Performance of Heat Recovery Ventilation System with Ground Source Brine Heat Exchanger Pre-Heating System in the Context of nZEB

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***Abstract* – The paper analyzes effectiveness of the ventilation unit pre-heating system with a ground source brine heat exchanger in a nearly zero energy building in Estonia. Focus is on the analysis of measured energy usage and possible effects on the energy usage of alternative solutions of the ventilation pre-heating system in terms of nearly zero energy building. The studied building was planned and realized according to the international passive house concept. To further lower the energy demand, the building was equipped with a solar thermal system and a photovoltaic solar system to cover the total final energy demand of the building, making it nearly zero energy building. The ventilation system is equipped with temperature and relative humidity sensors to measure supply, extract, exhaust air parameters and air parameters before and after the pre-heating system. Energy usage to pre-heat the ventilation airflow with a ground source brine heat exchanger was also measured. Our results show that annual energy used for pre-heating the ventilation airflow is around 420 kWh, which makes about 3% of the building's total energy usage. The efficiency of the ventilation unit heat exchanger was over 80 % in the winter season due to the pre-heating system.**

***Keywords* – ground source brine heat exchanger, nearly zero energy building, ventilation unit, frost protection.**

I. INTRODUCTION

Reduction in energy consumption in buildings is one of the main future energy targets of the European Union countries [1]. The ventilation heating loads constitute a growing part of the heating demand in new and retrofitted buildings due to the modern indoor air quality standards. Ventilation heat recovery systems can give substantial final energy reduction, but the primary energy benefit depends strongly on the type of the heat supply system, and also on the amount of electricity used for ventilation heat recovery [2]. Buildings with low energy demand with the mechanical ventilation system with heat recovery may even use more primary energy than the same buildings with the mechanical ventilation system with heat recovery, depending on the use of ventilation electricity [2].

Commonly, the use of electricity in the ventilation system is intended to prevent frosting of the heat exchanger. Frosting increases the pressure drop or decreases the flow rate through a heat exchanger and therefore reduces the performance of the fan. The layer of frost also decreases heat transfer between two air streams by increasing the thermal resistance of the separating walls [3]. To prevent those processes, simple electric frost protection coils are often used, although alternative systems exist, such as for reduction of supply airflows, ground-source air heat exchangers, ground-source brine heat exchangers, etc.

This paper analyzes the results of the efficiency measurements of a mechanical ventilation system with heat recovery and a ground-source brine heat exchanger system to prevent frosting in a nZEB detached house.

II. METHODS

A. Studied building and ventilation system

The building studied is the first certified Passive House in Estonia (Fig. 1 left) [4]. The house includes two stories and a basement with a total net floor area of 305 m^2 and enclosed volume of 1586 m^3. Thermal transmittance of the building envelope is as follows:

- external walls U 0.11 $W/(m^2K)$
- roof U 0.07 $W/(m^2K)$
- basement floor U 0.09 $W/(m^2K)$
- windows U 0.67 $W/(m^2K)$

The building is heated with a ground source heat pump and a hydronic wall heating system. Domestic hot water is heated with solar collectors and a ground source heat pump. Grid connected PV panels were installed on the roof.

In Estonia, the energy efficiency requirements are set for the annual usage of primary energy [5]. Primary energy takes account of the environmental impact according to the energy source, with the weighting factors:

- wood and other bio fuels: 0.75
- district heating: 0.9
- fossil fuel: 1.0
- electricity: 2.0

the primary energy usage criterion of the nZEB detached house is $\leq$ 50 $kWh/(m^2a)$.

First year measurements showed that the annual net delivered energy demand was 13,098 kWh and energy production with PV-panels was 12,054 kWh. Annual delivered energy need was 1044 kWh (3.5 kWh/m^2) and primary energy usage was 7.0 $kWh/(m^2a)$, which fulfills the nZEB criterion and is close to the net zero energy building energy efficiency requirement 0 $kWh/(m^2a)$.

