Analysis of Heating Energy of Ventilation and Underground Heat Exchanger in North European Passive Houses

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Abstract-- The paper is taking under consideration the two non-residental passive house buildings built in North Europe in Estonia. The first building is a community center of village Palamuse and the second monitored building is a kindergarten „Kaseke“ in Valga city. Both buildings were planned and designed according to the Austrian passivehouse standard requirements. In current paper energy consumptions of building services systems and thermal indoor climate parameters were measurements. According to these, the building services systems did not work properly and problems occured. Both buildings consumed considerably more energy in reality than indicated in energy simulations accomplished before the actual construction. Also it was discovered that the relative humidity levels in both buildings were considerably lower than recommended in Estonian standards. Besides the risk of condensation for the supply air in underground supply pipes in Nordic conditions was analysed. The analysis showed that there is a considerable risk of condensation in the pipes and the system should we avoided in Nordic conditions.

Keywords**:** Sustainability, Energy efficiency, Passive house, Urban development, dew point.

I. INTRODUCTION

The Passive House concept represents today's highest energy standard with the promise of slashing the heating energy consumption of buildings by an amazing 90%. Widespread application of the Passive House design would have a dramatic impact on energy conservation. Buildings are responsible for 48% of greenhouse gas emissions annually and 76% of all electricity generated in the world [1]. It has been abundantly clear for some time that the Building Sector is a primary contributor of climate-changing pollutants, and the question is asked: How do we best square our building energy needs with those of our environment and of our pocketbook? In the realm of super energy efficiency, the Passive House presents an intriguing option for new and retrofit construction; in residential, commercial, and institutional projects.

A Passive House is a very well-insulated, virtually air-tight building that is primarily heated by passive solar gain and by internal gains from people, electrical equipment, etc. Energy losses are minimized. Any remaining heat demand is provided by an extremely small source. Avoidance of heat gain through shading and window orientation also helps to limit any cooling load, which is similarly minimized. An energy recovery ventilator provides a constant, balanced fresh air supply. The result should be an impressive system that not only saves up to 90% of space heating costs, but also provides a uniquely terrific indoor air quality.

A Passive House is a comprehensive system. "Passive" describes well this system's underlying receptivity and retention capacity. Working with natural resources, free solar energy is captured and applied efficiently, instead of relying predominantly on ‘active’ systems to bring a building to ‘zero’ energy. High performance triple-glazed windows, super-insulation, an airtight building shell, limitation of thermal bridging and balanced energy recovery ventilation make possible extraordinary reductions in energy use and carbon emission.

Today, many in the building sector have applied this concept to design, and build towards a carbon-neutral future. Over the last 10 years more than 15,000 buildings in Europe - from single and multifamily residences, to schools, factories and office buildings - have been designed and built or remodeled to the passive house standard. A great many of these have been extensively monitored by the Passiv Haus Institut in Darmstadt, analyzing and verifying their performance.

II. PASSIVE HOUSE PERFORMANCE CARACTERISTICS

In order to design a passive house following requirements have to be fulfilled:

1. Airtight building shell ≤ 0.6 ACH @ 50 pascal pressure, measured by blower-door test;
2. Annual heat requirement ≤ 15 kWh/m^2/year;
3. Primary Energy ≤ 120 kWh/m^2/year.

In addition, the following are recommendations, varying with climate:

1. Window u-value ≤ 0.8 W/m^2/K;
2. Ventilation system with heat recovery with ≥ 75% efficiency with low electric consumption @ 0.45 Wh/m^3;
3. Thermal Bridge Free Construction ≤ 0.01 W/mK.

The figure 1 below shows the principle of the passive houses.

