Ventilative Cooling on the test bench

– Learnings and conclusions from practical design and performance evaluation

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Ventilative Cooling is a strong option for passive cooling with minimal energy input. Yet, applications of Ventilative Cooling (VC) have to be designed with utmost care. Misinterpretations of bordering conditions and users' preferences may spoil the concept. The article in hand presents guidance derived from real applications and simulation. It is based on a paper presented at the 38th AIVC - 6th TightVent & 4th venticool Conference, 2017 "Ventilating healthy low-energy buildings" held on 13-14 September 2017 in Nottingham, UK.

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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]

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

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 Pthermal / Pelectrical . 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. EN16798-3 (table 14) defines the second best category of Specific Fan Power (SFP) the SFP1 category which means lower than 500 W/(m^3.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 cate-

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[1] Kolokotroni, M., Heiselberg, P. (2015).

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

gory "SFP 0+" 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. Outdoor Air inlet via automated staircase windows. Ventilative Cooling of the central stairways. Extract Air led through less than 10 m ducts and being exhausted 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]

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 an exemplary 24 m² room this leads to the need of at least ACH 8,0 h^{-1}, better ACH 10,0 h^{-1}. This is 10 to 20 times higher than ACH for hygienic aspects. Thus, unlink the function of Night Ventilation from the function of hygienic ventilation. Besides, trusting on windows. Even in case of single sided ventilation in still air only 3 K temperature difference at 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]

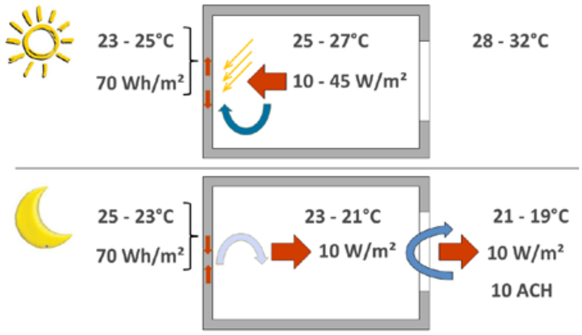

Figure 2. Scheme of typical VC temperatures, loads and airchangerates.

Operating schedule of mechanical VC

If mechanical, 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 (with lower temperature differences).

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 ΔT of 1K carry the thermal load of 340 W. If driven mechanically at "SFP 1" at 500 Wel/(m³.s) this will cause an electrical load of 140 W. Thus, running automated Ventilative cooling at low ΔT is only sensible in naturally driven systems. Even then, 2 K seems to be a recommendable threshold.

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

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

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

Figure 3 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]

Hybrid Ventilative Cooling

There's 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 sided: 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.

From one of our short time case studies we extrapolated the following scenarios of hybrid cooling: **Figure 4** (top) 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 4** (bottom) illustrated the same, but against an outdoor temperature dataset with constantly plus 3 K. **Figure 4** 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.[6]

