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Potential of natural ventilation in shopping centres

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SUMMARY
The indoor environmental quality (IEQ) is a fundamental requirement for a well performing shopping centre. This paper contains a pilot study of the potential of using hybrid ventilation (a combination of automatically controlled natural and mechanical ventilation - respectively NV and MV) in shopping centres with focus on both the achieved IEQ and energy consumptions for air movement.

By thermal building simulations it is found that there exists an interesting potential for hybrid ventilation of shopping centres, which can lead to great savings in the electrical energy consumptions for ventilation and cooling without compromising IEQ.

KEYWORDS
Indoor environmental quality (IEQ), Natural ventilation, Hybrid ventilation, Shopping centre, Energy savings.

INTRODUCTION
The energy consumptions of shopping centres for cooling and ventilation are significant in order to create high IEQ for the customers and employees of the centres. Most of the year the centre needs cooling in order to remove the high internal heat gains from e.g. electrical lighting, people, equipments etc.

In the last couple of years controlled natural ventilation has been applied in modern non-domestic buildings such as schools and offices with positive results of the IEQ and occupant satisfaction (Hummelgaard et al., 2007). Besides a higher IEQ natural ventilation usage the natural forces such as thermal buoyancy and wind pressure differences for air movement without the use of electrical energy. Furthermore controlled natural ventilation is a passive cooling technique by the usually lower outdoor temperature and thus very energy efficient when it comes to removing internal heat loads.

By the use of thermal building simulation this paper analyses the potential for hybrid ventilation of the stores in a shopping centre by looking on both the IEQ and the savings in electrical energy consumption for air movement. The results will be compared with traditional mechanical ventilation.

METHODS
This paper takes point of reference in stores combined with an atrium as we know from many existing shopping centres. The method behind is steady state calculations of the natural ventilation based on fundamental rules for wind and thermal buoyancy (SBI, 2002) and thermal building simulations in BSim. As default weather data from London has been used.

To gain an overall knowledge related to different types of stores we have chosen three different cases to present in this paper. The models of the stores are created with assumptions of materials and internal heat gains, which are based on a typical design from practical experiences. All stores have a rectangular layout with a width of 10 m and a floor to ceiling height of 3 m. Since we are working with natural ventilation the depth of the stores is very important. For rooms being naturally ventilated with cross ventilation the depth should not exceed 5 times the floor to ceiling height (SBI, 2002). Case 1 and 2 fulfil this recommendation, while case 3 will due to the use of ducts be able to increase the room depth up to 10 times the floor to ceiling height. We expect that the furniture does not exceed a height of 2.5 m above the floor in order to ventilate the stores together with the adjacent atrium.

A typical requirement for the thermal IEQ in shopping centres is an indoor temperature in the stores between 22 – 26º C during opening hours. The internal heat load is set to be 50 W/m^2 in total, consisting of lights, equipments and people. 2/3 of the total internal heat load is produced by light. The intensity of the light is fixed in the stores, and not demand controlled depending on the daylight in the stores. People and equipments share the last part of the internal heat loads with 60 % and 40 %, respectively.

Based on thermal steady state calculations the capacity of the natural ventilation system is determined (SBI, 2002). All air flow rates for in- and outlet of respectively mechanical and natural ventilation are balanced and demand controlled.

The mechanical air change rates for all cases have a maximum capacity of 5 h^{-1}. The inlet air from the mechanically ventilation can be cooled or heated if required. The minimum and maximum inlet temperature is respectively 16º C and 40º C in all cases.

The possible air change rate of the natural ventilation in case 1 and 2 is assumed to be 4.5 h^{-1} on the upper floor and 5 h^{-1} on the lower floor, due to the additional stack effect on the lower floor. For case 3 two scenarios are considered, with natural air change rates of respectively 2 h^{-1} and 1 h^{-1}, due to the limitations of the sizes of the ducts.

