REDUCING ENERGY CONSUMPTION IN AN EXISTING SHOPPING CENTRE USING NATURAL VENTILATION

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ABSTRACT

The energy consumption needed for establishing a good indoor climate in shopping centres is often very high due to high internal heat loads from lighting and equipment and from a high people density at certain time intervals. This heat surplus result in a need for cooling during most of the year, typically also during the winter, and often the needed cooling is provided by a mechanical ventilation system with integrated mechanical cooling.

However, for certain areas, especially the hallways connecting the individual shops, natural ventilation might be an energy efficient alternative or supplement to the traditional mechanical system.

This paper presents a case study on an existing shopping centre in Copenhagen, Denmark (Fields shopping centre). The building owner's key reason for considering natural ventilation was a desire to improve the thermal indoor climate in the hallways, and, at the same time, reduce the energy consumption for ventilation.

On this background, WindowMaster conducted a number of simulations in the dynamic simulation program BSim2002. These calculations suggested a significant energy saving potential (60% reduction) and a significant improved thermal indoor climate (70% reduction of annual hours above 28 °C) by adding natural ventilation to the ventilation strategy.

Thus, in the beginning of 2011 the building owner decided to install automatically controlled natural ventilation in the hallways in the shopping centre in addition to the existing mechanical ventilation system. The basic control idea was to use the natural ventilation system in the summer and transient seasons and the mechanical ventilation system in the winter (hybrid ventilation).

Measurements of the thermal indoor climate in the first year (September 2011 - august 2012) show that the indoor climate has improved significantly. In this year, the actual results outperform the expected results from the simulations, and the building owner has expressed his satisfaction with the improvements in the thermal indoor climate.

KEYWORDS
Thermal building simulation, energy savings, natural ventilation, hybrid ventilation, natural cooling, shopping centre, case study, log-data analysis.

INTRODUCTION

As of today, only few shopping centres have adopted natural ventilation in the hallways. This might be caused by a limited number of reference cases thus creating uncertainty for the building owner about the potential benefits in terms of reduced CO_2 emissions, running costs and improved indoor climate.

It has however been demonstrated in a number of practical cases e.g. Ernst-August-Galerie in Germany [1] and Green Light House in Denmark [2] that the use of natural ventilation in combination with mechanical ventilation might give significant improvements in the thermal indoor climate and the energy consumption in comparison with pure mechanical ventilation. Both cases have a DGNB certificate showing high performance on ecological quality and indoor climate.

In general, natural ventilation is preferable to mechanical ventilation in multi-storey rooms as the heat and stale air generated in the air volume is easily expelled through automatically opened roof windows. Such rooms exist not only in the hallways of shopping centres, but also in many other buildings, like atriums in office buildings, hallways in airports, exhibition halls, production halls and in sport facilities. Thus, the results and principles given in this paper are useful in a number of building types.

The Fields shopping centre, see Figure 1 was completed in 2004 and it is as of today the biggest shopping centre in Denmark and one of the largest in Scandinavia. It is located in Ørestad, Copenhagen and the total size of the centre is 115,000 m² with a total shopping area of 65,000 m². The centre contains more than 140 retailers and it is the workplace for around 2,500 employees. After the completion, the building owners have been committed to implementing new technologies for reducing the building energy consumption and increasing the shopping experience of the customers.

Originally the centre was equipped with a full mechanical ventilation system. However, as explained in the Abstract, in the beginning of 2011 it was decided to install automatically controlled natural ventilation in the hallways in the shopping centre to support the mechanical ventilation (hybrid ventilation). The purpose was twofold – in order to reduce energy consumption and to improve the thermal indoor climate for the benefit of customers and employees.

Automatically controlled natural ventilation is controlled depending on variations in the outdoor conditions measured from a weather station and the indoor climate measured from for example temperature/CO_2/humidity sensors and information about the usage of the building. Automatically controlled natural ventilation is highly advanced ventilation and should not be confused with manually controlled natural ventilation.

This paper presents the dynamic building simulations which were used as basis for the decision to implement natural ventilation in the building, together an analysis of the log-data of the indoor climate obtained during the first year of service. Results for the thermal indoor climate and energy consumption for ventilation are presented.

