This article is based on a paper presented at the 39th AIVC - 7th TightVent & 5th venticool Conference, 2018 "Smart ventilation for buildings" held on 18-19 September 2018 in Antibes Juan-Les-Pins, France.

Key findings on Ventilative Cooling

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This paper sums up the key findings on Ventilative Cooling (VC) which has proven a solid and highly energy efficient solution to support summer comfort. It offers detailed insights on VC elements, their application and control strategies linked to well-operating VC systems. Beyond that hands-on information on algorithms for early stage air-flow estimation as well as key performance indicators are stated.

Keywords: Ventilative Cooling, Ventilative Cooling Performance Indicators, Natural Ventilation, Airflow Rate, Summer Comfort, Air Velocity, Operability, Reliability

Over the course of the IEA EBC Annex 62 in depth research on Ventilative Cooling (VC) such as short time performance measurements, user surveys, involvements in VC-building-design, long-term case studies and expert interviews has been carried out. This paper presents a list of key performance-indicators derived from successful VC solutions as well as a list of major challenges and examples of successful practical solutions.

Three qualities turned out to be crucial as regards success or failure of Ventilative Cooling applications:

1. Sufficient **Airflow**
2. Appropriate **Temperatures**
3. **Usability** and Reliability

Airflow

Ensure sufficiently high airflow

Sufficient airflow, whether naturally or mechanically induced is crucial for Ventilative Cooling systems. Design for significant air change rates is necessary in order to get a VC-system working. An air change rate (ACH) of greater 3 h^{-1} is mandatory, whereas an ACH greater 5 h^{-1} is recommended to achieve substantial heat removal and justify noteworthy investments.[1]

The analysis of case studies showed, that the percentage opening area to floor area ratio (POF) has to be around 2–8%, whereas in temperate climates with dry hot summers ratios at the higher end have been recorded.

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[1] Holzer, P. et al. (2017), p.3

The analysed case studies show no correlation of building category concerning POFs. These values do not take into account the flow effects of the opening, but may be used as rule of thumb in early design stages.[2]

Favour airflow through architectural apertures

Airflow through architectural apertures is a most effective and most economic technology to achieve sufficient airflow. Simple architectural aperture deliver impressive airflow already at relatively low temperature differences or wind pressure levels. The algorithm proposed by de Gids & Pfaff offers a quick and still reliable estimation for airflow of single sided ventilation through one opening, driven by temperature difference inside/outside as well as wind velocity.

$$U_m = \sqrt{C_1 U_{10}^2 + C_2 h \Delta T + C_3} \qquad (1)$$

$$Q = \frac{1}{2} A U_m \qquad (2)$$

A	Opening area [m^2]
C_1	Wind constant (0.001)
C_2	Buoyancy constant (0.0035)
C_3	Turbulence constant (0.01)
h	Window height [m]
Q	Volume flow rate [m^3/s]
U_{10}	Reference wind speed measured at the height of 10 m [m/s]
U_m	Mean velocity [m/s]

E.g., a window of 1 m^2 (0.5 m width and 2 m height), at a temperature difference of only 2 K and a mean wind velocity of only 0.5 m/s already offers an impressive airflow of 120 m^3/h.

Enhance airflow by powerless ventilators

Powerless ventilators generally make use of wind pressure to generate either additional pressure driving supply air flow or – more often – generate a negative pressure driving extract air. The most widely used are Venturi ventilators, powerless rotating ventilators and wind scoops. Powerless ventilators are generally robust, inexpensive and very effective. Again, their effects depend inevitably on the presence of wind.

Industrial Venturi ventilators reach pressure coefficients up to (–1), leading to remarkable negative pressures of:

- 4 Pa at an undisturbed wind speed of 2.5 m/s;
- 60 Pa at an undisturbed wind speed of 10 m/s.

Venturi roofs ventilators and Venturi chimney caps are offered throughout the world as robust and effective air flow enhancing devices for exhaust air (**Figure 1**).

Figure 1. Prefabricated ventilators which utilize the Venturi effect.[3]

Design for very low pressure drops

A very low pressure drop is mandatory for successful VC application:

Buoyancy is widely used as a natural driving force in VC applications. Still, it is important to accept its limitations: If the air driving force is buoyancy, VC shall be designed for pressure drops of less than 5 Pa.

