Energy Performance Indicators for Ventilative Cooling

Flourentzos Flourentzou[1*], Jerome Bonvin[1]

[1] Estia SA
EPFL Innovation Park
1015 Lausanne, Switzerland
www.estia.ch
**flourentzou@estia.ch*

ABSTRACT

The lack of indicators assessing ventilative cooling effectiveness in a way to compare it with active cooling technics, makes its acceptance more difficult. Practitioners, norms, standards and guidelines are used to design and evaluate cooling systems in terms of Cooling Power (CP) or Seasonal Energy Efficiency Ratio (SEER). What could be the CP of a passive technique based on a day to night offset of the cooling process? What could be the SEER of mechanical night ventilation for summer cooling?

IEA Annex 62 research collaboration for ventilative cooling developed energy performance indicators to characterise natural and mechanical ventilative cooling. The Cooling Requirement Reduction (CRR) expresses the cooling effectiveness of a ventilation strategy. It indicates to which extend an alternative strategy, like natural or mechanical night ventilation, meets the cooling needs, compared to those of a standard scenario without ventilative cooling. The ventilative cooling SEER (SEERvc) relates the additional electrical energy to run ventilation, with the Cooling Requirement Reduction. It can be compared to the SEER of conventional cooling systems.

In this paper we define in details these indicators and use them to assess different ventilative cooling systems, applied to a standard ventilative cooling test building, defined in IEA Annex 62 research works. We use them also to compare the effectiveness of ventilative cooling in specific climatic zones, with different thermal masses and different solar protection boundary conditions.

The results show that mechanical ventilative cooling with Specific Power Input >0.4 W/(m^3/h), running more than 800 hours per year for night cooling, might be even less efficient than conventional air conditioning systems of SEER > 3. They also show that the only real "free cooling" is natural ventilative cooling. A parametric analysis illustrates how with the use of these indicators we may quantify the risk of high-energy consumption due to bad design choices, such as very low thermal mass, bad ventilation control, bad solar control or a combination of them.

KEYWORDS

ventilative cooling, performance indicators, passive cooling, IEA annex 62

1 INTRODUCTION

Modern high energy-performance buildings, with high-level envelope insulation and high airtightness have not a single dissipative element. Natural ventilative cooling is the only means of evacuating heat, without increasing energy consumption. Under these new conditions in building industry we observe increased overheating problems, even in Nordic climates. A recent survey of the court of auditors in Vaud Canton in Switzerland showed that in 9 out of 10 recent sustainable and high energy-performance state-buildings present overheating problems. It also showed that buildings with mechanical ventilative cooling present very high electrical consumption. (Court of Auditors - Vaud 2015). Summer overheating becomes a common problem all over Europe, from Mediterranean See to Baltic Sea. IEA Annex 62 revisits ventilative cooling technics in this new conditions and tries to assess simulation methods, define key performance indicators and recommend principles for standards and guidelines to integrate ventilative cooling (Kolokotroni, Heiselberg 2015).

This article is focused on energy performance indicators.

2 VENTILATIVE COOLING PERFORMANCE INDICATORS

Annex 62 distinguishes 4 categories of indicators: system performance indicators, component performance indicators, boundary conditions and sensibility indicators.

2.1 System indicators for comfort and energy performance

System indicators refer to the performance of the whole ventilative cooling system, generally of a room but it can also be of the entire building. There are system indicators concerning comfort and others concerning energy performance. This article uses 2 system indicators:
- The number of hours the internal temperature exceeds EN 15251 adaptive comfort zone 2. This indicator is used also in the Swiss standard SIA 180 (EN standards, Swiss standards).
- Cooling Requirements Reduction (CRR), which is defined in chapter 3.

2.2 Component indicators

Component indicators refer to the performance of particular part of the ventilative cooling system. The ventilation effectiveness of a window or a set of windows is a component indicator. It can be expressed as the window airflow at 2°C and at 5°C temperature difference without wind presence.
Concerning energy performance indicators we define and test in this article 2 component indicators of a mechanical ventilation system:
- Ventilative Cooling Seasonal Energy Efficiency Ratio (SEERvc).
- Ventilative Cooling Advantage of a passive component compared to conventional cooling machine.
These component indicators are also defined in chapter 3.

2.3 Boundary conditions

Almost all the ventilative cooling indicators need a dynamic simulation and this make the control of simulation assumptions more difficult. The time-dependent variables, like heat gains, opening and closing the windows, which is sometimes conditional, solar gains, external climatic conditions need explicit and rigorous control of assumptions. This is the reason why we specify explicitly this category of indicators. Chapter 4 is especially dedicated to the boundary indicators with the main assumptions of the test case simulations.

2.4 Sensibility indicators

This family of indicators test the result uncertainty due to input uncertain data but also due to risks of bad use of some components of the system. In this case, we use the sensibility indicator evaluating the risk of blind partial use.