Figure 1. Picture of the shopping centre

BUILDING AND VENTILATION PRINCIPLES
The roof above the hallways is made of glazed sections as illustrated in Figure 2 and Figure 3. In the glazed areas automatically controlled window openings are established. Through these openings air enters and leaves the hallways. Based on WindowMaster's experience, the hallways have been partitioned into eight zones in the simulations – divisions which are later followed in the design of the system implemented in the building.

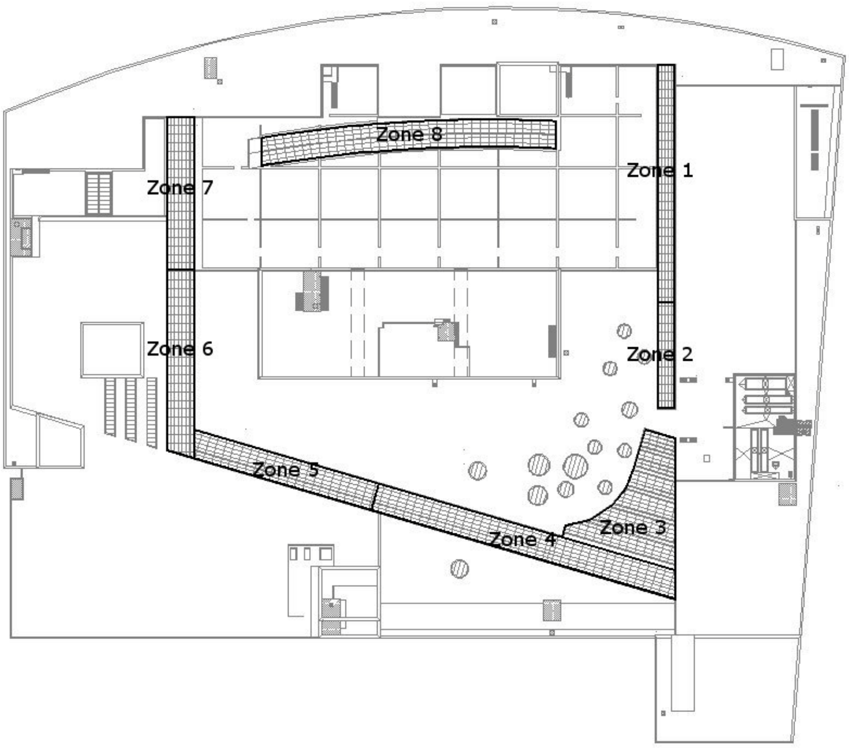

Figure 2.Drawing of the shopping centre roof including marking of the eight zones.

Figure 3. Picture of hallways from the inside and from the roof.

Natural ventilation uses the natural driving forces (wind and thermal buoyancy) for moving air and is therefore able to ventilate without any energy consumption for air movement (SFP=0). Therefore, in situations where the room or building in consideration needs cooling, natural ventilation is able to supply fresh air without energy consumption. This is an advantage for the shopping centre since warm air can be removed, while at the same time the energy consumption for air movement is reduced.

In Figure 4 the natural ventilation principle for the hallways is illustrated.

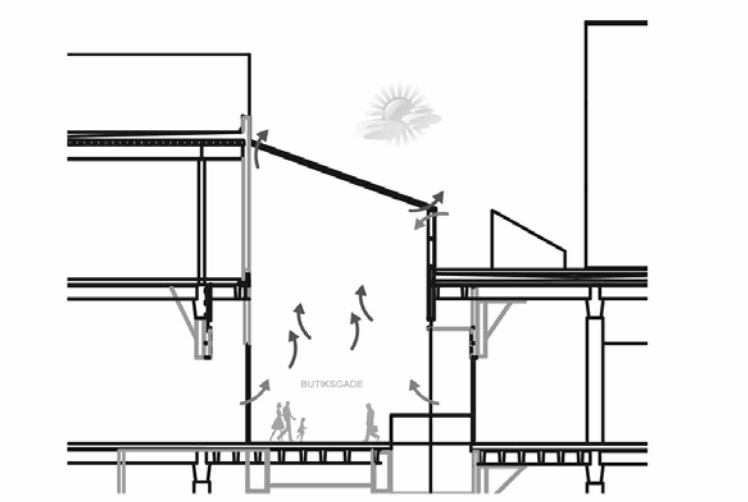

Figure 4. Ventilation principle for the natural ventilation system in the shopping centre

The primarily ventilation principle is stack-ventilation. This type of ventilation is primarily driven by warm air rising to the top whereby it creates a pressure difference which drives the ventilation.

