STRATEGIC PLATFORM FOR INNOVATION AND RESEARCH IN INTELLIGENT POWER [IPOWER]

WP1 - T1.I.4 SMART METER CASE STUDY – TEST FACILITY AND INTERFACE

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1 TABLE OF CONTENTS

2 SUMMARY

As part of the iPower project different solutions for activating demand response are investigated, developed and demonstrated. Demand response in dwellings is mainly related to the Work Package 1, where different research and innovation tasks are carried out. One of the innovation tasks (T1-I.4) is the smart meter case study with the objective of develop cheap units for control of a heat pump via smart meters capable of enabling the control schemes from the iPower research tasks T1-R.5 to T1-R.6. Awaiting the research results on controllers, the focus has until now been on developing the test facility and the interface that can enable the control schemes. The present report describes the outcome of these efforts.

Danish Technological Institutes EnergyFlexHouse, a low energy building, was chosen as site for the test facility. In the house was installed a Zigbee based home automation system (Develco Products) and a number of smart meters (Kamstrup) with Zigbee interface. The house is heated by a ground source heat pump (Nilan) with an integrated controller (Lodam), which was control enabled by implementing a relay with Zigbee interface. Further, interface to the test facility gateway and a backend was developed in order to gather data and be able to control the facility. The backend was also connected to a load forecast webservice (ENFOR). In a period from 28 September 2012 to 27 January a family was living in the house to generate load and give feedback on the system. A very simple control strategy preventing the heat pump from starting up in 3 hour period each day was carried out in a 2 weeks period.

The results demonstrated that it was possible to shut down the heat pump for a relatively long period with only a minor fall in temperature in low energy houses - mainly due to the long time constant in such buildings. However, the feedback from the family also showed that people can be quiet sensitive to even small temperature fluctuations. The preliminary forecast exercises showed that it might be possible to handle such information as a cloud based solution. Many lessons were learned during the test period concerning data gathering, connectivity and communication with the different components, that can be used in the further work. Based on this the next steps should be:

1. Further develop the forecast service
2. Implement a controller based on the iPower research tasks, forecast service and price signal
3. Install equipment in more houses including houses of the older building stock
4. Proof of concept tests

3 INTRODUCTION

This report is concerning a smart meter case study on demand response (task T1.I.4 of Work Package 1 in the framework of the strategic platform for innovation and research in intelligent power, *iPower*)

3.1 OBJECTIVE

The general objective of the case study is to develop cheap units for control of a heat pump via smart meters capable of enabling the control schemes from the iPower research tasks T1-R.5 to T1-R.6. A test facility for proof of concept of flexible power in homes via smart meters will be developed. Proof of concept tests will be carried out in Danish Technological Institutes EnergyFlexHouse [www.energyflexhouse.dk] for selected solutions.

3.2 APPROACH

As the control schemes from the research tasks were not ready at the time of first test period (October 2012 to January 2013), the focus has been on developing the test facility and the interface that can enable the control schemes. Tests were carried out in EnergyFlexHouse for selected simplified solutions including interaction with a heat load forecast server. A test family participated in the tests. Data sets were collected to be used as input for developing of control schemes and forecast services.

3.3 TIME TABLE

The case study was carried out in the period from Q3-2012 to Q1-2013 according to the following time table:

1. Installation of a setup with smart meter and sensors hooked up in a Home Area Network and connected to ethernet through gateway at test site **(Q3-2012)**.
2. Family moving in at test site **(Q4-2012)**
3. Establishing a data base and data sets set to be used for analysis and heat demand forecasts **(Q4-2012)**
4. Simple on/off control of heat pump with the test setup **(Q4-2012/Q1-2013)**
5. Evaluation of case study **(Q1-2013)**

4 TEST FACILITY

The facility selected for test is Danish Technological Institutes EnergyFlexHouse complex with two low energy buildings, that were put into operation during the autumn of 2009 [www.energyflexhouse.dk].

4.1 BUILDING ENVELOPE

The two EnergyFlexHouses are two-storied, single-family houses with a total heated gross area of 216 m² each. One building is furnished as a living lab and occupied by typical families who test the energy services (EnergyFlexFamily), the other is an unoccupied laboratory facility (EnergyFlexLab). For the smart meter case study, the EnergyFlexFamily is used.

Figure 1 The EnergyFlexFamily house (forefront), EnergyFlexLab (behind).

The house is provided with a heat pump connected to a low temperature floor heating system servicing all rooms. There is an advanced control system with individual room thermostats and room temperature set-back. The set-back function was turned off during the test period.

The house is a 'net Zero energy building' which means that the house produces as much energy as it consumes on annual basis including electricity for household and transport with an electrical vehicle. This is possible because of the 60 m^2 Photo Voltaics (PV) system on the roof. The electrical vehicle is however not used in this test period.

A met mast is located next to the houses which measures wind speed, wind direction, outdoor temperature. Further, global and diffuse irradiation is measured.

4.2 HEATING AND VENTILATION SYSTEM

An integrated heating and ventilation system is installed consisting of:

- Nilan JVP3 Ground source heat pump:
    - Rated heat output: 3 kW
    - Inverter for variable speed of compressor

  A supplement electric resistance heater with heat output of 2 kW was turned off during the test

- Lodam control (SMC 200) with additional built-in relay to control on-off operation
    - Only heating (JVP3) is controllable
- Domestic hot water (not controlled in this test) is made by separate ventilation air heat pump with backup electric heating element and a storage tank of 180 liter. All equipment (including JVP3) is built together, placed within the same casing and sold on the market as Nilan VP18 Compact JVP

4.3 OTHER ELECTRIC EQUIPMENT

The house is equipped with electric household appliances and lighting corresponding to the needs of a typical family. These includes A-labelled fridge-freezer, dishwasher, washing machine, dryer, oven, microwave oven, television and radio.

4.4 TEST FAMILY

The family of the test period consists of two parents and two boys of age 5 and 9. The father works in an IT-firm and the mother works in a bank. They have no pets.

They moved in September 28th 2012 and out again January 27th 2013.

5 SMART METER, SENSORS AND GATEWAY

The EnergyFlexHouse had prior to this case study already a large number of state-of –the- art meters and sensors installed as well as a comprehensive data acquisition system. However, as the objective is to develop and test cheap units, a number of new standard Zigbee enabled sensors and meters were installed from the companies Develco Products and Kamstrup. A sketch with the most sensors and meters is seen on Figure 2

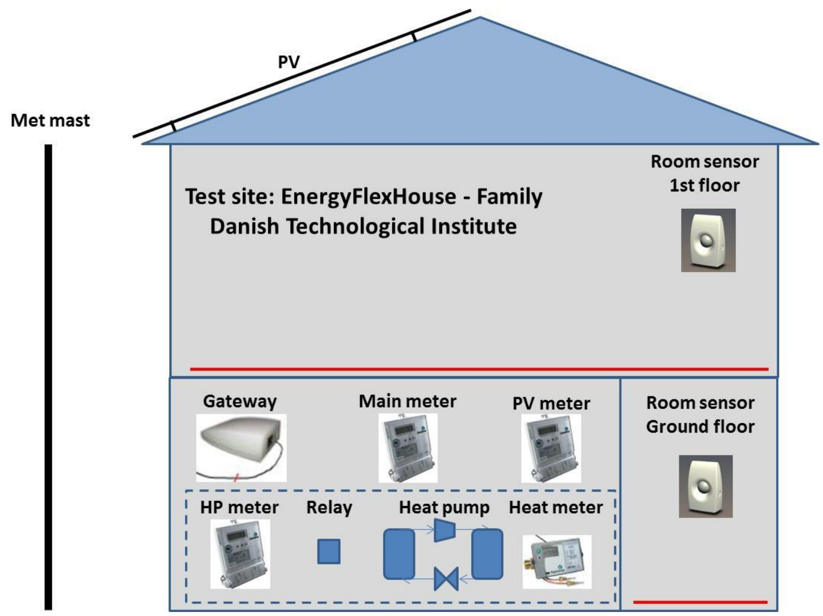

Figure 2 Sensors and meters placed within the test facility

All equipment is designed with Zigbee interfaces using either the Home Automation or Smart Energy protocols.