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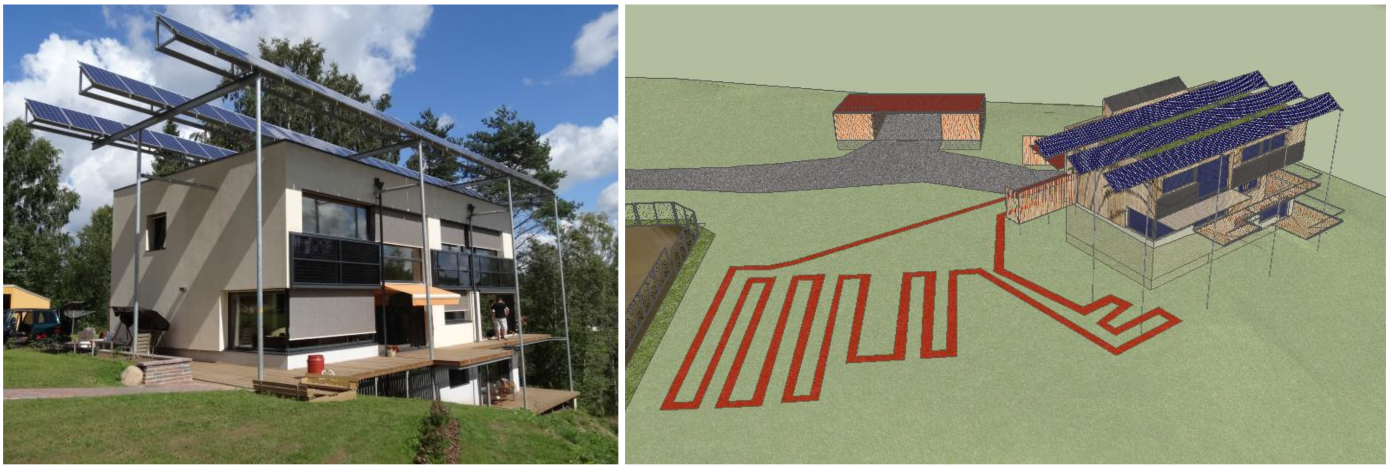

Fig. 1. View from the SW direction (left) and position of the pre-heating system ground loop (right).

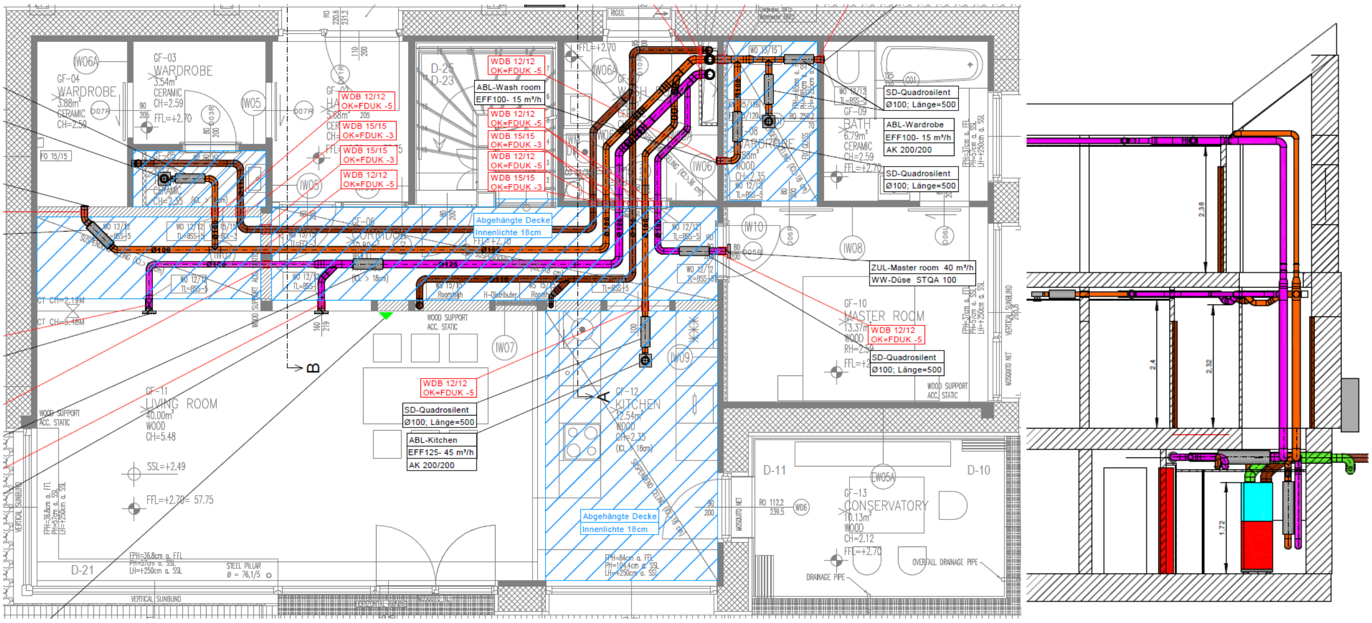

Fig. 2. First floor ventilation plan (left) and ventilation section (right).

