
Seattle, WA	28.97	36.70	39.23	39.30	39.10	38.88
Chicago, IL	52.24	59.44	63.44	65.41	65.55	65.34
Boise, ID	44.41	51.57	54.07	54.50	54.32	54.08
Burlington, VT	54.87	60.11	63.62	66.64	69.17	71.27
Helena, MT	48.95	52.11	54.23	56.07	57.59	58.89
Duluth, MN	65.18	66.79	67.82	68.64	69.25	69.78
Fairbanks, AK						

Table A.59. Annual energy savings for GSHPs (kWh/m²-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	84.91	84.36	83.84	83.29	82.67	82.02
Houston, TX	97.35	97.23	96.89	96.49	96.04	95.52
Phoenix, AZ	83.52	83.95	84.30	84.46	84.48	84.34
Memphis, TN	118.29	125.97	126.70	126.21	125.55	124.80
El Paso, TX	82.06	83.06	83.47	83.85	84.02	83.91
San Francisco, CA	82.11	92.86	92.56	91.95	91.25	90.52
Baltimore, MD	134.02	158.62	162.69	162.39	161.83	161.14
Albuquerque, NM	101.50	118.48	122.59	122.14	121.46	120.69
Seattle, WA	91.36	115.72	123.72	123.95	123.31	122.59
Chicago, IL	164.74	187.44	200.06	206.28	206.72	206.05
Boise, ID	140.04	162.62	170.50	171.87	171.29	170.54
Burlington, VT	173.05	189.55	200.64	210.16	218.12	224.77
Helena, MT	154.38	164.33	171.03	176.80	181.62	185.72
Duluth, MN	205.55	210.64	213.88	216.46	218.38	220.06
Fairbanks, AK						

A-16 Reheat Using Condenser Waste Heat

Table A.60. Annual energy savings for reheat using condenser waste heat (kBtu/ft^2-yr).

Location	Heat Recovery
Miami, FL	9.03
Houston, TX	7.17
Phoenix, AZ	0.09
Memphis, TN	3.36
El Paso, TX	0.14
San Francisco, CA	0.04
Baltimore, MD	2.36
Albuquerque, NM	0.01
Seattle, WA	0.03
Chicago, IL	0.90
Boise, ID	0.00
Burlington, VT	0.80
Helena, MT	0.00
Duluth, MN	0.25
Fairbanks, AK	0.01

Table A.61. Annual energy savings for reheat using condenser waste heat (kWh/m^2-yr).

Location	Heat Recovery
Miami, FL	97.21
Houston, TX	77.13
Phoenix, AZ	1.01
Memphis, TN	36.18
El Paso, TX	1.51
San Francisco, CA	0.41
Baltimore, MD	25.44
Albuquerque, NM	0.11
Seattle, WA	0.33
Chicago, IL	9.74
Boise, ID	0.00
Burlington, VT	8.57
Helena, MT	0.01
Duluth, MN	2.69
Fairbanks, AK	0.06

A-17 Grey Water Heat Recovery

Table A.62. Annual energy savings for reheat using grey water heat recovery (kBtu/ft²-yr).

Location		
Miami, FL		
Houston, TX		
Phoenix, AZ		
Memphis, TN		
El Paso, TX		
San Francisco, CA		
Baltimore, MD		
Albuquerque, NM		
Seattle, WA		
Chicago, IL		
Boise, ID		
Burlington, VT		
Helena, MT		
Duluth, MN		
Fairbanks, AK		

Table A.63. Annual energy savings for reheat using grey water heat recovery (kWh/m²-yr).

Location		
Miami, FL		
Houston, TX		
Phoenix, AZ		
Memphis, TN		
El Paso, TX		
San Francisco, CA		
Baltimore, MD		
Albuquerque, NM		
Seattle, WA		
Chicago, IL		
Boise, ID		
Burlington, VT		
Helena, MT		
Duluth, MN		
Fairbanks, AK		

APPENDIX B

Summary of Energy Model Schedules (Barracks)

Table B.1. Hourly schedule values (hours 1-12).

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
Seasonal-Reset-Supply-Air-Temp-Sch	Temperature	3/31	All	16	16	16	16	16	16	16	16	16	16	16	16
		9/30	All	13	13	13	13	13	13	13	13	13	13	13	13
		12/31	All	16	16	16	16	16	16	16	16	16	16	16	16
ALWAYS_ON	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ALWAYS_OFF	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
Dual Zone Control Type Sched	Control Type	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
HTGSETP_SCH	Temperature	12/31	Summer Design	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			Winter Design	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WD	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WE, Holiday	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			Other	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
CLGSETP_SCH	Temperature	12/31	Summer Design	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			Winter Design	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WD	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WE, Holiday	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			Other	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
humidity sched	Any Number	12/31	All	50	50	50	50	50	50	50	50	50	50	50	50
MinOA_Sched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
NOTHING	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
CONSTANT	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_OCC_SCH	Fraction	12/31	WD, Summer Design	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.2	0.2	0.2	0.2
			Sat, Winter Design	0.75	0.75	0.75	0.75	0.75	0.75	0.65	0.6	0.2	0.2	0.2	0.2
			Sun, Hol, Other	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.2	0.2	0.2	0.2
BLDG_LIGHT_SCH	Fraction	12/31	WD, Summer Design	0.25	0.25	0.25	0.25	0.25	0.25	0.4	0.7	0.25	0.25	0.25	0.25

Schedule	Type	Through	Day of Week	1	2	3	4	5	6	7	8	9	10	11	12
				Hour of Day											
			Sat, Winter Design	0.25	0.25	0.25	0.25	0.25	0.25	0.3	0.25	0.25	0.25	0.25	0.25
			Sun, Hol, Other	0.25	0.25	0.25	0.25	0.25	0.25	0.3	0.25	0.25	0.25	0.25	0.25
lobby Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_left Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_right Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
laundry Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_EQUIP_SCH	Fraction	12/31	WD, Summer Design	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3
			Sat, Winter Design	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.3
			Sun, Hol, Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5
lobby Equipt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
lobby Occupt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	0	0	0	0
			Sat	1	1	1	1	1	1	1	1	0	0	0	0
			Sun	1	1	1	1	1	1	1	1	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
ceiling_2 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Occupt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	0	0	0	0
			Sat	1	1	1	1	1	1	1	1	0	0	0	0
			Sun	1	1	1	1	1	1	1	1	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
Activity level stair_left	Any Number	12/31	WD	160	160	160	160	160	160	160	160	160	160	160	160
			Sat	160	160	160	160	160	160	160	160	160	160	160	160
			Sun	160	160	160	160	160	160	160	160	160	160	160	160
			Other	160	160	160	160	160	160	160	160	160	160	160	160
stair_right Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_right Occupt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	0	0	0	0
			Sat	1	1	1	1	1	1	1	1	0	0	0	0
			Sun	1	1	1	1	1	1	1	1	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
MINOA_LAUNDRY_SCHED	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlenumHtg-SetP-Sch	Temperature	12/31	All	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
PlenumClg-SetP-Sch	Temperature	12/31	All	40	40	40	40	40	40	40	40	40	40	40	40
Zone Control Type Sched	Control Type	12/31	Summer Design	2	2	2	2	2	2	2	2	2	2	2	2
			Winter Design	1	1	1	1	1	1	1	1	1	1	1	1
			Other	4	4	4	4	4	4	4	4	4	4	4	4
FanAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HVACOperationSchd	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
FanmodeSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
CoolingCoilAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	0	0	0	0
ReheatCoilAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	0	0	0	0
INFIL_SCH	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
Room SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Room SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Room SHW Temp Sched	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
Room SHW Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
laundry SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry SHW Temp Sched	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
laundry SHW Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
RoomSHW	Fraction	12/31	All	0	0	0	0	0	0	0.1	0.4	0.2	0	0	0
LaundrySHW	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlantOnSched	Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 1	COMPACT HVAC Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 4	COMPACT HVAC Any Number	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
WORK_EFF_SCH	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
AIR_VELO_SCH	Any Number	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING_SCH	Any Number	04/30	All	1	1	1	1	1	1	1	1	1	1	1	1
		09/30	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ACTIVITY_SCH	Any Number	12/31	All	120	120	120	120	120	120	120	120	120	120	120	120
units_gr_lf Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_lf Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_lf Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_lf Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_gr_rt Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_rt Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_rt Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_rt Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_s_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_s_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_s_g Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_s_g Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_n_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_n_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_n_g Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_n_g Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
units_2_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_s Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_s Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_n Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_n Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_s Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_s Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_n Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_n Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
laundry Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
laundry Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
SWHSys1-Loop-Temp-Schedule	Temperature	12/31	All	54	54	54	54	54	54	54	54	54	54	54	54
SWHSys1 Water Heater Setpoint Temperature Schedule Name	Temperature	12/31	All	60	60	60	60	60	60	60	60	60	60	60	60
SWHSys1 Water Heater Ambient Temperature Schedule Name	Temperature	12/31	All	22	22	22	22	22	22	22	22	22	22	22	22

Table B.2. Hourly schedule values (hours 12-24).

				Hour of Day											
Schedule	**Type**	**Through**	**Day of Week**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Seasonal-Reset-Supply-Air-Temp-Sch	Temperature	3/31	All	16	16	16	16	16	16	16	16	16	16	16	16
		9/30	All	13	13	13	13	13	13	13	13	13	13	13	13
		12/31	All	16	16	16	16	16	16	16	16	16	16	16	16
ALWAYS_ON	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ALWAYS_OFF	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
Dual Zone Control Type Sched	Control Type	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
HTGSETP_SCH	Temperature	12/31	Summer Design	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			Winter Design	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WD	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			WE, Holiday	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
			Other	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
CLGSETP_SCH	Temperature	12/31	Summer Design	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			Winter Design	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WD	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			WE, Holiday	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
			Other	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
humidity sched	Any Number	12/31	All	50	50	50	50	50	50	50	50	50	50	50	50
MinOA_Sched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
NOTHING	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
CONSTANT	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_OCC_SCH	Fraction	12/31	WD, Summer Design	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.7	0.7	0.8
			Sat, Winter Design	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.5	0.75
			Sun, Hol, Other	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.5	0.75
BLDG_LIGHT_SCH	Fraction	12/31	WD, Summer Design	0.25	0.25	0.25	0.25	0.25	0.25	0.7	0.7	0.7	0.7	0.5	0.4

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
			Sat, Winter Design	0.25	0.25	0.25	0.25	0.25	0.25	0.7	0.7	0.7	0.7	0.5	0.4
			Sun, Hol, Other	0.25	0.25	0.25	0.25	0.25	0.25	0.7	0.7	0.7	0.7	0.5	0.4
lobby Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_left Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
stair_right Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
laundry Lights	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
BLDG_EQUIP_SCH	Fraction	12/31	WD, Summer Design	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.6	0.7	0.7	0.5	0.3
			Sat, Winter Design	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5
			Sun, Hol, Other	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3
lobby Equipt	Fraction	12/31	WD	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	1	1	1	1	1	1	1	1	1	1	1	1
			Sun	1	1	1	1	1	1	1	1	1	1	1	1
			Other	1	1	1	1	1	1	1	1	1	1	1	1
lobby Occupt	Fraction	12/31	WD	0	0	0	0	0	1	1	1	1	1	1	1
			Sat	0	0	0	0	0	1	1	1	1	1	1	1
			Sun	0	0	0	0	0	1	1	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_1 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0