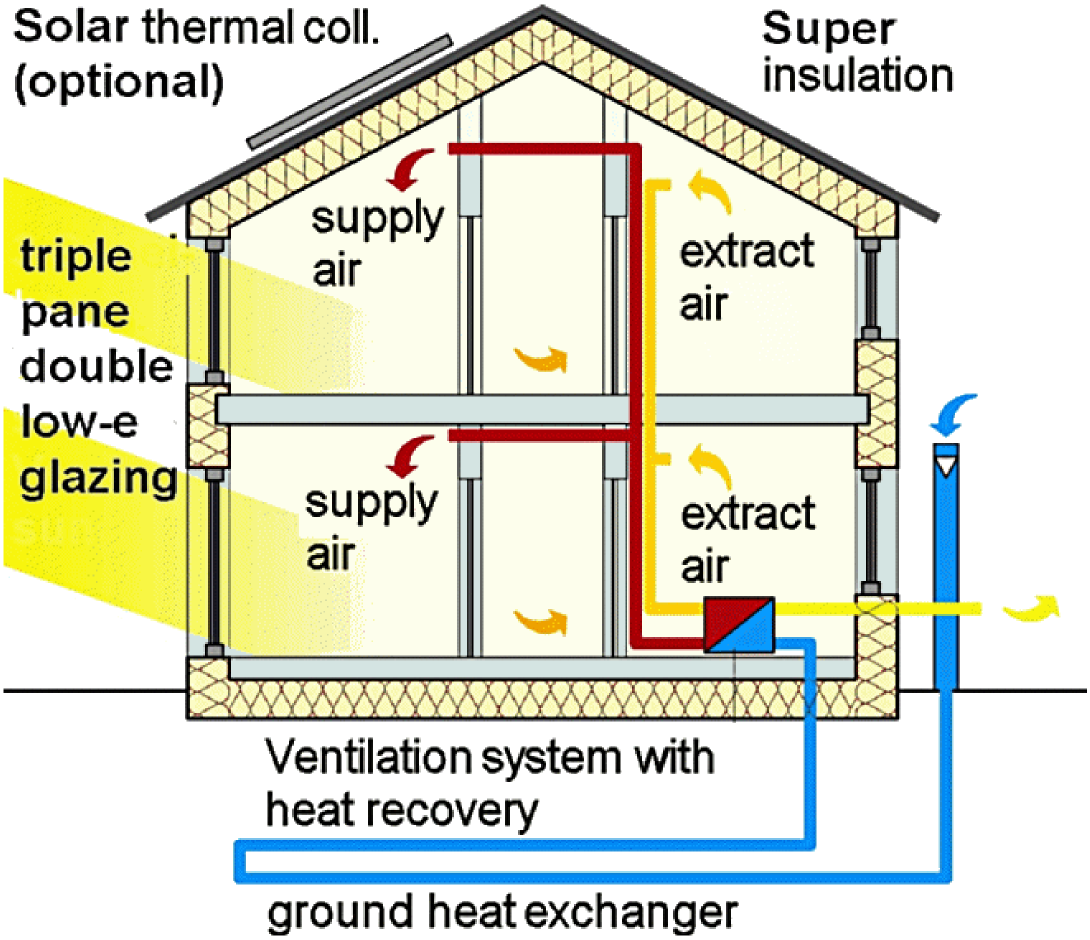

Fig. 1 Passive house scheme

III. THE PASSIVE HOUSE PLANNING PACKAGE (PHPP)

The Passive House Planning Package (PHPP) is a spreadsheet based design calculation tool aimed at architects and designers to assist the design of houses to the Passivhaus standard. This version of the calculation tool is a reduced functionality demonstration version. The PHPP energy balance module has been shown to be able to describe the thermal building characteristics of passive houses surprisingly accurately [2]. This applies particularly to the new technique for calculating the heating load, which was developed specifically for Passive Houses. The spreadsheet has 33 component worksheets that deal with considerations such as: summer climate, u-values, heating, cooling, the details of building areas, thermal bridges, window types, shading, heat loss through the ground, ventilation, electricity demand for both domestic and non-domestic cases, compact hear pumps and boilers [3]. As it is spreadsheet based, designers can use PHPP to evaluate design solutions immediately without the need to wait for dynamic simulations to run. The tool provides a demonstration of the capability of the full PHPP spreadsheet to aid the design of passive houses to the Passivhaus standard.

IV. PALAMUSE COMMUNITY CENTRE

The Palamuse Community centre is a brand new building finished in December 2009 and has been operating since then. The building area is 726,9 m^2 and volume is 1674 m^3. Tabel nr 1 gives information regarding the buildings U-values [4].

Table **1** Palamuse Community centre building design information.

Item	**U-value W/(K*m^2)**
Wall	0,08
Window glass	0,55
Window frames	0,7
Floor on the soil	0,08
Roof	0,06

The calculated heating demand for the building was 12 W/m^2. Picture 1 illustrates the building.

Pic. 1 Palamuse Community centre

V. STAGES OF ENERGY CALCULATION

Energy calculation shall include at least the following stages:

1) calculation of net energy demands, including calculations of net energy demand for heating of rooms, net energy demand for heating ventilation air, net energy demand for heating of domestic water, and net energy demand for cooling of rooms;
2) calculation of summer-time room temperatures;
3) approximate calculation of the heating system on the basis of the efficiency factor of the heat source or the thermal factor of the heat pump system and the electricity consumption of the auxiliary equipment;

VI. KINDERKARTEN KASEKE

The building was originally built in 1966, retrofitted in 2008 and been in operation since 2009. It was the first non-residential passive house project in Estonia. The building area is 1279,8 m^2 and volume is 4208 m^3. Tabel nr 2 gives information regarding the buildings U-values. The calculated heating demand for the building was 11,1 W/m^2. Picture 2 illustrates the building. Upper picture is the picture of south facade and lower picture of North facade.

Table 2 Kasekese kinderkarten design information [5].

Item	**U-value W/(K*m^2)**
Wall	0,1
Window glass	0,7
Window frames	0,76
Floor on the soil	0,13
Roof	0,08

Pic. 2 Kinderkarten Kaseke

VII. RESULTS

Both buildings were monitored during their first year in operation. The monitoring results for heating energy for Palamuse community centre indicated that the yearly heating energy consumption was 38,5 kWh/(y*m^2) that is 56 % more than requirement for the passive house criteria and about 60% more than what the PHPP calculations showed.

