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Evaluation of Two Heat Pump Systems in Nearly Zero Energy Buildings (nZEB)

Ola, Gustafsson M.Sc. [a]*, Caroline Haglund Stignor Ph.D.[a], Helena Nakos Lantz M.Sc.[a]

[a]SP Technical Research Institute of Sweden, Borås SE-501 15, Sweden

Abstract

The compulsory energy labelling for heat pumps within the European Union will have a large influence on the design of heat pump systems. In the future, most buildings will be nearly Zero Energy Buildings (nZEBs). Due to these reasons we should learn more about real operation conditions for heat pumps in nZEBs and how well these are reflected by the performance data for the labelling, in order to be able to influence a revision of the regulations if so needed.

In this study, operation parameters such as flow temperature (heating water) and brine temperature were analyzed in real operation in two different nZEBs. Factors that were studied were compressor control technology (on/off or inverter), performance of an extra storage tank for the heating system and choice of distribution system.

The results show that the flow temperature was higher than what is described in the standard harmonized with the labelling regulation (EN14825) for a low temperature application. However, the brine temperatures were often considerably higher than the test conditions described in EN14825. The conclusion is that more similar test data from heat pumps in nZEBs are needed when the regulation is to be revised five year after publication in order to secure that heat pumps optimized for the label also are optimized for real operation in a nZEB. Another finding was that in order to reach the highest overall energy performance the heat pump and the heating system must be optimized together and not separately, which often is the case today.

Keywords: heat pump; nZEB; on/off; inverter; efficiency; energy labelling; standardization

1. Introduction

1.1. Background

The updated Energy Performance of Buildings Directive, 2010/31/EU (EPBD2) requires very low energy consumption in all newly or re-constructed buildings from year 2021 and onward. Across Europe there are a number of Nearly Zero Energy Buildings (nZEB) that meet the requirements of the EPBD2, but the concept is still in the pilot or demonstration stage according to Wemhöner and Kluser [1]. Previous research has shown that heat pumps are an attractive solution for these buildings seen from energy point of view. Also, in these houses heat pumps are often used because of the flexibility they offer - they allow for greater freedom in designing the

* Corresponding author. Tel.: +46-10-516-5120; fax: +46-33-19-1979.
E-mail address: ola.gustafsson@sp.se.

building envelope and they can provide both room heating/cooling and domestic water heating simultaneously [2,3]. Moreover, heat pumps can be effectively linked to various heat sources and sinks and they can provide load balancing in a future smart grid. However, one conclusion from the same studies was that there are no commercially available products that are of the right capacity or that are cost compatible.

It was shown that a liquid / water heat pump was the most efficient heating option from both an energy and cost perspective in a nZEB [2]. Since the total heating demand in the nZEB is small, the cost of the heat pump system is limited for the system to have a competitive LCC. A heat pump system in combination with some form of heat storage is also an attractive alternative in future smart energy systems where intermittent renewable energy sources (e.g. wind and solar) are becoming more common. Therefore it is very important to increase the knowledge of how the heat pump's operating parameters (e.g. flow temperature, brine temperature, efficiency etc.) in actual operation in a nZEB are affected by speed control, combined with the storage tank, the choice of heating system etc. This experience is then used to compare these operating conditions with the theoretical assumption made when calculating the efficiency of which is the basis for the (European) Ecodesign and Energy Labeling requirements for this type of heat pumps [4, 5]. This knowledge is important at the time when these rules are revised about 5 years after publication, as it is of the highest importance that the heat pumps that get the best energy labeling are also those that lead to maximum energy savings for the user and the society.

1.2. Scope

The scope of this study was to:

- increase the knowledge of how different operation parameters are affected by an inverter-controlled system, compared with an on-off system, the different types of distribution system, to thereby provide data on how well the energy label correspond to reality
- increase the knowledge of how the interconnection of a tank affect the operating parameters of a heat pump system, in order to obtain data for guiding how heat pump systems can be developed for future smart grids and use of electricity produced on-site

2. Method

This study is based on evaluation of two different heat pump systems in two almost identical nZEBs in Sweden. One of the heat pump systems consist of an on/off controlled heat pump with an extra storage tank and the other nZEB has a heating system with an inverter controlled heat pump. More information about the houses and their heating systems is found in Table 1.

