Business and Technical Concepts of Deep Energy Retrofit of Public Buildings - IEA EBC Annex 61

EBC
Energy in Buildings and Communities Programme

Optimization of Bundles of Core Energy Conservation Technologies for Deep Energy Retrofit

Subtask A

Objectives

- **Analyze and optimize characteristics of limited bundles of ECM to be used in Deep Energy Retrofit Projects (providing 50-60% site energy use reduction compared to the baseline)**
- **Three categories of Buildings:**
  - **Barracks/dormitories/subsidized public housing**
  - **Offices**
  - **Educational buildings (schools, training facilities, etc)**
- **16 climate zones covering all climate conditions in Europe and North America**
- **Energy prices: Gas 2.7c/kWh – 9.7c/kWh; Electricity: 8c/kWh - 35c/kWh**

Modeling team

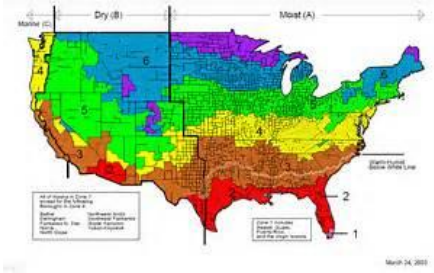
Country	Organization	Name	Building type		
			B/D/H	Of	Ed/Tr
Austria	AEE	Heimo Staller	Y		
Canada	McMaster University	Samir Chidiac		Y	
Denmark	Danish Building Research Institute, SBi	Kirsten Engelund Thomsen			Y
Estonia	Tallinn University of Technology	Targo Kalamees, Kalle Kuusk, Simon Ilomets, Üllar Alev, Endrik Arumägi	Y		
	University of Tartu	Tonu Mauring			
Germany	KEA	Martina Riel		Y	
	Passive House Institute	Berthold Kaufmann			
UK	University of Reading	Runming Yao		(UK/China)	
USA	USACE ERDC	Alexander Zhivov	Y	Y	
	NREL	Michael Deru			Y
	USACE ERDC	Richard Liesen	Y	Y	?
	USACE ERDC	Michael Case	Y	Y	?
	Ebert and Baumann Cons. Engrs.	Annie Marston			
	M.E. GROUP, INC	Ravi Maniktala, Miles Dake		Y	
	Pennsylvania State University	Mohammad Heidernejad	Y	Y	Y

Approach

- Each building modeler will use building models they have proposed for the study and conduct the study using climate zone (s) of their country (using representative cities as minimum and for all 15 climates zones if they chose to;
- Conduct modeling for the following scenarios and calculate site and source energy use:
  - **Scenario 1** - Baseline: pre-1980 standard to describe the building envelope and systems. Think about building use and systems operation schedules as well as appliances and their use in W/m2, which I suggest to keep the same for all scenarios, though they will be improved/reduced over time;
  - **Scenario 2** – Business as usual (the base case) – building improvement to meet minimum current standards (usually related to energy efficiency of fans, motors, chillers, furnaces, lighting fixtures, etc). E.g., for the USA this will be the ASHRAE Standard 90.1 2010, which is referred to in the recent 10 CFR-433. Typical energy use reduction using such approach does not exceed 10-15% from the baseline. For Germany this will be EnEV 2014 with a typical energy use reduction of 30- 40% at a level which is allowed for +30% compared to the requirements for a new building.
  - **Scenario 3** – Investigate what it will take (optimize parameters of the core technology bundles listed in Appendix 2, including listed in the Table below), to achieve 50% energy user reduction against the baseline or select the minimum current requirement (whatever is more stringent)
  - **Scenario 4** – Investigate characteristics / parameters of the core technology bundles listed in attachment 2) to achieve the current national dream energy use intensity levels in the renovated building (e.g., passive house requirement). The site and source energy to be achieved here shall be presented in kWh/m² (total for heating, cooling and electricity);
- Calculate annual energy cost for all scenarios using different levels of energy cost
- Calculate the budget increase limit against the base case for scenarios 3 and 4, which can be used for energy enhancements using SCALAR RATIOS developed by the ASHRAE