Case 1
The first case represents an upper floor store with an opening directly in the façade and access to the opening in the lantern of the atrium. In Figure 1 the ventilation principle is illustrated.
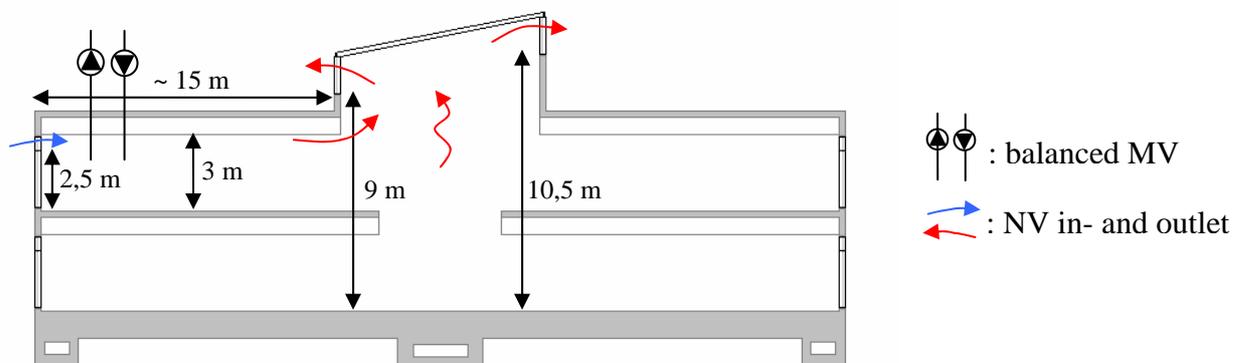

Figure 1. Illustration of the section of store and common area of the shopping centre. In case 1 the natural ventilation passes through the automatically controlled opening in the façade and the upper openings in the lantern.

The façade is oriented to the South, the exhibition window is provided with internal solar shadings with a shading coefficient of 0.35 in where as to the automatically controlled windows have no shadings. Windows in the façades have g-value of 0.4, corresponding to 40 % of the total solar energy on the windows transmits to the stores. The windows in the façade are from floor to ceiling.

Case 2

The second case represents a double floor store with an additional internal opening between the storeys. Each storey has openings in the façade and access to the lantern of the atrium with openings to the outside. The orientation of the facade and data of the solar shading and glass in windows are similar to case 1. In Figure 2 the ventilation principle is shown.
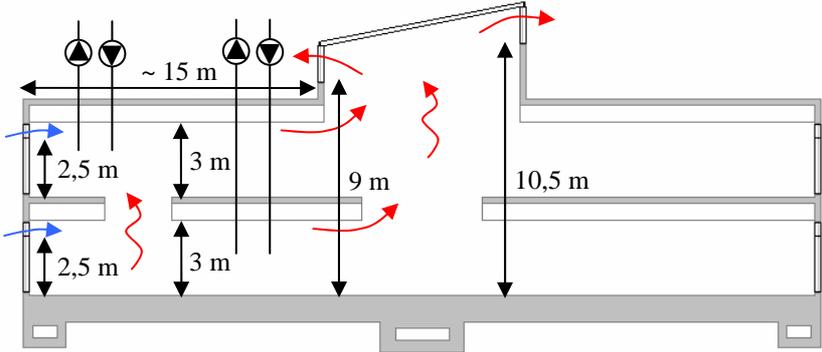

Figure 2. Illustration of the section of store and common area of the shopping centre. In case 2 the natural ventilation passes through the automatically controlled opening in the façade and the upper openings in the lantern.

Case 3

The third case represents a store with double depth and no openings or windows in the façade. The natural ventilation takes place through ducts as well as the openings in the lantern of the atrium. The use of ducts can be constructed in many ways. The dominant driven force can be either the thermal buoyancy or the wind depending on the weather conditions. In Figure 3 the ventilation principle is shown.
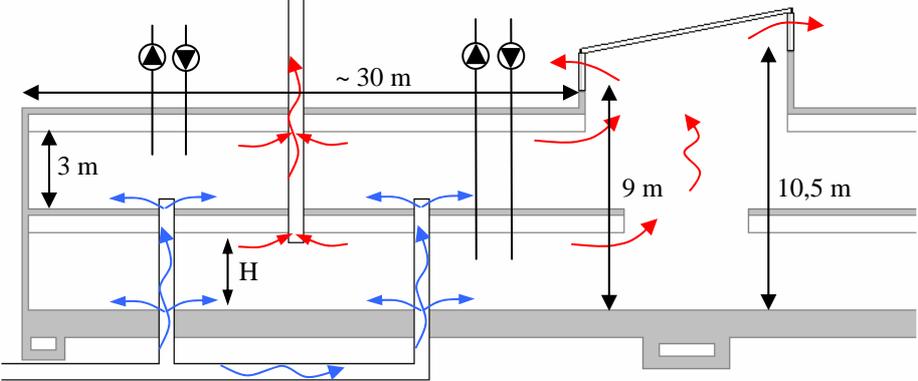

Figure 3. Illustration of the section of stores and common area of the shopping centre. In case 3 the natural ventilation only passes through ducts. The heated air from the stores can leave through exhaust ducts or the upper opening in the lantern.