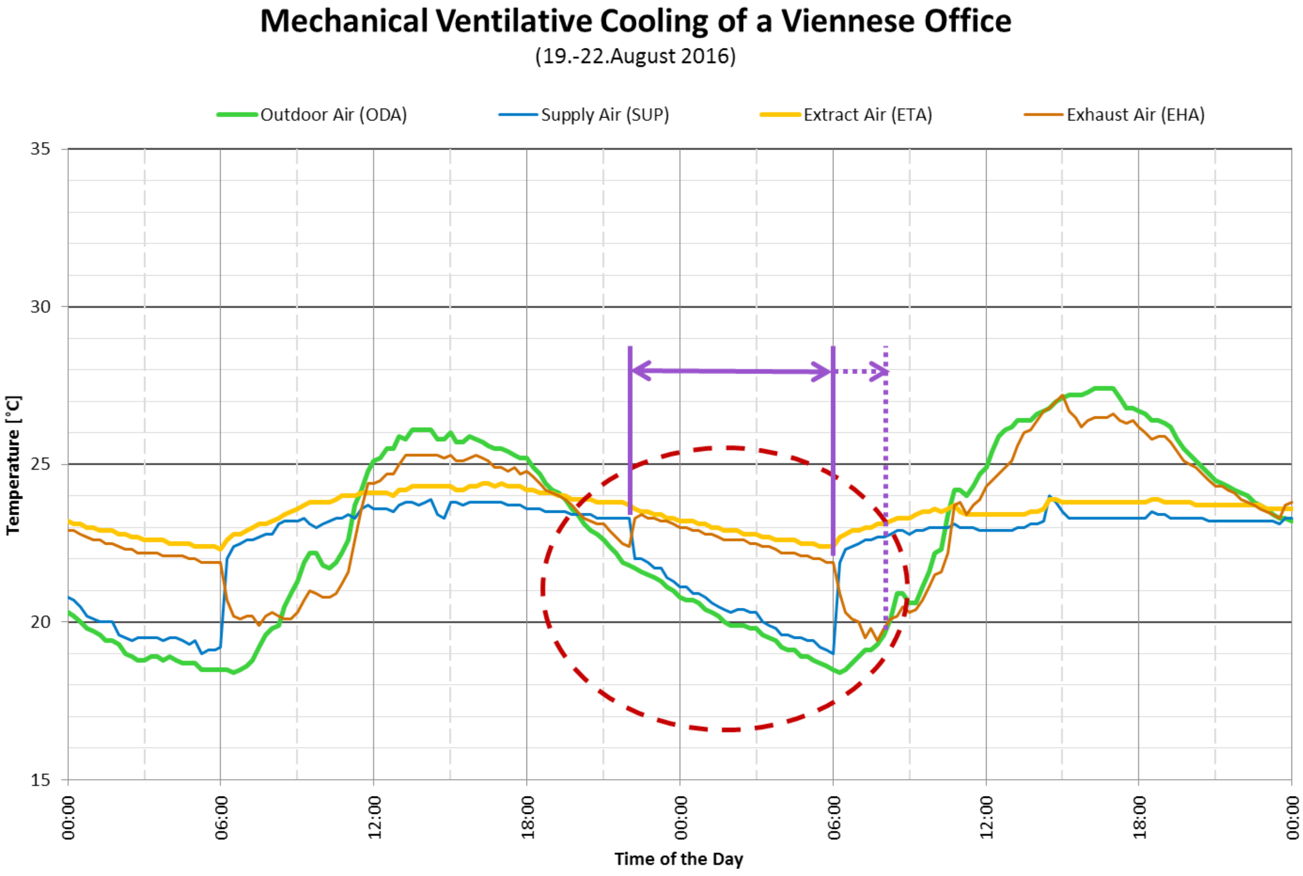

Figure 3. Temperature profile of mechanical Ventilative Cooling system in an office.

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

[6] Holzer (2016)

