

HYBRID VENTILATION – THE VENTILATION CONCEPT IN THE FUTURE SCHOOL BUILDINGS?

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ABSTRACT

Hybrid ventilation (HV), as a combination of automated natural ventilation (NV) and balanced mechanical ventilation (MV), provides opportunities to use the advantages of both ventilation systems during the seasons in order to reduce energy demand and at the same time obtain comfortable indoor climate.

For this study a comparison of NV, MV and HV systems applied to an existing school building has been made by means of detailed modelling in the widely adopted simulation program IESVE. The energy demand for heating and ventilating the building in the different ventilation modes was calculated for three key European cities; Munich, Copenhagen and London. Control strategies were set to obtain the same indoor climate for all ventilation systems, and the indoor climate classification was made according to EN15251 [4].

The overall ambition in the study has been to make a very realistic modelling of state-of-the-art MV and NV systems and apply these systems to an existing school building renovated to fulfill expected energy performance requirements for 2015 buildings.

It is noteworthy that the results show that the energy performance of the MV and NV systems are nearly the same in terms of primary energy, while it is showed that HV enables energy savings of 44-52% compared with MV and NV. This corresponds to a total primary energy consumption for the NV and MV of 18-21 kWh/m² per year in all three locations, while the HV consumption was only 9-10 kWh/m² per year.

Calculation of the total investment of the different systems including maintenance, operation (electricity and heating) and capital cost (products and installation) showed that in the first year MV was found to be 2.5 to 4 times more expensive than NV. By selecting HV 25% of the total investment could be saved compared to a MV system. The differences between the systems were found to be the same in a 20 year timeframe

KEYWORDS

Hybrid ventilation; natural ventilation; mechanical ventilation; ventilation in schools; comparison of different ventilation strategies; Energy; IAQ.

INTRODUCTION

From the literature it is known that the combination of automatic NV and MV is a promising opportunity to achieve significant energy savings in buildings while maintaining a comfortable indoor climate. HV might as such be a key technology for designers in need of means to fulfil the ever stricter energy requirements while at the same time provide the user with a healthy and comfortable indoor climate.

Many studies of HV are available in the literature. The Reshyvent project [11] investigated HV in residential buildings, while the Hybvent project [7] studied the applicability for non-residential buildings. A number of case studies investigated in the international project IEA ECBCS-Annex 35 [7] show that there can be achieved significant energy savings in hybrid ventilated buildings, especially through reduction in fan and cooling energy demand. The case studies for school buildings show that the HV system saves 17-55 % in a year compared to a solitary mechanical system. Examples also include Cron & Inard [3] who investigated classrooms and found the best results for HV in the warmer regions, compared to MV without heat recovery, and in the warmest regions, compared to NV with heat recovery. Emmerich [5] found that heating demand is reduced most in cold regions, and fan electricity is reduced to a maximum in warm regions. Sowa & Karas [9] found a reduction of about 60 % for heating demand and about 40 % for fan electricity in a HV simulation for a real school. Heikkinen et al. [6] who investigated ventilation concepts for a school in Finland, only found a very little possible reduction in heating demand, but also a reduction of 70 % in fan electricity.

Thus, the literature contains a number of publications and in general, HV is demonstrated to result in significant energy savings. The present study investigates whether this conclusion will also be valid in schools in the near future (2015), using state-of-the-art MV and NV systems and a school building fulfilling expected 2015 performance requirements. In order to give a true comparison between the energy performances of the systems, nearly identical indoor air quality and thermal climates in the buildings have been created. The simulations are carried out for three large European cities with different climates; Copenhagen, London and Munich. The study also calculates the expected CO₂ emissions and the economical costs from selecting the different systems.

SCHOOL BUILDING GEOMETRY, PROPERTIES AND LOCATION

Building layout

The school building has one storey with eight classrooms, four on each side of the corridor and is oriented North/South. The ceiling height varies from 2.8 to 4.5 m for all ventilation types and the area of one classroom is 76 m², the volume is 278 m³. The geometry of the building can be seen in Figure 1.

Construction properties

Some of the construction properties attached to the models are listed in Table 1.

The glass ratio of the outer façade is 45 % and the g-value is 0.63 and light transmittance is 0.74. Only the larger windows have an external sun screening with a shading coefficient of 0.2.



Figure 1. Layout of the school building.

