International Energy Agency

EBC Annex 62 Ventilative Cooling

Project Summary Report

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June 2019

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Published by AECOM Ltd, St George's House, 5 St George's Road, Wimbledon, London SW19 4DR, United Kingdom

Participating countries in EBC: Australia, Austria, Belgium, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and the United States of America.

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Cover picture: The natural ventilation system at CML Kindergarten, Portugal, a case study
Source: Guilherme Carrilho da Graça

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Project Summary

The current trend in building energy efficiency towards nearly-zero energy buildings in many industrialised countries has inadvertently led to increased cooling demands. In fact, post-occupancy studies of high performance buildings have commonly revealed that the most frequently reported type of problem has been elevated indoor temperature levels. This situation has been encountered particularly in high performance residential buildings. This has been on account of the usual design process being too simplified and being based to a large extent on previously acquired experience and existing rules of thumb.

To reach a low energy need for heating, designers have typically applied guidelines created in the past for ‘passive solar’ buildings. For such buildings, insulation and airtightness have not been required to achieve the more demanding current levels, and today’s designers may therefore underestimate or even neglect the need for cooling loads to be addressed. For offices and other non-residential buildings, the challenges differ from residential buildings and mainly relate to the development of new approaches to reducing the existing energy use for cooling to meet high performance requirements.

Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces. This effective use of outside air reduces the energy use of cooling systems while maintaining thermal comfort. The most common technique is the use of increased ventilation airflow rates and ventilation during the night-time, but other technologies may be considered as well. In high performance buildings in temperate climates for example, the cooling demands depend less on the outdoor temperature, and more on solar insolation and internal heat gains. This naturally gives better potential for the use of ventilative cooling, as the cooling demand not only arises in the summer, but can occur all year round.

To counter increased cooling demands, ventilative cooling strategies were considered to be a closely-related group of low energy approaches with good potential as effective solutions. Therefore, the research and development objectives of the project were defined as follows:

– Analyse, develop and evaluate suitable design methods and tools for prediction of cooling need, ventilative cooling performance and risk of overheating in buildings.
– Give guidelines for integration of ventilative cooling in energy performance calculation methods and regulations, including specification and verification of key performance indicators.

– Extend the boundaries of existing ventilation solutions and their control strategies and develop recommendations for flexible and reliable ventilative cooling solutions that can create comfortable conditions under a wide range of climatic conditions.
– Demonstrate the performance of ventilative cooling solutions through analysis and evaluation of well-documented case studies.

The participating countries in this project were Australia, Austria, Belgium, P.R. China, Denmark, Finland, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Switzerland, United Kingdom, and USA. At the start of the project, the general technological development status of ventilative cooling for residential buildings was judged to be low in the participating countries, but with good potential identified for technology transfer between those countries. Moreover, there was considered to be only limited awareness among occupants and designers on how to cool such buildings in an efficient and energy optimal way. In contrast, the general status for offices and other non-residential buildings with full mechanical ventilation was thought to be reasonably advanced in the participating countries, although the increased use of electricity for fans would lessen the energy advantage. Again, good potential for technology transfer among those countries was identified at the outset for non-residential buildings.

It was determined during project planning that in most of the participating countries, prediction tools previously developed as part of their national mandatory energy rating systems are typically used for residences and small office buildings. Such tools are capable of computing basic estimates of cooling loads and within some of them the risk of overheating as well. For the design of large offices and other non-residential buildings, more detailed thermal calculation tools are typically used for evaluating the cooling need and overheating risk. While the technological development status of these calculation methods in the participating countries was estimated to be low, certain countries were assessed to be more advanced, also giving the opportunity for technology transfer.

Through the technological advances made in this project, the participants clearly demonstrated that ventilative cooling can have considerable impact on reducing the risk of overheating in all climates experienced within their countries. In cold and moderate climates, the risk of overheating can be eliminated completely, while in warm and hot climates supplementary cooling solutions are needed to ensure acceptable comfort levels. In cold climates, for example in Oslo, daytime ventilative cooling is sufficient to remove the cooling loads, while in most other climates it is essential to apply night cooling strategies to efficiently remove excess heat. In warm and hot climates, daytime ventilative cooling strategies have very limited effect, while night cooling strategies are more efficient.

By investigating 91 case studies of real buildings in the participating countries, the project has concluded a number of key lessons learned. Foremost of these is that ventilative cooling systems were found to be a cost-effective and energy efficient type of design for most of the case studies, but particularly for those with naturally ventilated systems. However, the design of a building incorporating ventilative cooling can be challenging and may require a lot of detailed building information to be taken into account.

A reduction of overheating and improvement of thermal comfort conditions were evident in the case study buildings that used outside air. It was determined that designing with the integration of manual operation and control was important, particularly in a residential setting.

The project has also found that while ventilative cooling systems may be designed to have high levels of thermal comfort, indoor air quality and energy performance, achieving these simultaneously was found to be difficult. All of the case studies emphasised that monitoring a building's performance post occupancy is important, if not essential, in building performance optimisation. Engaging with the building owners and operators as early as possible, even during the design stage, is integral to guaranteeing building performance for indoor air quality, thermal comfort, or energy savings. In some case studies, this specifically meant educating or working with the facilities operator or manager for the building, in others it meant educating the building occupants themselves.