Operation parameters such as flow temperatures, brine temperature were analyzed in real operation in the two different nZEBs. The results from the different systems were compared to see if the temperatures in a system with an inverter controlled heat pump is favorable compared to the temperatures in a system with an on/off controlled heat pump. The comparison also contributes to increased knowledge about how the brine temperature is affected by on/off versus continuous operation. For the heating system with the on/off heat pump the flow temperature to the tank was also compared to the flow temperature out to the floor heating system to evaluate the efficiency impact of an extra storage tank.

The evaluation done in this study is based on measurements performed from the summer 2015 to the summer 2016. The relevant measurement equipment is shown in Figure 1 including schematic representation of placement of flow meters and temperature sensors. The temperature sensors used are PT100 sensors with a total measurements uncertainty of ±0.5K. This study present data evaluated over the complete measurement period but also present some examples of specific time events (from hours to days) to show upon cases where the differences of the systems becomes clear.

Table 1. Technical information about the two different nZEBs and their heating systems evaluated in this study.

		
Size	▪ 166 m², 22 kWh/m²/yr (space heating and DHW)	▪ 166 m², 20 kWh/m²/yr (space heating and DHW)
Ventilation	▪ Balanced ventilation system with heat recovery	▪ Balanced ventilation system with heat recovery
Heating source	▪ Ground source heat pump (4.5 kW, on/off controlled) ▪ Storage tank 150l. ▪ Borehole 90 m (81m active) ▪ Dimensioning temperature: 0°C	▪ Ground source heat pump (6 kW, inverter controlled) ▪ Borehole 90 m (71m active) ▪ Dimensioning temperature: 0°C
Heating system	▪ Floor heating both floors ▪ Dimension temperature: 36°C at dimensioning outdoor winter temperature	▪ Low temperature radiators, upper floor ▪ Floor heating, 1st floor
Solar	▪ PV-panels 3000 kWh/yr	▪ PV-panels 3000 kWh/yr
Habitants	▪ Simulated family	▪ Real family