Climates

US DOE Climate Zones



1a-7a – humid
2b-8b – dry
3c, 5c - marine

Country	Climate zone(s)	Representative City
Austria	4a and 5a	Braganza, Innsbruck, Klagenfurt, Linz, Wien, Eisenstaedt, Graz
Canada	5c, 6a, 7, 8	Edmonton, Ottawa, Vancouver
Denmark	5a	Copenhagen
Estonia	6a	Tartu
Finland	6a and 7	Vantaa, Jyväskylä, Sodankylä
Germany	5a	Wurzburg
UK	4a	London
UK/China	4a	Beijing
USA	1a-8b	Miami, Houston, Phoenix, Memphis, El Paso, San Francisco, Baltimore, Albuquerque, Seattle, Chicago, Colorado Springs, Burlington, Helena, Duluth, Fairbanks

Core Technologies Bundle

Category	Name	Specification
Building Envelope	Roof insulation	Level to be defined through modeling
	Wall insulation	Level to be defined through modeling
	Slab Insulation	Level to be defined through modeling
	Windows	Parameters to be defined through modeling
	Doors	Parameters to be defined through modeling
	Thermal bridges remediation	See the BE Guide
	Air tightness	0.15 cfm/ft2 (for USA)
	Vapor Barrier	See the BE Guide
	BE QA	See the BE Guide
Lighting and Electrical Systems	Lighting design , technologies and controls	See the USACE Lighting Guide
	Advanced plug loads, smart power strips and process equipment	TopTen (Europe, USA), Top Tier EnergyStar, FEMP Designated, etc
HVAC	High performance motors, fans, furnaces, chillers, boilers, etc	ASHRAE Std 90.1 2013 and EPBD (Table will be provided in the Guide)
	DOAS	See the Guide
	HR (dry and wet)	>80% efficient, see the Guide
	Duct insulation	Based on EPBD requirements
	Duct airtightness	Based on EPBD requirements
	Pipe insulation	Based on EPBD requirements

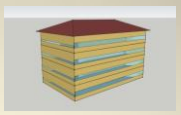
Baseline and Current Minimum Energy Standards for Building Renovation

Country	Baseline	Current Minimum Requirement
Austria		
Canada		
Denmark		
Estonia		
Finland		
Germany	Before WSVO 1977	for refurbishment: EnEV 2014 +40%: refurbishments are allowed for 40% higher level than new building.
UK		
USA	ASHRAE Std 90.1 1980	ASHRAE Std 90.1 2010

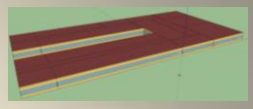
Building Models used by the Modeling Team

USA, ERDC
Climate Zones 1-8

Barracks

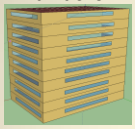


Office, Battalion HQ

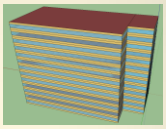


General Instruction Building

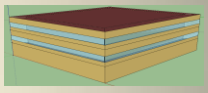
USA, PSU
Climate zones 1-8



Dormitory



Campus Lab



Campus Office

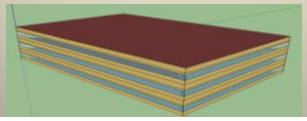
Estonia, TTU

Public housing, Climate zone 6A

USA, ME Group

Dormitory, Climate zone 5B

UK, Reading University



Office Building
London, climate zone 4A
Beijing, climate zone 4A

Building Models used by the Modeling Team

Germany, KEA
Germany, PHI

School Building, Climate Zone 5A

Austria, AEE

Public housing, Climate Zones 4A and 5A

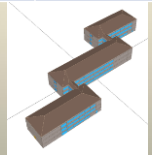
Denmark, Danish Building Research Institute, SBi

