Ea Energy Analyses

26-02-2013
NH, RB

Electricity demand as frequency controlled reserve – experimental results

Introduction

The power system frequency (present in all power outlets) reveals the energy balance in the synchronous electricity system. In order to control power system frequency and ensure a stable operation of the power system, transmission system operators use ancillary services. One of the important ancillary services is automatic frequency control (also called primary reserves), which reacts fast to frequency deviations. During the past one to two decades the quality of the power system frequency in the Nordic power system has decreased. As seen on Figure 1 the number of minutes pr. month that the frequency is outside the “normal” ±100 mHz band has more than 10-doubled over the six years.

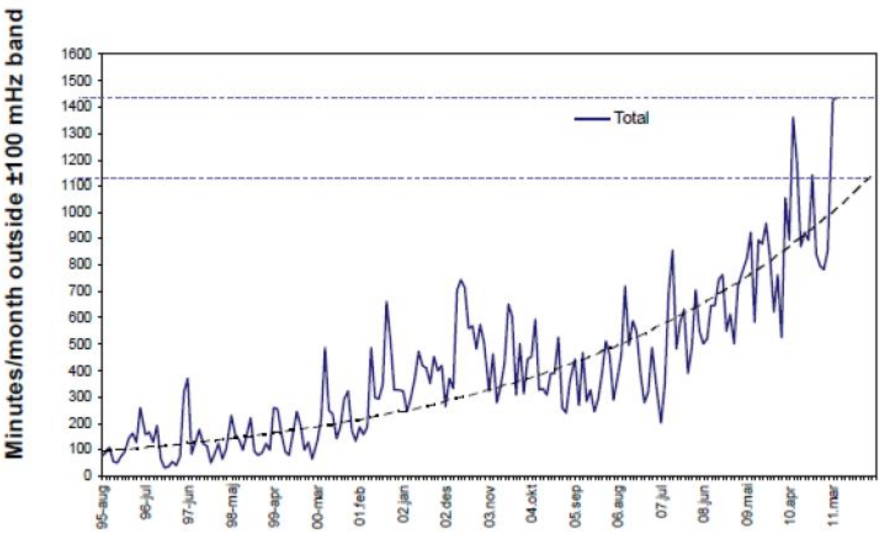

Figure 1: Graph showing the Nordic frequency quality. Development in the number of minutes/month that the frequency was outside the ± 100 mHz-band from summer 1995 to primo 2011.

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As renewable energy sources increase their penetration in the electricity market, some of the traditional providers of frequency regulation services, will be displaced, motivating the search for novel providers such as demand-side resources. The potential of using electricity demand as frequency controlled reserves has been investigated in Short et al. (2007), Lu and Hammerstrom (2006) and Xu et al (2011).

Demand side options include both reduction and increase of electricity demand as a response to frequency deviations. Decreasing frequency indicates an imbalance towards too little power generation, and thus disconnection of electricity demand can help to re-establish the energy balance in this case. On the other hand, higher consumption can help to stabilizing the system in case of overfrequencies.

Response to frequency deviations should happen quickly, i.e. with a delay of less than 1 second. Many underfrequency events have duration of less than 30 seconds – only the very serious events call for a disconnection of load for more than 1 minute up to maximum 10 minutes.

The pilot project on Bornholm

This paper presents the results of field experiments using demand as a frequency controlled reserve (DFCR) on 1) household appliances via an home automation unit: "Electronic Housekeeper" and 2) Devi electrical heaters in homes and offices with a Smartbox developed and programmed by Center for Electric Power and Energy (CEE) at the Technical University of Denmark. Furthermore the project includes field experiments with bottlecoolers and other appliances. These experiments and results are reported in Douglass et al. (2013). Read more about the pilot project on Bornholm in Centre for Electrical Technology, DTU (2008).

The first section describes the 22 electrical space heaters and their response as normal reserves and disturbance reserves as defined by the Nordic Grid Codes.

The second section will summarize the results and lessons learned from the experiment with 15 Electronic Housekeepers on Bornholm from 2011 to spring 2012.

DFR design

The electrical heaters used in the experiment are resistive radiators in private residences with a rated power consumption ranging from of 500 W to 2000 W. The resistive radiators are controlled by thermostats using a dead band around the desired temperature. The thermostat shuts off the radiator when the surrounding temperature rises above the high set point and turns on the radiator, when the surrounding temperature falls below the lower set-point.

The DFCR controller adds an offset to the set points depending on the system frequency. The set points are are thereby lowered in such a way that the thermostat turn off at a lower temperature than normal, making the radiator less likely to be on at low system frequency. The set point offset is proportional to the fall in system frequency.

The frequency controlled reserves are in the Nordel area divided into two subcategories: Normal Reserve and Disturbance Reserve. For the electrical heaters only the requirements for normal reserve were used in the experiment. The normal reserves are active in the range 49.90 Hz - 50.10 Hz.

The plot below shows an indealised control of an electrical heater with an average power usage of 225 W and a max capacity of 450 W. When Normal Reserves are active we would therefore expect the average power usage to reflect this with a linear frequency response in the 49.90 Hz - 50.10 Hz interval. The slope of the curve is proportional to the actual heat demand.

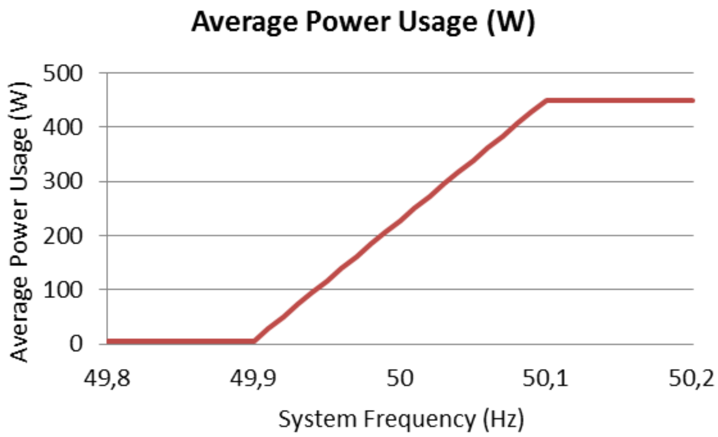

Figure 2: Average power usage under normal reserve of an electrical heater with a normal average power usage of 225 W.

DEVI Electrical Space Heaters

The DFCR system for electrical space heaters was deployed in 22 houses during January 2012. Data was collected during the period 2012/01/23 until 2012/12/14. Due to the complexity in deploying and validating the functionality of the DFCR devices only some of these devices will be part of the analysis of this report.

The DFCR systems consist of two parts: A commercially available thermostat for electrical space heater (DEVI, Danfoss), which has been modified to expose a serial port to an external controller, and an external controller ("Smartbox") which was produced for this experiment from off-the shelf components. The appliance modification was carried out by an electrician, but the firmware install and component test of the external controller was done by DTU. Due to logistics it was not possible to validate and test the external controller functions during the hardware installation. Because of this no valid data from 16 DFCR devices was collected during the research experiment, either because of defect installations or defect controller firmware. Only 6 devices will therefore be part of the analysis of this report.

Due to lack of heating demand during the summer period the focus of analysis will be on the period 2012/10/03 to 2012/12/19. The electrical heaters used in the analysis are resistive radiators in private residences with a rated power consumption of ranging between 500 W and 2000 W.

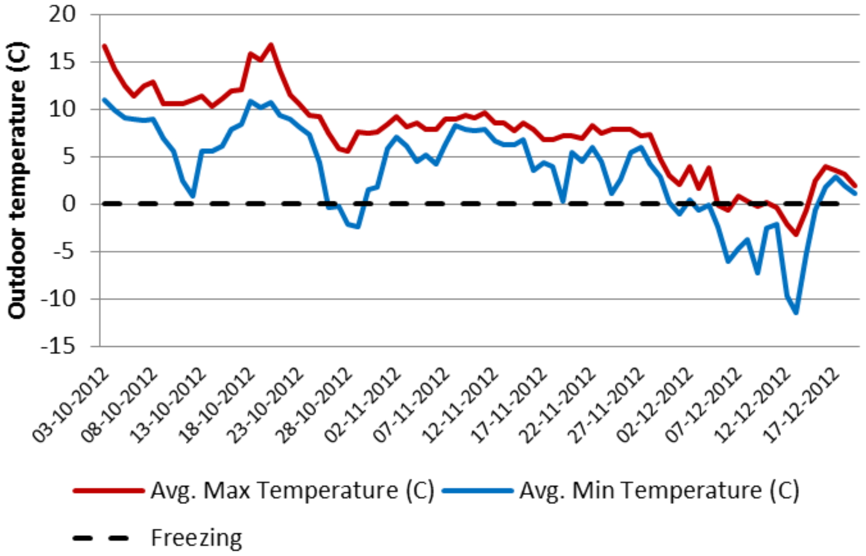

Figure 3: Daily outdoor temperature of Rønne, Bornholm druing the periode 2012/10/03 to 2012/12/19. [KILDE: http://www.bornholmervejr.dk/]

Data on power consumption and system frequency, as well as parameters specific to the appliance under control are sampled once per minute, and stored into a large internal memory. In addition, when a large frequency excursion occurs, data is collected at a high resolution (as often as every 2 seconds). This data is periodically uploaded to a database. All measurements are time stamped. The 6 boxes have an average of 2823 to 2888 measurement a day with a standard deviation of the number of measurements ranging from 128.5 to 25.2 during the period in focus. We therefore have a uniform an comparable data set for all days and all 6 boxes.

