An investigation of ventilation control strategies for louver windows in different climate zones

Leonie Scheuring*[1], Bernhard Weller[1]

1 Institute of Building Construction, Technische Universität Dresden,
August-Bebel-Str. 30
01219 Germany
leonie.scheuring@tu-dresden.de

ABSTRACT

Guaranteeing high indoor air quality and high degree of user satisfaction at the same time is one of the challenges when improving the energy efficiency of a building. Current non-residential buildings mainly use mechanical ventilation systems to ensure high air quality. Mechanical ventilation systems are known for minimising heat losses but at the same time lead to higher installation, operating and maintenance costs. Furthermore, mechanically conditioned rooms may lead to the sick building syndrome caused by the lack of operable windows. Natural ventilation being more accepted by users has the potential to guarantee energy efficiency of buildings in conjunction with people satisfaction.

Present natural ventilated buildings pose the risk of higher energy demand and less indoor air quality due to user's behaviour. Controlled natural ventilation based on indoor CO_2-concentration and room air temperature is needed. However, the efficiency of a control strategy highly depends on climate zone and control parameters. This paper aims to explore the impact of different control strategies on the energy efficiency of an operable louver window. The most efficient strategy is then compared to a mechanical ventilation system

In a simulation four window opening strategies based on CO2 concentration were tested in Mediterranean, subtropical and moderate climate zone. Only at very cold and very warm conditions a difference in the different natural ventilation strategies was observed. When comparing the natural ventilation conditions to mechanical ventilation major differences were found. In almost all climate conditions natural ventilation outperformed the mechanical ventilation. In several climatic conditions energy consumption by the natural ventilation system was 10 fold lower than by mechanical ventilation, conflicting the common view that mechanical ventilation is the more efficient system.

KEYWORDS

Indoor air quality, natural ventilation, control strategies, louver window, energy performance.

1 INTRODUCTION

Natural ventilation still struggles against constraints about its energy efficiency and the lack of thermal comfort. Even some national energy standards demand for mechanical ventilation (EnEV, Minergie) to meet their requirements. Nevertheless, natural ventilation has been brought into the scientific focus during the last years (Prieto 2017) due to its potential to reduce the risk of the Sick Building Syndrom and its capacity to save energy by night ventilation (Becker 2002, Gratia 2004, Wang 2009). The results show that in moderately warm summer climates and warm Mediterranean climates (Becker 2002) as well as in cold climates of northern China (Wang 2009) natural ventilation at night substantially reduces cooling loads.

However, during daytime ventilation is difficult to control and inadequate user behaviour for manual natural ventilation poses the risk to not maintain the indoor air quality. This problem can be overcome with controlled natural ventilation (automated window opening). For this purpose control strategies need to be established to define the window openings.

Control strategies for natural ventilation can control indoor air quality as well as indoor air temperature (Schulze 2013). However, whereas indoor air temperature can also be controlled by heating and cooling systems a controlled natural ventilation is necessary to regulate the indoor air quality. In office rooms the internal temperature gains are very high so that passive cooling by natural ventilation can effectively reduce the cooling loads. Therefore, the control strategies should have the indoor air CO_2- concentration as the main parameter and as a second parameter the indoor air temperature.

The main challenge defining the thresholds for the CO_2 control strategy is to overcome an overcooling or an overheating occurring by too long opening times. In this paper the lower CO_2 concentration, which defines the closing point of the window, will be examined. The performance of four different strategies will be analysed for the energy demands cooling, heating, lighting and auxiliary energy for ventilation. Furthermore, investigations of the influence of different climate zones on the efficiency of control strategies are still missing and will be examined in this publication.

In addition, this publication aims to compare the efficiency of natural and mechanical ventilation. Therefore a simulation of a mechanical ventilation under the same climatic conditions will be compared to the results of the natural ventilation.

2 METHODOLOGY

A simulation model is build up with Energyplus and evaluated for four control strategies and for three locations – Wiegendorf (central Germany), Madrid (Spain) and Hanoi (Vietnam). For these locations the energy performance will be evaluated. The analysis is performed in a time step of one second and results are shown as sums of every month individually. The control strategy with the lowest energy consumption is compared to a mechanical ventilated system for each of the three locations.