The monitoring results for kinderkarten Kaseke revealed that the yearly heating energy consumption was 13 kWh/(y*m^2) whih is a very good result. However the total energy consumption for the building was as high as 166 kWh/(y*m^2) as a result of constantly working ventilation system.

So in total the Palamuse Community centre consumed 92 kWh/m2 energy which can be considered as the lowest energy consuming commercial building in Estonia. The mentioned buildings is one of the fiew A standard buildings in Estonia. The requirements for different energy standards in Estonia are presented in figure 2.

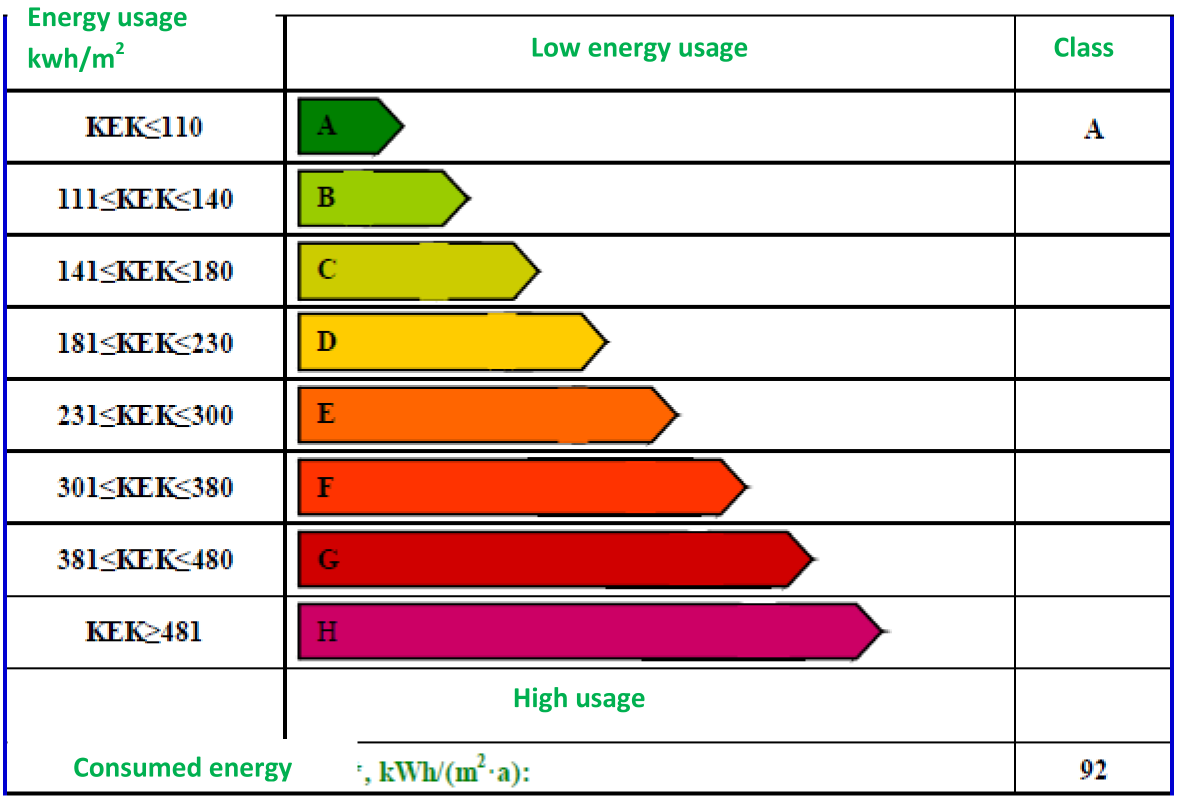

Fig. 2 Total energy consumption and energy class for for Palamuse community centre

Figure 3 indicates the energy class for Kasekese kinderkarten. It should be said here that although the measured energy use for the kinderkarten was 166 kWh/m^2 it would be possible to achieve the energy leval around 120 kWh/m^2 when improving the work of ventilation system.