3 DEFINITION OF 3 ENERGY PERFORMANCE INDICATORS

Ventilative cooling provides comfort in place of an air conditioning system. Standard EN 15251 defines adaptive comfort (EN and ISO standards). ISO 7730 defines comfort according to Fanger's theory. Swiss norm SIA 180 accepted the two standards equivalent. However, the occupants can achieve adaptive comfort only in spaces where they may open the windows. For this reason, in closed spaces, or in spaces where the windows are not supposed to open during the hours of use, only ISO 7730 remains valid.
European standard EN 15255 defines a model to evaluate cooling requirements of a space. However, this standard does not define normalised boundary conditions. In the Swiss case, SIA 382/1 defined a set of normalised boundary conditions for the calculation of cooling requirements and SIA 180 defined boundary conditions for the calculation of internal temperature. For general-purpose spaces they consider acceptable adaptive comfort zone 2 and for closed spaces 10% PPD according to ISO 7730. Standard boundary conditions define

occupation schedules (internal gains, occupation density, airflow rates for indoor environment quality), standard meteorological files and set point temperature at 26°C (Swiss standards).

3.1 Cooling Requirements Reduction - CRR

This energy performance indicator expresses the ratio of cooling requirements saved of a scenario with respect to the one of the reference scenario (Equation 1).

$$CRR = \frac{Q_{t,c}^{ref} - Q_{t,c}^{scen}}{Q_{t,c}^{ref}} \qquad \text{Equation 1}$$

Where $Q_{t,c}^{ref}$ is the cooling requirements of the reference scenario and $Q_{t,c}^{scen}$ is the cooling requirements of the ventilative cooling scenario.

CRR can range between a negative value and +1. If CRR is positive, it means that the ventilative cooling system reduces the cooling requirements of the building. If CRR is equal to 1, the ventilative cooling scenario has no cooling requirements. If CRR is zero, the ventilative cooling scenario does not reduce the cooling requirements of the building and if it is negative, ventilative cooling increases them (increased ventilation induces more heat that the one it extracts from the building).
CRR calculates cooling effectiveness of any ventilative cooling scenario, mechanical or natural.

3.2 Seasonal Energy Efficiency Ratio of the ventilative cooling system - $SEER_{VC}$

When the driving force of ventilative cooling is mechanical system, cooling requirement reduction is not for free. It has an energy consumption. The ratio of the saved cooling requirements and the extra electricity consumed by the ventilation system for ventilative cooling, during the whole cooling season, gives $SEER_{VC}$. It expresses the energy efficiency of the mechanical system (Equation 2).

$$SEER_{VC} = \frac{Q_{t,c}^{ref} - Q_{t,c}^{scen}}{E_{el,v}} \qquad \text{Equation 2}$$

Where $E_{el,v}$ is the extra electrical consumption of the ventilation system for ventilative cooling.

When the mechanical system is a ventilator or an air-handling unit providing ventilation for other purposes (hygienic ventilation), $SEER_{VC}$ accounts only the extra energy needed for ventilative cooling. This indicator is similar to the SEER of any conventional air conditioning unit and makes it possible to compare the ventilative cooling energy performance to the energy performance of conventional air conditioning systems.

3.3 Ventilative cooling advantage ADV_{VC}

In buildings with the possibility to have conventional air conditioning, someone may need to decide if it is preferable to spend energy for ventilative cooling or for air conditioning. It is not always preferable to use mechanical ventilative cooling in the place of air conditioning when ventilative cooling cannot achieve the interior desired temperature conditions. The Specific Power Input (SPI) of the ventilation system, the extra number of hours it needs to run for ventilative cooling during the cooling season, the temperature difference between inside and outside, are factors that affect $SEER_{VC}$. Ventilative cooling advantage (ADV_{VC}) indicator defines the benefit of the ventilative cooling, i.e. the cooling energy difference divided by the energy for ventilation.

$$ADV_{VC} = \frac{E_{el,c}^{ref} - E_{el,c}^{scen}}{E_{el,v}}$$ Equation 3

Where $E_{el,c}^{ref}$ is the electrical consumption of the cooling system in the reference case, $E_{el,c}^{scen}$ is the electrical consumption of the cooling system in the ventilative cooling scenario and $E_{el,v}$ is the extra electrical consumption of the ventilation system for ventilative cooling.

If ADV_{VC} is lower than one, electrical consumption of the ventilation system is lower than the one of the cooling system. If ADV_{VC} is equal to 1, the electrical consumption of ventilation system is equal to this of the cooling system.