2.1 Case study

The investigations are carried out for an office room in a multistorey building. It is located in the ground floor, south orientated, surrounded above, beneath and besides by rooms conditioned equally. The office room is designed for four users with a net floor area of 32 m² according to the German industrial safety guideline ASR A1.2. The transparent area of the south-orientated wall is 3.85 m² designed in accordance with DIN 5034-1. The geometry is shown in figure 1. It consists of three parts: on the left side a non-operable window, in the middle an operable window and on the right side a non-operable window. For the operable window a louver window is used with an area of 2 m x 1.587 m. The louver window consists of three operable louvers, which open simultaneously. The louvers open fully to the outside with a nearly horizontal end position. This leads to a ventilation performance comparable with the performance of a casement window but at the same time there is no casement protruding into the room.

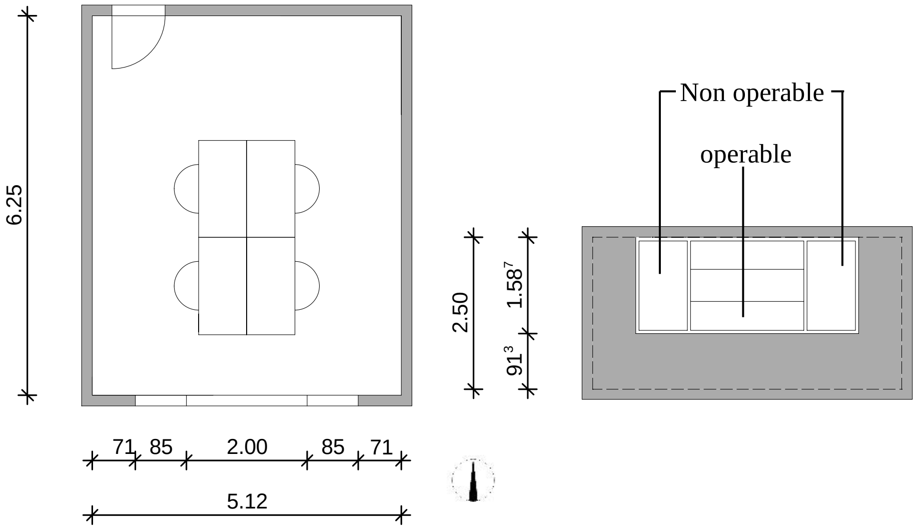

Figure 1 Case study office room – floor plan and south view.

The structural elements are made of concrete, nonstructural elements are made of sand-lime brick. The thermal properties go along the German Energy Saving Regulation 2016 (EnEV). The Solar Heat Gain coefficient is determined in accordance with the German standard for overheating in summer DIN 4108-2. The minimum value to satisfy the standard is chosen. The construction elements and the thermal properties are shown in table 1.

Table 1: Construction and thermal properties of the office room

Construction Element	**U-Value**	**Solar Heat Gain coefficient (SHGC)**	**Material and thickness of the structural element**
External wall	0.28 W/(m^{2}K)	-	25 cm concrete
Louver window and non operable windows	1.27 W/(m^{2}K)	0.54	-
Ceiling	adiabatic	-	20 cm concrete
Internal walls	adiabatic	-	11.5 cm sand-lime brick

The office room is designed for four people. However, it is not fully occupied during the working hours. The occupancy schedule is shown in Figure 2 and is based on the German standard DIN 18599 as well as the schedule for electric equipment and lighting hours. Lighting hours are from 7 am to 6 pm – during the working hours. The lights are equipped with a daylight sensor and are dimmed according to the required illumination level of 500 lux. The internal heat gains for people, lighting and electric equipment are shown in table 2.

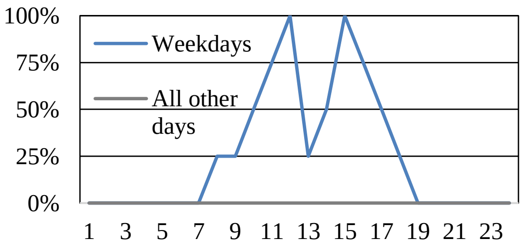

Figure 2 Occupancy and electric equip. schedule (100% = 4 people and 224 W from electric equip.)

