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Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

DTU Civil Engineering
Department of Civil Engineering

BYG R-455
March 2021

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Rapport BYG R-455
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Forsidefoto: Adam Rasmus Jensen
Udgivet af: DTU, Institut for Byggeri og Anlæg, Brovej, Bygning 118, 2800 Kgs. Lyngby
www.byg.dtu.dk
ISBN: 87-7877-557-4 (elektronisk udgave)

Content

1. Introduction

The report describes the monitoring system and the measurements for the PVT-E system installed in the row house in Stengården, Denmark. The system consists of a new roof design with PV and PVT panels connected to a battery and a heat pump.

The system consist of 16 PVT-E modules with a total gross area of 40 m² and 2 PV modules with a total gross area of 5 m² on the south facing roof and 20 PV modules with a total gross area of 50 m² on the north facing roof. The panels are connected to a 7.5 kWh Fronius battery and a modulating Danfoss Varius Pro+ heat pump of 3-12 kW.

Figure 1-1 shows a schematic sketch of the system with the applied measurement equipment. The space heating demand, the domestic hot water consumption, the electricity consumption, the heat and electricity production of the panels, the solar radiation, the outdoor temperature, the indoor climate and system temperatures were measured. In this way, the detailed operation of the system could be followed.

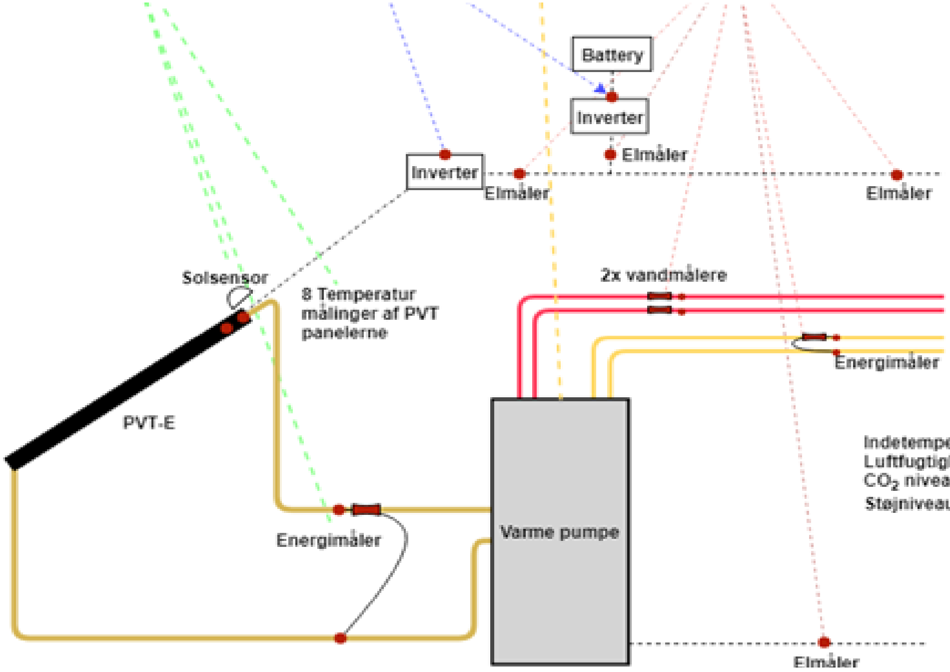

Figure 1-1 Schematic sketch of PVT system with monitoring equipment.

In the following the measurements and observations are presented along with the few adjustments made during the period from December 2019 to August 2019.

2. Outdoor temperature

The outdoor temperature is measured in order to determine the performance. It was detected early on that the temperature measurements from the Danfoss sensors was recording too high temperatures because of influence from the other installations in the shed. An additional sensor was installed with a radiation shield, see Figure 2-1. The pictures also shows an infra-red photo of the shed showing the heat interference from the installations onto the Danfoss sensors.