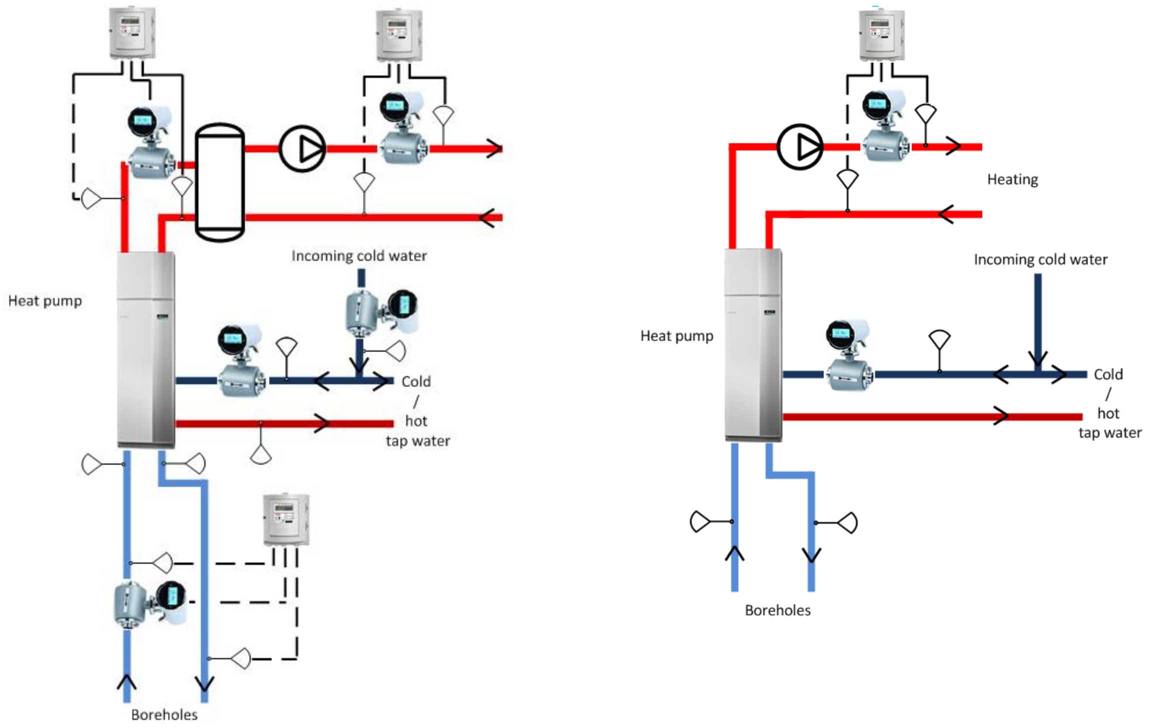

Figure 1. Schematics of the measurement equipment in the two heating systems. To the left the system with an on/off heat pump and an extra storage tank is shown. On rhe right the system with the inverter controlled heat pump is shown.

3. Results

3.1. Heating system temperatures

The forward and return flow temperatures are evaluated in the two heating systems. Figure 2 and Figure 3 show these temperatures at a two hour period at an outdoor air temperature of 2°C. The reason why these particular occasions are chosen is to be able to compare with the 2°C condition in part load according to the standard EN 14825 [6]. Since both nZEBs that are evaluated in this study are located in Sweden only the "Cold Climate" is used as a reference. The on/off heating system is installed in a house with floor heating on both floors. Hence, the "low temperature application" is relevant for comparison. In Figure 2 it can be see that the forward flow temperature reaches 34°C just before the heat pump switches off. The temperature given in EN 14825 for a low temperature application is 27°C. Also the measured return temperature is considerably higher than the temperature in EN14825.

Figure 3 shows that the forward and return flow temperature in the inverter controlled heating system which is installed in a house where both floor heating and low temperature radiators are installed. Due to the radiators, the medium temperature application (as prescribed in EN14825) should be used as a reference. However, the forward flow temperature is right in between the medium and low temperature application level for the 2°C condition, 37°C and 27°C respectively.

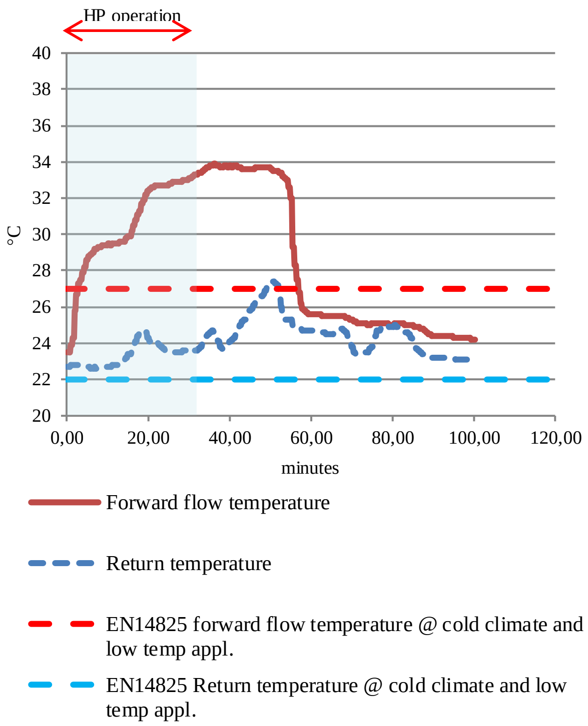

Figure 2. Forward and return flow temperature for the "on/off" heating system at an occasion when the outdoor temperature is 2°C.