Table 2: Internal gains

	Internal gains	**Reference**
People	126 W/person	DIN EN 15251
Lighting	10.63 W/m^2	DIN 18599-10
Electric equip.	7 W/m^2	DIN 18599-10
CO_2-production rate	$3.82\cdot10^{-8}$ $m^3/s\cdot W$	ASHRAE Standard 62.1-2007

2.2 Natural Ventilation Model

The model is built up in EnergyPlus. The single sided ventilation through the louver window is obtained using the EnergyPlus Design Flow Rate method. The method is based on Coblenz and Achenbach (Achenbach 1963) according to the following equation:

$$V = V_{design} \cdot F_{schedule} \cdot [A + B \cdot (T_{zone} - T_{odb}) + C \cdot (WindSpeed) + D \cdot (WindSpeed^2)] \quad (1)$$

The method uses a defined airflow volume (V_{design}) and modify it depending on the actual thermal difference between inside (T_{zone}) and outside (T_{odb}) temperature as well as the current wind speed. The coefficients A to D determine the effect of wind speed and temperature difference on the airflow volume. EnergyPlus offers to choose from several sets of predetermined coefficients. For the analysis BLAST coefficient set (A=0.606; B=0.03636; C=0.1177; D=0) was used because it distinguishes summer and winter conditions. (EnergyPlus 2018). Using these factors a typical summer day would result in the bracket term becoming 1, leading to:

$$V = V_{design} \cdot F_{schedule} \quad (2)$$

While for a typical winter day the bracket term is 2.75, resulting in:

$$V = V_{design} \cdot F_{schedule} \cdot 2.75 \quad (3)$$

V_{design} is determined by the equation described in Bäumler (Bäumler 2016) for a single sided ventilation.

$$V_{design} = ½ \cdot A_{geom} \cdot C_v \cdot \sqrt{\frac{\Delta p \cdot 2}{\rho_a}} \quad (4)$$

V_{design} is calculated to 0.2201 m^3/s with A_{geom} of 2.32 m^2 and C_v of 0.58 for the louver window and Δp of 0.069 Pa for a an inside temperature of 20 °C and an outside temperature of 19 °C and a room located in the ground floor.

Control strategies

$F_{schedule}$ takes either the value 1 for the opened or the value 0 for the closed window. The decision if $F_{schedule}$ is 0 or 1 is triggered by the CO_2 concentration and the temperature in the room. In the control strategy the thresholds for these parameters are defined.

The window opens at the upper CO_2 limit of 900 ppm which is the maximum CO_2 concentration in the moderate category II of the European Standard DIN EN 15251. The lower limit, which indicates the window closure, varies from 500 ppm to 800 ppm with a step of 100 ppm so that four strategies will be analysed.

The passive cooling control strategy differs between occupancy time and non-occupancy time. During occupancy time the window opens for cooling if the indoor air temperature is above 25 °C and the outside temperature is more than 3 Kelvin below the inside air temperature. The window closes when the operative inside air temperature reaches 22 °C. During non-occupancy time the window opens when the inside air temperature is above 23 °C and the outside temperature is more than 3 Kelvin below the inside temperature and closes when inside air temperature drops under 18 °C. The strategies are implemented through the EnergyPlus Energy Management System (EMS).

2.3 Mechanical Ventilation Model

The most energy efficient natural ventilation strategy is compared to a mechanical ventilation system for each location. The mechanical ventilation should regulate the indoor air quality in the same way as the natural ventilation system. In order to achieve the required indoor air quality (900ppm CO2) a constant airflow volume of 7 l/(s pers) is defined by DIN EN 15251-12.

2.4 HVAC System

In both simulation models an ideal heating and cooling system is used. This ideal heating and cooling system is chosen in order to not have a dependency on specific heating and cooling energy losses due to a defined HVAC system. The heating set point temperature is defined to 21 °C from 6 am to 6 pm at weekdays and 17 °C during night and weekends. Cooling set point temperature is defined as 24 °C from 6 am to 6 pm during weekdays and 26 °C for all other times. For the natural ventilated system heating and cooling are switched off during window opening time.