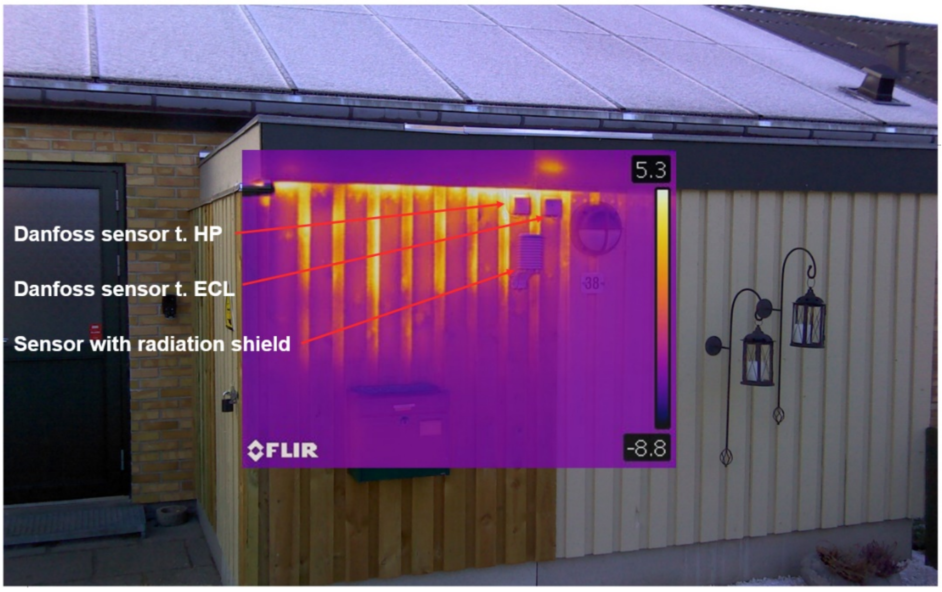

Figure 2-1 Placements of the Danfoss sensors and the new sensor with radiation shield.

The measurements with the sensor with the radiation shield is compared with measurements from DTU in Kgs. Lyngby in order to validate the measurements. The comparison can be seen on Figure 2-3, where a good correlation is obtained.

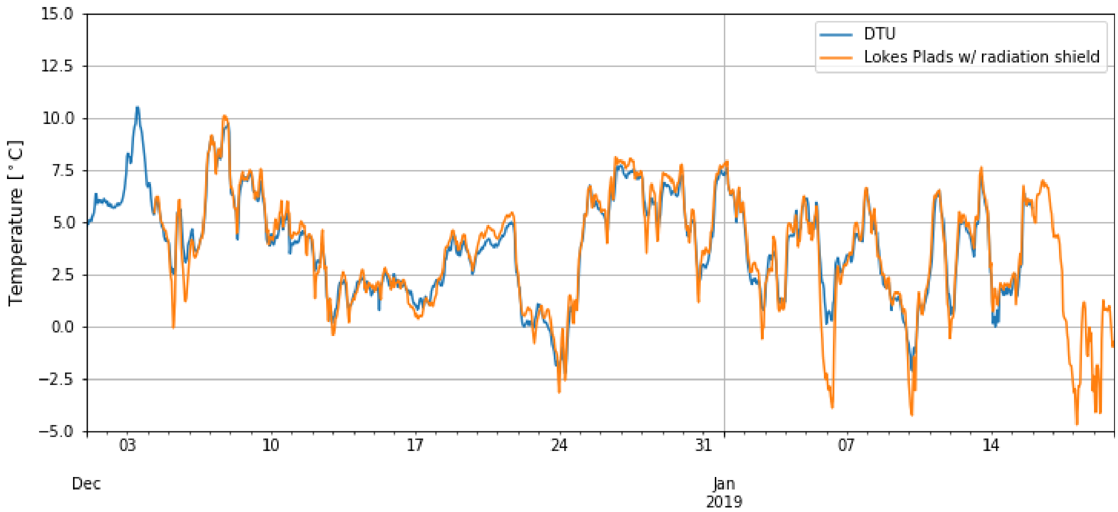

Figure 2-2 Comparison between outdoor temperature measurements in Stengården and DTU Kgs. Lyngby.

The outdoor temperature measured during the whole measuring period can be seen on Figure 2-4 with increasing temperatures in the summer period.