The use of ducts means there will be a higher pressure loss compared to case study 1 and 2. This has to be overcome by the natural forces or by using an assist fan. Depending on the design of the ducts such as materials, opening areas, geometry, size and velocity the pressure losses may vary.

RESULTS
The thermal simulations of all case studies are made for a 12 months period in order to establish an overview of the achieved IEQ during all seasons and the annually need for natural and mechanical ventilation.

The basic hybrid solution includes controlled natural ventilation with night cooling together with a mechanical ventilation system with a full capacity as previously described. This basic hybrid solution is compared to other solutions of ventilation such as: a hybrid solution without night cooling, a hybrid solution with a 50% reduction of the mechanically ventilation capacity and a solution with pure mechanical ventilation.

The capacity of the mechanically ventilation system is divided into the following four capacity ranges: 0-5%, 6-50%, 51-95% and 96-100%, since the ventilation capacity most of the time occurs in the lowest and upper 4-5 %. The results of each case show the percentage of duration time for each capacity range. Furthermore, the annually numbers of hours with the operative temperatures above 26 and 27º C are analyzed according to the recommendations in several standards (EN 15251, 2007 & DS 474, 1995).

The significant internal heat loads demands a high air flow rate during the openings hours. Since the inlet air supply is outdoor air there exist no problems with high CO_2 levels. The levels in all zones correspond to class II, corresponding to CO_2-concentrations of 500 PPM above outdoor concentrations (EN 15251, 2007).

Case 1
In this case all four different solutions of ventilation will be compared. Figure 4a shows percentage of usage for the four capacity ranges for the mechanical ventilation system. Figure 4b shows the annually number of hours with temperatures above 26º C, during opening time.
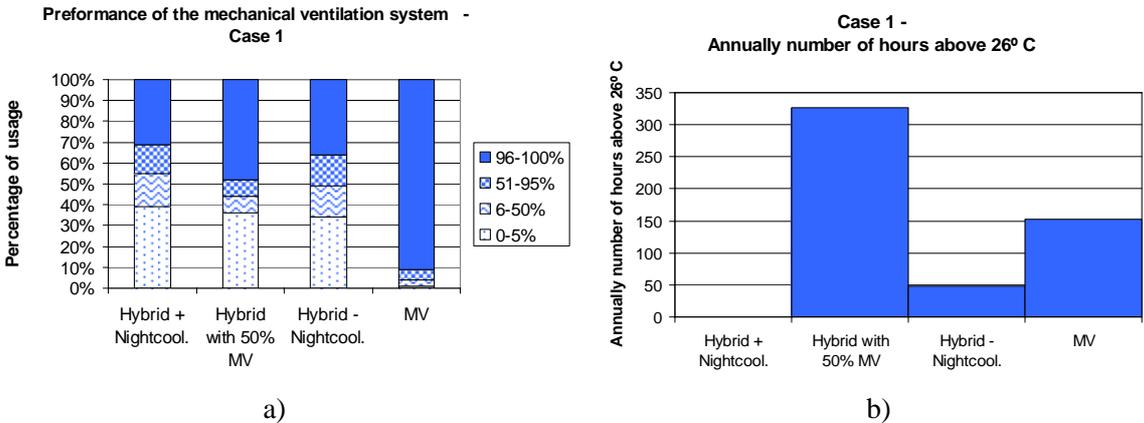

Figure 4. a) Percentage of the four capacity ranges for the mechanically ventilation system by all four solutions. b) Annually number of hours during the opening time with operative temperatures above 26º C.