5.1 ZIGBEE EQUIPMENT

The Zigbee enabled equipment installed is:

- SE Ethernet Gateway
- HA PIR & Room temperature sensor, ground floor
- HA PIR & Room temperature sensor, 1st floor
- SE Kamstrup 382, Main electricity meter
- SE Kamstrup 382, PV electricity meter
- SE Kamstrup 382, HP electricity meter
- SE Kamstrup Multical 602, Heat meter
- HA On/Off relay for heat pump control

Optionally it is possible to use two extra relays of types:

- HA Wall plug relay (contains a power meter)
- SE 30A relay

HA = Home Automation, SE = Smart Energy, refering to respective Zigbee protocols

The two optional relays, one of each, were configured, but not used during the test period. Specifications for these relays can be found on the Develco Products web-page [www.develcoproducts.com]

6 INTERFACE, BACKEND AND FORECASTING

To be able to communicate with the equipment installed in the EnergyFlexHouse, a server and a SQL database was established. In addition, Windows programs were developed to handle data processing and exchange of data with SQL database and the external forecasting web service ENFOR Press [www.enfor.dk]. The data flow is seen on Figure 3.

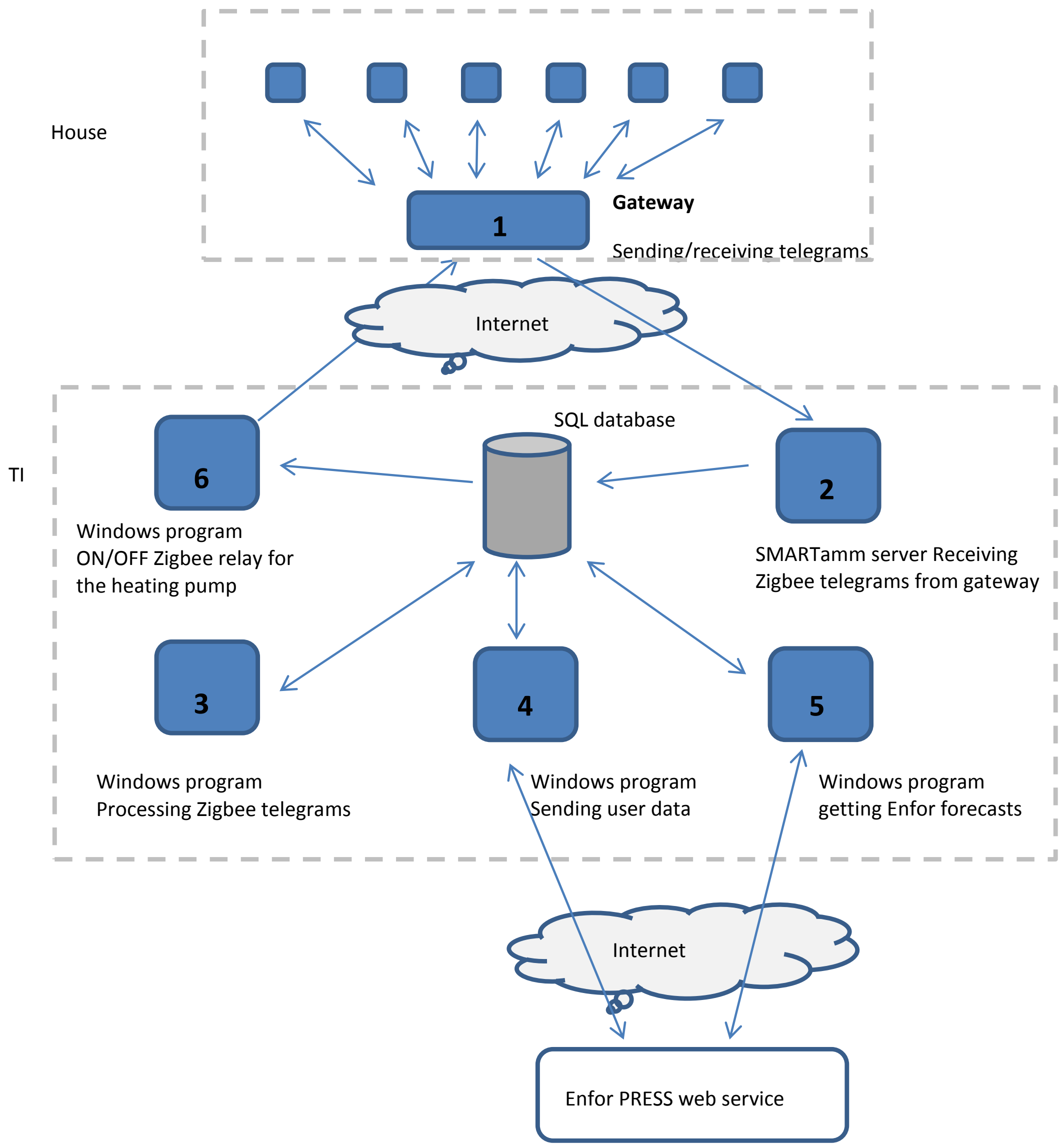

Figure 3 Sketch with data flow for the test facility, TI = Danish Technological Institute

The structure of the setup and data flow is as follows:

Several sensors measuring power consumption, temperatures, etc are placed in the house. Temperatures are collected every 2 minutes (due to some standard settings, but might be changed to another interval), whereas all the power consumptions are collected every 5 minutes.

These sensors communicate wireless, using Zigbee protocol, to a gateway (**1**) connected to the house Internet router. The gateway is programmed to send telegrams through Internet to a SMARTamm server located at Danish Technological Institute. 'SMARTamm server' is a trade name of Develco Products ('amm' = automatic meter management). Develco Products did the server setup.

Telegram is the name given for all messages between the gateway and the SMARTamm server.. A computer at Danish Technological Institute is running an application as a SMARTamm server (**2**). This server is listening for incoming telegrams from the gateway and save all the telegrams in a database (Microsoft SQL server) for further processing. The SMARTamm server is written in Java.

Every minute a Windows program (**3**) read and processes these telegrams in the database to extract the measured values from the different sensors. The resulting data are then saved in the database for further operations.

Every 15 minutes a Windows program (**4**) looks for the data saved in the database and send the temperatures and the house general instant electrical consumption to ENFOR Press web service. ENFOR uses these values to calculate power consumption forecasts.

Every 1 hour a Windows program (**5**) is calling Enfor PRESS web service to get a 24 hour power consumption forecast for the next day. The forecast is saved in the database too, but at the moment overwritten each hour. However, the important issue is that the forecast for the next day can be retrieved at any time the day before, but will usually improve as the next day is approached.

A Windows program (**6**) is used to switch ON/OFF the heating pump between predefined time intervals. At **(6)** other routines, e.g. real controllers for the heat pump or relays for other equipment, can be incorporated.

All the Windows programs have been developed with the Microsoft .NET framework.

7 TEST EXECUTION

The test family in EnergyFlexHouse (EFH) was invited to live in the house for 4 month and moved in September 28th 2012.

During their stay, a number of incidents related to the building service systems occurred including break down of main supply cable to the building, heat pump service call needed just before Christmas and other unexpected events.

In relation to the case study there were also a few challenges. Getting the SMARTamm server to work properly behind DTI firewalls was one of them, but also issues related to the sensors/meters and the interface to the ENFOR Press web service did take some time to solve.

The original plan is seen in the table below. However, due to the above mentioned incidents and challenges main test results are from a short period in December and from a 2 weeks period in January. In addition some extra tests regarding room temperature drop after heat pump turn-off and room temperature rise after heat pump turn-on were conducted after the family moved out.

Main tasks	**November 2012**	**December 2012**	**January 2013**
0. setup, configuration and creating database			
1. Collecting data and generating data set to ENFOR			
2. Switching off heat pump in certain periods			

7.1 COLLECTING DATA AND GENERATING DATA SET TO ENFOR

The data used for ENFOR Press forecasting tool is electric power (active) measured every 5 minutes at the main meter of the building and the room temperature. After some alignment of time stamps the interface was up running by mid-December. However, from just before Christmas to the beginning of January, the heat pump was not in normal operation, so the learning period for the ENFOR Press system has been rather short and insufficient to draw exact conclusions.

7.2 SWITCHING OFF HEAT PUMP IN CERTAIN PERIODS

Switching off the heat pump in certain periods started 14th of January and lasted until 27th of January. It was decided to make a simple time scheduled strategy for switching on/off the heat pump. 3 hours each afternoon the heat pump was switched off and the room temperature drop registered.

After the family moved out, the tests continued with longer periods without heating.