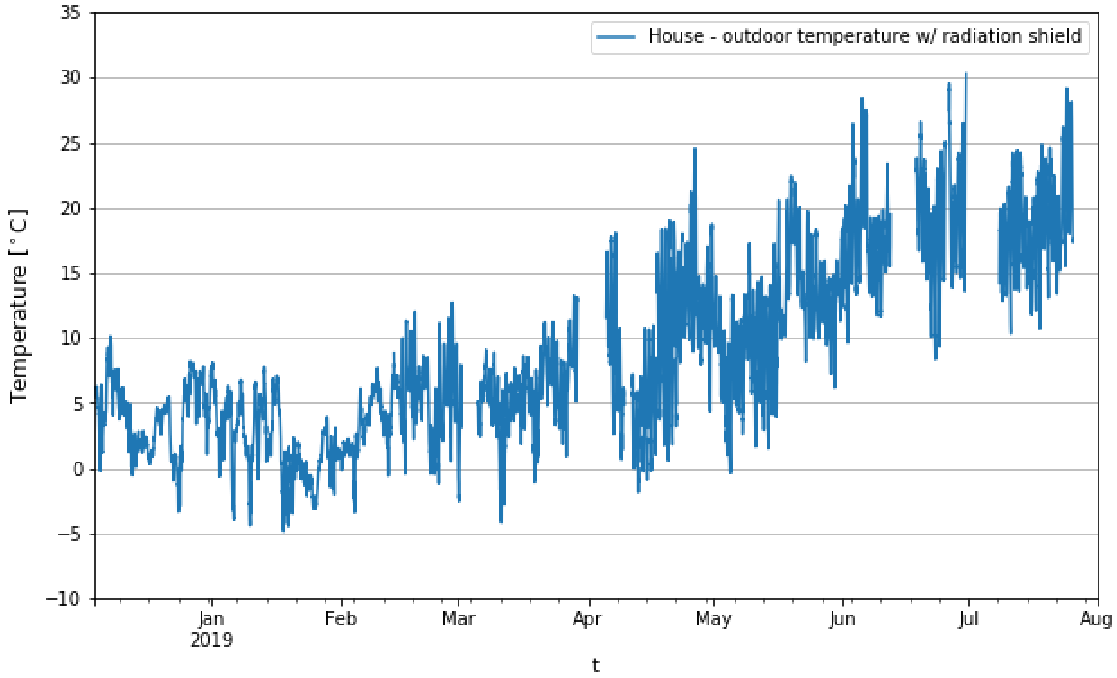

Figure 2-3 Outdoor temperature during the measuring period.

3. Energy use

The energy use presented here is the space heating and domestic hot water consumption in the house in Stengården.

3.1 Space heating

The inlet and outlet temperatures for space heating system, the indoor temperature, the outdoor temperature and the heat consumption can be seen on Figure 3-1. It is seen that the space heating demand is very low compared to the size of the heat pump. The highest space heat demand is lower than 2 kW, while the lowest power of the heat pump is 3 kW. The heat pump is therefore strongly oversized resulting in very short operation periods and relatively low efficiency of the heat pump. In this connection it should be noted, that no small heat pumps suitable for the low space heating demand were available on the market at the start of the project.