The project has created a decision making tool that is capable of assessing the potential effectiveness of ventilative cooling strategies by taking into account building envelope thermal properties, occupancy patterns, internal gains, ventilation needs and the outdoor climate. This tool is intended for assessing the application of ventilative cooling at the conceptual design phase. Further, the project has developed new key performance indicators to characterise the energy benefits of ventilative cooling.

Following a state of the art review of the existing situation, recommendations have been devised for adequate implementation of ventilative cooling in standards, legislation and compliance tools, with the main focus on natural ventilative cooling parameters. In fact, the project has developed new work items relevant to ventilative cooling recently approved for application by the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO). The outcomes include recommendations relevant for European, ISO and national standards, as well as to national and regional legislation.

Project duration
2012 - 2018 (completed)

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Project Outcomes

1. Background

Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces. This effective use of outside air reduces the energy use of cooling systems while maintaining thermal comfort. The most common technique is the use of increased ventilation airflow rates and ventilation during the night-time, but other technologies may be considered as well.

The current development in building energy efficiency towards nearly-zero energy buildings (nZEBs) in many industrialised countries represents a number of new challenges to design and construction. One of the major new challenges is the increased need for cooling arising in highly insulated and airtight buildings such as these. The cooling demand depends less on the outdoor temperature, and more on solar radiation and internal heat gains. This naturally gives better potential for the use of ventilative cooling technologies, because the cooling need is not only in summer, but actually occurs all year round.

In most post-occupancy studies of high performance buildings, elevated temperatures form the most frequently reported type of problem. Also, conventional buildings can experience high temperatures resulting in a high need for cooling (for example commercial buildings with too high internal gains). There are several reasons as to why we presently are facing this situation in high performance buildings.

For **residential buildings**, the design process is much more simplified than for commercial buildings and is to a very large extent based on experiences and rules of thumb. To reach a low energy need for heating, designers typically apply guidelines for passive solar buildings developed in the past, in which insulation and airtightness levels were far from current levels, and they underestimate the need for cooling, or might not even take it into account.

Prediction of energy use in residential buildings is often based on simplified monthly methods and it is estimated for the residence as a whole. Averaging the need for cooling in both time and space underestimates the total cooling demand. Excess heat in spaces exposed to solar radiation is considered to be distributed fully to other spaces and excess solar radiation during daytime is partly distributed to night-time. Due to these simplifications, the real need for cooling to ensure acceptable temperature levels in all spaces will be higher than the predicted one. Cooling and overheating in dwellings have so far not been considered a design challenge, especially in colder climates. Therefore, the developed solutions to address cooling issues available for residential application are very limited, are often too simplified and might not be well-adapted for practical application. In a few cases, where the cooling challenge was addressed by a 'one-of-a-kind' design, it was found that the solutions were expensive and needed careful commissioning to function.

Finally, especially for owners of high performance buildings in cold climate countries, cooling might be an unknown challenge that they have not experienced before. They do not know how to effectively reduce the overheating in their buildings and their behaviour might instead actually worsen the problem. If technologies such as solar shading and ventilative cooling are applied, it is critical to use an appropriate control and operation strategy, taking into account occupant behaviour, to make sure that they operate successfully.

For **offices and other non-residential buildings**, the challenges are different from residential buildings and are mainly related to the development of new approaches towards reduction of the existing energy use for cooling. Sometimes, the cooling potential of outdoor air is already utilised in a mechanical ventilation system. However, due to thermal comfort issues and the risk of draught, limited temperature differences between supply air and room can be utilized making heat recovery or air pre-heating necessary. The result of this is a cooling capacity reduction and an increased airflow rate - sometimes with a factor of more than five. In mechanical ventilation systems, this leads to an increase in energy use for air distribution and an increased investment in equipment. As a result, the energy and cost advantage of utilising the free cooling potential of the outdoor air in a mechanical ventilation system compared to a mechanical cooling solution might become very limited.

These limitations do not apply to the same extent when the outdoor air cooling potential is applied to a free-running building (naturally ventilated building) and thus the appropriate use of ventilative cooling in connection with natural ventilation in non-residential buildings could contribute significantly to a reduction of the energy use. Secondly, for buildings that are heavily insulated and airtight, the variations in excess heat load will significantly vary between occupied and unoccupied hours and between cloudy and sunny days. The dynamic thermal characteristics have a relatively high influence on energy use, and therefore, for reduction of cooling demand, exploitation of building thermal mass as heat storage in combination with night cooling is important for energy optimization.

2. Objectives

The objectives of the project were to:

– Analyse, develop and evaluate suitable design methods and tools for prediction of cooling need, ventilative cooling performance and risk of overheating in buildings.
– Give guidelines for integration of ventilative cooling in energy performance calculation methods and regulations including specification and verification of key performance indicators.

- Extend the boundaries of existing ventilation solutions and their control strategies and develop recommendations for flexible and reliable ventilative cooling solutions that can create comfortable conditions under a wide range of climatic conditions.
- Demonstrate the performance of ventilative cooling solutions through analysis and evaluation of well-documented case studies.

3. Definition and Principles

Ventilative cooling (VC) is defined as the application of the cooling capacity of the outdoor air flow by ventilation to reduce or even eliminate the cooling loads and / or the energy use by mechanical cooling in buildings, while guaranteeing a comfortable thermal environment.

