Ventilative Cooling on the test bench - Learnings and conclusions from practical design and performance evaluation

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ABSTRACT

Based on 3 short time performance measurements, 4 visits together with user-interviews, 3 involvements in Ventilative Cooling (VC)-building-design, 2 long-term case studies and 11 expert interviews the paper presents a list of key performance-indicators of successful Ventilative-Cooling solutions as well as challenges together with examples of their successful overcoming.

Information has been collected from projects located in Austria, using Ventilative Cooling, both natural and mechanical ventilation, in both residential and office buildings, mainly in urban surroundings.

The list of key-performance indicators is:

1. Design for very low pressure drop in the VC-system.
2. Design for significant air change rates in the VC-system.
3. Limit the operating time of automated VC to periods that physically make sense.
4. Keep the VC-System free from Influences from AC-Components.
5. Enhance VC-effects by heat transmission from adjacent rooms
6. Design the VC-system for summer comfort at elevated air temperatures
7. Strictly emphasise Operability and Reliability of VC Components because the challenges hide behind details:
   - Safety & security aspects dealing with injury, burglary and vandalism
   - Thermal Performance limitations
   - Comfort aspects dealing with noise, dust and humidity
   - Operational aspects dealing with (mis)adjustments in the control systems
   - Economic aspects dealing with investment and maintenance

KEYWORDS

Ventilative Cooling performance indicators, Ventilative Cooling challenges

1 INTRODUCTION

Based on short time performance measurements, visits together with user-interviews, involvements in VC-building-design, long-term case studies and expert interviews the paper presents a list of key performance-indicators of successful Ventilative Cooling solutions and a list of major challenges together with examples of their successful overcoming.

2 KEY-PERFORMANCE INDICATORS

2.1 Design for very low pressure drop in the VC-system

A very low pressure drop is mandatory for successful VC application.
If the air driving force is buoyancy, typically design for less than 5 Pa.
If the air driving force is mechanical ventilation, design for less than 100 Pa.

Driving force by buoyancy equals: [1]

$$\Delta p = \left(\frac{1}{30}\right) \times \Delta T \times h \quad (1)$$

Δp: pressure difference [Pa], ΔT: temperature difference [K], h: height [m]

This leads to driving forces in the range of 5 Pa, rarely more. Wind pressure might help with another 5 Pa, equalling the dynamic pressure at a wind speed of ≈3 m/s.

Driving force by mechanical ventilation technically can be raised to some hundred Pa, but economically and ecologically is limited by the call for high power efficiency (COP), given by 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 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. [2]

A well performing example of a VC exhaust ventilation was monitored in a recent Viennese social housing project. The air is (1) drawn in via automated staircase windows, (2) guided through the central aisles, (3) drawn out via <10 m duct length by a central exhaust ventilator. 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. [3]

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[1] Kolokotroni, M., Heiselberg, P. (2015).
[2] Calculations based on an average ventilator efficiency ratio of 50% and air temperature rising by 3 K.
[3] Holzer, P. et al. (2016)

Figure 1: Air inlet window with chain actuator (left) Exhaust ventilator on roof (right)

2.2 Design for significant air change rates in the VC-system

ACH > 3 h^{-1} is mandatory, ACH > 5 h^{-1} is desirable
to achieve substantial heat removal and justify noteworthy investments.

In VC applications, the nightly air change rate very often is the bottleneck. The following picture shows the balance of temperature and energy flow in a standard room within a characteristic Central European summer.

A massive wall, ceiling or floor may store up to 70 Wh/m² within one day. To release this heat by night ventilation, seven hour duration of specific heat flow of 10 W/m² is necessary. In a 24 m² room, under realistic circumstances this leads to the need of at least ACH 8,0 h^{-1}, better ACH 10,0 h^{-1}. ACH 5 is five to ten times more than needed for hygienic aspects only. Thus, unlink the function of Night Ventilation from the function of hygienic ventilation. Besides, trust windows. In the worst case of single sided ventilation in still air at only 3 K temperature difference a fully opened window of 2 m height and 0,5 m width will already provide an air exchange of approx. ≈300 m³/h. [4]