8 RESULTS OF TESTS

The results in this section serve as a proof of concept in this regard, that the equipment, the test facility and the forecast server has been tested and are now interconnected, so control strategies developed in the iPower research tasks can be implemented and tested in EnergyFlexHouse in the future.

The results also show the room temperature and the electricity and heat demand profiles both without control of the heat pump and with a simple on/off control. Further, actual electricity profiles are compared with forecasted electricity profiles.

The results are especially interesting in relation to low-energy buildings and their flexibility as low energy buildings will be built as standard from 2015 according to the Danish Building Code. Feed-back from the family is found in section 9.

8.1 ELECTRICITY AND HEAT DEMAND PROFILES WITHOUT CONTROL

Figure 4 shows total electrical power for all appliances in the house and covers 24 hour profiles for 4 days in a row between the 13th and 16th of December 2012. The sampling rate is 5 minutes. From this figure, electric power peaks are seen mainly in the period from 15:00 to 18:00 on weekdays. Figure 5 and 6 shows room temperature, heat demand and electric power based on average hourly values of one day, 14th of December. A rather constant picture of the heat consumption is seen through the day – the peak of electric power in the period 16:00-17:00 is due to cooking.

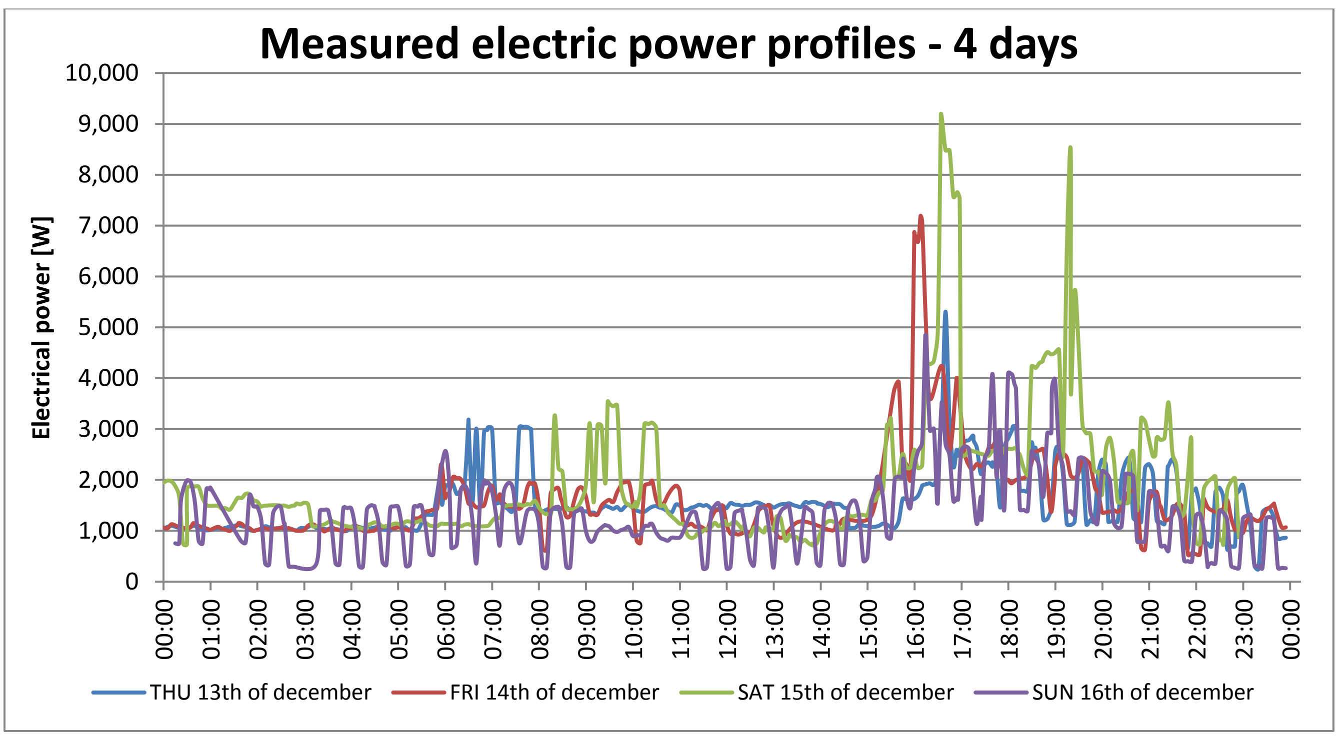

Figure 4: Electrical power the 13th to the 16th of December.

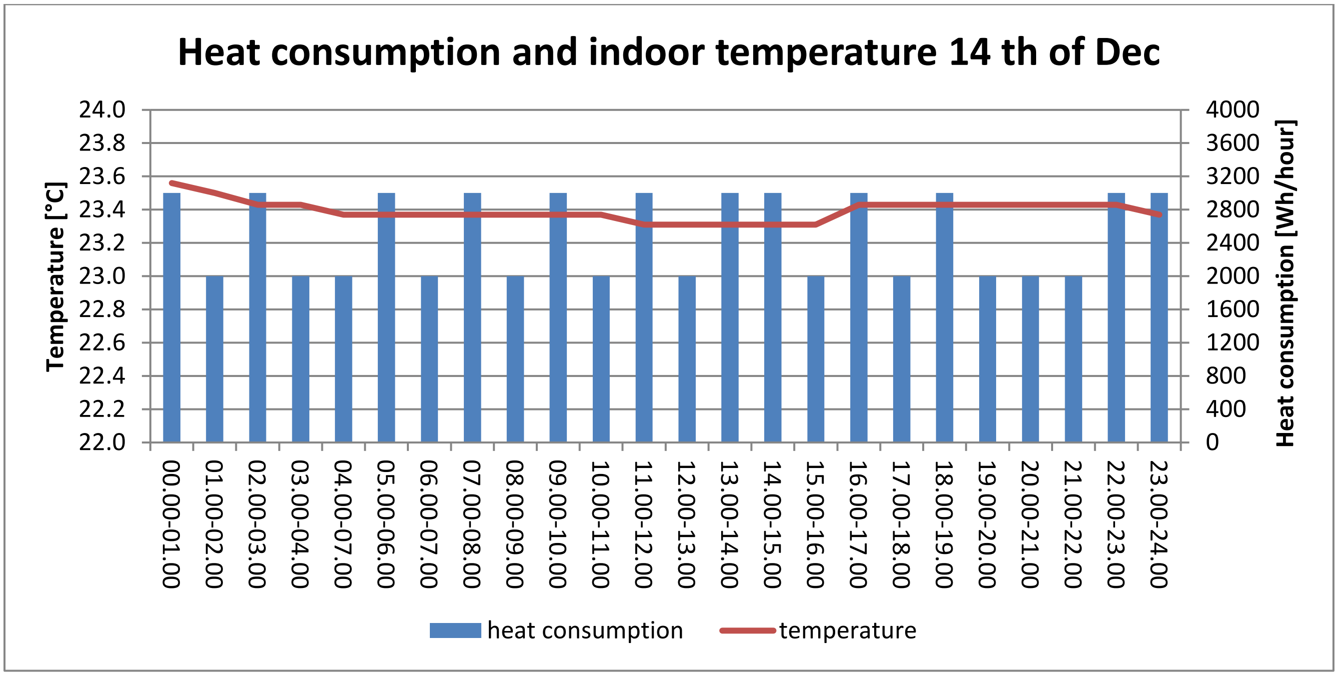

Figure 5: Measured data for the heat consumption and temperature in the living room on the 1st floor the 14th of December 2012