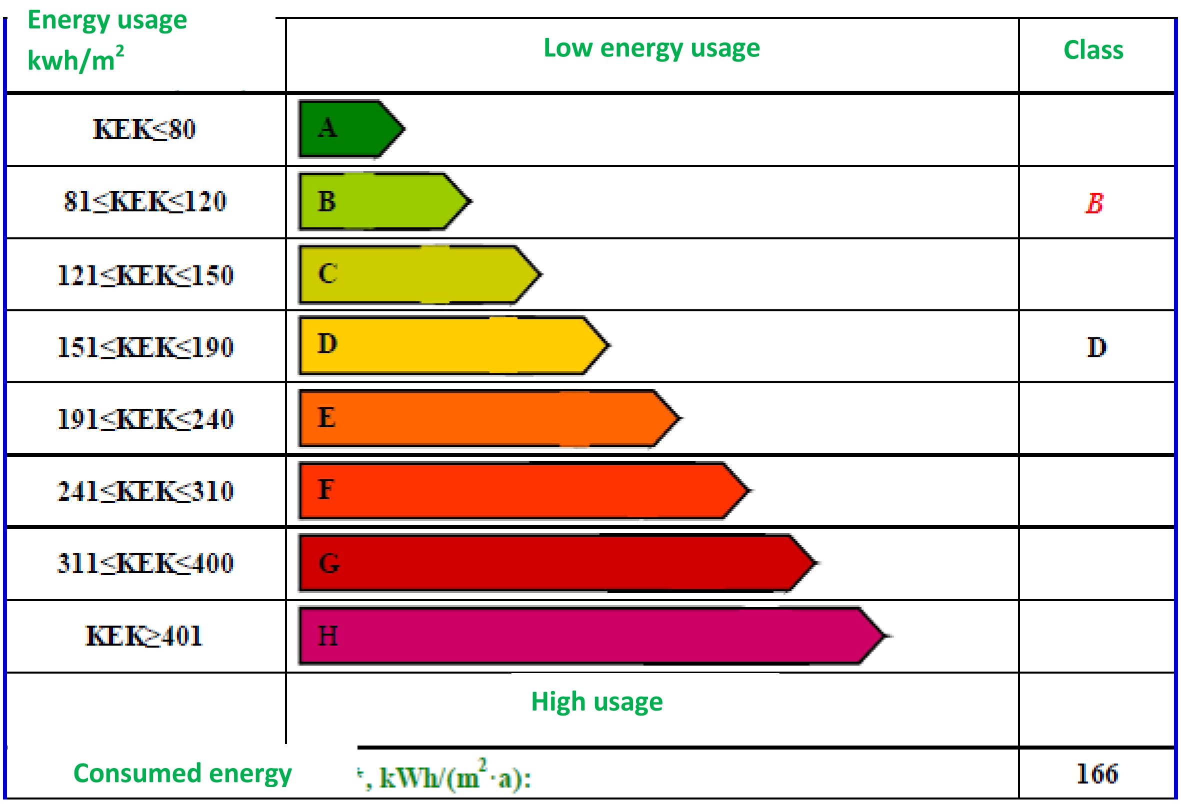

Fig. 3 Total energy consumption and energy class for for Kasekese kinderkarten

Also the thermal indoor climate parameters including indor temperature, CO2 levels and relative humidity was measured. Figure 4 shows the measured indoor temperature at Palamuse community centre and figure 5 at Kasekese kinderkarten. Figure 6 shows CO2 results for Palamuse community centre and figure 7 for Kasekese kinderkarten. It can be concluded that temperature neither the CO2 levels were not a problen neither in Palamuse community centre neither in Kasekese kinderkarten in Valga.

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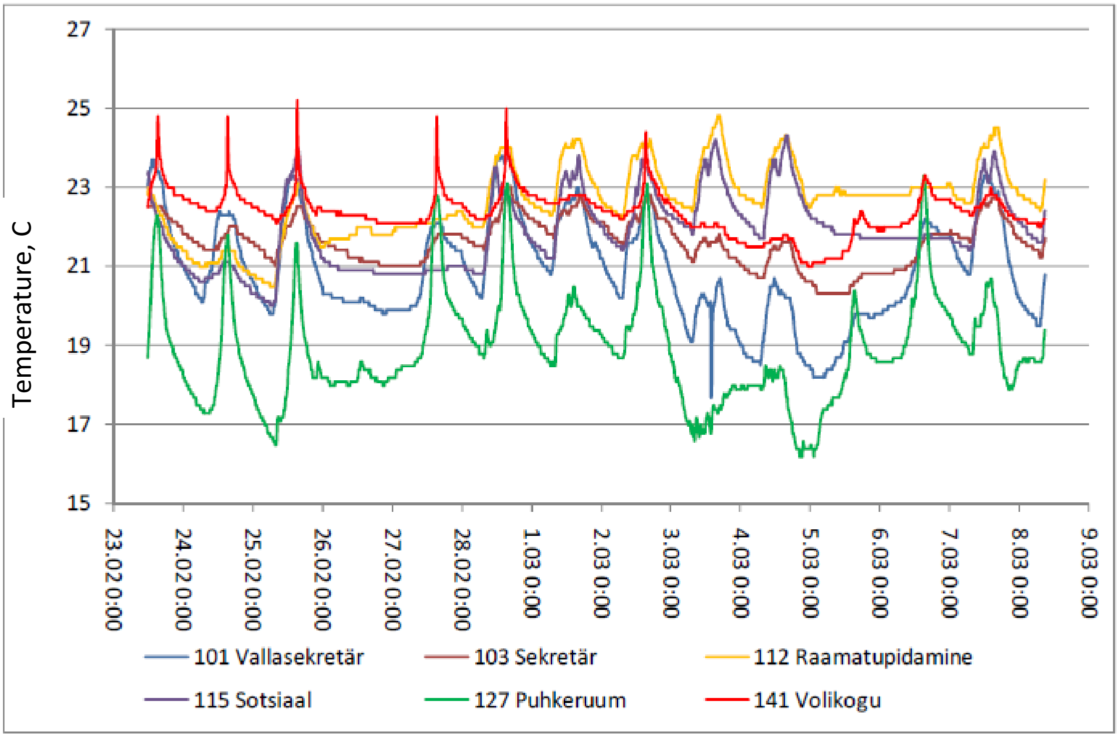