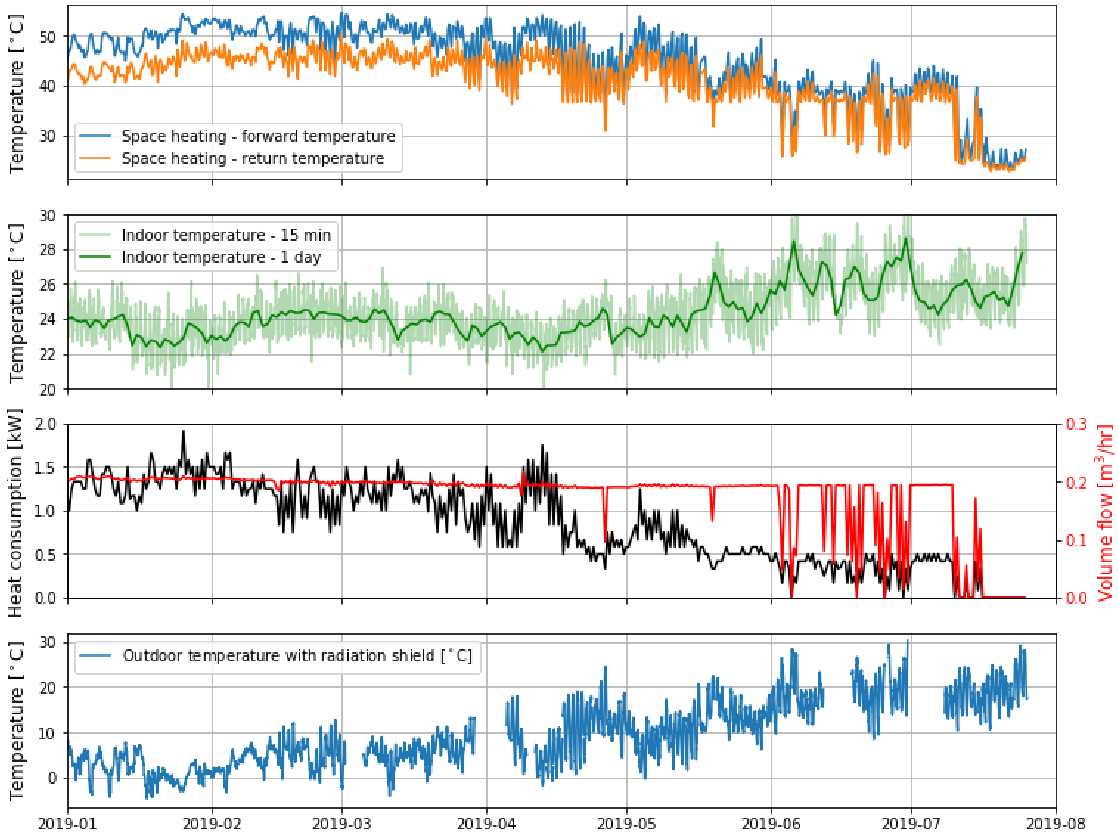

Figure 3-1 Temperatures and energy for space heating in the house in Stengården.

The daily heating demand in the house is dependent of the mean daily outdoor temperature, as it is seen on Figure 3-2.

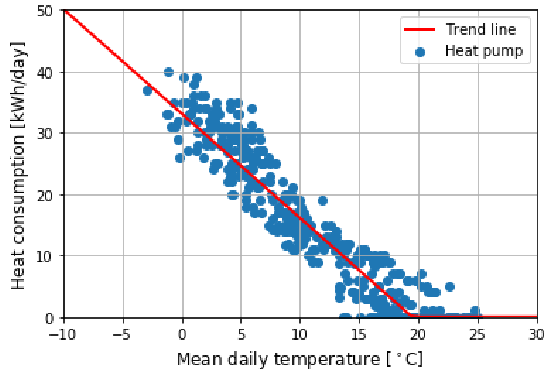

Figure 3-2 Daily heating consumption as a function of the mean daily outdoor temperature.

3.2 Domestic hot water

The directly measured temperatures for the hot and cold domestic water during hot water draw offs are shown on Figure 3-3. The cold water inlet temperature is fluctuating, since the measurement due to inertia of the temperature sensor is not accurate in the very start of hot water draw offs. Therefore, the measured cold water temperature is corrected, see the green curve on Figure 3-3. It is obvious that the cold water temperature vary through the year with a minimum of about 7°C in March and a maximum of about 19°C in August. The hot water temperature is also fluctuating during hot water draw offs due to sensor inertia. Therefore, the hot water temperature is assumed constant at 58°C

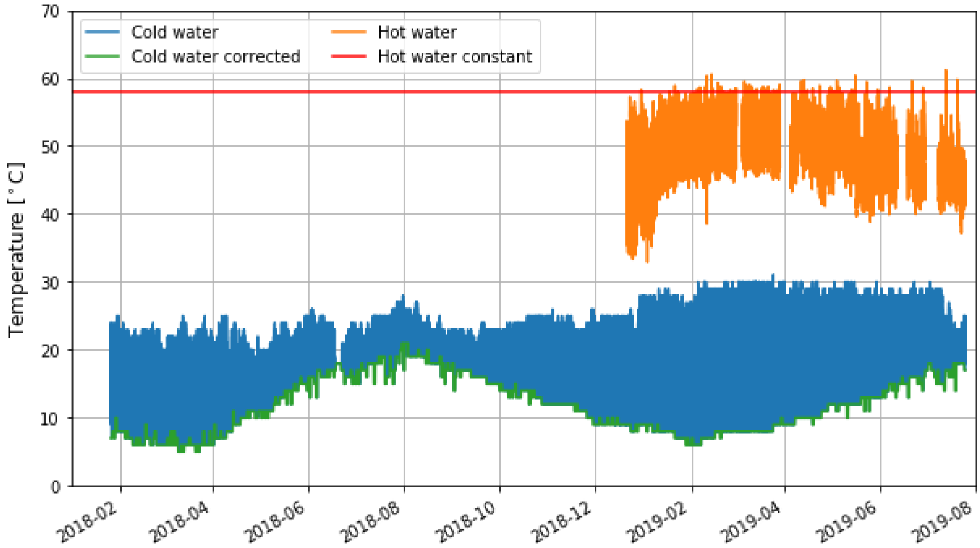

Figure 3-3 Temperature measurements of the cold and hot water in the house in Stengården.

