POTENTIALS AND LIMITATIONS OF VENTILATIVE COOLING STRATEGIES IN THE MODERATE CENTRAL EUROPE CLIMATE REGION

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ABSTRACT

The paper in hand investigates the potentials and limitations of ventilative cooling strategies in the moderate Central Europe climate region of Vienna, Austria, offering a a basic load break down of the thermodynamic night ventilation sub-processes plus an overview over frewuent practical limtations and finally a recent monitoring result from a single family model home.

Even in urban areas within the moderate continental climate of Austria, night flush ventilation may contribute a daily cooling potential of 70 Wh per square meter of thermally active wall-, ceiling and floor area, resulting realistically in possible cooling contributions up to 150 Wh per square meter of treated floor area, leading to mean cooling loads during exemplary five hours of the day up to 30 W per square meter of treated floor area, what clearly improves the summerly thermal building performance significantly.

Ventilative cooling has a number of very tempting strengths, being
- highly efficient
- immensively long lasting and robust
- supportive of flexibility
- supportive of climate sensitive archchitectural design
- supportive of adaptive comfort concepts with rich and healthy thermal sensations

The bottleneck in the system of Night Flush Ventilation is the need for a high air change rate during the night hours, which has to be pushed up to 10 air changes per hour, if the physical potential is to be made full use of.

Besides, a number of constructive and operational limitations occur, which, if overseen to face, spoil the possible contributions of ventilative cooling. Those are burglary, wind and rain, intimacy, noise, insects, usability and finally, if automated, the energy demand for vents and controls. Facing these operational limitations there's still a significant demand for technical development.

KEYWORDS
Ventilative cooling, night flush ventilation, climate sensitive architectural design

INTRODUCTION

Objectives

The paper in hand addresses potentials and limitations of ventilative cooling strategies in the moderate central Europe climate region.

Background and Motivation

Ventilative cooling, namely night flush ventilation, played a significant role in Central Europe’s building tradition and still is a frequent design strategy to prevent from summerly overheating in residential buildings. Still, observation, monitoring outcomes and simulation results show a recent tendency to overestimate the effects of ventilative cooling or spoil its potentials by ignoring essential rules of implementation.

Thus, the paper offers an analysis of the basic physical relations that drive ventilative cooling, interpretations of monitoring results and finally design recommendations, against the background of climate situation and building tradition of Central Europe, Austria, and against the Author’s professional experience in researching and teaching for sustainability in building design at Danube University since 1996, being now head of the Department for Building and Environment.

BOUNDARY CONDITIONS FOR VENTILATIVE COOLING

Building tradition

Ventilative cooling, namely Night Flush Ventilation, played a significant role in Central Europe’s building tradition: Stone and brick made buildings have been deliberately designed for night flush cooling strategies, handled by manual operation of shutters during the day and window opening during the night hours. Going along with window areas of maximum 30% of the façades’ total areas, residential interiors could usually been kept at operative temperatures lower than 27°C.

Climate

Austria belongs to the climatic zone Dfb according to Koeppen-Geiger, being addressed as the Cold Temperate Continental Climate with even precipitation in all months and warm summers. [1]

Summerly monthly mean temperatures so far stay closely below 20°C, with daily peaks during heatwaves up to 34°C and further. At clear sky conditions there are significant day-night temperature swings, at amplitudes of typically 7K in rural areas and 5K in urban surroundings.

Figure 2 shows the Nicol Graph of Vienna’s Climate, based on Meteonorm hourly data, with the monthly mean temperatures in bold blue, the monthly mean values of the daily temperature highs and lows in light blue, the comfort temperature for free running mode buildings with adaptive options in red and the monthly mean value of daily sunshine hours in yellow columns. [2], [3]