CRR, $SEER_{VC}$ and ADV_{VC} indicators refer to a baseline scenario, which needs to be standardized according to national conditions. For the purpose of this study, standard scenario uses the Swiss standard conditions of occupation according to SIA 2024, airflow rates for hygienic ventilation and internal heat gains according to the same standard, and windows closed with no extra ventilation for ventilative cooling.

4 BOUNDARY CONDITIONS AND CALCULATION METHODS

We used as case study one of the meeting rooms of a primary school, located in Saviese (Switzerland). The meeting room is 5.12 m wide, 7 m long and 2.8 m high. The Saviese primary school was built in 2014 and was designed to get a Minergie® label (Flourentzou, Ritz et Al 2015). Therefore, the building envelope is highly air tight and insulated.

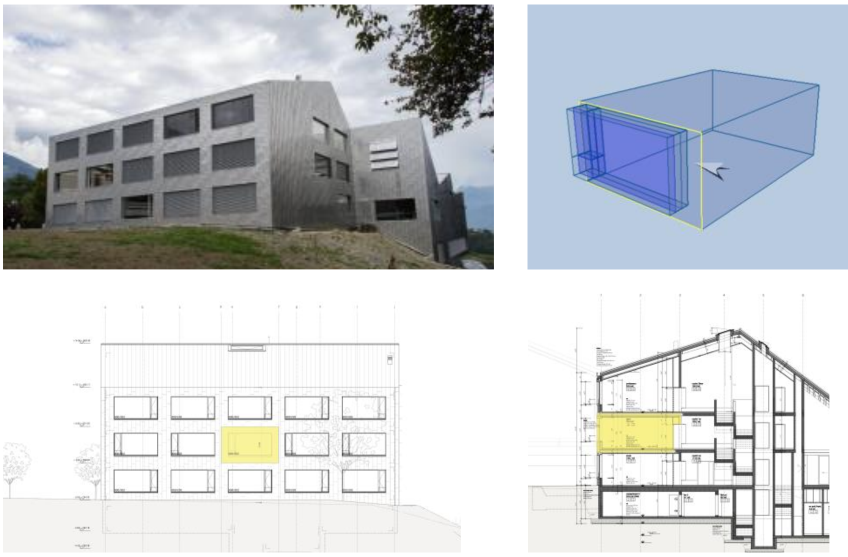


Figure 1: Saviese primary school. The modelled office-meeting room is the one highlighted.

The meeting room has only one window that is 4.00 m wide and 2.02 m high. The glazed area consists of a side-hung window of 1 m² (0.64 m wide per 1.56 m high) and fixed window of 7.9 m². An exterior blind with adjustable slats shades both the side hung window and the fixed window. Blind g value is 0.1 and glazing g value 0.45 and the orientation is west.

The discharge coefficient of the blind has been measured in the meeting room in a single-sided ventilation experiment. The results are:

- Blind open: Cd = 0.62
- Blind with slats at 45° or blind closed: Cd = 0.45-0.47

Simulation boundary condition for the opening partially open 20 cm with the blinds closed assumes the discharge coefficient Cd = 0.25.

Simulation boundary condition for blind control with standard scenario assumes g glazing = 0.45 and g blind 0.1 when incident I>200 MJ/m2 and Text>22°C with blinds 100% rolled down.
Two additional sensibility indicators calculate performance indicators, one, R1, with blinds 50% closed and the other R2, with no blind use.
Occupation schedules follow the Swiss standard conditions SIA 2024 (Swiss Standards). If we summary these conditions we have a variable occupation from 7:00 to 18:00 with maximum internal gains from occupants 5 W/m^2, 15 W/m^2 for lighting with natural light autonomy of 32%, and other internal gains of 7 W/m^2. Internal gains totalize 150 Wh/m^2 per day.
The real thermal characteristics of the envelope (20 cm insulation - U_{wall} = 0.16 W/m^2, triple glazing U_{win} =0.9 W/m^2) respect the recommendations of a high performance energy passive standard (Minergie®). We transpose the level of envelope performance for southern climates to 10 cm - U_{wall}=0.35 W/m^2 for insulation and double glazing U_{win}=2.5-3.1 W/m^2 for windows

4.1 Ventilative cooling strategies as simulation boundary conditions

Ventilative cooling strategies are rarely specified precisely. In Annex 62 simulation programs evaluation we found programs considering night ventilation as ventilation during specified night hours, as ventilation when internal temperature is higher than external temperature, sometimes with a limitation when internal temperature is lower than a certain threshold, sometimes not. We note that the results of system indicators are very sensitive on ventilation strategy assumptions and conditions on assumptions.
We define 3 ventilative cooling strategies in addition to the standard scenario. For each strategy we show the boundary conditions

Table 1: Ventilative cooling strategies

Strategy Name	When	T in Condition	T out Condition	Cooling extra Airflow*
A. Standard ventilation	7:00-18:00	-	-	0
B. Day ventilation	7:00-18:00	Ti > 23 °C	Ti > To	Window stack*
C. Night ventilation natural	24h	Ti > 23 °C	Ti > To	Window stack
D. Night ventilation mechanical	24h	Ti > 23 °C	Ti - To > + 2°C	5.2 $m^3/h.m^2$

* During occupation (7:00 - 18:00) there is a basic airflow rate of 2.6 $m^3/h.m^2$ for hygienic ventilation and outside occupation hours there is a basic airflow rate of 0.3 $m^3/h.m^2$
* Stack ventilation is calculated dynamically according to Bernoulli's equation, using the window dimensions and discharge coefficients and in-out temperature difference without wind influence.

