CERT Final Report

open energi
smart revenue generation

Contents

Introduction

The UK government Carbon Emission Reduction Target scheme is an obligation on energy suppliers to reduce the carbon emissions of their consumers by creating energy efficiency programmes. As part of the scheme, energy suppliers may contribute by sponsoring a 'Demonstration Action' to quantify the carbon-saving potential of cutting-edge, clean technologies. Open Energi is the provider of one such technology: its patented, "Smart Grid" **demand side energy balancing technology** has the potential to lower the carbon overheads of the UK electricity grid by supporting greater efficiency in fuel-burning generation units and – at large volumes – displacing them from the grid.

Under CERT, npower has sponsored Open Energi to carry out Europe's largest field trial of Smart Grid home appliances. Working with Indesit, Open Energi has enabled its technology in four fridge and freezer types covering 80% of the UK market and has installed a total of 1000 fridges in UK homes over two phases of the trial. Trial fridges have been under close observation throughout the trial period of May 2010 to March 2012 using home monitoring technology. In the larger second phase, trial participants were selected by demographic group, including Priority Group at 30% levels.

The trial has confirmed that energy balancing services can be provided to the UK electricity grid by fridges in UK homes and is judged to be a success. As a result of the trial, carbon savings attributed to each pilot fridge are estimated at approximately **1 tonne CO2 per fridge lifetime**[1]. This is equivalent to travelling by car for 3000 miles, or – for a common fridge-freezer type in the trial – 50% of the carbon associated with fridge lifetime electricity consumption[2]. Importantly, the trial showed that the smart fridge technology is robust when the fridge is in use, and gave information on how seasonality and time of day influence the level of contribution. Over the World Cup in 2010 it was possible to see live examples of "TV pick-ups" (half-time spikes in electricity demand) and provide key demonstrations of the technology in action.

Challenges were faced over the course of the trial. Notable difficulties were in obtaining customer engagement in the second phase of the trial for install of home monitoring technology. This resulted in a smaller set of fridges being fitted with the home monitoring device than anticipated. As of March 2012 most second phase fridges had been rolled out, and a good level of data had been reached, with more than 200 monitoring devices installed. A decision was taken jointly by Open Energi and npower to issue the trial report using the information gathered so far, supported by a strong result from the first phase of the trial.

This document provides a report on the findings of the trial, including a description of the data analysis and carbon saving calculation, and learning points obtained. The report is supported by an independent review of the trial, authored by the energy consultancy firm KEMA, providing a detailed audit of the data set used and confirming the trial results (see Appendix B).

[1] This estimated carbon saving has not been confirmed by Ofgem.
[2] As estimated by the National Energy Foundation, 1 MWh domestic electricity consumption at a typical generation mix creates 0.5 tonnes CO_2 emissions.

How the Technology Works

Open Energi's patented technology allows energy storage appliances such as refrigerators, hot water systems and air-conditioners to provide an energy-balancing service to the grid System Operator. Grid balancing is provided by a reserve of power available for bi-directional, real-time adjustment and ensures stability of supply in the face of generation losses, or unpredictable surges in demand or supply. The grid system frequency is an indicator of supply and demand imbalances; the System Operator (National Grid in the UK) must maintain the system frequency to within 1% of 50 Hz by utilising balancing services.

Due to a lack of storage capability, balancing services on the electricity grid are currently provided by a mix of coal, gas and hydro-generation plants that can adjust output in real-time. The mechanism for providing this output adjustment is known as "governor frequency droop control": when grid frequency moves above the target of 50 Hz, generation output is proportionally reduced; when grid frequency moves below the target of 50 Hz, generation output is proportionally increased.

Such a service can be provided by altering the demand on the grid in a similar way. Open Energi's technology reads the grid frequency of power supply to an appliance and adjusts its power consumption accordingly. When grid frequency increases, total demand from Open Energi-enabled appliances is proportionally *increased* to absorb the surplus energy. When grid frequency decreases, total demand is *decreased* to deliver energy back to the grid. This is achieved by adjusting the timing of electricity consumption where the appliance permits it. Operation of the appliance is not altered; for the refrigerator this means that food stays cold and is not frozen, in line with user-defined set-points.

In Figure 1, an example is given – from the trial – of the technology in action. During the World Cup of 2010 a large number of people watching the games posed a potential problem for National Grid. At match half time, a large increase in demand was expected, as people took the opportunity to e.g. make a cup of tea, flush the toilet or turn on the lights. National Grid prepared for this spike in demand by scheduling a surplus of generation on the grid. As a result, the grid frequency started to increase. The response of the fridges was to turn on and store the extra energy, ready for use. At the start of half time, the surge in demand caused the frequency to drop suddenly. The trial fridges decreased their consumption in turn, putting energy back onto the grid.

At sufficient scale, this behaviour helps to stabilise the grid system frequency. Such demand side technologies will be key in the electricity grids of 2020 and beyond, as intermittent wind generation is increasingly added to the generation mix.

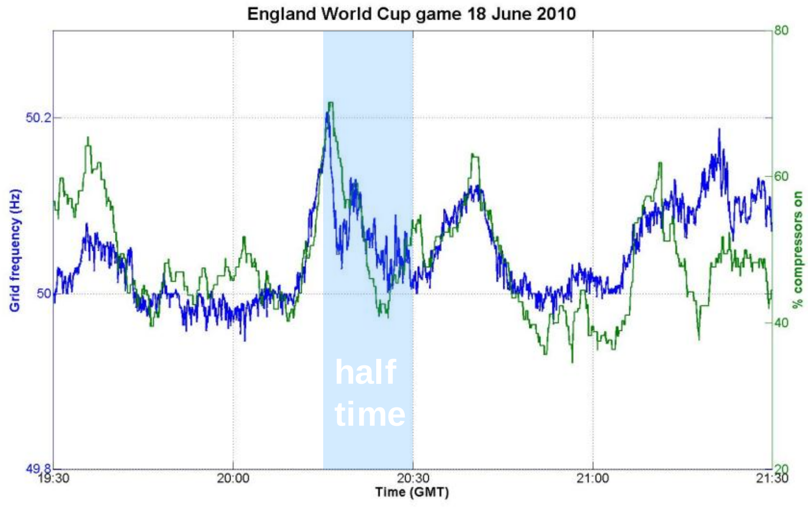

Figure 1. Frequency tracking over England World Cup game 18 June 2010.

Trial Description

Trial Phases

The trial fridges are of four model types:

- the No-Frost Combi Fridge-Freezer (with automatic defrost);
- the Static Combi Fridge-Freezer (without defrost);
- the Upright Freezer; and
- the TableTop Fridge (fitting under a kitchen counter).

The first phase of the trial was for 300 No-Frost Combi fridges installed in UK households. Approximately 280 households were fitted with home monitoring systems (see below) and the first phase data collection period ran May – October 2010.

The trial size for the second phase was set at 390 Static Combi fridges, 180 Upright freezers and 80 Table Top fridges, making a total of 650 further fridges in the trial. These fridge models were all expected to be equipped with home monitoring systems, using a period of 6-12 months of data to obtain a trial outcome. The original plan required that all fridges and home monitoring devices be installed by end of December 2011 in order to meet CERT timescales.

Changes were made to the plan as a result of third party delays and other delivery challenges faced. Third party delays resulted in a late start to the home monitoring system roll-out (September 2011); additionally it has been difficult engaging with trial participants to install home monitoring technology - contact coming many months after the trial launch date - and roll-out progress is slow, requiring a further 12 months to hit the original target.