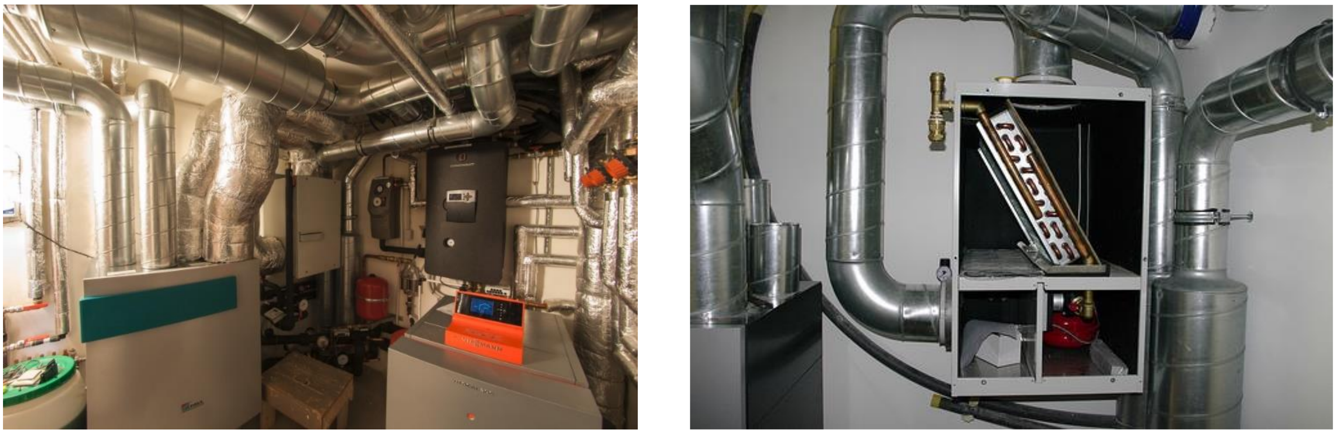

Fig. 3. Ventilation unit (left) and ground source brine heat exchanger (right).

The building has a mechanical ventilation system with heat recovery. Fresh air heating is supplied to the living-room and bedrooms and then exhausted from the kitchen and bathrooms (Fig. 2). The airflows of the ventilation system are 280 m^3/h, which corresponds to an average air change rate of 0.4 h^{-1}. The ventilation unit (Paul Novus 300) (Fig. 3 left) has an exhaust side heat recovery efficiency of 93% according to the Passive House Institute certification system [6].

The frost protection of the ventilation unit is solved with a ground source brine heat exchanger (GSBHE). The system has 226 m (with 40 mm diameter) plastic brine loop with 50 % ethylene glycol-water mixture installed into the ground (Fig. 1 right) and connected to the ventilation airflow pre-heating unit (Paul Sole Defroster SD-550) (Fig.3 right) with the heating capacity of 2500 W. The system is controlled with temperature measurements before the pre-heating unit. Switch on setpoint is the airflow temperature <1 °C.

B. Measurements

Temperature and relative humidity of the ventilation airflow were measured with sensors (Ø5 mm · 51 mm, measurement range: – 40 °…+100 °C and 0…100 %, accuracy: ±0.3 °C and ±2%) in five points (Fig. 4):

- outdoor air (1)
- air before the pre-heating unit (2)
- air after the pre-heating unit (3)
- supply air (4)
- extract air (5)
- exhaust air (6)

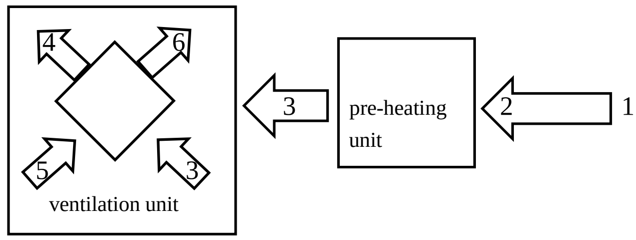

Fig. 4. Measuring points of the ventilation airflow.

GSBHE energy production from the ground brine loop was measured with a heat meter to determine energy usage for the pre-heating ventilation airflow.

