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Measured load profiles and heat use for "low energy buildings" with heat supply from district heating

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Abstract

In the development towards nearly zero energy buildings (nZEB) the load profiles for the heat demand and the heat use of the buildings are expected to be changed considerably compared to the situation today. This change will influence the design and the overall profitability of district heating (DH). Earlier heat use measurements have shown that the real heat use of LEB, for several reasons, quite often seems to be somewhat higher than the values from theoretical calculations. This means that knowledge on measured values of the total heat load profiles and the heat use from all types of LEB will be important for evaluating the economy and the competitiveness of DH in the future.

The primary goal of the paper is to present measured load profiles and yearly heat use for three different blocks of flats connected to the DH-system in Trondheim, Norway. Official dimensioning outdoor temperature in Trondheim is -19°C.

The presented load profiles show statistical hourly mean specific maximum values for the three buildings. Specific values for the yearly heat use and the outdoor temperature value when the heat demand goes down to zero, change point temperature (CPT) are also presented. System efficiency of the domestic hot water (DHW) system in the buildings is also given. The presented information is assumed to be useful in the planning of DH-systems for the future.

Keywords: District heating; Load profiles; Heat use; Low energy buildings; Domestic hot water

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1. Introduction and background

As a reference to the two LEB in this study, one of the three buildings is built according to the technical building code in Norway from 2010 (TEK10). The other two are built according to the actual Norwegian guidelines: Norwegian standard, NS 3700:2010, Criteria for passive houses (PH) and low energy (LE) houses – Residential buildings [1] where LE has two classes. One of the two LEB is built to meet the LE criteria (class 1), and the other one to meet the PH criteria in these guidelines.

In new built LEB connected to district heating in Norway, it is today quite common to install some sort of heat pumps in the buildings. One of the reasons for this is that according to the special requirements on the energy performance certificate for buildings in Norway, it is hard to get an A rated building when the heat supply to the building is district heat only.

Both the LE and the PH building in this study have a heat pump installation to supply base load heat. The LE building has a ground source heat pump (LE+hp), and the PH building gets heat from a condenser of a cooling system in a neighbouring shopping center - (PH+hp).

All three buildings have so called "balanced, mechanical ventilation" with heat exchangers (HE). The requirement for the efficiency of the heat exchangers is ⩾ 70% for the LE buildings and ⩾ 80% for the TEK10 and the PH buildings. Detailed specifications of the three buildings are shown in Table 1.

Table1. Specifications of the three buildings

	TEK10	* LE+hp	PH+hp
Total heated area of the blocks (m^2)	~3750	~3400	~2380
Number of flats	49	39	26
Average heated area per flat (m^2)	~77	~87	~92
Ventilation air ($m^3/h \cdot m^2$) (Min. average values)	≥1.2	≥1.3	≥1.3

* The heating system in this building is providing some heat to a car shed and also to a smaller snow melting area.

To get a reasonably good picture of the real heat use of a building often so called heat load-temperature, HT-curves, are used. Here the measured heat load values are correlated to the actual outdoor temperature. Figure 1 shows a basic, theoretical curve of the heat load correlated to the outdoor temperature in a building that has heat demands for space heating, heating of ventilation air and hot tap water.

We see from figure 1 that the theoretical curve has two buckling points. The first one from the left shows the outdoor temperature where the space heating demand becomes zero. The second one shows the outdoor temperature from which it is only heat demand for DHW. In between these buckling points some heat is needed for heating the ventilation air. The slope of the curve in this area depends on the amount of ventilation air, the efficiency of the heat exchanger in the ventilation system, and the ratio between the heat demand for space heating and for ventilation air.