Most of the opening area for natural ventilation is established in the glass roof above the hallways - only about 2% of the opening area is established in the facade. This distribution is not optimal, but caused by the fact that the natural ventilation system is retrofitted to an existing building. For a new shopping centre, where natural ventilation is included from the early design phase, it is recommended that the opening area is more evenly distributed between facades and roofs in order to achieve an optimal placement of the neutral pressure level. Nevertheless, the natural ventilation system capacity in the Fields shopping centre is still high as openings are placed in different levels in the roof and since it was possible to place some openings in the facade.

SIMULATION TECHNIQUES AND ASSUMPTIONS

The method used is thermal building simulation of the hallways made in the dynamic simulation program BSim2002 [3]. The software simulates the thermal indoor environment and energy performance during a year based on the specific constructions, usage and the outdoor weather conditions. Weather data from Denmark is used (DRY [4]). Based on steady state calculations, made prior to the dynamic simulation, the capacity of the natural ventilation system is determined. The methods are described in [5] and [6].

The natural ventilation system modelled is demand controlled, as the heat loads from especially people and sun changes a lot during the opening hours.

Figure 5 shows an illustration of the 3D section of the hallways which was modelled in the simulation software. This section is representative for all the hallways since these were sufficiently similar with regard to their design, internal heat loads and solar gain.

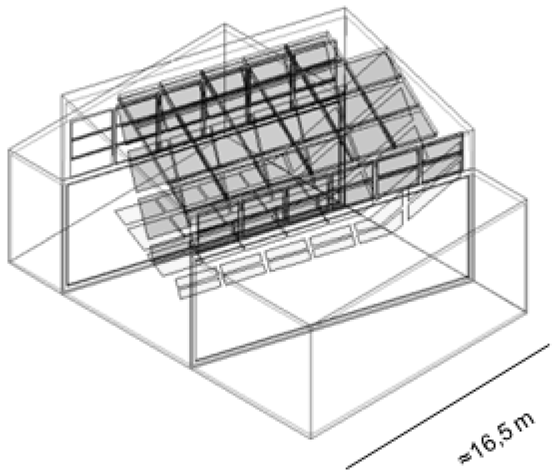

Figure 5. Calculation model for the BSim2002 simulations

Three different ventilation strategies were modelled to investigate the thermal indoor environment and the energy saving potential:

Model 1: Mechanical Ventilation (MV)

- In this model, the already existing system with mechanical ventilation was modelled in detail
- No natural ventilation system was added
- In the calculations it is assumed that the mechanical ventilation system is a CAV system with a ventilation rate of 4 h^{-1} and a heat recovery coefficient of 0.7
- The inlet air is at least 17°C
- The mechanical ventilation system is turned off during the night

Model 2: MV in winter, NV in summer (hybrid ventilation)

- In the second model, the mechanical natural ventilation was used in the winter only (week 1-15 and 46-52, in total 22 weeks of the year)
- A new natural ventilation system was implemented in the transient season and during the summer time (week 16-45, in total 30 weeks of the year)
- The natural ventilation system is set to have a maximum capacity of 4 h^{-1} and it is assumed that the natural ventilation is automatically controlled and utilized for both day ventilation and night cooling.

Model 3: MV all year, NV in summer (hybrid ventilation)

- The third model allowed the natural ventilation and mechanical ventilation to run at the same time in the summer (same weeks as given above)
- The purpose is to further reduce the number of warm hours in the hallways
- During summer mode the mechanical ventilation system is activated when the operative indoor temperature reach 26°C

For all three calculations the opening hours is Monday to Friday 10AM - 8PM and Saturday - Sunday from 10AM to 5PM. The people load is 5 m^2/person and the usage level is 100 % Monday - Friday from 2PM - 6PM and 50% in the rest of the time on weekdays. Saturday and Sunday the usage level is set to 90 % from 10AM - 5PM. The lightning level is set to 30W/m^2 in the opening hours. The g-value of the glass in the roof is 0.3.

SIMULATION RESULTS

Figure 6 shows the results of the thermal building simulations for the three models. The figure shows the total number of hours in the hallways for which the operative roomtemperature is above 28°C, 30°C and 32°C respectively. Note that only hours within the opening hours of the shopping centre have been counted. It is clearly demonstrated that usage of a natural ventilation system in the summer and transient seasons will reduce the number of "warm hours" significantly – from 677 hours to 182 hours above 28°C. It is noted that the results after installing natural ventilation would have been even better if the system had been implemented in the building from the early design phase.