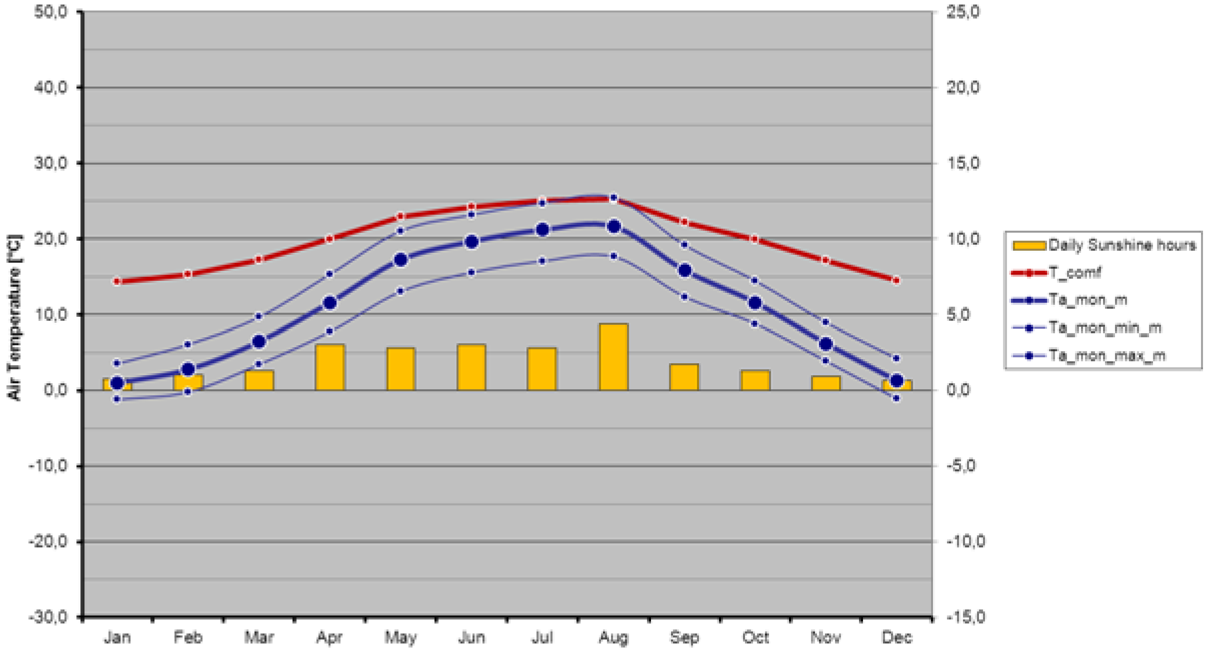

Figure 1.Nicol Graph of the climate of Vienna.

Figure 2 shows the psychometric chart of Vienna, again baesd on Meteonorm data, using the 10_year_extreme mode, thus partly representing already an outlook to climate change.

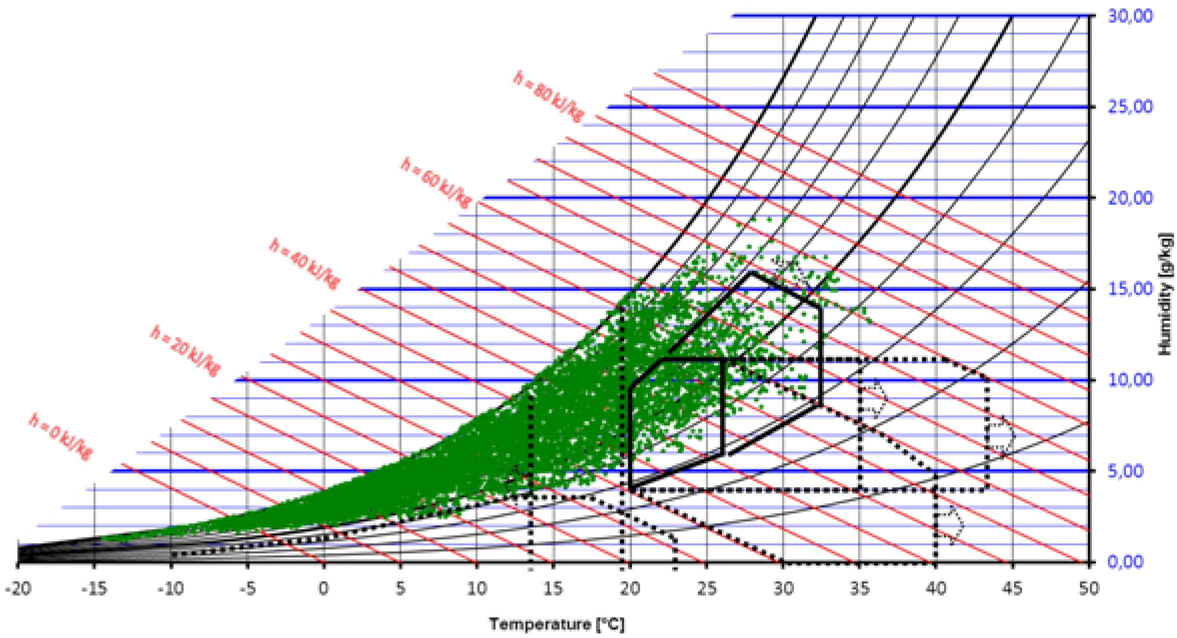

Figure 2. Psychometric chart of Vienna.