Since data is not collected uniformly every 1 minute the measurements are aggregated into 1 minute average values. Thus high resolution measurements are represented as an average over 1 minute.

The results

Since the rated power consumption of the electrical heaters varies the power consumptions has been normalised in such a way that all boxes have a normalised rated power consumption of 100 % full load

Several of the electrical heaters were used as a secondary heating source the primary being wood stoves, further electrical heating devices, or other types of heating. Due to this the electrical heaters were off at periods independent of the system frequency thereby impacting the average power usage.

We will start out by looking at all 6 boxes.

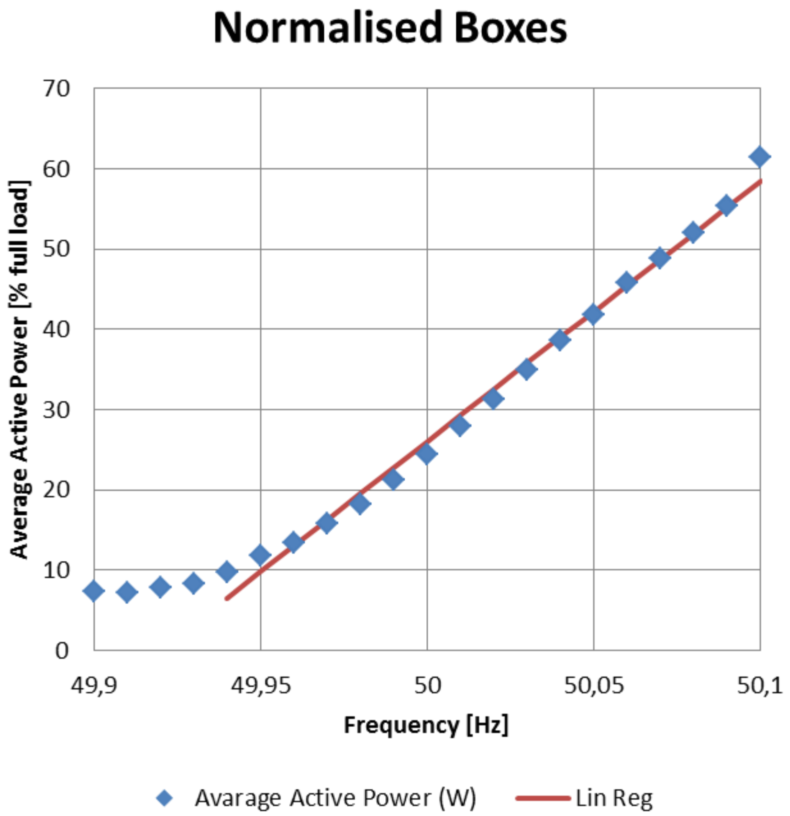

Figure 4: Frequency response of all 6 boxes with a normalised power usage. Average daily outdoor temperature: 5.5 °C.

The linear response is visible until 49.93 Hz. At this frequency value, the power consumption reaches 7 percent full load and cannot be reduced further. These last 7 percent can be due demand when the maximum disconnection time has been exedded. At 50.10 Hz, the average power consumption is 61 % full load, giving a frequency response equivalent to 54% of full load. The electrical heater should use the same amount of power with or without normal reserve, so the average power usage should be the same in the both cases. The average power consumption was 26 % full load, so by having a frequency response of 54 % the frequency response can be expressed as 0.317 % Full load/mHz seen as the best fit slope in Figure 4.

We then consider the same type of plot while deviding the data observation into two separate groups; a group containing all frequency and power usage observation while the outdoor temperature is below the average outdoor temperature of the observation period and vice versa. The power consumption of the low temperature period should be higher than the power consumtion of the high temperature period. This higher average power consumtion during the low temperature period should result in steeper slope of the frequency response and likewise a flatter slope during the high temperature period.

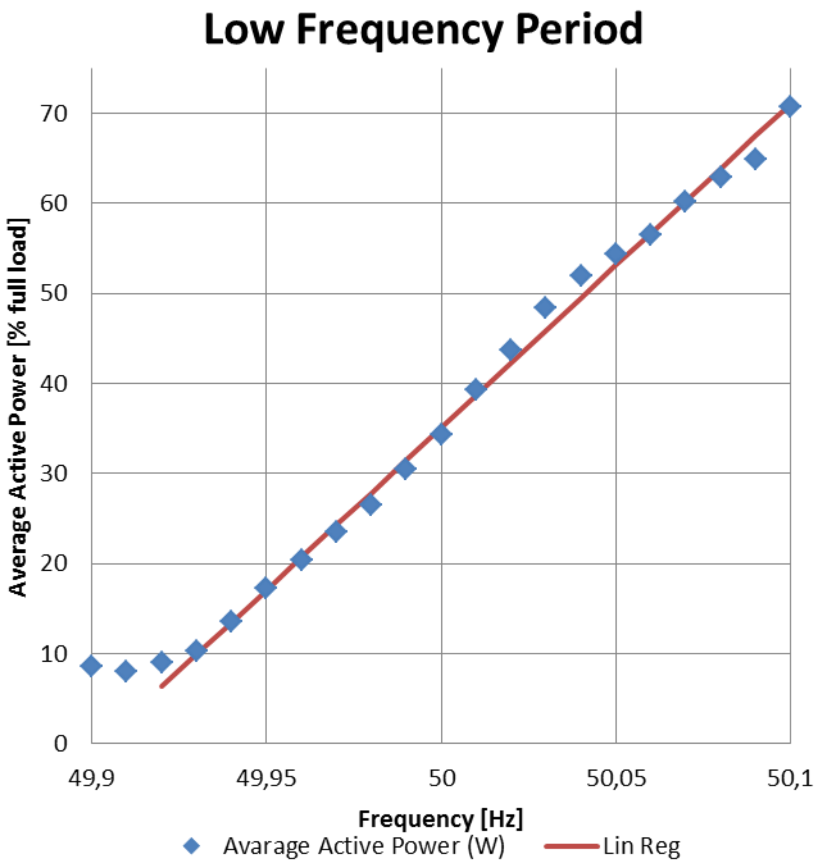

Figure 5: Frequency response of all 6 boxes with a normalised power usage. Average daily outdoor temperature below: 5.5 °C.

Here the frequncy response is visible down to 49.92 Hz and at 50.1 Hz the average power consumption is 70 %. This results in a frequency response of 63 % and can be expressed as 0.35 % Full load/mHz .

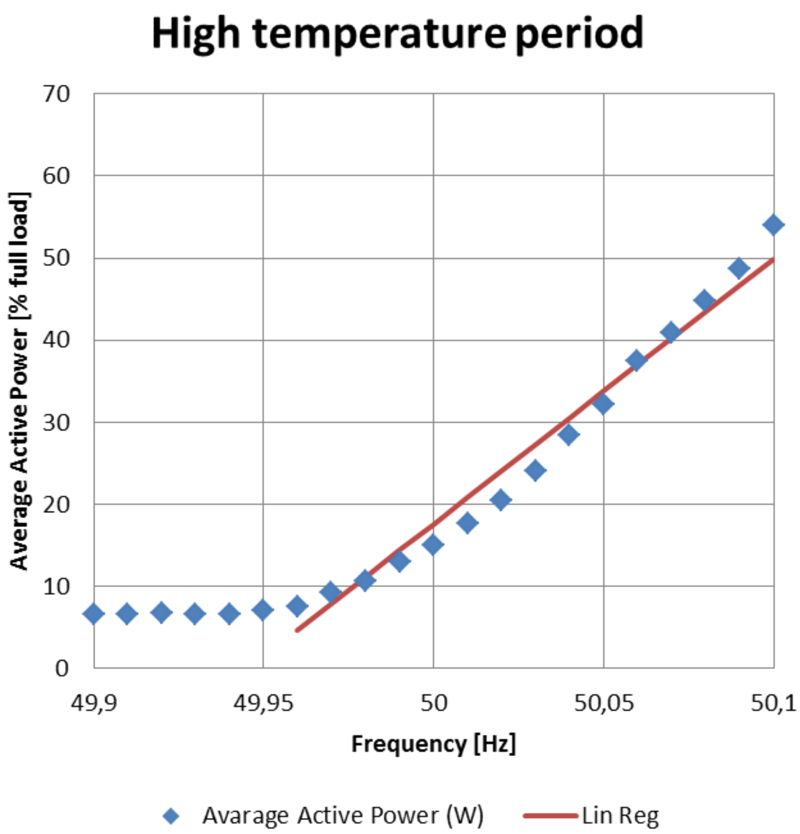

Figure 6: Frequency response of all 6 boxes with a normalised power usage. Average daily outdoor temperature above 5.5 ^{o}C.

Here the frequncy response is visible down to 49.96 Hz and at 50.1 Hz the average power consumption is 54 %. This results in a frequency response of 47 % and can be expressed as 0.385 % Full load/mHz .

Power consumption

From the result above, the boxes seem to provide the desired frequency response, but the question is: Is this a result of only a few boxes having great frequency response and the rest not at all? The first clear observation should be that the average power consumption at 50.1 Hz is not close to 100 percent full load (because a modest temepratiure in the period).

In order to analyse whether the 6 boxes all collect valid measurements, we will start by looking at the power consumption independent of the system frequency.