Ventilative cooling utilizes the cooling and thermal perception potential of cool outdoor air and the air driving force can be natural, mechanical, or a combination of the two. The most common techniques are the use of increased daytime ventilation airflow rates and / or night-time ventilation.

The project developed appropriate ventilative cooling principles for different outdoor climatic conditions and building ventilation systems. These are summarized in Table 1.

4. Rationale

Ventilative cooling can be an attractive and energy efficient natural cooling solution to reduce cooling loads and to avoid overheating

Temperature difference	Ventilative cooling	Supplementary cooling options
Cold (ΔT more than 10°C)	Minimize air flow rate - draught free air supply	-
Temperate (2°C - 10°C lower than comfort zone)	Increasing air flow rate from minimum to maximum	Strategies for enhancement of natural driving forces to increase air flow rates Natural cooling strategies like evaporative cooling, earth to air heat exchange to reduce air intake temperature during daytime
Hot and dry (ΔT between -2°C and +2°C	Minimum air flow rate during daytime Maximum air flow rate during night time	Natural cooling strategies like evaporative cooling, earth to air heat exchange, thermal mass and phase change material (PCM) storage to reduce air intake temperature during daytime. Mechanical cooling strategies like ground source heat pump, mechanical cooling
Hot and humid	Natural or mechanical ventilation should provide minimum outdoor air supply	Mechanical cooling / dehumidification

1 Temperature difference between indoor comfort temperature and mean outdoor air temperature.

Table 1. Overview of typical ventilative cooling strategies applied depending on outdoor climatic conditions and type of ventilation system [1]

in buildings. Ventilation is already present in most buildings through mechanical and / or natural systems and by adapting them for cooling purposes, cooling can be provided in a cost-effective way (the prospect of lower investment and operation costs). Ventilative cooling can remove excess heat gains, as well as increase air velocities and thereby widen the thermal comfort range.

As cooling becomes a need not only in the summer period, the possibilities of utilizing the cooling potential of low temperature outdoor air increases considerably. However, it is most effective to address the cooling challenge through a combination of measures, including utilization of the potential of other passive measures like solar shading and thermal mass activation.

Naturally, expectations of ventilative cooling performance will vary between different countries because of climate variations, energy prices and other factors. In countries with cold climates, ventilative cooling can avoid the trend to use air conditioning in new buildings, which has occurred in response to heavily insulated and air tight building designs, higher occupant expectations and the requirements of building regulations, codes and standards. In countries with warm climates, it can reduce the reliance on air conditioning and reduce the cost, the energy penalty and the consequential environmental effects of full year-round air conditioning.

To illustrate potential expectations for ventilative cooling performance in different climates, the predictions of expected thermal comfort and cooling requirements reduction by utilization of ventilative cooling have been calculated for the same building configuration located in different climates. Figure 1 shows the impact of ventilative cooling in the form of cooling requirement reduction and expected reduction in overheating hours in different climates. Ventilative cooling can have considerable impact on the risk of overheating in all climates. In cold and moderate climates the risk of overheating can be eliminated completely, while in warm and hot climates supplementary cooling solutions will be needed to ensure acceptable comfort levels. In cold climate (for example Oslo) daytime ventilative cooling is sufficient to remove the heat loads, while in most other climates it is essential to apply night cooling strategies to efficiently remove excess heat loads. In warm and hot climates daytime ventilative cooling strategies have very limited effect, while night cooling strategies are more efficient.

5. Key Performance Indicators

A qualitative survey conducted among the participating countries revealed that in many countries energy performance calculations do not explicitly consider ventilative cooling as a cooling option for achieving energy performance. Therefore, the appropriate treatment of ventilation requirements for ventilative cooling and its effect on cooling energy demand reduction is unclear and available tools used for such calculations might not be well suited to model its impact. Secondly, no specific key performance indicators focused on ventilative cooling