The daily hot water consumption for the house in Stengården is in average around 100 Liter, see Figure 3-4 left, which matches the assumed hot water consumption for an average family in Denmark. The Hot water consumption shown in kWh is seen on Figure 3-4 right.

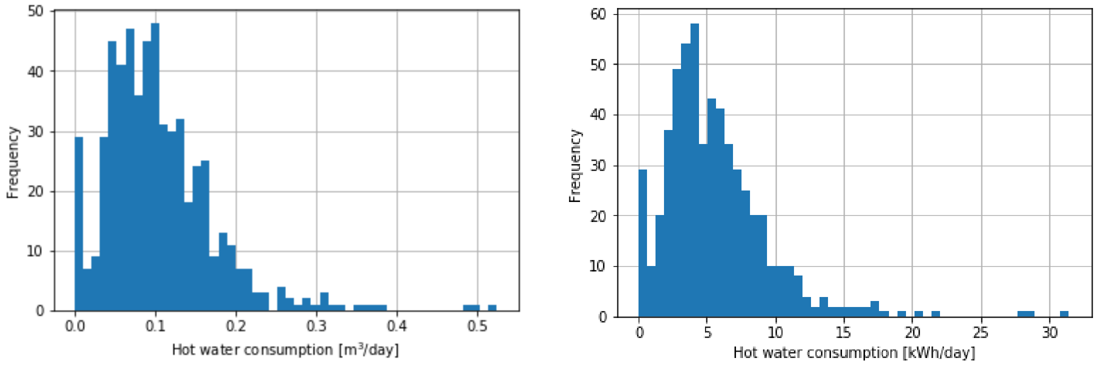

Figure 3-4 Daily hot water consumption for the house in Stengården.

3.3 Summary energy use

The daily energy space heating demand and domestic hot water consumption are shown together on Figure 3-5, and the monthly space heating demand and domestic hot water consumption are shown on figure 3-6. As expected is the energy use for space heating dependent on the season. It is also noticed, that the hot water consumption is higher in winter than in summer.

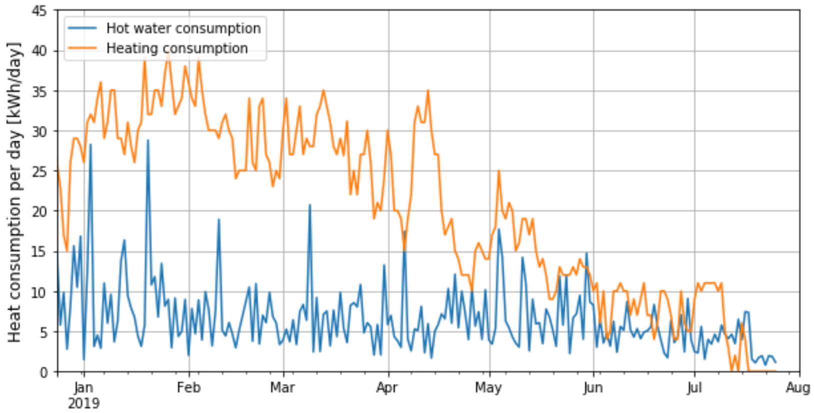

Figure 3-5 The daily energy use for space heating and domestic hot water.

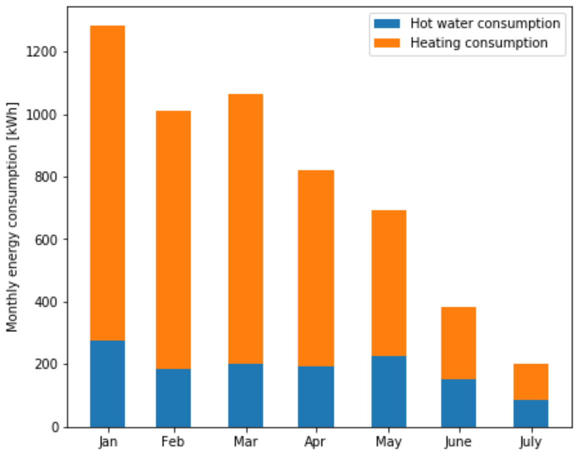

Figure 3-6 The monthly energy use for space heating and domestic hot water.