4.2 Other boundary conditions

Air temperature set point for cooling requirement calculation during the hours of use: 26°C, according to Swiss norm SIA 2040
Air temperature set point for heating requirement calculation: 21°C

4.3 Calculation models and simulation tools

Annex 62 tested several dynamic simulation tools (EnergyPlus - US, BSim - DK, LESOSAI, - CH, SIA TEC-Tool - CH, TRNSYS - DE, DIAL+ - CH) to evaluate how do they take into account dynamically bulk airflow coupled with dynamic temperature evolution. Most of the simulation programs use EN 13790 or EN 13791 model to calculate interior temperature and Bernoulli's equation to calculate stack ventilation airflow rate. Some models may take into account wind influence, other not. In general it was observed good correlation between monitored and simulated temperatures and airflow rates.

For the purpose of this paper, DIAL+ calculates indoor temperature (EN 13791), cooling and heating requirements and maximum cooling and heating power (EN 15265, EN 15255), number of hours outside adaptive comfort zone EN 15251. The software uses Cocroft equations to consider multiple windows in different heights and Meteonorm meteorological files (Paule et Al, 2012).

5 SIMULATION RESULTS

5.1 Cooling Requirement Reduction

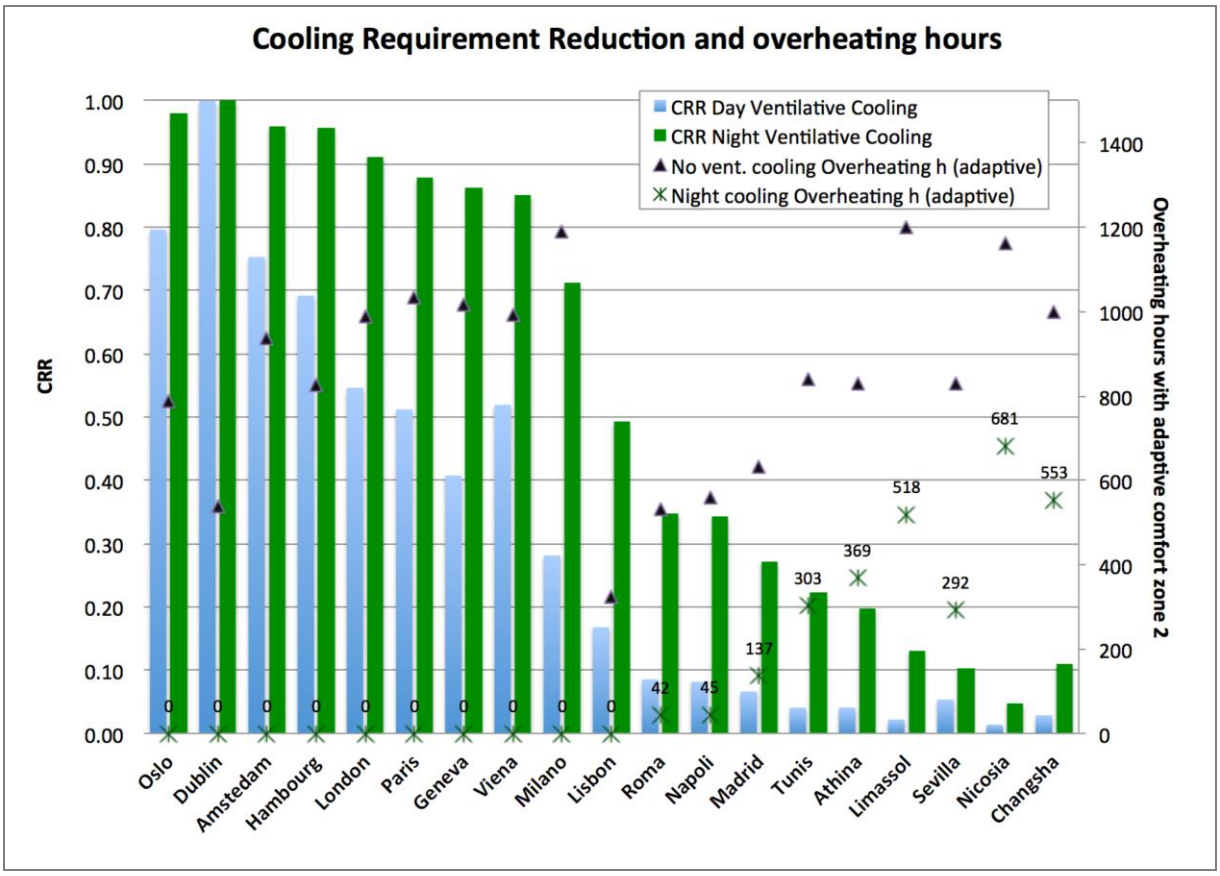


Figure 2: CRR for day and night ventilative cooling strategy and overheating hours according to class 2 adaptive comfort indicator for a standard scenario without ventilative cooling and a scenario with night cooling.

Table 2: Cooling requirements for a selection of sites [kWh]

	Dublin	London	Geneva	Vienna	Lisbon	Napoli	Athina	Nicosia
Heating demand [kWh/m^{2}y]	15.5	10.9	19.9	18.6	14	26.6	20.8	14.8
A. Standard ventilation scenario	52	238	292	260	274	380	634	999
B. Day ventilation	0	108	173	125	228	349	608	985
C. Night ventilation natural	0	21	40	39	139	250	509	952
D. Night ventilation mechanical	0	14	30	23	131	223	449	710
R1 Blinds 50% without ventilative cooling	99	315	384	337	491	592	862	1270
R2 Blinds 0% without ventilative cooling	346	625	724	657	919	981	1280	1780

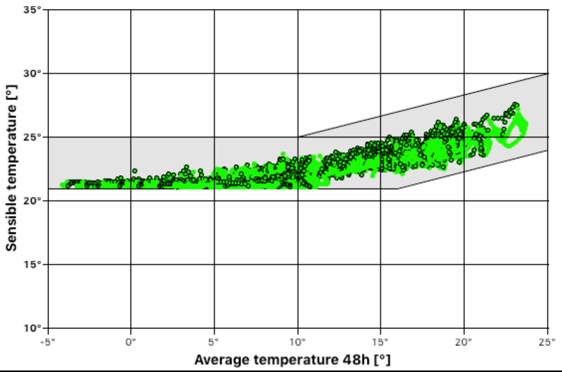
The results of figure 2 and table 2 show that near zero office buildings show results of the same order for heating demand (10-25 kWh/m^2) and overheating hours without a ventilative cooling strategy (500-1200 hours outside adaptive comfort zone 2). Compared to the buildings before 2000, the results confirm that modern buildings reduced significantly heating demand (10-30 kWh/m2 instead of 100) but at the same time rise significantly cooling

demand, especially for cold climates. This confirms Annex 62 initial hypothesis that summer comfort and cooling become a problem for all climates and necessity for a deep understanding of ventilative cooling strategy.
CRR graph and corresponding overheating hours for night ventilative cooling scenario show a very interesting result. This strategy may solve the problem for climates from Oslo to Milano. A ventilative cooling scenario with CRR up to 60% achieves adaptive comfort acceptable conditions. If we have a look on day ventilative cooling strategy, we may see on the graph that climates like Hambourg, Amsterdam, Oslo, Dublin may achieve CRR > 0.6. London, Paris, Geneva, Vienna, Milano may achieve adaptive comfort with night cooling but not with only day ventilative cooling. Lisbon is really on the limit. A southern Atlantic