To decide the best estimate of the curve in figure 1 from measured data we need to perform a statistical regression analyze of the measured values. For several natural reasons the measured values may vary quite a lot for a certain outdoor temperature. The resolution on the heat load axis in such diagrams will normally be mean values for one hour, one day or one week. In the actual work the resolution is one hour.
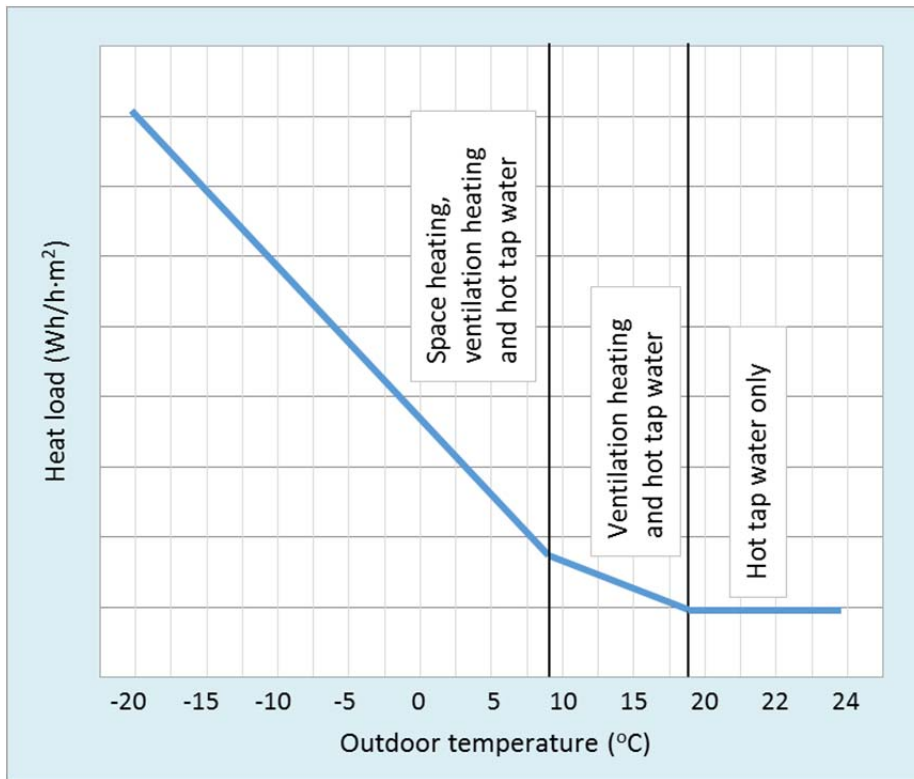

Figure 1. Generalized, theoretical HT-curve [4]

In older days, where the buildings had no mechanical ventilation, the actual curve had only a buckling point where the heat for space heating and natural ventilation becomes zero. Even today it is common to make the statistical analysis for such curves only with one buckling point called the change point temperature (CPT). This point represents the outdoor temperature for which the heat demand for space heating and ventilation air becomes zero. For the most common buildings this is assumed to give an acceptable picture of the heat use of the buildings. The statistical analyses in this work are done with only one CPT.

2. Methods/Methodology

The load profiles are developed from measured hourly values of the delivered district heat to the blocks of flats. The DH-system is own by Statkraft Varme AS in Trondheim who has provided the measured data.

The measured hourly values are treated statistically mainly by the statistical tool STATA [2]. More detailed results from these statistical analyses will be presented in an ongoing PhD-work at NTNU in Trondheim, Norway [3]. Some results are also derived by a method developed through the work on a PhD theses [4] made at NTNU.

3. State of the art

To make measurements of the heat demand of buildings have until the latest years been time consuming and rather expensive. There are therefore not shown too many results from such measurements in the literature. The ongoing effort to reduce the heat use in new buildings gives a running need to do measurements and document the actual improvements of the heat performance of new categories of LEB compared to theoretical calculations.