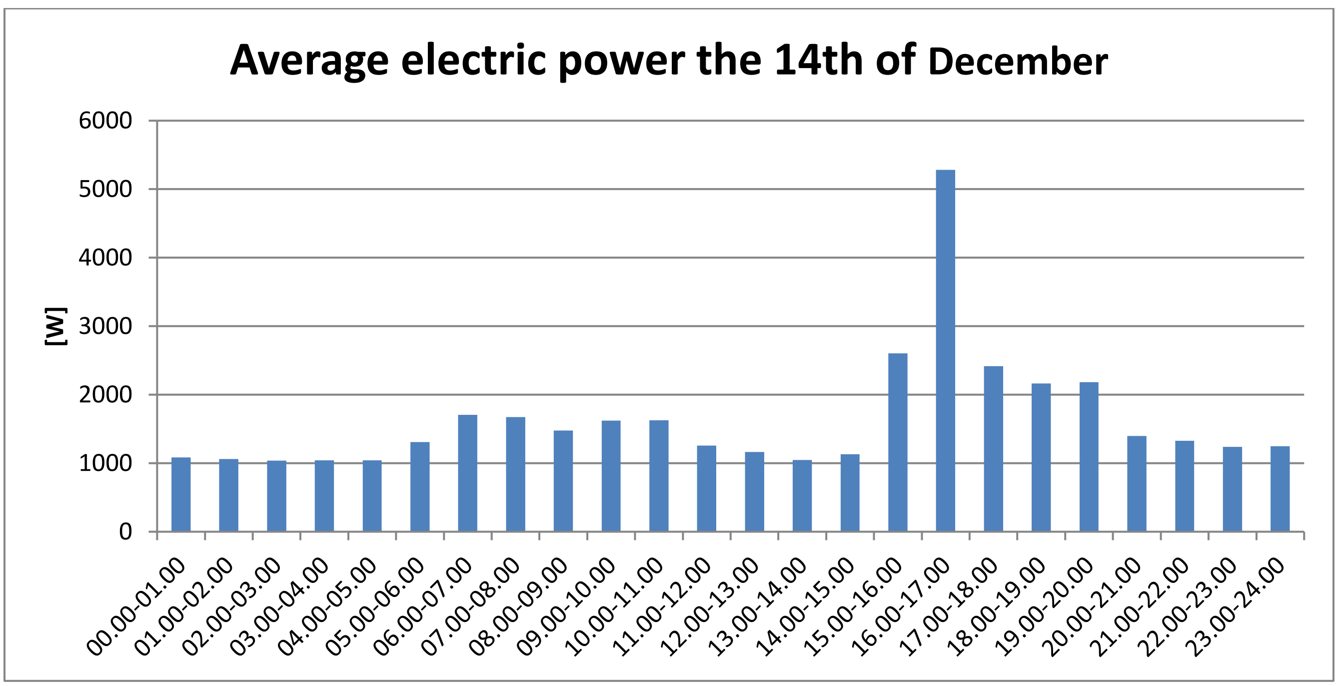

Figure 6: Average electric power per hour – measured – 14th of December 2012

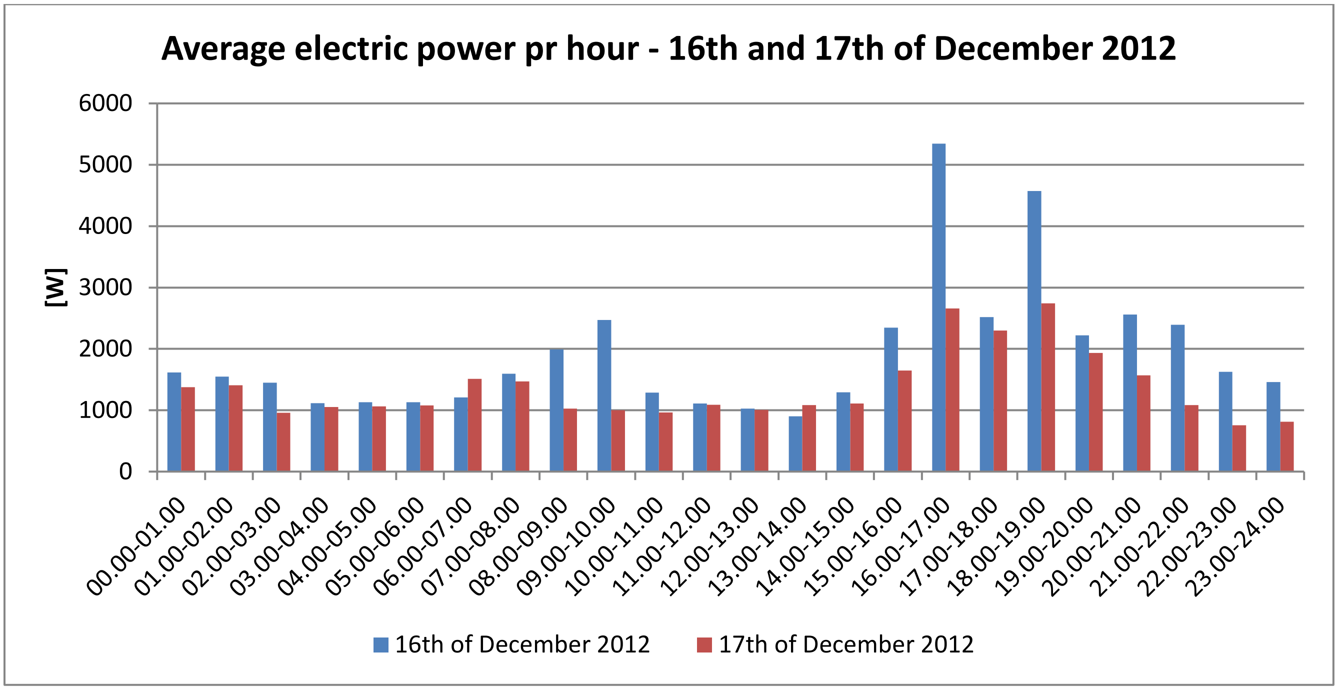

Figure 7: Average electric power per hour, 16th and 17th of December 2012

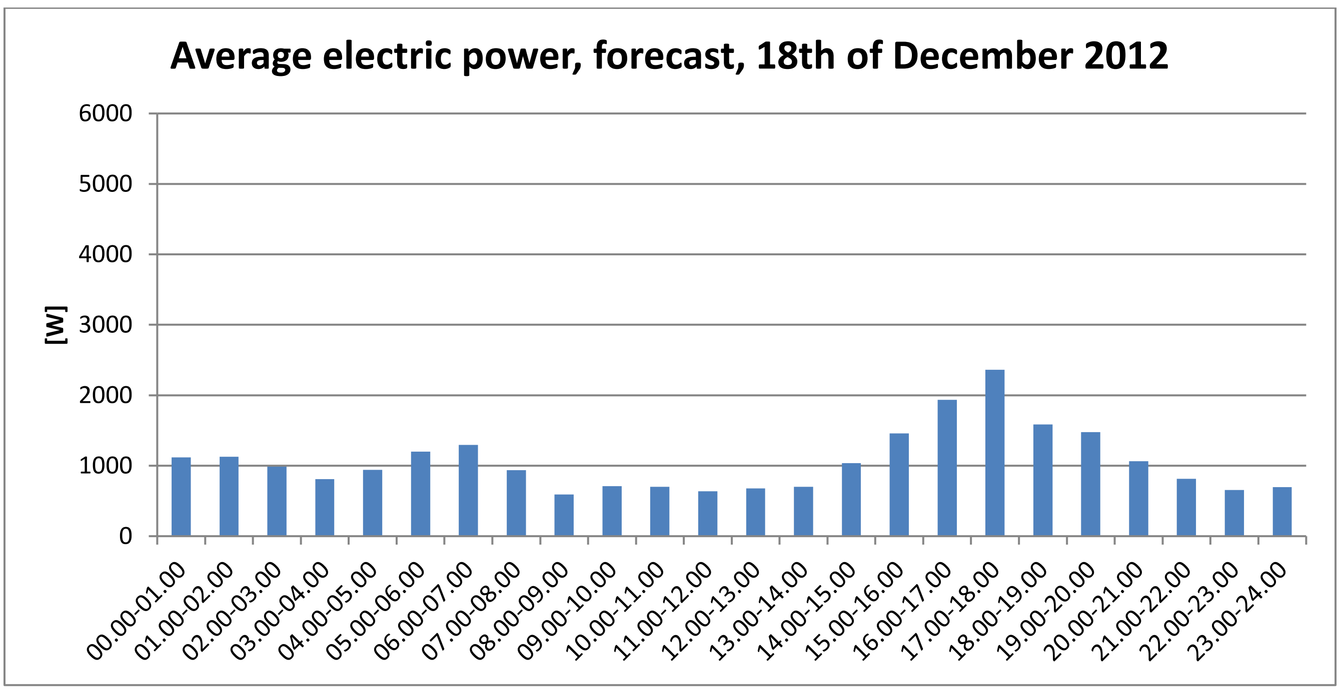

Figure 8: Forecast for the average electric power the 18th of December 2012 (based on only four days data to ENFOR Press)

Figure 7 shows the measured consumption for two days in December 2012, and Figure 8 shows the forecast of the next day. In this case the forecasting tool has only had very little time (a few days) to learn about the house - the forecasted profile looks very similar to the profile of the day before. Due to heat pump failure, it was not possible to compare the forecast with measured consumption in this case and we are not able to draw further conclusions.

