Impact of hybrid ventilation and sewage heat recovery on the energy performance of a low energy building; a feasibility study

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Abstract

A hybrid ventilation system including sewage heat recovery for low energy buildings has been investigated using TRNSYS. Energy from solar collectors is used in combination with the heat recovered from the sewage system to preheat the ventilation air and the cold water for domestic use. Results show that the new system renders a possibility to use natural ventilation in passive houses and zero energy buildings. The annual auxiliary energy need for the new system is lower than for a conventional fan driven ventilation systems using air/air heat recovery units. Depending on technical solution and site of installation, the system can provide free cooling during the summer. Since the new system mainly runs on natural forces it is also more silent compared to standard mechanical ventilation systems.

1. Introduction

As the insulation is increased in a building the price of the construction rises. At a certain point there is no longer any reason of adding insulation. In order to continue improving the energy performance of the future buildings new and innovative solutions are important. At the same time it is important that the technical solutions and appliances are in harmony with the general opinion of the people living in the buildings. If the occupants doesn't like or understand the technology there is a risk of misuse or disconnection.

Reducing the need of bought energy can be made in mainly two ways: decreasing the energy consumption or increasing the alternative energy production. In this article we discuss a way to reduce the energy demand for a building. We investigate a ventilation system that uses solar heat and heat from the sewage to preheat the ventilation air and the domestic hot water. The ventilation system uses natural driving forces, both thermal and wind, when present. If these forces are too low the ventilation is complemented with a fan. This combination and multifunctional use of the recovered energy at different temperature levels results in a ventilation system that could be suitable for low energy buildings, e.g. passive houses or Net Zero Energy Buildings (NZEB:s).

2. Method

Simulations of the energy use in a reference building has been carried out with the dynamic energy simulation program TRNSYS [1]. Different systems for ventilation and sewage water heat recovery were thereby tested. A system with natural ventilation with an indirect heat recovery system is compared with a mechanical ventilation system both including a sewage heat recovery system. The reference building is a so-called passive house [2]. This means that the energy demand of the building is so low that the heat may be supplied through the ventilation air, i.e. there is no need for separate radiators to maintain the desired indoor temperature.

The different systems can be seen in Fig 1. In the upper left corner, the concept of the hybrid ventilation system is shown. The air is let into the building at the ground floor and is let out through the roof. The heat exchangers circuit is shown in broken lines. The brine in the circuit is pumped between the cross flow heat exchangers. The heat exchanger labelled HX R is located just below the roof. It recovers some of the heat from the exhaust air. The heat in the brine is then delivered in the heat exchanger, labelled HX 1, to the incoming air. Second from the right upper row shows the concept of mechanical ventilation with heat recovery. This type of ventilation is common in low energy buildings, e.g. passive houses. In our simulations, it is given the same heating source as the left system, a heat pump connected to a ground collector. Simulations was performed for six different systems, four using the natural ventilation technique, System 1-4 and two that uses the mechanical system, System A-B. System 1 shown in Fig. 1 uses a water/air heat exchanger, labelled HX 2, to heat the ventilation air. The heat is supplied from a tank, TANK 3. The energy to the tank is supplied from the heat pump, H.P., connected to a ground collector, G.C. The heated air supplies the building, shown in the upper right corner in the figure. System 2 shown to the right in Fig. 1 is the same as System 1 but it also includes a solar thermal collector.

The system in Solgården is labelled System 3. The auxiliary energy for heating the building is supplied to the ventilation air. System 3 uses the same tank, heat pump, ground collector and solar collector system as System 2. As can be seen, the difference to System 2 is the heat recovery system, HX 1 and HX R. The most developed system, System 4, is shown second from left in the lower row in Fig 1. It is based on System 3 but it also includes two extra storage tanks, TANK 1 and TANK 2. These tanks are mainly grey water sewage tanks, i.e. the sewage from the toilets is not included. The sewage is let in to tank 2. This is indicated with a green arrow in the figure. The sewage is then passed on to tank 1 before it is disposed out of the building. The solar collector loop, labelled S.C. in the figure is shown in blue. The solar energy is always heat exchanged in the main storage tank, TANK 3. After this the solar collector loop continues either back to the bottom of the collector or to the sewage tanks. If the temperature in the bottom of TANK 1 is below a chosen value, 30°C in the performed simulations, the solar heat is exchanged in all of the tanks. The energy that is stored in the two sewage tanks is used to preheat the incoming cold water and the ventilation air. The first circuit, i.e. the lowest in the figure, goes from the tank to the heat pump connected to the ground collector. The ground collector ensures that the inlet brine to TANK 1 is not too low, to avoid freezing. The second brine circuit connects TANK 2 to the second heat exchanger, HX 2. If the heat is not enough to keep the building on the desired temperature, extra heat can be supplied from TANK 3. This is not shown in the figure to avoid too many connections. Also pumps and controllers have been left out for visual clarity in the figures. The domestic hot water is preheated by the sewage tanks before reaching its final temperature in TANK 3. System A & B are shown in the lower right of Fig 1. System A is without and System B is with the sewage heat recovery system used by System 4. The difference to System 3 & 4 is that a mechanical ventilation system with heat recovery, labelled Mech, has replaced the natural ventilation system.