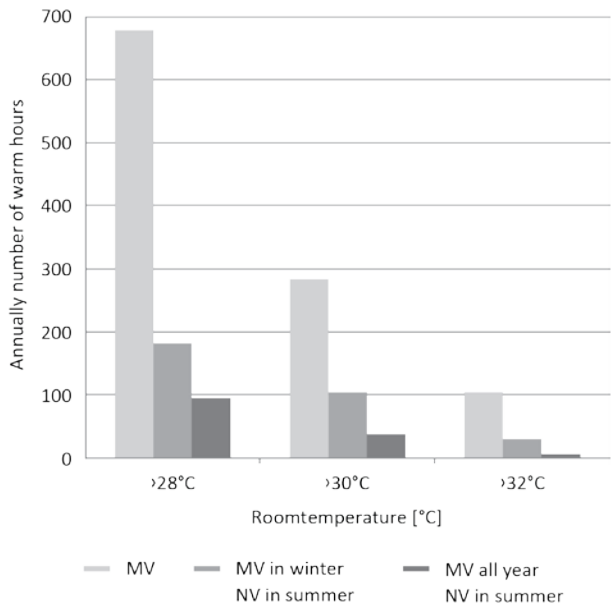

Figure 6. Annual number of hours with roomtemperature above 28, 30 and 32 °C.

Based on the simulations, calculation of the electrical energy consumption for air transport has also been made, see Figure 7. Energy consumption for heating is not included as the natural ventilation system is only used when there is a need for cooling (week 16-45). It is seen that the introduction of natural ventilation has a potential for reducing the energy consumption for ventilation by almost 60% (~ 40 kWh/m^2 year). To achieve these savings in practice, this requires that the mechanical ventilation system can be switched off – this is therefore an important design criterion for hybrid ventilated buildings.

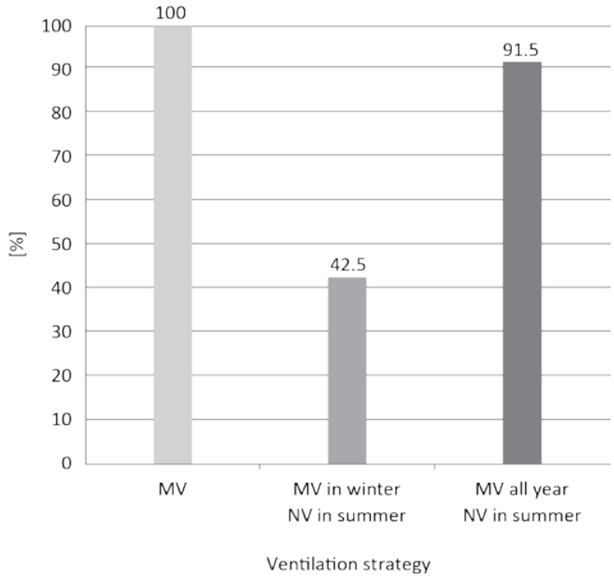

Figure 7. Energy consumption for air transport (indexed).

The results also show that in Model 3, where both natural and mechanical ventilation is used during the summer an additional reduction of 87 hours above 28°C could be achieved. This strategy does of course increase the energy consumption for the mechanical ventilation system significantly, but an 8.5% reduction compared with the pure MV system is still achieved. This is due to the fact that it is possible to turn off the mechanical system in selected periods.

The results suggest that there is a significant potential for reducing energy consumption in hallways of shopping centres by the use of natural ventilation. It is noted that the savings would have been even higher if the natural ventilation system had been designed into the building from the early design phase.

MEASUREMENTS

In reality the hallways are split into eight indoor climate zones. In each zone four or five combined temperature and CO_2 sensors are placed. These sensors form the basis for calculation of an average value for the temperature and the CO_2 level in the actual zone. The values are used for regulating the natural ventilation system and deciding whether the mechanical system should be turned on or off.

Figure 8 shows an example of a sensor placement.