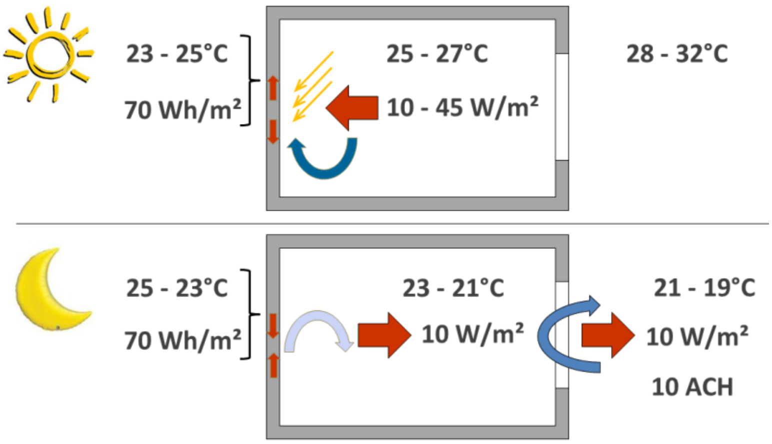

Figure 2: Scheme of typical VC temperatures, loads and airchangerates

[4] According to formula I.14 from ISO 13791:2012 $m_{a,T} = c_d \ \rho \frac{A_T}{3}\left(\frac{\Delta\theta \, g \, H}{T_m}\right)^{0,5}$

2.3 Limit the operating time of automated VC to periods that physically make sense

If automated, run the VC system only at a temperature difference potential of 2 K or higher. Do not shoulder the challenges of VC during periods of weak performance.

Automated VC always consumes resources, such as energy and maintenance. Sometimes it interferes with the expectations of occupants, e.g. in case of noise.

Note: 1.000 m³/h at 1 K rise in temperature carry the thermal load of 340 W. If driven mechanically at "SFP 1" at 500 $W_{el}/(m^3.s)$ this will cause an electrical load of 140 W. Thus, running automated Ventilative cooling at low indoor-outdoor temperature differences is only effective in naturally driven systems. Even there, 2 K seem to be a recommendable threshold.

The following figure shows short time monitoring results from mechanical ventilative cooling in a Viennese office during a mild summer period. Outdoor Air Temperature (green) undergoes the extract air temperature (yellow) at 22:00. Ventilation runs from 22:00 to 06:00, which turns out to be a good choice regarding the start, but could have been extended regarding the end. [5]

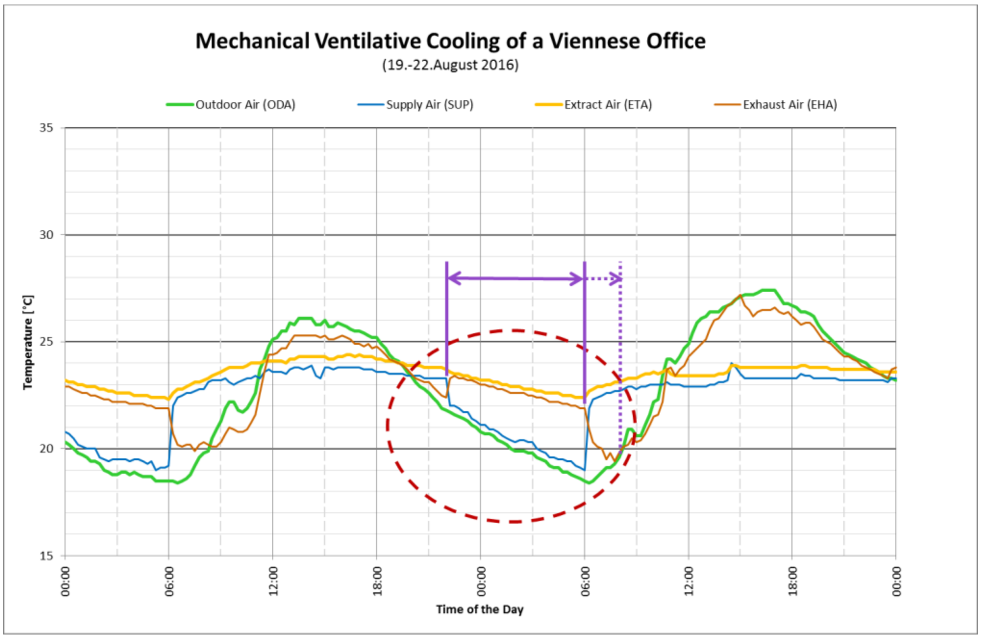

Figure 3: Temperature profile of mechanical Ventilative Cooling system in an office

[5] Holzer, P. et al. (2016)

2.4 Keep the VC-System free from Influences from AC-Components

Sometimes there are good reasons, to add some AC-components even within Ventilative Cooling concepts. If doing so, make sure that within the same building zone the AC components are strictly shut off during operation of Ventilative Cooling. A parallel operation of VC and AC has to be safely avoided.