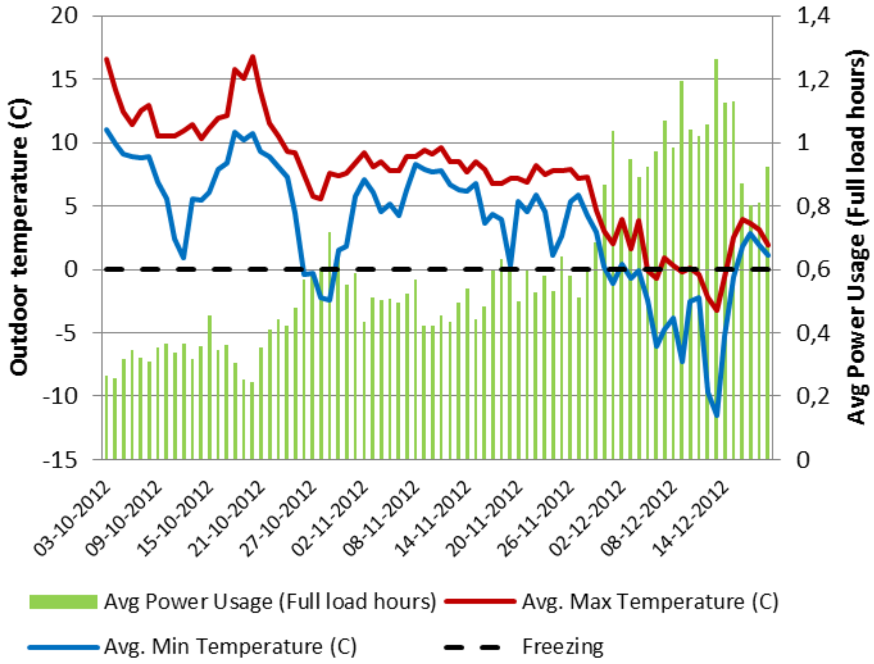

Figure 7: Outdoor temperature for Rønne (Bornholm) during the period 2012/10/03 to 2012/12/19 as well as the normalised average power usage of all boxes.

As seen in Figure 7 the power consumption of the 6 boxes corresponds to the outdoor temperature of the period, so the radiators are obviously on when they need to be. As mentioned above some of the electrical radiators are only used as a secondary heating source. This can be illustrated by comparing box number 2021 and 2042. The household of Box 2021 uses a wood stove as their primary source of heating and have the following power usage (see Figure 8).

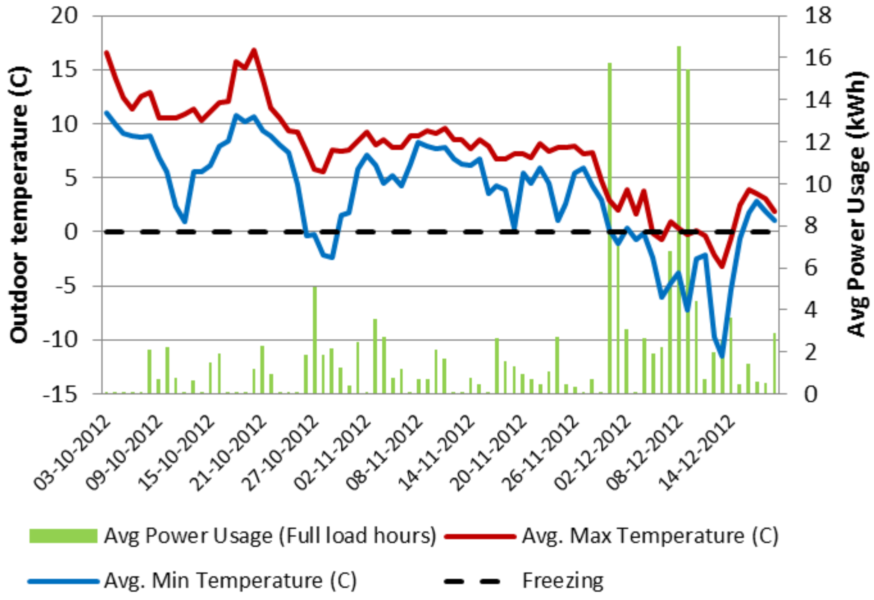

Figure 8: Average power consumption kWh/day of box 2012.

The household of Box 2042 exclusively uses electrical heating and have a measured power usage as shown on Figure 9.

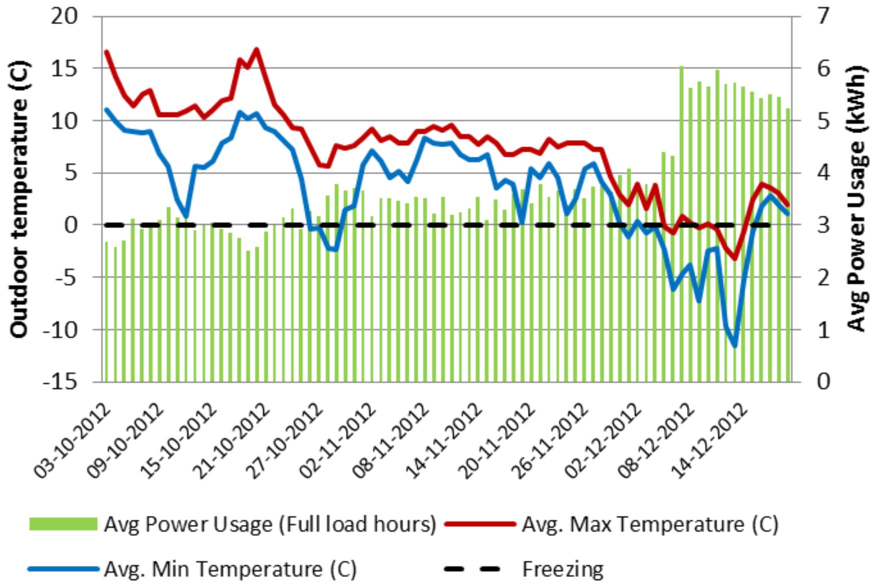

Figure 9: Average power consumption of box 2042.

This illustrates that these two boxes will have different influence on the frequency response.

To further highlight the relation between outdoor temperature and power consumption a plot of all outdoor temperatures can be observed.

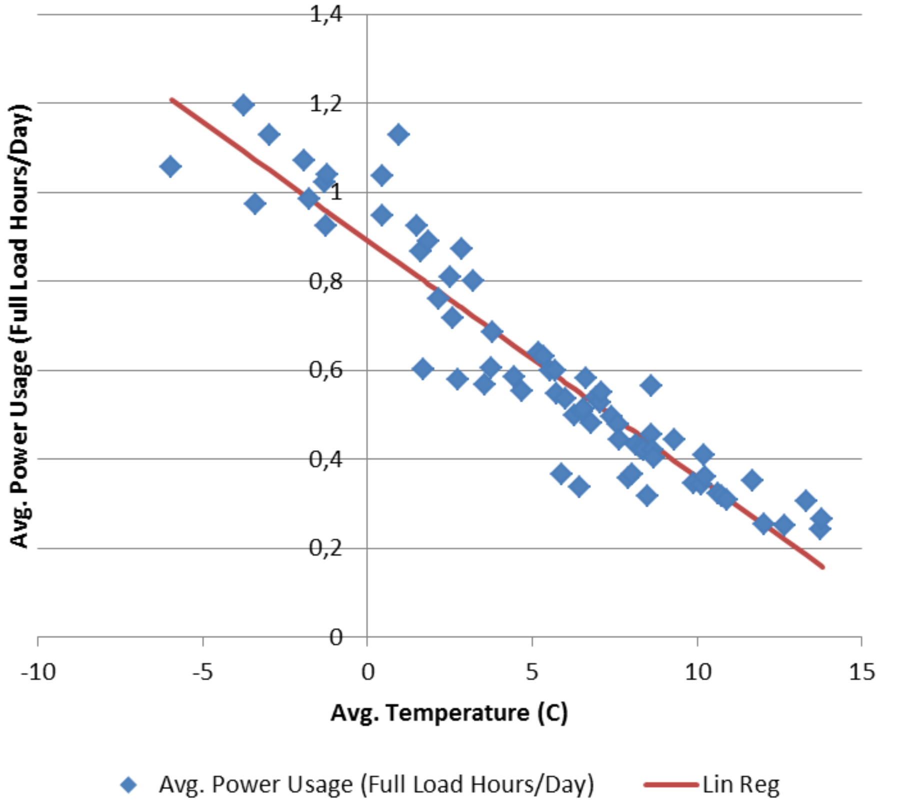

Figure 10: Outdoor temperature and Average power consumption from 2012-10-03 to 2012-12-19.

As seen in Figure 10 the average power consumption follows the outdoor temperature. This would then confirm that the boxes are collecting valid power consumption measurements.

Temperature and offset values

Next we will look at whether the electrical radiators react according to their temperature offset value. Below is illustrated the active power usage of Box 2037 as well as the ambient indoor temperature as measured by the thermostat during half a day mid-December (see Figure 11). As seen the temperature rises each time the radiator is on, and drops when the radiator is off.