4. Results

Figure 2 shows the actual measured values and the regression model values that make up the HT-curve for the PH+hp building for hour 10 on week days (WD). For weekends (WE) we get similar, but somewhat different, curves depending on changes in the activity in the building. Similar HT-curves are made for all 24-hours to get the complete picture of the variation of the heat load. We see that the lowest measured outdoor temperature in the actual measurement period is -11°C.
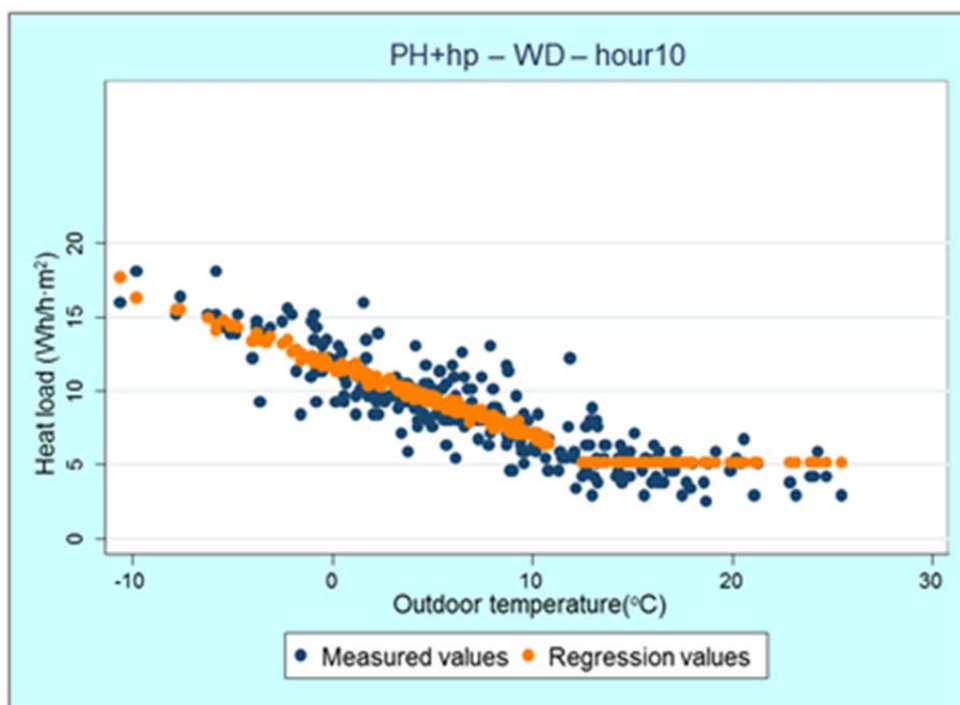

Figure 2. HT-curve for hour 10 on weekdays [3]

The measured district heat load values of a certain hour are depending on several other factors than the outdoor temperature in the actual hour. Depending on e.g. the thermal mass of the building we will have a time delay effects from the temperatures in earlier hours. By adding a third term to the linear equation you may get a better fit to the measured values.

From figure 2 we see that the red-orange regression values do not make a complete straight line. This is due to the fact that in this paper a time delay term is added to the linear equation. Normally it is considered satisfactorily to make a pure linear regression analyse to get sufficient accuracy for the actual purpose in such studies.

In figure 3 we see that the peak loads for the TEK10 and the PH+hp buildings occur in the morning hours. We may assume that this is normally due to an increased ventilation rate and the use of hot tap water for showers and hand washing. The figure also indicates that an increased amount of hot tap water is used in the afternoon hours for these two buildings as shown by the peaks around the hours 17 and18.

From the heat load profile for the LE+ph building we can correctly draw the conclusion that there are storage tanks installed in the local heating system. The reason for that is to get a steady heat collection from the heat pump. As we see, this will to a great extent even out the load profile.
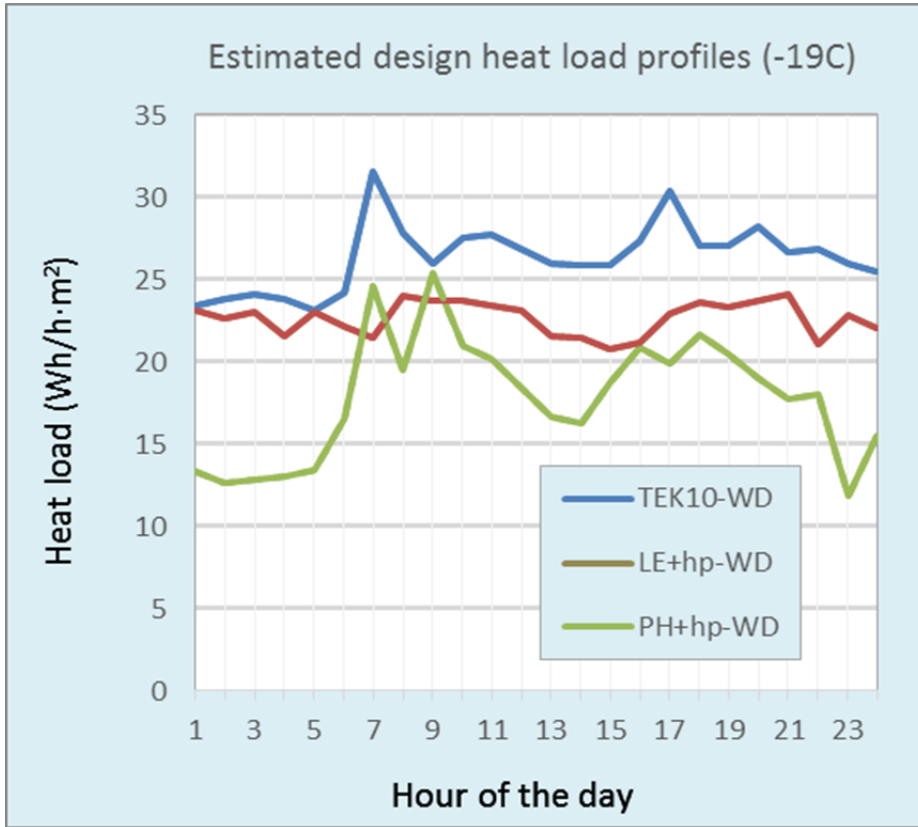