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Building Regulations

Austrians building regulations strictly ask for proving the summer performance of buildings.

Residetial homes must not override 27°C operative temperature at given climatic bordering conditions of a summerly heatwave, proved by fixed calculation methods, based on periodically repeated daily runs of ambient temperature and solar irradiation. Additionally a calculatory cooling demand of zero has to be achieved.

In case of office buildings, the externally induced cooling demand, that's the part of the cooling demand driven by transmission and solar gains, has to be kept lower than 1,5 kWh per cubic meter of treated interior space.

In both cases night flush ventilation is taken into account, but limited to very pessimistic assumptions, such as night-time air change rates of maximum 3 $^{1}/_{h}$.
Comfort ventilation, increasing summerly thermal comfort by moving air, isn't taken into account at all. [4]

POTENTIALS AND LIMITATIONS

Physical Potentials

The process of night flush ventilation may be cut into four specific sub-processes:

1st the loading of the thermal masses of the room's surfaces.
2nd the storing of heat within the thermal mass behind the room's surfaces.
3rd the unloading of heat from the thermal mass behind the room's surfaces.
4th the removing of heat from the room to the cool outside night.

See Figure 3 for a vizualization of the full process of night flush ventilation with its four sub-processes.

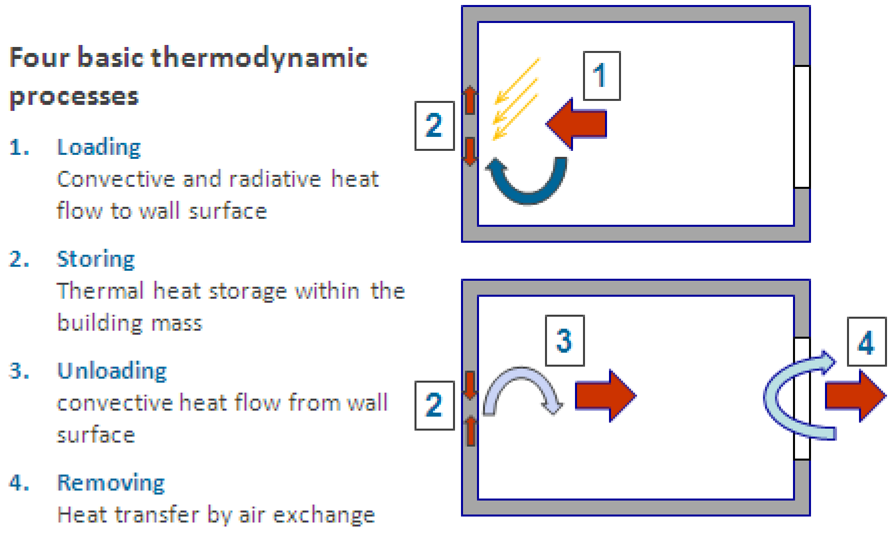

Figure 3. Physical processes of night flush ventilation.

Sub-process 1, the loading of the thermal masses of the room's surfaces, is driven by both convection and possibly radiation. Based on realistic bordering assumptions, the specific thermal load reaches 10 to 45 W per square meter of surface. See Figure 4 for the basic equations.

- **$p_{loading}$ … Specific Heat Flow Loading [W/m$^2_{wall}$]**
- $p_{loading} = (T_{air} - T_{wall}) * \alpha_{conv} + I_{rad} * (1/\rho)$

- $(T_{air} - T_{wall}) \cong 2K$
- $\alpha_{conv} \cong 5\ W/m^2K$
- $I_{rad} \cong 70\ W/m^2$
- $\rho \cong 50\%$

- **$p_{Loading} \cong 10 - 45\ W/m^2$**

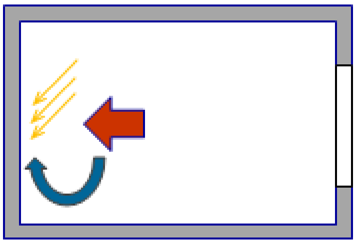

Figure 4. Sub-Process of Loading.

Sub-process 2, the storing of heat within the thermal mass behind the room's surfaces, follows the physical potential of heat storage and release within a 24h time period. The specific heat storage capacity may reach roughly 70 Wh per square meter of surface, which fits to the specific load of sub-process one. See Figure 5 for the basic equations.