School Building, Climate zone 5A

Canada, McMaster University

Building Type	Number of storey's	Building area, m²	Climates zones
Low rise office	2	9,000	5A ,5C, 6A, 7, 8
Medium rise office	10	45,000	5A, 5C, 6A, 7, 8
High rise office	18	81,000	5A, 5C, 6A, 7, 8

USA, NREL

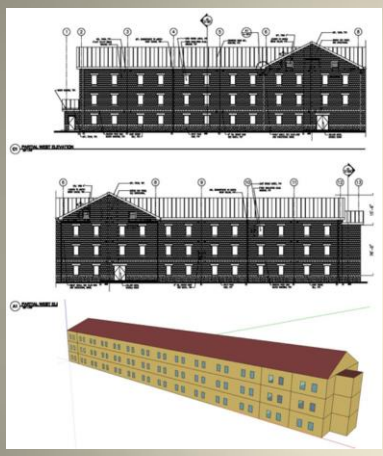


Educational Building Complex, Zone 3C

Panel Discussion

Tõnu Mauring, University of Tartu, (Estonia)
Samir Chidiak, Mc Master University, (Canada)
Heimo Staller, AEE (Austria)
Martina Riel, KEA (Germany)
Kirsten Engelund Thomsen, SBI AAU (Denmark)
Alexander Zhivov, ERDC

Army Barracks Building



Climate Zone	City
1A	Miami, FL
2A	Houston, TX
2B	Phoenix, AZ
3A	Memphis, TN
3B	El Paso, TX
3C	San Francisco, CA
4A	Baltimore, MD
4B	Albuquerque, NM
4C	Seattle, WA
5A	Chicago, IL
5B	Colorado Springs, CO
6A	Burlington, VT
6B	Helena, MT

Model Building contains 56 double occupancy units.
Each apartment unit has two bedrooms with a storage area, one shared bathroom, a kitchen, a mechanical room, and a storage area.
The first floor has 18 units, a laundry room, a common area, a mechanical room, and a storage area.
The second and third floors have 19 units. Each floor is 1696 m^2 and the building is 5088.4 m^2

Building Component	Baseline Building Model	Base Case Building Model	Efficient Building Model
Area	54,771 sq ft (5088.4 m^2)	Same as baseline	Same as baseline
Floors	3	Same as baseline	Same as baseline
Orientation	Long axis running east and west	Same as baseline	Same as baseline
Window to wall ratio	15% on north and south facades	Same as baseline	Same as baseline
Window type	Standard 90.1-1980	Standard 90.1 2010	See Table 4
Wall construction	Steel frame	Same as baseline	Same as baseline
Wall insulation	Standard 90.1-1980	Standard 90.1 2010	See Table 3
Roof construction	Sloped roof and attic with insulation at the roof level	Sloped metal roof and attic with insulation at the ceiling level	Sloped metal roof and attic with insulation at the ceiling level
Roof insulation	Standard 90.1-1980 equal to the "insulation entirely above deck"	Standard 90.1-2010 equal to the "insulation entirely above deck"	See Table 3
Infiltration	1.2 cfm/sq ft @ 0.3 inch w.c.	0.4 cfm/sq ft @ 0.3 inch w.c.	0.15 cfm/sq ft @ 0.3 inch w.c.
Lighting	Rooms - 1.1 W/sq ft (11.8 W/m^2) Corridors: 1.1 W/sq ft (11.8 W/m^2) See Table 6	Rooms – 1.0 W/sq ft (10.8 W/m^2) Corridors: 0.5 W/sq ft (5.4 W/m^2) See Table 6	Rooms – 0.6 W/sq ft (6.5 W/m^2) Corridors: 0.35 W/sq ft (3.8 W/m^2) See Table 6
Plug loads	1.7 W/sq ft (18.3 W/m^2) plus refrigerator and range	1.7 W/sq ft (18.3 W/m^2) plus refrigerator and range	0.835 W/sq ft (W/m^2) plus refrigerator and range
Temp set points	70°F (21.1C) heating; 75°F (23.9 C) cooling, no set back	Same as baseline	Same as baseline
HVAC	DOAS (2.1 COP), central natural gas boiler hot water system (0.80 E_t), 4-pipe Fan Coil Units (FCU's) for zone temperature control.	DOAS (2.87 COP), central natural gas boiler hot water system (0.80 E_t), 4-pipe Fan Coil Units (FCU's) for zone temperature control.	DOAS (4.4 COP), central natural gas boiler hot water system (0.80 E_t), 4-pipe Fan Coil Units (FCU's) for zone temperature control.
DHW	Standard natural gas boiler (0.8 E_t)	Standard natural gas boiler (0.8 E_t)	Condensing natural gas boiler (0.95 E_t)