Figure 3. Design heat load profiles (WD) [3]

In figure 4 we see duration curves for the measured specific load for the three buildings for the actual year (2014). We see that the measured maximum loads for the actual year are somewhat lower than the design heat loads in figure 3 and Table 2 which are estimated values by the regression lines down to the formal dimensioning outdoor temperature of -19°C.

We also see that the curves are stepped, depending on the resolution of the heat meters. For the TEK10 building the steps are rather big. This indicates that the heat meter for this building is oversized. One consequence of this oversizing is that most likely the shown maximum load for the TEK10 building is somewhat lower than it would have been with a correct dimensioned heat meter with an appropriate resolution.
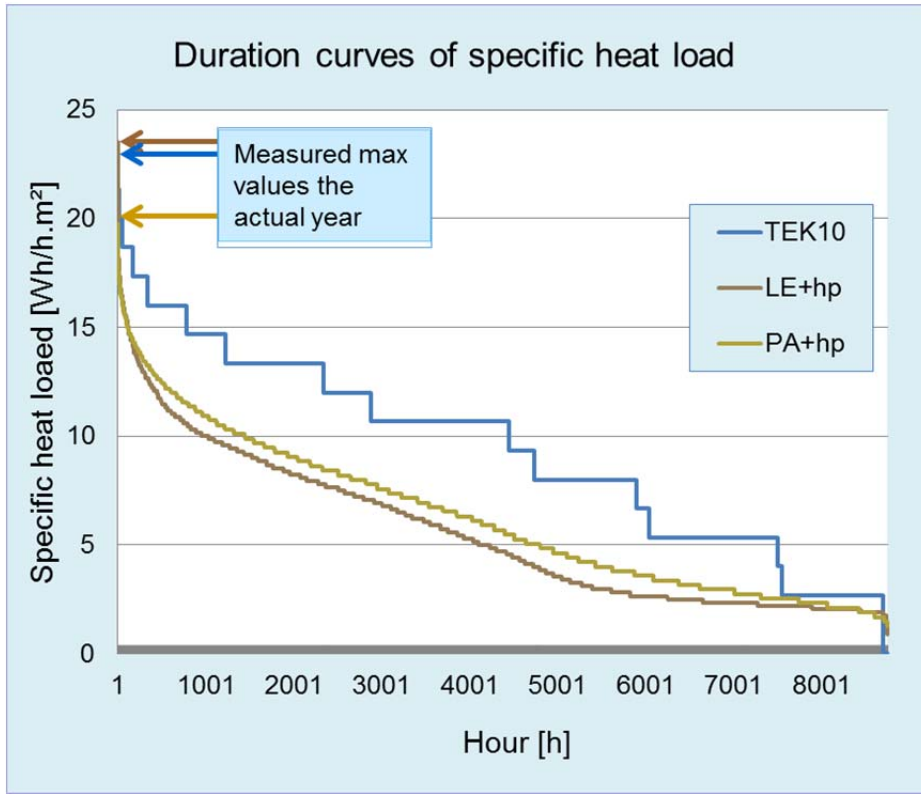
Figure 4. Calculated duration curves of measured specific heat load for the three buildings [4]