- **$q_{storing}$ … Specific Heat Storage Capacity [Wh/m$^2_{wall}$]**
- $q_{storing} = \Delta T_{wall} * m_{wall} * c_p$

- $\Delta T_{wall} \cong 2K$
- $c_p \cong 1kJ/kgK \cong 0{,}28\ Wh/kg$
- $m_{wall} \cong 0{,}1\ m * 1.200\ kg/m^3 = 100\ kg/m^2$

- **$q_{storing} \cong 70\ Wh/m^2$**

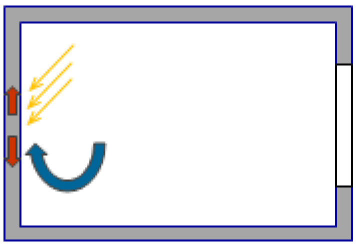

Figure 5. Sub-Process of Storing.

Sub-process 3, the unloading of heat from the thermal mass of the room's surfaces, is driven by convection only. Radiation is neglectible, since the room's surfaces may be assumed to not differ significantly in surface temperature. Thus, the specific thermal load may be assumed with 10 W per square meter of surface, which again fits to the system. See Figure 4 for the basic equations.

- $p_{unloading}$ … **Specific Heat Flow Unloading [W/m^2_{wall}]**
- $p_{unloading} = (T_{wall} - T_{air}) * \alpha_{conv}$

- $(T_{wall} - T_{air}) \cong 2K$
- $\alpha_{conv} \cong 5\ W/m^2K$

- $p_{unloading} \cong$ **10 W/m^2**

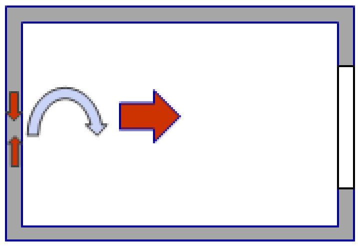

Figure 6. Sub-Process of Unloading.

Sub-process 4, the removing of heat from the room to the cool outside night, turnes out to be the bottleneck. Outside air temperature in urban areas of Austria gets no lower than 19°C. Thus, based on the asssumption of an air change rate of only 2,5 $^1/_h$, the specific heat flow removing is limited to only 2,5 per square meter of surface, which certainly doesn't spport the system properly. See Figure 7 for the basic equations.

- $p_{removing}$ … **Specific Heat Flow Removing [W/m^2_{wall}]**
- $p_{removing} = (T_{interior} - T_{ambient}) * c_p * (V/A) * n$

- $T_{interior} - T_{ambient} \cong 2\ K$
- $c_p \cong 0{,}33\ W/m^3_{air}K$
- $V/A \cong 1{,}5$
- $n = 2{,}5\ ^1/_h$

- $p_{removing} \cong$ **2,5 W/m^2!**

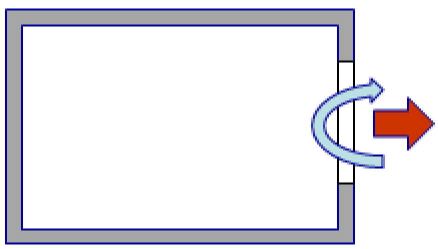

Figure 7. Sub-Process of Removing.

To remove the load of 10 W per square meter of surface, either the temperature difference or the air change rate has to be incresed significantly. Since the temperature difference isn' to change, an air change rate of up to 10 1/h has to be introduced to fully make use of the given ventilative coooling potential.

Against the climate of Austria the assumption as regards temperature differences of 2 K each are quite realistically defined. See Figure 8. Total Load Breakdown. for the full picture of the combined load balances:

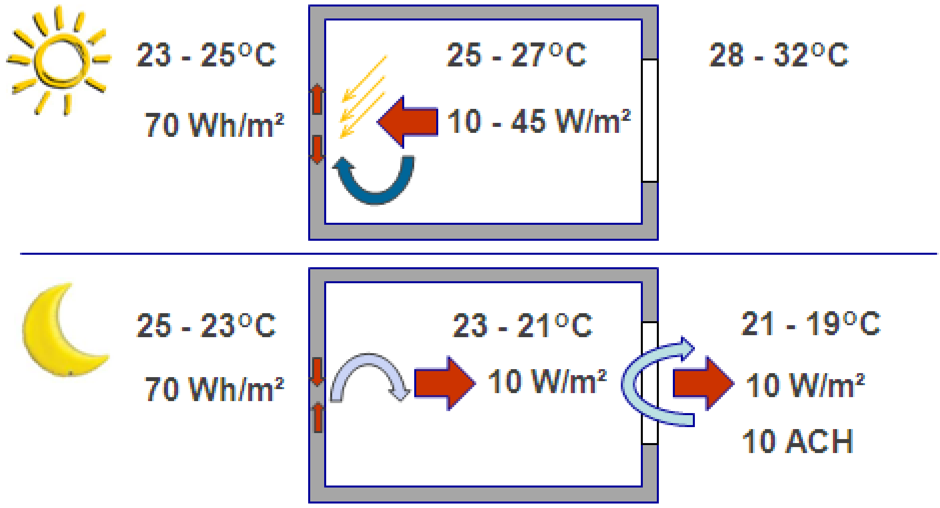

Figure 8. Total Load Breakdown.