				Hour of Day											
Schedule	**Type**	**Through**	**Day of Week**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
ceiling_2 Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
ceiling_2 Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Lights	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
roof_space Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_left Occupt	Fraction	12/31	WD	0	0	0	0	0	1	1	1	1	1	1	1
			Sat	0	0	0	0	0	1	1	1	1	1	1	1
			Sun	0	0	0	0	0	1	1	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
Activity level stair_left	Any Number	12/31	WD	160	160	160	160	160	160	160	160	160	160	160	160
			Sat	160	160	160	160	160	160	160	160	160	160	160	160
			Sun	160	160	160	160	160	160	160	160	160	160	160	160
			Other	160	160	160	160	160	160	160	160	160	160	160	160
stair_right Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	0	0	0	0	0
			Sat	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
			Sun	0	0	0	0	0	0	0	0	0	0	0	0
			Other	0	0	0	0	0	0	0	0	0	0	0	0
stair_right Occupt	Fraction	12/31	WD	0	0	0	0	0	1	1	1	1	1	1	1
			Sat	0	0	0	0	0	1	1	1	1	1	1	1
			Sun	0	0	0	0	0	1	1	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Equipt	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
laundry Occupt	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
MINOA_LAUNDRY_SCHED	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlenumHtg-SetP-Sch	Temperature	12/31	All	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
PlenumClg-SetP-Sch	Temperature	12/31	All	40	40	40	40	40	40	40	40	40	40	40	40
Zone Control Type Sched	Control Type	12/31	Summer Design	2	2	2	2	2	2	2	2	2	2	2	2
			Winter Design	1	1	1	1	1	1	1	1	1	1	1	1
			Other	4	4	4	4	4	4	4	4	4	4	4	4
FanAvailSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HVACOperationSchd	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
FanmodeSched	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
CoolingCoilAvailSched	Fraction	12/31	All	0	0	0	0	0	1	1	1	1	1	1	1
ReheatCoilAvailSched	Fraction	12/31	All	0	0	0	0	0	1	1	1	1	1	1	1
INFIL_SCH	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
Room SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Room SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Room SHW Temp Sched	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
Room SHW Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry SHW Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
laundry SHW Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry SHW Temp Sched	Temperature	12/31	All	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33
laundry SHW Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
RoomSHW	Fraction	12/31	All	0	0	0	0	0	0	0.1	0.1	0.1	0	0	0
LaundrySHW	Fraction	12/31	WD	0	0	0	0	0	0	0	1	1	1	1	1
			Sat	0	0	0	0	0	0	0	1	1	1	1	1
			Sun	0	0	0	0	0	0	0	1	1	1	1	1
			Other	0	0	0	0	0	0	0	0	0	0	0	0
PlantOnSched	Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 1	COMPACT HVAC Any Number	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
COMPACT HVAC-ALWAYS 4	COMPACT HVAC Any Number	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
WORK_EFF_SCH	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
AIR_VELO_SCH	Any Number	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING_SCH	Any Number	04/30	All	1	1	1	1	1	1	1	1	1	1	1	1
		09/30	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
ACTIVITY_SCH	Any Number	12/31	All	120	120	120	120	120	120	120	120	120	120	120	120
units_gr_lf Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_lf Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_lf Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_lf Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_gr_rt Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_gr_rt Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_gr_rt Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_gr_rt Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_s_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_s_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_s_g Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
unit_s_g Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
unit_n_g Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
unit_n_g Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
unit_n_g Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
unit_n_g Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_s Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_s Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_2_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_2_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_2_n Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_2_n Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_s Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_s Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_s Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_s Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
units_3_n Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
units_3_n Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
units_3_n Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
units_3_n Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
laundry Water Equipment Latent fract sched	Fraction	12/31	All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
laundry Water Equipment Sensible fract sched	Fraction	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
laundry Water Equipment Temp Sched	Temperature	12/31	All	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3	43.3
laundry Water Equipment Hot Supply Temp Sched	Temperature	12/31	All	55	55	55	55	55	55	55	55	55	55	55	55
SWHSys1-Loop-Temp-Schedule	Temperature	12/31	All	54	54	54	54	54	54	54	54	54	54	54	54
SWHSys1 Water Heater Setpoint Temperature Schedule Name	Temperature	12/31	All	60	60	60	60	60	60	60	60	60	60	60	60
SWHSys1 Water Heater Ambient Temperature Schedule Name	Temperature	12/31	All	22	22	22	22	22	22	22	22	22	22	22	22

APPENDIX C

ECM Performance Data (Admin Facilities)

C-1 Increased Wall Insulation

Table C.1. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline (kBtu/ft^2-yr)

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	5.42	5.51	5.68	5.75	5.78
Houston, TX	6.32	6.65	7.35	7.65	7.79
Phoenix, AZ	8.18	8.56	9.32	9.61	9.79
Memphis, TN	4.75	5.22	6.27	6.84	7.13
El Paso, TX	6.25	6.65	7.51	7.87	8.05
San Francisco, CA	11.41	11.95	12.99	13.37	13.58
Baltimore, MD	4.40	4.85	6.10	6.69	7.08
Albuquerque, NM	6.18	6.75	8.05	8.62	8.95
Seattle, WA	3.34	3.68	4.56	5.02	5.30
Chicago, IL	5.32	5.91	7.34	8.10	8.61
Boise, ID	6.43	7.14	8.71	9.54	10.04
Burlington, VT	4.58	5.02	6.27	7.00	7.48
Helena, MT	4.85	5.34	6.77	7.53	8.03
Duluth, MN	5.28	5.77	7.05	7.95	8.55
Fairbanks, AK	7.39	7.82	9.19	10.12	10.80

Table C.2. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline (kWh/m^2-yr)

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	17.10	17.37	17.92	18.12	18.23
Houston, TX	19.95	20.98	23.19	24.13	24.58
Phoenix, AZ	25.79	26.99	29.39	30.32	30.86
Memphis, TN	14.98	16.45	19.76	21.57	22.47
El Paso, TX	19.70	20.98	23.69	24.82	25.39
San Francisco, CA	35.98	37.68	40.98	42.17	42.83
Baltimore, MD	13.87	15.31	19.23	21.10	22.34
Albuquerque, NM	19.48	21.29	25.39	27.18	28.22
Seattle, WA	10.53	11.60	14.40	15.83	16.71
Chicago, IL	16.77	18.64	23.15	25.53	27.14
Boise, ID	20.28	22.51	27.47	30.09	31.67
Burlington, VT	14.43	15.84	19.78	22.07	23.58
Helena, MT	15.28	16.83	21.36	23.73	25.33
Duluth, MN	16.65	18.21	22.23	25.08	26.98
Fairbanks, AK	23.29	24.67	28.97	31.92	34.07

Table C.3. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline ($/ft²·yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	$0.14	$0.14	$0.14	$0.14	$0.14
Houston, TX	$0.10	$0.11	$0.12	$0.12	$0.12
Phoenix, AZ	$0.15	$0.15	$0.16	$0.17	$0.17
Memphis, TN	$0.07	$0.08	$0.09	$0.10	$0.10
El Paso, TX	$0.10	$0.10	$0.11	$0.11	$0.12
San Francisco, CA	$0.16	$0.16	$0.17	$0.17	$0.18
Baltimore, MD	$0.07	$0.08	$0.10	$0.10	$0.11
Albuquerque, NM	$0.08	$0.08	$0.10	$0.10	$0.11
Seattle, WA	$0.04	$0.05	$0.06	$0.07	$0.07
Chicago, IL	$0.07	$0.07	$0.09	$0.10	$0.10
Boise, ID	$0.07	$0.08	$0.10	$0.11	$0.11
Burlington, VT	$0.07	$0.07	$0.09	$0.10	$0.11
Helena, MT	$0.05	$0.06	$0.07	$0.08	$0.09
Duluth, MN	$0.06	$0.06	$0.08	$0.09	$0.09
Fairbanks, AK	$0.08	$0.08	$0.09	$0.10	$0.11

Table C.4. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline (kBtu/ft²·yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	5.47	5.56	5.74	5.80	5.83
Houston, TX	11.14	11.59	12.44	12.71	12.87
Phoenix, AZ	11.99	12.74	13.58	13.92	13.81
Memphis, TN	17.76	18.61	20.35	21.00	20.82
El Paso, TX	14.37	14.96	16.10	16.54	15.47
San Francisco, CA	13.81	14.37	15.48	15.87	15.92
Baltimore, MD	25.62	27.05	29.76	30.83	30.80
Albuquerque, NM	22.63	23.80	25.99	26.80	26.61
Seattle, WA	25.50	26.74	29.05	29.96	29.87
Chicago, IL	34.04	35.97	40.06	41.68	42.09
Boise, ID	30.22	31.90	35.36	36.67	36.87
Burlington, VT	39.63	41.79	46.55	48.38	49.40
Helena, MT	42.64	45.13	49.79	51.71	51.45
Duluth, MN	52.67	55.83	61.84	64.25	66.10
Fairbanks, AK	75.33	80.08	88.95	92.55	96.10

Table C.5. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline (kWh/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	17.26	17.53	18.09	18.29	18.38
Houston, TX	35.14	36.54	39.22	40.07	40.58
Phoenix, AZ	37.81	40.17	42.84	43.90	43.56
Memphis, TN	56.01	58.69	64.17	66.24	65.67
El Paso, TX	45.31	47.17	50.79	52.15	48.79
San Francisco, CA	43.54	45.30	48.81	50.05	50.20
Baltimore, MD	80.79	85.31	93.84	97.23	97.12
Albuquerque, NM	71.36	75.04	81.96	84.51	83.91
Seattle, WA	80.41	84.31	91.62	94.49	94.20
Chicago, IL	107.36	113.44	126.33	131.43	132.72
Boise, ID	95.30	100.60	111.51	115.63	116.26
Burlington, VT	124.97	131.80	146.78	152.56	155.77
Helena, MT	134.46	142.33	157.02	163.08	162.24
Duluth, MN	166.09	176.08	195.02	202.62	208.46
Fairbanks, AK	237.56	252.52	280.51	291.86	303.05

Table C.6. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline ($/ft²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Miami, FL	$0.14	$0.14	$0.14	$0.14	$0.14
Houston, TX	$0.18	$0.19	$0.20	$0.20	$0.20
Phoenix, AZ	$0.21	$0.22	$0.24	$0.24	$0.24
Memphis, TN	$0.27	$0.28	$0.30	$0.31	$0.31
El Paso, TX	$0.22	$0.23	$0.24	$0.25	$0.22
San Francisco, CA	$0.19	$0.20	$0.21	$0.21	$0.21
Baltimore, MD	$0.42	$0.44	$0.48	$0.50	$0.49
Albuquerque, NM	$0.28	$0.29	$0.32	$0.32	$0.32
Seattle, WA	$0.34	$0.36	$0.38	$0.40	$0.39
Chicago, IL	$0.42	$0.44	$0.49	$0.51	$0.51
Boise, ID	$0.34	$0.36	$0.40	$0.41	$0.41
Burlington, VT	$0.61	$0.64	$0.71	$0.73	$0.74
Helena, MT	$0.50	$0.52	$0.57	$0.59	$0.58
Duluth, MN	$0.59	$0.63	$0.69	$0.72	$0.73
Fairbanks, AK	$0.78	$0.83	$0.91	$0.94	$0.97

Table C.7. Annual energy savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline – international locations (kWh/m^2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	8.06	8.59	10.18	11.13	11.76
Ottawa	6.58	6.92	7.96	8.63	9.10
Vancouver	4.95	5.34	6.34	6.87	7.20
Stuttgart	18.60	20.81	25.68	27.79	28.99
Copenhagen	6.70	7.31	9.11	10.18	10.88
Helsinki	8.28	8.86	10.52	11.47	12.09
Tampere	8.90	9.53	11.32	12.35	13.02
Lyon	3.67	3.93	4.71	5.18	5.51
Marseille	1.81	1.94	2.32	2.56	2.74
Nantes	2.55	2.74	3.30	3.64	3.88
Paris	3.88	4.17	4.99	5.49	5.82
London	15.36	17.29	21.59	23.46	24.52
Milan	4.33	4.59	5.35	5.79	6.07
Naples	1.95	2.00	2.14	2.21	2.25
Palermo	1.61	1.60	1.60	1.59	1.59
Rome	1.72	1.75	1.85	1.89	1.92

Table C.8. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline – Canadian locations ($/ft^2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	$0.05	$0.05	$0.06	$0.07	$0.07
Ottawa	$0.04	$0.04	$0.05	$0.05	$0.05
Vancouver	$0.03	$0.03	$0.03	$0.03	$0.03