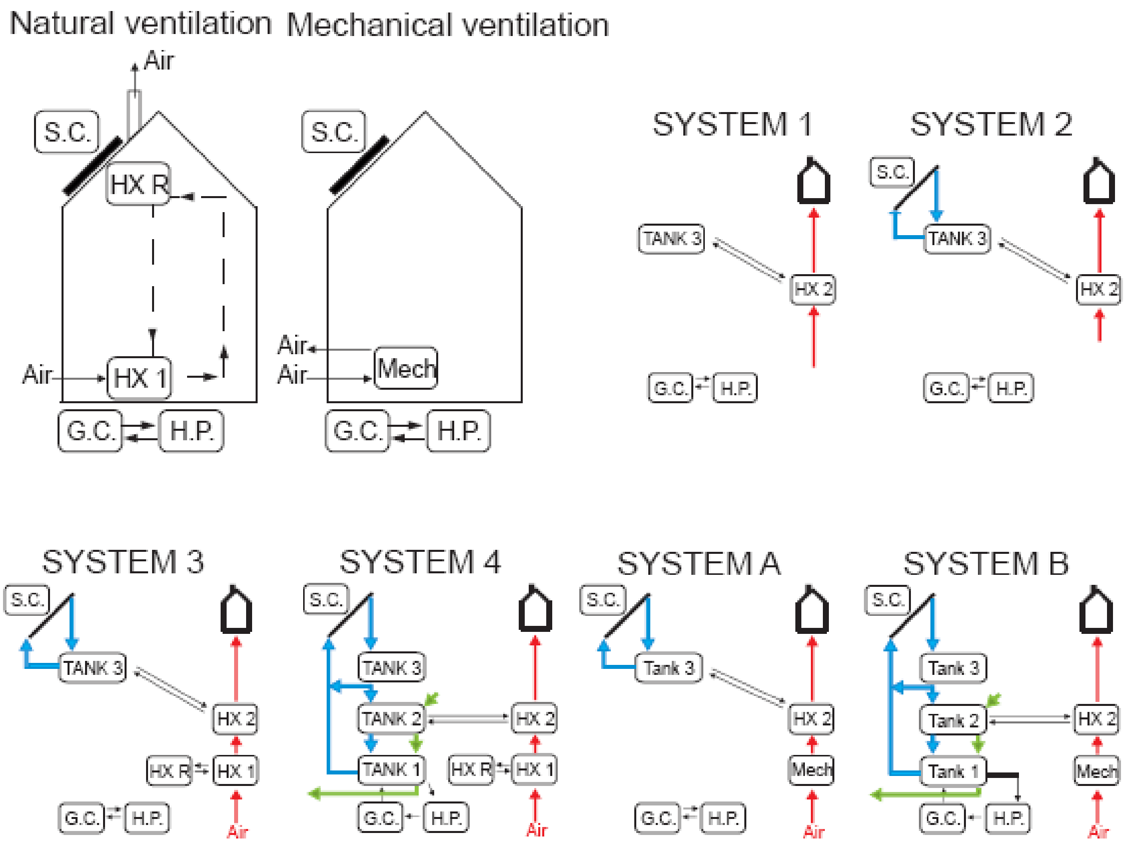

Fig. 1. Upper row to the left shows the two types of ventilation systems. System 1-4 & A-B is shown with blue colour for solar collector loop, green for sewage flow, red for ventilation air and black lines for brine circuits.