Building Element	U-Value [W/m ² K]
Ground Slab	0.08
Exterior Walls	0.12
Roof	0.08
Windows	0.9-1.1

Table 1. Construction properties

Internal heat loads

There are 28 students and one teacher in each classroom, resulting in an occupancy density about 2.6 m²/person, which is a typical occupant density for schools. There is assumed 95 % occupancy during lessons (Monday to Friday from 8 am to 2:50 pm) taking into account absent persons. Vacation time is 12 weeks per year in total (week 7, 14, 20, 26 - 31, 42 and 51 - 52). The occupancy during vacation is set to 10 % from 8:00 am to 2:50 pm from Monday to Friday, which takes into account summer courses or maintenance. There is no occupancy during weekends.

Each person has a heat load of 75 W sensible heat and 50 W latent heat corresponding to an adult with an activity level of 1.2 met. This assumes a heat emission of 70 W/m² skin surface and a skin surface of 1.8 m². Children with a lower body mass normally also have a higher level of activity of about 1.4 met (81 W/m²skin surface). Assuming a skin surface of 1.5 m² per child, the heat emission for all persons is quite the same.

Each student and teacher is expected to have a computer, which is switched on 50 % of the time during occupancy. There are typically not so many computers in a classroom today, but it is expected that the use of computers will increase in the future.

The lighting (fluorescent lighting) shall provide a luminance intensity of 300 lux at the table and has a maximum heat load of 15 W/m², which corresponds to an effective lighting system.

Outdoor climatic conditions

The locations chosen for the comparison are Copenhagen, Munich and London. These three cities are typical European cities with different climates and therefore different possible opportunities for HV. Copenhagen has a cold winter and a cool summer, whereas Munich has a colder winter and a warm summer. London, located close to the sea, has a maritime climate with a mild winter and a cool summer.

REQUIREMENTS ON INDOOR AIR QUALITY AND THERMAL COMFORT

Many studies have shown that existing schools have a poor indoor climate with CO₂ levels sometimes exceeding 2-4,000 ppm [2]. These levels are clearly adversely affecting the learning ability of the school children [10][12][13] - and these levels must be improved. However, general adoption of the current Category II requirements in EN15251 with a maximum CO₂ concentration of 900ppm seems unrealistic in schools for two key reasons: First, the air exchange rate for a typical 60 m² class room with a room height of 2.8m and 29 persons needs to be at least 6-7 ACH. This will create problems with air speeds in the comfort zone in the majority of existing schools. Second, it is also noted that the financial abilities of the public authorities in most countries does not support such strict requirements. In fact, they could prove to be a barrier against improving the indoor climate in existing schools simply because the systems become too expensive.

The classification of the thermal comfort and indoor air quality in the buildings are based on EN 15251. For the school building Category III with an acceptable level of expectation is applied for the assessment of indoor climate.

DIMENSIONING OF VENTILATION SYSTEMS

To maintain the air quality according to Category III of EN 15251 the necessary air flow rate was calculated by the air flow rates per m² given in the standard for persons in a classroom and low emissions from the building. This results in a flow rate of 2.4 l/sm² and a total air flow rate of 180 l/s, 648 m³/h. The total flow rate for all 8 classrooms is 1,440 l/s or 5,148 m³/h. For maintaining temperature different air change rates were tested in the simulation. Due to these results a maximum air exchange of 4.6 per hour was chosen for summer and night ventilation. This is a flow rate of 360 l/s or 1,296 m³/h for one classroom and 2,880 l/s or 10,368 m³/h for all classrooms.

Natural ventilation

For the NV every second high level window on both sides of the room can be opened with motors to realize cross ventilation. The resulting openable window area for the automated windows is 4.1 m² and 5.4 % of the room area.

A temperature difference of 1 K and 5 K between inside and outside is resulting in a nearly 4 and 9 fold air exchange, respectively. A wind speed of 0.5 m/s and 1 m/s is resulting in a 5 and 10 fold air exchange rate, respectively (calculated according to the British Standard Method [1]). Outdoor conditions with 0.5 m/s wind speed and a temperature difference above 1 K should be available during most time of the year for all three locations and are also adequate for temperature maintaining ventilation in summer.

Mechanical ventilation

For the MV in the school building four smaller decentralized units are utilized. The system was dimensioned for the maximum air flow rate according to air quality and indoor temperature (10,368 m³/h). The specifications of the four units are selected amongst available market products, resulting in a total flow rate of 15,680 m³/h.