Table C.9. Annual energy cost savings for wall insulation and reduced infiltration over Standard 90.1-1989 baseline – European locations (euro/m^2-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Stuttgart	€ 2.38	€ 2.60	€ 3.08	€ 3.29	€ 3.41
Copenhagen	€ 0.81	€ 0.88	€ 1.06	€ 1.16	€ 1.23
Helsinki	€ 0.80	€ 0.86	€ 1.03	€ 1.13	€ 1.19
Tampere	€ 0.88	€ 0.94	€ 1.12	€ 1.23	€ 1.29
Lyon	€ 0.35	€ 0.37	€ 0.45	€ 0.50	€ 0.54
Marseille	€ 0.15	€ 0.16	€ 0.19	€ 0.22	€ 0.24
Nantes	€ 0.18	€ 0.19	€ 0.24	€ 0.27	€ 0.30
Paris	€ 0.32	€ 0.34	€ 0.41	€ 0.46	€ 0.50
London	€ 1.49	€ 1.64	€ 1.97	€ 2.11	€ 2.19
Milan	€ 0.61	€ 0.63	€ 0.68	€ 0.72	€ 0.74
Naples	€ 0.37	€ 0.37	€ 0.36	€ 0.35	€ 0.35
Palermo	€ 0.41	€ 0.40	€ 0.39	€ 0.39	€ 0.38
Rome	€ 0.26	€ 0.25	€ 0.22	€ 0.20	€ 0.18

Table C.10. Annual energy savings for wall insulation and reduced infiltration over the no-insulation baseline – international locations (kWh/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	70.27	74.06	81.40	84.20	85.69
Ottawa	62.77	66.15	72.68	75.20	76.54
Vancouver	34.45	36.00	38.86	39.91	40.46
Stuttgart	18.60	20.81	25.68	27.79	28.99
Copenhagen	19.42	21.51	26.30	28.45	29.68
Helsinki	73.52	76.79	82.97	85.30	86.53
Tampere	76.78	80.28	86.91	89.42	90.75
Lyon	27.55	29.01	31.82	32.91	33.51
Marseille	17.03	17.80	19.24	19.78	20.08
Nantes	22.73	23.84	25.92	26.70	27.14
Paris	29.49	31.05	34.06	35.23	35.85
London	15.36	17.29	21.59	23.46	24.52
Milan	4.33	4.59	5.35	5.79	6.07
Naples	1.95	2.00	2.14	2.21	2.25
Palermo	1.61	1.60	1.60	1.59	1.59
Rome	1.72	1.75	1.85	1.89	1.92

Table C.11. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline – Canadian locations ($/ft²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Edmonton	$0.51	$0.53	$0.57	$0.59	$0.59
Ottawa	$0.44	$0.46	$0.50	$0.51	$0.52
Vancouver	$0.22	$0.23	$0.24	$0.24	$0.24

Table C.12. Annual energy cost savings for wall insulation and reduced infiltration over the no-insulation baseline – European locations (euro/m²-yr).

Location	Base Plus 1 in	Base Plus 2 in	Base Plus 4 in	Base Plus 6 in	Base Plus 8 in
Stuttgart	€ 2.38	€ 2.60	€ 3.08	€ 3.29	€ 3.41
Copenhagen	€ 2.51	€ 2.71	€ 3.19	€ 3.40	€ 3.52
Helsinki	€ 7.82	€ 8.14	€ 8.73	€ 8.96	€ 9.08
Tampere	€ 8.19	€ 8.53	€ 9.18	€ 9.43	€ 9.57
Lyon	€ 3.12	€ 3.27	€ 3.56	€ 3.67	€ 3.73
Marseille	€ 1.97	€ 2.05	€ 2.17	€ 2.22	€ 2.25
Nantes	€ 2.39	€ 2.49	€ 2.67	€ 2.73	€ 2.77
Paris	€ 2.99	€ 3.14	€ 3.41	€ 3.52	€ 3.58
London	€ 1.49	€ 1.64	€ 1.97	€ 2.11	€ 2.19
Milan	€ 0.61	€ 0.63	€ 0.68	€ 0.72	€ 0.74
Naples	€ 0.37	€ 0.37	€ 0.36	€ 0.35	€ 0.35
Palermo	€ 0.41	€ 0.40	€ 0.39	€ 0.39	€ 0.38
Rome	€ 0.26	€ 0.25	€ 0.22	€ 0.20	€ 0.18

C-2 Increased Roof Insulation

Table C.13. Annual energy savings for increased roof insulation (kBtu/ft^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	0.07	0.07	0.07	0.07	0.07
Houston, TX	0.74	0.75	0.75	0.74	0.74
Phoenix, AZ	0.57	0.58	0.57	0.57	0.57
Memphis, TN	1.48	1.48	1.47	1.47	1.47
El Paso, TX	0.44	0.46	0.43	0.42	0.46
San Francisco, CA	1.13	1.13	1.13	1.09	1.13
Baltimore, MD	2.73	2.73	2.73	2.73	2.73
Albuquerque, NM	1.96	1.97	1.97	1.97	1.97
Seattle, WA	2.06	2.05	2.02	2.02	2.05
Chicago, IL	4.08	4.08	4.08	4.07	4.07
Boise, ID	3.31	3.32	3.32	3.32	3.31
Burlington, VT	5.14	5.14	5.14	5.15	5.15
Helena, MT	4.40	4.41	4.41	4.41	4.41
Duluth, MN	6.67	6.67	6.67	6.67	6.67
Fairbanks, AK	7.59	7.59	8.53	7.78	8.23

Table C.14. Annual energy savings for increased roof insulation (kWh/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	0.22	0.22	0.22	0.22	0.22
Houston, TX	2.34	2.37	2.36	2.34	2.34
Phoenix, AZ	1.81	1.82	1.80	1.80	1.80
Memphis, TN	4.67	4.68	4.65	4.65	4.65
El Paso, TX	1.39	1.44	1.34	1.34	1.44
San Francisco, CA	3.56	3.56	3.57	3.44	3.57
Baltimore, MD	8.60	8.61	8.60	8.60	8.60
Albuquerque, NM	6.17	6.21	6.22	6.21	6.21
Seattle, WA	6.49	6.48	6.38	6.38	6.48
Chicago, IL	12.85	12.87	12.86	12.83	12.84
Boise, ID	10.45	10.46	10.46	10.46	10.45
Burlington, VT	16.21	16.22	16.22	16.23	16.23
Helena, MT	13.88	13.91	13.91	13.91	13.91
Duluth, MN	21.03	21.03	21.03	21.03	21.02
Fairbanks, AK	23.93	23.92	26.90	24.53	25.94

Table C.15. Annual energy cost savings for increased roof insulation ($\$/ft^2 yr$).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	$0.00	$0.00	$0.00	$0.00	$0.00
Houston, TX	$0.01	$0.01	$0.01	$0.01	$0.01
Phoenix, AZ	$0.01	$0.01	$0.01	$0.01	$0.01
Memphis, TN	$0.02	$0.02	$0.02	$0.02	$0.02
El Paso, TX	$0.00	$0.00	$0.00	$0.00	$0.00
San Francisco, CA	$0.01	$0.01	$0.01	$0.01	$0.01
Baltimore, MD	$0.04	$0.04	$0.04	$0.04	$0.04
Albuquerque, NM	$0.02	$0.02	$0.02	$0.02	$0.02
Seattle, WA	$0.03	$0.03	$0.02	$0.02	$0.03
Chicago, IL	$0.04	$0.04	$0.04	$0.04	$0.04
Boise, ID	$0.04	$0.04	$0.04	$0.04	$0.04
Burlington, VT	$0.07	$0.07	$0.07	$0.07	$0.07
Helena, MT	$0.05	$0.05	$0.05	$0.05	$0.05
Duluth, MN	$0.07	$0.07	$0.07	$0.07	$0.07
Fairbanks, AK	$0.07	$0.07	$0.07	$0.07	$0.07

Table C.16. Annual energy savings for increased roof insulation ($kWh/m^2 yr$).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	1.13	1.34	1.50	1.63	1.72
Ottawa	1.01	1.16	1.27	1.37	1.43
Vancouver	-0.55	-0.66	-0.67	-0.65	-0.62
Stuttgart	5.14	6.30	6.85	7.17	7.38
Copenhagen	1.51	1.80	1.99	2.12	2.22
Helsinki	6.73	8.02	8.53	8.84	9.05
Tampere	7.67	9.19	9.80	10.16	10.42
Lyon	0.53	0.62	0.66	0.70	0.74
Marseille	-0.39	-0.49	-0.58	-0.62	-0.64
Nantes	-0.05	-0.09	-0.13	-0.15	-0.15
Paris	0.64	0.76	0.81	0.86	0.90
London	4.20	5.21	5.68	5.95	6.12
Milan	0.67	0.94	1.10	1.21	1.30
Naples	-0.80	-0.80	-0.78	-0.76	-0.74
Palermo	0.07	0.13	0.18	0.21	0.25
Rome	-0.98	-1.00	-1.01	-1.00	-0.98

Table C.17. Annual energy cost savings for increased roof insulation – Canadian locations ($\$/ft^2 yr$)

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	$0.00	$0.00	$0.00	$0.00	$0.00
Ottawa	$0.00	$0.00	$0.00	$0.00	$0.00
Vancouver	-$0.01	-$0.02	-$0.02	-$0.02	-$0.02

Table C.18. Annual energy cost savings for increased roof insulation – European locations (euro/m²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Stuttgart	€ 0.70	€ 0.85	€ 0.93	€ 0.97	€ 1.00
Copenhagen	€ 0.02	€ 0.05	€ 0.08	€ 0.09	€ 0.10
Helsinki	€ 0.32	€ 0.34	€ 0.34	€ 0.34	€ 0.35
Tampere	€ 0.44	€ 0.49	€ 0.50	€ 0.50	€ 0.51
Lyon	-€ 0.12	-€ 0.15	-€ 0.16	-€ 0.17	-€ 0.17
Marseille	-€ 0.23	-€ 0.28	-€ 0.31	-€ 0.33	-€ 0.34
Nantes	-€ 0.20	-€ 0.25	-€ 0.27	-€ 0.29	-€ 0.30
Paris	-€ 0.13	-€ 0.15	-€ 0.17	-€ 0.18	-€ 0.18
London	€ 0.38	€ 0.48	€ 0.53	€ 0.56	€ 0.58
Milan	-€ 0.06	-€ 0.03	-€ 0.02	€ 0.00	€ 0.01
Naples	-€ 0.20	-€ 0.20	-€ 0.20	-€ 0.20	-€ 0.19
Palermo	€ 0.02	€ 0.03	€ 0.04	€ 0.05	€ 0.05
Rome	-€ 0.25	-€ 0.26	-€ 0.26	-€ 0.26	-€ 0.26

C-3 Attic Insulation

Table C.19. Annual energy savings for increased attic insulation (kBtu/ft²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	1.47	1.73	1.81	1.83	1.83
Houston, TX	4.59	5.27	5.51	5.51	5.53
Phoenix, AZ	4.97	5.64	5.31	5.41	5.47
Memphis, TN	7.92	8.85	9.18	9.19	9.27
El Paso, TX	6.36	7.12	7.48	7.56	7.05
San Francisco, CA	6.26	7.01	7.29	7.40	7.48
Baltimore, MD	11.65	13.06	13.46	13.72	13.88
Albuquerque, NM	10.65	11.69	12.28	12.42	12.58
Seattle, WA	10.19	11.33	11.86	12.03	12.17
Chicago, IL	15.68	17.36	18.02	18.40	17.75
Boise, ID	14.19	14.97	15.48	15.78	15.97
Burlington, VT	18.53	20.90	21.61	22.03	22.27
Helena, MT	19.17	21.36	22.21	22.67	22.88
Duluth, MN	24.30	28.15	29.03	29.58	29.88
Fairbanks, AK	35.24	38.91	40.42	41.19	41.74

Table C.20. Annual energy savings for increased attic insulation (kWh/m^2-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	4.62	5.45	5.71	5.76	5.78
Houston, TX	14.49	16.63	17.38	17.38	17.45
Phoenix, AZ	15.66	17.79	16.75	17.08	17.24
Memphis, TN	24.97	27.90	28.94	28.97	29.25
El Paso, TX	20.05	22.45	23.59	23.85	22.24
San Francisco, CA	19.74	22.10	23.00	23.33	23.59
Baltimore, MD	36.74	41.20	42.45	43.26	43.76
Albuquerque, NM	33.58	36.86	38.74	39.18	39.67
Seattle, WA	32.12	35.72	37.41	37.93	38.38
Chicago, IL	49.45	54.75	56.82	58.02	55.98
Boise, ID	44.75	47.21	48.82	49.75	50.36
Burlington, VT	58.42	65.92	68.15	69.48	70.22
Helena, MT	60.44	67.36	70.03	71.50	72.15
Duluth, MN	76.64	88.77	91.56	93.27	94.24
Fairbanks, AK	111.12	122.70	127.46	129.89	131.62