C. Efficiency of heat recovery

Efficiency of heat recovery (1) was calculated with the measured values of the airflow temperatures

$$\eta = \frac{t_{supply} - t_{after\ pre-heating}}{t_{extract} - t_{after\ pre-heating}} \qquad (1)$$

where: η - efficiency of heat recovery
t_{supply} - supply air temperature
$t_{after\ pre-heating}$ - air temperature after the pre-heating unit
$t_{extract}$ - extract air temperature

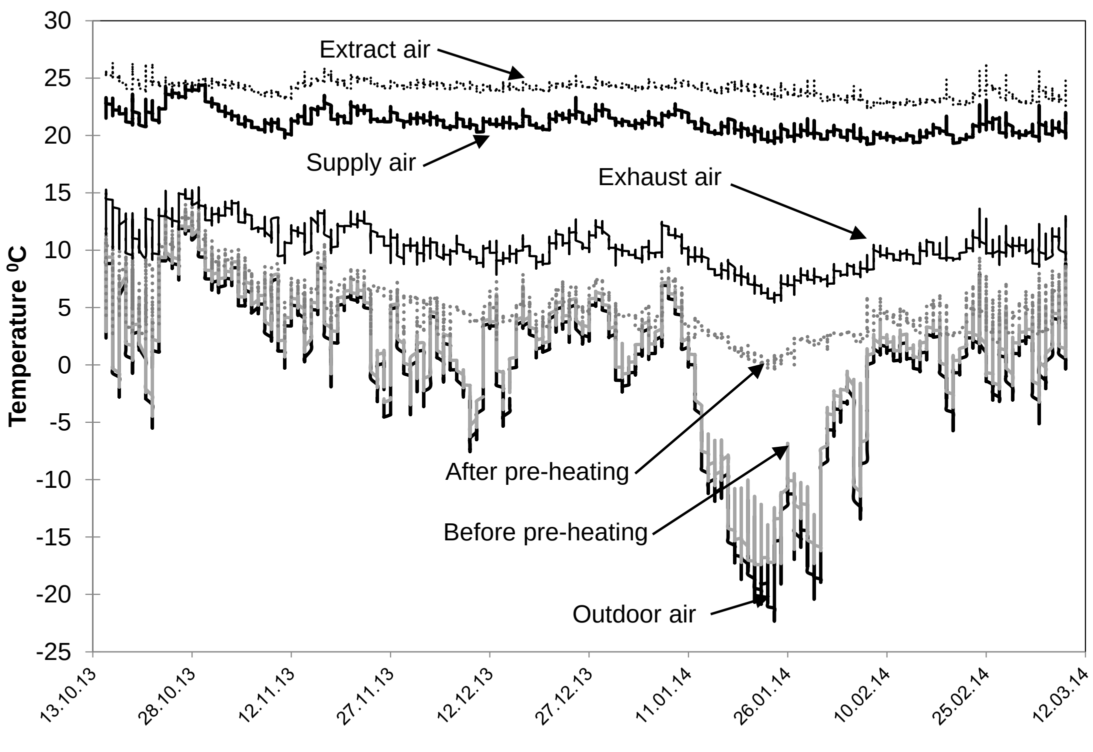

Fig. 5. Temperatures of ventilation airflows.

III. RESULTS

Airflow temperature measurements showed that the outdoor air temperature rose up to 5 °C in the air duct before the pre-heating unit during the coldest period. The pre-heating unit held the airflow temperature above 0 °C and the supply air temperature was relatively constant around 21–22 °C during the measurement period without an additional heating coil inside the ventilation unit. Extract air temperature was also relatively constant around 24–25 °C during the measurement period. Exhaust air temperature was above 5 °C, meaning that the frosting of the ventilation unit heat exchanger was avoided during the measurement period.

Efficiency of the heat recovery was between 0.78 and 0.96 during the measurement period (Fig. 6) due to pre-heating unit, which held the ventilation unit intake air temperature above 0 ^{0}C. Lower outdoor temperatures (−22 °C) had no effect on the efficiency of the ventilation heat recovery. Average efficiency value was 0.84. Higher efficiency (over 0.9) was in the period when the outdoor air temperature rose up to 12 °C.

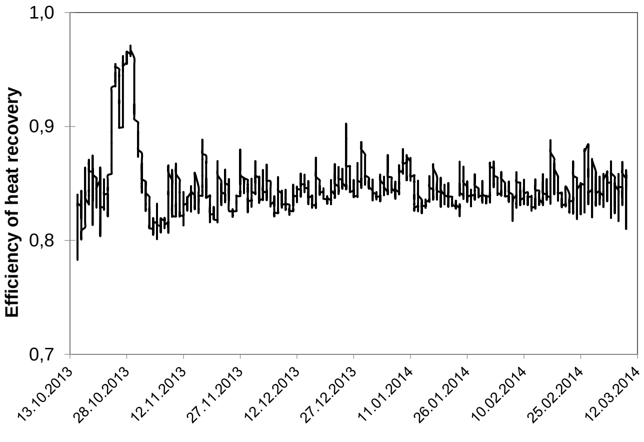

Fig. 6. Efficiency of heat recovery.