Fig. 4 Measured indoor temperature levels in different rooms in Palamuse community centre

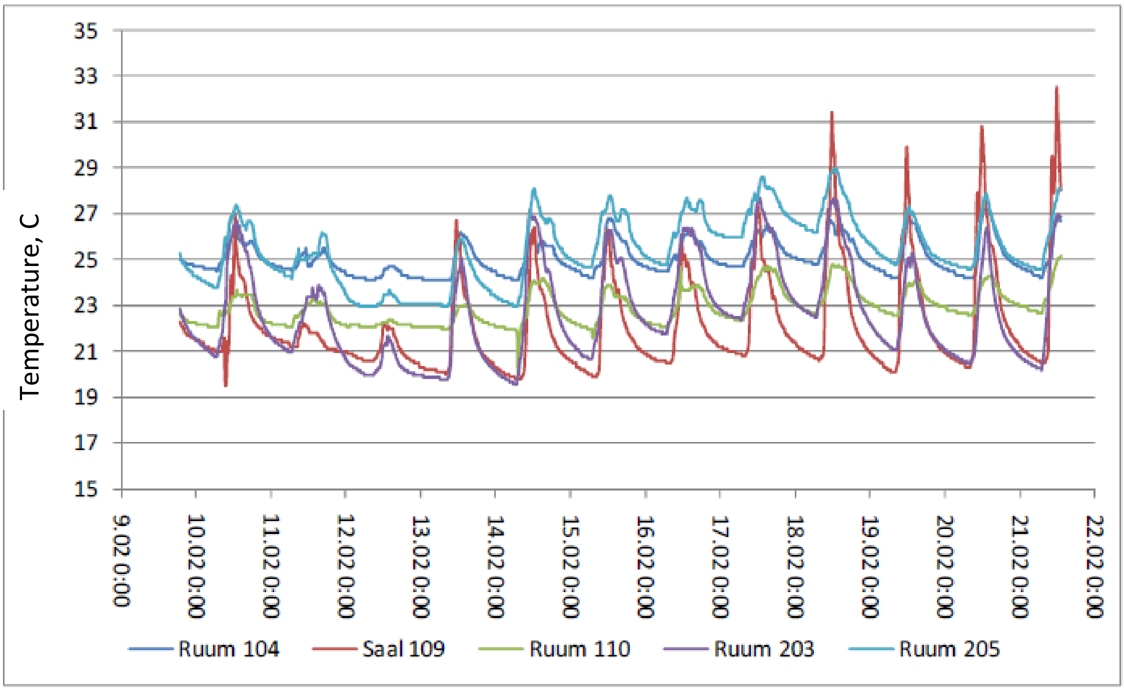

Fig. 5 Measured indoor temperature levels in different rooms in Kasekese kinderkarten