As of March 2012, a majority of Static Combi and Upright Freezer units have been installed in participant homes, with the Table Top fridge waiting on npower marketing communication to begin roll-out. More than 200 home monitoring devices are installed in the field[3]. In order to meet CERT timescales and remain in budget for the project Open Energi froze the data set on 16 March 2012 and issued this report at the end of that month. To minimise disruption, Table Top fridges continued to be installed with trial participants as planned.

In spite of changes made, a strong result is available for the second phase for two of the three second phase fridge models, with field data allowing verification of initial estimates and 6 months' data available to confirm the seasonal and user effects witnessed in the first phase of the trial. For the TableTop fridge, initial laboratory estimates are used to obtain a carbon saving estimates, drawing on the fact that for the three field-tested fridge types lab estimates and field estimates are consistent (to better than 10%).

[3] As of 16 March 2012, 377 units, 134 home monitoring systems are installed out of 390 Static Combi fridge-freezers; 119 units, 81 home monitoring systems are installed out of 180 Upright freezers.

Trial Architecture

Open Energi's demand side technology is embedded in the fridge electronic control board and acts autonomously to provide an energy balancing service – see Figure 2. For the purpose of the trial only, the fridge was also fitted with a home monitoring system to report back to Open Energi's server database. In this way a large-scale data collection exercise allowed service levels to be measured over the trial duration.

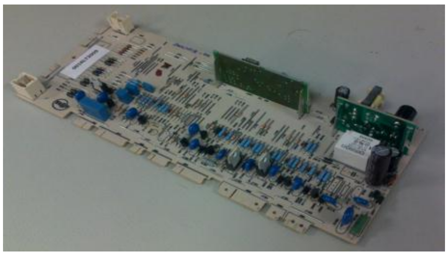

Figure 2. Open Energi-enabled Indesit Fridge Control Board.

The home monitoring system is made up of three additional components:

1. A "hardware key" serial interface between the fridge and the monitoring device. This component was developed by Indesit to protect the fridge electronic board from the data requests of the monitoring device, and acts as a RAM memory buffer.
2. A "Remote Energy and Data Monitor (READm)". This passive monitoring device was developed by Open Energi for the purpose of the CERT trial and connects to the fridge hardware key to gather data such as fridge temperature and door state. The fridge plugs into the READm, which also acts as a smart meter. See Figure 3.

Figure 3. READm.

3. HomePlug 1.0 power line communications, allowing communication between the READm through the home internet router to the Open Energi server database. This home network technology is in common use and was bought off the shelf.

With the home architecture described above, the READm is able to communicate to Open Energi's secure server.

Trial Participants

For the first phase of the trial, participants were mainly npower employees and housing association tenants. For the second phase of the trial, a larger pool of trial applicants allowed selection by demographic group. In consultation with the Energy Savings Trust, Open Energi designed fridge owner selection criteria to capture the spread of fridge behaviours relating to technology service levels, namely: fridge temperature settings, fridge contents, fridge usage (door opening profiles associated with meal-times and TV habits), ambient temperature and household occupancy levels.

The key factors affecting these variables were judged to be the number and age of people in the household. Also identified as important was household affluence, which is known to affect attitudes and household habits as well as energy consumption, and might affect fridge usage. The trial selection criteria also targeted a quota of 30% Priority Group applicants (benefit recipients and likely fuel poor) in the proportion they are found among the UK population.

Different fridge models are accounted for by creating three matched samples with equal sized groups according to the following criteria. Priority group was targeted at 30% levels. A reserve list of 50% in each final category was held in order to account for withdrawn applications. Categories used and an example selection path is shown in Figure 4.

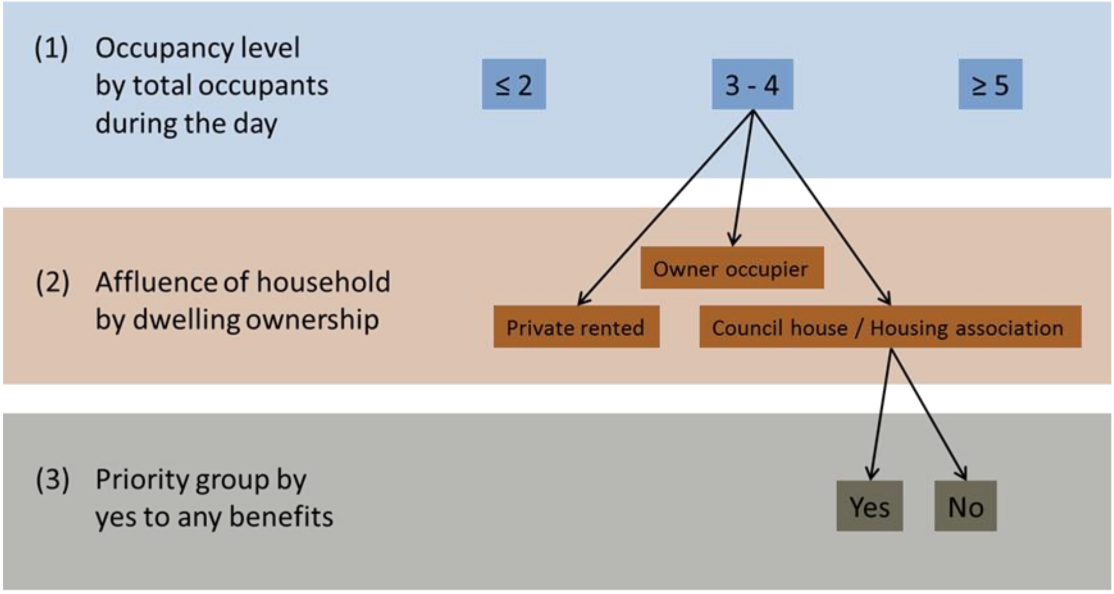

Figure 4. Selection criteria of demographic groups.

Carbon Savings Calculation

Carbon saving via Open Energi's demand side energy balancing services is made at the level of the electricity grid, rather than at the level of the home user. Indeed, the home user will see no change to the electricity bill, and – with an embedded, autonomous-acting technology – is not required to alter behaviour in any way. Open Energi's technology saves carbon on the electricity grid by displacing energy balancing reserve from fossil fuel generators.

For coal and gas plants, the carbon footprint of maintaining reserve for balancing services is separate from the carbon associated with burning fuel for power generation. For example, a coal plant will convert fuel to electricity at an optimum efficiency setting, with a given carbon footprint. In order to provide bi-directional energy balancing the generator must operate at a sub-optimal setting. This additional inefficiency has a carbon footprint of its own, which can be offset by removing the balancing function from the generator and replacing it with a zero-carbon, demand-side service such as Open Energi's.

An estimate of the carbon footprint associated with this additional inefficiency is provided by the energy consultancy firm KEMA (see Appendix A), who are also providing an independent audit of this trial (see Appendix B). Using information from National Grid, KEMA estimated that **1 MW of generation reserve will waste 2,276 tonnes of CO_2 per year** (see Appendix A for more details). Typically for generation providers, this reserve is bi-directional: the generator is part-loaded and able to increase or decrease output. From the trial, the average bi-directional reserve "capacity" provided by a trial fridge over a 15 year lifetime, incorporating typical use conditions, over different seasons, and over a mix of household demographics, is converted into carbon using KEMA's estimate.

Measuring capacity from the fridges over the course of the trial is analogous to the case of another energy balancing provider: pumped storage. This provider uses electricity at times of surplus supply to pump water into a storage reservoir at a high location. When grid frequency falls from 50 Hz, water is released from the reservoir and generates electricity through the gravitational force of falling water through a turbine. To measure the service capacity of the pumped storage mechanism over any period of time, one must measure the potential energy in the water reservoir over time and add it to the electrical energy released day-by-day for balancing service provision. This number is then offset by the amount of energy used for pumping the water back again.