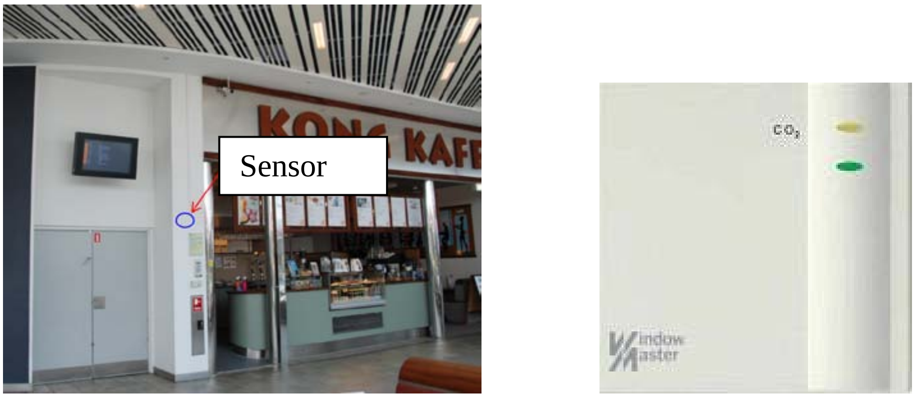

Figure 8. Example of placement of temperature/CO2 sensor and detail showing the sensor.

Figure 9 shows actual measured temperatures in four representative hallways for one of the warmest summerweeks in Denmark, 2012 (week number 33). In this week, the hallways were ventilated using both the natural and the mechanical ventilation system (hybrid ventilation).

Figure 9 clearly shows that the natural ventilation system is capable of conditioning the thermal indoor climate in the hallways during hot periods in the year. The local outside temperature (measured on the roof) in the end of the week is close to 35 °C while the indoor temperature, despite the high heat loads, is kept below 28 °C in general.

Note also that the room temperature experienced by the occupants will feel lower than the calculated temperature due to the air speed which it is possible to establish when natural ventilation is used. The air movement may reduce the experienced temperature with up to 2-3°C. This additional cooling effect is beneficial during hot periods and will be experienced as a cool breeze by the occupants.

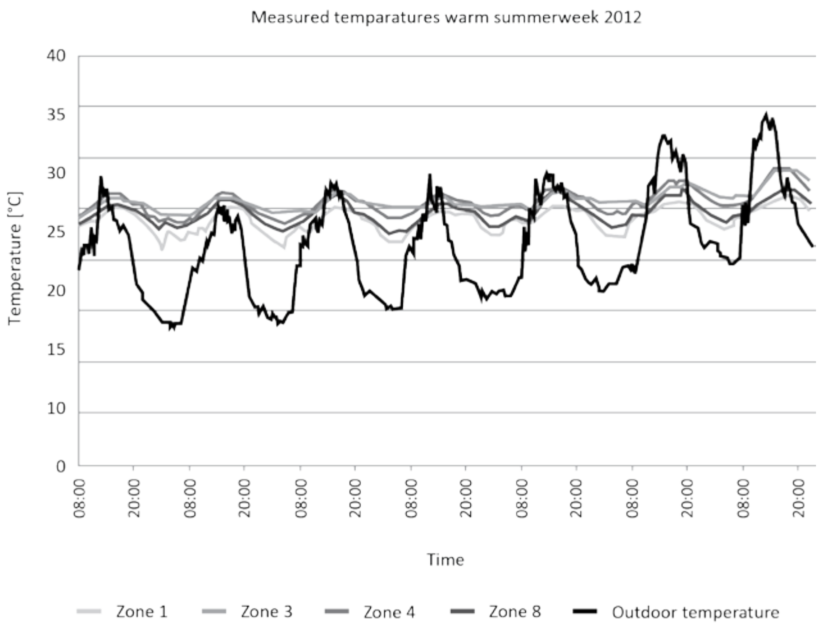

Figure 9. Measured temparatures in four representative hallways in a warm summerweek in august 2012.

Figure 10 shows the number of warm hours for one of the hallways - zone 3. The temperature has been logged for the period 01.09.2011 - 31.08.2012 – i.e. a whole year. It is noted that zone 3 is one of the warmest areas - which is also indicated in Figure 9. During this period, the system is ventilated using both the natural and mechanical ventilation system. Note, that Figure 10 compared with Figure 6 use a different temperature interval for the bars. This has been chosen since there are no temperatures above 30°C in the building – in fact the temperatures are almost entirely below 28°C.