Table C.21. Annual energy cost savings for increased attic insulation ($\$/ft^2$-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Miami, FL	$0.03	$0.04	$0.04	$0.04	$0.04
Houston, TX	$0.06	$0.07	$0.07	$0.07	$0.07
Phoenix, AZ	$0.08	$0.09	$0.08	$0.08	$0.08
Memphis, TN	$0.11	$0.12	$0.12	$0.12	$0.12
El Paso, TX	$0.08	$0.09	$0.09	$0.09	$0.09
San Francisco, CA	$0.07	$0.08	$0.08	$0.08	$0.08
Baltimore, MD	$0.17	$0.19	$0.19	$0.20	$0.20
Albuquerque, NM	$0.11	$0.13	$0.13	$0.13	$0.13
Seattle, WA	$0.13	$0.14	$0.15	$0.15	$0.15
Chicago, IL	$0.17	$0.19	$0.20	$0.20	$0.19
Boise, ID	$0.16	$0.16	$0.17	$0.17	$0.17
Burlington, VT	$0.25	$0.28	$0.29	$0.29	$0.30
Helena, MT	$0.20	$0.22	$0.23	$0.23	$0.24
Duluth, MN	$0.25	$0.29	$0.30	$0.31	$0.31
Fairbanks, AK	$0.29	$0.32	$0.34	$0.34	$0.35

Table C.22. Annual energy savings for increased attic insulation – international locations (kWh/m²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	1.16	1.38	1.52	1.63	1.69
Ottawa	0.99	1.15	1.24	1.33	1.37
Vancouver	-0.83	-1.02	-1.09	-1.09	-1.13
Stuttgart	6.52	7.89	8.50	8.85	9.10
Copenhagen	1.65	1.99	2.20	2.31	2.41
Helsinki	7.63	8.61	9.10	9.38	9.58
Tampere	8.52	9.88	10.47	10.98	11.20
Lyon	0.47	0.56	0.57	0.58	0.60
Marseille	-0.63	-0.79	-0.88	-0.95	-0.97
Nantes	-0.25	-0.33	-0.40	-0.44	-0.46
Paris	0.58	0.68	0.72	0.73	0.75
London	5.32	6.47	6.99	7.29	7.48
Milan	1.42	1.66	1.79	1.88	1.95
Naples	-0.92	-0.97	-0.98	-0.97	-0.97
Palermo	0.05	0.08	0.10	0.14	0.16
Rome	-1.14	-1.23	-1.27	-1.28	-1.29

Table C.23. Annual energy cost savings for increased attic insulation – Canadian locations ($/ft²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Edmonton	$0.00	$0.00	$0.00	$0.00	$0.00
Ottawa	$0.00	$0.00	$0.00	$0.00	$0.00
Vancouver	-$0.02	-$0.02	-$0.02	-$0.03	-$0.03

Table C.24. Annual energy cost savings for increased attic insulation – European locations (euro/m²-yr).

Location	Base Plus R-10	Base Plus R-20	Base Plus R-30	Base Plus R-40	Base Plus R-50
Stuttgart	€ 0.81	€ 0.98	€ 1.06	€ 1.10	€ 1.14
Copenhagen	€ 0.01	€ 0.04	€ 0.06	€ 0.06	€ 0.07
Helsinki	€ 0.38	€ 0.32	€ 0.32	€ 0.32	€ 0.32
Tampere	€ 0.46	€ 0.48	€ 0.48	€ 0.54	€ 0.54
Lyon	-€ 0.18	-€ 0.21	-€ 0.23	-€ 0.25	-€ 0.25
Marseille	-€ 0.31	-€ 0.37	-€ 0.41	-€ 0.43	-€ 0.44
Nantes	-€ 0.28	-€ 0.34	-€ 0.37	-€ 0.39	-€ 0.40
Paris	-€ 0.19	-€ 0.23	-€ 0.25	-€ 0.26	-€ 0.27
London	€ 0.44	€ 0.55	€ 0.60	€ 0.63	€ 0.65
Milan	€ 0.09	€ 0.10	€ 0.11	€ 0.12	€ 0.13
Naples	-€ 0.23	-€ 0.24	-€ 0.24	-€ 0.24	-€ 0.24
Palermo	€ 0.01	€ 0.02	€ 0.02	€ 0.03	€ 0.03
Rome	-€ 0.29	-€ 0.31	-€ 0.32	-€ 0.32	-€ 0.33

C-4 Cool Roofs

Table C.25. Annual energy savings for cool roof ($kBtu/ft^2$-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	0.22	0.40
Houston, TX	0.17	0.31
Phoenix, AZ	0.08	0.10
Memphis, TN	0.11	0.20
El Paso, TX	0.13	0.12
San Francisco, CA	0.18	0.28
Baltimore, MD	0.08	0.12
Albuquerque, NM	0.11	0.11
Seattle, WA	0.15	0.17
Chicago, IL	0.05	0.06
Boise, ID	0.05	0.05
Burlington, VT	0.00	0.00
Helena, MT	0.04	0.04
Duluth, MN	-0.03	-0.03
Fairbanks, AK	-0.02	-0.02

Table C.26. Annual energy savings for cool roof (kWh/m^2-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	0.68	1.26
Houston, TX	0.55	0.98
Phoenix, AZ	0.26	0.32
Memphis, TN	0.35	0.62
El Paso, TX	0.40	0.37
San Francisco, CA	0.57	0.89
Baltimore, MD	0.26	0.38
Albuquerque, NM	0.36	0.35
Seattle, WA	0.47	0.53
Chicago, IL	0.16	0.17
Boise, ID	0.16	0.16
Burlington, VT	0.01	0.01
Helena, MT	0.14	0.14
Duluth, MN	-0.10	-0.10
Fairbanks, AK	-0.07	-0.07

Table C.27. Annual energy cost savings for cool roof ($\$/ft^2$-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Miami, FL	$0.00	$0.01
Houston, TX	$0.00	$0.01
Phoenix, AZ	$0.00	$0.00
Memphis, TN	$0.00	$0.00
El Paso, TX	$0.00	$0.00
San Francisco, CA	$0.01	$0.01
Baltimore, MD	$0.00	$0.00
Albuquerque, NM	$0.00	$0.00
Seattle, WA	$0.00	$0.00
Chicago, IL	$0.00	$0.00
Boise, ID	$0.00	$0.00
Burlington, VT	$0.00	$0.00
Helena, MT	$0.00	$0.00
Duluth, MN	$0.00	$0.00
Fairbanks, AK	$0.00	$0.00

Table C.28. Annual energy savings for cool roof – international locations (kWh/m^2-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Edmonton	-0.09	-0.09
Ottawa	-0.09	-0.09
Vancouver	0.29	0.29
Stuttgart	0.05	0.05
Copenhagen	0.06	0.06
Helsinki	0.00	0.00
Tampere	0.00	0.00
Lyon	0.30	0.36
Marseille	0.44	0.72
Nantes	0.58	1.32
Paris	0.13	0.13
London	0.09	0.09
Milan	0.26	0.29
Naples	0.33	0.48
Palermo	0.37	0.71
Rome	0.30	0.30

Table C.29. Annual energy cost savings for cool roof – Canadian locations ($\$/ft^2$-yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Edmonton	$0.00	$0.00
Ottawa	$0.00	$0.00
Vancouver	$0.00	$0.00

Table C.30. Annual energy cost savings for cool roof – European locations (euro/m²·yr).

Location	Cool Brown (r= 0.27)	Cool White (r = 0.65)
Stuttgart	€ 0.00	€ 0.00
Copenhagen	€ 0.01	€ 0.01
Helsinki	€ 0.00	€ 0.00
Tampere	€ 0.00	€ 0.00
Lyon	€ 0.04	€ 0.04
Marseille	€ 0.03	€ 0.06
Nantes	€ 0.04	€ 0.10
Paris	€ 0.00	€ 0.00
London	€ 0.00	€ 0.00
Milan	€ 0.02	€ 0.02
Naples	€ 0.03	€ 0.04
Palermo	€ 0.03	€ 0.06
Rome	€ 0.02	€ 0.02

C-5 Building Airtightness

Table C.31. Annual energy savings for increased building airtightness (kBtu/ft²·yr).

Location	0.32 ACH	0.18 ACH
Miami, FL	1.83	2.55
Houston, TX	1.73	2.29
Phoenix, AZ	1.00	1.36
Memphis, TN	1.87	2.30
El Paso, TX	0.91	1.10
San Francisco, CA	0.20	0.21
Baltimore, MD	2.91	3.40
Albuquerque, NM	1.63	1.82
Seattle, WA	0.73	0.77
Chicago, IL	4.43	5.17
Boise, ID	2.67	2.99
Burlington, VT	6.86	8.11
Helena, MT	3.80	4.49
Duluth, MN	9.53	11.33
Fairbanks, AK	17.10	21.19

Table C.32. Annual energy savings for increased building airtightness (kWh/m²-yr).

Location	0.32 ACH	0.18 ACH
Miami, FL	5.76	8.06
Houston, TX	5.46	7.23
Phoenix, AZ	3.16	4.30
Memphis, TN	5.89	7.25
El Paso, TX	2.87	3.48
San Francisco, CA	0.62	0.65
Baltimore, MD	9.17	10.71
Albuquerque, NM	5.14	5.74
Seattle, WA	2.30	2.43
Chicago, IL	13.96	16.30
Boise, ID	8.43	9.44
Burlington, VT	21.63	25.57
Helena, MT	11.98	14.15
Duluth, MN	30.05	35.73
Fairbanks, AK	53.94	66.81

Table C.33. Annual energy cost savings for increased building airtightness ($/ft²-yr).

Location	0.32 ACH	0.18 ACH
Miami, FL	$0.05	$0.07
Houston, TX	$0.04	$0.06
Phoenix, AZ	$0.02	$0.03
Memphis, TN	$0.03	$0.04
El Paso, TX	$0.02	$0.02
San Francisco, CA	$0.00	$0.00
Baltimore, MD	$0.05	$0.06
Albuquerque, NM	$0.02	$0.02
Seattle, WA	$0.01	$0.01
Chicago, IL	$0.05	$0.06
Boise, ID	$0.03	$0.03
Burlington, VT	$0.09	$0.11
Helena, MT	$0.04	$0.04
Duluth, MN	$0.10	$0.12
Fairbanks, AK	$0.13	$0.16

Table C.34. Annual energy savings for increased building airtightness – international locations (kWh/m²-yr).

Location	0.32 ACH	0.18 ACH
Edmonton	8.13	10.80
Ottawa	7.29	9.61
Vancouver	0.82	0.78
Stuttgart	11.43	16.22
Copenhagen	8.42	11.11
Helsinki	13.60	18.78
Tampere	14.99	20.70
Lyon	3.64	4.79
Marseille	0.95	1.21
Nantes	1.57	1.93
Paris	3.75	4.90
London	9.23	12.96
Milan	3.80	4.98
Naples	0.36	0.50
Palermo	0.40	0.71
Rome	0.83	1.11

Table C.35. Annual energy cost savings for increased building airtightness – Canadian locations ($/ft²-yr).

Location	0.32 ACH	0.18 ACH
Edmonton	$0.23	$0.24
Ottawa	$0.22	$0.23
Vancouver	-$0.24	-$0.39

Table C.36. Annual energy cost savings for increased building airtightness – European locations (euro/m²-yr).