Table 2. Specific yearly heat use, max heat load and equivalent duration time of maximum load

	TEK10	LE+hp	PH+hp
Yearly heat use from the DH system (kWh/m²)	~82	~52	~52
Max heat load from the DH system (Wh/h·m²)	~32	~24	~26
Equivalent duration time of max DH load (h)	~2562	~2167	~2000
Calculated requirements on max. yearly heat use according to TEK10 and NS 3700:2010 (kWh/m²)	~85	60	45

From table 2 we see that the TEK10 building is just about to meet the criteria on heat use according to the actual building code. For the LE+hp building we see that the value for the heat use from DH is lower than the requirement according to NS 3700:2010. But, since this building gets additional heat from the heat pump we can't really decide from these figures if the building really meets all the criteria as a LE building. The overall picture for this building is also being confused by the fact that the heating system is providing some heat to a car shed and also to a smaller snow melting area. For the PH+hp building we see that the value for yearly district heat supply is higher than the

requirement according to NS 3700:2010 even if the building gets additional heat from the heat pump. This gives a clear indication that this building does not meet the criteria as a PH building.
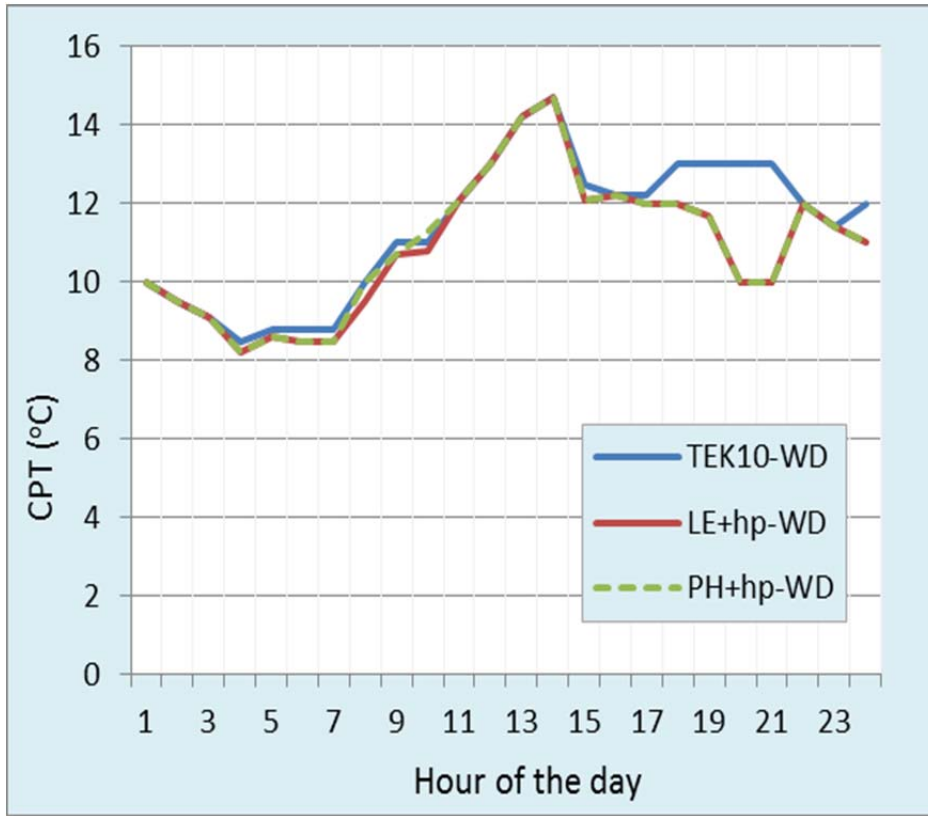

Figure 5. CPT for week days (WD) [3]

In figure 5 we see the curves of the hourly values of CPT from the analyses of the actual buildings in this study on WD. During night time we should theoretically expect that the CPT values for the TEK10 building would be somewhat higher than for the LE+hp building and that the values for the LE+hp building would be somewhat higher than for the PH+hp building. We see from the figure that the CPT values are more or less the same for all three buildings except for the hours from 18-21 for the TEK10 building.