Table 3. Wall and Roof Insulation Values

Climate Zone	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
Walls (in order from most to least stringent)															
Wall Insulation Passive House R-Value	R-19+ R7.5ci	R-19+ R15ci	R-19+ R15ci	R-19+ R20ci	R-19+ R20ci	R-19+ R10ci	R-19+ R25ci	R-19+ R25ci	R-19+ R20ci	R-19+ R30ci	R-19+ R30ci	R-19+ R40ci	R-19+ R40ci	R-19+ R50ci	R-19+ R50ci
WBDG, Army specs—Steel-Framed Walls	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R12.5ci	R-13+ R12.5ci	R-13+ R12.5ci	R-13+ R12.5ci	R-13+ R18.8ci	R-13+ R18.8ci	R-13+ R18.8ci	R-13+ R18.8ci
90.1-2010 addenda bb—Steel-Framed Walls	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci
189.1–2009—Steel-Framed Walls	R-13+ R5.0ci	R-13+ R5.0ci	R-13+ R5.0ci	R-13+ R5.0ci	R-13+ R5.0ci	R-13+ R5.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci	R-13+ R10.0ci
ASHRAE AEDG—Steel-Framed Walls	R-13.0	R-13.0	R-13.0	R-13+ R3.8ci	R-13+ R3.8ci	R-13+ R3.8ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R21.6ci
90.1–2007—Steel-Framed Walls	R-13.0	R-13.0	R-13.0	R-13+ R3.8ci	R-13+ R3.8ci	R-13+ R3.8ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci	R-13+ R7.5ci
Roofs (in order from most to least stringent)															
Roof Insulation Passive House R-Value	R-25	R-30	R-30	R-35	R-35	R-25	R-45	R-45	R-35	R-55	R-55	R-70	R-70	R-80	R-90
WBDG, Army specs—Roofs insulation above deck	R-25	R-25	R-25	R-25	R-25	R-25	R-30	R-30	R-30	R-30	R-30	R-40	R-40	R-40	R-40
90.1-2010 addenda bb—Roofs insulation above deck	R-20	R-25	R-25	R-25	R-25	R-25	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-35	R-35
189.1–2009—Roofs insulation above deck	R-20	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-25	R-30	R-30	R-35	R-35
ASHRAE AEDG—Roofs insulation above deck	R-15	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20
90.1–2007—Roofs insulation above deck	R-15	R-15	R-15	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-20	R-30