3 RESULTS

In the simulation three locations were compared for their energy demand for lighting, heating and cooling. These locations differed in their climatic conditions. The first location, Wiegendorf (Germany), is in European continental climate with average temperatures of -0.3 °C in January and 17.2 °C in July. In the second location Madrid (Spain) Mediterranean climate with average temperature of 5 °C in January and 24 °C in July is found. In the third location subtropical climate leads to temperatures of 16.6 °C in January and 29.1 °C in July. The energy demand for these locations was simulated (time step one second) and values were summed up for each month.

Four strategies of natural ventilation were compared for each location individual (figures 3-5). These were based on the CO_2 concentration and the temperature within the room. Windows were opened according to the temperature thresholds described in part 2.2 of this paper and when CO_2 was above 900 ppm and were closed when either A: 500 ppm, B: 600 ppm, C: 700 ppm or D: 800 ppm CO_2 were reached. This leads to longer window opening phases with A and shorter but more frequent opening phases towards D.

These strategies were compared side by side in graphs 3-5 where strategy A is depicted with dark blue bars for cooling, red bars for heating and orange bars for lighting, while strategy D is shown in light blue (cooling), light red (heating) and yellow (lighting). The total height of a bar represents the sum of energy demand for lighting, heating and cooling.

In the simulation for Wiegendorf the majority of the energy is consumed for the heating, due to cold winters while demand for lighting is relatively low and stable during the year and energy needed for cooling is neglectable (figure 3).

The total energy demand for Wiegendorf is low between April and October (less than 2000 Wh/m² per month). During this period no substantial differences were observed between the different ventilation strategies. In contrast, energy demand in winter months (December-February) is high (4000 Wh/m² per month). The majority of energy consumed in these months is needed for heating (2000-3000 Wh/m² per month). A strong difference was observed between strategy A and the other three strategies. Energy demand for strategy A with windows closing at 500 ppm CO_2 is much higher than with the other strategies (heating energy in December for A: 4100 and D: 2900 Wh/m²). This trend is already visible in March and November but is less pronounced.

Thus for winter months with heating energy consuming more than 1000 Wh/m² the ventilation strategy with the shortest opening time should be chosen to achieve a reduction of up to 20 percent of the total energy demand. While in months with less than 1000 Wh/m² for heating the ventilation strategy has not an impact on the energy efficiency.

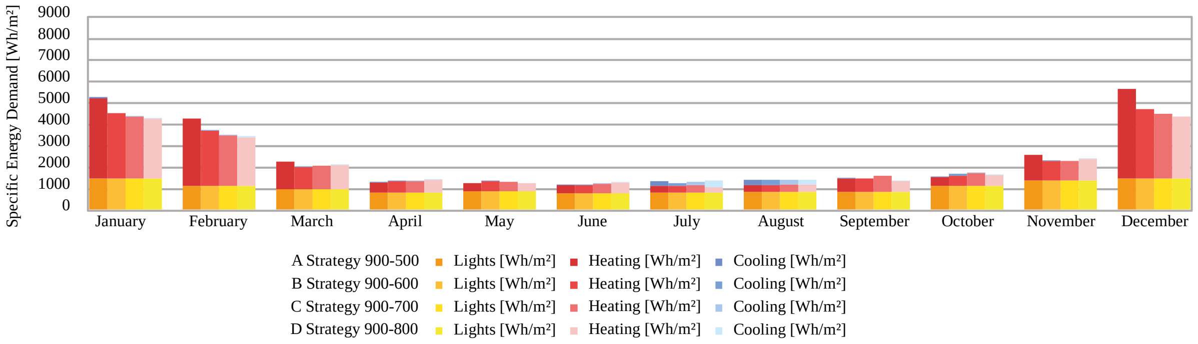

Figure 3 Specific energy demand for Wiegendorf – comparison of 4 ventilation strategies.

In the simulation for Madrid the total energy demand generally was low (~2000 Wh/m² per month) except for July and August where approximately 6000 Wh/m² per month were needed. This increase was due to energy needed for cooling. There is no obvious difference in the impact of the ventilation strategies on the energy consumption neither for cooling in summer nor for heating in winter. There is a minimal trend in December indicating that ventilation strategy A consumes more energy for heating than the other strategies. Interestingly, this is the only month for the Madrid simulation where heating energy consumption reaches approximately 1000 Wh/m² per month, confirming that 1000 Wh/m² per month might be threshold above which ventilation strategy effects become visible on the heating loads.