2.1. Data

Some of the most important data for the simulation is listed below.

- Domestic hot water use, 180 litres at 55°C
- Sewage flow, 360 litres at 30°C and 100 litres at 10°C
- Tank 3 size, 400 litres
- Tank 1&2 size, 50 litres
- Solar collector, 12 m^2 at 70° tilt
- Building, UA-value 62.7 W/K, glazed area approx. 21m^2
- Ventilation 0.5 ach = 180 m^3/h
- Heat pump, 1200 W, SPF 2.5 working from 5°C to 60°C
- Heat recovery in mechanical system 75%

Throughout the simulations the domestic hot water was set to 180 litres per day at 55°C. The hot water consumption profile is a simplification from measurements performed in Sweden [3]. During the simulations as many parameters as possible were kept constant. This allows the results to be interpreted more easily. On the other hand, what is optimum for one system might not be optimum for another. This is why some parameters such as pump speeds and control parameters were optimized for each system. For Systems A & B the ventilation fan is assumed to be running the full year. The electrical energy consumption for the fan was set to 1.12 Watts per l/s of air flow. This was the lowest energy consumption used by a mechanical ventilation system with heat recovery in a test performed by the Swedish energy agency [4]. The natural ventilated systems, i.e. System 1-4, are estimated to run on thermal and wind driven forces 90% of the year. The estimation is built on wind and temperature data from Swedish climate. During the remaining part of the year a fan assists the ventilation. This fan is assumed to use the same power as the fan used in Systems A & B. No attention was paid to cooling of the building.

3. Results

The annual energy need for the six systems is shown in Fig 2. The energy needed for the pumps and the fan is given in black, while the auxiliary energy supplied to the heat pump is given in grey. As can be seen System 3 need about the same amount of energy as System A. The increased energy consumption due to the luck of mechanical ventilation with heat recovery in compensated with the low energy use by the fan and the pumps. It can also be seen that System 4 needs less energy than System B. This is also due to the low energy need by the fan and the pumps but it is also due to the sewage heat recovery system. Since System 4 uses the energy in the sewage tanks more efficiently than System B the energy need is reduced more for System 4. System 4 will, since it has a less effective heat recovery, be exposed to cooler air in HX 2. This means that more energy from the sewage tanks can be used in System 4 than by System B. Consequently the energy use is lowered more for System 4 than for System B when installing the sewage heat recovery system.