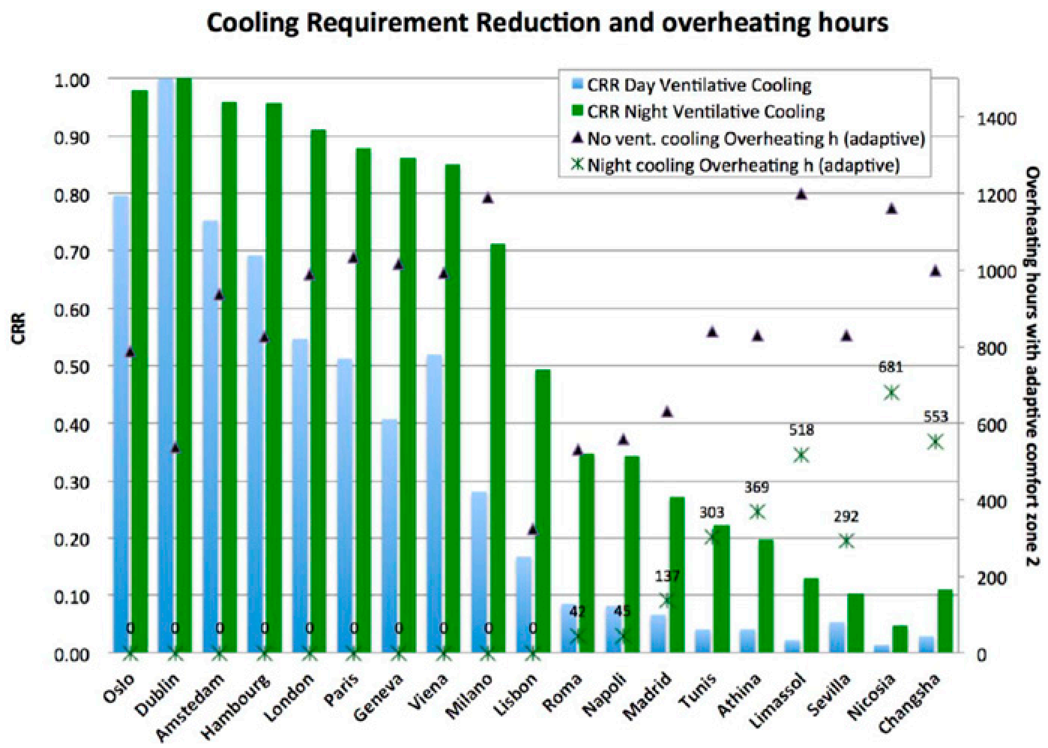

Figure 1. Expected cooling requirement reduction for day and night ventilative cooling strategy and overheating hours according to class 2 adaptive comfort indicator for a standard scenario without ventilative cooling and a scenario with night cooling [1].

performance were available. This is also a major barrier for application and further development of the technology, as it makes it difficult to evaluate and compare the ventilative cooling performance and other technologies for cooling and ventilation.

The project thus discussed and developed Key Performance Indicators to represent the performance of ventilation cooling within four different categories:

– SYSTEM INDICATORS: ‘System’ refers to all the components that together allow the functioning of the ventilative cooling strategy. Therefore, system indicators reflect building performance in both energy and thermal comfort terms.
– COMPONENT INDICATORS: Component indicators represent the performance of each component of the ventilative cooling system (that is opening efficiency, ventilation unit, SPF of cooling system, and so on). Component indicators are complementary indicators to be used for component design and selection, compliance verification and in Statement-of-Requirements for a building.
– BOUNDARY CONDITIONS INDICATORS: Boundary conditions indicators represent the assumptions on input data or building operating conditions (that is level of internal gains, solar gains, thermal mass, window surface area, solar transmission, airflow - natural or mechanical, ventilation and occupation schedules, weather data)

under which the system indicators are calculated. Boundary condition indicators aim to ease the control of assumptions on input data and identify tricky projects or errors.

- SENSITIVITY INDICATORS: Sensitivity indicators communicate the uncertainty on predicted / expected performance (design phase) due to assumptions and boundary conditions. They also indicate the risk of divergence of real performance to the predicted one (compliance phase) due to building use, occupant behaviour, and weather conditions, as well as in relation to the varying capacity of passive solutions.

Examples of system indicators that were developed and tested in the project are as follows:

- The Cooling Requirement Reduction (CRR), which is defined as the percentage of cooling requirements saved in a ventilative cooling scenario compared to the reference scenario.
- The Seasonal Energy Efficiency Ratio (SEER), which is defined as the cooling requirement saving divided by the electrical consumption of the ventilation system.
- Ventilative Cooling Advantage (ADVVC), which is defined as the benefit of the ventilative cooling, that is the cooling energy difference divided by the energy needed for ventilation.
- Percentage Outside the Range (POR), which is defined as the number or the percentage of hours of occupation (Oh) when the - actual or simulated - indoor operative temperatures are outside a specified comfort range
- Degree-hours Criterion (DhC), which is defined as time during which the actual operative temperature exceeds the specified comfort range during occupied hours weighted by a factor that depends on the difference between actual or calculated operative temperature, θop, at a certain hour, and the lower or upper limit, θop,limit, of a specified comfort range.

6. Cooling Potential

Decisions about application of ventilative cooling in buildings are made in the conceptual design phase and it is important to be able to assess the ventilative cooling potential without the need for rigorous analysis. Ventilative cooling is dependent on the availability of suitable external conditions to provide cooling and buildings with different use patterns, envelope characteristics and internal loads level will react differently to the external climate conditions. Therefore, the ventilative cooling potential analysis must include climate considerations, building characteristics and use.

The project developed a ventilative cooling potential tool (‘VC Tool’) capable of assessing the potential effectiveness of ventilative cooling strategies by taking into account building envelope thermal properties, occupancy patterns, internal gains, ventilation needs and the outdoor climate.

The tool is freely accessible on the project website including the user guide and examples to guide users through its application. Figure 2 illustrates the tool graphical user interface (GUI) with visualization of inputs and outputs.

The VC Tool analysis is based on a single-zone thermal model applied to user-input climatic data on hourly basis. For each hour of the annual climatic record of the given location, an algorithm splits the total number of hours when the building is occupied into the following groups:

Ventilative Cooling Mode [0]: When the outdoor temperature is below the heating balance point temperature, no ventilative cooling is required since heating is needed.

Ventilative Cooling Mode [1]: Direct ventilation with airflow rate maintained at the minimum required for indoor air quality can potentially ensure comfort.

Ventilative Cooling Mode [2]: Direct ventilative cooling with increased airflow rate can potentially ensure comfort. The tool calculates the airflow rate required to maintain the indoor air temperature within the comfort temperature ranges.