Location	0.32 ACH	0.18 ACH
Stuttgart	€ 1.12	€ 1.58
Copenhagen	€ 0.65	€ 0.78
Helsinki	€ 1.22	€ 1.63
Tampere	€ 1.37	€ 1.84
Lyon	€ 0.15	€ 0.15
Marseille	-€ 0.11	-€ 0.19
Nantes	-€ 0.17	-€ 0.29
Paris	€ 0.11	€ 0.08
London	€ 0.69	€ 0.95
Milan	€ 0.22	€ 0.24
Naples	-€ 0.09	-€ 0.13
Palermo	€ 0.05	€ 0.10
Rome	-€ 0.01	-€ 0.03

C-6 Advanced Windows

Table C.37. Annual energy savings for advanced windows (kBtu/ft²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	1.09	1.33	2.03	2.61	1.94	2.84	2.42	2.07
Houston, TX	1.99	2.73	3.04	3.94	3.52	4.38	4.73	4.36
Phoenix, AZ	2.13	2.99	3.58	4.57	4.07	5.23	4.97	5.00
Memphis, TN	-0.29	0.70	0.81	1.97	2.08	3.57	3.03	3.72
El Paso, TX	1.90	2.63	2.74	3.83	3.79	4.41	4.61	5.02
San Francisco, CA	-0.38	0.47	0.52	1.45	1.42	2.02	2.22	2.83
Baltimore, MD	-1.08	0.74	0.52	2.70	2.55	3.74	4.19	5.62
Albuquerque, NM	-0.80	0.61	0.12	2.57	2.20	2.48	3.48	4.13
Seattle, WA	-0.34	1.17	1.37	3.70	3.00	4.58	4.97	5.42
Chicago, IL	-1.80	0.84	0.16	2.92	3.07	4.46	5.64	7.08
Boise, ID	-1.15	1.06	0.60	2.65	3.15	4.45	5.12	6.68
Burlington, VT	-3.71	-0.57	-1.42	1.34	1.94	3.35	4.46	6.67
Helena, MT	-3.19	-0.39	-1.20	1.21	2.13	2.87	3.99	6.49
Duluth, MN	-4.81	-0.79	-1.89	1.48	2.53	3.96	5.54	8.64
Fairbanks, AK	-6.07	0.08	-0.53	3.57	4.04	6.26	7.89	11.83

Table C.38. Annual energy savings for advanced windows (kWh/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	3.43	4.21	6.41	8.23	6.13	8.94	7.63	6.51
Houston, TX	6.29	8.61	9.58	12.41	11.11	13.80	14.92	13.75
Phoenix, AZ	6.72	9.43	11.28	14.40	12.84	16.49	15.66	15.76
Memphis, TN	-0.93	2.20	2.57	6.22	6.56	11.26	9.57	11.74
El Paso, TX	5.99	8.31	8.66	12.08	11.95	13.91	14.55	15.83
San Francisco, CA	-1.20	1.50	1.64	4.56	4.49	6.36	7.00	8.91
Baltimore, MD	-3.39	2.33	1.63	8.51	8.03	11.79	13.23	17.72
Albuquerque, NM	-2.53	1.92	0.38	8.12	6.93	7.81	10.96	13.01
Seattle, WA	-1.07	3.70	4.32	11.66	9.47	14.45	15.67	17.10
Chicago, IL	-5.69	2.66	0.52	9.22	9.68	14.08	17.77	22.32
Boise, ID	-3.64	3.34	1.89	8.36	9.95	14.04	16.14	21.07
Burlington, VT	-11.71	-1.81	-4.46	4.23	6.12	10.56	14.07	21.04
Helena, MT	-10.07	-1.23	-3.77	3.82	6.71	9.05	12.59	20.47
Duluth, MN	-15.17	-2.48	-5.97	4.68	7.99	12.49	17.46	27.24
Fairbanks, AK	-19.14	0.26	-1.68	11.25	12.74	19.75	24.90	37.30

Table C.39. Annual energy cost savings for advanced windows ($/ft²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Miami, FL	$0.03	$0.03	$0.05	$0.07	$0.05	$0.07	$0.06	$0.05
Houston, TX	$0.03	$0.04	$0.06	$0.07	$0.06	$0.08	$0.08	$0.07
Phoenix, AZ	$0.04	$0.05	$0.07	$0.09	$0.07	$0.10	$0.09	$0.08
Memphis, TN	$0.00	$0.01	$0.02	$0.04	$0.03	$0.06	$0.05	$0.06
El Paso, TX	$0.03	$0.04	$0.05	$0.07	$0.06	$0.08	$0.07	$0.07
San Francisco, CA	$0.00	$0.01	$0.02	$0.03	$0.02	$0.03	$0.03	$0.04
Baltimore, MD	-$0.01	$0.02	$0.02	$0.06	$0.05	$0.07	$0.07	$0.09
Albuquerque, NM	$0.00	$0.01	$0.01	$0.04	$0.03	$0.04	$0.05	$0.05
Seattle, WA	$0.00	$0.02	$0.02	$0.05	$0.04	$0.06	$0.07	$0.07
Chicago, IL	-$0.02	$0.01	$0.01	$0.04	$0.04	$0.06	$0.07	$0.08
Boise, ID	-$0.01	$0.01	$0.01	$0.03	$0.04	$0.05	$0.06	$0.07
Burlington, VT	-$0.05	$0.00	-$0.01	$0.03	$0.03	$0.06	$0.07	$0.09
Helena, MT	-$0.03	$0.00	-$0.01	$0.02	$0.03	$0.04	$0.05	$0.07
Duluth, MN	-$0.05	-$0.01	-$0.02	$0.02	$0.03	$0.05	$0.06	$0.09
Fairbanks, AK	-$0.04	$0.00	$0.00	$0.04	$0.04	$0.06	$0.07	$0.10

Table C.40. Annual energy savings for advanced windows – international locations (kWh/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Edmonton	3.16	12.79	11.46	18.94	20.22	23.98	-1.47	1.96
Ottawa	2.79	11.60	10.30	17.30	18.35	21.73	-1.95	1.61
Vancouver	7.82	13.90	9.89	17.43	15.64	13.88	3.17	3.73
Stuttgart	1.65	6.20	6.44	9.47	10.75	13.38	0.13	1.96
Copenhagen	1.54	7.13	6.53	10.90	11.75	13.91	0.08	1.04
Helsinki	7.48	18.61	17.61	26.37	28.36	33.27	5.69	6.70
Tampere	6.89	18.43	17.60	26.50	28.76	34.25	5.05	6.27
Lyon	17.47	25.20	20.52	30.00	28.17	27.09	13.10	12.76
Marseille	23.70	30.21	23.76	33.97	30.50	26.53	17.11	17.16
Nantes	17.72	24.79	20.21	28.90	26.91	25.00	13.43	13.12
Paris	13.90	21.55	18.09	26.42	25.54	25.45	10.92	10.49
London	1.68	5.53	6.12	8.39	9.76	12.16	0.84	2.27
Milan	16.53	24.41	19.90	29.16	27.51	26.97	11.48	11.92
Naples	27.89	34.20	26.39	37.38	32.73	27.31	19.58	19.82
Palermo	35.93	41.87	30.82	44.40	37.17	29.22	24.18	24.60
Rome	26.10	31.65	24.67	34.73	30.55	25.33	18.64	18.92

Table C.41. Annual energy cost savings for advanced windows – Canadian locations ($/ft²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Edmonton	$1.77	$2.75	$1.86	$3.26	$2.82	$2.39	$0.58	$0.84
Ottawa	$1.56	$2.46	$1.64	$2.95	$2.52	$2.13	$0.40	$0.71
Vancouver	$2.00	$2.71	$1.66	$3.01	$2.35	$1.56	$0.83	$0.90

Table C.42. Annual energy cost savings for advanced windows – European locations (euro/m²-yr).

Location	Window I	Window II	Window A	Window B	Window C	Window D	Window E	Window F
Stuttgart	-€ 0.14	€ 0.71	€ 0.09	€ 1.17	€ 0.88	€ 0.67	-€ 1.06	-€ 0.76
Copenhagen	-€ 0.26	€ 0.66	-€ 0.24	€ 1.17	€ 0.70	€ 0.23	-€ 1.36	-€ 1.19
Helsinki	€ 5.95	€ 7.72	€ 6.25	€ 8.76	€ 8.07	€ 7.42	€ 4.34	€ 4.44
Tampere	€ 5.94	€ 7.78	€ 6.31	€ 8.87	€ 8.20	€ 7.59	€ 4.31	€ 4.43
Lyon	€ 6.97	€ 8.55	€ 6.48	€ 9.35	€ 8.12	€ 6.83	€ 4.84	€ 4.84
Marseille	€ 8.04	€ 9.50	€ 7.12	€ 10.23	€ 8.75	€ 7.05	€ 5.55	€ 5.61
Nantes	€ 6.93	€ 8.41	€ 6.37	€ 9.09	€ 7.86	€ 6.47	€ 4.80	€ 4.84
Paris	€ 6.39	€ 7.84	€ 5.98	€ 8.58	€ 7.50	€ 6.32	€ 4.47	€ 4.48
London	-€ 0.10	€ 0.46	€ 0.03	€ 0.78	€ 0.58	€ 0.39	-€ 0.75	-€ 0.56
Milan	€ 6.76	€ 8.44	€ 6.38	€ 9.20	€ 7.99	€ 6.82	€ 4.48	€ 4.64
Naples	€ 8.60	€ 10.13	€ 7.58	€ 10.78	€ 9.17	€ 7.32	€ 5.82	€ 5.96
Palermo	€ 9.85	€ 11.42	€ 8.37	€ 12.08	€ 10.07	€ 7.87	€ 6.59	€ 6.71
Rome	€ 8.37	€ 9.61	€ 7.21	€ 10.19	€ 8.64	€ 6.75	€ 5.75	€ 5.88

C-7 Overhangs

Table C.43. Annual energy savings for overhangs (kBtu/ft^2-yr).

Location	Overhangs
Miami, FL	0.73
Houston, TX	0.43
Phoenix, AZ	0.96
Memphis, TN	0.29
El Paso, TX	0.23
San Francisco, CA	0.32
Baltimore, MD	-0.47
Albuquerque, NM	-0.12
Seattle, WA	2.00
Chicago, IL	-0.27
Boise, ID	0.60
Burlington, VT	-0.15
Helena, MT	0.21
Duluth, MN	-0.32
Fairbanks, AK	2.63

Table C.44. Annual energy savings for overhangs (kWh/m^2-yr).

Location	Overhangs
Miami, FL	2.30
Houston, TX	1.36
Phoenix, AZ	3.01
Memphis, TN	0.92
El Paso, TX	0.72
San Francisco, CA	1.02
Baltimore, MD	-1.48
Albuquerque, NM	-0.39
Seattle, WA	6.32
Chicago, IL	-0.86
Boise, ID	1.90
Burlington, VT	-0.47
Helena, MT	0.66
Duluth, MN	-1.01
Fairbanks, AK	8.28

Table C.45. Annual energy cost savings for overhangs ($/ft^2-yr).

Location	Overhangs
Miami, FL	$0.02
Houston, TX	$0.02
Phoenix, AZ	$0.02
Memphis, TN	$0.01
El Paso, TX	$0.02
San Francisco, CA	$0.02
Baltimore, MD	$0.00
Albuquerque, NM	$0.01
Seattle, WA	$0.03
Chicago, IL	$0.00
Boise, ID	$0.01
Burlington, VT	$0.01
Helena, MT	$0.01
Duluth, MN	$0.00
Fairbanks, AK	$0.03

Table C.46. Annual energy savings for overhangs – international locations (kWh/m^2-yr).

Location	Overhangs
Edmonton	4.42
Ottawa	3.30
Vancouver	4.28
Stuttgart	0.34
Copenhagen	1.11
Helsinki	4.48
Tampere	4.45
Lyon	5.42
Marseille	6.57
Nantes	6.02
Paris	5.44
London	0.47
Milan	5.83
Naples	7.29
Palermo	7.36
Rome	7.46

Table C.47. Annual energy cost savings for overhangs – Canadian locations ($/ft^2-yr).

Location	Overhangs
Edmonton	$4.42
Ottawa	$3.30
Vancouver	$4.28

Table C.48. Annual energy cost savings for overhangs – European locations (euro/m²-yr).