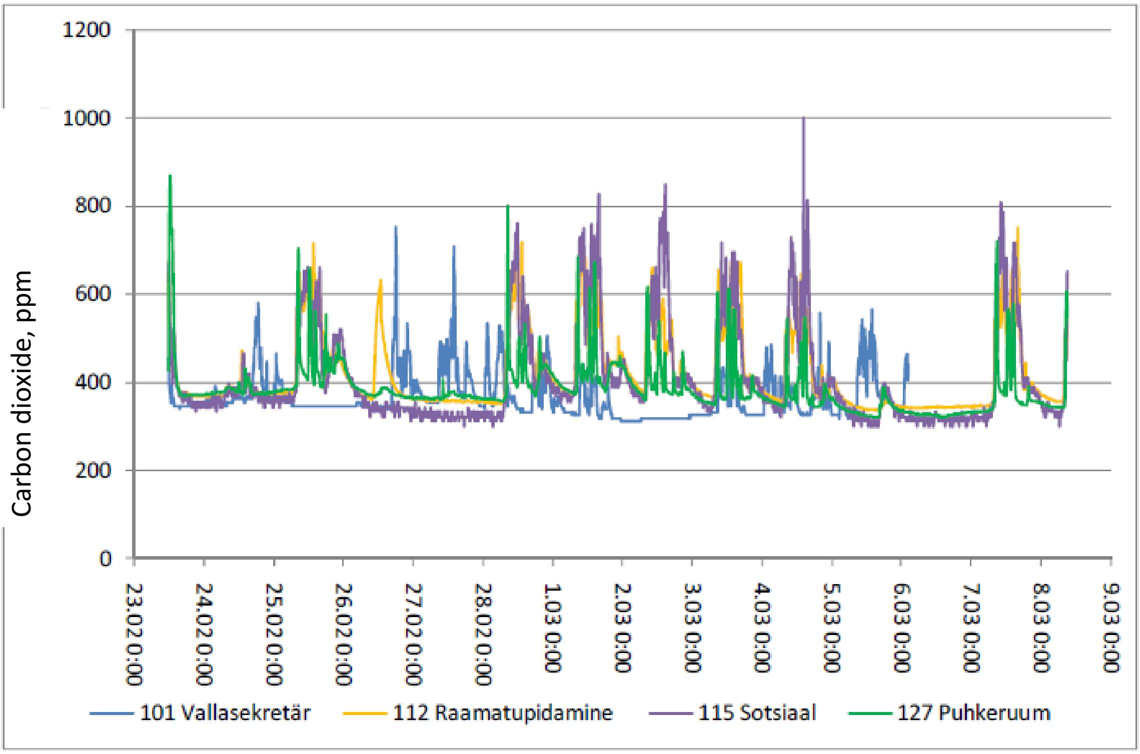

Fig. 6 Measured CO2 levels in different rooms in Palamuse community centre

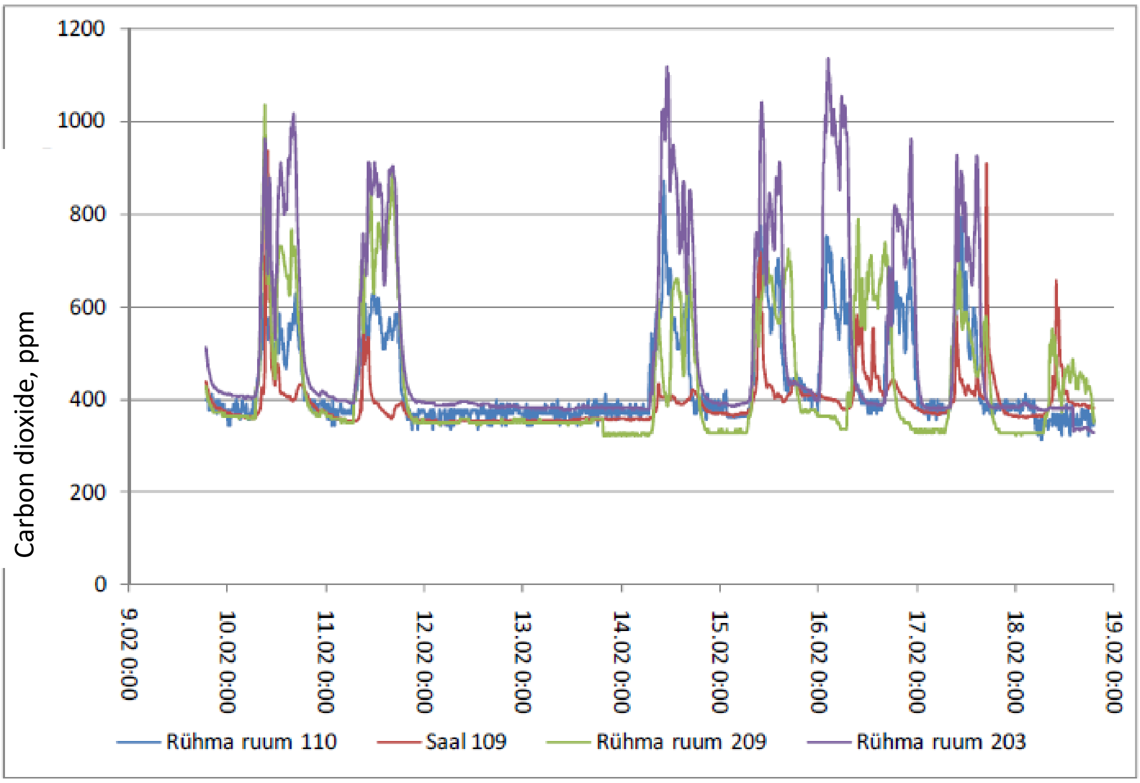

Fig. 7 Measured CO2 levels in different rooms in Kasekese kinderkarten

While the temperature and CO2 levels mainly stayed inside the limits stated in Estonian standards, temperature was in between 21 and 25 °C and CO2 levels did not exceed 1000 ppm there were problems with relative humidity levels.

Figure 8 presents the relative humidity measurement results for Palamuse community centre and figure 9 for Kasekese kinderkarten. In figure 8 and 9 there is relative humidity indicated in y axis and the rooms where the measurements accomplished in x axis. As can be seen from the figures the relative humidity levels were constantly below 30% which is not a good result. Estonian standards indicate that the relative humidity should not be below 30%. However in Palamuse community centre the relative humidity levels were in between 8-27% while in Kasekese kinderkarten in between 7 -32 %.