Ventilative Cooling Mode [3]: Direct evaporative cooling (DEC) can potentially ensure comfort even if direct ventilation alone is not useful.

Ventilative Cooling Mode [4]: Direct ventilative cooling is not useful.

Figure 3. Ventilative cooling potential of the case studies as predicted by the VC Tool [1].

7. Technologies and System Integration

There are no ventilative cooling technologies and components as such. In nearly all cases, ventilative cooling systems consist of a combination of technologies and components, which can be used in purely naturally driven or in purely mechanically driven ventilation systems. However, in order to permit the correct design and functioning

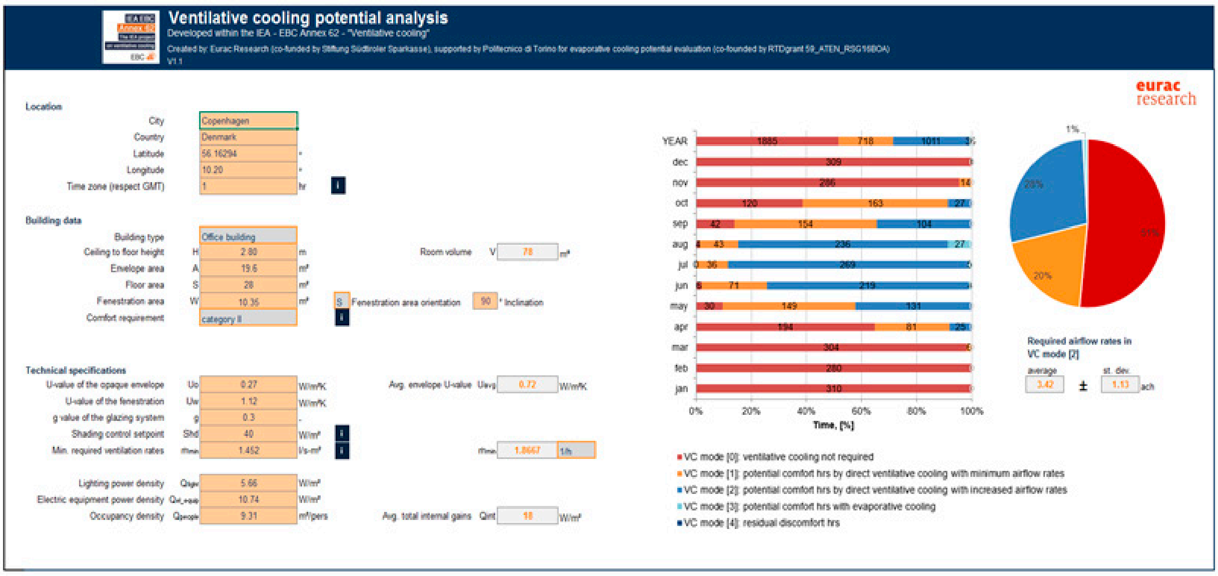

Figure 2. VC Tool GUI with input data and output visualization [1].