8.2 ELECTRICITY AND HEAT DEMAND PROFILES WITH CONTROL STRATEGY

Based on these preliminary tests, a simple control strategy was implemented (stop 3 hours each day in the period 15:00 to 18:00) from 14th of January until 27th of January. Figure 9 shows total electrical power (main meter) for all appliances in the house and covers 24 hour profiles for 4 days in a row between the 14th and 17th of January 2013. The sampling rate is 5 minutes. Compared to the profiles of Figure 4, a reduction of power level is seen from 15:00 and onwards. Figure 10 and 11 shows room temperature, heat demand and electric power based on average hourly values of one day, 16th of January, which was a very cold day. Due to the turned off direct electricity supply heater, the heat pump was not able to deliver the desired comfort temperature, but because of solar irradiation comfort was reached during the period where the heat pump was turned off. After the family moved out, a test without heating for 6.5 hours was carried out. The results are seen in Figure 12 and 13. A room temperature drop of 0.6 degrees takes place over the period.

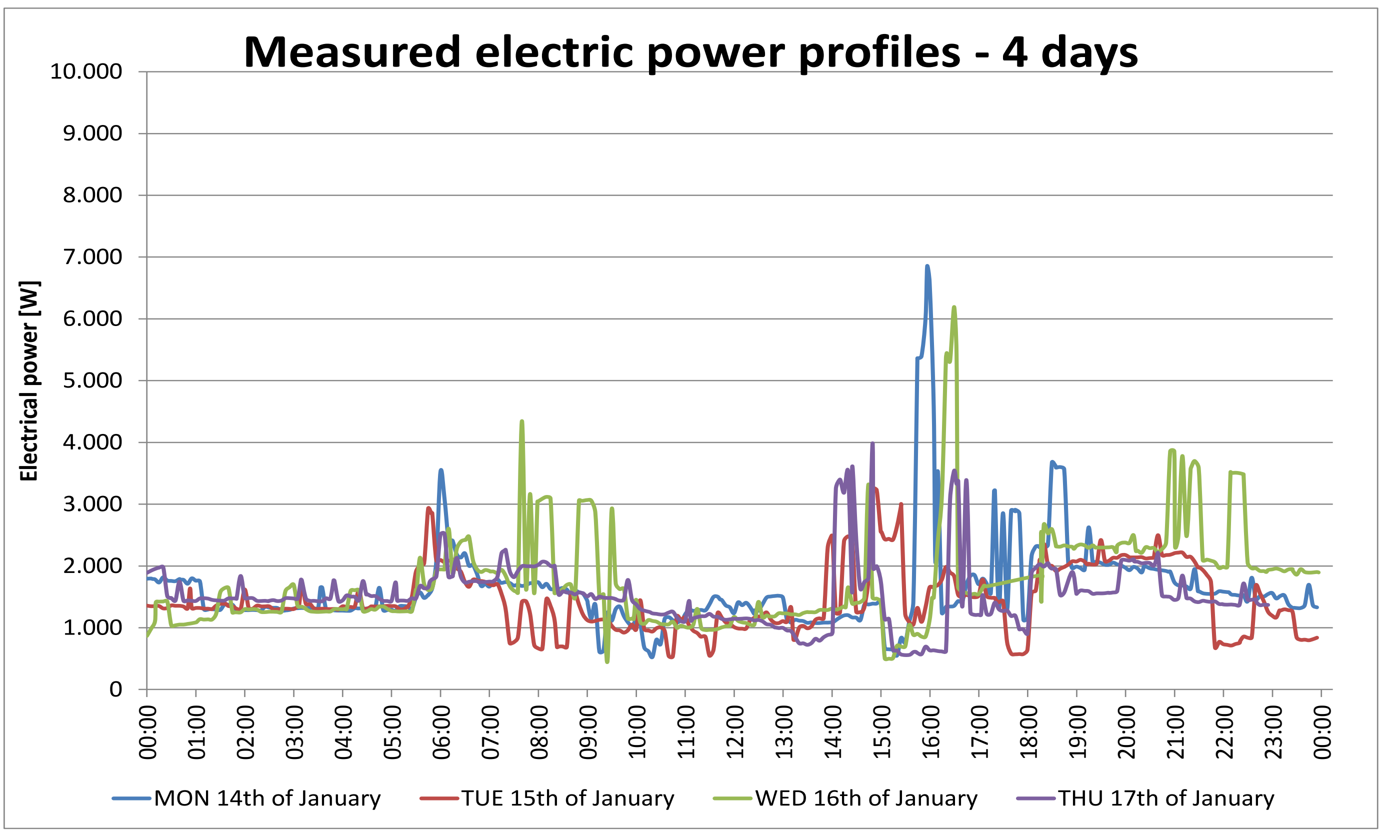

Figure 9: Electric power in the test period 14th to 17th of January

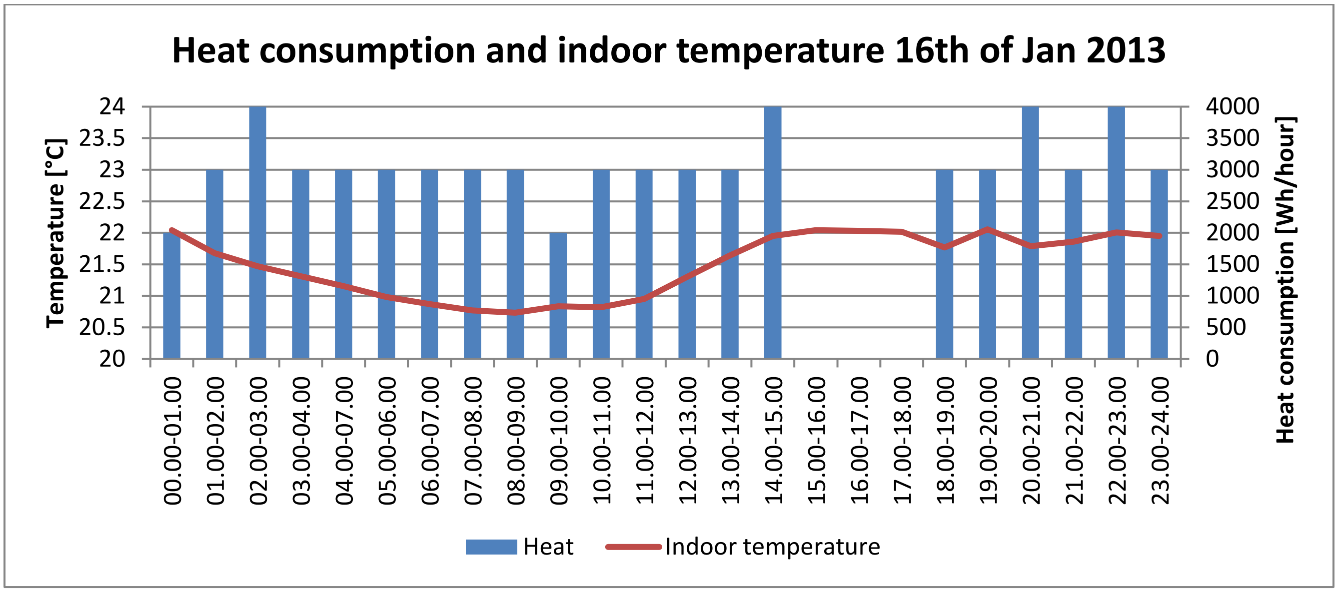

Figure 10: Heat consumption in the test period, the 16th of January 2013 – heat pump turned off at 3 pm (UTC)