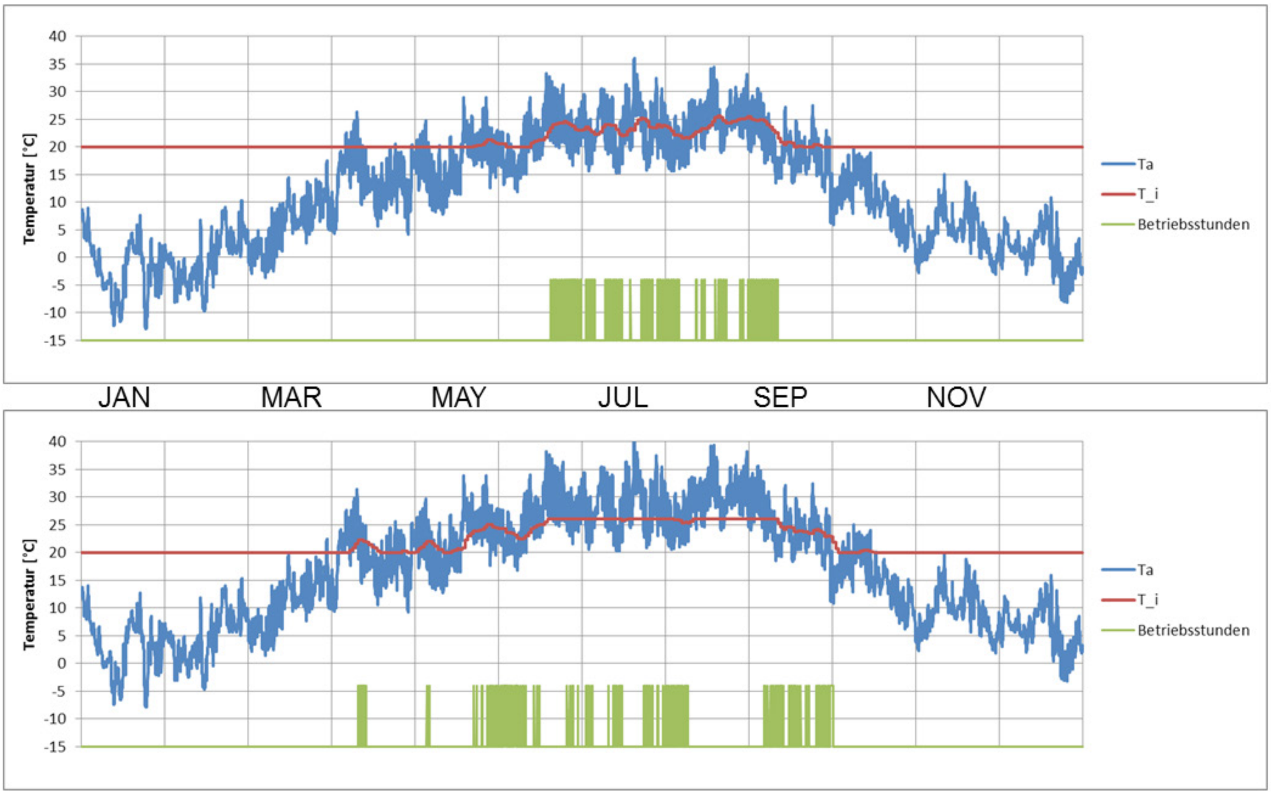

Figure 4. Days with climatic VC potential before and after a 3K outdoor climate change.

Ventilative cooling effects from adjacent rooms

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

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.

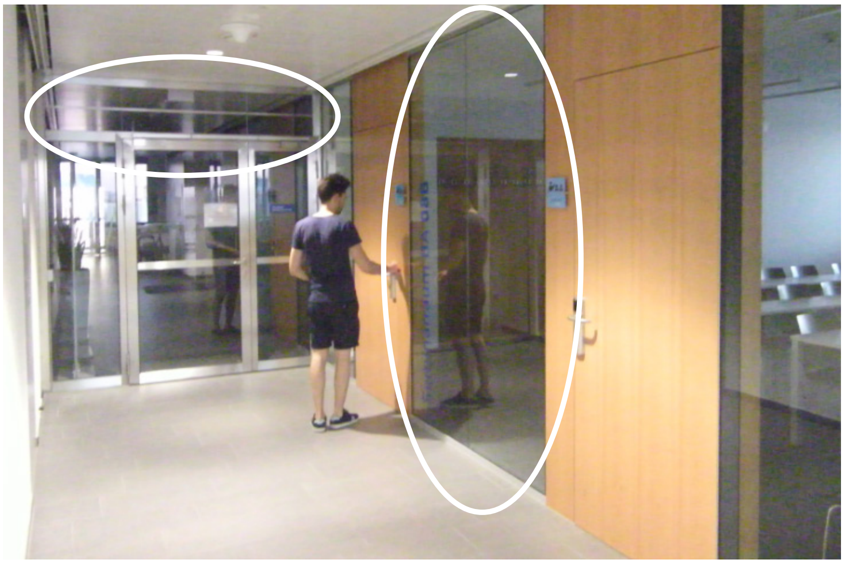

Figure 5. Glazed partition walls with high U-values and overflow orifice.

Figure 5 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. [7]

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

Thermal comfort at elevated air movement

Air movement is a strong driver of thermal comfort. It is well suitable to passive cooling.

Figure 6, 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.

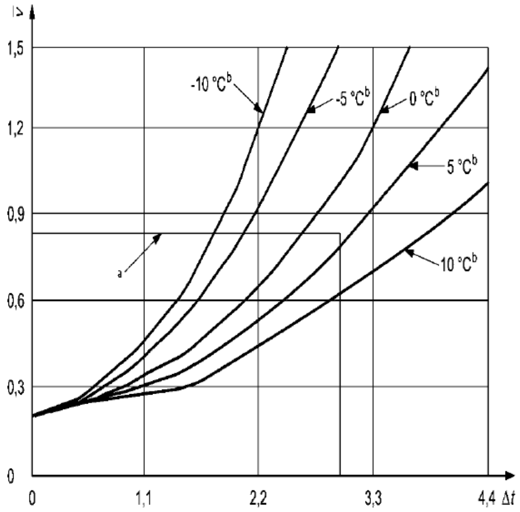

Figure 6. Mean air speed over elevation of comfort temperature.