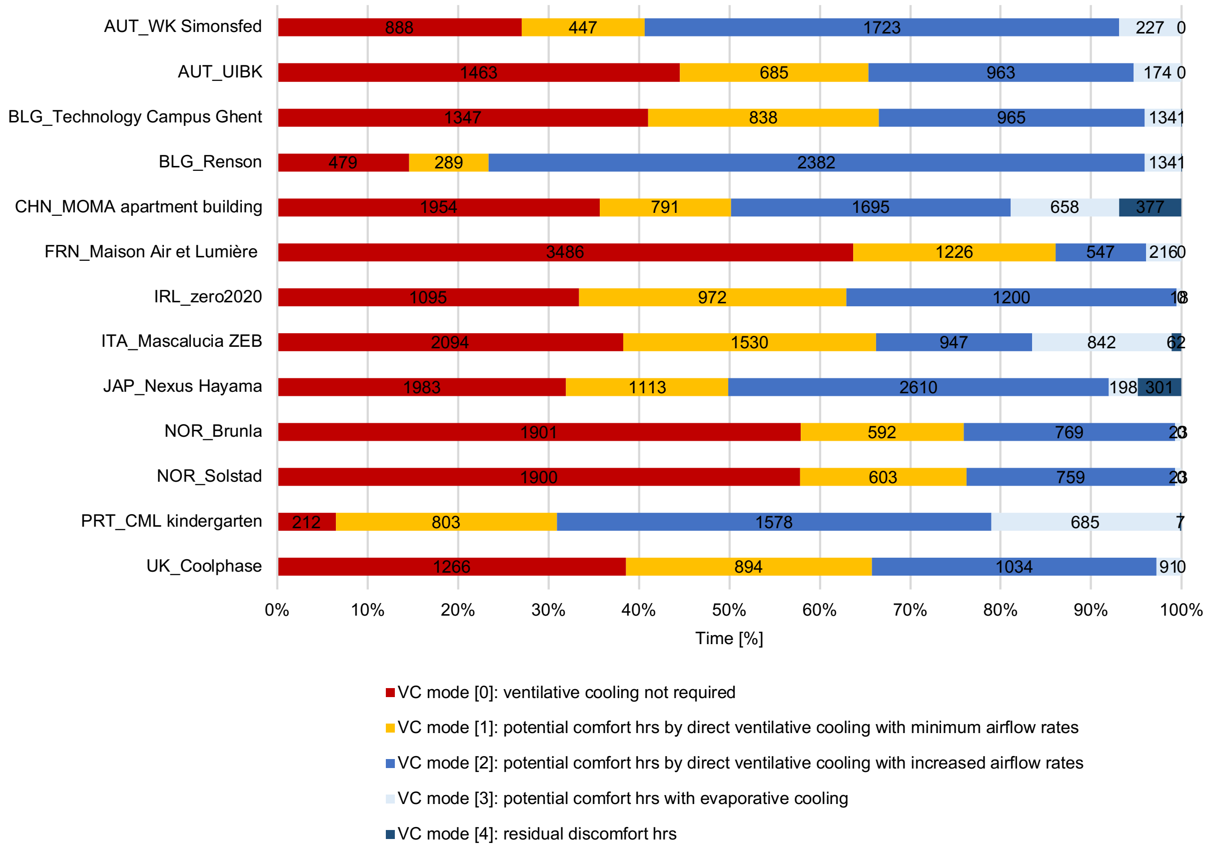

Figure 3. Ventilative cooling potential of the case studies as predicted by the VC Tool [1].

of a ventilative cooling system, the availability and integration of appropriate technologies and components is essential. Table 2 shows a way to characterize typical technologies and components used in ventilative cooling systems. The functionality, use and integration of technologies and components into ventilative cooling systems is described in the Ventilative Cooling Source Book [3]. Various ventilative cooling system solutions were also developed and further optimized in the project and are reported in the Source Book [3]. These solutions cover the application of different technologies for ventilative cooling (diffuse ceiling, PCM energy storage, slot louvres, cooling jets, window opening control strategies, and so on), different application areas (office, supermarket, kindergarten, single family house, and so on) and climates.

8. Recommendations for Standards and Regulations

A review on the treatment of ventilative cooling in national codes and standards was carried out in the project focusing on ventilative cooling aspects in: (a) building codes, (b) national energy demand calculations, and (c) implementation of ventilative cooling in current national building regulations. The

Functionality	Component
Air Flow Guiding	Windows, Rooflights, Doors, Dampers, Flaps, Louvres, Special Effect Vents
Air Flow Enhancing	Chimneys, Atria, Venturi Ventilators, Wind Towers, Wind Scoops
Passive and Natural Cooling	Convective Cooling, Evaporative Cooling, Phase Change Cooling
Control and Automation	Chain Actuators, Linear Actuators, Rotary Actuators, Sensors

Table 2. Characterization of functionality of typical components in ventilative cooling systems [3].

results are presented in detail in the review report [4].

It was concluded from the surveys that ventilative cooling requirements in regulations are complex and five categories of parameters were identified that need clarification in the national codes to facilitate ventilative cooling: (a) energy use for cooling, (b) building parameters influencing ventilative cooling, (c) ventilation requirements - both ventilation amounts and ventilation openings and positions, (d) safety, and (e) temperature, air velocity and humidity requirements.

Countries in the European Union are required to implement the Energy Performance of Buildings Directive (EPBD). However, for some countries, such as Italy, while national implementation is expected, it is not yet realized. And even if a certain energy performance level is required, energy demand for cooling is not necessarily considered. This leads to the unwanted situation that a calculation of energy demand for cooling is not required for all countries, thus rendering the energy benefit of ventilative cooling invisible in those national regulations.

In the USA every state sets its own regulations. In the review report, only the California building codes are discussed in detail. Compared to the European codes, the California building code has no fixed value for the energy demand, or an equivalent coefficient for a building, but a comparison to an energy calculation of a standard building is necessary, which is described in the building code.

For several countries, including the Netherlands, Belgium, Denmark, and Norway, production of an energy performance certificate requires a total annual energy demand calculation, not separated into heating and cooling. If energy demand for cooling is not considered separately, the energy demand for cooling can be compensated by other means (reduced heating, sustainable energy production) diminishing the usefulness of ventilative cooling in such regulations.

Several countries include the energy demand from mechanical ventilation and de-humidification in their calculations. These aspects have an influence on ventilative cooling by influencing the choice for mechanical or natural ventilation, if auxiliary and parasitic energy use by mechanical ventilation is considered separately. If de-humidification is considered, this might pose extra demands on the type of ventilative cooling that can be installed, with or without de-humidification.

In Switzerland, there is a minimum requirement on electricity use in buildings, which is electrical energy use of buildings estimated at design cannot exceed a given value. Active cooling, lighting, ventilation and use of auxiliary installations are considered in the electrical energy use. In other words, if you want to apply active cooling, this poses limits on lighting, ventilation and the use of auxiliary installations. However, according to dynamic calculations based on ISO 15591, ventilative cooling may reduce cooling needs in Switzerland down to zero.

It was also revealed that energy performance calculations in many countries do not explicitly consider ventilative cooling. Therefore, available tools used for energy performance calculations might not be well-suited to model the impact of ventilative cooling, especially in annual and monthly calculations. There might be need for the development of an international standard on ventilative cooling, which should also address calculation methods.

Based on the review, the project participants investigated, developed and reported recommendations for adequate future implementation of ventilative cooling in standards, legislation and compliance tools with the main focus on natural ventilative cooling parameters [5]. The work included both recommendations in relation to EN, ISO and national standards, as well as to national / regional legislation. National compliance tools concerning ventilative cooling were evaluated through the status and recommendations of each area.