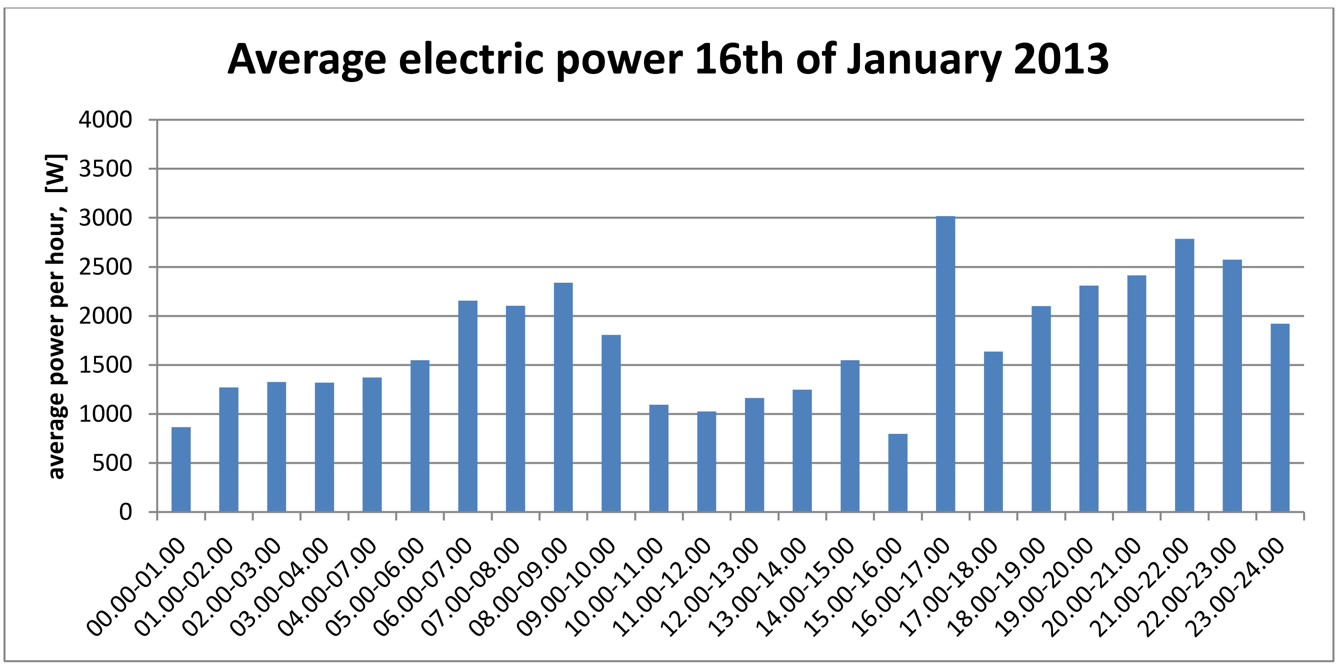

Figure 11: Average electric power per hour the 16th of January 2013 - test period

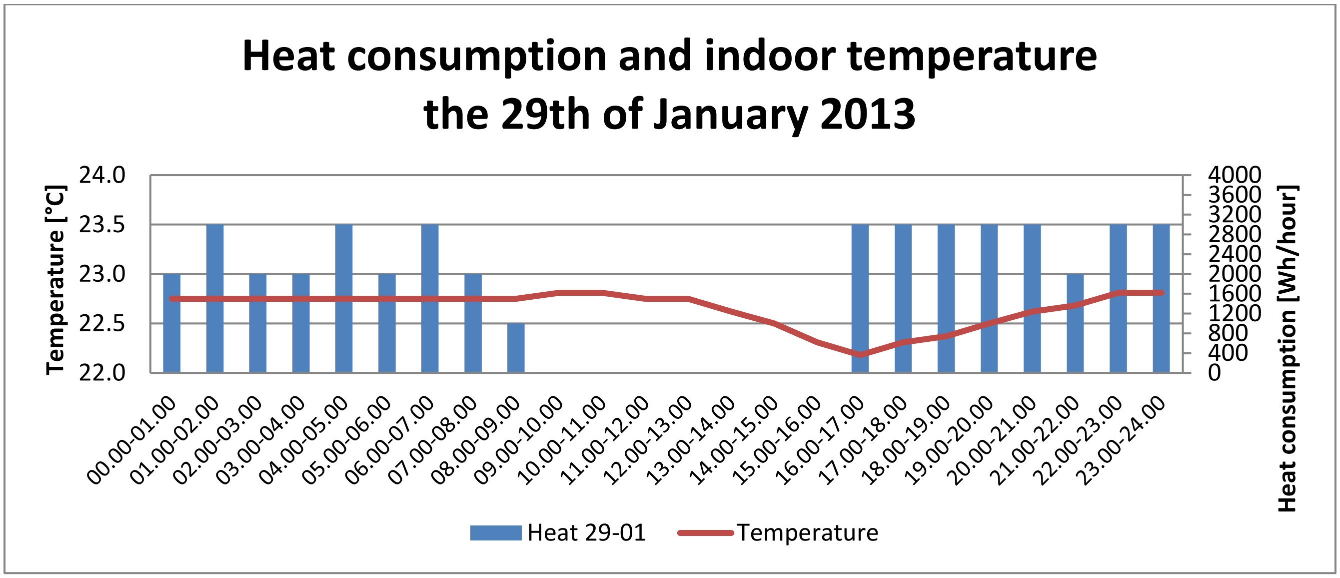

Figure 12: Heat consumption and indoor temperature per hour the 29th of January 2013 – empty house

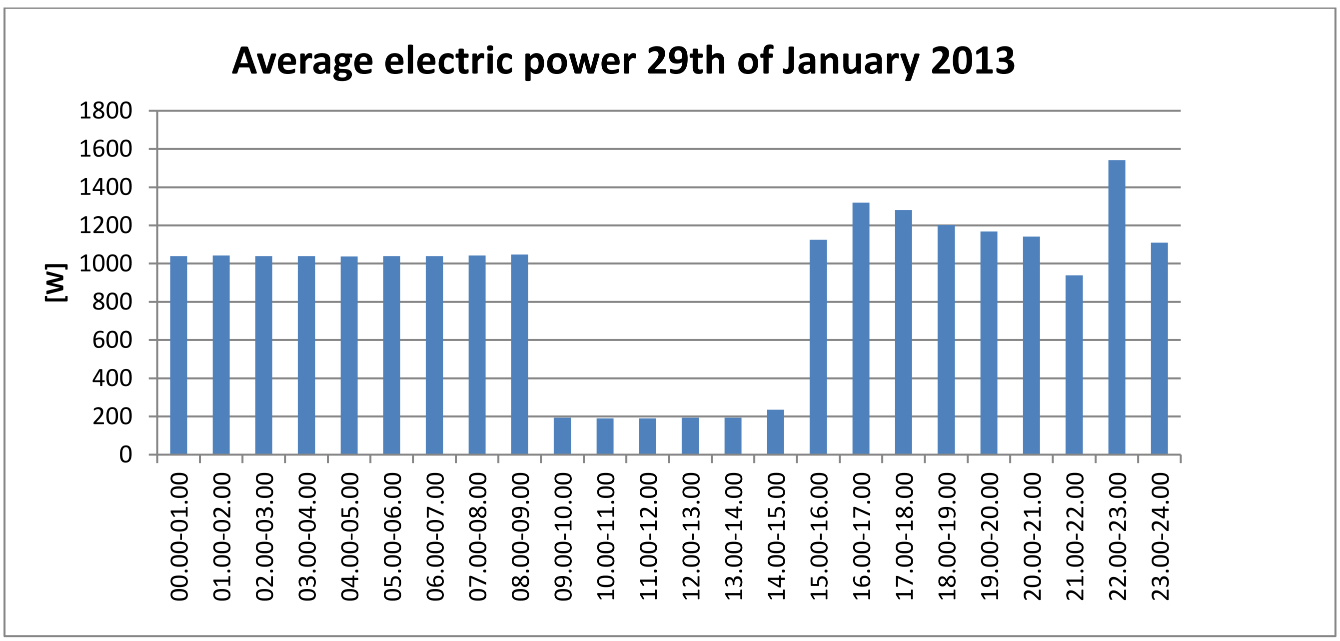

Figure 13: Average electric power per hour the 29th of January 2013 – empty house. Heat pump turned off at 8.30 am (UTC). Heat pump turned on at 3 pm (UTC)

Finally, to get a picture of the dynamics of the building, some cooling off and heating up tests were made over a period of several days with logging of room and outdoor temperatures, see Figure 14 and 15.