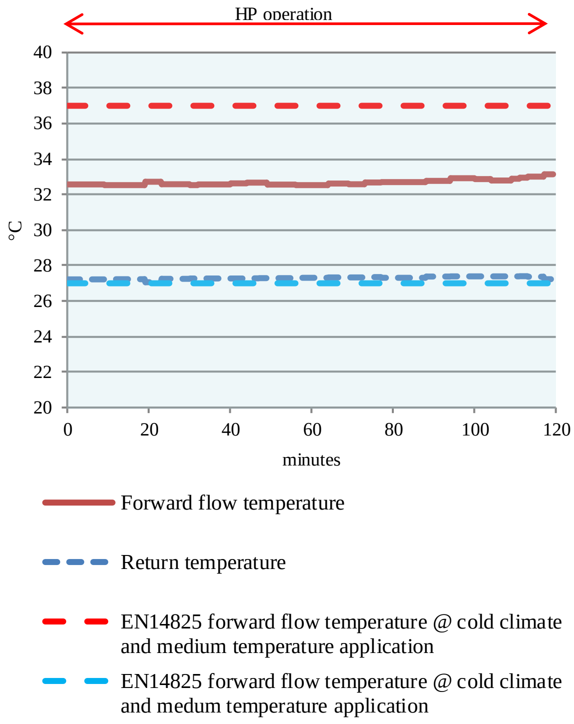

Figure 3. Forward and return flow temperature for the "inverter" heating system at an occasion when the outdoor temperature is 2°C.

3.2. Use of an extra storage tank in the heating system

In the heating system with an on/off controlled heat pump an extra buffer storage tank for the space heating system water is installed. The reason is that the capacity of the heat pump (nominal capacity = 4.5kW) for most of the year is higher than the heating demand of the well-insulated house. The storage tank enables longer operation time of the heat pump which reduces the wear of the compressor. In addition, it could offer the possibility to store heat produced by running the heat pump on electricity produced on-site (by PV-panels).

The water in the tank is continuously circulated to the heating system and when the heat pump switches on, the tank is charged by an increase of the temperature in the tank. Figure 4 presents the installation of the tank and the extra fluid pump for the heating system as well as the measurement equipment used. The figure also shows the flows of energy in and out of the tank together with the energy that is stored momentarily in the tank. The flow of the water from the heat pump to the tank is larger than the flow out to the heating system, therefore there is a net flow of energy into the tank represented by increase of the green dashed line when the heat pump is operating (minutes 0-34). The large variation of the heating power to the heating system is due to a variation in flow set by the floor heating system control.

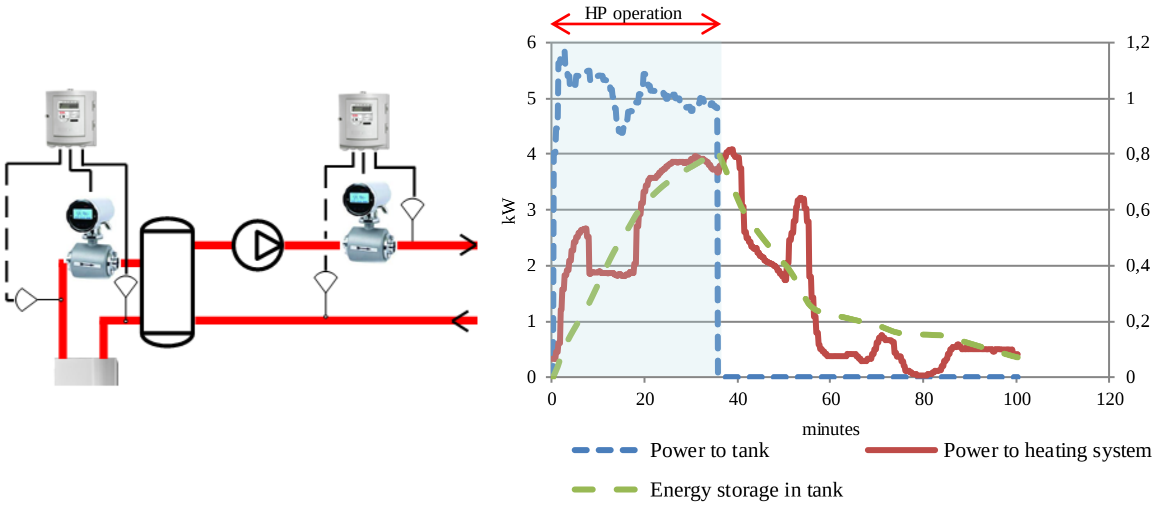

Figure 4. To the left: installation of the tank and the extra fluid pump. To the right: storage and energy flows in and out of the tank.