Operability and reliability of VC-components

The operability of Ventilative Cooling Components, especially of the airflow guiding and airflow enhancing components, is a key success criteria.

The following aspects have been identified as critical in an operational context: [8]

- 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

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.

Figure 7 illustrates an example of protection against rain and burglary 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, blocking the window.

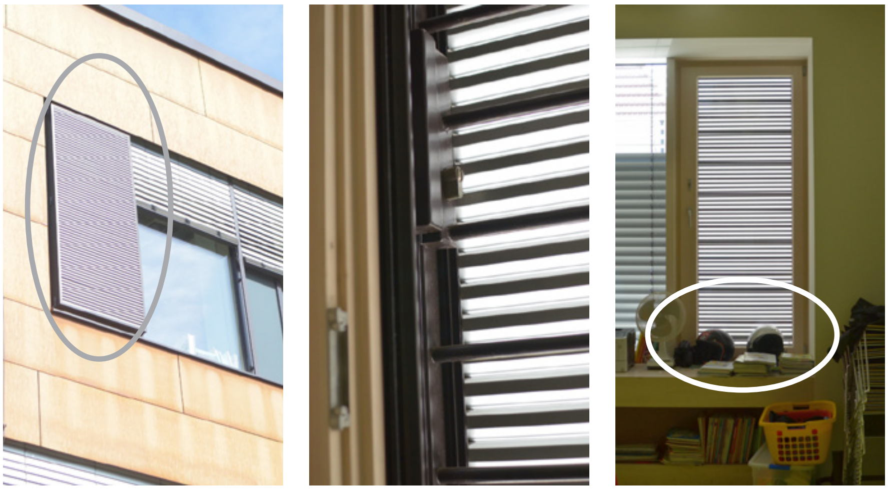

Figure 7. Window for manual night ventilation secured against rain burglary and fall but blocked by books.

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

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 **Figure 8**: A window which can be operated both manually and automated. The handle is combined with an electro-mechanical device that disconnects the chain actuator from the window-frame, 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.