Project participants also developed new work items relevant to ventilative cooling applications that recently have been approved in the European Committee for Standardization (CEN). The scope of this work is to make technical documents focusing on design aspects of ventilative cooling, and natural and hybrid ventilation systems in residential and non-residential buildings. The work has been officially started up in CEN/TC 156 and includes three activities:

1. Ventilative cooling systems: The main focus is thermal comfort (preventing overheating); document type is a Technical Specification; work is started up in WG/21 in CEN/TC 156.
2. Natural and hybrid ventilation systems in non-residential buildings: The main focus is indoor air quality; document type is a Technical Specification; work is started up in WG/20 in CEN/TC 156.
3. Design process of natural ventilation for reducing cooling demand in energy-efficient non-residential buildings: The main focus is thermal comfort (design process to prevent overheating); document type is an ISO standard; work is started up in WG/2 in ISO/TC 205.

At the time of writing, a further activity was due to be initiated:

4. Expansion of natural and hybrid ventilation in residential buildings in upcoming "Revision of EN 15665:2009 and CEN/TR 14788:2006": The main focus would be indoor air quality; document type is an EN standard; work planned to be started up in WG/2 in CEN/TC 156.

The initiated activities are planned as Technical Specifications (normative documents of lower status than EN Standards) and as an EN standard under CEN/TC 156. These technical documents provide a good opportunity to define design aspects of ventilative cooling and natural and hybrid ventilation systems for the European and international standardization context, in particular by applying findings from this project.

As for CEN, new work items relevant to ventilative cooling applications have also been proposed in the International Organization for Standardization (ISO), aimed at producing a descriptive technical document focusing on the design process and aspects of natural ventilation systems: *Design process of natural ventilation for reducing cooling demand in energy-efficient non-residential buildings. (ISO/TC 205), NP 22511*; work is started up in WG/2.

9. Performance Documentation

Naturally, expectations of ventilative cooling performance will vary between different countries because of climate variations, energy prices and other factors. In countries with cold climates, ventilative cooling can avoid the trend to use mechanical air conditioning in new buildings, which has occurred in response to heavily insulated and air tight building designs, higher occupant expectations and the requirements of building regulations, codes and standards. In countries with warm climates, it can reduce the reliance on air conditioning and reduce the cost, the energy penalty and the consequential environmental effects of full year-round air conditioning.

Well-documented case studies using ventilative cooling from across the world were collected in the project. These include three office buildings, five educational buildings, four residential, one mixed use, and one kindergarten. Eight of the case studies have rural surroundings and seven have urban surroundings. Four case studies were refurbishment projects. For these case studies, rich information was available about their design, construction and operational performance that are presented in specific case study brochures available on the project website.

From the case studies, a number of key lessons learned have been reported. Some of these relate to the conclusion that the design of a building incorporating ventilative cooling can be challenging and may require a lot of detailed building information. While the case studies represent a wide range of building types, building use, climatic conditions, and so on, each design challenge was different. The main key lessons from all case studies were as follows:

– Detailed building simulation is important when simulating ventilative cooling strategies. Most case studies analysed highlighted the need for reliable building simulations in the design phase of a system. This was considered most important when designing for hybrid ventilation strategies in which multiple mechanical systems need harmonization. Some studies also concluded that simulating window opening in detail was important.
– Customisation may be an important factor in designing a ventilative cooling system. In order to ventilate certain buildings, it may be necessary to design custom components. Some case studies highlighted the need to have custom-designed systems that were specific to national regulations and the use of a building or space. Some consideration should also be given to the client expectations around specific issues like rain ingress and insect exclusion.
– Ventilative cooling systems were considered as a cost-effective and energy efficient design by most case studies, but particularly with naturally ventilated systems. It was indicated that designing with the integration of manual operation and control was important, particularly in a domestic setting.

While systems were designed to provide high levels of comfort, indoor air quality and energy performance, achieving these simultaneously was difficult. All case studies emphasized that monitoring the performance of a building post-occupancy is important, if not essential in building performance optimization. While some key lessons were more specific than others, the following general observations were made:

– Engaging with the building owners or operators as soon as possible is integral to guaranteeing building performance for indoor air quality, comfort or energy savings. For some case studies this specifically meant educating or working with the facilities operator or manager for the building, for others it meant educating the building occupiers themselves. It was suggested by some that this engagement should occur already in the design stage.
– Ventilative cooling in operation is generally a good option. Case studies note the reduction of overheating and improvement of comfort conditions in the buildings that used outside air. However, correct maintenance and calibration of the systems is integral to maintaining performance.
– Some case studies highlighted the need to better exploit the outside air with lower external air control limits during typical and night-time operation. Others suggested that exploiting the thermal mass of a building was key. However, it was noted that care must be taken when considering these low temperatures, as some in case studies, particularly in cold climates, more incidences of overcooling than overheating were observed.

A conclusion from the case studies is that the best contemporary designs combine natural ventilation with conventional mechanical cooling. When properly designed, and implemented, these hybrid approaches maximize the ventilative cooling potential while avoiding overheating during the warmer months. The study also showed that a lot can be learned from collecting information about ventilative cooling case studies that have demonstrated through measurement that they perform well and their internal environments are comfortable for an acceptable period of the occupied time. But, due to the heterogeneity of the cases analyzed, it was difficult to draw general conclusions regarding recommendations for designers. The characteristics of each case study appeared unique due to the need for the approach to respond to a specific climate, building usage, morphology, and client criteria.