This could be explained by several reasons e.g. that the ventilation system is running with higher ventilation rate some more hours for the TEK10 building than the other two buildings. But all together the results give an indication that the thermal qualities of the three buildings are not very different due to the fact that CPT for the marginal heat supply from the DH system is more or less the same during the night hours 4-7.

In figure 6 we see the curves of the hourly values of CPT for WE. These curves show more or less the same tendency as for the WD. But here we se that the CPT values for the TEK10 building has a tendency to be higher than for the other buildings in the hours 14-21.The difference in the CPT curves for WE are marginal, and may be explained by the fact that it could be within the margin of error of the analysing method. From figure 5 and 6 we also see that the CPT for all three buildings is in the range of 8°C during night time where the amount of ventilation air is assumed to be at the minimum level according to the requirements
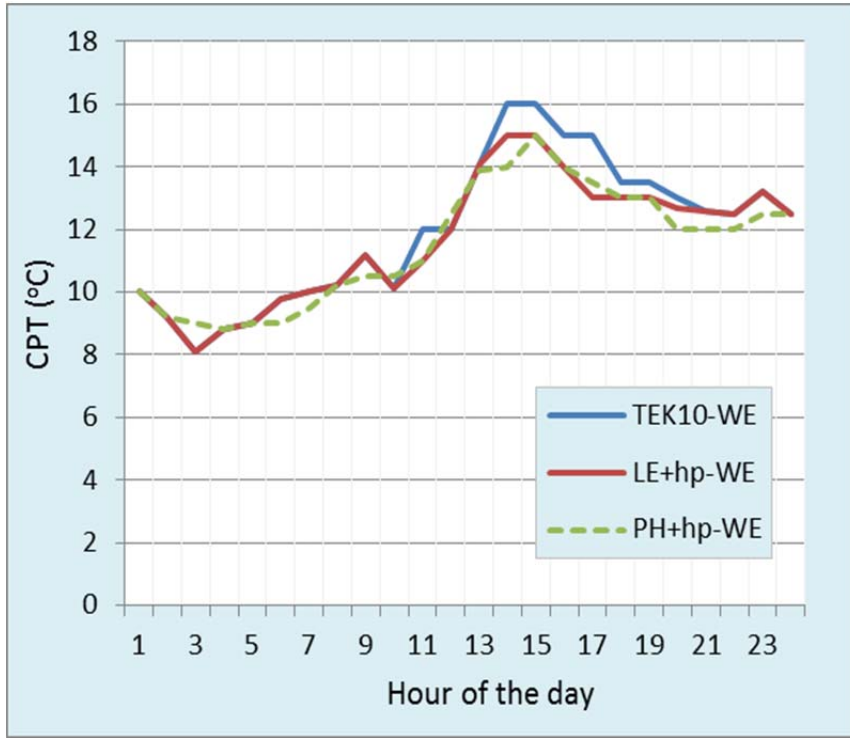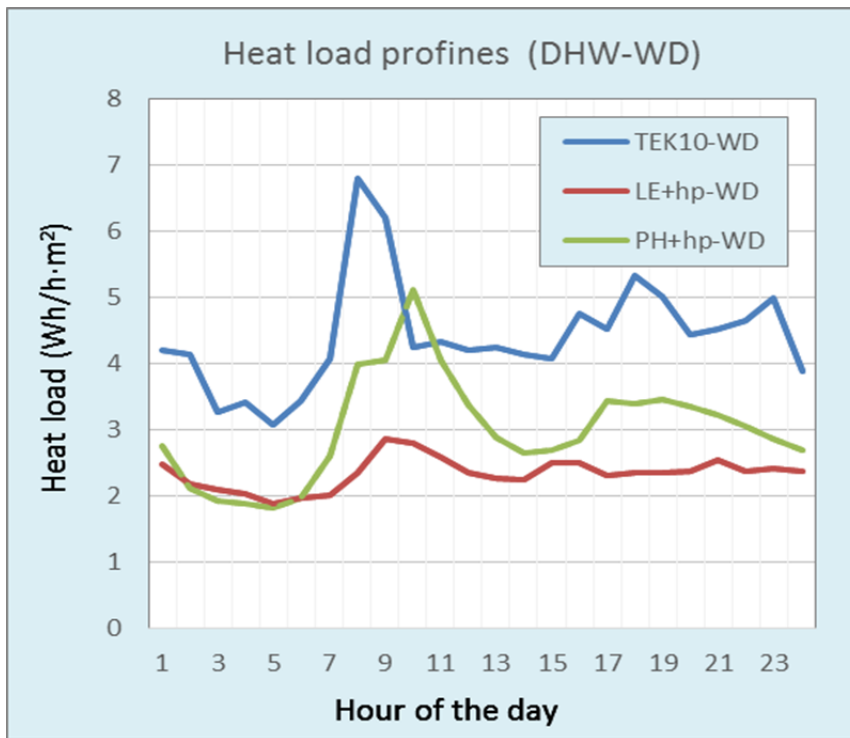
Figure 6. CPT for week end (WE) [3]