The drawback with a storage tank is that there is a temperature loss in the tank (probably primarily due to mixing in the tank). Hence, the temperature out to the heating system is lower than it would have been if no tank is installed. This reduces the efficiency of the total system somewhat. Figure 5 shows the temperature to the tank, to the heating system and the difference in between these temperatures. For the time that the heat pump is operational (the first 34 minutes), the average of the difference of the temperatures is approximately 1.2K. Hence there is a temperature penalty of 1.2K corresponding to an efficiency loss of approximately 3-5% due to the storage tank. In addition, there is an efficiency loss due to the fact that the heat pump is operating on/off and not continuously. The reason is that the forward flow temperature during the time when the heat pump is operational must be higher to compensate for a lower temperature when the heat pump idles. Hence, both the on/off behaviour and the tank result in a temperature increase of approximately 3K representing an efficiency loss of around 8%.

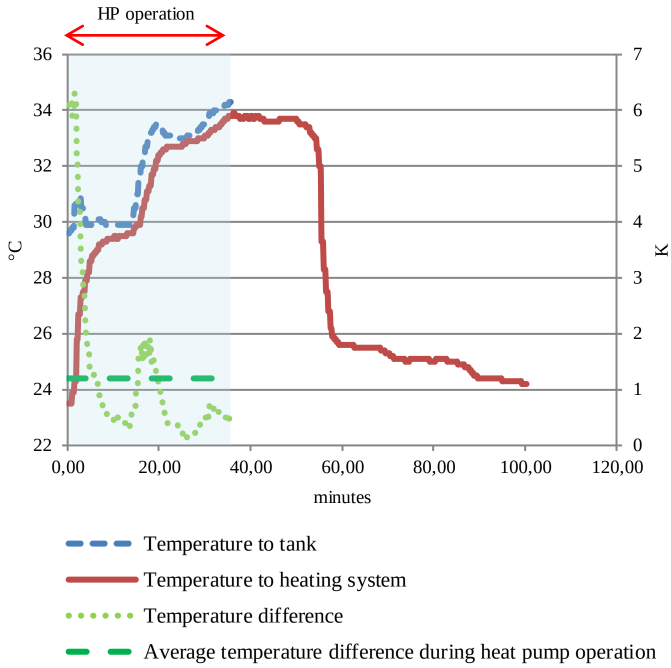

Figure 5. Forward flow temperatures for on/off heat pump with an extra storage tank. Borehole temperatures

The borehole temperature is strongly correlated to the amount of energy that is extracted from it. Figure 6 shows the borehole temperatures of both measurement sites and the outdoor temperature. The borehole temperature is calculated as the average of the minimum temperature (for each extraction cycle) during the 5 initial days of each month. This gives a representative figure of the brine temperature that is circulated to the heat pump during operating time. However, it does not take into account the first turnover of the liquid in the borehole, when the liquid is slightly warmer. Therefore, it under-estimates the liquid temperature into the heat pump during operation, and probably slightly more for the on-off system compared to the inverter controlled system. This temperature is an important factor for the total efficiency of the heat pump.

The borehole temperature in both systems somewhat follow the outdoor temperature profile, and is therefore related to the energy needed for heating the house. However, it can be seen that the borehole temperatures are lower in March and in April compared to November and December even though the outdoor temperature is similar. The reason is that the borehole temperature has been reduced during the colder winter months (January and February) due to higher rates of heat extraction.