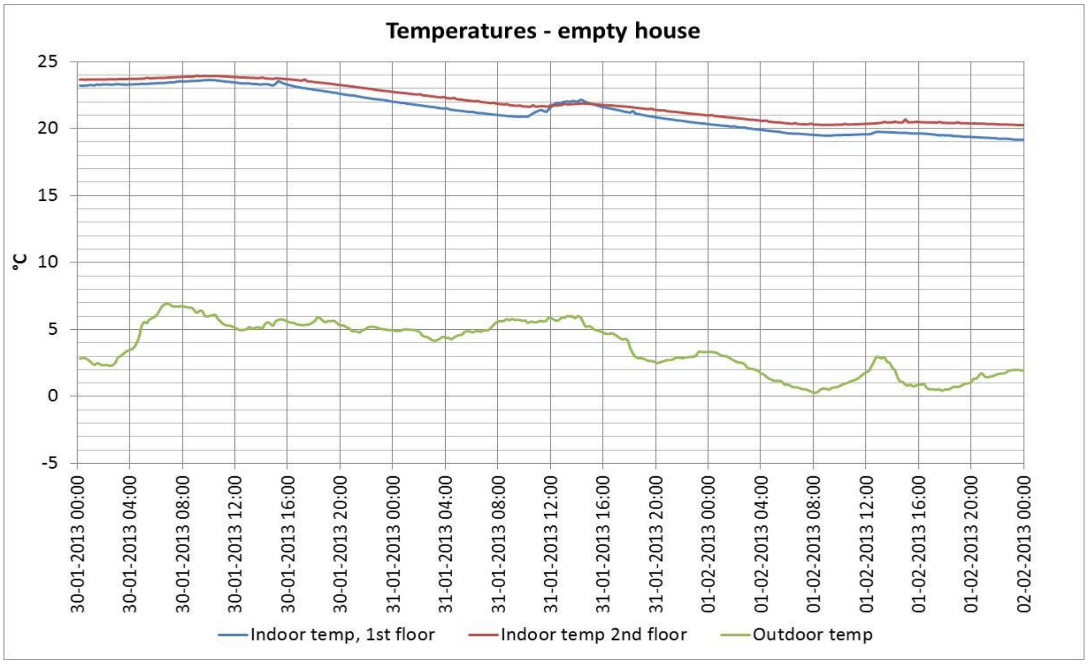

Figure 14: Indoor temperature, 30th of January to 2nd of February. Heat is turned off 30th of January at 9 o'clock

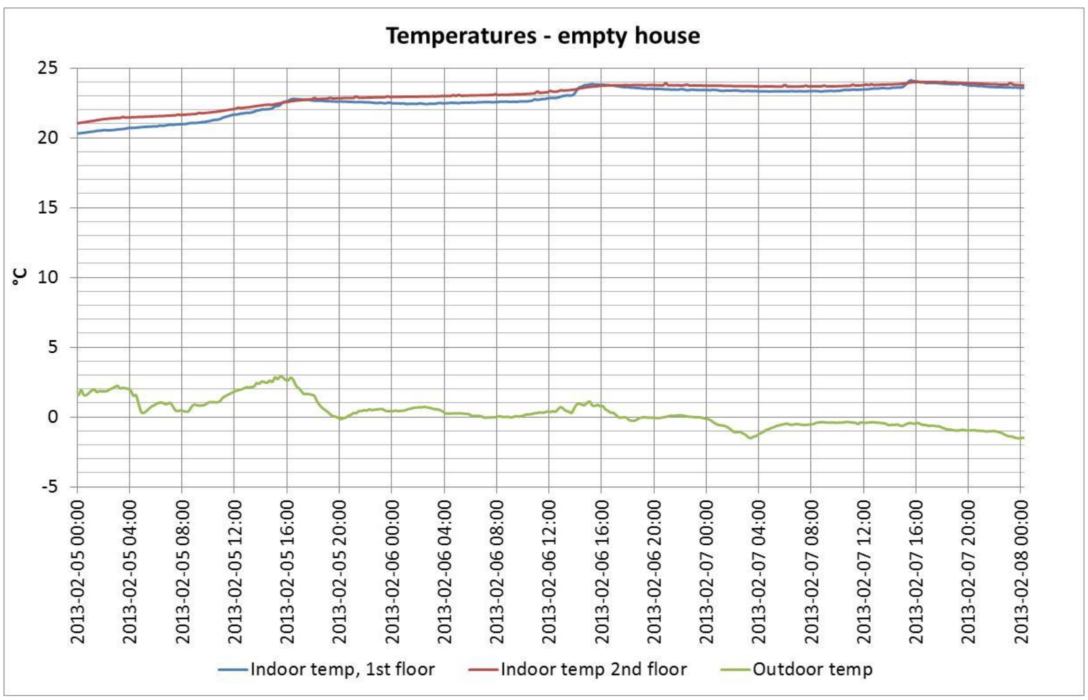

Figure 15: Indoor temperature, 5th of February to 6th of February 2013. Heat is turned on 4th of February at 10 o'clock

In other investigations of the EnergyFlexHouse, the time constant has been estimated to about 40 hours. This results in relatively slow cooling and heating of the house, which can be seen on the figures. The heat pump was stopped 30th of January at 9 in the morning and during the next 24 hours the temperature only dropped about 2 degrees. In this respect, low energy houses have large potential in terms of flexibility, but will because of the relatively low heat demand also be less problematic in terms of congestions in the distribution grid. It is important to observe the relatively large heating up time as well!

8.3 LOAD FORECASTING

It is in fact not really useful to compare the forecast with the actual measurements, as the learning curve has been too short. Further, ENFOR Press is made for heat load forecasting, where the input load in this test has been electrical power of the main meter which is also including appliances. However, Figure 16 gives an overall picture of how it might look like for a forecasted electric power of the house. In general it should be discussed how to use load forecasting, how to convert heat load into electric power and in what context the load forecasting can be used.

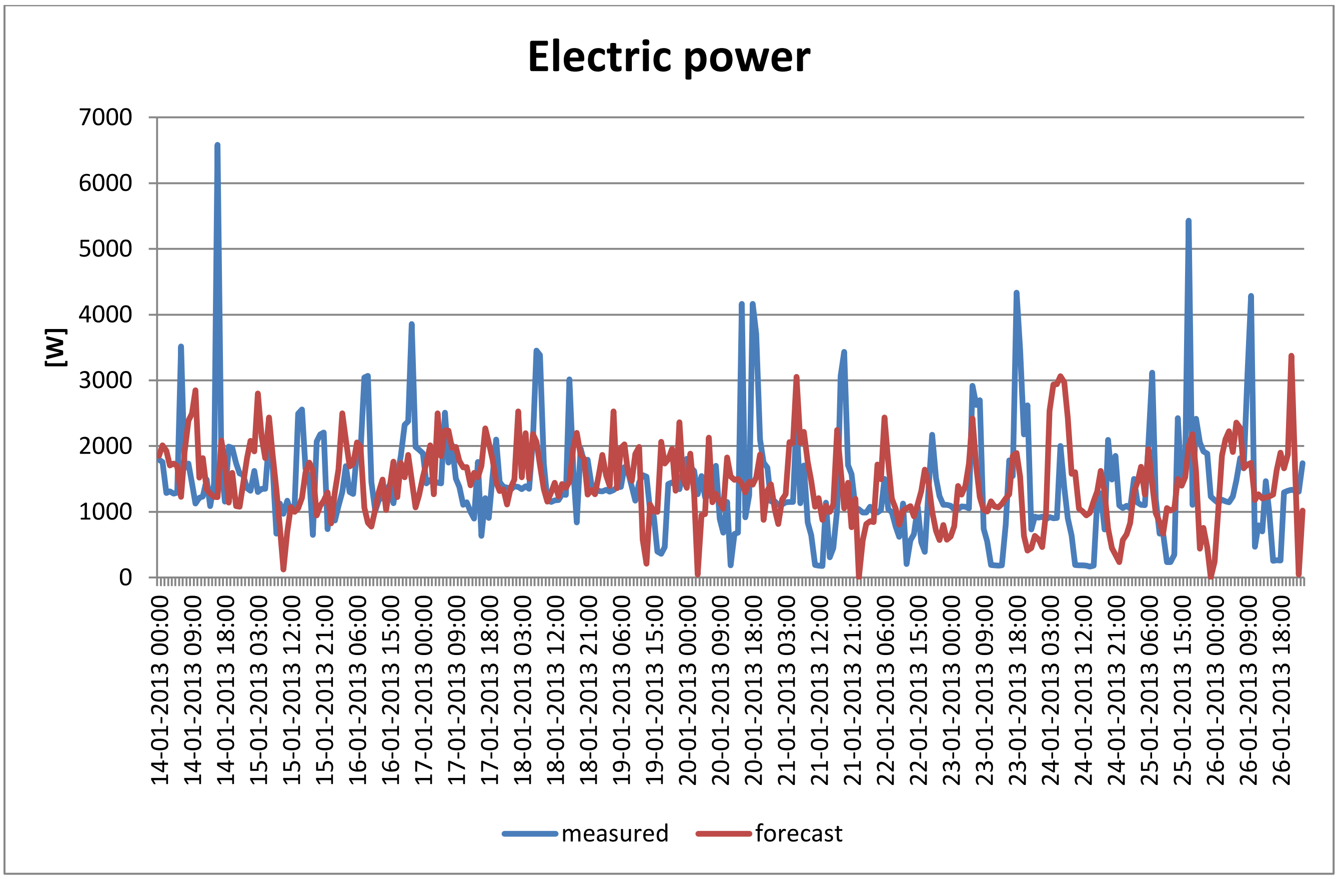

Figure 16: Electric power – forecast and measured – 14th of January to 27th of January