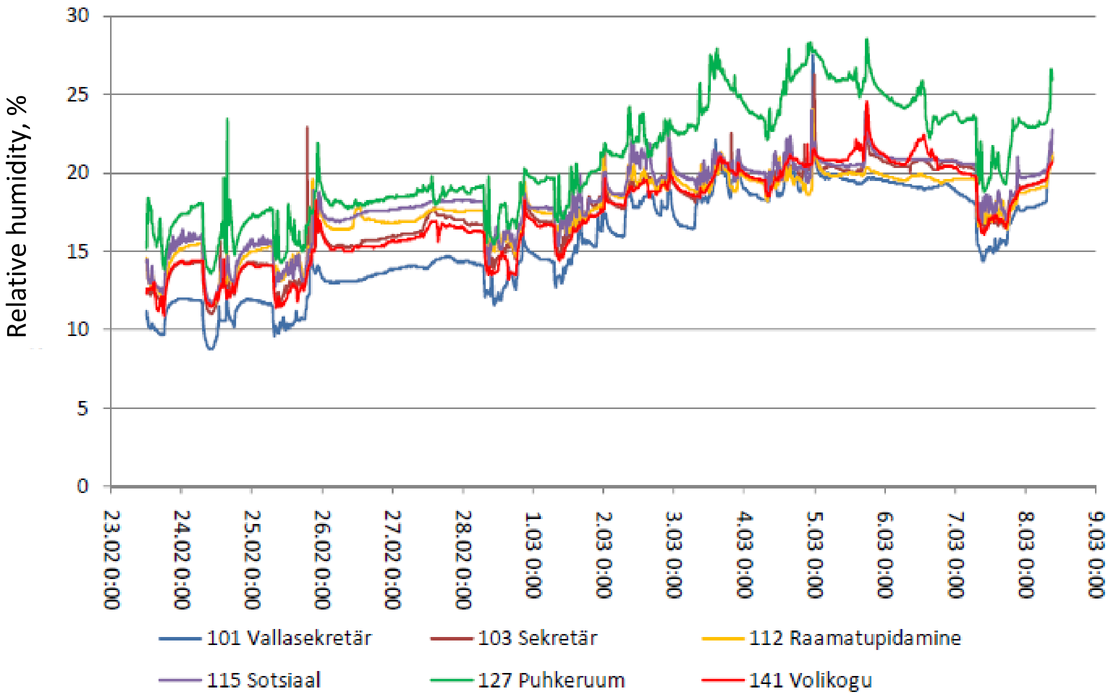

Fig. 8 Relative humidity measurement results for Palamuse community centre

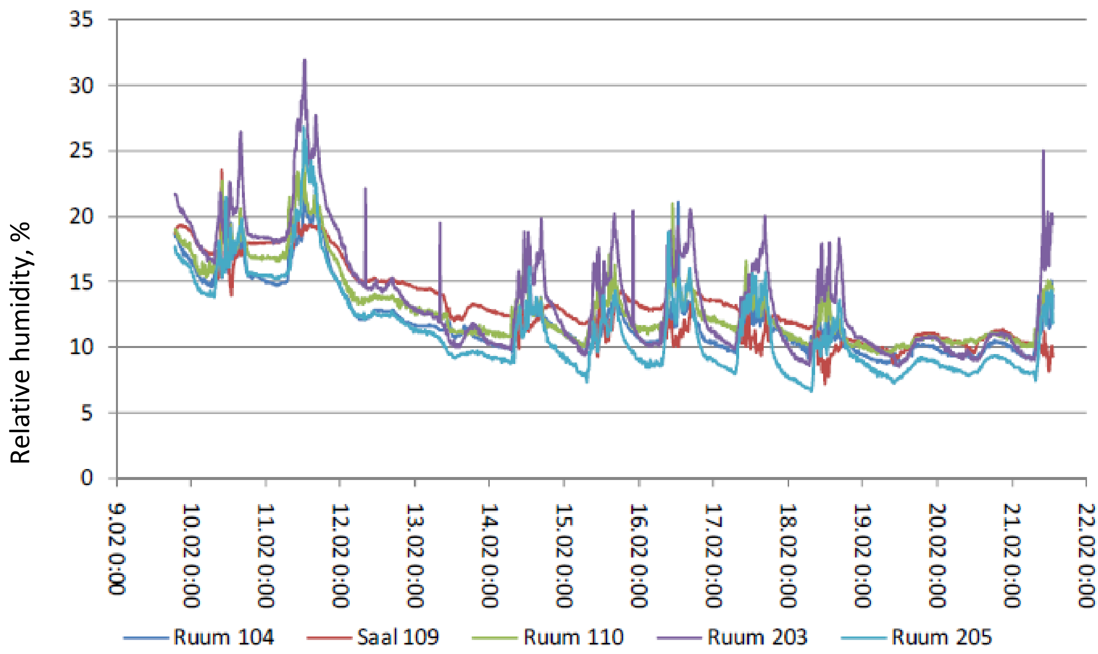

Fig. 9 Relative humidity measurement results for Kaseke kinderkarten

VIII. RISK OF CONDENSATION

A ground-coupled heat exchanger is an underground heat exchanger loop that can capture or dissipate heat from the ground. They use the Earth's near constant subterranean temperature to warm or cool the supply air. Sometimes it is recommended to implement the ground-coupled heat exchangers to passive house concept. The current paper analysed the risk of condensation for the supply air in underground supply pipes in Estonian conditions. Figure 10 illustrates the results. The blue line on the figure responds to the ground temperature or more precicely said the pipes inner surface temperature and the red line for the dew point temperature.