Relative humidity of the ventilation airflows was also measured (Fig. 7). The ventilation unit had a plate heat exchanger without humidity recovery. Therefore, humidity of the supply airflow depended on the temperature and humidity of the outdoor air. During the coldest period, the relative humidity of the supply air decreased below 10%, but the relative humidity of the extract airflow was above 30%.

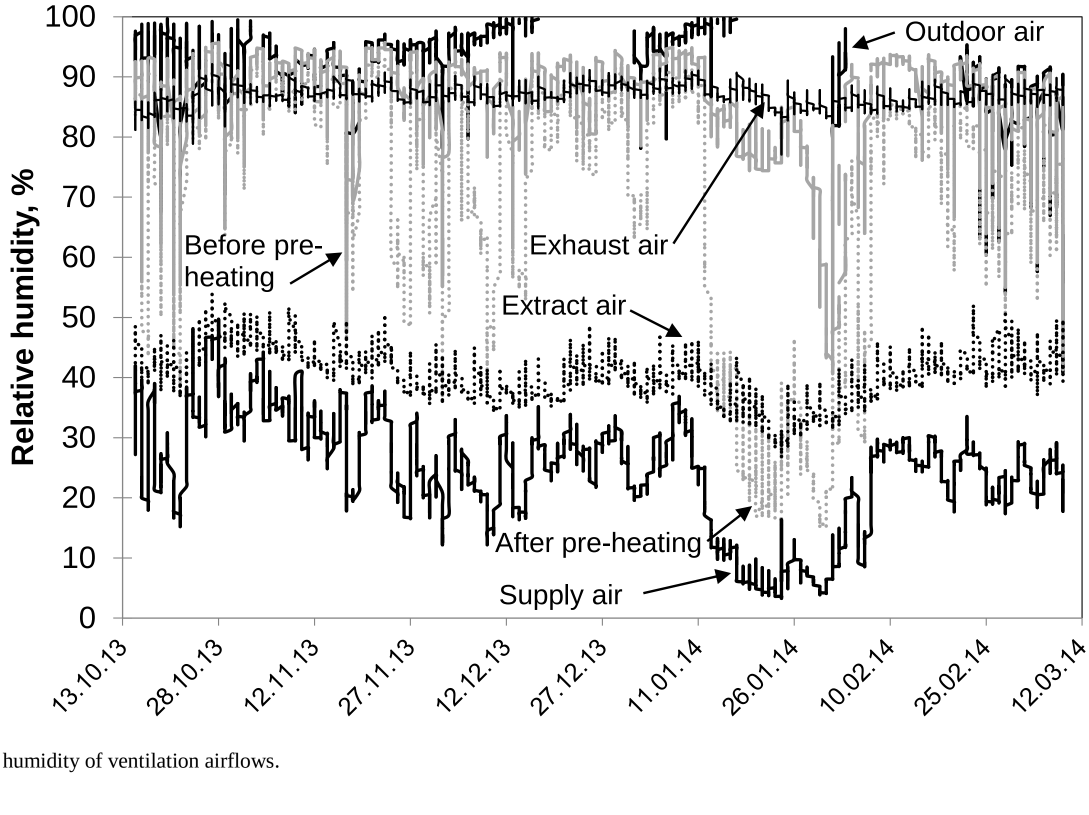

Fig. 7. Relative humidity of ventilation airflows.

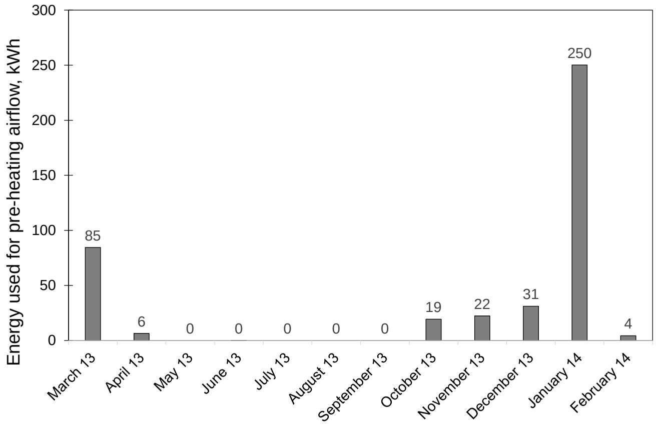

Fig. 8. Energy used for the pre-heating ventilation airflow.