Figure 7. Heat load profiles for DHW for WD [3]

In figure 7 we see the typical morning peaks for DHW for the TEK10 and the PH+hp buildings. We also see that the morning peak for the PH+hp building is partly delayed a couple of hours. This indicates that quit few of the residents in this building do not have to get up and go to work early in the morning. This tendency may be explained by the fact that this new building is situated on the top of a shopping mall close to the centre of the city. We know that quite a few of the pensioners nowadays are selling their one family houses in the suburbs and move to flats in new built blocks in the city centres. For the LE+hp building we see that the peaks of the DHW load profile is flattened out due to the heat storage system. The morning peak is also slightly delayed due to the storage system.
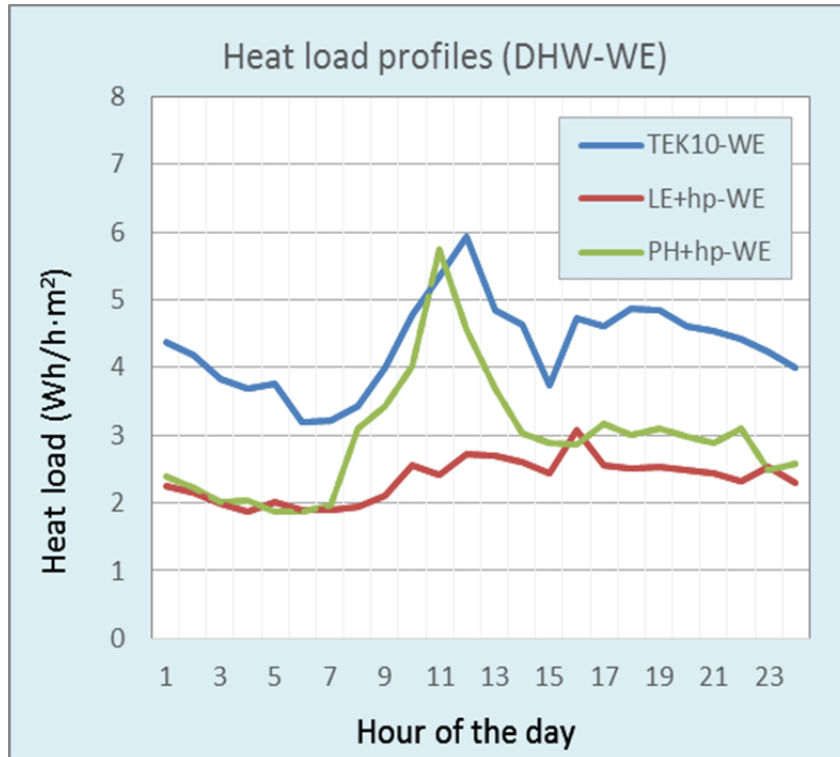

Figure 8. Heat load profiles for DHW for WE [3]

In figure 8 we see that we may assume that quite a few of the "working people" in the TEK10 building are getting out of bed several hours later on WE than on WD. The same tendency we also see for the LE+hp building. For the PH+hp building we see that most of the residents in the building, as we could expect, seem to be pretty much following the same routines on WE as on the WD.

Efficiency of the domestic hot water system and the heat contribution from the heat pump system in the actual buildings

In figure 8 we see that we may assume that quite a few of the "working people" in the TEK10 building are getting out of bed several hours later on WE than on WD. The same tendency we also see for the LE+hp building. For the PH+hp building we see that most of the residents in the building, as we could expect, seem to be pretty much following the same routines on WE as on the WD.