The pressure loss for the supply and the exhaust pipe system is only 80 Pa for the supply system and 80 Pa for the exhaust system. The filter classes were F7 for supply air and F5 for exhaust air causing an additional pressure of 40 Pa due to dirt. The SFP value for the whole system is 993 J/m³ - which probably is among the best available on the market currently. There were assumed no additional heating unit and no cooling unit. As the 'Demand

Controlled Ventilation' is working with a constant pressure loss in the main pipes the setting for the external pressure was hold constant.

The heat recovery system is a state-of-the-art counter-flow plate heat exchanger with low-energy deicing function and the sensible heat effectiveness in the simulation was set to 92 %, which is the temperature efficiency including the effects of the motor heat at 1800 m³/h, 75 % of the design flow rate.

Hybrid ventilation

For the HV there are applied two decentralized units dimensioned for the air flow rate only according to air quality (5,148 m³/h). To maintain indoor temperature in summer NV is utilized with a flow rate of 10,368 m³/h.

The pressure loss in the MV system for the supply and the exhaust pipe system is then about 132 Pa for the supply system and 143 Pa for the exhaust system. Pressure loss from filters, sensible heat effectiveness and heating/cooling unit is the same as the MV. SFP value for the whole system is 1135 J/m³.

CALCULATION METHOD

The energy demand and the indoor climate of the building were simulated in the widely adopted simulation the program VE-Pro (version 6.4.0.7, Integrated Environmental Solutions Limited, Glasgow, UK). This program has a special device for calculating more complex HVAC systems (ApacheHVAC) and also a very reliable calculation tool for NV (MacroFlo), which is able to calculate NV and effects from wind turbulence on air exchange, considering special features like the aspect ratio and sash type of the opening. The calculation was done in 1 min steps to achieve realistic results for natural and especially natural pulse ventilation. The results are derived from 6 min averages of the calculation.

For the assessment of indoor climate, CO₂ levels inside the building were used as indicator for indoor air quality and operative room temperature was used as indicator for thermal comfort. The values were obtained during occupancy in one representative room, and the requirements to the thermal comfort and indoor air quality were based on EN15251.

CONTROL STRATEGIES

The transfer of the control strategy to the simulation models was done as close as possible to WindowMaster's control strategy. Sometimes changes were necessary due to the restrictions of the simulation software or to obtain a similar thermal comfort and indoor quality.

Natural ventilation

NV in this investigation is defined as automated NV through high level windows on both sides of the rooms. The windows are opened and closed to a specific amount with small motors. The opening width is defined by a controller, which uses indoor and outdoor climatic parameters to calculate the appropriate opening width. This precise opening is necessary, because the resulting air flow rate is not only depending on the climatic parameters, but also very much on the opening width of the windows. A precise air flow is necessary to avoid too high ventilation rates, which cause additional heat losses or a bad thermal comfort due to low temperatures or a high draught ratio, and to provide a good air quality at the same time.

There is implemented three different opening strategies; continuous ventilation with a varying opening degree, pulse ventilation with the maximum opening degree calculated due to weather for a short time and night ventilation. The first strategy is utilized for control of air

quality during the whole year and indoor temperature in summer. The second strategy is only for additional control of indoor air quality during winter and transient times, where the opening width for continuous ventilation is restricted due to comfort reasons. The third strategy is utilized for an additional cooling of the rooms in summer. In addition, the windows are opened to maximum after occupancy to ventilate the rooms completely with fresh air until outdoor air quality is reached.

Mechanical ventilation

The flow volume of the MV is defined due to improvement of indoor air quality and reduction of overheating. Therefore the maximum flow volume is utilized, when either the flow rate due to carbon dioxide level or the indoor air temperature rises above a certain point. Furthermore night ventilation is only active during the warmer periods

Hybrid ventilation

The HV control strategy is a combination of the natural and mechanical control strategy. The main strategy is to use the best aspects of both systems in order to reach the best possible values for energy consumption and indoor quality.

During winter season only MV is activated as the heat recovery of the system helps saving energy to heating. NV has best results during summer where good indoor air quality and temperatures easily can be reached. In addition, the motors of the windows need much less electricity than the fans for MV and the flow rate can be raised only by opening the windows a little more without using additional energy. This is also the benefit from NV during night time.

During the transient season it depends most of the times on internal situations, if MV or NV is the best solution. Therefore the system chooses automatically between the two systems depending on indoor temperature as indicator for heating or possible cooling demand.