Practical Limitations

In spite of it's still significant physical potential, night flush ventilation is in danger of being limited by a number of practical circumstances. These are

- burglary, wind, rain, noise,
- insects, particles,
- usability, intimacy and – if automated –
- energy demand for fans and control units.

All those practical circumstances may spoil the possible effects of night flush ventilation and in fact often do. Deliberate design efforts have to be undertaken to ensure the necessary air change rates during the night hours.

Another critical design issue arises from the fact, that with stack effect ventilation, the ventilated zone is strictly devided into an inlet-air-zone and an exhaust-air-zone, with the later getting no outside air, but only already heated up inside air. It is important to deliberately take this effect into account and e.g. do not place sleeping rooms in the exhaust-air-zone.

Finally, people from moderate climates don't seem to intuitively know how to handle night flush ventilation, at least not in modern, high performance buildings. They tend to open the windows even if it's warmer outside than inside.

Exemplary Monitoring Results

Recent monitoring results have been recently collected from the Austrian VELUX model home, a carbon neutral, plus energy building in the neighborhoud of Vienna. The house was properly designed for night flush ventilative cooling, equipped with automated sunscreens and with aotomated window opening, being proven by dynamic simulation runs. [5]

Recent air temperature monitoring in the most critical room, with data taken between March and August 2012, shows indoor air temperture levels staying most of the time clearly inside the category B benchmarks of the adaptive comfort model of EN 15251. [6]

There are only eight very specific occurancies of overriding the upper comfot limit significantly. Based on the social post occupancy monitoring it could be proven that at these specific eight days the inhabitants experimentally tried to override the automated window opening, and failed.

See Figure 9, Room Air Temperature above Running Mean Outdoor Temperature, including a photo of the house with the window of the room of investigation highlighted.

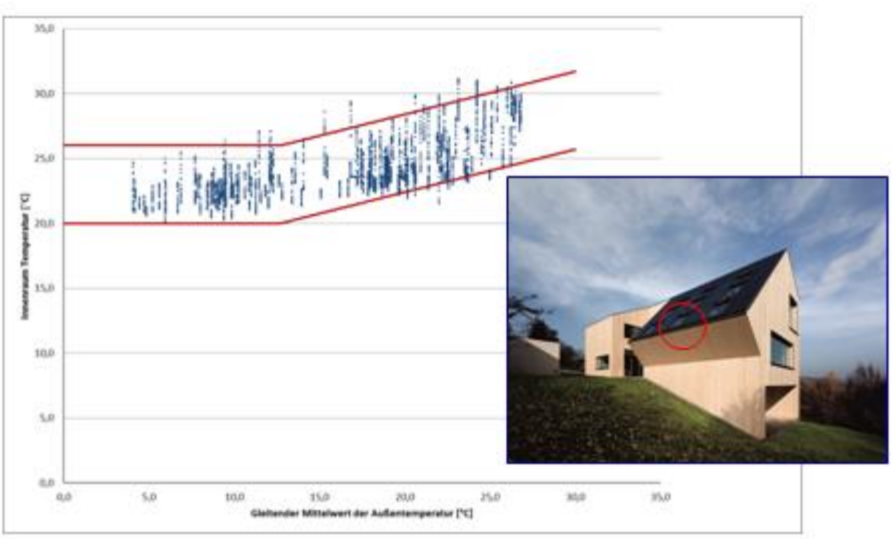

Figure 9. Room Air Temperature above Running Mean Outdoor Temperature.

CONCLUSIONS

Even in urban areas within the moderate continental climate of Austria, night flush ventilation may contribute a daily cooling potential of 70 Wh per square meter of thermally active wall-, ceiling and floor area, resulting realistically in possible cooling contributions up to 150 Wh per square meter of treated floor area, leading to mean cooling loads during exemplary five hours of the day up to 30 W per square meter of treated floor area, what clearly improves the summerly thermal building performance significantly.

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