4. Indoor temperature

The indoor temperature in the measuring period is between 22-25 °C which can be seen on Figure 4-1 where the frequency of the measured indoor temperature is given. The indoor temperature is always higher than 20°C.

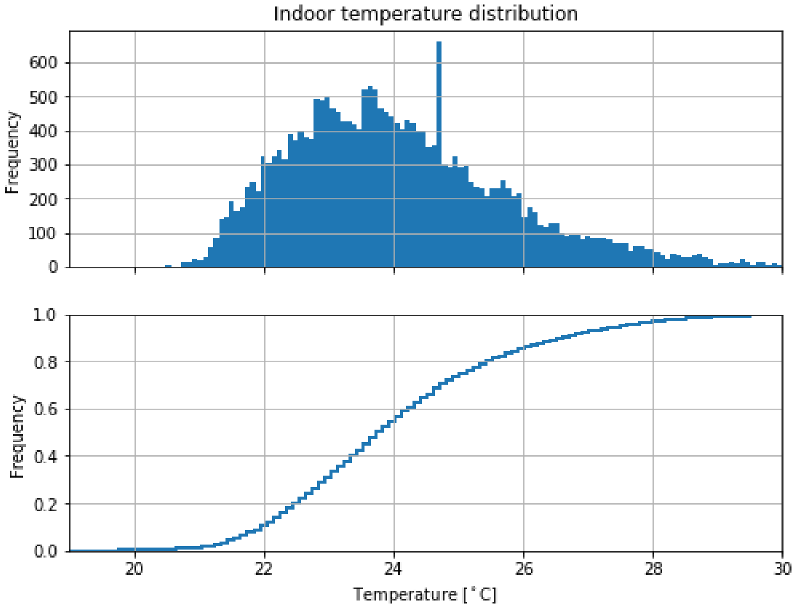

Figure 4-1 The indoor temperature in the house during the measuring period.

The indoor humidity is given on Figure 4-2, and the measurements are collected in the kitchen/living room of the house. The humidity is between 44-47 %, which is within the recommended values for the indoor climate in a family house.

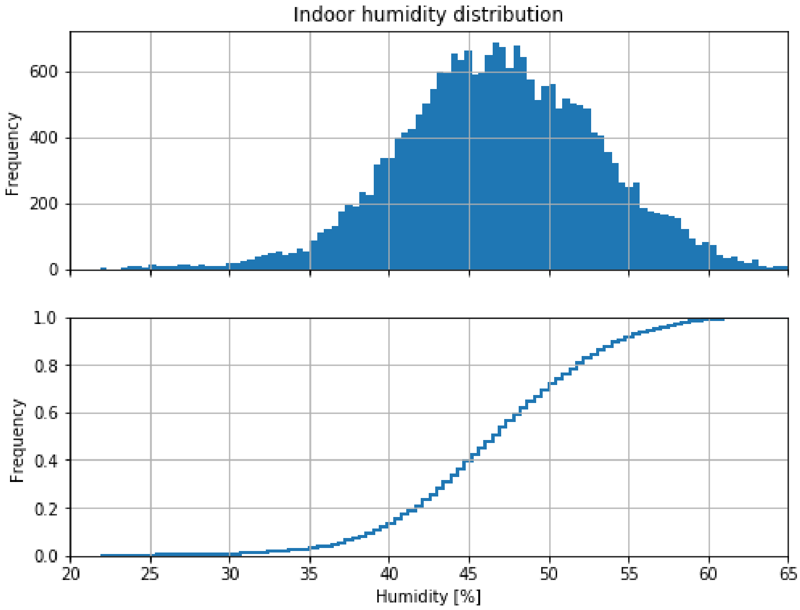

Figure 4-2 The indoor humidity in the house during the measuring period.

The indoor CO2 concentration is given on Figure 4-3, and the measurements are collected in the kitchen/living room of the house. The threshold value is for the CO_2 is 1000 ppm. The figure shows that 20 % of the time the CO_2 concentration is above the recommended value.