climate achieves CRR 0.5 but still 0 overheating hours with night cooling. For other Mediterranean and hot continental climates we may see that night ventilative cooling reduces cooling requirements by 10-35% but it cannot achieve complete adaptive comfort conditions. Overheating hours are reduced to 45-700 hours instead of 500-1200 hours without a ventilative cooling strategy. Although the effectiveness of this strategy is limited in hot summer days with hot nights, it is really effective in midseason. The added value of this strategy for hot climates is to reduce the cooling period. Cooling needs for climates like Athens are reduced to zero until mid may and after mid September.
The question is not only the quantitative value of CRR, which is a powerful indicator to evaluate energy performance of a ventilative cooling strategy and compare it with a conventional cooling system. Indicators with the quality of the achieved comfort and the deviation risk from the comfort objectives should complete decision aid information. In table 2 we may read the risks R1 and R2 in terms of cooling requirements and see 300% to 400% rise for cold climates and 50% to 200% rise for hot climates. A building with bad blind control in Geneva has the same cooling requirements with a building with good blind control in Athens. In cold climates, night ventilative cooling is not any more a sufficient strategy for a building with a bad blind control.
In table 3 we can see on the left column that although Amsterdam, Geneva and Milano have CRR > 0.6 for a night cooling strategy, they do not provide the same quality of comfort. In the same way we may see for hot climates the comparison of comfort conditions for Lisbon, Roma and Athens with CRR < 0.5. This table shows the necessity to use energy indicators in synergy with comfort indicators to drive decisions.
The analysis of these results rises a question: why do we calculate the cooling requirements reduction with cooling requirements calculated with a constant set point temperature (in our case 26°C) and not with an adaptive set point temperature like the adaptive comfort criterion? We have indeed calculated the cooling requirements for many climates with the two temperature set point criteria and found a perfect correlation line given as $Q_{adaptive}=0.61\ Q_{26°C}$. The R^2 of this correlation is 0.98. This explains why in almost all climates we have 0 overheating hours with CRR > 0.6 and justifies the use of a standard cooling requirement calculation with a fix set point temperature, available in most commonly used dynamic simulation programs of the market.
If we compare these results with climate oriented indicators, like for example Climatic Cooling Potential (Artman N et Al 2008) we observe the same general tendency, but with performance indicators depending on both climate and the building, we have more nuance in the answers concerning a particular building with a given use. CRR results are also in accordance with results for Passive Ventilative Cooling (PVC) potential and can be seen as complementary (Chiessa G et Al 2015). With CRR applied for example with day and night ventilative cooling strategies, we see on figure 2 that day ventilative cooling may provide sufficient comfort for some oceanic climates (CRR>0.6) but not for continental climates where night cooling is necessary. And we may go further on; analyzing sensibility indicators