If the air driving force is mechanical ventilation, pressure drop can technically be raised, but economically and ecologically is limited by the call for high power efficiency (COP). COP of VC is defined as the ratio of $P_{thermal}$ / $P_{elecrtical}$. A total pressure drop of 100 Pa will lead to a power efficiency (COP) of ≈ 20, which is a reasonable benchmark, compared to a mechanical chiller. EN 13779 defines the best category of Specific

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[2] O'Sullivan, P. O'Donovan, A. (2018), p.24

[3] Passivent Airstract roof ventilation terminals, https://specificationonline.co.uk/directory/passivent/products/airstract-roof-ventilation-terminals (05/06/2018)

Fan Power (SFP) lower than 500 W/(m³·s), equalling a pressure drop of 250 Pa. In Ventilative Cooling this is still too much. VC applications have to be designed within the non-existing category "SFP 1+" with a specific fan power of lower than 200 W/(m³·s), equalling a pressure drop of 100 Pa.[4]

A well performing example of VC exhaust ventilation has been monitored in a Viennese social housing project. The air is drawn in via automated staircase windows, guided through the central aisles, drawn out via <10 m duct length by a central exhaust ventilator on the roof of the building. The monitoring proofed a Specific Fan Power (SFP) lower than 170 W/(m³·s), equalling a total pressure drop of 85 Pa, resulting in COP = 24 at an extract air flow of 22.000 m³/h.[5]

Temperature

Efficient operation of VC is highly dependent on outdoor air temperatures. Natural airflow rates are strongly linked to temperature differences (ΔT) between indoor and outdoor air temperatures. Especially in dense urban areas day night swings might not be sufficient for effective night ventilation. Site specific circumstances however can make a big difference. Green outdoor spaces, like parks with trees and unsealed surfaces, may provide adequate reduction of night temperatures. Orientation of air inlet openings should consider such circumstances.

Exploit available temperature differences, limit VC to periods which physically make sense

VC system should only operate at a sufficient temperature difference potential of indoor to outdoor temperature. A recommendable threshold is $\Delta T \geq 2$ K. In the case of a long term monitored building of the University of Innsbruck the set point for VC operation has even been raised to 3 K, with the benefit of a much more stable and robust operation pattern of VC.

Figure 3 shows short time monitoring results from mechanical ventilative cooling in a Viennese office during a mild summer period. Mechanical ventilation runs from 22:00 to 06:00. Outdoor Air Temperature (green) undergoes the extract air temperature (yellow) at 22:00. The monitoring results show that the start point is well set. As ΔT has its peak in the early morning hours the operation of the operation time should be extended to fully benefit from low outdoor temperatures.[6]

Design the VC system for summer comfort at increased air temperatures

The ability of thermal mass to absorb thermal energy is highly dependent on the prevailing indoor air tempera-

Figure 2. Air inlet window with chain actuator (left) Exhaust ventilator on roof (right).

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[4] Calculations based on an average ventilator efficiency ratio of 50% and air temperature rising by 3 K.

[5] Holzer, P. et al. (2017), p.2

[6] Holzer, P. et al. (2017), p.4

ture. Thus, it is mandatory for successful VC application, to allow slightly elevated air temperature in the room. A constantly low air temperature throughout the day will ruin a possible contribution of VC.

Thus, VC has to be safeguarded by indoor climate concepts that secure thermal comfort at elevated levels of air temperature. Elevated air velocity can be an appropriate measure.

Air movement is the most effective mean of extracting heat from the human body, both by convection and evaporation in and ordinary indoor environment. Thus, air movement, hereby addressed as comfort ventilation, is not a measure for extracting heat from houses but of extracting heat from human bodies. The effect of raising the personal neutral temperature by moving air is quantitatively described in many comfort Standards (i.e. ISO 7730:2005, Appendix G).

Air movement may be provided both by natural airflow, whereas heat transfer has to be prevented, and by mechanical fans. Box fans, oscillating fans or ceiling fans are well known and proven for increasing the interior air speed and improving thermal comfort. Higher air speeds permit the buildings to be operated at a higher set-point temperature and thus to reduce its cooling needs. Air circulation fans allow the thermostat to increase by >2°K. Thus, fans can meet up to 40% of the cooling need of buildings.

Usability and reliability

User integration is crucial for a functioning VC system and a well excepted indoor environment. There might be discrepancies concerning the desired operation of VC components (e.g. the scheduled opening and closing of windows) and user preferences, which have to be taken into account. Case study documentations show best results when automated components also allow for manual control. Such implementations prove to be the most adaptable and reliable solutions, where VC systems work well and users are satisfied.[7]

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[7] O'Sullivan, P. O'Donovan, A. (2018), p.30