Figure 4a shows a great saving potential by using any of the hybrid solutions. Hybrid solutions with or without night cooling are almost similar. The hybrid solution with 50% reduction of the mechanically ventilation capacity shows the most savings - not only because of the percentage of usage, but also since the capacity ranges are given in percentage and not by the actually air flow. However, Figure 4b shows that reducing the mechanical ventilation capacity is not acceptable for the thermal IEQ, since there is more than 300 hours with temperature above 26° C und more than 200 hours with temperatures above 27° C. Even by the pure mechanical ventilation system we find around 150 hours with temperature above 26° C during openings hours. None of the other ventilation solutions than the solution with the reduced mechanical ventilation capacity have temperatures above 27° C. The overall best solution according to this pilot study, both regarding to the thermal IEQ and energy savings, is the basic hybrid solution with night cooling. In Figure 5 the air flows for the mechanical and the natural ventilation by the basic hybrid solution are shown, respectively.
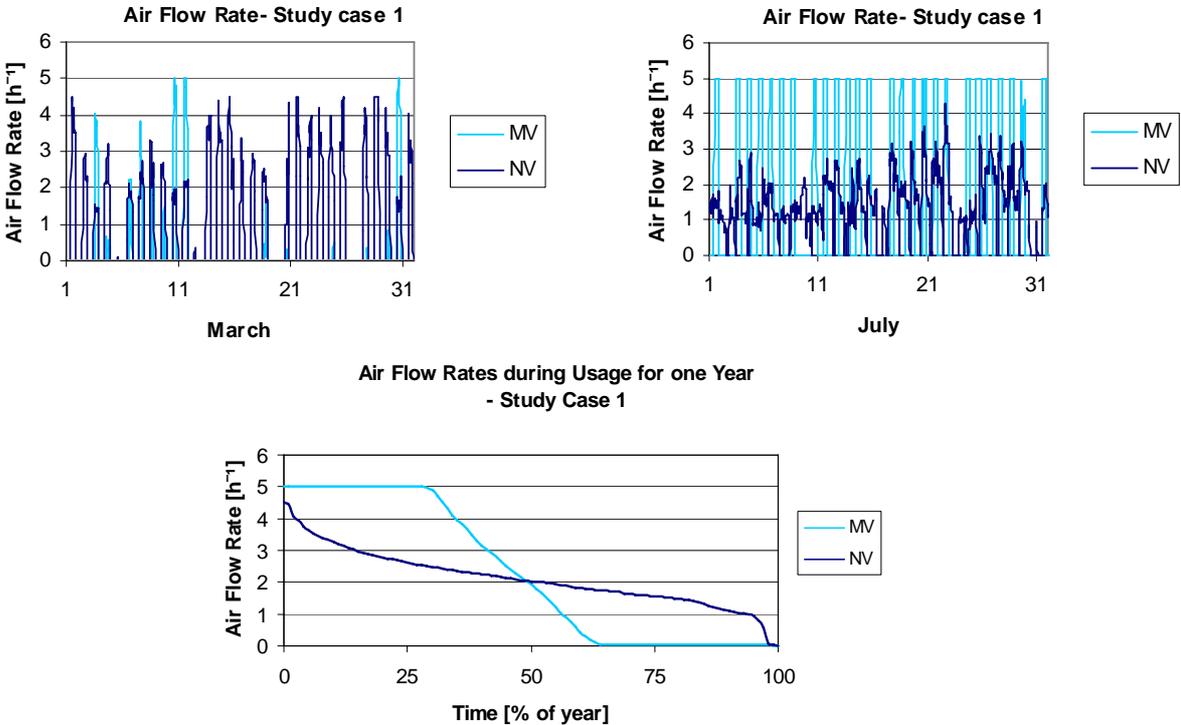

Figure 5. The upper two figures illustrate the air flow rates for March and July in case 1 – basic hybrid solution with night cooling. The dark and light blue line indicates the air flow rate for respectively the mechanical and natural ventilation. The lower figure illustrates a sum-curve of the two ventilation rates during the occupancy time.

The figures show very clearly that automatically controlled natural ventilation in many periods during the year is able to remove the entire heat load with only occasionally having assisting mechanical ventilation. During the summer period there is a perfect cooperation between the natural and mechanical ventilation. But most often during summer period the mechanical ventilation system has to run at full capacity in order to achieve the required IEQ.

Case 2
Since the hybrid solution with reduced mechanical ventilation capacity in case 1 shows very unsatisfying results for the indoor climate, this solution will be left out of the result for case 2.