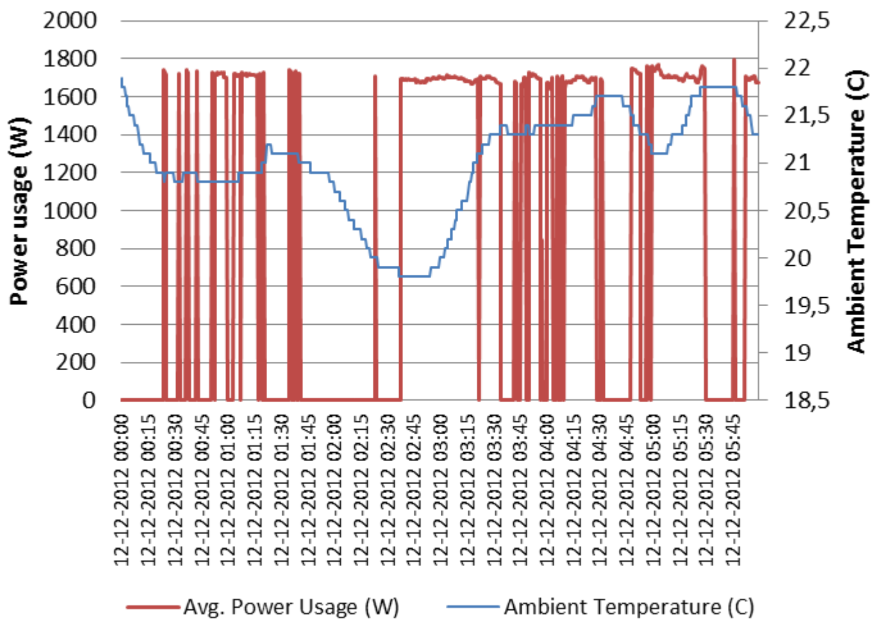

Figure 11: Power usage of Box 2037 as well as the ambient temperature measured by the thermostat

Zooming in on the first 6 hours of that period we now look at whether or not the thermostat actually switches on and off according to the set-point as they change dictated by the system frequency. The box changes the set-point with a precision of 1/10th of a degree. The result of this behaviour seen in the figure below.

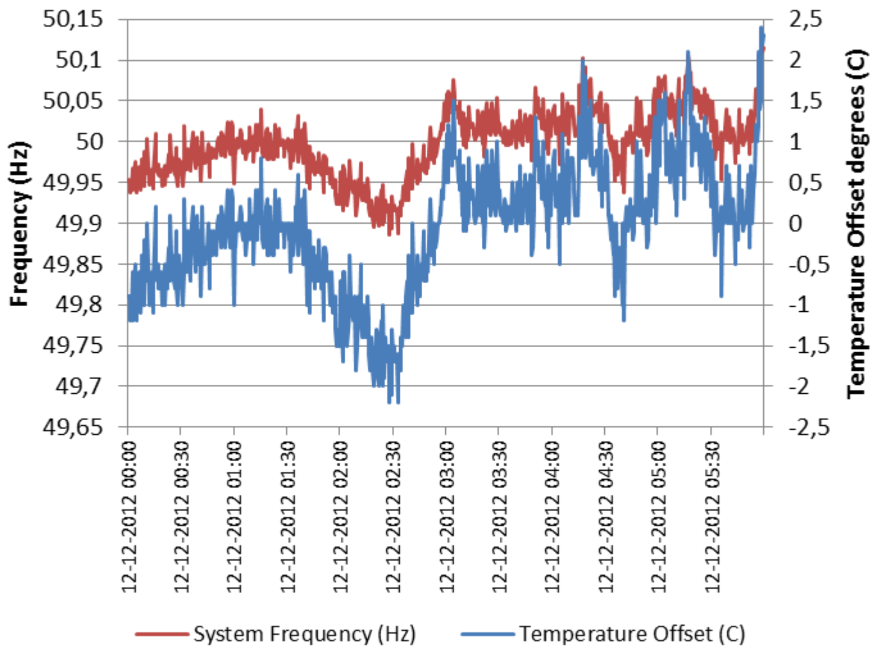

Figure 12: System frequency (Hz) and device offset values in ^{0}C

This offset is then added to the user defined set-point. In the figure below this shifted set-point is shown with an original set-point of 21^{o} C. Furthermore the ambient temperature and on/off indicator of the radiator is shown.

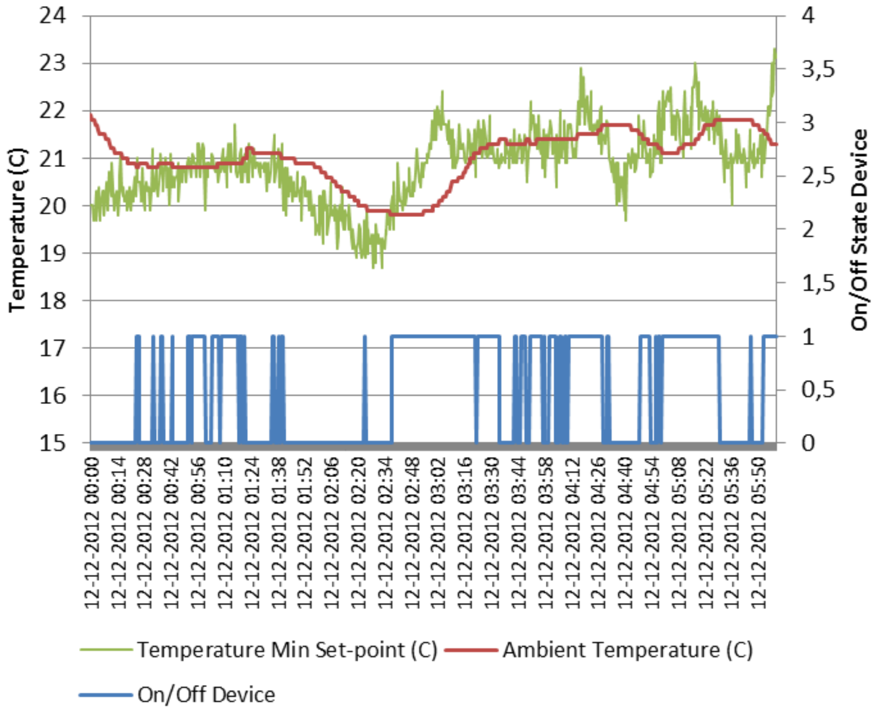

Figure 13: Temperature offset, ambient temperature, and on/off indicator.

As the temperature rises above the dead-band the device turns off.

Frequency

Turning back to the system frequency we will now analyse the behaviour and volatility of the frequency and how this affect the frequency response of the boxes and thereby how this potentially impact the user comfort.

Looking again at the frequency response of the average power usage of all the boxes as well as system frequency mass we get the following plot.

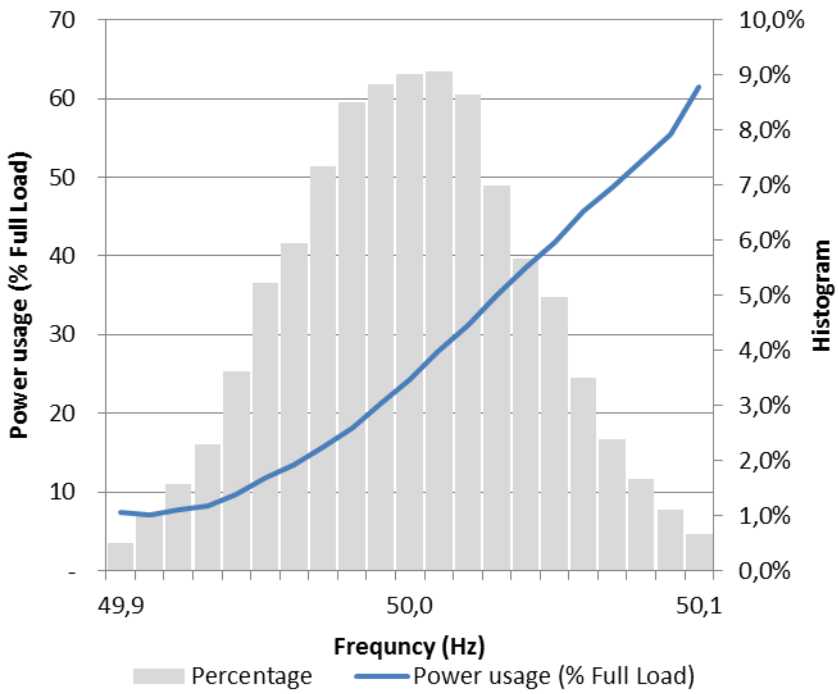

Figure 14: Histogram of frequency and frequency response.

From this we get that 98.4 % of the frequencies lie wihtin the interval 49.9 Hz and 50.1 Hz and 80.2 % lie within the interval 49.95 Hz and 50.05 Hz. 0.95 % is above 50.1 Hz, 0.58 % is below 49.9 Hz. This correspond to 1620 min/month outside the normal range (this should be evaluated against the data in **Fejl! Henvisningskilde ikke fundet.**).

Looking at the frequency response interval of the 6 boxes the normalised power usage quantiles come out as seen in

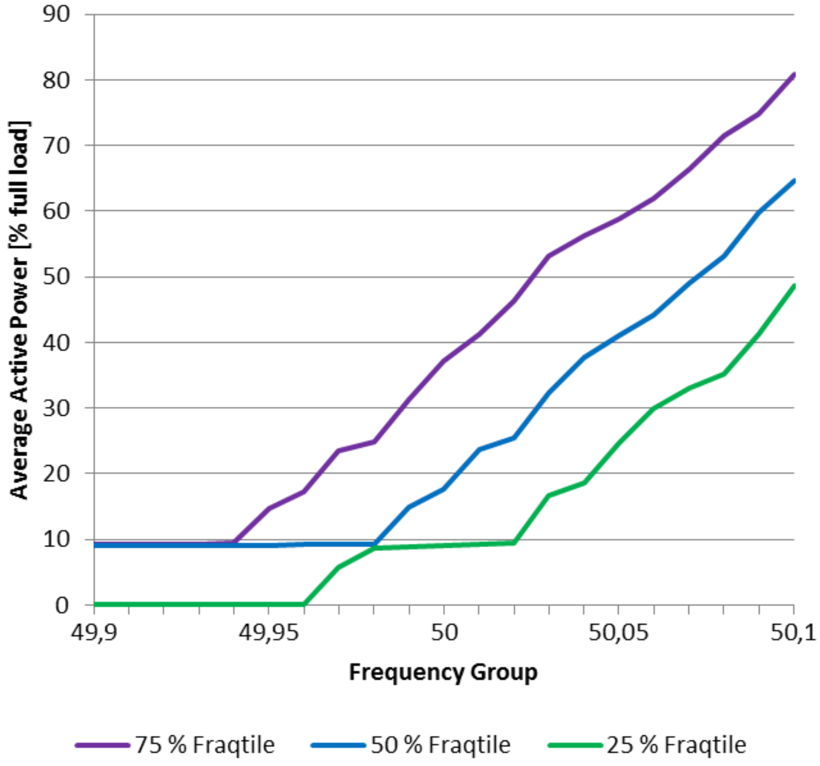

Figure 15.