10. International Ventilative Cooling Application Database

An international ventilative cooling application database has been developed based on desktop research, by the project participants. This database contains 91 buildings located in Europe. Building datasheets offer illustrative descriptions of buildings of different usages, sizes and locations, using ventilative cooling as a means of indoor comfort improvement, and for each building include:

- general building specifications: address, building category, year of construction, special qualities, location, climate;
- ventilative cooling site design elements: solar site design and wind exposure design, evaporative effects from plants or water;
- ventilative cooling architectural design elements: shape, morphology, envelope, construction and material;
- ventilative cooling technical components: airflow guiding components, airflow enhancing components, passive cooling components;
- actuators, sensors and control strategies;
- building energy systems: heating, ventilation, cooling, electricity;
- building ownership and facility management structures.

Overall the main characteristics of the buildings in the database are:

- Building use is predominantly office (55%), educational (21%) or other (22%). Only 8% are residential.
- Location is predominantly urban (60%).
- Ventilative cooling site design elements are applied in 65%, quite equally distributed between solar site design, wind exposure design and evaporative effects.
- Ventilative cooling architectural design elements are applied in 95%, dominated by morphology, envelope and construction-material (66% to 78%), less by form (49%).
- Airflow guiding ventilation components are used widely in 99% of the buildings, dominated by windows, rooflights, doors (96%), significantly more seldom by dampers, flaps, louvres (44%) or by special effect vents (5%).

– Airflow enhancing ventilation components are applied in 66%, fully dominated by atria (63%), with some chimneys (16%), and only very rare cases of others.
– Passive cooling components are used in 26%, dominated by convective cooling components (22%), with only very rare cases of others.
– Actuators are identified in 66%, dominated by chain actuators (57%), followed by linear actuators (9%).
– Sensors are identified in 88%, including the frequent use of temperature, humidity, CO_2, wind, rain and solar radiation.
– Control strategy is reported as hybrid in 58%, automatic in 29%, or as manual only in 4%.

The database can be found at: http://venticool.eu/annex-62-publications/deliverables

Project Participants

Country	Organisation
Australia	University of Wollongong
Austria	Institute of Building Research and Innovation
Belgium	Belgium Building Research Institute KU Leuven
P.R. China	Hunan University
Denmark	Aalborg University Danish Technological Institute VELUX A/S WindowMaster A/S
Finland	Turku University of Applied Sciences SAMK
Ireland	Cork Institute of Technology
Italy	Eurac Research Politecnico di Torino Politecnico di Milano UNIPA

Country	Organisation
Japan	Osaka University Ritsumeikan University Multidisciplinary Research Institute, LIXIL Corporation
The Netherlands	Eindhoven University of Technology TU Delft
Norway	Norwegian University of Science and Technology SINTEF Energy Research
Portugal	University of Lisbon
Switzerland	Estia
United Kingdom	Brunel University
USA	Massachusetts Institute of Technology

Project Publications

1. Heiselberg, P. *Ventilative Cooling Design Guide.* IEA EBC Annex 62 Ventilative Cooling. Available at: www.iea-ebc.org
2. O'Sullivan, P. and Zhang, G.Q. *Ventilative Cooling Case Studies.* IEA EBC Annex 62 Ventilative Cooling. Available at: www.iea-ebc.org
3. Holzer, P. and Psomas, T. *Ventilative cooling Source Book*, IEA EBC Annex 62 Ventilative Cooling. Available at: www.iea-ebc.org
4. Kolokotroni M, Heiselberg P. *Ventilative cooling. State of the art review*. 2015; ISBN 87-91606-25-X. Available at: www.iea-ebc.org
5. Plesner, C. and Duer, K. *Recommendation on ventilative cooling for standards and regulation*. IEA EBC Annex 62 Ventilative Cooling. Available at: www.iea-ebc.org

EBC and the IEA

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the IEA Energy in Buildings and Communities (IEA EBC) 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. (Until March 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)
The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

– Integrated planning and building design

– Building energy systems

– Building envelope

– Community scale methods

– Real building energy use

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18:	Demand Controlled Ventilation Systems (*)
Annex 19:	Low Slope Roof Systems (*)
Annex 20:	Air Flow Patterns within Buildings (*)
Annex 21:	Thermal Modelling (*)
Annex 22:	Energy Efficient Communities (*)
Annex 23:	Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24:	Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25:	Real time HVAC Simulation (*)
Annex 26:	Energy Efficient Ventilation of Large Enclosures (*)
Annex 27:	Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28:	Low Energy Cooling Systems (*)
Annex 29:	Daylight in Buildings (*)
Annex 30:	Bringing Simulation to Application (*)
Annex 31:	Energy-Related Environmental Impact of Buildings (*)

Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Resilient Energy Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant Behaviour-Centric Building Design and Operation
Annex 80: Resilient Cooling

Working Group -	Energy Efficiency in Educational Buildings (*)
Working Group -	Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group -	Annex 36 Extension: The Energy Concept Adviser (*)
Working Group -	HVAC Energy Calculation Methodologies for Non-residential Buildings
Working Group -	Cities and Communities

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