Fridge service levels are measured in a similar way. The time a fridge spends available for response is the 'reservoir' or availability, and the time spent responding to the grid frequency is the electrical energy released for balancing services. These two quantities are averaged, scaled by the fridge motor consumption and added together to create a single capacity number in Watts. Unlike the pumped storage, no additional power consumption is required to create the capacity as the fridge thermostat does that on its own. The calculation is described in more detail over the rest of this section.

Carbon Savings Calculation

Carbon savings per fridge is given by the following equation:

$$Carbon\ Savings[tCO_2] = Carbon\ Coefficient\left[\frac{tCO_2}{year\ \cdot W_{reserve}}\right] \cdot Capacity[W_{reserve}]\ \cdot ApplianceLifeTime[years]$$

Carbon Coefficient

The Carbon Coefficient is the reduction of CO_2 emissions per year, per unit of reserve capacity provided by Open Energi's demand-side technology. As described above, the idea behind this coefficient is that the capacity for response (in MW) provided by a population of smart fridges will displace an equivalent reserve capacity in generators and translates directly to carbon savings, with 1 MW of displaced, bi-directional[4] generation reserve saving 2,276 tonnes CO_2 per year. See Appendix A for more details.

Fridge Capacity

The Capacity of the fridge to provide balancing services is a sum of "reservoir" Availability plus Response energy delivered over a constantly-moving grid frequency.

$$Capacity\ [W_{reserve}] = Availability[W_{reserve}] + Response[W_{reserve}].$$

Availability

Availability is:

- The expected individual contribution to a large-scale frequency event
- A "reservoir" of response per fridge.

This availability is calculated as follows:

$$Availability\ [W_{reserve}]\ = PC_{load}[W] \cdot \frac{Availability_{\ T,av}[\%\ in\ time]}{100},$$

where:

- PC_{load} is the power consumption of the fridge motor when it is consuming – e.g. 100 Watts.
- $Availability_{\ T,av}[\%\ in\ time]$ is the Total Average Availability: total percentage of time that the smart fridge is available to provide response. Note that the fridge is not always available as it must obey its own thermostat control first (if the fridge interior is too warm, the fridge motor may not turn off).

  There are two different availabilities: one to increase consumption (high response) and one to decrease consumption (low response).

$$Availability_{\ High}[\%\ \text{in time}] = \frac{Total\ time\ Available\ to\ turn\ ON}{Total\ Time\ Reporting};$$

$$Availability_{\ Low}[\%\ \text{in time}] = \frac{Total\ time\ Available\ to\ turn\ OFF}{Total\ Time\ Reporting}.$$

  The carbon coefficient 2,276 tonnes CO_2 accounts for 1 MW of both high and low reserve. This is interpreted as meaning that 1 MW of high Capacity is equivalent to 1,138 tonnes CO2; 1 MW low

[4] Bi-directional reserve means that 1 MW capacity to increase power **and** 1 MW capacity to decrease power is equivalent to 2,276 tCO_2 per year.

Capacity is equivalent to 1,138 tonnes CO2. Thus in the Carbon Savings calculation, a Total Average Availability is used, which is the average of both High and Low Availabilities:

$$Availability_{T,av}[\%\text{ in time}] = \frac{Availability_{\text{High}}[\%\text{ in time}] + Availability_{Low}[\%\text{ in time}]}{2}.$$

Response

Occasionally the fridge will respond to grid frequency and either bring forward its motor consumption (high response), or cut it short (low response). The time a fridge spends responding is small but is an important part of the total service description.

Each time the appliance provides frequency response (switches due to grid frequency), the time reported as Response is the minimum time on for high response (4 minutes) and minimum time off for low response (8 minutes). Note that the responding time is at least this period and sometimes longer, so the method used is an *underestimate.*

High response (and similarly low Response) is calculated as follows:

$$Response_{High}[\%\text{ in time}] = Nswitches_{ON} \cdot MinTime_{ON}\,[min] \cdot \frac{100}{TimeReporting[min]}.$$

As for the Availability estimate, the percentage of time spent responding is converted into Watts using the fridge motor power:

$$Response[W_{reserve}] = PC_{load}[W] \cdot \frac{Response_{T,av}[\%\ in\ time]}{100};$$

with

$$Response_{T,av}[\%\text{ in time}] = \frac{Response_{\text{High}}[\%\text{ in time}] + Response_{Low}[\%\text{ in time}]}{2}.$$

Example of calculation

As an example, a fridge plugged into the mains with a power consumption of 100 W and:

- Available low 30% of the time
- Available high 35% of the time
- Responding low 2% of the time
- Responding high 3% of the time

will provide 100 Watts x average(32%, 38%) = 35 Watts of Capacity. Using the calculation method described at the beginning of the section, capacity is converted into carbon over a 15 year lifetime as follows:

Carbon Savings = 2,276 x 0.000001 x 35 x 15 = 1.19 tonnes CO_2.

Factors and Effects

Factors influencing capacity levels are

1. **Ambient temperature**, which influences warming and cooling rates and how much time the fridge motor spends on. For example, availability to turn off is expected to increase in the summer, and decrease in the winter due to the altered motor on-time.
2. **Fridge use**, such as leaving the door open for extended periods of time. Opening the door can cause the temperature of the fridge to increase past allowable thresholds, making the fridge motor unavailable for response.
3. **Fridge modes**, not all of which permit frequency response. For example, the fridge may move into a defrost cycle, or the home user may start a “super cooler” mode to cool a bottle of wine quickly. Such modes take priority over frequency response and the fridge motor is unavailable for their durations.
4. **Age of the fridge**: over time, the fridge behaviour is subject to change due to loss of motor efficiency and wear and tear of the appliance insulation. The expected change is that warming rates will increase and cooling rates will decrease, leading to an overall increase in the time the fridge motor spends on. This is a similar effect to high ambient temperatures: availability to turn off will increase while availability to turn off will decrease.

The trial design controls for factors 1-3. A range of temperatures is observed over each phase of the trial and an effect estimated. Fridge use and different modes are incorporated into the overall capacity average, over the different demographic groups that influence them. As it will be shown by the results below, the change in high and low availabilities due to outside temperature, compensates each other giving almost a constant Total Average availability at any outside temperature. In the same way, this behaviour can also be expected for the ageing of the appliance.

Trial Phase 1 Report

Summary of results

The analysis for the first phase of the trial was carried out over a six month period May – October 2010 (summer to autumn).

A summary of results from the first phase is listed below:

1. The carbon saving estimate per fridge lifetime is 1.01 tonnes CO_2.
2. The main factor in service level variation is outside air temperature, with a diurnal shift of 10% in high and low availability levels, and a seasonal shift of 10% in high and low availability levels over summer to autumn. The impact on average availability, however, is negligible, and total carbon savings are not seasonal.
3. The impact of fridge use is minimal, with no significant difference measured. A small reduction in availability is thought to be due to extended lunchtime fridge use at weekends, but this is impossible to distinguish from the effect of grid frequency patterns that also show weekday – weekend differences.
4. The smart fridge technology is robust in field conditions: capacity levels estimated during the field trial are within 2% of capacity levels estimated in the lab.

Service levels from field measurements

The estimates of availability over the summer period of 2010 are shown in Table 1. The average availability over the trial period is estimated at 35% for High and 29% for Low. This means that the appliance is able to provide high frequency response for 35% of the time and to provide low frequency response for 29% of the time. Additionally, high response was provided for 2.5% of the time and low response for 7.5% of the time.

Table 1. Phase 1: Lab estimates and field measurements over trial.