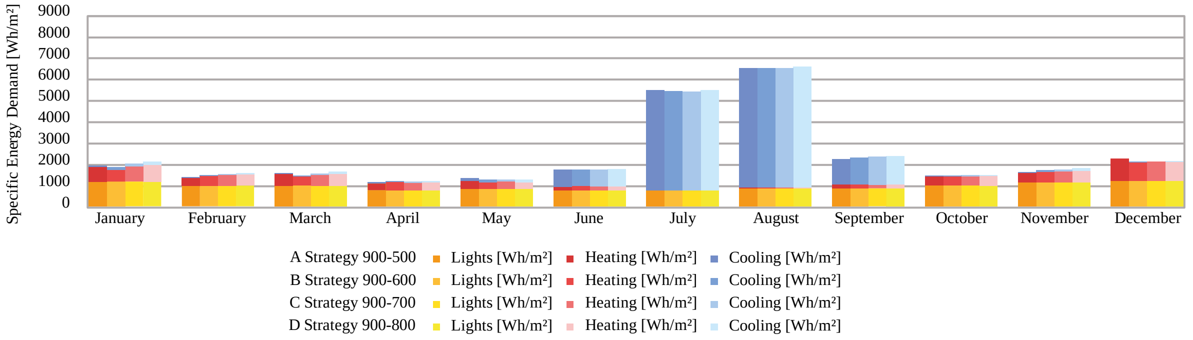

Figure 4 Specific energy demand for Madrid – comparison of 4 ventilation strategies.

Hanoi (figure 5) has a high energy consumption with the majority of energy being required for cooling. December, January and February have nearly no need for temperature regulation (less than 1000 Wh/m² per month) and therefore nearly no differences between the ventilation strategies were observed. From May to September, the highest energy consumption with cooling demands above 11000 Wh/m² per month were noted. For these months the ventilation strategy leads to a difference in energy performance indicating that strategy A uses the most and strategy D the least energy (approximately 1000 Wh/m² per month difference). In the months March, April, October and November there is still a relatively high demand for cooling energy (between 2000 and 10000 Wh/m² per month), however the differences between the ventilation strategies are low. In April and November energy demand for cooling is similar to that of Madrid in July and August. And in agreement to each other both simulation do not show a major impact of the ventilation strategy on the energy consumption.

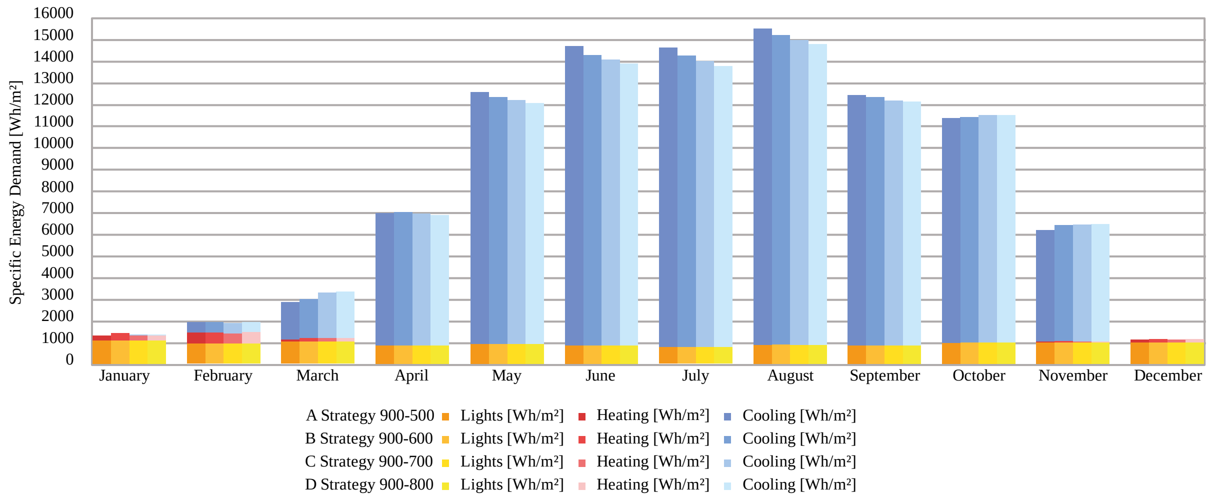

Figure 5 Specific energy demand for Hanoi – comparison of 4 ventilation strategies.