Location	Overhangs
Stuttgart	€ 0.34
Copenhagen	€ 1.11
Helsinki	€ 4.48
Tampere	€ 4.45
Lyon	€ 5.42
Marseille	€ 6.57
Nantes	€ 6.02
Paris	€ 5.44
London	€ 0.47
Milan	€ 5.83
Naples	€ 7.29
Palermo	€ 7.36
Rome	€ 7.46

C-8 Exterior Vertical Fins

Table C.49. Annual energy savings for exterior vertical fins (kBtu/ft²-yr).

Location	Exterior Vertical Fins
Miami, FL	1.66
Houston, TX	1.68
Phoenix, AZ	2.05
Memphis, TN	0.88
El Paso, TX	0.92
San Francisco, CA	1.19
Baltimore, MD	-0.62
Albuquerque, NM	0.61
Seattle, WA	3.06
Chicago, IL	-0.56
Boise, ID	1.11
Burlington, VT	-0.47
Helena, MT	0.44
Duluth, MN	-0.87
Fairbanks, AK	1.68

Table C.50. Annual energy savings for exterior vertical fins (kWh/m^2-yr).

Location	Exterior Vertical Fins
Miami, FL	5.22
Houston, TX	5.28
Phoenix, AZ	6.47
Memphis, TN	2.76
El Paso, TX	2.90
San Francisco, CA	3.75
Baltimore, MD	-1.94
Albuquerque, NM	1.94
Seattle, WA	9.66
Chicago, IL	-1.78
Boise, ID	3.50
Burlington, VT	-1.48
Helena, MT	1.40
Duluth, MN	-2.73
Fairbanks, AK	5.31

Table C.51. Annual energy cost savings for exterior vertical fins ($/ft^2-yr).

Location	Exterior Vertical Fins
Miami, FL	$0.05
Houston, TX	$0.04
Phoenix, AZ	$0.05
Memphis, TN	$0.02
El Paso, TX	$0.03
San Francisco, CA	$0.03
Baltimore, MD	$0.01
Albuquerque, NM	$0.02
Seattle, WA	$0.05
Chicago, IL	$0.00
Boise, ID	$0.02
Burlington, VT	$0.01
Helena, MT	$0.02
Duluth, MN	$0.00
Fairbanks, AK	$0.03

Table C.52. Annual energy savings for exterior vertical fins – international locations (kWh/m²-yr).

Location	Exterior Vertical Fins
Edmonton	5.93
Ottawa	5.38
Vancouver	6.05
Stuttgart	0.73
Copenhagen	1.93
Helsinki	5.20
Tampere	5.11
Lyon	7.23
Marseille	9.21
Nantes	7.68
Paris	6.81
London	0.86
Milan	7.59
Naples	9.14
Palermo	9.65
Rome	9.23

Table C.53. Annual energy cost savings for exterior vertical fins – Canadian locations ($/ft²-yr).

Location	Exterior Vertical Fins
Edmonton	$5.93
Ottawa	$5.38
Vancouver	$6.05

Table C.54. Annual energy cost savings for exterior vertical fins – European locations (euro/m²-yr).

Location	Exterior Vertical Fins
Stuttgart	€ 0.73
Copenhagen	€ 1.93
Helsinki	€ 5.20
Tampere	€ 5.11
Lyon	€ 7.23
Marseille	€ 9.21
Nantes	€ 7.68
Paris	€ 6.81
London	€ 0.86
Milan	€ 7.59
Naples	€ 9.14
Palermo	€ 9.65
Rome	€ 9.23

C-9 Energy Recovery Ventilators

Table C.55. Annual energy savings for ERVs (kBtu/ft²-yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	1.85	2.19	2.54
Houston, TX	1.76	2.01	2.26
Phoenix, AZ	0.86	0.99	1.12
Memphis, TN	1.86	2.03	2.18
El Paso, TX	0.71	0.75	0.79
San Francisco, CA	-0.43	-0.53	-0.62
Baltimore, MD	3.24	3.43	3.56
Albuquerque, NM	1.57	1.60	1.59
Seattle, WA	0.25	0.20	0.14
Chicago, IL	5.20	5.50	5.69
Boise, ID	2.87	2.96	2.99
Burlington, VT	8.31	8.87	9.26
Helena, MT	4.06	4.29	4.45
Duluth, MN	11.49	12.32	12.89
Fairbanks, AK	20.46	22.35	23.69

Table C.56. Annual energy savings for ERVs (kWh/m²-yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	5.85	6.92	8.00
Houston, TX	5.56	6.35	7.13
Phoenix, AZ	2.72	3.13	3.55
Memphis, TN	5.88	6.41	6.88
El Paso, TX	2.25	2.37	2.49
San Francisco, CA	-1.37	-1.66	-1.94
Baltimore, MD	10.21	10.83	11.23
Albuquerque, NM	4.95	5.03	5.03
Seattle, WA	0.79	0.62	0.45
Chicago, IL	16.39	17.35	17.96
Boise, ID	9.05	9.33	9.43
Burlington, VT	26.19	27.97	29.19
Helena, MT	12.81	13.53	14.02
Duluth, MN	36.22	38.85	40.66
Fairbanks, AK	64.53	70.48	74.72

Table C.57. Annual energy cost savings for ERVs ($/ft²-yr).

Location	ERV 60	ERV 70	ERV 80
Miami, FL	$0.05	$0.06	$0.07
Houston, TX	$0.04	$0.05	$0.05
Phoenix, AZ	$0.02	$0.02	$0.03
Memphis, TN	$0.03	$0.03	$0.03
El Paso, TX	$0.01	$0.01	$0.01
San Francisco, CA	-$0.03	-$0.03	-$0.03
Baltimore, MD	$0.04	$0.04	$0.04
Albuquerque, NM	$0.01	$0.01	$0.01
Seattle, WA	$0.00	-$0.01	-$0.01
Chicago, IL	$0.04	$0.05	$0.05
Boise, ID	$0.03	$0.03	$0.03
Burlington, VT	$0.09	$0.09	$0.10
Helena, MT	$0.03	$0.03	$0.03
Duluth, MN	$0.11	$0.11	$0.12
Fairbanks, AK	$0.12	$0.13	$0.13

Table C.58. Annual energy savings for ERVs – international locations (kWh/m²-yr).

Location	ERV 60	ERV 70	ERV 80
Edmonton	9.03	10.09	11.06
Ottawa	8.09	9.00	9.81
Vancouver	0.61	0.57	0.55
Stuttgart	14.28	16.51	18.68
Copenhagen	8.99	10.06	11.08
Helsinki	14.48	16.50	18.37
Tampere	15.98	18.23	20.31
Lyon	3.45	3.86	4.24
Marseille	0.48	0.53	0.60
Nantes	1.23	1.31	1.36
Paris	3.65	4.05	4.39
London	11.58	13.32	14.99
Milan	3.72	4.15	4.55
Naples	-0.15	-0.15	-0.10
Palermo	-0.13	-0.02	0.15
Rome	0.24	0.33	0.45

Table C.59. Annual energy cost savings for ERVs – Canadian locations ($/ft²-yr).

Location	ERV 60	ERV 70	ERV 80
Edmonton	$0.13	$0.13	$0.13
Ottawa	$0.12	$0.12	$0.12
Vancouver	-$0.17	-$0.20	-$0.23

Table C.60. Annual energy cost savings for ERVs – European locations (euro/m²-yr).

Location	ERV 60	ERV 70	ERV 80
Stuttgart	€ 0.78	€ 0.90	€ 1.02
Copenhagen	€ 0.37	€ 0.40	€ 0.42
Helsinki	€ 0.70	€ 0.79	€ 0.88
Tampere	€ 0.80	€ 0.90	€ 0.99
Lyon	€ 0.04	€ 0.04	€ 0.03
Marseille	-€ 0.12	-€ 0.14	-€ 0.15
Nantes	-€ 0.15	-€ 0.18	-€ 0.21
Paris	€ 0.02	€ 0.01	€ 0.00
London	€ 0.48	€ 0.55	€ 0.62
Milan	€ 0.08	€ 0.08	€ 0.09
Naples	-€ 0.11	-€ 0.12	-€ 0.13
Palermo	-€ 0.04	-€ 0.02	€ 0.00
Rome	-€ 0.08	-€ 0.09	-€ 0.08

C-10 Indirect Evaporative Cooling

Table C.61. Annual energy savings for indirect evaporative cooling (kBtu/ft²-yr).

Location	IDEC	IDEC+HR
Miami, FL	6.09	6.11
Houston, TX	4.42	4.78
Phoenix, AZ	13.03	13.11
Memphis, TN	3.39	4.22
El Paso, TX	8.03	8.48
San Francisco, CA	1.29	1.48
Baltimore, MD	3.48	5.41
Albuquerque, NM	5.99	7.19
Seattle, WA	1.70	2.35
Chicago, IL	4.26	7.37
Boise, ID	5.26	7.24
Burlington, VT	5.15	9.89
Helena, MT	3.55	6.33
Duluth, MN	5.01	11.63
Fairbanks, AK	5.97	17.59

Table C.62. Annual energy savings for indirect evaporative cooling (kWh/m²-yr).

Location	IDEC	IDEC+HR
Miami, FL	19.19	19.26
Houston, TX	13.93	15.08
Phoenix, AZ	41.08	41.34
Memphis, TN	10.68	13.30
El Paso, TX	25.31	26.74
San Francisco, CA	4.06	4.67
Baltimore, MD	10.98	17.05
Albuquerque, NM	18.90	22.67
Seattle, WA	5.36	7.42
Chicago, IL	13.44	23.23
Boise, ID	16.58	22.84
Burlington, VT	16.25	31.18
Helena, MT	11.19	19.96
Duluth, MN	15.81	36.66
Fairbanks, AK	18.81	55.48

Table C.63. Annual energy cost savings for indirect evaporative cooling ($/ft²-yr).

Location	IDEC
Miami, FL	$0.18
Houston, TX	$0.13
Phoenix, AZ	$0.31
Memphis, TN	$0.08
El Paso, TX	$0.25
San Francisco, CA	$0.05
Baltimore, MD	$0.10
Albuquerque, NM	$0.14
Seattle, WA	$0.03
Chicago, IL	$0.08
Boise, ID	$0.07
Burlington, VT	$0.11
Helena, MT	$0.07
Duluth, MN	$0.06
Fairbanks, AK	$0.08

Table C.64. Annual energy savings for indirect evaporative cooling – international locations (kWh/m²-yr).

Location	IDEC	IDEC+HR
Edmonton	1.82	7.46
Ottawa	3.23	8.23
Vancouver	0.95	3.06
Stuttgart	2.02	9.08
Copenhagen	0.51	6.02
Helsinki	1.79	8.69
Tampere	1.62	9.11
Lyon	5.53	8.21
Marseille	6.69	7.83
Nantes	3.97	5.90
Paris	3.83	6.86
London	1.01	6.97
Milan	6.79	9.70
Naples	4.52	5.16
Palermo	-0.10	0.05
Rome	2.18	2.97

Table C.65. Annual energy cost savings for indirect evaporative cooling – Canadian locations ($/ft²-yr).

Location	IDEC
Edmonton	$0.22
Ottawa	$0.34
Vancouver	$0.13

Table C.66. Annual energy cost savings for indirect evaporative cooling – European locations (euro/m²-yr).

Location	IDEC
Stuttgart	€0.33
Copenhagen	€0.09
Helsinki	€0.29
Tampere	€0.26
Lyon	€0.88
Marseille	€1.06
Nantes	€0.66
Paris	€0.62
London	€0.14
Milan	€1.08
Naples	€0.74
Palermo	€0.03
Rome	€0.38

C-11 Hybrid Evaporative Cooling

Table C.67. Annual energy savings for hybrid evaporative cooling (kBtu/ft²-yr).

Location	IDEC
Miami, FL	5.27
Houston, TX	4.07
Phoenix, AZ	14.76
Memphis, TN	3.35
El Paso, TX	8.75
San Francisco, CA	1.42
Baltimore, MD	3.54
Albuquerque, NM	6.51
Seattle, WA	1.73
Chicago, IL	4.18
Boise, ID	5.95
Burlington, VT	5.04
Helena, MT	3.84
Duluth, MN	4.91
Fairbanks, AK	6.03

Table C.68. Annual energy savings for hybrid evaporative cooling (kWh/m²-yr).