Table 4. Window Values

	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7A	8A
	Miami, FL	Houston, TX	Phoenix, AZ	Memphis, TN	El Paso, TX	San Francisco, CA	Baltimore, MD	Albuquerque, NM	Seattle, WA	Chicago, IL	Colorado Springs, CO	Burlington, VT	Helena, MT	Duluth, MN	Fairbanks, AK
Windows															
Passive Haus Window Specifications															
U-Value (Btu/h/ft^2/°F)	0.26	0.26	0.26	0.26	0.26	0.26	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
U-Value (W/m^2/K)	1.48	1.48	1.48	1.48	1.48	1.48	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
SHGC	0.25	0.25	0.25	0.39	0.39	0.39	0.39	0.39	0.39	0.49	0.49	0.49	0.49	0.49	0.49
VT	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50	>0.50
WWR	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%	<30%
Army WBDG— Window Specifications															
U-Value (Btu/h/ft^2/°F)	0.45	0.45	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.33	0.33
U-Value (W/m^2/K)	2.56	2.56	2.56	2.56	2.56	2.56	2.38	2.38	2.38	2.38	2.38	2.38	2.38	1.87	1.87
SHGC	0.25	0.25	0.25	0.37	0.37	0.37	0.39	0.39	0.39	0.39	0.39	0.39	0.39	NR	NR
VT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
ASHRAE 189.1 Window Specifications															
U-Value (Btu/h/ft^2/°F)	1.20	0.75	0.75	0.55	0.55	0.55	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.35	0.35
U-Value (W/m^2/K)	6.81	4.26	4.26	3.12	3.12	3.12	2.56	2.56	2.56	2.56	2.56	2.56	2.56	1.99	1.99
SHGC	0.25	0.25	0.25	0.25	0.25	0.25	0.35	0.35	0.35	0.35	0.35	0.40	0.40	0.45	0.45
VT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
ASHRAE 90.1-2007 Window Specifications															
U-Value (Btu/h/ft^2/°F)	1.20	0.75	0.75	0.65	0.65	0.65	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.45	0.45
U-Value (W/m^2/K)	6.81	4.26	4.26	3.69	3.69	3.69	3.12	3.12	3.12	3.12	3.12	3.12	3.12	2.56	2.56
SHGC	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.40	NR	NR
VT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Army Proposed															
Army Required															

Results for Climate Zone 3

Scenarios	Site Electricity Intensity (kWh/ m²)	Site Electricity Reduction (%)	Site Gas Intensity (kWh/m^2)	Site Gas Reduction (%)	Site Total Energy (kWh)	Site Total Energy Reduction (%)
Baseline	219.81	0	144.38	0	1,853,140	0
ASHRAE 90.1 2010	178.49	18.79	120.3	16.68	1,520,394	18%
Baseline - 50%	106.21	51.68	58.7	59.34	839,120	55%

Package	Energy Reduction, %
Pre-1980 Baseline	0
Envelope Package	20.9
Infiltration Package	23.2
Lighting Package	26.3
HVAC Package	35.7
Energy Recovery Package	**45.1**
DHW Package	**48.9**
Internal Equipment Package	**54.7**

Results for Climate Zone 5

Scenarios	Site Electricity Intensity (kWh/ m²)	Site Electricity Reduction (%)	Site Gas Intensity (kWh/m^2)	Site Gas Reduction (%)	Site Total Energy (kWh)	Site Total Energy Reduction (%)
Baseline	182.33	0	248.39	0	2,191,689	0
ASHRAE 90.1 2010	151.92	16.68	184.17	25.86	1,710,159	22%
Baseline plus 50%	90.57	50.33	72.66	70.75	830,580	62%

Package	Energy Reduction, %
Pre-1980 Baseline	0
Envelope Package	26.4
Infiltration Package	29.2
Lighting Package	31.4
HVAC Package	39.2
Energy Recovery Package	**55.2**
DHW Package	**58.3**
Internal Equipment Package	**62.1**

Results for Climate Zone 6

Scenarios	Site Electricity Intensity (kWh/ m^2)	Site Electricity Reduction (%)	Site Gas Intensity (kWh/m^2)	Site Gas Reduction (%)	Site Total Energy (kWh)	Site Total Energy Reduction (%)
Baseline	152.86	0	327.42	0	2,443,868	0
ASHRAE 90.1 2010	132.94	13.03	242.61	25.9	1,910,958	22%
Baseline - 50%	79.02	48.31	82.15	74.91	820,087	66%

Package	Energy Reduction, %
Pre-1980 Baseline	0
Envelope Package	26.9
Infiltration Package	30.0
Lighting Package	31.9
HVAC Package	39.0
Energy Recovery Package	60.6
DHW Package	63.4
Internal Equipment Package	66.4