The results above (figure 3-5) were gained using a simulation of natural ventilation. These now were compared to a simulation of the same locations with mechanical ventilation to test if such system would be more efficient than the natural ventilation. For this purpose the energy demand of the best natural ventilation strategy of each month was compared to the energy demand by mechanical ventilation (e.g. for Hanoi in June strategy D and in November strategy A was used).

In the simulation of Wiegendorf from April to October natural ventilation is more energy efficient than mechanical ventilation (figure 6). The effect seems to depend on the outer temperatures and peaks in the summer months. In August mechanical ventilation consumes 8000 Wh/m² to cool down the room while by natural ventilation 550 Wh/m² is needed for heating and cooling. In the winter months (December-February) both systems are comparably efficient. Only in March and November the mechanical ventilation uses less energy than the natural ventilation. A difference of 500 Wh/m² are observed.

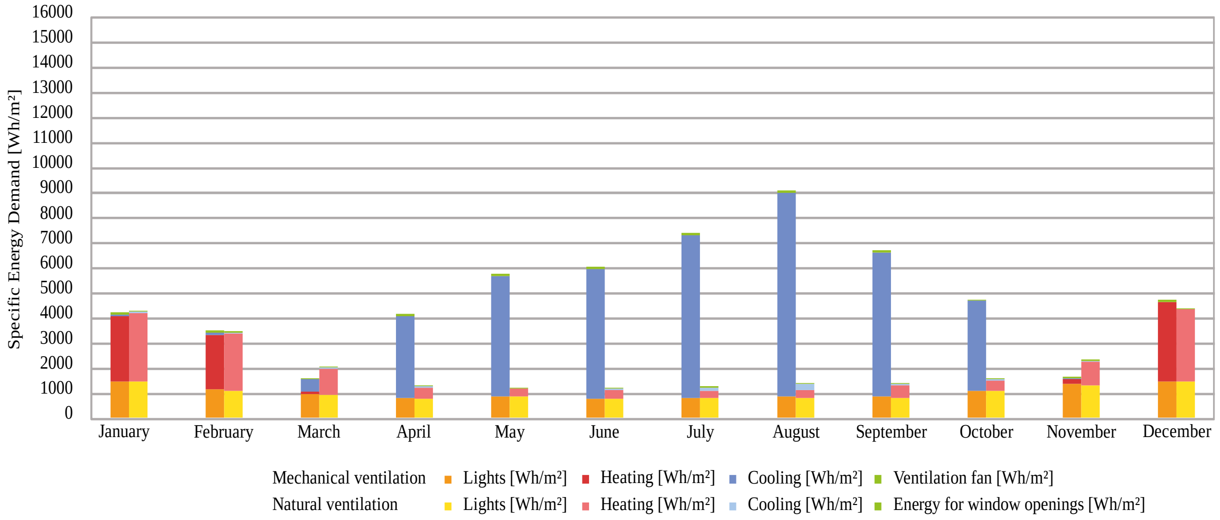

Figure 6 Specific energy demand for Wiegendorf – comparison of natural ventilation with mechanical ventilation.

In the Madrid simulation the natural ventilation is more efficient than the mechanical ventilation in all months. In the hottest months (July and August) mechanical ventilation consumes approximately 10000 Wh/m² for cooling while natural ventilation requires only 50 % of that. In milder months like September and October very little energy is needed (less than 1000 Wh/m²) for cooling by natural ventilation while mechanical ventilation still requires approximately 8000 Wh/m². For the other months similar effects are seen with natural ventilation requiring 10-20 % of energy that is needed by mechanical ventilation. Only in December both systems demand similar amounts of energy.