9 FEED-BACK FROM FAMILY

The family was not all the time satisfied with the indoor temperature but this was also the case before the test period began. The family was sensitive to fluctuations in the indoor temperature and was observant that the temperature did not fall below 22 degrees. At home in their own house they always have a constant temperature at 22 degrees with no fluctuations, according to themselves, and this was the ideal situation for them.

In EnergyFlexHouse it was not possible to have a constant temperature all time, since the house is very high insulated and airtight which results in the indoor temperature rising very easily, when the sun is shining. However, the case is not the same the other way around. When the outdoor temperature suddenly drops (e.g. as on 16th of January 2013), the indoor temperature also falls - because of the ventilation and higher heat loss and because the heating system is low temperature floor heating which reacts very slowly. Further, the heat pump capacity was limited as the electric resistance supplement heater was turned off during the test period. It can easily take half a day to reestablish 22 degrees after there has been a great outdoor temperature drop.

At Figure 17 the outdoor and indoor temperature in EnergyFlexHouse at the ground floor and the 1st floor are shown. The living room and kitchen is located on the 1st floor.

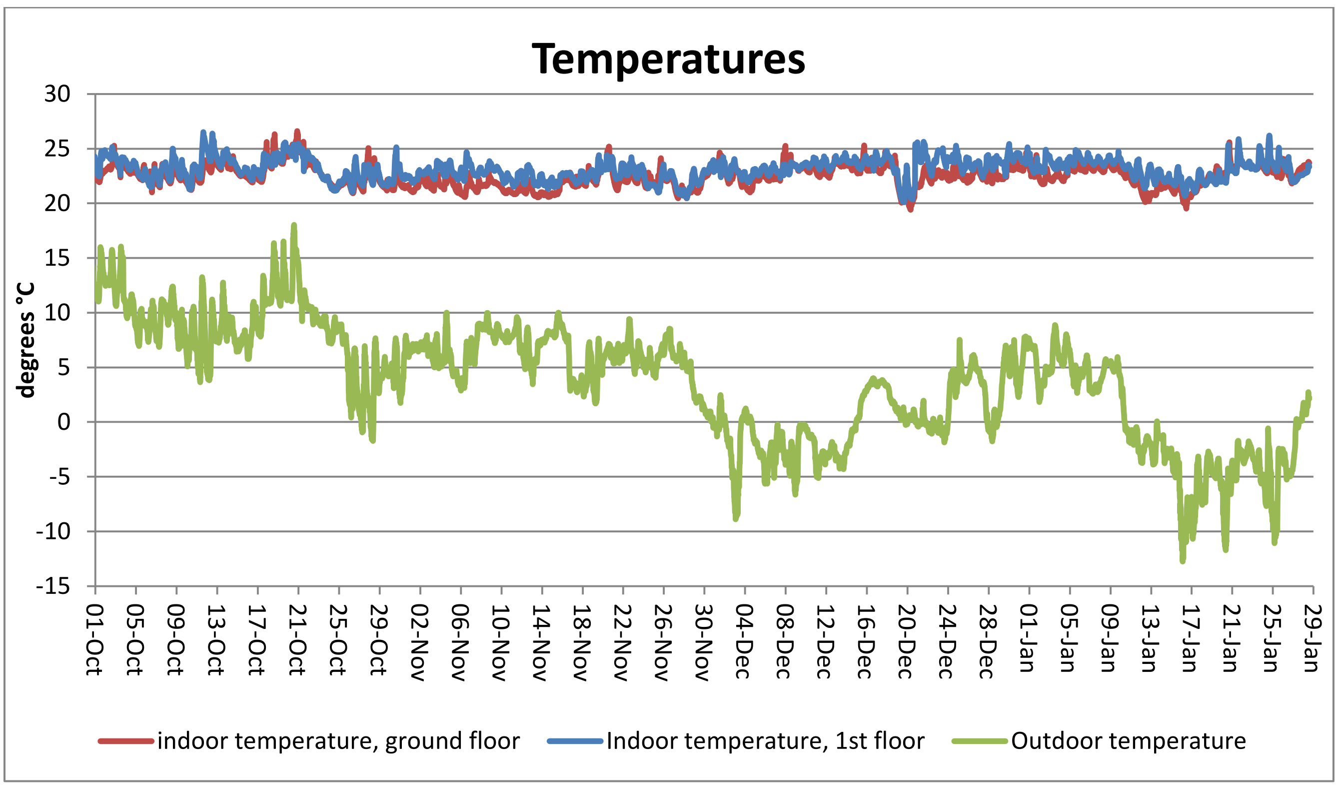

Figure 17: The indoor and outdoor temperature in the entire period

9.1 FAMILY OPINIONS – IN GENERAL

At the final interview, before the family moved back home, they again expressed their dislike of fluctuating temperatures. They felt, they could have 18 degrees in one room and 23 degrees in another. As seen on Figure 17, this was actually never the case: In the living room at the 1st floor the temperature didn't get below 20 degrees and the lowest temperature in the bedrooms, facing north, situated on the ground floor was 19.8 °C (measured with other equipment than the zigbee-equipment). The temperature was only below 20 degrees two times in the whole period, the first time was when the heat pump was out of order just before Christmas, and the second time was when the outdoor temperature dropped rapidly to under -12 degrees in the middle of January 2013.

This says that this family in general is not so adaptable to heat fluctuations and difficult to satisfy regarding comfort. One reason might have been they were able to see on the room thermostat displays every time the temperature dropped below 22 degrees. For them this situation was considered "freezing cold".

9.2 FAMILY OPINIONS - IN THE TEST PERIOD

Despite the complaints during their stay, the family did not take notice of indoor temperature fluctuations in the period were the heat pump was turned on/off which was the last two weeks in January, 14th of January to 27th of January. In this period, the family wasn't bothered with low temperature or fluctuations. They actually felt it was too hot sometimes even though the mean temperature value was 0.3 degrees lower in this period compared to earlier (23.1 °C → 22.8 °C).

Actually, windows and doors were sometimes opened by the family in this period to get temperature down.

9.3 CONCLUSION REGARDING BEHAVIOR

The feedback and the observations had among other things shown that:

- there can be a gap between measured and observed comfort
- too much focus on temperature comfort bands and the ability to actually see the measured temperatures of each room on displays might lead to a control regime, where the user will constantly check if the service is delivered
- some users might not be open to flexibility in room temperature at all (unless they do not know).
- sometimes there are other sources of discomfort, than what the use of the heat pump flexibility imposes (special weather situations, limited capacity of heat pump, complex energy service systems etc.).

It should be underlined, that in this test, the family has not had a real incentive e.g. economical, to accept fluctuating temperatures so the results might be biased by that.

10 PERSPECTIVE – WHAT IS NEXT?

A test facility with smart meters, sensors, heat pump and gateway was established in Danish Technological Institutes EnergyFlexHouse – a low energy house. Interface and backend was developed in order to communicate with the gateway and with an external forecast service. The functionality of the whole setup was tested with a very simple control strategy of timing the heat pump to turn on/off in specific time periods. A family moved into the house for the test period and gave valuable feedback on the comfort. Based on this the next steps should be:

1. Further develop the forecast service
2. Implement a controller based on the iPower research tasks, forecast service and price signal
3. Install equipment in more houses including houses of the older building stock
4. Proof of concept tests