An exemplary case has been observed during Annex 62 in one of the case study buildings: In an atrium of an office building a mechanical ventilation system automatically started into operation for dehumidification parallel to buoyancy driven night ventilation. The mistake was observed and fixed during the monitoring. [6]

Another case has been observed in a single family home with both mechanical crossflow ventilation with heat recovery and automated window ventilation: The balance between these two systems was highly problematic until there has been agreed upon a strict alternative-bivalent approach: The mechanical system now operates only up to an outdoor temperature of 12°C. The automated window ventilation fully takes over if outdoor temperature rises further. The switching point was defined upon consideration of energy efficiency and draft risk.

Finally, we found ongoing discussion, if Ventilative Cooling still is a good option, as soon as Air-conditioning is applied. And, furthermore, if Ventilative Cooling still is a good option, when climate change or urban heat island effect raise the ambient temperatures: The answer is two time: Yes, it is, as long as air-conditioning is limited to moderate set point temperatures, e.g. 26°C and as long AC and VC are run strictly in alternative mode.

For one of our short time case studies we extrapolated the following scenarios of hybrid cooling: Figure one by green columns illustrates the days within a year with Ventilative Cooling being appropriate to keep the indoor set point temperature of 26°C. Sometimes VC won't be sufficient. If so, AC has to take over. Figure two illustrated the same, but against an outdoor temperature dataset with constantly plus 3 K. The figure shows, that the periods of necessarily running the AC are rising during summer, but cooling need also extends to early summer and late summer when, VC will take over. In fact, both the number of VC-days and the sum of thermal load being removed by VC stays constant.[7]

[6] Holzer, P. et al. (2016)
[7] Holzer (2016)

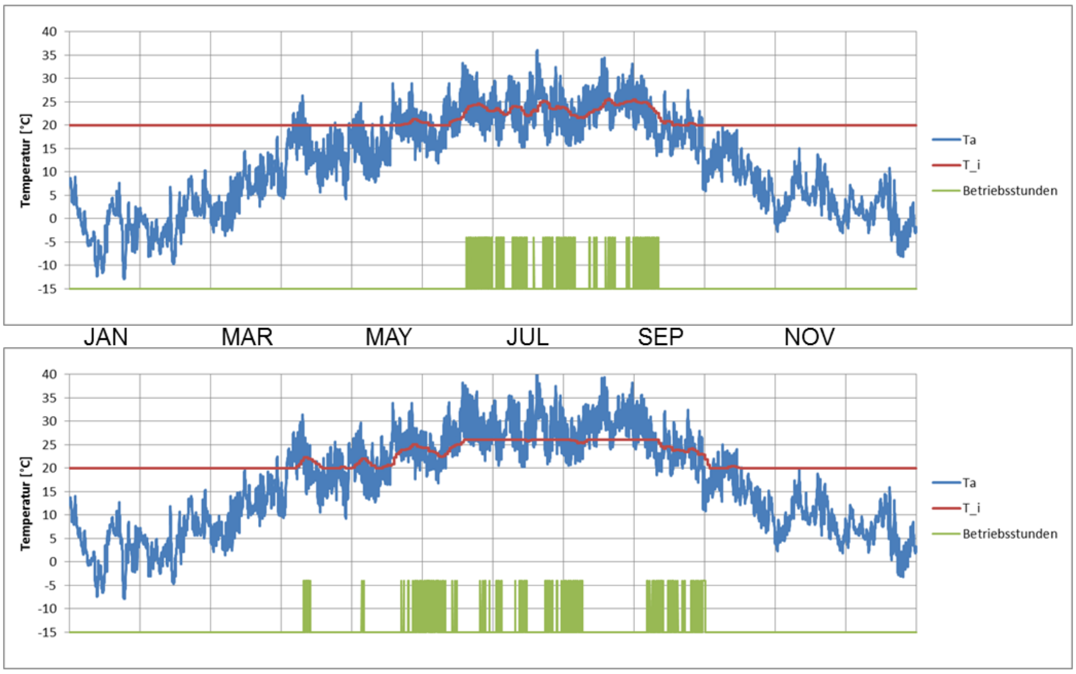

Figure 4: Days with climatic VC potential before and after a 3K outdoor climate change

2.5 Enhance VC-effects by heat transmission from adjacent rooms

There are promising examples for enhancing the effect of ventilative cooling by connecting adjacent rooms with deliberately high thermal conductivity.