Location	IDEC
Miami, FL	16.61
Houston, TX	12.82
Phoenix, AZ	46.56
Memphis, TN	10.55
El Paso, TX	27.60
San Francisco, CA	4.48
Baltimore, MD	11.15
Albuquerque, NM	20.54
Seattle, WA	5.45
Chicago, IL	13.17
Boise, ID	18.77
Burlington, VT	15.90
Helena, MT	12.11
Duluth, MN	15.48
Fairbanks, AK	19.01

Table C.69. Annual energy cost savings for hybrid evaporative cooling ($/ft²-yr).

Location	IDEC
Miami, FL	$0.16
Houston, TX	$0.12
Phoenix, AZ	$0.35
Memphis, TN	$0.08
El Paso, TX	$0.27
San Francisco, CA	$0.06
Baltimore, MD	$0.11
Albuquerque, NM	$0.15
Seattle, WA	$0.03
Chicago, IL	$0.08
Boise, ID	$0.08
Burlington, VT	$0.10
Helena, MT	$0.08
Duluth, MN	$0.06
Fairbanks, AK	$0.08

Table C.70. Annual energy savings for hybrid evaporative cooling – international locations (kWh/m²-yr).

Location	IDEC
Edmonton	2.31
Ottawa	4.68
Vancouver	1.69
Stuttgart	2.68
Copenhagen	0.61
Helsinki	2.13
Tampere	1.88
Lyon	8.05
Marseille	10.64
Nantes	5.33
Paris	4.96
London	1.34
Milan	10.21
Naples	8.55
Palermo	4.47
Rome	5.32

Table C.71. Annual energy cost savings for hybrid evaporative cooling – Canadian locations ($/ft²-yr).

Location	IDEC
Edmonton	$0.26
Ottawa	$0.47
Vancouver	$0.20

Table C.72. Annual energy cost savings for hybrid evaporative cooling – European locations (euro/m²·yr).

Location	IDEC
Stuttgart	€ 0.43
Copenhagen	€ 0.10
Helsinki	€ 0.34
Tampere	€ 0.30
Lyon	€ 1.25
Marseille	€ 1.66
Nantes	€ 0.86
Paris	€ 0.79
London	€ 0.18
Milan	€ 1.59
Naples	€ 1.34
Palermo	€ 0.71
Rome	€ 0.85

C-12 DOAS with FCU

Table C.73. Annual energy savings for DOAS with FCU (kBtu/ft²·yr).

Location	DOAS with FCU
Miami, FL	-0.67
Houston, TX	3.03
Phoenix, AZ	0.95
Memphis, TN	4.14
El Paso, TX	2.05
San Francisco, CA	5.35
Baltimore, MD	8.56
Albuquerque, NM	3.68
Seattle, WA	6.28
Chicago, IL	13.38
Boise, ID	10.09
Burlington, VT	16.17
Helena, MT	12.75
Duluth, MN	22.40
Fairbanks, AK	41.79

Table C.74. Annual energy savings for DOAS with FCU (kWh/m^2-yr).

Location	DOAS with FCU
Miami, FL	-2.10
Houston, TX	9.54
Phoenix, AZ	3.01
Memphis, TN	13.05
El Paso, TX	6.46
San Francisco, CA	16.86
Baltimore, MD	26.99
Albuquerque, NM	11.60
Seattle, WA	19.80
Chicago, IL	42.21
Boise, ID	31.81
Burlington, VT	50.98
Helena, MT	40.20
Duluth, MN	70.63
Fairbanks, AK	131.79

Table C.75. Annual energy cost savings for DOAS with FCU ($/ft^2-yr).

Location	DOAS with FCU
Miami, FL	-$0.05
Houston, TX	-$0.05
Phoenix, AZ	-$0.06
Memphis, TN	-$0.01
El Paso, TX	-$0.10
San Francisco, CA	-$0.15
Baltimore, MD	-$0.05
Albuquerque, NM	-$0.07
Seattle, WA	$0.01
Chicago, IL	$0.01
Boise, ID	$0.08
Burlington, VT	$0.02
Helena, MT	$0.00
Duluth, MN	$0.13
Fairbanks, AK	$0.06

C-13 DOAS with Radiant Heating and Cooling

Table C.76. Annual energy savings for DOAS with radiant heating and cooling (kBtu/ft²-yr).

Location	Radiant
Miami, FL	3.97
Houston, TX	2.57
Phoenix, AZ	2.57
Memphis, TN	2.67
El Paso, TX	-2.29
San Francisco, CA	-5.08
Baltimore, MD	5.88
Albuquerque, NM	-0.73
Seattle, WA	3.22
Chicago, IL	10.36
Boise, ID	4.26
Burlington, VT	12.97
Helena, MT	7.20
Duluth, MN	16.91
Fairbanks, AK	38.93

Table C.77. Annual energy savings for DOAS with radiant heating and cooling (kWh/m²-yr).

Location	Radiant
Miami, FL	12.53
Houston, TX	8.12
Phoenix, AZ	8.11
Memphis, TN	8.42
El Paso, TX	-7.21
San Francisco, CA	-16.01
Baltimore, MD	18.55
Albuquerque, NM	-2.31
Seattle, WA	10.16
Chicago, IL	32.67
Boise, ID	13.45
Burlington, VT	40.90
Helena, MT	22.71
Duluth, MN	53.32
Fairbanks, AK	122.76

Table C.78. Annual energy cost savings for DOAS with radiant heating and cooling ($/ft²-yr).

Location	Radiant
Miami, FL	$0.12
Houston, TX	$0.08
Phoenix, AZ	$0.07
Memphis, TN	$0.05
El Paso, TX	$0.00
San Francisco, CA	-$0.07
Baltimore, MD	$0.10
Albuquerque, NM	$0.00
Seattle, WA	$0.04
Chicago, IL	$0.12
Boise, ID	$0.05
Burlington, VT	$0.17
Helena, MT	$0.07
Duluth, MN	$0.17
Fairbanks, AK	$0.31

Table C.79. Annual energy savings for DOAS with radiant heating and cooling – international locations (kWh/m²-yr).

Location	Radiant
Edmonton	45.16
Ottawa	33.59
Vancouver	28.91
Stuttgart	21.89
Copenhagen	10.26
Helsinki	14.50
Tampere	21.06
Lyon	9.71
Marseille	43.66
Nantes	47.40
Paris	53.74
London	32.12
Milan	49.52
Naples	19.35
Palermo	21.03
Rome	53.75

Table C.80. Annual energy cost savings for DOAS with radiant heating and cooling – Canadian locations ($/ft²-yr).

Location	Radiant
Edmonton	$3.95
Ottawa	$4.11
Vancouver	$4.44

Table C.81. Annual energy cost savings for DOAS with radiant heating and cooling – European locations (euro/m^2-yr).

Location	Radiant
Stuttgart	€ 5.04
Copenhagen	€ 3.60
Helsinki	€ 4.33
Tampere	€ 4.44
Lyon	€ 4.38
Marseille	€ 5.21
Nantes	€ 3.94
Paris	€ 3.73
London	€ 3.24
Milan	€ 4.94
Naples	€ 6.36
Palermo	€ 7.52
Rome	€ 5.76

C-14 Ground Source Heat Pumps

Table C.82. Annual energy savings for GSHPs (kBtu/ft^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	6.78	6.62	6.48	6.33	6.16	5.98
Houston, TX	13.05	12.97	12.90	12.82	12.74	12.64
Phoenix, AZ	12.32	12.53	12.72	12.89	13.03	13.11
Memphis, TN	16.05	16.87	16.80	16.67	16.51	16.34
El Paso, TX	10.31	10.63	11.07	11.26	11.19	11.03
San Francisco, CA	13.05	12.96	12.87	12.77	12.67	12.57
Baltimore, MD	22.52	22.83	22.72	22.58	22.42	22.25
Albuquerque, NM	15.21	15.41	15.32	15.18	15.03	14.86
Seattle, WA	16.69	16.61	16.50	16.38	16.25	16.12
Chicago, IL	31.36	32.03	31.93	31.77	31.60	31.42
Boise, ID	25.24	25.48	25.37	25.22	25.07	24.90
Burlington, VT	34.43	36.01	36.79	37.17	37.21	37.06
Helena, MT	29.00	29.83	30.29	30.61	30.82	30.92
Duluth, MN	41.29	40.69	40.23	39.72	39.16	38.57
Fairbanks, AK	6.78	6.62	6.48	6.33	6.16	5.98

Table C.83. Annual energy savings for GSHPs (kWh/m^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	21.38	20.89	20.44	19.95	19.41	18.85
Houston, TX	41.15	40.92	40.68	40.43	40.17	39.88
Phoenix, AZ	38.86	39.51	40.10	40.65	41.10	41.34
Memphis, TN	50.63	53.20	52.99	52.57	52.08	51.54
El Paso, TX	32.51	33.53	34.92	35.52	35.30	34.79
San Francisco, CA	41.15	40.88	40.59	40.28	39.97	39.65
Baltimore, MD	71.02	71.99	71.65	71.20	70.69	70.16
Albuquerque, NM	47.97	48.61	48.30	47.87	47.39	46.87
Seattle, WA	52.65	52.38	52.03	51.64	51.25	50.85
Chicago, IL	98.90	101.02	100.68	100.19	99.65	99.09
Boise, ID	79.61	80.36	80.00	79.54	79.05	78.53
Burlington, VT	108.57	113.57	116.03	117.23	117.34	116.88
Helena, MT	91.45	94.06	95.52	96.54	97.21	97.52
Duluth, MN	130.22	128.33	126.86	125.26	123.49	121.64
Fairbanks, AK	21.38	20.89	20.44	19.95	19.41	18.85

Table C.84. Annual energy cost savings for GSHPs ($/ft^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Miami, FL	$0.16	$0.15	$0.15	$0.14	$0.14	$0.13
Houston, TX	$0.14	$0.14	$0.14	$0.13	$0.13	$0.13
Phoenix, AZ	$0.16	$0.17	$0.17	$0.18	$0.18	$0.18
Memphis, TN	$0.17	$0.19	$0.19	$0.19	$0.18	$0.18
El Paso, TX	$0.01	$0.02	$0.03	$0.04	$0.03	$0.03
San Francisco, CA	-$0.08	-$0.09	-$0.09	-$0.09	-$0.10	-$0.10
Baltimore, MD	$0.17	$0.18	$0.18	$0.17	$0.17	$0.16
Albuquerque, NM	$0.05	$0.06	$0.06	$0.05	$0.05	$0.05
Seattle, WA	$0.13	$0.13	$0.13	$0.13	$0.12	$0.12
Chicago, IL	$0.20	$0.20	$0.20	$0.20	$0.19	$0.19
Boise, ID	$0.24	$0.24	$0.24	$0.24	$0.23	$0.23
Burlington, VT	$0.23	$0.25	$0.25	$0.25	$0.25	$0.24
Helena, MT	$0.13	$0.14	$0.14	$0.14	$0.14	$0.14
Duluth, MN	$0.29	$0.28	$0.28	$0.27	$0.26	$0.25
Fairbanks, AK	$0.16	$0.15	$0.15	$0.14	$0.14	$0.13

Table C.85. Annual energy savings for GSHPs – international locations (kWh/m^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Edmonton	83.06	83.75	83.83	83.87	83.89	83.91
Ottawa	74.24	74.94	75.05	75.11	75.15	75.18
Vancouver	51.97	52.06	52.09	52.11	52.12	52.12
Stuttgart	73.28	78.76	79.20	79.32	79.40	79.45
Copenhagen	44.54	46.23	46.33	46.38	46.42	46.44
Helsinki	113.22	115.58	115.71	115.78	115.82	115.85
Tampere	119.67	122.37	122.55	122.63	122.67	122.71
Lyon	58.36	59.19	59.35	59.43	59.49	59.52
Marseille	54.11	55.28	55.57	55.72	55.81	55.88
Nantes	51.51	51.85	51.94	51.98	52.02	52.04
Paris	54.73	55.11	55.20	55.26	55.29	55.31
London	56.71	60.83	61.06	61.15	61.21	61.25
Milan	59.04	60.01	60.26	60.38	60.47	60.52
Naples	52.19	53.63	54.08	54.28	54.40	54.49
Palermo	57.79	59.29	59.78	60.01	60.16	60.25
Rome	48.85	50.11	50.53	50.73	50.86	50.95

Table C.86. Annual energy cost savings for GSHPs – Canadian locations ($/ft^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Edmonton	$9.53	$9.60	$9.61	$9.62	$9.63	$9.63
Ottawa	$8.88	$8.97	$8.99	$9.00	$9.01	$9.01
Vancouver	$7.27	$7.28	$7.29	$7.29	$7.29	$7.29

Table C.87. Annual energy cost savings for GSHPs – European locations (euro/m^2-yr).