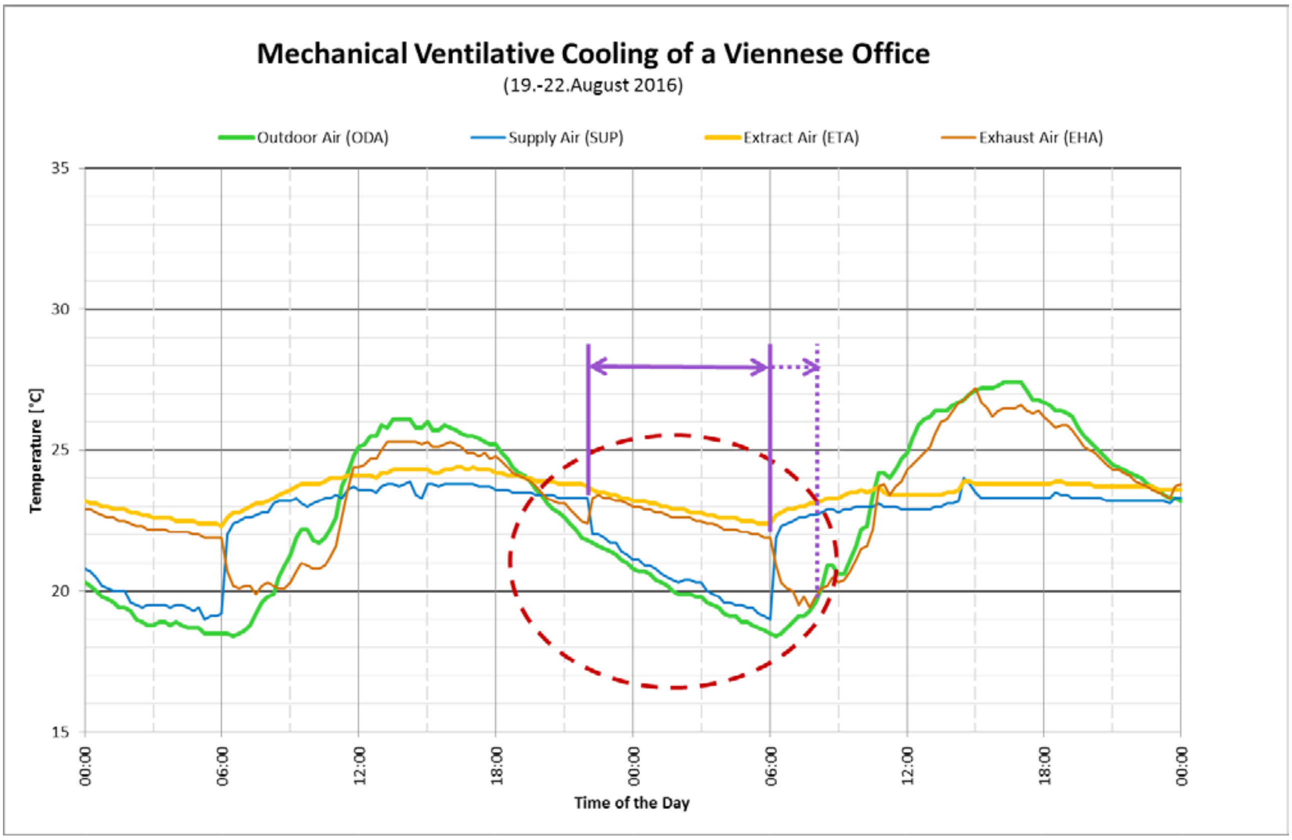

Figure 3. Temperature profile of mechanical Ventilative Cooling system in an office.

One example of such a combination from a Viennese primary school has been documented, where windows (shown in **Figure 4**) are used for night ventilation. They allow users to manually open the window which increases user acceptance, but still are controlled automatically for night ventilation which ensures high efficiency of VC.

Strictly emphasise Operability and Reliability of VC components

The operability of VC components, especially of the airflow guiding and airflow enhancing components, is key to success of the whole VC system. The following aspects are related to previous chapters and offer close links to practical VC application.

Safety and security measures have to be taken into account from early design stages on. They play an important role especially in public buildings where users and visitors might not be that well informed about the building's technical equipment. For automated components, like windows, flaps or louvres, entrapment prevention is mandatory. The best solution comes by making moveable parts of VC components inaccessible for users. If placed at heights above 2 m they are usually save. Another option is to use pressure sensitive sealing as shown in **Figure 4**. This measure needs additional installation care and raises maintenance costs, but allows for placement of VC components in positions reachable by users.

Post occupancy optimisation is mandatory in VC applications: There should be a constant monitoring and parametric optimisation during a period of one year. This cannot be substituted by sophistic building automation. Quite the contrary, post occupancy optimisation turns out most important, for VC systems of high technology levels. It has also been reported, that occupants take less responsibility for maintaining indoor climatic conditions and engage less with the building use over the course of the first months after occupation of the building, which makes well configured automated systems even more vital.

Conclusions

Ventilative Cooling proves to be a robust, cost and highly energy efficient solution to ensure climatic indoor comfort in buildings in both cool and warm temperate climate. Taking on the findings and results from this paper and the Annex 62 will help to make its implementation successful and promote its application on a broad scale. For further results and in depth reading please refer to the official Annex 62 deliverables cited in the references below. ■

Figure 4. Automated window, with optional manual operation and resistance sensitive gasket.

Acknowledgements

This paper is based upon the findings of Annex 62 Ventilative Cooling, within the IEA EBC programme. The authors express their thanks to their colleagues within Annex 62 and to their national funding authority in Austria the Federal Ministry for Transport, Innovation and Technology.

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