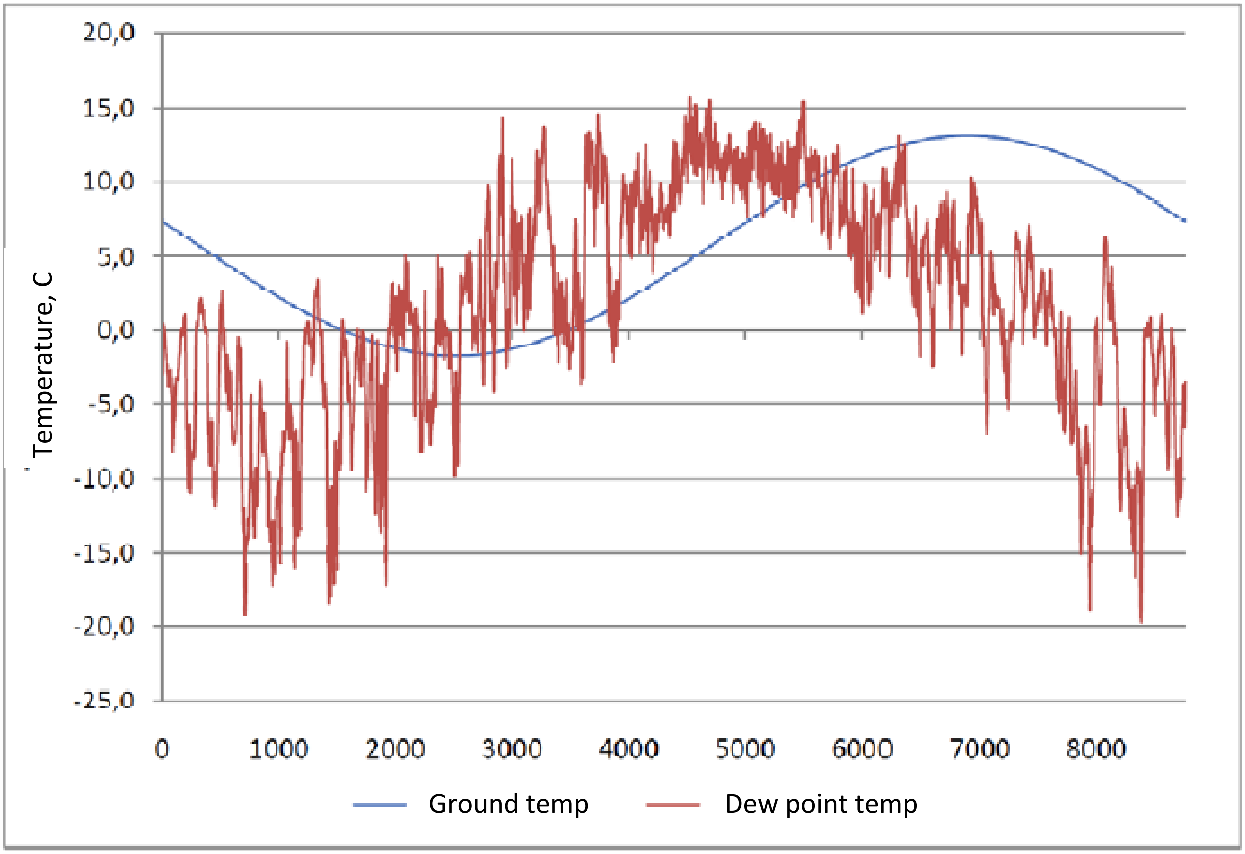

Fig. 10 Dew point temp. in an underground supply pipes

The analysis indicated that in about 2500 – 5500 hours a year there might be a risk of condensation in underground supply pipe. By that the system is not suitable for Nordic conditions like in Estonia.

IX. CONCLUSION

There are totally two non-residental passive house buildings built in Estonia. The first building is a community center of village Palamuse and the second is a kindergarten „Kaseke“ in Valga city. Both buildings were planned and designed according to the passivehouse criteria. In current paper energy consumptions of building services systems and thermal indoor climate parameters were measured. According to these measurements, the Palamuse community centre consumed considerably more heating energy than the calculations accomplished prior the construction had shown. Kasekese kinderkarten at the other hand had problems with ventilation system resulting the total primary energy consumption to be very high. Also serious problems considering low relative humidity levels in both buildings were discovered. In the end the ground-coupled heat exchanger was analyzed in Estonian conditions. It was found that in considerable amount of hours a year there might be a risk of condensation in underground supply pipe. By that the system is not suitable for Nordic conditions like in Estonia.

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