We found examples of both residential and University buildings, with the central staircases and hallways being used for VC, while the adjacent rooms are thermally connected with building-elements of deliberate poor insulation quality.

This may be a very cost effective solution. It’s comparably easy to effectively ventilate staircases and hallways, while it is costly and technically challenging to apply automated night ventilation to flats or to numerous single offices.

The following figure shows an example from a 1960’s high-rise office building of Vienna’s Technical University which has recently been refurbished to Plus-Energy-Standard, including buoyancy driven Night Ventilation of the staircases and hallways. The offices and seminar rooms are separated from the hallway by single-pane laminated safety glass. The overflow orifice for night ventilation is situated above the lockable hallway door. [8]

[8] Holzer, P. et al. (2016)

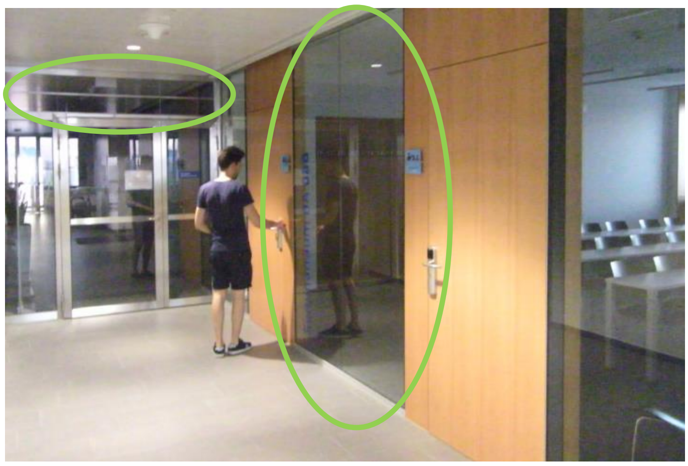

Figure 5 Glazed partition walls with high U-values and overflow orifice

2.6 Design the VC-system for summer comfort at elevated air temperatures

Good VC performance needs elevated indoor air temperatures.

Thus, both architecture and building technology have to support the VC-system by designing for summer comfort at elevated indoor air temperatures, e.g. by offering additional technical devices for personal comfort control or by encouraging people to let go strict dress codes.

Ventilative Cooling will not work, if daytime indoor temperatures are kept already at “modern” HVAC-standards.

Encourage your client based upon findings of adaptive comfort research as well as upon findings of resultant temperature at elevated air movement (both to be found in ISO 7730:2005).

The following figure, taken from ISO 7730:2005 illustrates the medium airspeed necessary to elevate the comfort temperature from 26°C for standard summer clothing (0,5 clo) and for standard sitting tasks (1,2 met). Note: Airspeed of only 1 m/s without any technical cooling already elevates the comfort temperature by 3 K.

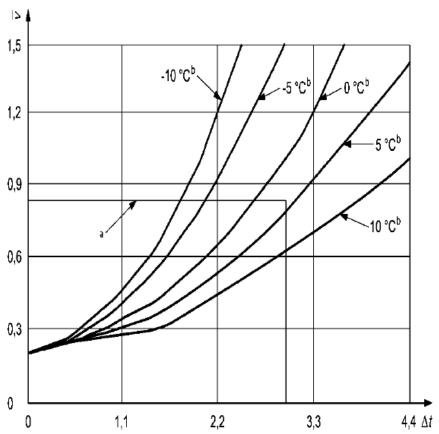

Figure 6: Mean air speed over elevation of comfort temperature

2.7 Strictly emphasise Operability and Reliability of VC-Components

In manually controlled as well as in automated systems the operability of Ventilative Cooling Components, especially of the airflow guiding and airflow enhancing components, turns out to be a key success criteria.

Within Annex 62 we identified these aspects as challenges of Ventilative Cooling in an operational context: [9]

- Safety & security aspects dealing with injury, burglary and vandalism
- Thermal Performance limitations
- Comfort aspects dealing with noise, dust and humidity
- Operational aspects dealing with (mis)adjustments in the control systems
- Economic aspects dealing with investment and maintenance

We learned: Keep operation strictly simple!

If VC is manually controlled, design ventilation openings free from interference with storage area and furniture, place opening handles very ergonomically, chose robust and long lasting mechanisms, always include anti-slam devices which prevent the ventilation openings slamming in case of draught.

