Hybrid Ventilation as an Energy Efficient Solution for Low Energy Residential Buildings

Peter Foldbjerg[1*] and Thorbjørn Færing Asmussen[1]

[1]VELUX A/S, Daylight Energy and Indoor Climate, Ådalsvej 99, 2970 Hørsholm, Denmark

[*]*Corresponding email: peter.foldbjerg@velux.com*

SUMMARY

The energy performance of two hybrid residential ventilation systems have been investigated and compared to an all mechanical system. The hybrid systems were a manual control based on fixed dates, and an automatic control which chooses the energy optimal mode on an hourly basis. Three different climates were investigated (Helsinki, Berlin and Paris). Results from the thermal simulations show that the energy demand of the hybrid systems is less than the all mechanical system. The reduction with the manual control is in the range of 0 – 3.4 kWh/m², while the automatic control has a larger potential in the range of 2.7 – 4.4 kWh/m². Natural ventilation is more energy efficient than mechanical ventilation for 26% - 45% of the year. Achieving the potential of the intelligent control requires a control system and automatically openable windows. Presently, no such control systems for residential buildings is widely available at a low cost. As the legislation on energy demands is being tightened, automatic hybrid ventilation control becomes increasingly attractive.

IMPLICATIONS

Hybrid ventilation can be a cost-efficient measure to reduce the energy demand of new and future energy-efficient residential buildings.

KEYWORDS

Hybrid ventilation, natural ventilation, residential buildings, energy efficient ventilation.

INTRODUCTION

As the energy demand of residential buildings is reduced due to continued tightening of building codes, the electricity demand for operating the house will represent an increasing part of the total demand. Pumps, fans and other equipment will represent an increasing part of the energy use for residential buildings. The European Union has 20% energy savings by 2020 as a target (European Commission, 2008), and member states are obliged to draw up national plans increasing the number of nearly zero-energy buildings (European Commission, 2010).

Mechanical ventilation systems with heat recovery provide good energy performance in the heating season. But the mechanical ventilation systems for residential buildings are often designed to be in operation all year, which include the summer period. Even though systems can often bypass the heat exchanger during summer, an electricity demand for fan operation remains. If natural ventilation is used instead during the summer period, the electricity demand for fan operation is eliminated. A previous study showed that the performance of the control system is the main factor, and that automatic control performs better than manual control systems in intermediate and warm climates (Foldbjerg, 2010).

METHODS

The energy performance of residential buildings with hybrid ventilation systems is compared to fully mechanically ventilated buildings. The demand for heating and fan operation is determined for three scenarios shown in Table 1.

Table 1. Short description of the three scenarios simulated.

All mechanical	Mechanical ventilation with heat recovery all year.
Hybrid with manual control	Change from mechanical to natural ventilation at a specific date, where the optimal date is determined for each location, based on minimizing the energy demand
Hybrid with automatic control	Sensor-based control switches between mechanical and natural ventilation based on outdoor conditions, which hour-by-hour chooses the most energy efficient mode of operation

The analyses have been performed for three locations in: Helsinki (Finland), Berlin (Germany), and Paris (France). The used software was the dynamic simulation tool IES VE version 6.02 (IES VE, 2010). A 1½-storey house with an 8x12 m footprint is used at all locations. The house is defined in (Kragh, 2008). See Figure 1 for a visual representation.

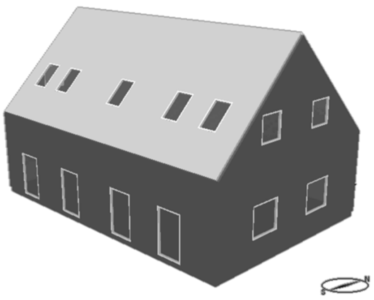

Figure 1. Visual representation of the house used in the study.

The total floor area is 163 m², and the window area corresponds to 20% of the floor area, i.e. 23 m² façade window and 4 m² roof window. The windows have a declared U-value of 1.4 W/m²K in vertical position, and a g-value of 0.60. The floor has a U-value of 0.2 W/m²K, walls have a U-value of 0.3 W/m²K, and the roof has a U-value of 0.2 W/m²K.