Figure 6a shows percentage of usage for the four capacity ranges for the mechanical ventilation system for the upper floor where Figure 6b shows percentage of usage for the 4 capacity ranges for the mechanical ventilation system for the bottom floor.
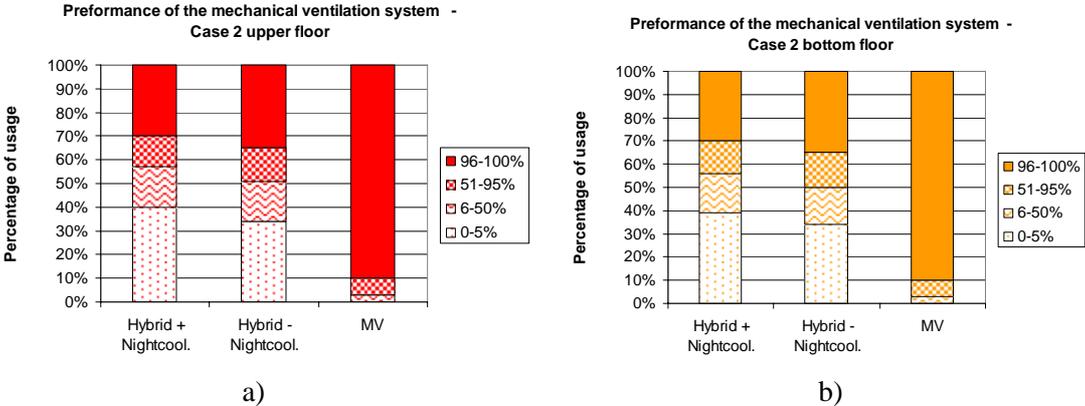

Figure 6. a) Percentage of the four capacity ranges for the mechanically ventilation system for the upper floor. b) Percentage of the four capacity ranges for the mechanically ventilation system for the lower floor.

Figure 6a and Figure 6b show that there are more or less no differences between the two floors. The results are also very close to the ones found for case 1. Figure 7 shows the annually number of hours with operative temperatures above 26º C during opening hours. No hours above 27º C are found for any of the solutions.
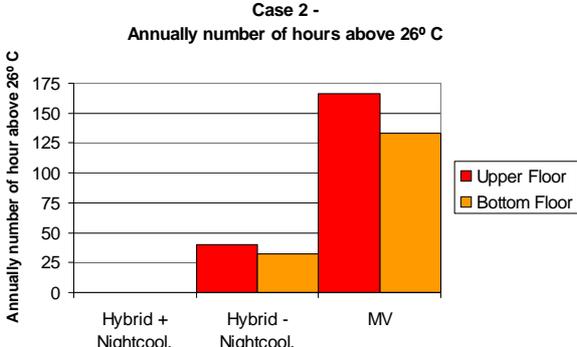

Figure 7. Annually number of hours during the opening hours with operative temperatures above 26º C.

The tendency is the same as found in case 1, where only a basic hybrid ventilation solution with night cooling has zero hours with temperatures above 26º C during opening hours. Not surprisingly the numbers of hours with temperatures above 26º C are rising from the bottom to the top floor.

Case 3
Case 3 differentiates from the other study cases by using ducts and no openings in the façade for natural ventilation. Based on the result from case 1 and 2 only the basic hybrid solution with two levels of air change rates and pure mechanical ventilation will be compared. Figure 8 shows percentage of usage for the four capacity ranges for the mechanical ventilation

system. Since there are no windows in the façade, there is no additional heat gain from solar radiation, and therefore all solutions have no hours with temperatures above 26 and 27° C.
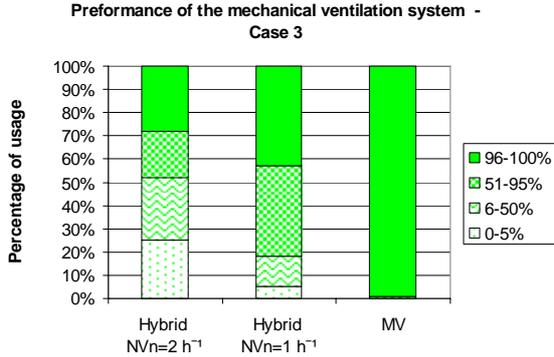

Figure 8. Percentage of the four capacity ranges for the mechanically ventilation system by basic hybrid solution (with an air change rate of natural ventilation of respectively 2 h^{-1} and 1 h^{-1}), or a pure mechanical ventilation system.

Figure 8 shows that with an air change rate of 2 h^{-1} good saving can be made. Even if the possible air change rate by natural ventilation reduces to only 1 h^{-1} savings can still be made.