	Laboratory Capacity	Field		
		Availability (%)	Response (%)	Capacity
High	37% 29.6 W	35	2.5	37.5% 30 W
Low	35% 28.0 W	29	7.5	36.5% 29.2 W
			Total Capacity	**37 % 29.6 W**

The availability and the response are added together to get the corresponding Capacity in time: 37.5% for High Capacity and 36.5% for Low Capacity, which gives a Total Average Capacity of 37% in time. Since the power of the compressor is estimated at 80W, the power equivalent of the availability is 30 W for high and 29.2 W for low; or **29.6W of Total Average Capacity** overall. Using the Carbon Coefficient calculated by KEMA and for a lifetime of 15 years, that Capacity gives a Carbon Savings estimate of **1 tonne of CO_2 per fridge lifetime**.

Service levels from lab measurements

Lab estimates were obtained by logging the availability of the appliance at 50Hz (no responses, so no actual service provided) and in an average ambient temperature of 20°C. The appliance was not used over that time, meaning that it was empty (no packets inside any of the cavities) and no door openings.

Table 1 shows that a capacity of 37% or 29.6 Watts obtained from field data is consistent with the laboratory estimate of 36.5% or 29.2 Watts, at levels of 1-2%. This gives a first view of the low influence that the grid frequency and the usage of the fridge have on the service and shows the robustness of the technology.

Factors and Effects Analysis

Seasonal effects

Field data shows that ambient temperature plays a great role in the appliance duty cycle and hence in the availability to provide service.

Figure 5 shows a qualitative correlation between ambient temperature and high (red) and low (blue) availability. The dots in the figure are daily averages of availability plotted against temperature, which gives the tendency lines drawn. As expected, it can be observed that the availability to switch off tracks the temperature gradient while the availability to switch on tracks it in the opposite direction.

Over the total period, a maximum change in the daily availabilities (high and low) of 10% was seen. The total average availability (green line in Figure 5) – used for the carbon estimate – can be seen to remain relatively constant at around 30%.

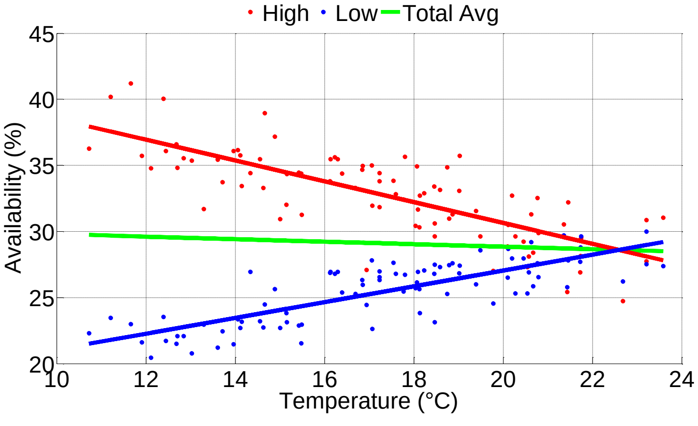

Figure 5. No-Frost: Temperature effect on availability.

Daytime effect & fridge usage

The effect of the ambient temperature is by far greater than that of the usage. It can be seen throughout the seasons, and even over a day, how the availability changes tracking the ambient temperature. There is no similar clear effect of the usage on the availability. This is probably because the interaction of the user is either short/minimal (packets introduced inside the appliances are not too warm, fridge door openings are short) or negligible as compared to the other factors.

As shown in Figure 6, average high and low availabilities over a day have a characteristic shape that repeats for all the models involved in the trial. In the figure, each day in the week is represented as a separate line, with weekdays being all in blue.

The shape of average availability over a day is mainly due to the typical daily average ambient temperature profile (see Figure 8). Since outdoors ambient temperature is used, there is a delay of about 5 hours between the actual outdoors ambient temperature and the one ‘seen’ by the appliance due to the inertia of the house it is in.

Figure 9 shows the relationship between that 5-hour delayed ambient temperature and the average availabilities (high – red; low – blue). The dots are given by weekly averages, which give the linear correlations drawn for high and low. As expected, low availability tracks temperature in the same direction, i.e. low availability increases when temperature does, while high availability does so in opposite direction, i.e. high availability decreases when temperature increases.

The fridge usage in terms of door openings is shown in Figure 7. It can be observed that there is no clear relationship between the door openings profile and the daily availability profile. However, there is a small gap between high availability in a week-day and during the week-end at around noon. That difference can be explained by the increase in door openings around noon during the week-end.

Another interesting effect that has been found is the effect grid frequency has in availability, which can be seen at around 3 pm in the daily high availability. There is actually a recurrent peak around 3 pm in week-days that does not occur during the week-end and hence the small difference in availability.

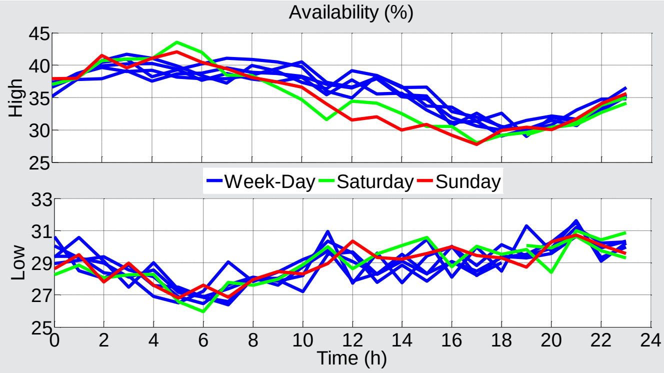

Figure 6. No-Frost: Availability Daily profile.

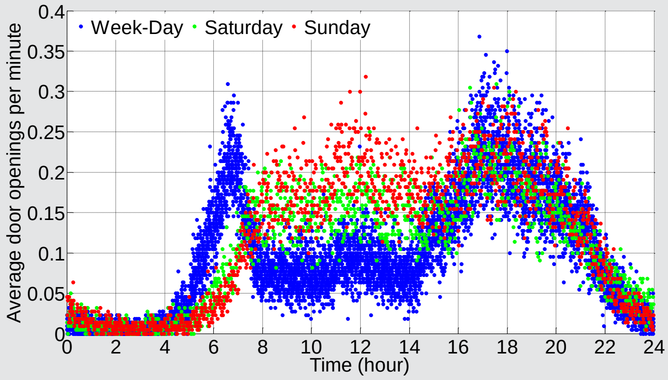

Figure 7. No-Frost: Average number of cooler door openings per minute.

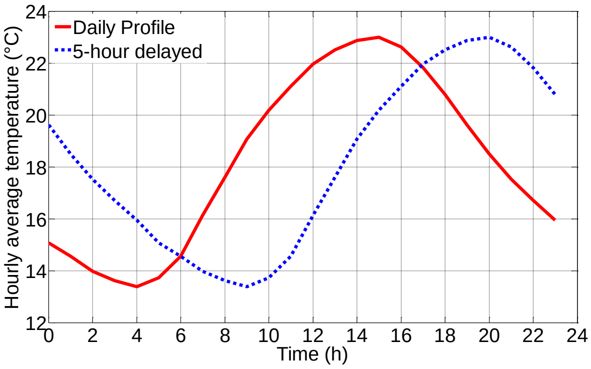

Figure 8. Phase 1: Daily average temperature profile.

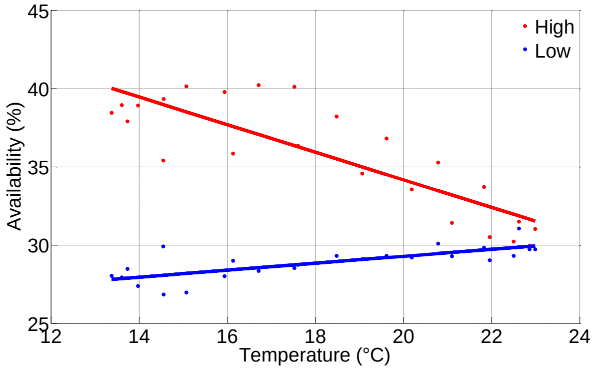

Figure 9. Phase 1: Daily temperature profile effect on daily availability.