Heating, shading and lighting

The heating is activated from October to May. The heating is set to avoid too low temperatures in accordance to Category III during occupancy (8 am 2:50 pm). During hours with no occupants in the building the set-point is 18°C.

The setting for the shading devices is controlled due to outdoor and indoor parameters. This is done to avoid overheating, which may affect indoor temperature and thermal comfort also a few days later. The device rises with a wind velocity above 12 m/s and/or an outdoor temperature below -6°C to avoid damages on the devices. The device lowers with a solar radiation above 100 W/m² and if the indoor temperature is above 23.5°C.

The dimming of the artificial light is controlled due to occupancy and to keep 300 lux in the rooms.

RESULTS

Temperature and CO₂

The results of thermal comfort and indoor air quality was evaluated for one south facing classroom as there only were found very small differences between a north- and south facing classrooms. Figure 2 shows the relative frequency of indoor temperatures during occupancy in accordance to the categories in EN15251. This is displayed for all three ventilation types in each location.

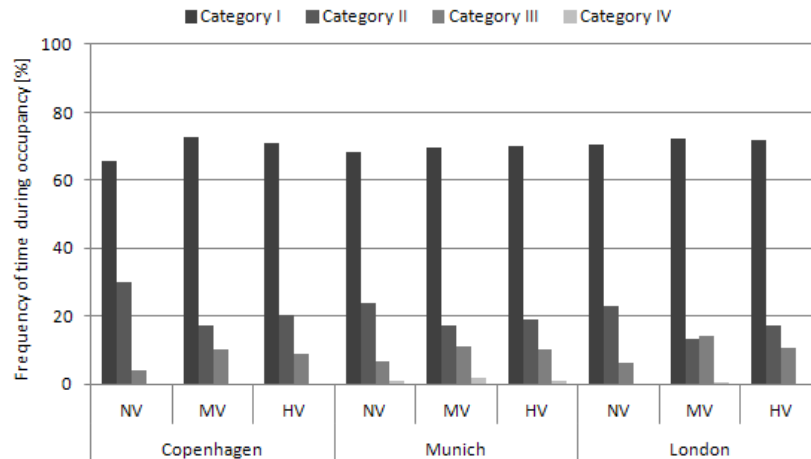


Figure 2. Relative frequency of indoor temperatures during occupancy in accordance to EN15251

Only very small temperature variations were found for the different locations. This implies that each of the three ventilation systems has the same thermal comfort level. A similar picture was found when comparing the CO₂ levels. The result showed that Category II could be reached in 45-55% of the time depending on the ventilation system, while the remaining time was fulfilling the requirements to Category III.

Primary energy

For the calculation of the total primary energy demand (sum of heating and fans electricity demand multiplied with primary energy factors) the nationally adopted primary energy factors have been used for the different locations; Munich (district heating: 0.7; electricity 2.6), Copenhagen (0.8; 2.5) and London (1.2; 2.92).

Figure 3 shows the primary energy consumption. Comparing the primary energy demand it can be seen, that heating demand can be reduced by nearly 70 % for HV compared to NV. Fans electricity can be reduced with 75 % for HV compared to MV. Total primary energy is almost the same for MV and NV, but can be reduced up to 50 % for HV.

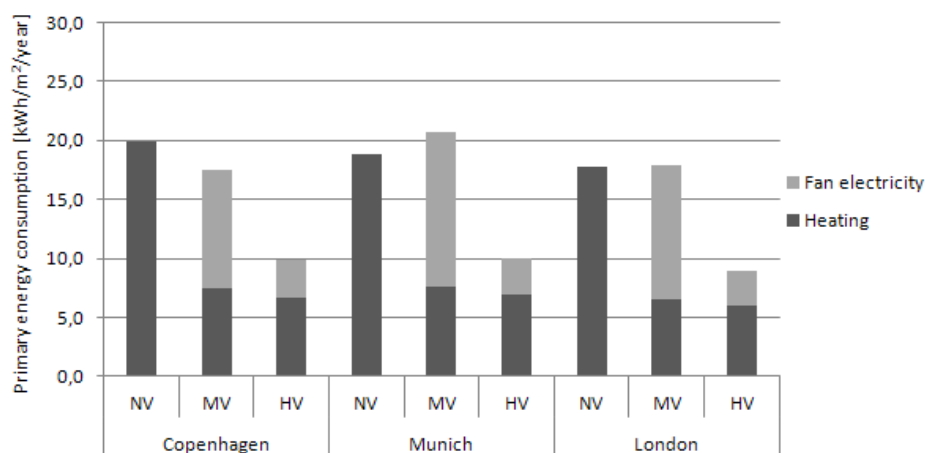


Figure 3. Primary energy consumption

CO₂ EMISSION

Calculation of the CO₂ emissions are based on the following figures; Munich (district heating 200 g/kWh and electricity 606 g/kWh), Copenhagen (104; 425) and London (206; 517). CO₂ emission due to electricity and heating is almost the same for NV and MV. Depending on the location the CO₂ emission ranges from 2.6-5.4 kg CO₂/m² per year. HV makes it possible to reduce this CO₂ emission up to 50%.