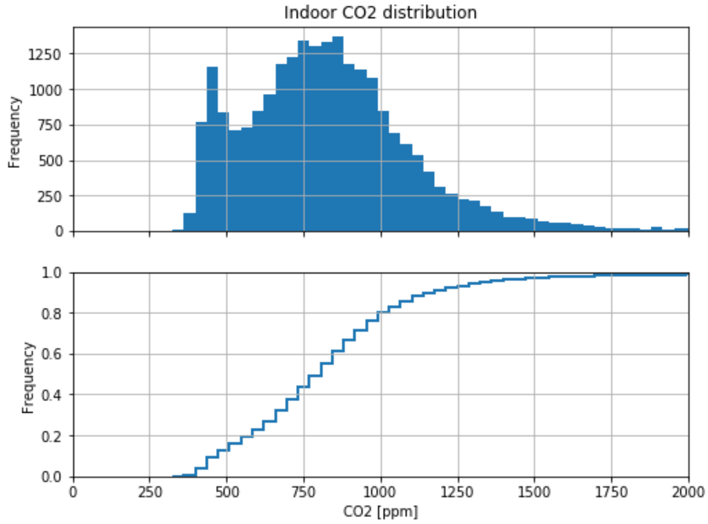

Figure 4-3 The indoor CO_2 concentration in the house during the measuring period.

5. HP electricity use vs. outdoor temperature

The daily electricity consumption of the heat pump as a function of the daily mean outdoor temperature is seen on Figure 5-1. As expected the electricity use of the heat pump is increasing as the outdoor temperature decreases and the need for space heating is increasing.

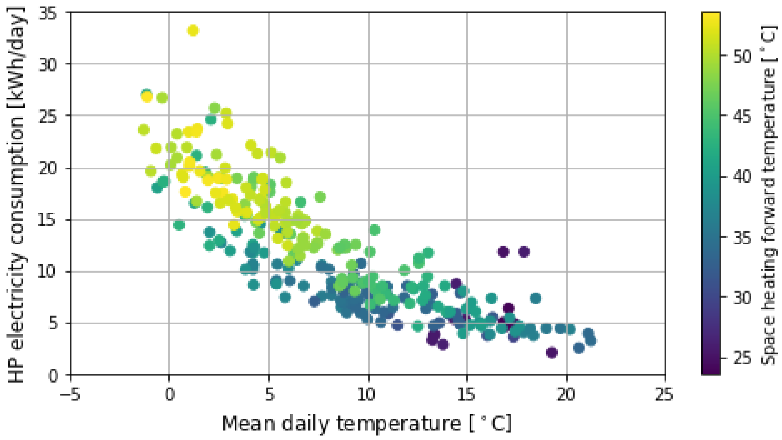

Figure 5-1 Daily electricity use of the heat pump.

6. COP heat pump

The COP for the heat pump as a function of the outdoor temperature is seen on Figure 6-1. The figure shows measured and corrected daily COP values of the heat pump. The measured values are the ratios between the sum of the space heating demand and the domestic hot water consumption and the electricity consumption of the heat pump. The corrected values are determined by including an estimated heat loss from the shed in which the heat pump is located.

The COP values are not especially high, both due to the fact that the heat pump is oversized and due to the high heat losses of the heat pump, the pipes and the tanks. In spite of these points, it is however estimated, that the efficiency of the heat pump is reasonable.

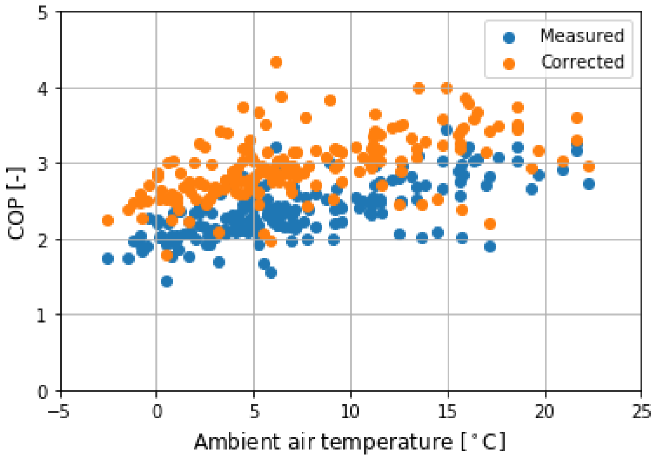

Figure 6-1 The COP for the heat pump as a function of the outdoor temperature.

A few times during the winter and spring the heat pump is automatically turned off due to too low heat transfer fluid temperatures in the PVT loop. This happens approximately at an inlet fluid temperature to the PVT modules of about -10°C. It happens in cold periods with low wind velocities and no clouds on the sky, so that the heat loss from the PVT panels is high. It is recommended to check if the control system can be adjusted to prevent these turn offs. The oversized heat pump results in a higher cooling rate of the PVT panels than the cooling rate for a well sized heat pump. Consequently, the oversized heat pump has contributed to the problem. It is estimated, that these operation problems only have a small influence on the yearly efficiency of the system.