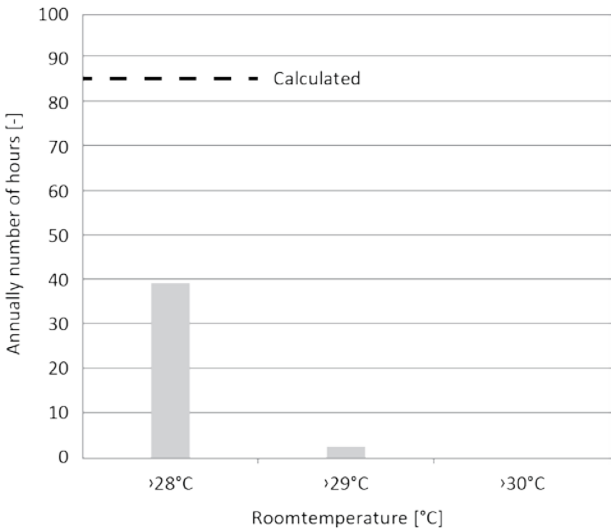

Figure 10. Annually number of hours above 28, 29 and 30 °C for the period 01.09.2011 - 31.08.2012 in hallway 2.

The number of hours with room temperatures above 28°C is approximately 40 for the year 2011 - 2012. In the dynamic simulation the annual number of hours was approximately 85 for simulation model 3 where mechanical ventilation was active all year and natural ventilation during summer and transient seasons. It is noted, that no recordings of the temperature levels in the hallways before the installation of the natural ventilation systems were made. Thus, the measured data from the building may only be compared with the simulation results.

However, based on the results after the installation of the natural ventilation system, it is clearly indicated that the theoretical calculations are accompanied by a real improvement in the indoor thermal climate. It is also noted that employees working in the centre has expressed that the indoor thermal climate has improved.

It is unfortunately not possible to present data on the electricity consumption as this was not recorded before the implementation of the natural ventilation system, and due to the fact that after the implementation a number of other energy optimization projects have been carried out. However the measured temperatures indicates a dramatic improvement in the thermal indoor climate and since natural ventilation is able to supply fresh air without energy consumption in situations where the room or building in consideration needs cooling the indoor climate has improved without increasing the energy consumption.

DISCUSSION

This particular case study is a renovation project where natural ventilation is established in hallways with existing mechanical ventilation. Natural ventilation was therefore not included from the early design phase. For a new shopping centre, where natural ventilation is included from the early design phase, the effect of the natural ventilation system can be even higher. For instance more openings can be established in the facades to increase the capacity of the ventilation and the relation between inlet air and the building constructions can be optimized for optimal night cooling.

For a new shopping centre it might as well be possible to include the shops in the natural ventilation strategy maybe for night cooling. E.g. small openings in the facades can let the outdoor air into the shops, where it cools down the construction and inventory during the night so the energy demand for cooling is reduced the following day.

For many low-energy buildings we see an almost year-round cooling demand. For these buildings we expect natural ventilation to have an even greater potential since the energy demand for ventilation almost can be eliminated as the electrical energy consumption for natural ventilation is zero.

Looking at a building in a life cycle and life cost perspective (LCA and LCC) natural and hybrid ventilation systems have a highly performance as well partly because the material consumption for a natural and hybrid ventilation system often is much less than for a mechanical ventilation system. This has been demonstrated in recent analysis of office buildings [7] [8].

CONCLUSION

This case study indicates a large potential for natural ventilation and hybrid ventilation in hallways in shopping centres as well as in similar rooms and buildings.

The dynamic building simulation shows that adding natural ventilation to the existing mechanical ventilation system can reduce the number of hours with operative room temperatures above 28°C with more than 80%. Measurements of the thermal indoor climate in the first year (September 2011 - august 2012) support the building simulation. In this year, the actual results outperform the expected results from the simulations, and the building owner has expressed his satisfaction with the improvements in the thermal indoor climate.

The dynamic simulation further shows that improving the thermal indoor climate can result in energy savings since the electrical energy consumption for air transport can be reduced. The size of the energy saving potential depends on the quality of the thermal indoor climate desired by the building owner – and they will be by far greatest if the mechanical system is switched off during the summer months. It has been demonstrated that doing so might result in an annual reduction of hours with operative room tempareatures above 28°C of approximately 70% and energy savings of almost 60%.

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