System setup

A heating system was assigned, with set point at 21°C. The internal loads consist of two persons occupying the building all year and equipment of 3.5 W/m². There is no cooling system installed but the windows are used to vent the building when the outdoor temperature is above 22°C with a maximum opening area of 25%. Half of the windows are used for venting. A constant air change rate of 0.5 ACH is assumed for both the mechanical and the natural ventilation system. For the natural ventilation system, this assumption is chosen to make the results comparable to the mechanical system. The used mechanical ventilation system is an efficient system with low energy consumption and good heat exchanger performance. The fan power consumption is 1.37 W/(l/s), equal to 82 W at an air change rate of 0.5 ACH. The efficiency of the heat exchanger of the heat recovery system is 88%, based on a well-performing residential system.

The Control Strategies of the hybrid system

The purpose of the hybrid ventilation control is to benefit from the advantages of the two ventilation solutions: The heat recovery of the mechanical and the free ventilation of natural ventilation. During the heating season the mechanical ventilation system will have the best energy performance due to the heat exchanger. In the summer period the natural ventilation will perform better as it uses no extra energy for fans (and there is no need for heat recovery).

The manual control algorithm is purely based on fixed dates for turning on or off the operation of the systems. The used dates are found empirically based on preliminary simulations of each location. The following dates were used:

- Start natural ventilation: April 1st
- End natural ventilation: November 15th

The automatic control algorithm is based on the energy demand for the two ventilation methods. The principle is show in Figure 2.

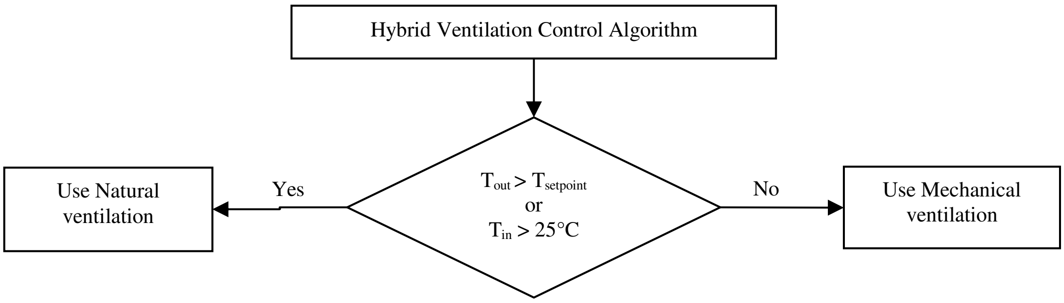

Figure 2: Principle of the automatic control algorithm.

Where T_{out} is the outdoor air temperature [°C], and T_{in} is the indoor operative temperature [°C]. $T_{setpoint}$ is the setpoint temperature for changing between natural and mechanical ventilation mode [°C]. The setpoint is determined based on the most energy efficient mode of operation, where the demand for heating and fan operation is included. The setpoint temperature depends on the energy performance of the house, as it will be lower for a high performance house. The optimal setpoint temperature was determined as the first step of the present study.

Operation costs

The costs for running the systems include costs for heating and electricity for fan operation. The energy cost is different for each location depending on taxes and energy sources. Statistical data about the energy prices has been found via energy.eu (2011). The Finnish natural gas price is assumed to be the average price for EU-25. See Table 2 for the price of natural gas in each country.

Table 2. Energy and filter costs.

	Energy costs (natural gas) [€/kWh]
Berlin	0.06
Helsinki	0.05
Paris	0.05

RESULTS

Setpoint temperature

The optimal setpoint temperature for the automatic control was determined for the design reference year by determining the primary energy demand for a series of setpoint temperature candidates. Figure 3 shows the primary energy demand, which is determined for Berlin only, as the outdoor temperature is considered the most important factor. The optimal setpoint temperature is identified as 12°C.

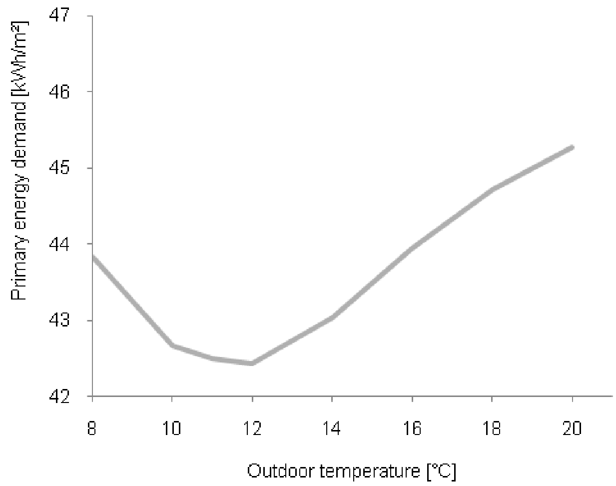

Figure 3. Primary energy demand for heating and fan operation depending on outdoor temperature based on Berlin.