If mechanical, put very intuitive operating devices at very intuitive places, be aware of stand by energy-consumption, operating noise levels, life cycles and maintenance; and find smart answers to questions relating to injury and vandalism.

Furthermore: Ensure strict rain protection: better by architecture than by rain sensors. Ensure burglary protection and consider needs for intimacy.

The next figure illustrates an example of a window, meant for manually operated night ventilation in an Austrian school, which was analysed within Annex 62: Protection against rain, burglary and fall is secured by a fixed metal grill in front of the window. But everyday operation of the window is handicapped by the exceptional deep windowsill, which invites users to use it as a shelf board, in fact blocking the window.

[9] Holzer, P. et al. (2015)

Figure 7 Window for manual night ventilation secured against rain burglary anfd fall but blocked by books

In our field research we found many examples how to deal with the risk of getting injured by automated ventilation openings, simple ones and sophisticated ones.

A high-tech example is shown in the next figure: A window which can be operated both manually and automated. The window handle is combined with an electro-mechanical device that disconnects the chain actuator from the window-frame, such allowing manual operation. Furthermore, the window gaskets are equipped with internal electronic sensors, ensuring an immediate interruption of the closing process if dedecting an unexpected resistance. The windows are installed in a Viennese school. The flipside of the coin is the higher costs for this level of function, and the notable need for maintenance.

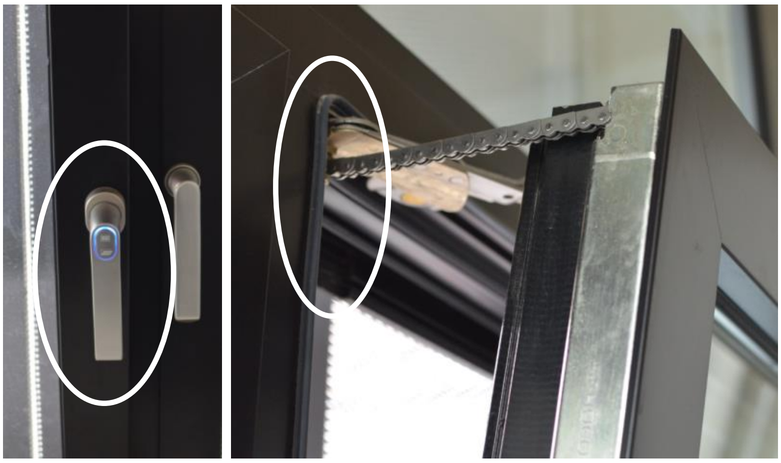

Figure 8 Automated window, with optional manual operation and resistance sensitive gasket

Another example showing the challenges of protecting against injuries was found at HCU “Hafencity University Hamburg”: Pictograms tell users not to interfere with the automated bottom hung ventilation windows, mounted already at elevations of > 2 m above floor level. Furthermore, protective grids secure venilation flaps.

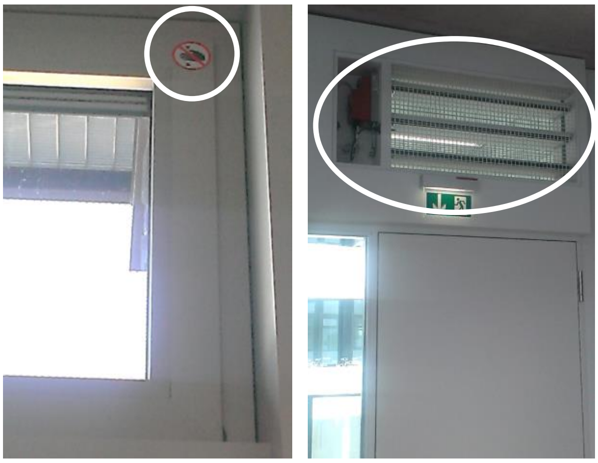

Figure 9: Ventilation flaps with additional warning pictogram and protective grid against finger injury

3 CONCLUSIONS

Ventilative Cooling proofs to be a robust and highly energy efficient solution to support summer comfort in buildings, not at just in NZEB's. Ventilative Cooling furthermore proofs being applicable in both cool and warm temperate climate. An International VC Building Database has been elaborated within Annex 62, so far documenting 99 buildings using Ventilative Cooling from 8 European Countries.[10]

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[10] Holzer, P., Moherndl, P., Psomas, T., O'Sullivan, P. (2016)