Location	GSHP 25-5x5	GSHP 50-5x10	GSHP 70-5x14	GSHP 90-5x18	GSHP 110-10x11	GSHP 130-10x13
Stuttgart	€ 9.69	€ 10.34	€ 10.42	€ 10.46	€ 10.48	€ 10.49
Copenhagen	€ 6.58	€ 6.81	€ 6.83	€ 6.85	€ 6.86	€ 6.86
Helsinki	€ 17.49	€ 17.79	€ 17.82	€ 17.84	€ 17.85	€ 17.86
Tampere	€ 18.21	€ 18.54	€ 18.59	€ 18.61	€ 18.62	€ 18.63
Lyon	€ 12.26	€ 12.46	€ 12.50	€ 12.53	€ 12.54	€ 12.55
Marseille	€ 12.94	€ 13.26	€ 13.34	€ 13.38	€ 13.40	€ 13.42
Nantes	€ 11.37	€ 11.46	€ 11.48	€ 11.49	€ 11.50	€ 11.51
Paris	€ 11.09	€ 11.18	€ 11.21	€ 11.22	€ 11.23	€ 11.24
London	€ 5.84	€ 6.23	€ 6.27	€ 6.29	€ 6.30	€ 6.31
Milan	€ 12.81	€ 13.07	€ 13.13	€ 13.17	€ 13.19	€ 13.20
Naples	€ 13.29	€ 13.68	€ 13.80	€ 13.85	€ 13.88	€ 13.91
Palermo	€ 15.35	€ 15.76	€ 15.89	€ 15.95	€ 15.99	€ 16.02
Rome	€ 12.18	€ 12.52	€ 12.63	€ 12.68	€ 12.72	€ 12.74

C-15 Reheat Using Condenser Waste Heat

Table C.88. Annual energy savings for reheat using condenser waste (kBtu/ft²-yr).

Location	Reheat
Miami, FL	1.34
Houston, TX	2.53
Phoenix, AZ	2.59
Memphis, TN	2.67
El Paso, TX	2.41
San Francisco, CA	3.74
Baltimore, MD	2.67
Albuquerque, NM	2.90
Seattle, WA	1.84
Chicago, IL	4.20
Boise, ID	3.23
Burlington, VT	4.31
Helena, MT	5.27
Duluth, MN	5.59
Fairbanks, AK	7.75

Table C.89. Annual energy savings for reheat using condenser waste (kWh/m²-yr).

Location	Reheat
Miami, FL	4.23
Houston, TX	7.98
Phoenix, AZ	8.17
Memphis, TN	8.41
El Paso, TX	7.60
San Francisco, CA	11.80
Baltimore, MD	8.42
Albuquerque, NM	9.13
Seattle, WA	5.80
Chicago, IL	13.25
Boise, ID	10.18
Burlington, VT	13.59
Helena, MT	16.61
Duluth, MN	17.62
Fairbanks, AK	24.45

Table C.90. Annual energy cost savings for reheat using condenser waste ($/ft²-yr).

Location	Reheat
Miami, FL	$0.02
Houston, TX	$0.03
Phoenix, AZ	$0.03
Memphis, TN	$0.03
El Paso, TX	$0.02
San Francisco, CA	$0.04
Baltimore, MD	$0.04
Albuquerque, NM	$0.03
Seattle, WA	$0.02
Chicago, IL	$0.04
Boise, ID	$0.03
Burlington, VT	$0.06
Helena, MT	$0.05
Duluth, MN	$0.06
Fairbanks, AK	$0.06

Table C.91. Annual energy savings for reheat using condenser waste – international locations (kWh/m^2-yr).

Location	Reheat
Edmonton	0.098
Ottawa	0.205
Vancouver	0.038
Stuttgart	0.105
Copenhagen	0.101
Helsinki	0.261
Tampere	0.142
Lyon	0.319
Marseille	0.379
Nantes	0.560
Paris	0.314
London	0.291
Milan	0.127
Naples	0.528
Palermo	1.676
Rome	0.485

Table C.92. Annual energy cost savings for reheat using condenser waste – Canadian locations ($/ft^2-yr).

Location	Reheat
Edmonton	$0.00
Ottawa	$0.02
Vancouver	$0.00

Table C.93. Annual energy cost savings for reheat using condenser waste – European locations (euro/m^2-yr).

Location	Reheat
Stuttgart	€ 0.02
Copenhagen	€ 0.02
Helsinki	€ 0.04
Tampere	€ 0.03
Lyon	€ 0.06
Marseille	€ 0.06
Nantes	€ 0.10
Paris	€ 0.05
London	€ 0.04
Milan	€ 0.02
Naples	€ 0.08
Palermo	€ 0.26
Rome	€ 0.08

APPENDIX D

Summary of Energy Model Schedules (Admin Facilities)

Table D.1. Hourly schedule values (hours 1-12).

Schedule	Type	Through	Day of Week	Hour of Day											
				1	2	3	4	5	6	7	8	9	10	11	12
BLDG_LIGHT	Fraction	12/31	WD	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9
			Summer Design	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.3	0.3	0.3
			Winter Design	0	0	0	0	0	0	0	0	0	0	0	0
			Sun, Hol, Other	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BLDG_EQUIP	Fraction	12/31	WD	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.9	0.9	0.9	0.9
			Summer Design	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5
			Winter Design	0	0	0	0	0	0	0	0	0	0	0	0
			Sun, Hol, Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
BLDG_OCC	Fraction	12/31	WD	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95
			Summer Design	0	0	0	0	0	0	1	1	1	1	1	1
			Sat	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.3	0.3
			Winter Design	0	0	0	0	0	0	0	0	0	0	0	0
			Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0
INFIL	Fraction	12/31	WD, Summer Design	1	1	1	1	1	1	0	0	0	0	0	0
			Sat, Winter Design	1	1	1	1	1	1	0	0	0	0	0	0
			Sun, Hol, Other	1	1	1	1	1	1	1	1	1	1	1	1
ALWAYS_ON	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HVACOperation	On/Off	12/31	WD, Summer Design	0	0	0	0	0	0	1	1	1	1	1	1
			Sat, Winter Design	0	0	0	0	0	0	1	1	1	1	1	1
			Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0
PlantOnSched	On/Off	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HTGSETP	Temp.	12/31	WD, Winter Design	15.6	15.6	15.6	15.6	15.6	21	21	21	21	21	21	21
			Summer Design	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
			Sat	15.6	15.6	15.6	15.6	15.6	15.6	21	21	21	21	21	21
			Sun, Hol, Other	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
CLGSETP	Temp.	12/31	WD, Summer Design	30	30	30	30	30	30	24	24	24	24	24	24
			Sat	30	30	30	30	30	30	24	24	24	24	24	24
			Winter Design	30	30	30	30	30	30	30	30	30	30	30	30
			Sun, Hol, Other	30	30	30	30	30	30	30	30	30	30	30	30
MinOAed	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
Dual Zone Control Type	Control Type	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
Seasonal-Reset-Supply-Air-Temp	Temp.	3/31	All	13	13	13	13	13	13	13	13	13	13	13	13
		9/30	All	13	13	13	13	13	13	13	13	13	13	13	13
		12/31	All	13	13	13	13	13	13	13	13	13	13	13	13
CW-Loop-Temp	Temp.	12/31	All	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
HW-Loop-Temp	Temp.	12/31	All	60	60	60	60	60	60	60	60	60	60	60	60
ACTIVITY	Any Number	12/31	All	120	120	120	120	120	120	120	120	120	120	120	120
WORK_EFF	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
AIR_VELO	Any Number	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING	Any Number	04/30	All	1	1	1	1	1	1	1	1	1	1	1	1
		09/30	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/31	All	1	1	1	1	1	1	1	1	1	1	1	1

Table D.2. Hourly schedule values (hours 13-24).

Schedule	Type	Through	Day of Week	Hour of Day											
				13	14	15	16	17	18	19	20	21	22	23	24
BLDG_LIGHT	Fraction	12/31	WD	0.9	0.9	0.9	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.1	0.05
			Summer Design	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	0.15	0.15	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
			Winter Design	0	0	0	0	0	0	0	0	0	0	0	0
			Sun, Hol, Other	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BLDG_EQUIP	Fraction	12/31	WD	0.8	0.9	0.9	0.9	0.9	0.5	0.4	0.4	0.4	0.4	0.4	0.4
			Summer Design	1	1	1	1	1	1	1	1	1	1	1	1
			Sat	0.35	0.35	0.35	0.35	0.35	0.3	0.3	0.3	0.3	0.3	0.3	0.3
			Winter Design	0	0	0	0	0	0	0	0	0	0	0	0
			Sun, Hol, Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
BLDG_OCC	Fraction	12/31	WD	0.5	0.95	0.95	0.95	0.95	0.3	0.1	0.1	0.05	0.05	0.05	0.05
			Summer Design	1	1	1	1	1	1	1	1	1	1	0.05	0.05
			Sat	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0
			Winter Design	0	0	0	0	0	0	0	0	0	0	0	0
			Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0
INFIL	Fraction	12/31	WD, Summer Design	0	0	0	0	0	0	0	0	0	0	1	1
			Sat, Winter Design	0	0	0	0	0	0	1	1	1	1	1	1
			Sun, Hol, Other	1	1	1	1	1	1	1	1	1	1	1	1
ALWAYS_ON	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HVACOperation	On/Off	12/31	WD, Summer Design	1	1	1	1	1	1	1	1	1	1	0	0
			Sat, Winter Design	1	1	1	1	1	1	0	0	0	0	0	0
			Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0
PlantOnSched	On/Off	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
HTGSETP	Temp.	12/31	WD, Winter Design	21	21	21	21	21	21	21	13	13	13	13	13
			Summer Design	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
			Sat	21	21	21	21	21	15.6	15.6	15.6	15.6	15.6	15.6	15.6
			Sun, Hol, Other	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
CLGSETP	Temp.	12/31	WD, Summer Design	24	24	24	24	24	24	24	24	24	24	30	30
			Sat	24	24	24	24	24	24	30	30	30	30	30	30
			Winter Design	30	30	30	30	30	30	30	30	30	30	30	30
			Sun, Hol, Other	30	30	30	30	30	30	30	30	30	30	30	30
MinOAed	Fraction	12/31	All	1	1	1	1	1	1	1	1	1	1	1	1
Dual Zone Control Type	Control Type	12/31	All	4	4	4	4	4	4	4	4	4	4	4	4
Seasonal-Reset-Supply-Air-Temp	Temp.	3/31	All	13	13	13	13	13	13	13	13	13	13	13	13
		9/30	All	13	13	13	13	13	13	13	13	13	13	13	13
		12/31	All	13	13	13	13	13	13	13	13	13	13	13	13
CW-Loop-Temp	Temp.	12/31	All	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
HW-Loop-Temp	Temp.	12/31	All	60	60	60	60	60	60	60	60	60	60	60	60
ACTIVITY	Any Number	12/31	All	120	120	120	120	120	120	120	120	120	120	120	120
WORK_EFF	Fraction	12/31	All	0	0	0	0	0	0	0	0	0	0	0	0
AIR_VELO	Any Number	12/31	All	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CLOTHING	Any Number	04/30	All	1	1	1	1	1	1	1	1	1	1	1	1
		09/30	All	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/31	All	1	1	1	1	1	1	1	1	1	1	1	1