Trial Phase 2 Report

Summary of results

The analysis for the first phase of the trial was carried out over a six month period October 2011 – March 2012 (autumn to winter). Data levels for the second phase were between 33-50% of the levels planned for the Static Combi and Upright Freezer models. For the TableTop fridge, lab estimates were used to give a carbon saving result for the trial. This is felt to be justified as field results from the other three fridge models are consistent with those measured in the lab.

A summary of results from the second phase is listed below:

1. The carbon saving estimate per fridge lifetime is 1.1, 1.3, 0.7 tonnes CO2 per lifetime for the Static Combi, Upright Freezer and TableTop fridges respectively.
2. The main factor in service level variation is outside air temperature, with diurnal and seasonal shifts of 15% and 10% for high and low availabilities for static and upright-freezer respectively. The impact on average availability, however, is negligible, and total carbon savings are not thought to be seasonal.
3. The impact of fridge use is minimal, with no significant difference measured.
4. The smart fridge technology is robust in field conditions: capacity levels estimated during the field trial are within 7% of capacity levels estimated in the lab for both Static Combi and Upright Freezer.

Service levels from field measurements

The **capacity estimates** from 1st December 2011 to 16th March 2012 are shown in Table 3 to Table 5. The calculation has been done following the guideline explained in the Carbon Savings Calculation chapter. The power of the compressors for each type is presented in Table 2.

Table 2. Phase 2 compressor sizes.

Static	**85 W**
Upright-Freezer	91 W
Table-Top	55 W

Using the Carbon Coefficient calculated by KEMA and for a lifetime of 15 years, that availability gives a Carbon Savings estimate of:

- **Combi Static: 1.1 tonnes of CO_2 per fridge lifetime**.
- **Upright-Freezer: 1.29 tonnes of CO_2 per fridge lifetime**.
- **Table-Top: 0.7 tonnes of CO_2 per fridge lifetime**.

Service levels from lab measurements

Laboratory estimates were obtained by logging the availability of the appliance at 50Hz (no responses, so no actual service provided). The appliance was not used over that time, meaning that it was empty (no packets inside any of the cavities) and no door openings.

Table 3 and Table 4 show that **field measurements are consistent with lab estimates** to better than 7%. Since there is no field data for the Table-Top model and laboratory estimates are consistent, they have been used to estimate its carbon savings value.

The availability has a strong dependence on the **operational settings of the appliance**. When the appliance is plugged into the mains and switched on for the first time, it starts running in the default settings: operational mode and temperature setting. In general, those default settings are usually maintained by the user:

- **UPFZ**: On average, the temperature setting used by the user is the default one, which stands in the middle of the range, and it was the one used for the laboratory estimates.
- **Static**: There are two operational modes – normal and eco –, which change significantly the availability provided by the appliance. Normal mode allows the user to set independently different temperature settings for cooler and freezer, although the default temperature setting is the most used when in normal mode. Eco is the default mode and it only has one temperature setting, which cannot be changed by the user once in eco mode. Most of the Combi Static in the field is kept in eco mode by the user. Lab estimates were calculated for both normal (in the default setting) and eco. For the availability comparison, the lab estimate used is a proportional value calculated from the number of static in each mode (about 60 % in eco and 40 % in normal mode).

Table 3. Static: Lab estimates and field measurements.

	Lab	Field		
	Capacity	Availability (%)	Response (%)	Capacity
High	41.5% 35.3W	45.1	2.2	47.3% 40.2W
Low	26.3% 22.4W	19.2	6.8	26% 22.1W
			Total Capacity	**36.7% 31.2W**

Table 4. UPFZ: Lab estimates and field measurements.

	Lab	Field		
	Capacity	Availability (%)	Response (%)	Capacity
High	44.6% 40.6W	48	4.9	52.9% 48.1W
Low	33.1% 30.1W	20.9	9.1	30% 27.3W
			Total Capacity	**41.5% 37.7W**

Table 5. Table-Top: Lab estimates measurements.

	Lab		
	Availability (%)	Response (%)	Capacity
High	61.7	0	61.7% 33.9W
Low	16.5	0	16.5% 9.1W
		Total Capacity	**39.1% 21.5W**

Factors and Effects Analysis

Seasonal effects

Similarly to phase 1 results, Field data shows that ambient temperature plays a great role in the appliance duty cycle and hence in the availability to provide service.

Figure 10 and Figure 11 show the qualitative correlation between ambient temperature and high (red) and low (blue) availability. The dots in the figure are daily averages of availability and temperature, which gives the tendency line drawn. As expected, it can be observed that the availability to switch off tracks the temperature gradient while the availability to switch on tracks it in the opposite direction.

The total average availability (in Figure 10 and Figure 11 , lines in green) – used for the carbon estimate – can be seen to remain relatively constant at around 30%.

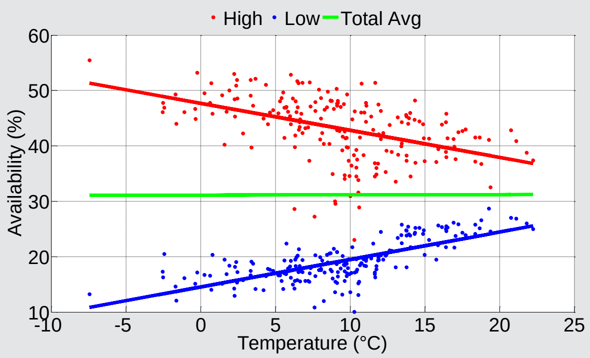

Figure 10. Static: Temperature effect on availability.

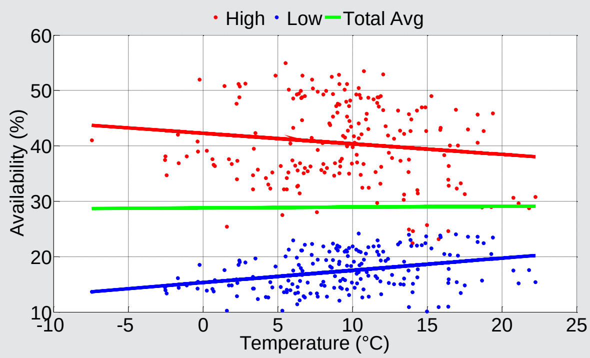

Figure 11. Upright-freezer: Temperature effect on availability.

Day time effect & fridge usage

As shown in Figure 12 and Figure 13, average high and low availabilities over a day have a characteristic shape that repeats for all the models involved in the trial. In the figure, each day in the week is represented as a separate line, with weekdays being all in blue.

The shape of average availability over a day is mainly due to the typical daily average ambient temperature profile (see Figure 16). Since outdoors ambient temperature is used, there is a delay of about 5 hours between the actual outdoors ambient temperature and the one ‘seen’ by the appliance due to the inertia of the house it is in.

Figure 17 shows the relationship between that 5-hour delayed ambient temperature and the average availabilities for the static and the upright-freezer (high – red; low – blue). The dots are given by weekly averages, which give the linear correlations drawn for high and low corresponding to each model. As expected, low availability tracks temperature in the same direction, i.e. low availability increases when temperature does, while high availability does so in opposite direction, i.e. high availability decreases when temperature increases.