DISCUSSION

This paper has investigated four scenarios for three different types of stores, which can be found in a common shopping centre. The primary analysis is done for stores and shopping centres around London. London has a temperate climate with fairly high temperatures over the year. To compare possible savings for other climates case 1 has been carried out for four different weather data. The assumptions and conditions of ventilation are the same: natural ventilation with night cooling and when needed assisting mechanical ventilation. Figure 9 shows the percentage of usage for the mechanical ventilation system and the annual number of hours, during opening hours, with operative temperatures above 26° C. No hours above 27° C are found for any set of the weather data.
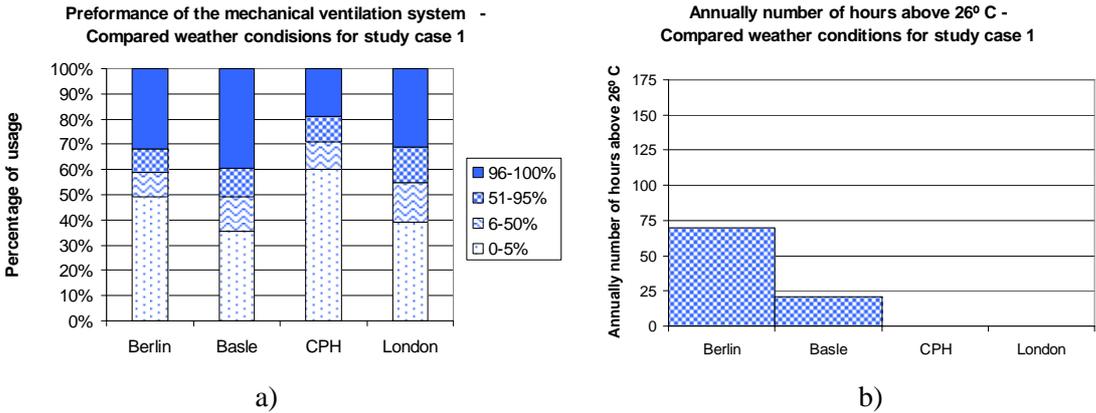

Figure 9. a) Percentage of the four capacity ranges for the mechanically ventilation system by the hybrid solution - case 1 for different weather data. b) Annually number of hours during the opening hours with operative temperatures above 26° C for different weather data.

As we see from Figure 9a and 9b a basic hybrid solution can be effective in several regions of Europe. Berlin shows great electrical energy savings for air movement[1] compared with a CAV ventilation system by over 50%, but due to the climate the annual number of hours with temperatures above 26° C lies above 70. We find the lowest savings in Basle, Switzerland with around 38% saving in total electrical energy consumption for air movement. Basle has due to the Rein valley a very warm and dry climate, which also brings 21 hours with temperatures above 26° C. London only shows a total saving in electrical energy consumption of 47%. Not surprisingly we find the biggest saving potential in electrical energy consumption for air movement in Copenhagen with a saving potential of 66%.

Even though this pilot study shows great savings by using natural ventilation combined with a mechanical ventilation system some additional points have to be taken into consideration for an optimal solution. The shopping centre surroundings have to be suited for hybrid ventilation. The stores have to be designed correctly for maximum exploration of the natural ventilation. This mainly concerns the opening possibilities, depth and establishment. Furthermore, local draught risk should be evaluated more in detail – e.g. with respect to practical measurements or CFD.

CONCLUSIONS
The pilot study in this paper has analysed the energy consumptions for air movement and IEQ in case of four types of ventilation by thermal building simulations in three different types of stores in a common shopping centre. After analysing three different types of stores, we could determine that significant savings can be made without deteriorating IEQ.

A basic hybrid solution, consisting of automatically controlled natural ventilation with night cooling and an assisting mechanical ventilation system with cooling/heating, shows a very promising saving potential in electrical energy consumption for air movement. For different climates in Europe we see potential saving in electrical energy between 1/3 and 2/3 together with a high level of IEQ. The analysis only describes the saving for electrical energy consumption for air movement. By using a hybrid solution also the need for cooling could be reduced. A pure natural ventilation system could bring even greater savings in electrical energy consumption, but to ensure a comfortable and productive indoor environment an assisting mechanical ventilation system with a cooling capacity which alone can remove the internal heat loads and provide the wanted indoor environment should be installed. In countries with much solar radiation and long periods of very warm and dry climate, the cooling capacity should also include removal of the additional solar heat gain.

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[1] The electrical energy consumption for the VAV ventilation is based on 2500 J/m^3. The electrical energy consumption from the CAV ventilation is based on 2200 J/m^3. The Electrical energy consumption for the natural ventilation per store is set to 100 kWh/year based on 10 motors for opening windows and one controller.