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 ventila-

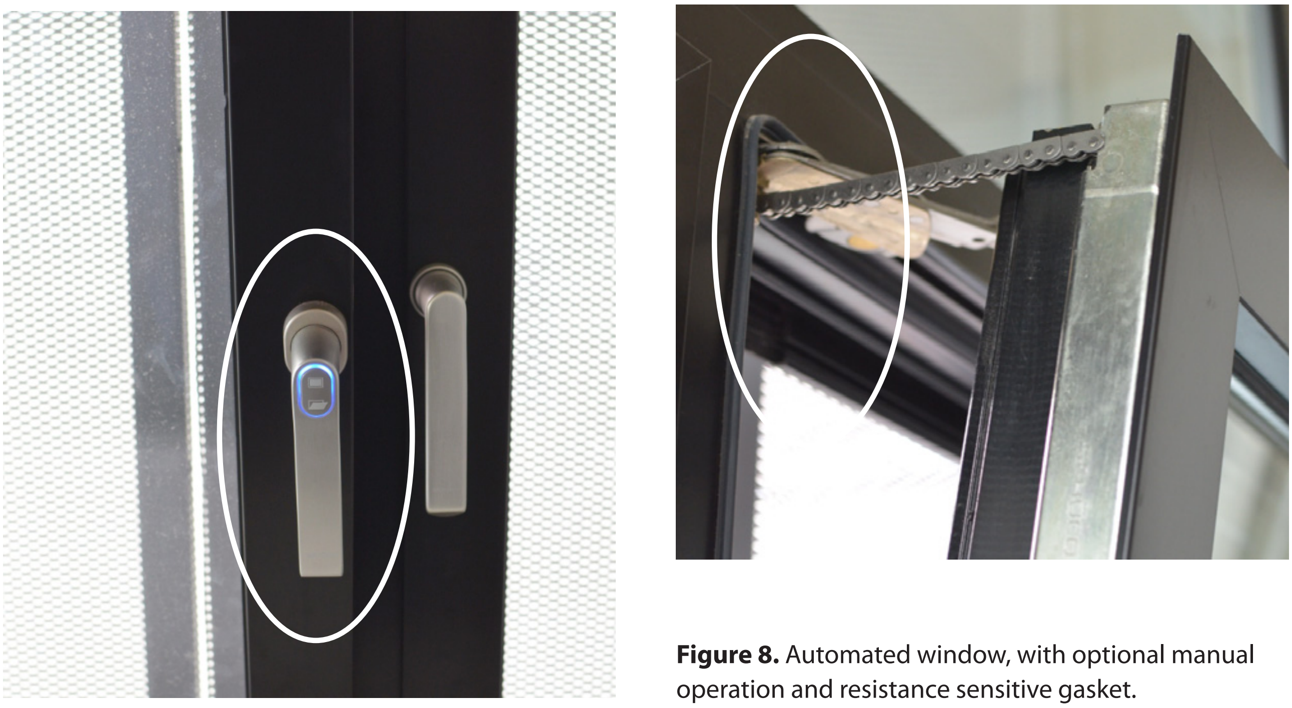

Figure 8. Automated window, with optional manual operation and resistance sensitive gasket.

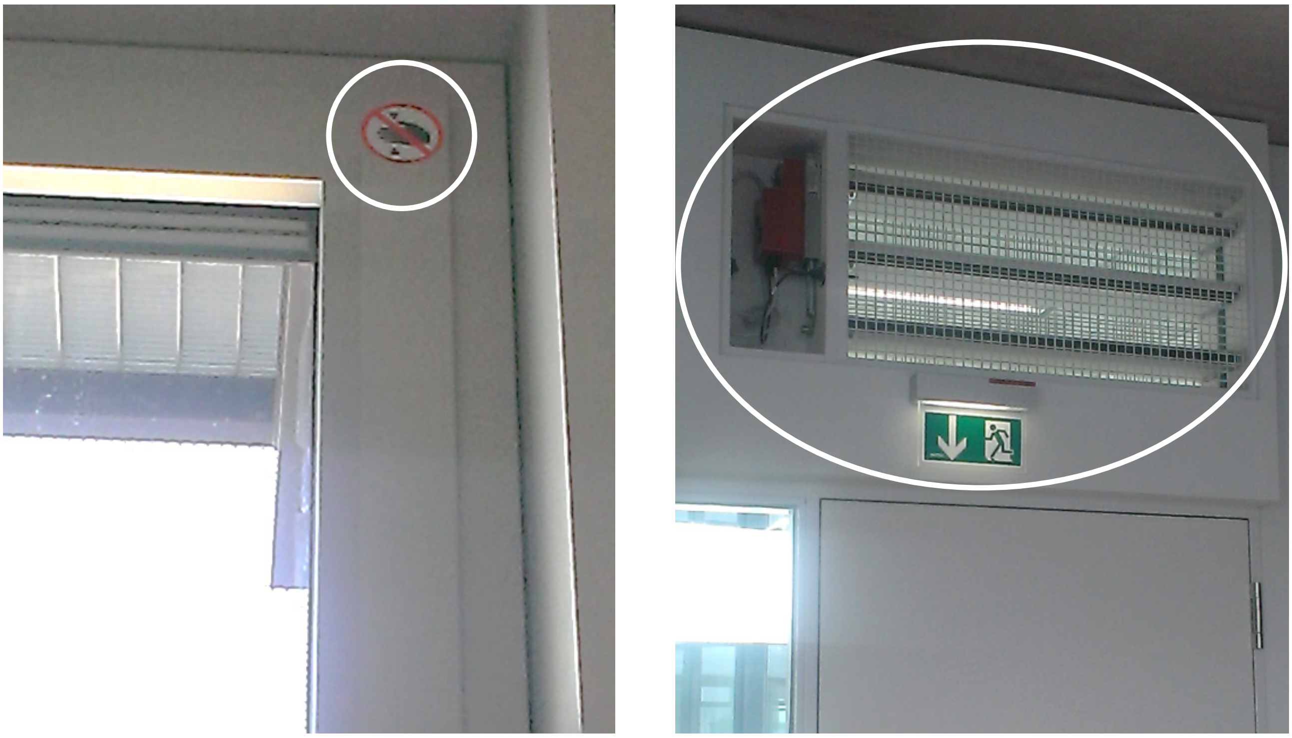

Figure 9. Ventilation flaps with additional warning pictogram and protective grid against finger injury.

tion windows, mounted already at elevations of > 2 m above floor level. Furthermore, protective grids secure venilation flaps (**Figure 9**).

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.[9] ■

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

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