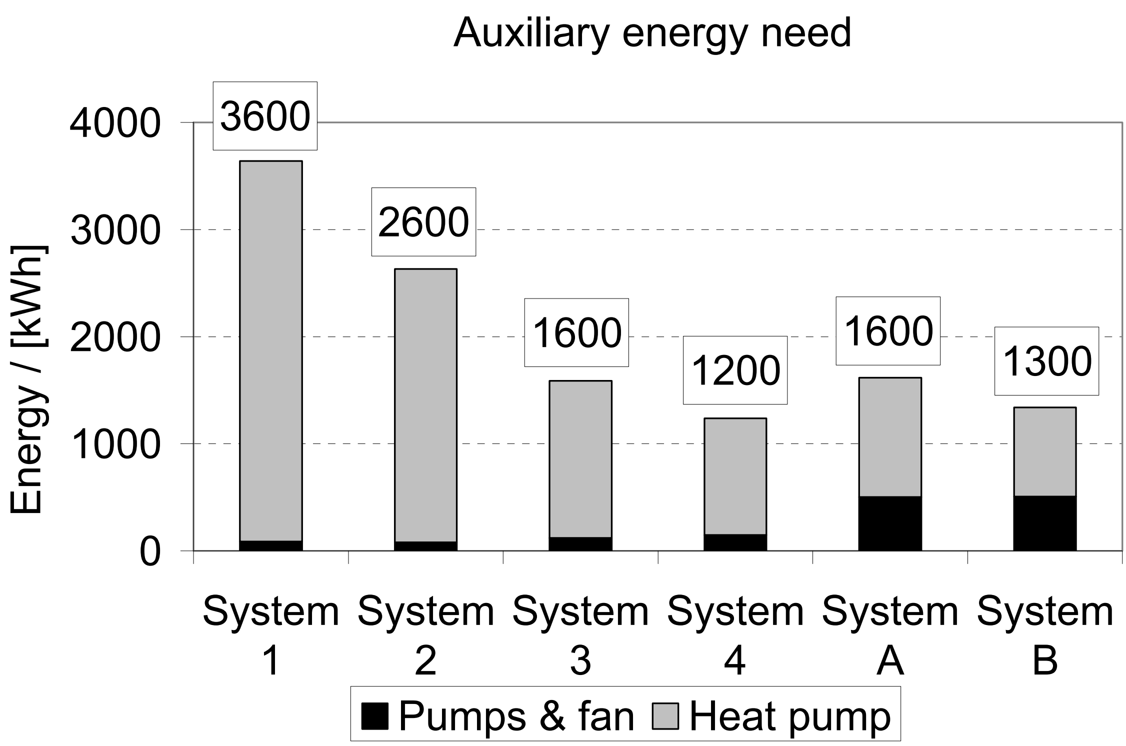

Fig. 2. The annual auxiliary energy need for the different Systems, 1-4 and A-B.

One of the more sensitive parts in the system is the air/water heat exchangers labelled, HX 1, HX 2 and HX R in Fig 1. To test the importance different efficiencies was tested with simulations using the developed TRNSYS deck. During this parametric study the efficiency was changed simultaneously for all of the three heat exchangers. The result from the study is shown in Fig 3. On the x-axis is the efficiency stretching from 30% up to 80%. The y-axis represents the annual auxiliary energy need for the entire building, including the domestic hot water use. The full red line shows the annual auxiliary energy need for System B. The dashed red line is for System A. The efficiency of the heat exchangers used by System A&B was fixed to 70%. Since these both systems use a mechanical fan it is easier to design heat exchangers that can live up to the assumed 70%. This might not be the case for the heat exchangers used by System 1-4 since they also have to have a low pressure drop not to deteriorate the ventilation flow. As can be seen the annual auxiliary energy need is strongly dependent on the efficiency of the heat exchangers. The efficiency of the heat exchangers must be at least about 65% if System 4 is to perform better than System B and at least 50% to outperform System A.

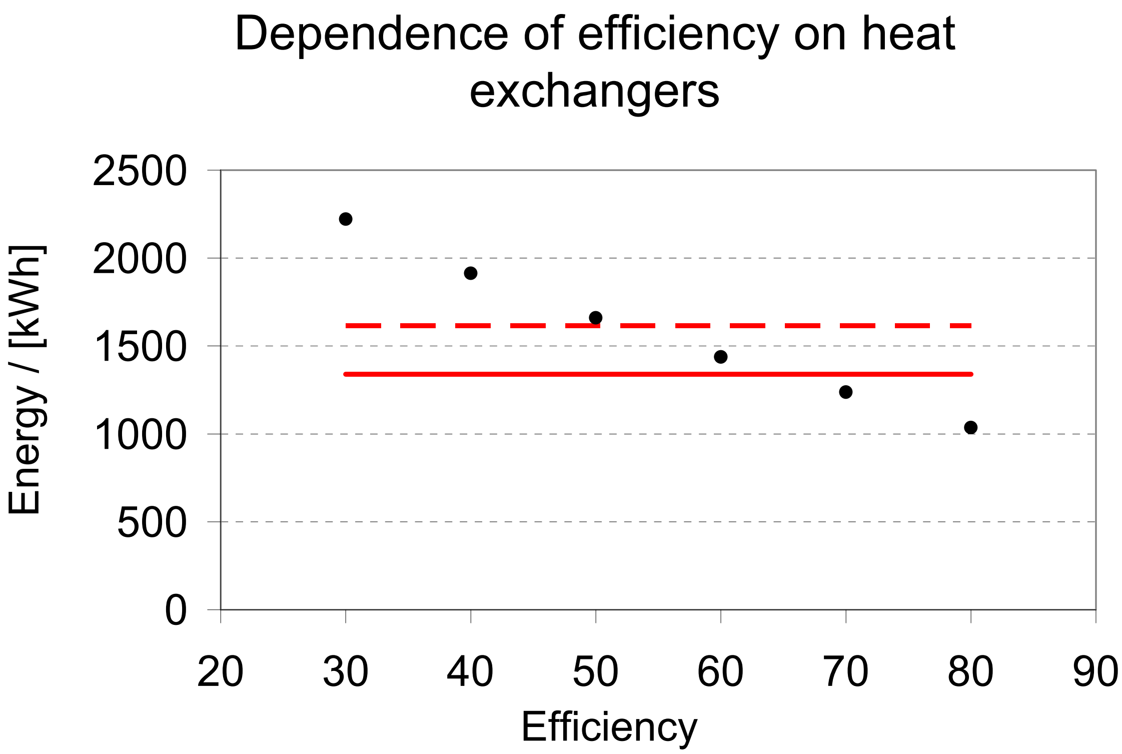

Fig. 3. The annual auxiliary energy need for System 4 as a function of the efficiency of the heat exchangers. The full and the dashed red line shows the annual auxiliary energy need for System B and System A respectively.