The fridge usage in terms of door openings is shown in Figure 14 and Figure 15. Note that Figure 14 only shows the opening of the cooler door, as there is no sensor in the freezer door. The upright-freezer has only one door/cavity. It can be observed that there is no clear relationship between the door openings profile and the daily availability profile. It is interesting to see the difference between the upright-freezer and the static in terms of door openings, as they have different usage patterns. Also, it is very likely that the opening patterns of the upright-freezer correspond to that of the freezer cavity in the static model.

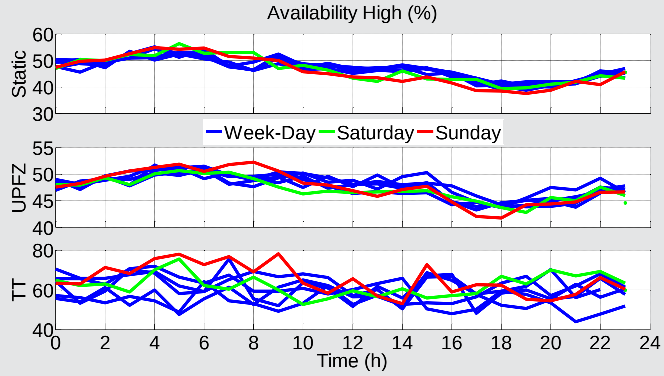

Figure 12. Phase 2: Availability High Daily profile.

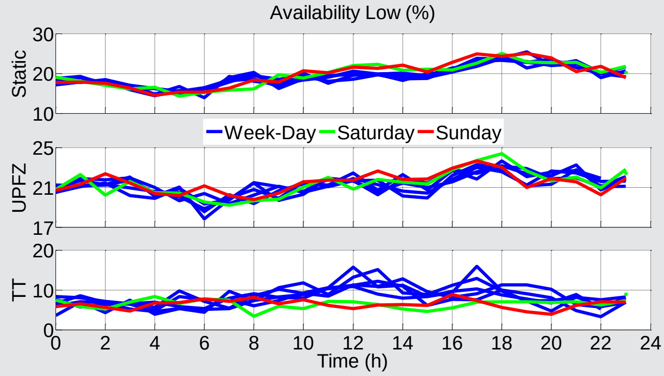

Figure 13. Phase 2: Availability Low Daily profile.

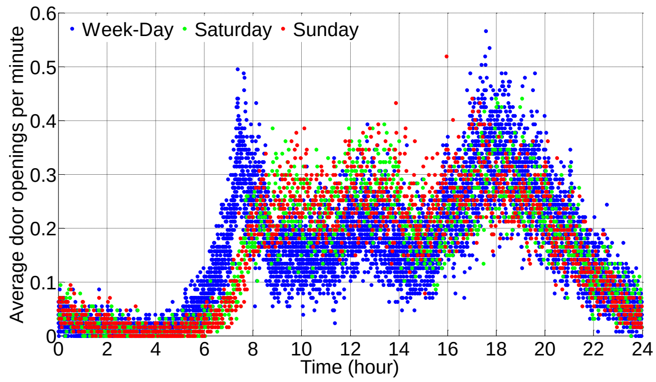

Figure 14. Static: Average number of cooler door openings per minute.

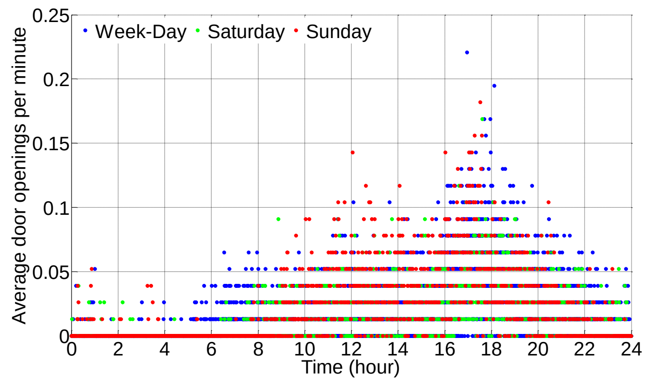

Figure 15. Upright-Freezer: Average number of door openings per minute.

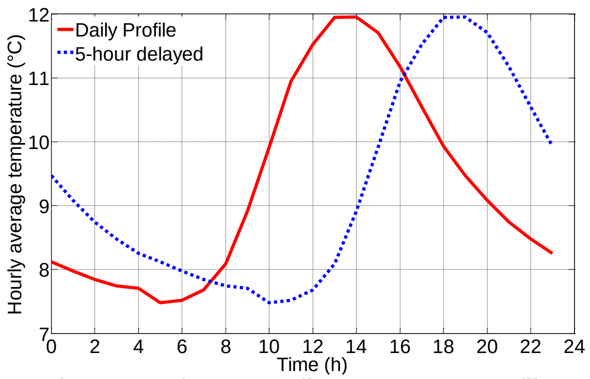

Figure 16. Phase 2: Daily temperature profile.

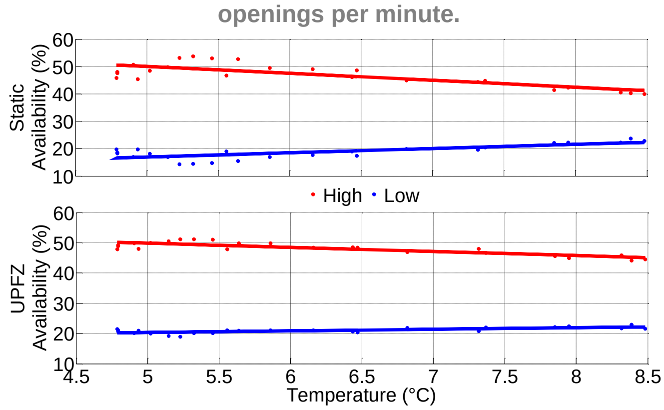

Figure 17. Phase 2: Daily temperature profile effect on daily availability.

Conclusions and Learning

This section accounts for the main conclusions and learning from the trial.

1. Open Energi's energy balancing fridge technology is robust and works as expected while the fridge is in use in the home, with stable average service levels observed.

2. No temperature control problems were observed due to Open Energi's addition to the fridge control circuit.

3. Seasonality, while a main factor in fridge motor consumption – with high outside air temperatures causing an increased on-time – is not important in the carbon saving potential of the technology. This is due to the fact that any reduction in the energy balancing capacity to turn on (with increased consumption) is largely made up for by an increase in the capacity to turn off. The carbon estimate relies on an average high and low availability and is largely unaffected.

4. A commercial service would rely on the energy balancing technology embedded in the fridge, together with some level of sample monitoring for verification of service provided. Following the experiences of the trial, Open Energi are better placed to design a monitor suitable for use in the trial.

Home monitoring system learning

- The failure point in the first phase of the trial was the READm lock-up causing a home monitoring system failure rate. This was amended for the second phase of the trial by introducing a watch-dog to restart the READm in case of failure.
- The failure point in the second phase of the trial was the fridge-READm interface (hardware key) lock-up causing a home monitoring system failure rate. This is thought to be the main cause of system failure, and was not present in the first phase of the trial. For a commercial solution a smart meter device is proposed, removing the interface and using power measurements only. Internal fridge data is of interest only for the trial.
- A failure point for the READm metering capability was the wired cable from the READm to the power socket. This was necessary for a faster pass through CE approval, but resulted in signal

attenuation and intermittency in reporting. Future smart meter solutions will either plug directly into the wall or use higher numbers of HomePlug units to amplify the signal.

- A success point for the HomePlug power line communications system was its plug and play capability: installers did not have to configure any routers or firewalls to be successful. A future solution will continue to use HomePlug through the home router, or an Open Energi wifi network, also through the router. At this stage is it not thought to be cost effective to use homes without broadband internet connection for planned sample monitoring.