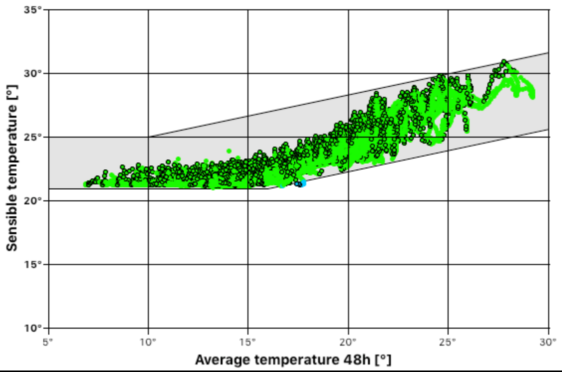
for insufficient blind control, and realize that night ventilative cooling is not sufficient for rooms with partial use of solar protection.

Table 3: CRR for night / day ventilative cooling strategies and adaptive comfort graph for night cooling strategy

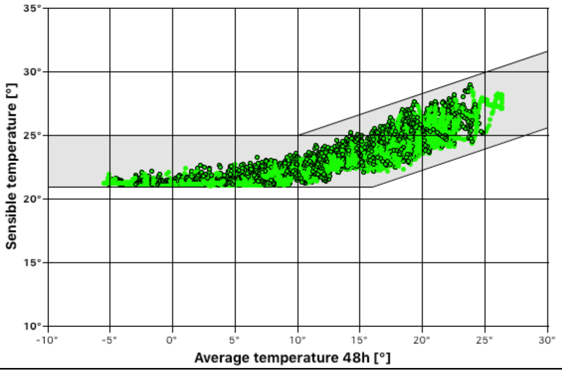
Amsterdam, CRR = 0.96 / 0.75



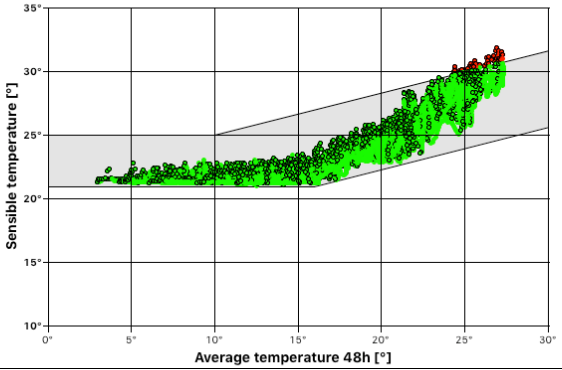
Lisbon CRR = 0.49 / 0.17



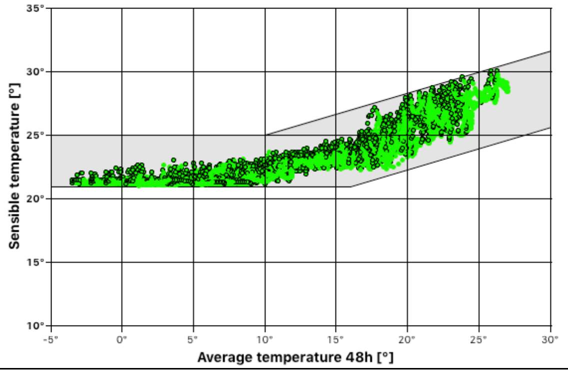
Geneva CRR = 0.86 / 0.41



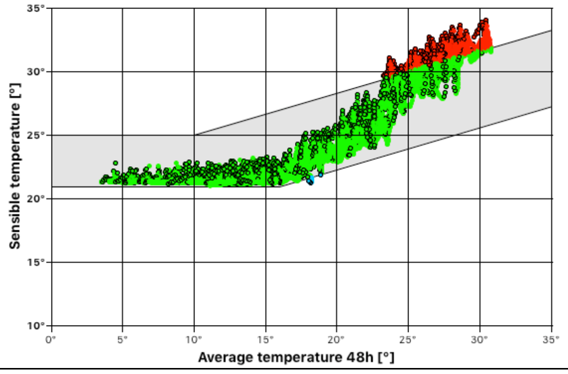
Roma CRR = 0.35 / 0.09



Milano CRR= 0.71 / 0.28



Athens CRR = 0.2 / 0.04



5.2 Seasonal energy efficiency ratio $SEER_{VC}$ and ventilative cooling advantage ADV_{VC}

If we concentrate on two cities, Geneva and Roma, and we assume a cooling system SEER=3 and a ventilation system SPI=0.45 W/(m^3/h) we have the results presented in table 4. In the reference scenario we produce the entire cooling requirements with a cooling machine of SEER=3. For scenario 2 and 3 we assume that natural ventilative cooling during day working hours and over 24h reduces cooling needs according to the simulations. For scenario 4 mechanical ventilative cooling is limited only from 01:00 to 07:00 and for scenario 5 mechanical ventilative cooling is switched on when ΔT>4°C without time limitation.

Table 4: $SEER_{VC}$ and ADV_{VC} for Geneva and Roma

	Geneva						Roma					
	Cool. R. kWh	Cool. Energy	Ventil. Energy	Total Energy	**$SEER_{VC}$**	**ADV_{VC}**	Cool. R. kWh	Cool. Energy	Ventil. Energy	Total Energy	**$SEER_{VC}$**	**ADV_{VC}**
1. Reference	292	97	0	97			351	117	0	117		
2. Day Nat VC	173	58	0	58			321	107	0	107		
3. 24h Nat VC	40	13	0	13			229	76	0	76		