Heating, Cooling and Lighting Power Energy Reduction

Scenario	Heating Energy Reduction,%			Cooling Energy Reduction, %			Lighting Energy Reduction, %		
	c.z. 3	c.z. 5	c.z. 6	c.z. 3	c.z. 5	c.z. 6	c.z. 3	c.z. 5	c.z. 6
Base Case	34%	37%	34%	32%	31%	26%	19%	19%	19%
DER	86%	86%	87%	61%	62%	62%	59%	59%	59%

DER in Climate Zone 6

Electricity Gas Details Total Resource Breakdown

Resource Type	January (kWh/m^2)	February (kWh/m^2)	March (kWh/m^2)	April (kWh/m^2)	May (kWh/m^2)	June (kWh/m^2)	July (kWh/m^2)	August (kWh/m^2)	September (kWh/m^2)	October (kWh/m^2)	November (kWh/m^2)	December (kWh/m^2)	Annual EUI (kWh/m^2)
Electricity	5.82	5.25	5.87	5.83	7.10	7.70	8.49	8.46	6.86	6.13	5.68	5.82	79.02

Details Total Resource Breakdown

End Use	January (kWh/m^2)	February (kWh/m^2)	March (kWh/m^2)	April (kWh/m^2)	May (kWh/m^2)	June (kWh/m^2)	July (kWh/m^2)	August (kWh/m^2)	September (kWh/m^2)	October (kWh/m^2)	November (kWh/m^2)	December (kWh/m^2)	Annual EUI (kW
INTERIORLIGHTS	1.35	1.22	1.35	1.31	1.35	1.31	1.35	1.35	1.31	1.35	1.31	1.35	15.91
INTERIOREQUIPMENT	3.87	3.49	3.86	3.74	3.86	3.74	3.86	3.86	3.74	3.87	3.75	3.86	45.50
FANS	0.54	0.49	0.54	0.52	0.54	0.52	0.53	0.53	0.52	0.54	0.52	0.54	6.35
PUMPS	0.02	0.01	0.01	0.01	0.02	0.04	0.05	0.04	0.02	0.01	0.01	0.02	0.24
COOLING	0	0.01	0.08	0.22	1.30	2.08	2.68	2.66	1.25	0.33	0.05	0.01	10.68
HEATRECOVERY	0.04	0.03	0.04	0.04	0.02	0.02	0.01	0.01	0.02	0.04	0.04	0.04	0.34
	5.82	**5.25**	**5.87**	**5.83**	**7.10**	**7.70**	**8.49**	**8.46**	**6.86**	**6.13**	**5.68**	**5.82**	**79.02**

Gas	12.25	9.07	8.00	5.74	4.59	4.13	4.19	4.21	4.22	5.63	8.47	11.66	82.15

Details Total Resource Breakdown

End Use	January (kWh/m^2)	February (kWh/m^2)	March (kWh/m^2)	April (kWh/m^2)	May (kWh/m^2)	June (kWh/m^2)	July (kWh/m^2)	August (kWh/m^2)	September (kWh/m^2)	October (kWh/m^2)	November (kWh/m^2)	December (kWh/m^2)	Annual EUI (kW
HEATING	8.09	5.31	3.84	1.71	0.42	0.10	0.03	0.04	0.20	1.47	4.44	7.50	33.14
WATERSYSTEMS	4.16	3.76	4.16	4.03	4.16	4.03	4.16	4.16	4.03	4.16	4.03	4.16	49.01
	12.25	**9.07**	**8.00**	**5.74**	**4.59**	**4.13**	**4.19**	**4.21**	**4.22**	**5.63**	**8.47**	**11.66**	**82.15**

	18.06	**14.32**	**13.87**	**11.57**	**11.69**	**11.83**	**12.60**	**12.67**	**11.08**	**11.76**	**14.15**	**17.48**	**161.17**