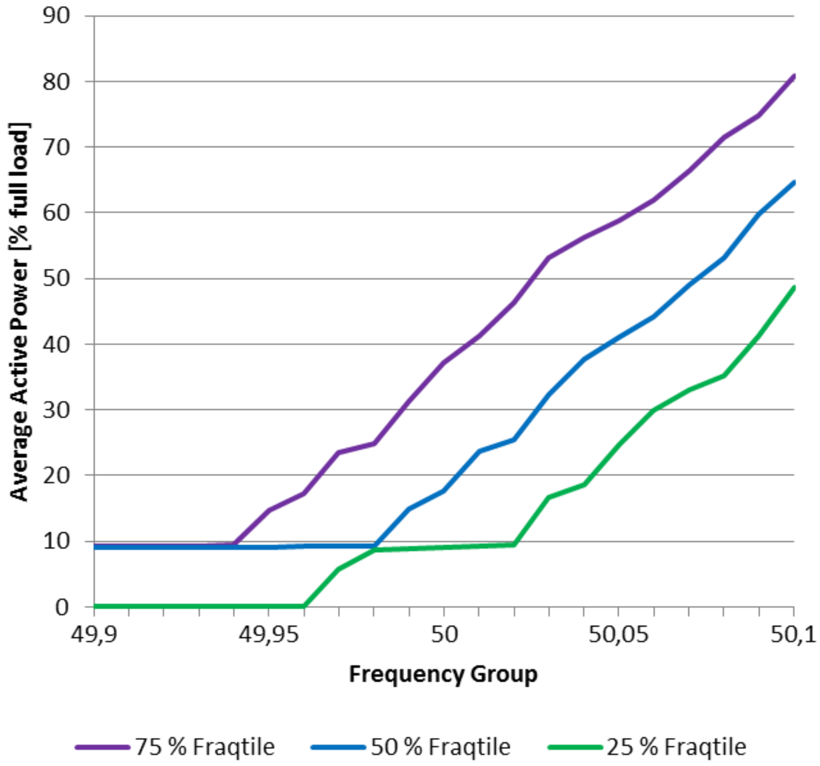

Figure 15: Power usage quantiles of system frequency group of 0.01 Hz.

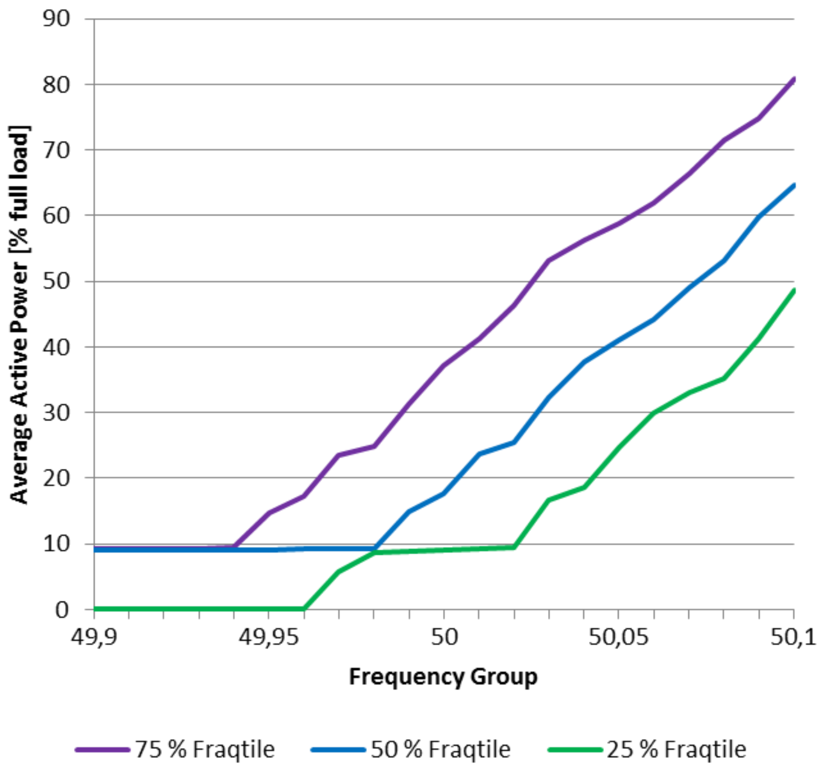

Figure 15 shows that regardless of variation in the load there is still a significant frequency response. As seen form the figure half of the meassurements at 50 Hz are between 9% load and 37% load. But at high loads (75 % fraqtile) as well as lower loads (25 % fraqtile) there is a clear linear frequency response. The lower loads can be because of the use of alternative heat sources, the heater temperature settings or the outdoor temperature.

Frequency correlation

How random are the measured frequency of the system and thus how big a role could frequency response play as a method to reduce frequency volatility? In order to analyse this we will perform a time-series analysis.

The correlation between the frequency in one minute and the frequency in the following minutes is calculated by the autocorrelation factor. If the corolation is 1 then the frequency is always the same. A low value (e.g. below 0.3) indicate little correlation.

The graph below shows that there is little correlation beyond 10 minutes, but frequency is auto correlated in the short term (0-10 minutes).

The relative rapid decrease of the correlation factor indicate the few demand problems would occur, e.g. in relation to electriv heating, where a typical time constant is in the order of hours.

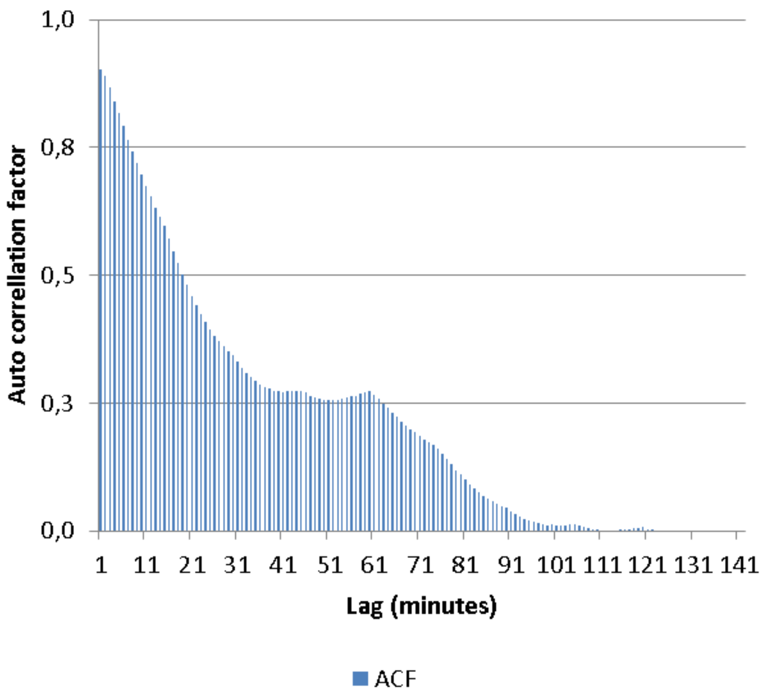

Figure 16: Autocorrelation of system frequency.

Time dependence and rebound effect

We expect a rebound effect on the power usage after a period of the heating being shut off. While the electrical heating has been turned off the room temperature will drop and thus there will be an additional need for heating in the period after. We would expect that if the frequency has been low (less than 49.98 Hz) in the previous 10 minutes, the electrical radiators would have been off relatively more often. This increases the probability of a higher power usage at the end the time interval rather in order to compensate for the drop in temperature. On the other hand if the average frequency has been high in the previous time interval we would similarly expect at lower usage power at the end the time interval in order to compensate for a relative rise in temperature (the heating is only off if the maximum temperature is reached and not because of frequency control). Thus the temperature in the room is affected by the history of the frequency.

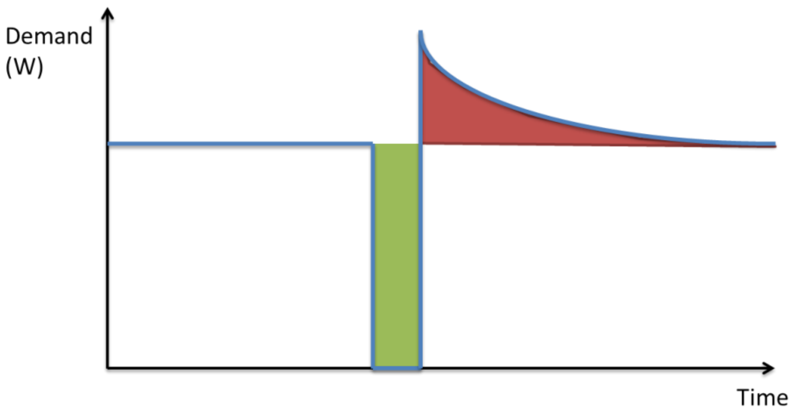

Figure 17: The electrical heater as an "energy storage". The green and red areas are expected to be more or less equal. Minor differences can occur due to change in efficiency and change in heat loss.