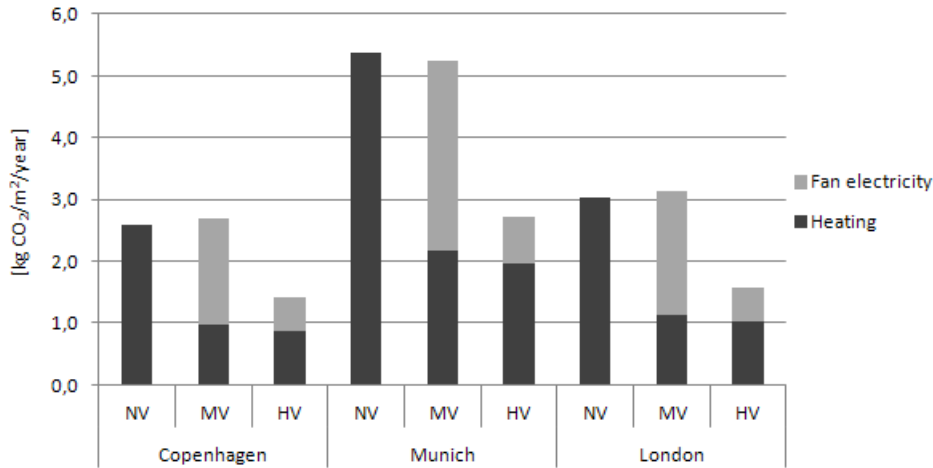


Figure 4. CO₂ emission

COST

The total investment of the different systems has been evaluated including costs for maintenance, operation (electricity and heating) and capital cost (products and installation) for the first year of operation (Figure 5) and during a period of 20 years (Figure 6). The prices are calculated by WindowMaster in close collaboration with a Danish ventilation contractor [8].

The maintenance cost for HV is almost the same as MV. Choosing NV this cost could be reduced with 70%. No significant difference was found between NV and MV for the operation cost during the first year. However, using HV this cost could be reduced with 50%. One of the major differences of the three systems is the capital cost. Here it was found that a MV system is more than four times as expensive as a NV system. For HV this was only a factor three. As a result of this big capital costs the total investment the first year is still in favour of NV with a factor four compared to MV and a factor three compared to HV. HV was found to be 25% cheaper than a full MV system.

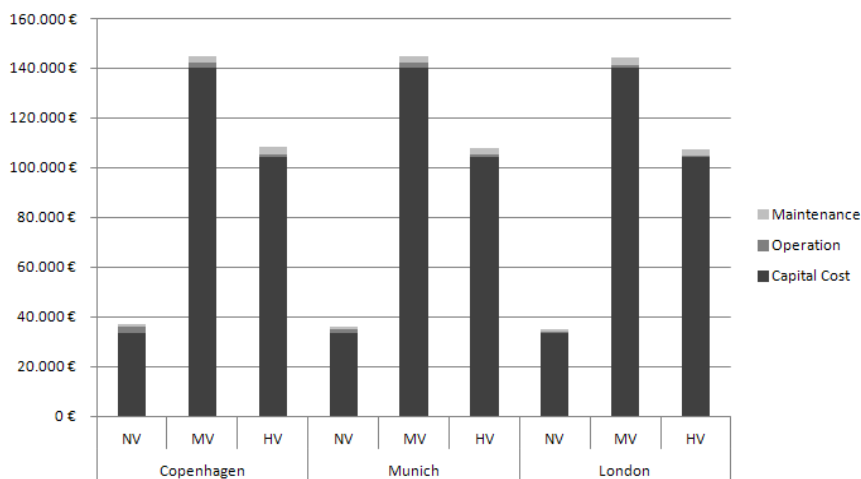


Figure 5. The total investment during the first year of operation

The total investment over a time period of 20 years showed almost the same pattern as the first year of operation. MV was found to be 2.5 to 3 times more expensive than NV on the total investment during a 20 year period. 25% could be saved choosing a HV system compared to a MV system.