The measurements show that the minimum temperature of the brine inlet into the inverter controlled heat pump system is in general 1K higher than the temperature of the borehole in the on/off system

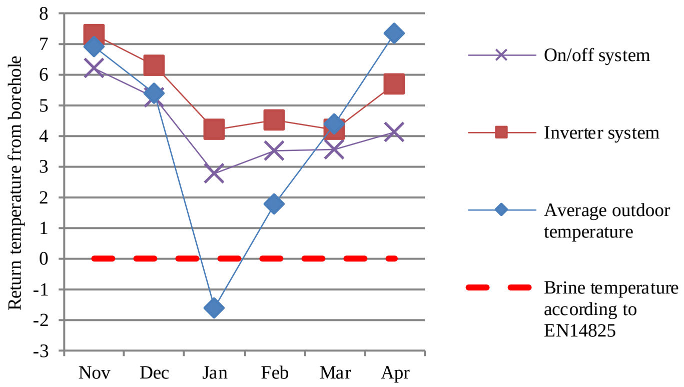

Figure 6. Borehole and outdoor temperatures of the heating season 15/16.

The testing standard EN 14825 for part load energy performance and calculation of seasonal performance of heat pumps states that a ground source heat pump should be tested with a brine temperature of 0°C (represented with the dashed line in Figure 6) independent of the part load operation and climate. The measurement results from the two nZEB in this study show that the minimum brine temperature on average (for the heating season) is 4.2 and 5.4 respectively. This is considerably higher than the 0°C temperature prescribed by the standard. The difference is even higher for the non-heating season, when only domestic hot water is heated.

4. Discussion and Conclusions

The results of this study indicate that the on/off heat pump on average operates with at 1-1,5K higher condensation temperature due to the extra storage tank that is installed to increase the cycle time of the heat pump. This relates to a loss of efficiency of approximately 3-5%. In addition, there is an efficiency loss due to the fact that the heat pump is not operating continuously but on/off. Both the on/off control and the tank result in a temperature increase of more than 3K representing an efficiency loss of around 8%.

The storage tank of 150 l in the on/off controlled heating system stores approximately 1kWh of energy by an average temperature increase of 6K.

The forward temperature is higher than expected compared with testing standard for part load energy performance and calculation of seasonal performance of heat pumps (EN14825) for the heating system with only floor heating. On the other hand, in the heating system with both floor heating and low temperature radiators the forward temperature is much lower than what the standard describes for a medium temperature application. One probable reason to the high forward temperatures in the on/off system is that the floor heating control adjusts the room temperature by very quick changes in the flow by frequent opening and closing of the different heating loops. Due to this control behavior the total flow of the heating water is quite low which is not optimal for the heat pump efficiency. We see two “smart” systems which should be optimized together but in this case do not interact in an optimal way.

EN14825, that the European energy label is based upon, prescribes a brine temperature that is lower that what was measured in this study. Hence, the calculated seasonal efficiency given by the standard is lower than what we should find in nZEBs disfavoring this type of heat pumps compared to heat pumps with other heat sources or other heating technologies such as gas boilers.

Some adjustments have been needed to increase the efficiency of the heating systems. This shows that initial adjustments and control is very important to fully use the energy saving potential of heat pumps.

References

[1] C. Wemhöner, R. Kluser, *Heat pump concepts for Nearly Zero Energy Buildings – Interim results of IEA HPP Annex 40,* IEA Heat Pump Conference 2014, Montreal, KN.2.5.1. 2014

[2] Persson, M., Ruud, S., Benson, J., Haglund Stignor, C., Boss, A., "*Heat pump systems for single family and multi family nZEB*" 11th IEA Heat Pump Conference. Montreal, paper O.2.5.2. 2014

[3]Wemhoener, C., *Heat Pump Concepts for Nearly Zero-Energy Buildings: Executive Summary*, IEA Heat Pump Centre, HPP-AN40-SUM, 2016

[4,5]:
EU, 2013a. Commission Delegated Regulation (EU) No 811/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device
EU, 2013b. Commission Delegated Regulation (EU) No 812/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device
EU, 2013c. Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to the ecodesign requirements of space heaters and combination heaters
EU, 2013d. Commission Regulation (EU) No 814/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to the requirements for water heaters and hot water storage tanks

[6] EN 14825:2016. Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance, CEN