Frequency response would thus force the curve of a power usage versus frequency plot of the low frequency group (below 49.98 Hz) to be above the curve of the high frequency group (frequencies being above 50.02 Hz), and still show a frequency response for both curves (see section below, as weel as Figure 18, Figure 19 and Figure 20).

We then consider the actual system frequency at progressive time points of 5, 10 and 20 minutes intervals and compare these with the average power usage at these 5, 10, and 20 minutes progressive time points. This is shown in the plots below (Figure 18, Figure 19 and Figure 20). Only points with more than 25 observations are included.

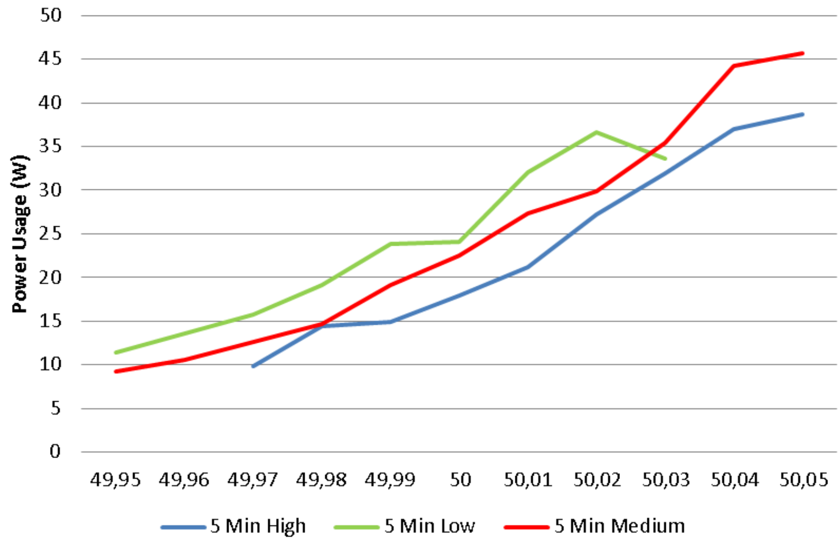

Figure 18: Rebound effect considering 5 minutes periods. Low < 49.98 Hz, Medium 49.98-50.02 Hz, High > 50.02 Hz

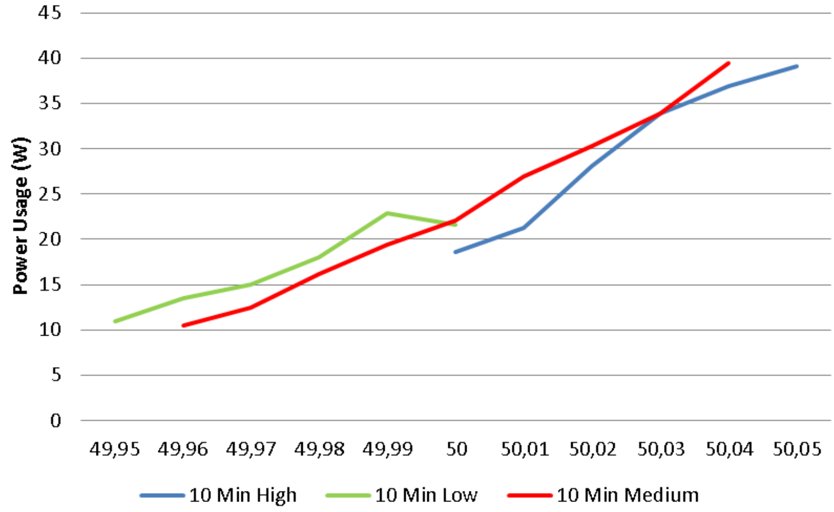

Figure 19: Rebound effect considering 10 minutes periods. Low < 49.98 Hz, Medium 49.98-50.02 Hz, High > 50.02 Hz

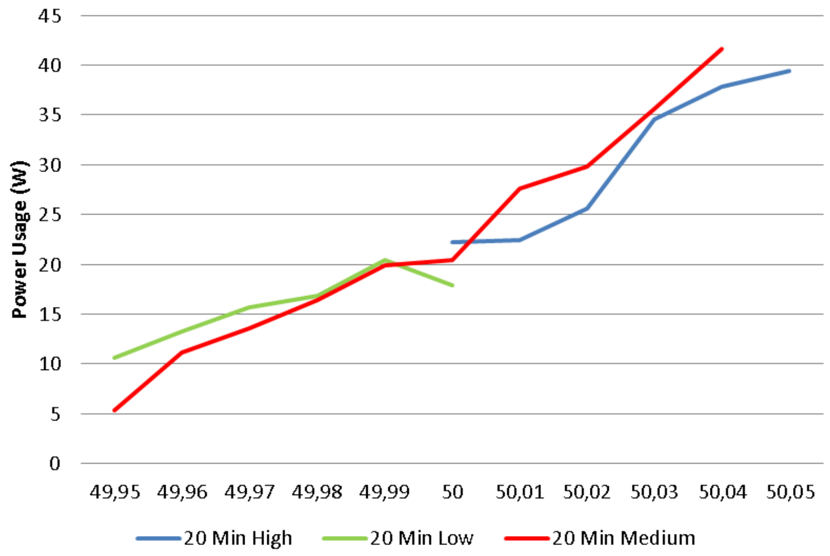

Figure 20: Rebound effect considering 20 minutes periods. Low < 49.98 Hz, Medium 49.98-50.02 Hz, High > 50.02 Hz

From these figures we see that rebound effect is present but that this rebound effect diminishes over longer time spans. Increasing the period span also reduce the number of high frequency observations after low frequency periods, as well as the number of low frequencies after high frequency periods.

Evaluation of the experiment

Electric heating is very relevant for the purpose of creating frequency controlled reserves. Electrical space heating is very influenced by climatic conditions and is thus only relevant during some periods of the year. Hot water production take place all year round.

As seen in Figure 4, Figure 5, and Figure 6 no frequency response was achieved for lower end frequencies within the normal reserve requirement. This seems to be correlated to outdoor temperature, and may suggest, that setpoint offsets should be adjusted according to outdoor temperature. In that case, frequency response is only linear for constant outdoor temperatures.

This experiment has demonstrated that the boxes are able to provide consistent and proportional frequency response. Regarding user comfort we have been in contact with all 6 participants whos Smartboxes are included in this analysis. The feedback we received was that they did not take any notice towards the boxes being in use and no change in confort was registrated. There have been no rigorous testing of whether the average power usage actually is the same with or without the smartbox. Also there have been no extensive survey of the user experience. Hence concluding that the user confort is uncomprised by this kind of frequency response would not be strictly supported by the experiment.

The delivered reserve is slightly affected by history of the frequency. If needed the effect could be minimised by adjusting the control parameters.

Some challenges have arisen during the experiment, especially exogenous influences on the power usage of the electrical heaters. Weather conditions and the presence of primary or secondary heat sources prevent the verification of whether an electrical radiator is off because of a low system frequency or other reasons.

Electronic Housekeepers

The main idea to include the Electronic Housekeepers (EHs) in the pilot project has been to demonstrate that an existing appliance and existing product (home automation) can be used for frequency control.

The software has been updated to include the DFCR-control. However, the marginal cost of including this function is zero for users that already have the hardware.

The principle of the EHs is very similar to the simple on/off-type of the DTU smart box (the external type):

- it switches power off when the frequency is low (it does not provide frequency control above 50 Hz)
- and switches power on again when the frequency is OK
- or when the maximum duration is reached

An EH consists of the EH-console and two Switchkeepers. See the pictures below.

Figure 21: The Electronic Housekeeper console and the two Switchkeepers

The Electronic Housekeeper is a console that can make it easy to switch off all electronic equipment and appliances in order to save electricity. It can also play music, stream online TV and send and receive SMS. It is a relatively simple plug-and-play appliance. The communication from the console to the Swithkeepers is wireless. The console requires electricity and a good wired internet connection.

The Switchkeepers measure the frequency and consumption and automatically disconnect and reconnect the appliances. It is a simple on/off switch – only dependant on the frequency. Thus it does not consider the temperature in the fridge any other settings of the appliance.

The two Switchkeepers (called SK1 and SK2) used in the research project are programmed differently. See the table below.

	SK1	SK2
Swith off frequency	49.9 Hz	49.85 Hz
Switch on frequency	49.93 Hz	49.92 Hz
Minimum duration of switch off	0.5 min.	4.25 min.
Maximum duration of switch off	5 min.	10 min.

Table 1: The settings of the Switchkeepers SK1 and SK2

As the SK2 Switchkeeper can be turned off for longer periods of time it is more suitable for devices with a compressor, such as refrigerators, freezers, heat pumps etc.

Data quality

The data collected from the EHs are in 2 series – one measuring the frequency and the consumption every 5 minutes and one measuring the frequency when an event occurs (when the Switchkeeper turns on or off).

The sampling period with 5-minutes values makes it difficult to document impact as many of the responses and reactions occur in seconds. Most disconnections are very short - the duration of the ”switch off” is less than 5 minutes.