System feasibility

Figure 4 shows the part of year when natural ventilation is used in the two hybrid controls strategies. In the manual control strategy, natural ventilation is used more than in the automatic control strategy. This includes hours during nighttime when mechanical ventilation would have been more energy efficient. The automatic control only uses natural ventilation when it is more energy efficient than mechanical ventilation. With the automatic control, natural ventilation is the most efficient mode of ventilation for 45% (Berlin), 26% (Helsinki) and 44% (Paris).

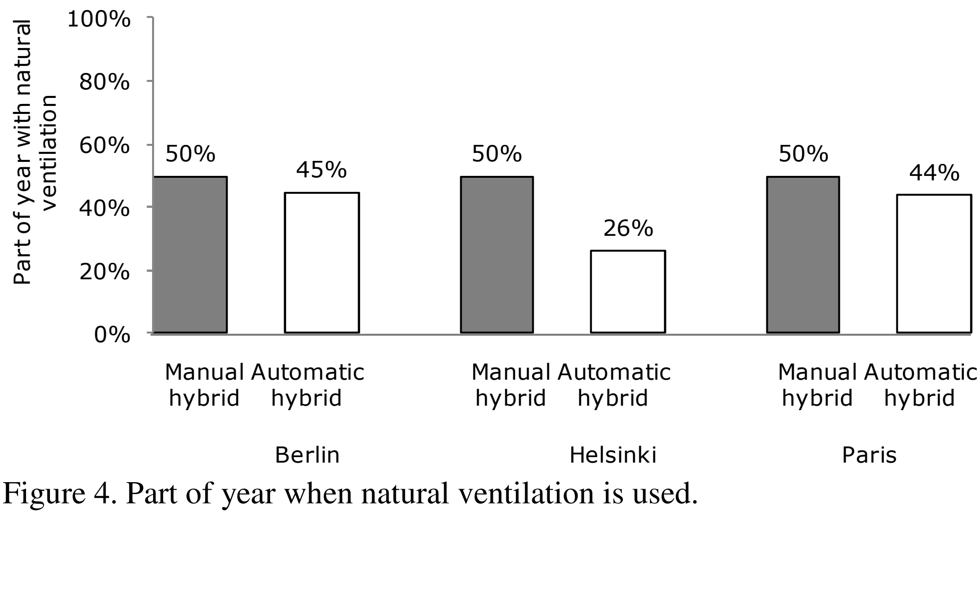

Figure 4. Part of year when natural ventilation is used.

Energy demands and cost of operation

For each location and case the energy demand as primary energy is calculated. The electricity is converted into primary energy with a factor of 2.5. The annual primary energy demand per square meter is shown in Figure 5. The figure also shows the savings potential in kWh/m² when using hybrid systems compared to the fully mechanical solution.