Appendix A : CO_2 Coefficient

This section contains an appended letter from KEMA describing the carbon saving coefficient and how it is obtained. Please note the letter refers to ‘RLtec’ which is the previous trading name of Open Energi.

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E-mail davy.thielens@kema.com

London, 10 November 2009

Subject: **Carbon Emissions for Reserve**

Dear Paul,

In response to your request to KEMA to investigate the possibility to express the carbon emissions for Reserve in the GB power system as a single value, please find below our findings.

Background

RLtec has developed and patented demand technology to make loads frequency responsive. Integrating this technology in appliances whose electric power requirements are less dependent on time, e.g. fridges, freezers, air conditioners and heaters, will enable energy balancing services to be provided to the national grid.

Reducing load in times of generation deficit reduces the need for having conventional power plants running on part-load, burning fuel at reduced efficiency and adding to carbon emissions.

RLtec estimates that each fridge fitted with its dynamic demand technology would reduce the CO2 emissions associated with these plants by about 1 tonne over the fridge's lifetime and if applied widely in the UK, RLtec estimates that dynamic demand could eliminate the need for 750 megawatt of Reserve holding, reducing greenhouse gas emissions by two million tonnes a year. National Grid's acknowledges the impact of these frequency response services and estimate the potential of domestic refridgerators to be around 500 MW in 2020[i]. Later this year, RLtec will commence an extensive field trial to validate both the technology and the contribution to system balancing.

RLtec is in discussion with Ofgem, the UK energy regulator, to have their technology accredited under the Carbon Emission Reduction Target (CERT) scheme. This scheme imposes a target on the gas and electricity transporters and suppliers by the UK Government to reduced carbon emissions in the domestic environment by 154 million tonne (lifetime) between 2008 and 2011.

For this technology to be accredited under CERT, the impact of this technology has to be expressed as Carbon Savings via a Carbon Coefficient. For more conventional energy efficiency and energy reduction schemes, the carbon savings are expressed as:

Carbon Savings = kWh x Carbon Coefficient

with the Carbon Coefficient expressed in CO_2/kWh and provided according to Schedule 3. The technology applied by RLtec in their fridge trial belongs to the category of Dynamic Demand. The carbon savings are than expressed as:

Carbon Savings = $W_{response\ mitigated}$ *x Carbon Coefficient*

With the Carbon Coefficient expressed in CO_2/W.

The Carbon Coefficient for mitigated reserve capacity as not yet been set for the CERT, but is of importance for the accreditation of RLtec's trial. To progress their trial, RLtec contracted KEMA to investigate this Coefficient.

Context

Expressing the carbon savings of reducing the amount of reserve needed on the system is not straight forward. National Grid published the amount of reserve needed on a yearly basis, including the breakdown per fuel type. Conversion of $MW_{reserve}$ per fuel to carbon emissions however depend on many parameters, e.g. the age of the plant, the heat rate of the plant (efficiency curve), drop in efficiency of plant run as balancing plant, the operating point (how far has the plant been 'pulled back' from its optimum) and the minimum stable operating level of the plant. Many of these parameters are commercially sensitive and therefore only typical values would be generally available.

In addition, to calculate the exact carbon savings of dynamic demand at any point in time, it is necessary to know the merit order at that time and determine the parameters of the last plant in the merit order delivering power and providing reserve services.

Such an intensive study will provide difficult, time consuming and only valid for that calculated moment in time. A more generic approach, and possible more suitable for this trial, would be based on more aggregated and averaged values and best practice assumptions.

Example calculation of additional carbon for holding of frequency reserve

National Grid has been dealing with the same issues regarding carbon emissions for reserve on the system. In their 'Security and Quality of Supply Standard‘ Amendment, GSR007, 10th Sept 2009, National Grid has published an example calculation of additional carbon for holding of frequency reserve. Below is a summary of their example, the full example can be found in Appendix A of this letter.

Based on their experience, National Grid assumes a reduction in station efficiency of coal-fired plant is 10%. On average, a coal plant used for balancing will emit 0.9 tCO2 per $MW_{reserve}$ per hour. Gas fired plants are less carbon intensive, with 0.4 tCO2 per $MW_{reserve}$ per hour.

National Grid estimates the reserve holding for the next 10-20 years to be half coal, half gas, given a carbon intensity of 0.26 tCO2 per MWh of reserve. Across a year, 1 $MW_{reserve\ holding}$ will have carbon impact of 2,276 tCO2.

Impact for RLtec

National Grid's example was calculated for emissions for extra reserve holding, but can be considered valid in both directions for changes in reserve holdings from this technology over the period for which this coefficient is expected to be used[ii]. RLtec's dynamic demand technology has to potential to reduce the amount of reserve that National Grid need to hold on the system, resulting in the carbon savings as calculated above.

If you have any questions relating this approach, please do not hesitate to contact me.

Your sincerely,

Davy Thielens
Consultant

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Appendix: page 55 of 'Security and Quality of Supply Standard‘ Amendment, GSR007, 10th Sept 2009, National Grid

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[i] Operating the Electricity Transmission Networks in 2020, National Grid, Initial Consultation, June 09

[ii] The validity could be challenged where the downward changes to reserve holding could lead to plants operating at set points with significantly different efficiencies than anticipated in the National Grid analysis.

Appendix B to Annex 4: Additional Carbon emissions from extra Reserve

For interest, this appendix estimates the extra carbon emissions, directly attributable to the extra holding of frequency reserve, as a consequence of increasing the Infrequent Infeed risk from 1320 to 1800MW.

For coal-fired plant, the CEGB experience was that operating at part-load caused a 10% loss in station efficiency – this used to be expressed in the 'Willans line'. Thus five gensets operating at 400MW each consume 10% more fuel, and thus emit 10% more carbon, than four gensets operating at 500MW. Both operating regimes send out 2000MW of power, but the first holds 500MW of reserve. 1 MWh generated from coal emits 0.9 T_CO2. Accordingly, under this regime, 500MWh of reserve is emitting 10% x 2000MWh x 0.9 = 180 T_CO2 per hour.

Gas-fired plant can operate more efficiently at part-load, although there are efficiency losses from under-utilising a steam turbine. For simplicity, 10% loss in efficiency; is used since gas-fired plant is intrinsically less carbon-intensive, at 0.4 T_CO2 per MWh generated. Reserve held on gas-fired plant will only emit 0.4 / 0.9 x 180 = 80 T_CO2, again for 500MWh of reserve. On average, it is reasonable to assume that incremental reserve will be held half on coal and half on gas over the next 10-20years, and so the average carbon intensity of reserve will be 130 ÷ 500 = 0.26 T_CO2 per MWh of reserve.

The central case cost benefit analysis is based on an increase of 1300MW of reserve held. So across a year, this will represent 1300MW x 8760hr x 0.26 = 3 MT_CO2 of additional carbon.

Appendix B : KEMA Audit

This section contains KEMA’s final audit report.

Independent technical verifiers of Open Energi CERT Trial – Phase 2

Project Polar Star

Open Energi
10010700-CES
Prepared by DNV KEMA UK Limited
London, May 02nd, 2012

REVISION HISTORY

Rev.	*Date*	*Description*	*Authors*	*Checker*	*Approver*
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1.0	2012-05-02	Final	PC, WU	TL	

Authorisation

Name: Willem Uijlings

Role: Senior Consultant

Signature:

Date: 02nd May 2012

Contents

Page

TABLES

FIGURES

EXECUTIVE SUMMARY

Open Energi has developed and patented a control technology to enable certain loads to adjust their time of demand in response to changes in the system frequency. Integrating this technology in appliances means that grid load requirements can be manipulated by making use of inherent internal energy storage (e.g. fridges, freezers, air conditioners and heaters), thus allowing energy balancing services to be provided to the national grid.