4. Mech 6h VC	90	30	67	97	**3.01**	**1.0**	244	81	67	148	**1.60**	**0.53**
5. Mech ΔT> 4°	36	12	112	124	**2.29**	**0.8**	222	74	78	152	**1.65**	**0.55**

Scenario 5 runs ventilative cooling 1349 hours in Geneva and 940 hours in Roma. As we can see from the results that $SEER_{VC}$ are poor and in most cases ADV_{VC} is lower than 1, compared to a conventional system of SEER=3. When there are no time limitations (scenario 5), ventilation energy is higher than scenario 4, with direct consequence even lower $SEER_{VC}$. For Geneva ADV_{VC} is very near to 1 for the optimum case, meaning that ventilative cooling with a dual ventilation system spends at least as many energy as an air-conditioning system of SEER = 3.

Sensibility analysis showed that the optimum time for ventilative cooling when we need to reduce the hours of use, in all climatic conditions is at 04:00, the optimum mechanical ventilative cooling duration is around 810 hours per cooling season (6 hours per night) with ventilative cooling switched on when ΔT>4°C. Even with these optimum operating conditions, with hot climates it is difficult to have a positive ADV_{VC} (i.e. a ventilative cooling SEER superior than the one of the cooling system). High performance dual ventilation systems have SPI>0.4 W/(m^3/h) and single flow systems SFP>0.1 W/(m^3/h).

The graphs of Figure 3 show the curve where ADV_{VC} = 1. These curves are calculated for a particular site and a particular scenario for a given building. The curves of Figure 3 represent the optimum mechanical ventilative cooling scenario 1:00-7:00 with an airflow of 5.6 m^3/hm^2.

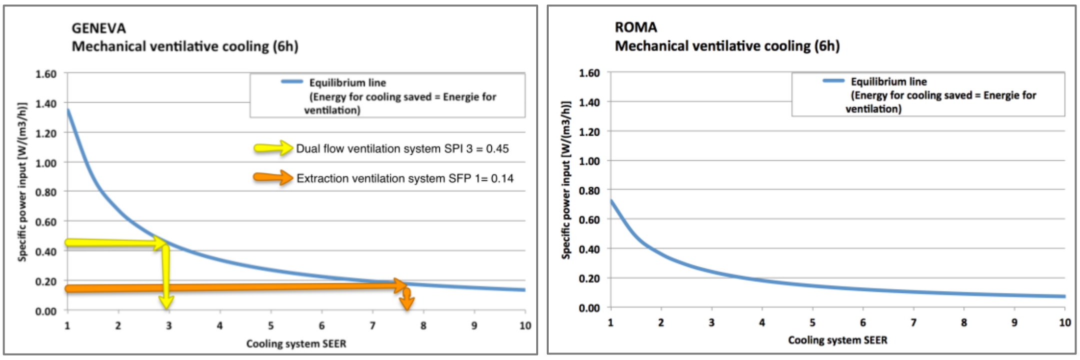


Figure 3: ADV_{VC} = 1 curves for Geneva and Roma.