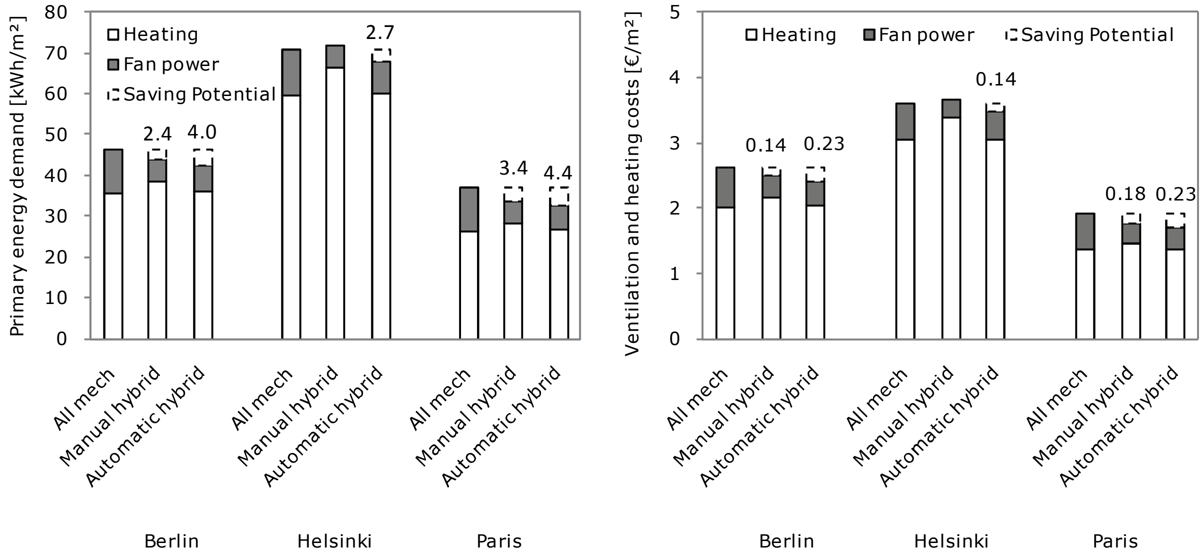

Figure 5. Annual primary energy demand (left) and annual system operation costs (right).

The saving potentials are in the range of 0 – 3.4 kWh/m² for the manual control, and in the range of 2.7 – 4.4 kWh/m² for the automatic control.

The reduction should be considered in relation to the maximum primary energy demand for current and future buildings in building regulations. For a maximum demand of 80 kWh/m², a 4 kWh/m² reduction corresponds to 5%, while 4 kWh/m² corresponds to 10% for a maximum demand of 40 kWh/m².

Operation costs

The costs are calculated based on the energy demands, see Figure 5. The saving potentials are in the range of 0.00 – 0.18 €/m² for the manual control, and in the range of 0.14 – 0.23 €/m² for the automatic control.

DISCUSSION

With the automatic control, natural ventilation is more energy efficient than mechanical ventilation with heat recovery for 26% - 45% of the year, highest for the warmest locations (Berlin and Paris).

Hybrid ventilation decreases the total primary energy demand at all locations. The decrease is largest with the automatic control (2.7 – 4.4 kWh/m²) but is also present for the manual control (0 – 3.4 kWh/m²). The slightly colder climate in Helsinki presents less potential for savings than Paris and Berlin. The reduction of operation costs with the manual control (0.0 – 0.2 €/m²) are close to the automatic control (0.1 – 0.2 €/m²); the operation costs of the two hybrid controls are lower than for a system with mechanical ventilation all year.

The manual control is dependent on choosing the optimal dates for changing from mechanical to natural operation. Weather conditions can vary from year to year, so these dates would not be the same from year to year in a physical implementation. The automatic control will adjust to actual climate conditions, and therefore the performance of the automatic system will be relatively better in a physical implementation than in this study.

A dedicated control device that chooses the optimal mode of operation for a residential building is presently not available on the mass market. As electrically operated windows are becoming increasingly widespread, the additional price of a control device that switched between natural and mechanical ventilation will be low. As the legislation on energy demands is being tightened, the investment to reduce the demand by 1 kWh/m² will increase. This will make automatic hybrid ventilation control increasingly attractive. A reduction of 4 kWh/m² would correspond to a saving of 10% of the maximum primary energy demand, in a future situation where the maximum primary energy demand is 40 kWh/m², as could be the case in many European countries by 2020.

REFERENCES

European Commission. 2008. *20 20 by 2020: Europe's Climate Change Opportunity, (COM (2008) 30 final)*. Commission of the European Communities, Brussels.

European Commission. 2010. *DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)*. Commission of the European Communities, Brussels .

Foldbjerg P and Asmussen TF. 2010. *Hybrid ventilation as a cost-effective ventilation solution for low energy residential buildings*. Proceedings of Clima2010 (2010). ISBN: 978-975-6907-14-6.

http://energy.eu. Europe’s Energy Portal (last accessed January 2011).

IES VE 6.1.0. 2010. http://www.iesve.com. Integrated Environmental Solutions Limited, Glasgow, UK.

Kragh J, Laustsen JB and Svendsen S. 2008. *Proposal for Energy Rating System of windows in EU. DTU-R201*. Technical University of Denmark.