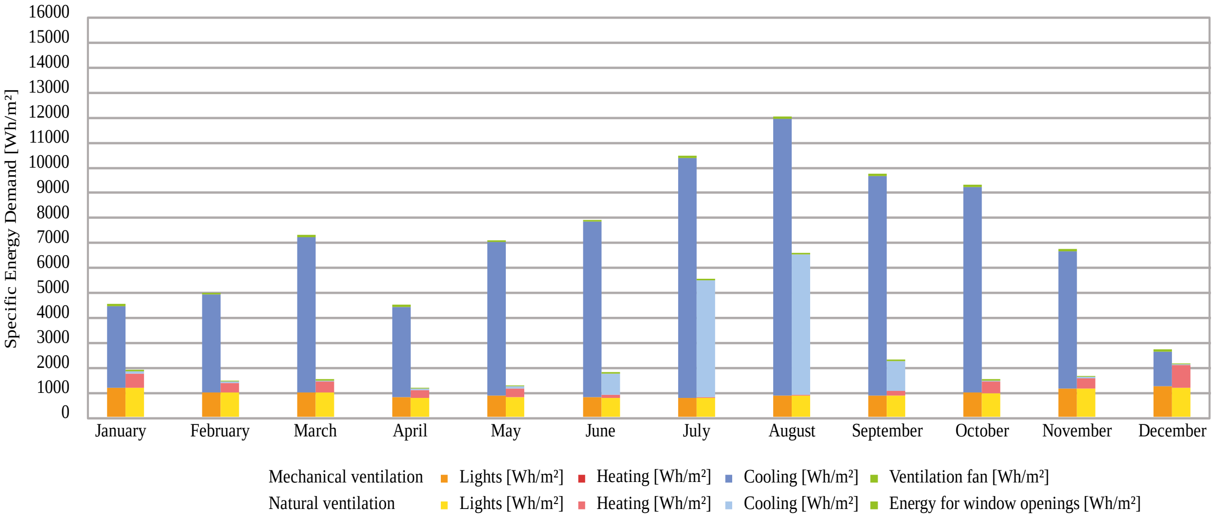

Figure 7 Specific energy demand for Madrid – comparison of natural ventilation with mechanical ventilation.

In the simulation of Hanoi in the summer months with extreme heat (June-August) there is little difference in the energy demand for natural and mechanical ventilation (with slight advantage of natural ventilation). However, in the colder months (November-March) natural ventilation is clearly more efficient than mechanical ventilation (e.g. Hanoi December 9000 Wh/m² per month for mechanical ventilation vs 3000 Wh/m² for natural ventilation). For the medium warm months (April, May, September and October) natural ventilation is more efficient but the effect is less pronounced.

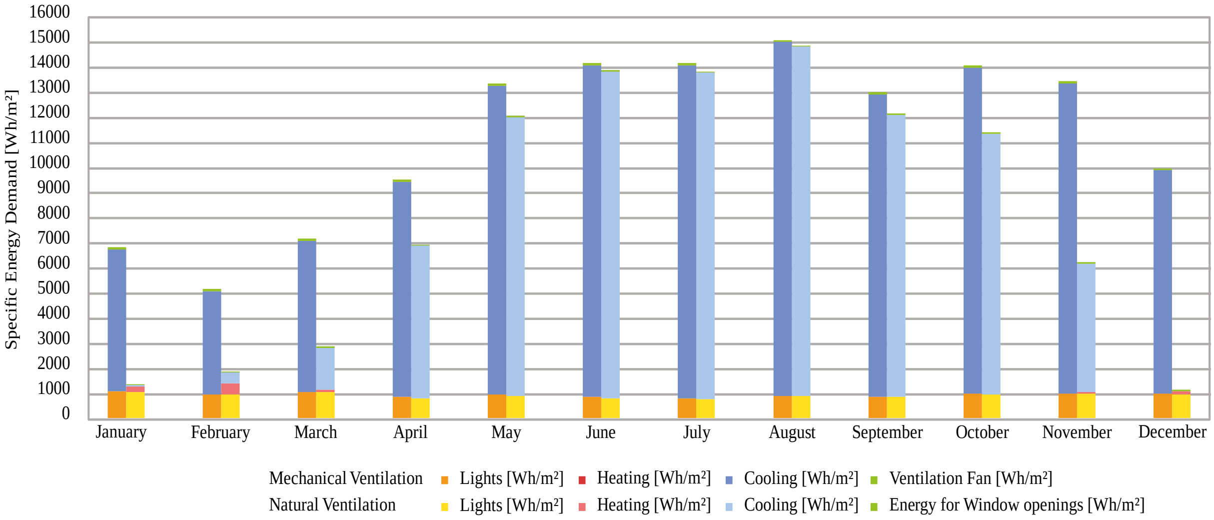

Figure 8 Specific energy demand for Hanoi – comparison of natural ventilation with mechanical ventilation.