From figure 7 and 8 we see that the average heat use for DHW in the TEK10 building is in the range of 4.5 W/m2. The lowest measured value in this house at night time is in the range of 3.1 W/m2. If we assume that this

represents the heat loss in the distribution system the efficiency of the DHW system is in the range of 30 %. Most likely this low value is due to the circulation loop. From figure 7 and 8 we also see that the average heat supply from the DH system for DHW for the LE+hp and PH+hp buildings is in the range of 2.9 and 2.5 W/m2 respectively.

If we assume that the heat use for DHW is more or less at the same level for all the three buildings, the heat contribution from the heat pumps for the LE+hp and PH+hp buildings is in the range of 1.6 and 2.0 W/m2 respectively in the summer season. These values correspond in total to a heat contribution from the heat pumps to each flat in the respective houses of about 3.3 and 4.4 kWh/day. In comparison, this study indicates that the heat use for DHW in the actual buildings is in the range of 10 kWh/day.

5. Discussion

From the fairly low heat contribution from the heat pumps in the summer season it seems relevant to raise the question: Is the heat contribution from the heat pump in the LE+hp building high enough to justify the installations according to relevant economic criteria? From this study this question can't be answered properly without doing more measurements related to the heat pump and collecting a lot of detailed data and doing extensive economic calculations. The use of the heat pump in the PA+hp building should anyway be justified by the fact that the motive here is to use heat that otherwise would have been lost.

We have noticed from figure 5 and 6 that the thermal qualities of the three buildings seem to be quite similar. Then it seems reasonable to raise the question if the heat pumps are installed for the purpose of meeting the demanded criteria on heat use according to NS3700:2010, or to achieve an A rated building according to the Norwegian requirement for the energy performance certificate for the building. In Norway the ranking of the buildings for the energy performance certificate is based on delivered energy to the buildings without corrections for the primary energy factors (PEF) for the actual energy sources.

The European Union has passed the REGULATION (EU) No 244/2012 "on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements". This regulation presupposes that the actual countries shall perform cost calculations at macroeconomic level where also additional costs of greenhouse gas (GHG) emissions are included. It seems relevant here to ask if installing heat pumps in houses heated by DH are cost-optimal in an optimal GHG perspective if the heat pumps are not needed for cooling purposes

6. Conclusions

The following conclusion may be drawn from the results of this study:

(1) The results from the study indicate that the thermal quality of the TEK10, LE+hp and PH+hp buildings are quite similar.
(2) The TEK10 building seems to meet the requirement on heat use set in the actual Norwegian building code.
(3) The LE+hp building seems not to meet the criteria on yearly heat use to be qualified as a LE building according to the Norwegian standard NS 3700:2010. But the fact that the heating system in this building is providing some heat to a smaller snow melting area is confusing the picture.
(4) It seems clear that the PH+hp building does not meet the heat use criteria to be qualified as a PH building according to the standard NS 3700:2010.
(5) The reduction in specific heat use from the DH-system for the LE+hp and the PH+hp buildings in this study is in the range of 35 % compared to the TEK10 building.
(6) The ratio between yearly heat use from the DH-system and the maximum heat load is decreasing from the TEK10 building to the LE+hp building and further to the PH+hp building. This means that it is a

development towards fewer kWh to charge the costs for the investments in heat load capacity in the DH system.

(7) The derived values for the heat contribution from the heat pumps to the DHW system during the summer season for the LE+hp and the PH+hp buildings indicate that the contribution is rather low – about 3.3 and 4.4 kWh/day respectively for each flat.

(8) Since the thermal qualities of the three buildings seem to be quite similar, it seems likely to assume that the installation of heat pumps in the LE+hp and the PH+hp buildings could partly be motivated by the aim to fulfil the heat use requirements set in NS 3700:2010, or to get an A rated building according to the Norwegian energy performance certificate system.

(9) According to Regulation (EU) No 244/2012, the cost efficiency of installing heat pumps in DH supplied buildings where cooling is not needed should be evaluated through an exhaustive study on cost-efficiency at macroeconomic level according to socio-economic criteria.

7. Acknowledgement

8. References

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