On the graph of Geneva we may see that for a ventilation system of SPI = 0.45 W/(m^3/h) (category 3) the maximum conventional cooling system SEER that can be replaced without loosing more energy is 3. For a single flow extraction system of SFP = 0.14 W/(m^3/h) (category 1), ventilative cooling has the advantage over conventional cooling systems. The cooling system must have a SEER > 7.7 to be more advantageous than ventilative cooling.

5.3 Example of CRR and $SEER_{VC}$ of two ceiling fans

Simulations for this example follow the same protocol and boundary conditions. The reference scenario is a day ventilative cooling scenario. To account for the effect of a ceiling fan we simulate the cooling requirements at 29°C, assuming that a ceiling fan at a medium speed may reduce the perceived temperature by 3°C. It is a realistic scenario where occupants open windows for fresh outside temperature and use ceiling fans when interior temperature is higher than 26°C. The interesting performance indicators of ceiling fans are found on table 5.

Table 5: Example of CRR and $SEER_{VC}$ of two ceiling fans 15W and 37W

	Cooling Requirements			Ceiling fan 15W		Ceiling fan 37W	
	at 26°C [kWh]	at 29°C [kWh]	**CRR**	El. Energy [kWh]	**$SEER_{VC}$**	El. Energy [kWh]	**$SEER_{VC}$**
Geneva	173	39	**0.77**	11.1	**12.0**	27.4	**4.9**
Rome	321	100	**0.69**	12.6	**17.5**	31.1	**7.1**

6 CONCLUSIONS

A set of ventilative cooling energy indicators is a powerful tool showing the potential of the passive strategies and offering the possibility to compare it with conventional cooling strategies. Natural ventilative cooling is a passive technique and can be called "free cooling". The only "cost" is the ability to leave the windows open in safety conditions during night. CRR analysis showed that this passive strategy is able to provide comfort for NZE buildings passively without extra energy consumption for continental European climates. It may reduce significantly cooling needs by reducing cooling season for hot Mediterranean climates. Ventilative cooling may replace cooling systems during mid season for these climates.

Mechanical ventilation is a more convenient strategy, running on independently of window use, but it costs energy. Energy performance indicators showed that even high energy-performance dual ventilation systems have a poor $SEER_{vc} < 3$. It is necessary to optimise the ventilative cooling hours to the minimum in order to get the best $SEER_{VC}$ and get the advantage over conventional cooling systems. Optimal conditions for office buildings in almost all the climates is a temperature difference of $\Delta T > 4°C$ and a time limitation of 6 hours centred on the coldest moment of the night at 4:00 am. This limitation (6 hours per night 1:00-7:00) reduces ventilation time to ~800 hours and gives higher $SEER_{VC}$.

7 REFERENCES

Kolokotroni M, Heiselberg P. (2015). Ventilative cooling state of the art. *Department of civil engineering, Aalborg University, Aalborg.*

Court of Auditors - Vaud (2015). Rapport 37, Audit du Développement Durable dans les bâtiments de l'Etat de Vaud, *Cour de Comptes du Canton de Vaud, Lausanne.*

Flourentzou F, Ritz K, Pantet S, (2017), Design and performance of controlled natural ventilation in school gymnasiums, International Journal of Ventilation, Vol. 16 , Iss. 2,

Artmann N., Manz H., & Heiselberg P. (2008), Passive Cooling of buildings by night-time ventilation. Duebendorf: *Schlussbericht. Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation, UVEK. Bundesamt für Energie BFE.*

Chiesa G, Grosso M. (2015), "Geo-climatic applicability of natural ventilative cooling in the Mediterranean area", *Energy and Buildings 2015 107 pp376-391*

Paule B., et al., DIAL+Suite (2012), A new suite of tools to optimize the global energy performance of room design, *Status Seminar, Zurich.*

Swiss Standards: SIA 180 (Thermal protection and interior climate in buildings), SIA 382/1 (Ventilation and airconditioning - genaral basis and required performance), SIA 2024 (Data concerning use of rooms and technical installations for energy calculations),

EN Standards: EN 15251 (Indoor environmental input parameters...), EN 15265 (Sensible room cooling load...), EN 15265 (Calculation of Energy use for heating and cooling), ISO 13790 (Energy performance of buildings - Calculation of energy use for space heating and cooling), ISO 13791 (Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling), EN ISO 7730 (Ergonomics of the thermal environment).