4 DISCUSSION AND CONCLUSIONS

In the Mediterranean climate zone (Madrid) no difference in the efficiency of the natural ventilation was observed with the four different CO_2 parameters for window opening. For the moderate climate (Wiegendorf) in the months with high heating loads as well as for the subtropical climate (Hanoi) in the months with high cooling demand an improvement of the energy performance of about 20 % could be reached by using strategy D (900-800 ppm CO_2) instead of strategy A (900-500 ppm CO_2). The limits where varying the natural ventilation strategy come into effect are an energy demand higher than 11000 Wh/m² for cooling and more than 1000 Wh/m² for heating. Within these limits the open strategy does not have an impact on the energy demand therefore the personal preferences of the employees in the office can be given a higher priority.

In this simulation climate conditions that demand highest energy for cooling lead to a situation where natural and mechanical ventilation are comparable (e.g. Hanoi in June-August). When less cooling energy is required natural ventilation was more efficient than mechanical ventilation (e.g. 50 % less energy needed in July in Madrid or November in Hanoi). In climate conditions where the natural ventilation only uses little energy for cooling (e.g. September in Madrid) the mechanical ventilation still consumes very high amounts of energy for cooling. This leads to very high differences in the energy performance in such months. At colder climate conditions this effect becomes smaller (e.g. April in Wiegendorf) up to a point where mechanical ventilation is more efficient than natural ventilation (March in Wiegendorf). There seems to be only a small window for this turning point as in conditions where heating is needed both systems perform comparably well.

It is likely that this effect is an interplay of the outside temperature and the office temperature (simulations with more people might lead to shifted results). In the current simulation the month where natural ventilation performed better than mechanical ventilation lay in an average outside temperature range of 7 °C to 27 °C. Temperature below 2 °C lead to comparably results of both ventilation systems. While there likely is a small temperature range where mechanical ventilation outperforms natural ventilation. In our test this was between 2-7°C.

These results indicate that in the building design phase it would be useful to analyse the climatic conditions to decide on the most energy efficient ventilation system (e.g. in scandinavik locations mechanical ventilation might perform better).

This studies were performed under clearly defined conditions (e.g. south orientated office room, solid construction of building). Simulation with other conditions (e.g. lightweight construction) may lead to different results. Therefore more simulations are needed to be able to generalize the data described in this publication.

5 REFERENCES

Achenbach, P.R.; Coblenz, C.W. (1963). *Field measurement of air infiltration in ten electrically heated houses.* ASHRAE Trans., 69, 306-358.

Bäumler, A. (2016). *Experimentelle Quantifizierung des thermischinduzierten Luftwechsels in Abhängigkeit vonder Fensteröffnungsart sowie Beurteilung derPotenziale der Nachtlüftung.* Dissertation Universität Kassel.

Becker, R.; Pacuk, M. (2002). *Inter-related effects of cooling strategies and building features on energy performance of office buildings.* Energy and Building, 34, 25-31.

EnergyPlus (2018*). EnergyPlusTM Version 8.9.0 Documentation Input Output Reference.* Washington, DC, USA: U.S. Department of Energy.

Gratia, E.; Bruyère, A. (2004). *How to use natural ventilation to cool narrow office buildings.* Building and Environment, 39 (10), 1157-1170.

Prieto, A.; Knaack, U.; Klein, T.; Auer, T. (2017). *25 Years of cooling research in office buildings: Review for the integration of cooling strategies into the building façade (1990–2014).* Renewable and Sustainable Energy Reviews, 71, 89-102.

Schulze, T.; Eicker, U. (2013). *Controlled natural ventilation for energy efficient buildings*. Energy and Buildings, 56, 221-232.

Wang, Z.; Yi, L.; Gao, F. (2009). *Night ventilation control strategies in office buildings*. Solar Energy 83 (10), 1902-1913.