Another issue is that many of the dataseries are flawed. There is a lack of consistency between collection of meter-data (5 minute measurements) and event-data. Sometimes the EHs have registered events without there being meter-data available (for weeks and months), or there are meter-data for longer periods without any events despite the frequency varying. Also it varies how many EHs are online. Some EHs are only online for very short periods during the research project. For the analysis we have tried looking at periods where as many EHs are online at the same time (20. February 2011 – 30. April 2011).

A small percentage of the data - 0,1% of total number of meter-data – have a frequency below 49 Hz or above 51 Hz. These flawed meassurements have not been included in the analysis. Also in some 5-minute intervals (0,1% of meter-data) the consumption was measured to be over 1 kWh for 5 minutes (equivalent to >12 kW effect). These has also not been included in the analysis.

When looking at a single unit it becomes evident that there are more errors. There are some double events where the same event is registered the same time twice. And there are examples of two ”switch off”-events in a row, without the unit being ”switch on” in the meantime. Also two ”switch on”-events in a row are observed.

In the design of the frequency control there where one reason for the unit to switch off:

- the frequency was measured to be under the “switch off frequency”

And two reasons for turning the unit back on:

- when the frequency has increased above the “switch on frequency”,
- or the maximum time for switch off was reached.

However if the time limit has been reached and the frequency is still low the unit will switch off immediately again. See the figure below showing the events of a SK1-unit and the frequencies. (More on this issue under “Evaluation of the experiment”).

It was the intention in the design of the EHs to protect the appliances with a minimum “on” time after disconnection. This could have been adapted to the individual appliance as in the case with some of the DTU Smartboxes. This is, however, a more expensive solution. It was included in the design, but unfortunately never implementet.

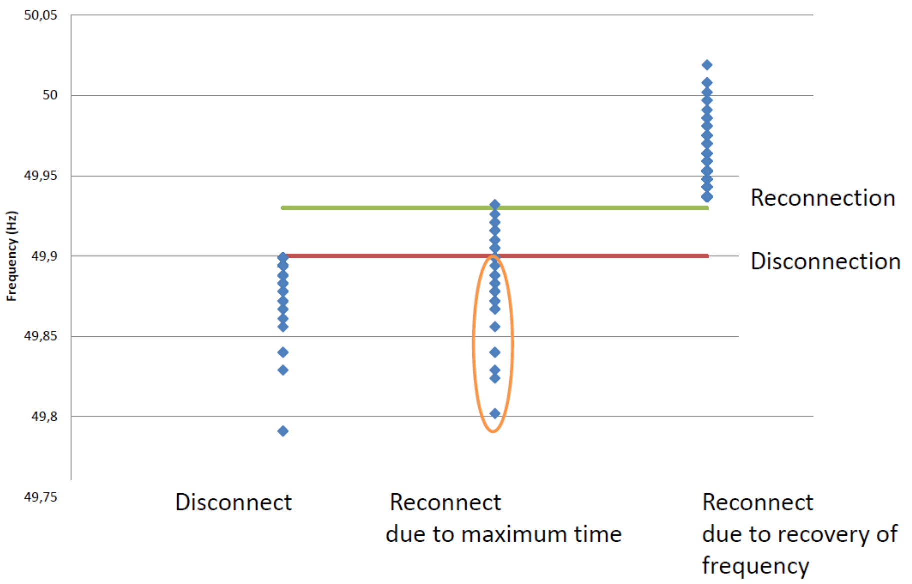

Figure 22: Example for an Electronic Housekeeper (SK1-type) connected to an electrical heater. 623 times the EH reconnected due to the time limit, however almost half the time the frequency was still below 49,9Hz.

The results

The goal of this part of the pilot project was to investigate the use of the Electronic HouseKeepers, thus the participants were told that they could connect ant type of appliance to the EH. Unfortunately there were a lot of problems with long disconnections in the early beginning of the project. Some of the equipment was flawed. The basement of one house got flooded as a submersible pump was disconnected and the content of three freezers were ruined. Luckyly two of the freezers were almost empty. This led to many participants choosing to connect the Switchkeepers to smaller and less important appliances, like lamps and even to the radio and ta a toaster.

Consumption

The average consumption of all the EHs is around 6 kWh/day per Switchkeeper (around 250 W effect per Switchkeeper). The graph below shows the daily consumption for all EH from 20th February 2011 to 30th April 2011. Many of the EHs have a relatively low consumption and only a few register a significant consumption in shorter periods. One Electronic Housekeeper is connected to an electrical heating unit and therefore has a higher consumption that all other boxes. This EH alone accounts for almost half the total consumption in the period.

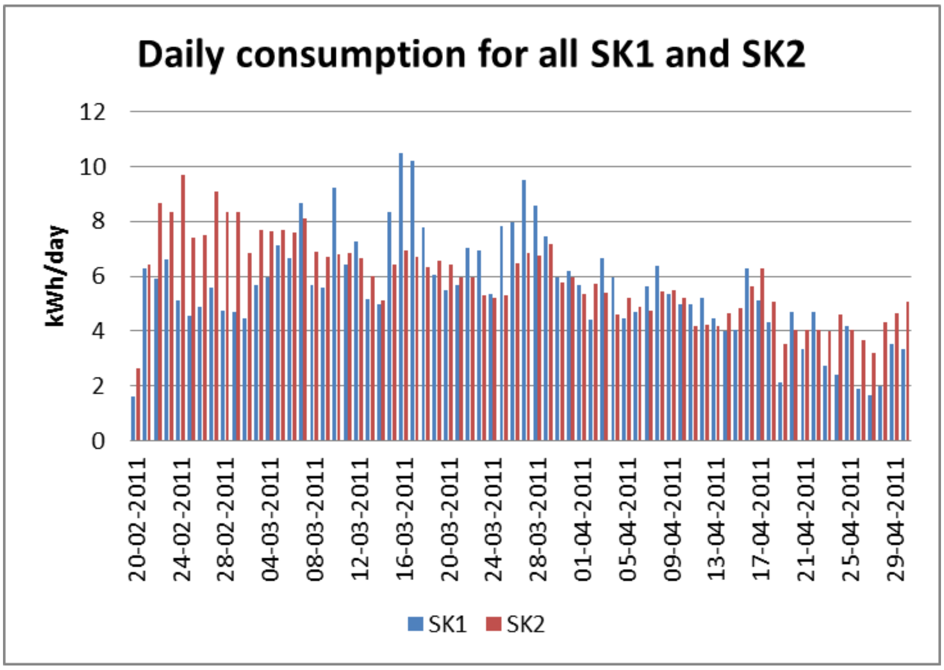

Figure 23: The consumption of all appliances connected to the switchkeepers SK1 and SK2 in the period from 20th February 2011 to 30th April 2011. This period is chosen as it was the period with

most EHs online and therefore one of the highest total consumption. Switchkeeper SK2 for the EH number 49e06 has a consumption of 2 kWh/day to 30 kWh/day in the week starting from 6th April.

There is a clear variation of the consumption over 24 hours for the EH connected to electrical heating, as the electrical heating is turned off at night and has a peak consumption when warming the hosue in the morning hours. However for the other EHs there is not a lot of variation – neither during the day nor during the year.

The units most suitable for frequency control is heating and cooling units as well as circulations pumps. Especially for heat pumps and electrical heaters there is be a significant variation of the consumption during the year. Depending on what type of appliances that will be regulated via frequency control in the future, the reserve might vary significantly in size.

Frequency

The graph below shows the frequency for all the EHs connected on the 5th of January 2011 in the 10-hour-period from 5:00 to 15:00. The frequency is measured every 5 minutes. As seen by the graph the frequency measurements are very close to each other. The variation can be due to small variation in the clocks. The standard deviation is usually below 0,05 Hz.

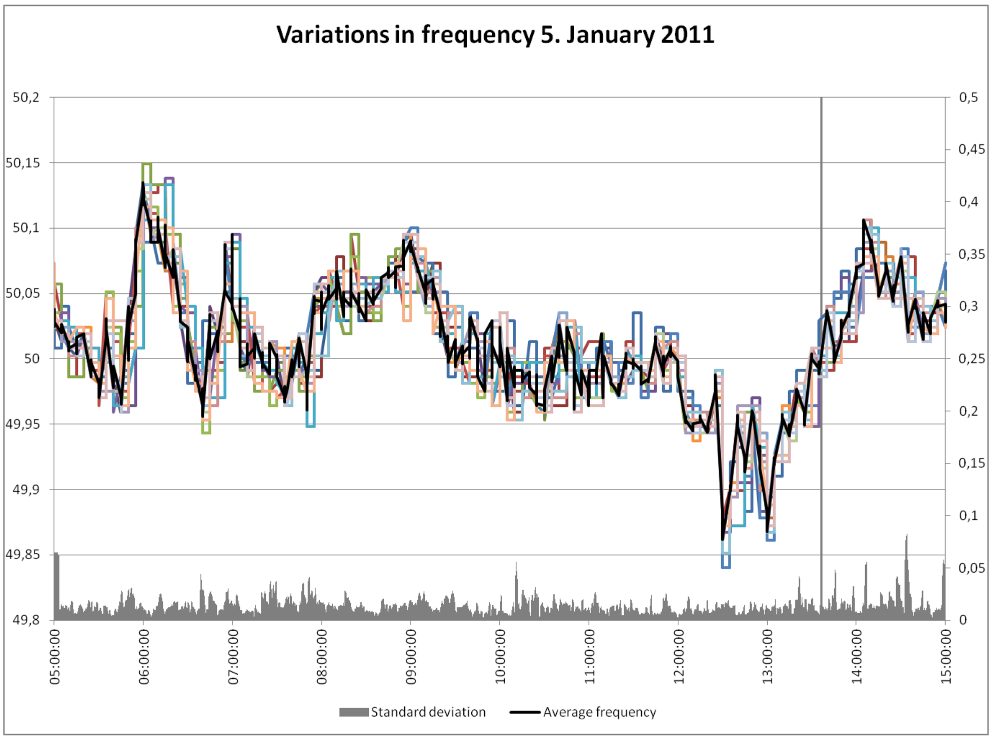

Figure 24: The frequency and the standard deviation of the frequency measured for the Electronic housekeepers.