7. PVT brine temperature

The forward temperature from the heat pump to the PVT modules and the return temperature from the PVT panels are shown on Figure 7-1. The temperatures are higher in the summer than in the winter. The measurements were resampled over ten hour periods.

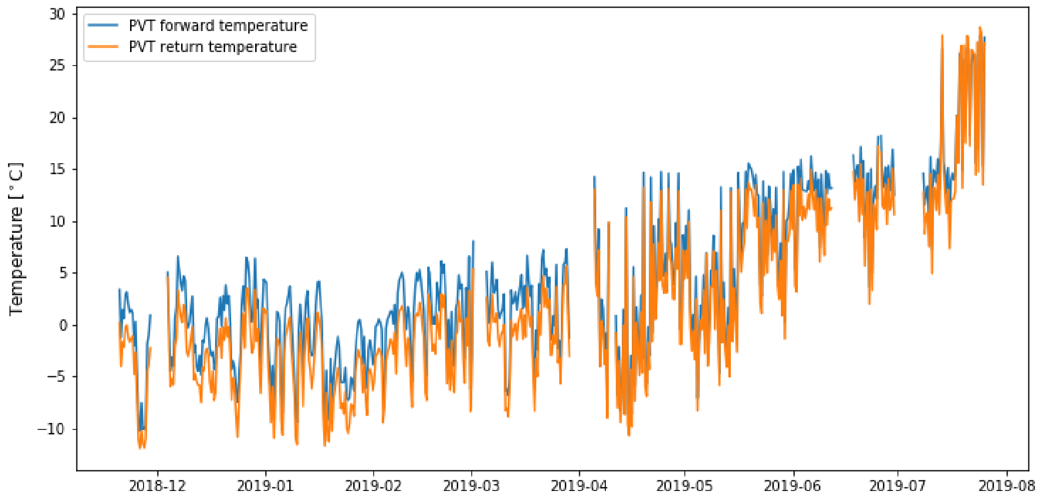

Figure 7-1 The forward and return temperature to the PVT panels.

Figure 7-2 shows return fluid temperatures from the PVT modules as functions of the forward fluid temperature to the PVT modules and as function of the outdoor air temperature. The difference between return temperature from the PVT panel and the ambient air temperature is especially influenced by the solar irradiance and the wind velocity. The return temperature can be cooled down to about 10 K below ambient temperature

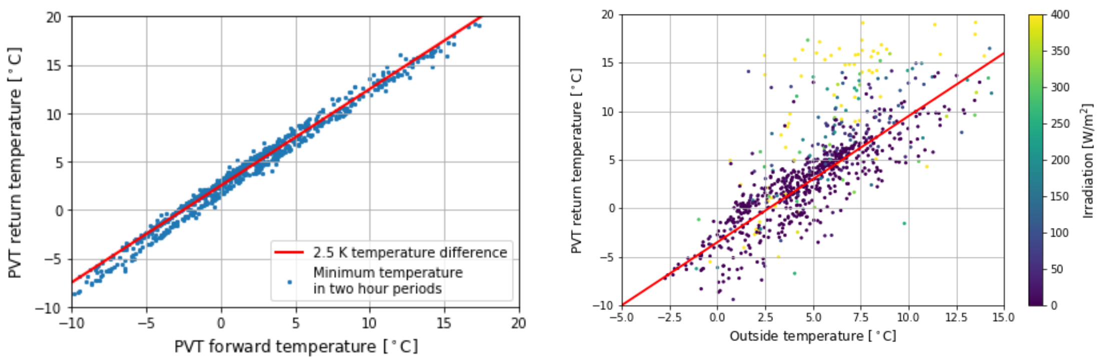

Figure 7-2 PVT return temperature as a function of the forward temperature and of the ambient temperature.

8. Summary

The PVT system worked as planned with a COP value of 3 in the measuring period. The COP value is not especially high, both due to the fact that the heat pump is oversized and due to high heat losses of the heat pump, the pipes and the tanks placed in the shed. It is judged, that the system principle is good, and that a PVT system will be an attractive solution if the heat pump and PVT panels are well sized and the heat pump, pipes and tanks are well insulated.

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BYG R-455
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ISBN: 87-7877-557-4

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