4. Conclusions

The main idea with the project was to study the possibility to construct a ventilation system that mainly runs on the forces supplied by nature, i.e. thermal and wind forces that compare well to a mechanical system. The investigated systems have advantages apart from the lower electrical energy use. Naturally ventilated buildings can always be supplied with fresh air. This is not the case for a mechanical system that will stop in case of a power failure. At the same time natural ventilation has a low level of disturbing noise. However, naturally ventilated buildings normally results in high energy consumption since heat recovery from the exhaust air is not present. The investigated system shows that it might be possible to construct a hybrid ventilated system with a low annual auxiliary energy need. This was shown in Fig. 2. However, this is strongly dependent on the efficiency of the heat exchangers used by the system. As was shown in Fig. 3, the efficiency of the heat exchangers must be at least 50% for System 4 to outperform System A.

The most important reason to why System 4 performs better than System B is that the high energy consumption by the electrical fan is strongly reduced. Apart from that System 4 uses the sewage tank not only to preheat the incoming cold water but also to preheat the ventilation air in a very efficient way. This multiple use of the energy makes is beneficial to let the solar collector deliver energy to the two sewage tanks. What system to choose for a new house is however not possible to answer from only the results of this study. There are advantages and disadvantages with both systems. The natural ventilation system is more quiet and is less sensitive to mechanical failures. However, the mechanical system provides a well tested ventilation system. This type of system is easy to install and it can be made to work in a number of different types of building. Buildings with special demands on the ventilation might be difficult to ventilate using only natural driving forces.

The auxiliary energy needs for the different systems presented in this article all comes from a heat pump. If electrical heating or wood burning would have been used instead of the heat pump all the numbers would have been much larger. The energy savings would be more evident if the systems were supplied only with electrical heat. Since the heat pump in System 4 and System B is a part of a system this was not possible.

5. Future

Several components need to be developed and tested before this system could be a competitive option. Most important for the system is probably the heat exchangers for the natural ventilation. The difficulty with the air flow rate in the system is multifaceted. Not only is it a problem to ensure a large enough flow during the summer but it is also a challenge to avoid excessive ventilation during extremely cold or windy periods. An effective control mechanism is a necessity. To ensure good ventilation levels a number of techniques have to be combined. This means that the driving forces for the ventilation has to be due to both temperature differences and wind pressure. The wind driven force can be increased with different types of ejectors [5]. There is also the possibility to use so called solar chimneys to enhance the driving force [6]. Another important point is the heat exchangers in the sewage water tanks. The sewage water tanks also have to be specially designed for the system. If care is not taken, fat from cooking, detergents etc. can stick to the heat exchangers. This will lead to a lower heat transfer rate and thus a lower efficiency in the system. There are however different techniques for cleaning the sewage water, which does not include sewage from toilets. For instance different kind of bio-filters [7] can be used to clean the water before it is let into the sewage tanks. There are however also technical advantages with natural ventilation systems. The risk of frost is limited to periods with ambient temperature below -20°C. Extra care has to be taken if such cold temperature is possible at the place of installation. The problem can be eliminated if the brine is preheated with a ground collector. Of course, the humidity in the exhaust air can condense but this does usually not cause any problems. Frost is a problem for many mechanical ventilations systems with heat recovery.

The ground collector can, if installed in such way, be used to provide free cooling of the building, which would then also help to restore heat to the cooled ground. The results presented in this article are without any regards to cooling. In the future we intend to investigate alternatives of systems. There are a large number of possible ideas to be tested, for instance preheating of the ventilation air in the ground or using a more sophisticated control strategy for the solar energy circuit.

The results from the simulations presented in this article shows that the project is worth to be further investigated. The next step in this project is to construct the different parts needed in the system and proceed with a detailed economic analysis.

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