The graph below shows the average power use for SK1 and SK2 units as a function of frequency. First of all it should be noted that the number of measurements with frequency below 49.9 Hz (or above 50.1 Hz) is very limited, thus the statistical significance is low for these frequency areas. As previously stated the average consumption of all the EHs is very moderate and some EHs are not used for longer periods of time.

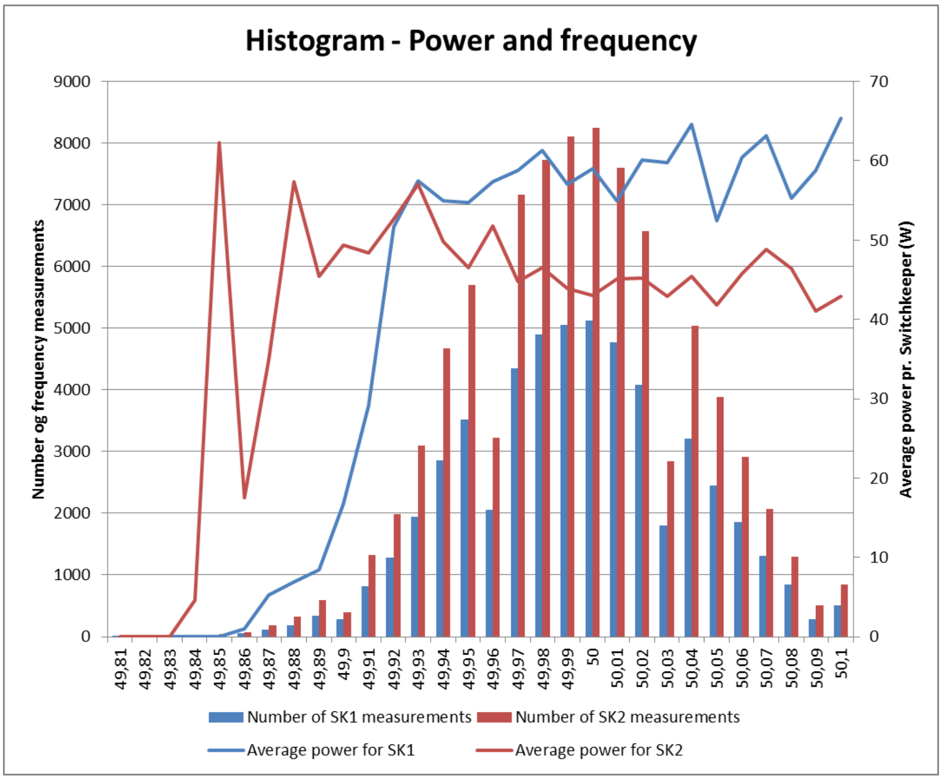

Figure 25: Histogram for 26 EHs (26 SK1s and 26 SK2s) in the period 2011-02-20 to 2011-04-30. The switch-off point for SK1s is at 49,9 Hz and for SK2s it is 49,85 Hz.

In theory the EHs should not have power consumption below the switch-off point for the Switchkeeper except when the maximum disconnection time is exceeded. For the SK1s this point is at 49,9 Hz and for SK2s it is 49,85 Hz. Above this point the average power use should be independent of the frequency (except for the rebound effect). The graph in Figure 25 confirms this theory, taking the statistical variations into account.

Examining the rebound effect

We have tried examining if we can find a rebound effect in the consumption for the Electronic Housekeepers. The rebound effect is an expected increase in the consumption after an interval where the EH has been turned off.

However because the consumption is only measured every 5 minutes, it is difficult to evaluate this. For example: for a specific Housekeeper, out of 3273 observations only for 17 observations the EH was off in more than 30% of the previous 5-minut interval. This leaves very little statistical significance.

Evaluation of the experiment

After the pilot project testing Electronic Housekeepers an evaluation form was sent out to the participants in order to hear their response to the experiment. 15 participants (out of 28) have responded to the questionnaire. Some did not respond as they only participated very shortly in the project. Most have responded that they found it interesting to participate in the research project – 7 people replied *completely agree* and 4 additional *agree* to this statement.

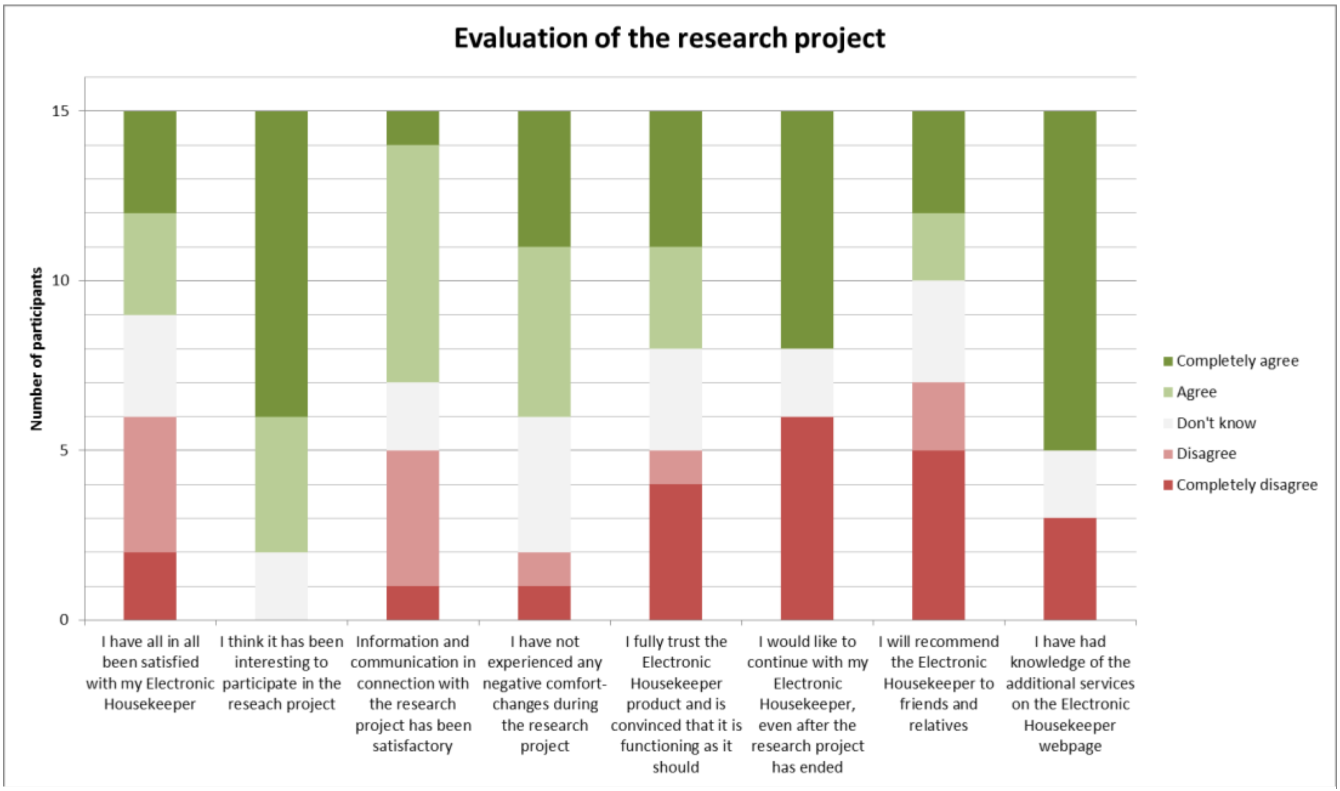

Figure 26: Results from the evaluation of the EH pilot project.

Even the respondents found the research project interesting, many of them where not thrilled about the Electronic Housekeeper technology. Three of the respondents noted that the Electronic Housekeeper product appears to be outdated - both the user interface, the speed and the stability. One of them suggested that an alternative with 'Ipad style' could be attractive. However the same participant also notes: ”Good radio”. Despite many technical problems the participants remained positive towards the project.

Four participants experienced problems with their freezer, fridge, and dryers when connected to the Electronic Housekeeper. In some cases the SK2-unit was defect and the problem was solved by changing the hardware. However the content of more than one freezer was ruined. These startup problems in the beginning of the pilot project led to several participants losing their faith in the Electronic Housekeeper. One participant notes in the evaluation that the EH was "an extra and unnecessary electricity consuming gadget". This participant felt that he was very aware of his electricity consumption and had no need for the Electronic Housekeeper. He participated in the project because he found the reseach project "beneficial for society and technical interesting". He also found that the EH switched his fridge off "rather often".

Another participant notes in the evaluation of the project that his radio (connected to a SK1 Switchkeeper) turns off rather often in approximately 30 seconds. Other times it can run for days without interruptions. He has tried finding a relation between the wind (and thus the assumed fluctuations in power production) and the disconnection of the radio (caused by frequency variations). But he found none. This example shows us that some of the participants have been very keen in following the electricity consumption and the research project. Despite problems with both the freezer and the submersible pump, the same participant is still optimistic and is happy to continue the research project, as he finds it interesting.

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