Energy usage measurement for pre-heating the ventilation airflow shows that pre-heating of the outdoor airflow was needed approximately for six months (Fig. 8). Total annual energy usage for pre-heating the ventilation airflow was 418 kWh. The highest monthly energy demand to pre-heat the ventilation airflow was on January 2014. The demand to pre-heat the ventilation airflow in February 2014 was significantly lower, which was the result of higher outdoor air temperature and the building owner's measure at the end of January 2014 to reduce ventilation airflows due to low relative humidity of the supply air. Annual electricity usage of the circulation pump was 43 kWh.

IV. DISCUSSION

Results given in Figures 5 and 6 show that the ventilation airflow pre-heating unit held the air temperature above 0 °C and possible frosting of the ventilation unit heat recovery unit was avoided. Therefore, the efficiency of the ventilation unit heat exchanger was over 80% throughout the measured period. Net energy demand for the frost protection of the ventilation unit would have accounted 3% of the net delivered energy demand of the building when the pre-heating would have been solved with the direct electric heating coil. 3% may not seem significant in terms of net delivered energy demand, but in our ambition to reach the energy requirements of the net zero energy building, the energy consumption for the pre-heating ventilation airflow with the electric heating coil would have increased the primary energy consumption approximately to 10 kWh/(m^2a). In primary energy consumption, a 40% increase is calculated with lower ventilation airflows than designed. The higher airflow rates will increase the primary energy demand significantly. Removal of the defrosting unit from the ventilation system in order to lower energy consumption is potentially a problematic solution, as earlier studies have shown that unless defrosting measures are taken into consideration, plate heat exchangers will end up being blocked by ice and may even get damaged in cold climate [7].

One way to compensate electricity demand for the ventilation unit frost protection with the electrical heating coil is to increase the PV-panels area by approximately 4 m^2. In Estonia maximum nominal power of the PV system connected to the grid for household use is 11.4 kW. Therefore, adding more PV-panels may not be an option. This means that in the context of net zero energy buildings where the overall energy demand is very limited and the size of the on-site renewable energy production system is also limited, the frost protection of ventilation heat exchanger unit cannot be realized with a direct electric heating coil. Alternative systems, such as the ground-source brine heat exchanger, should be used instead.

Economic aspects of different defrosting measures in nearly zero and net zero energy buildings need to be studied further. Future studies should analyze installation costs and maintenance costs of different frosting prevention systems in the nZEB buildings in order to understand better the economic viability of preventing frosting in the ventilation heat recovery unit.

V. CONCLUSION

The performance of the ventilation system with the ground source brine heat exchanger system of the first certified passive house in Estonia was monitored and assessed during the first full heating period after construction. The system performed well, providing frost protection for the mechanical ventilation system without major problems.

Airflow temperature measurements show that outdoor air temperature raised significantly air in the duct before the pre-heating during the coldest period. The pre-heating unit held the airflow temperature constant above 0 °C and the supply air temperature was relatively constant around 21–22 °C during the measurement period. Exhaust air temperature was above 5 °C during the measurement period, meaning that the frosting of the ventilation unit heat exchanger was avoided.

Efficiency of the heat recovery was between 0.78 and 0.96 during the measurement period. Lower outdoor temperatures had no effect on the efficiency of the ventilation heat recovery due to the pre-heating unit that held the ventilation unit intake air temperature over 0 °C. Average efficiency value was 0.84.

Ventilation unit had the plate heat exchanger without humidity recovery. Therefore, humidity of the supply airflow depended on the temperature and humidity of the outdoor air. During the coldest period, the relative humidity of the supply air decreased below 10%. Low relative humidity of the supply airflow reduced the indoor air relative humidity to 30% and the building owner decreased the ventilation airflow in order to avoid further reduction of the relative humidity of the indoor air.

Pre-heating of the outdoor airflow was needed approximately during six months of the year. Total annual energy usage for the pre-heating ventilation airflow was 418 kWh, which accounts for approximately 3% of the net delivered energy demand of the building. Monthly energy demand to pre-heat ventilation airflow was the highest in January when the outdoor temperature was the lowest. In February, the energy demand to pre-heat ventilation airflow was significantly lower as the outdoor air temperature was higher and the building owner reduced ventilation airflows due to the low relative humidity of the supply air.

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