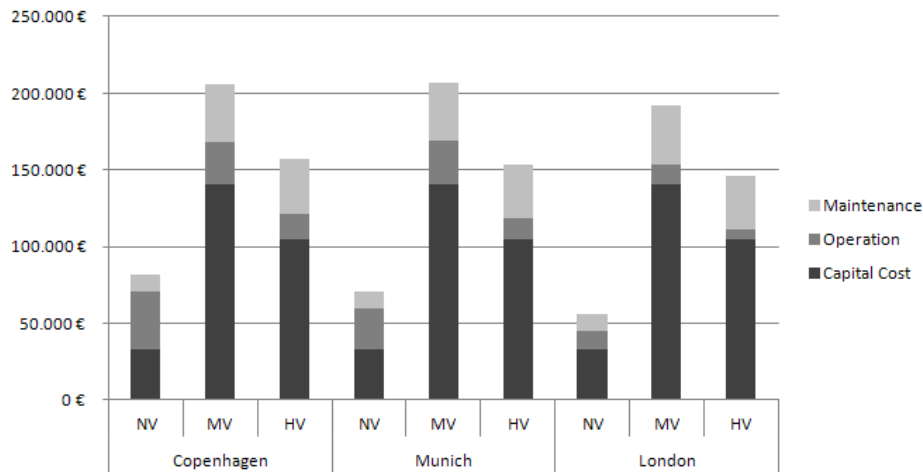


Figure 6. The total investment during a period of 20 years

DISCUSSION

The main ambition for the control strategies is to obtain the desired thermal comfort and indoor quality defined in EN15251 Category III and to obtain very similar indoor air quality for all three ventilation types. This is necessary for a useful comparison of energy demand resulting from the ventilation types. It should be noted that better indoor air quality and thermal comfort could have been obtained for all of the three ventilation systems if other requirements for CO₂ and temperature was chosen.

The transfer of the control strategy to the simulation models was done as close as possible to WindowMaster's control strategy. Sometimes changes were necessary due to the restrictions of the simulation software or to obtain a similar thermal comfort and indoor quality. It is believed that these simulations still are in accordance to the WindowMaster control system.

HV control strategy is a combination of the NV and MV control strategy. The main strategy is to use the best aspects of both systems, in order to optimise the balance between indoor climate and energy consumption. This is possibly the greatest challenge with HV and it is therefore necessary to have a control strategy that can take this into consideration.

During winter and summer the HV control strategy is almost straight forward. MV has the best results during cold periods, when there is a heating demand. The heat recovery of the system then helps saving energy of the building. During the summer period is it NV that has the best results. Good indoor air quality and thermal comfort can easily be reached without using any fan energy. The flow rate can be raised only by opening the windows a little more without using additional energy. NV has also the ability to benefit from night ventilation without using any additional energy.

The transient season is, however much more complicated and the most of the time it depends on the internal situation, if MV or NV is the best solution. Therefore it is very important to have an automatic system that can choose between the two systems depending on indoor temperatures as an indicator for heating or possible cooling demand. This is perhaps not that complicated. The complicated part is to make for instance MV stop and then start up the NV system due to the fact that the internal environment has change throughout the period where MV has been used. This strategy has been developed in these calculations.

CONCLUSION

The total primary energy demand (sum of heating and fans electricity demand multiplied with primary energy factors) for the NV and MV systems ranges from 18-21 kWh/m² per year in all three locations. For HV the total primary energy demand was only 9-10 kWh/m² per year.

The result shows that HV enables energy savings of 44-52% compared with MV. Compared to NV an energy saving from 46-50% could be reached. The heating demand can be reduced by nearly 70% for HV compared to NV. Fans electricity can be reduced with 75% for HV compared to MV. Total primary energy is almost the same for MV and NV, but can be reduced up to 50% using HV.

One of the major differences was to be found in the total investment of the different systems including maintenance, operation (electricity and heating) and capital cost (products and installation). Looking at the first year of operation and during a period of 20 years MV was found to be 2.5 to 4 times more expensive than NV. By selecting HV 25% of the total investment could be saved compared to a MV system.

The results demonstrate clearly that HV should be considered for schools in addition to NV and MV. Overall the HV makes it possible to save money for heating and electricity during operation time and to save up to 50% of the CO₂ emissions.

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