Open Dynamic Demand™ technology turns fridges into smart appliances, able to provide power frequency response services to the UK electricity grid which are normally provided by conventional power stations.

To be able to provide power reserve, contracted power stations are operated at a lower capacity, which has a negative impact on the efficiency performance of the plant. The reduction in capacity hold for frequency response helps to reduce the levels of CO_2 emissions in the UK.

Therefore, the frequency response services given by the fridges would reduce the need of reserve capacity hold by the power plants in the electricity system and thus contribute to the reduction of CO_2 emissions.

In order to demonstrate and assess the patented control technology, Open Energi has carried out a large field trial using the Open Dynamic Demand™ technology to make home appliances compatible with the "smart grid" concept. The trial was sponsored by nPower under the UK government CERT scheme.

At Ofgem's request, Open Energi appointed DNV KEMA as independent technical specialist and verifier of the deployment of this field trial programme and for validation of the carbon savings calculations. This report covers Phase 2 of the trial and is the second independent report by DNV KEMA for Open Dynamic Demand™ technology.

In this report the calculated CO_2 savings show that one fridge supplied with Open Dynamic Demand™ technology reduces the emissions by approximately 1 tCO_2 over its lifetime. These calculations are based on Open Energi's definition and National Grid estimates for reserve capacity and associated emissions.

Even if the fridges have limited storage capacity, the trial shows that this technology generates a contribution to the CO_2 emissions reduction without compromising customer's comfort levels.

In addition, the Phase 2 of the trial shows robust data results confirming the ability of the Open Dynamic Demand™ technology to provide Dynamic Demand response to National Grid.

1 BACKGROUND – PHASE 1

1.1 History

The original trial for Phase 1 and Phase 2 was scheduled to start in July 2008, with a deadline fixed for March 2011. However, due to the formal approval received from Ofgem in November 2008 (Phase 1), the official start date was postponed to January 2009. The first fridges were eventually deployed in January 2010 and the installation continued during the first quarter of the year.

DNV KEMA provided a base line audit programme during the preparation phase and verified the deployment and results of Phase 1. The last data audit for Phase 1 was performed over the period 22nd – 28th February 2011.

The objective of Phase 1 was to verify the robustness of the technology in a field trial and estimate the carbon savings from a single fridge supplied with Open Dynamic Demand™ electronics over its lifetime. The DNV KEMA report confirmed its validity in terms of how it was designed, the response given by the appliances, and finally the analytical derivation of the carbon savings. The report concluded that Phase 1 has been successful and provided useful insights into the chosen approach and its implementation.

1.2 Results

Two particular observations were made in Phase 1.

1) Communication problems have been encountered, with a number of READm units failing to respond and being investigated by Open Energi. The suspected problem was an overflow in the Microsoft TCP/IP stack that was causing the device external communications to fail. The problem was fixed by updating the firmware on the device and, as an extra measure, a watchdog was included to reboot if the stack would overflow. This solution has been implemented in the READm units used in Phase 2. Nevertheless, these communication problems did not affect the quality of the data used for the analysis in Phase 1.

2) The seasonality and end user behaviour have an impact on the devices availability of up to 10 % between winter and summer periods.

Apart from the points mentioned above, Phase 1 provided a good level of confidence that Phase 2 of the trial was well prepared and that useful data on this particular carbon saving technology will be made available at its conclusion.

2 SCOPE AND DELIVERABLES OF PHASE 2

In the last months of 2011, three new fridge models were deployed and in January 2012 the first relevant data became available.

Although Phase 2 of the trial was initially meant to last for a year and be reported accordingly, the Carbon Emission Reduction Target (CERT) scheme will end in December 2012. Open Energi and nPower therefore decided to conduct the analysis of Phase 2 with the data available until March 2012.

DNV KEMA was asked to verify Phase 2 on the basis of the available data, applying the 5 criteria designed in Phase 1:

A. Distribution of Fridge Responses
B. Trend in Frequency
C. Rate of Change of Frequency
D. Response Level Availability
E. Trigger Frequencies

A detailed explanation of the above criteria is described in the next sections. In addition, a more detailed verification is given for the relationships between the measures in criteria D. Furthermore, the results from the analysis were taken to calculate the CO_2 savings in accordance to Open Energi's definition of the Dynamic Demand (DD) technology used.

DNV KEMA also took a more qualitative approach, as opposed to the more quantitative analysis taken for Phase 1, aiming for two main results:

- Comparison between Phase 1 and Phase 2 outcomes, in order to confirm the estimated levels of CO_2 savings over the fridge's lifetime;
- Detailed analysis when possible correlations and/or significant differences were found.

3 DEVICES ANALYSED

As mentioned above, Phase 1 of the trial consisted of 300 fridges of one type. To test possible different behaviour between different fridge models (and therefore to conduct robust analysis), Phase 2 consisted of 500 fridges of 3 different types:

- *Upright freezer (UPFZ)*
- *Combi static*
- *Table top*

When this analysis was conducted, 373 Static fridges were installed. Out of these 373 installed Static fridges, 125 were equipped with a READm device. 125 Upright freezers were also installed and 86 were equipped with a READm device. There were no table top appliances deployed when the analysis reported in this document were conducted.

Therefore, for Phase 2, the final device population comprised the following:

- Combi Static fridges with READm device deployed
    - 32 % complete (100 % is 390 appliances)
- Upright Freezer with READm device deployed
    - 48 % complete (100 % is 180 appliances)
- Table top with READm device deployed
    - 0 % complete (100 % is 90 appliances).

4 TECHNICAL DATA VERIFICATION

4.1 Data Audit Structure

This section describes the source data provided to DNV KEMA and the criteria used for the overall assessment.

As mentioned earlier, DNV KEMA Phase 1 audit focused on the assessment of a dataset composed by the totality of the planned fridges in operation (300 appliances). In this second phase a different approach was agreed with Open Energi. Instead of conducting the analysis on the total population of the fridges which composed the trial, the assessment was conducted on a restricted sample, where 10 devices were analysed for a period of two separate weeks (see next paragraph).

Representative data series were selected by Open Energi on DNV KEMA's suggestion. The criterion for this selection was based on:

- a robust representation of the entire fridge population, comprising a total of 10 devices coming from the two types of fridges equipped with the READm device;
- a time series for the selected devices for a period of 7 days in two different months.

The reason for the approach taken was mainly driven by the necessity to analyse the performances of the fridges having limited data available. An analysis could only be performed over the winter season. Moreover, the analysis conducted last year already confirmed the reliability of the data coming from the devices.

Therefore, in this phase a more qualitative analysis was conducted for a robust, restricted sample.

4.1.1 Source Data

As mentioned above, the sample was composed by 10 devices:

i. 6 Static Fridges (IDs: 1392, 1394, 1400, 1405, 1407 and 1420)
ii. 4 Upright-Freezer (IDs: 817, 1170, 1226 and 1242)

This sample was analysed for a period of two separate weeks:

a. From 19/11/2011 to 25/11/2011 and from 26/02/2012 to 03/03/2012 for the 6 static fridges;
b. From 26/11/2011 to 02/12/2011 and from 01/02/2012 to 07/02/2012 for the 4 up-right-Freezer.

As agreed, Open Energi supplied the data sets in Microsoft Excel format containing similar information as for Phase 1, namely: (i) fridge ID; (ii) model; (iii) event timestamp; (iv) cooler cavity temperatures; (v) freezer cavity temperature; (vi) freezer evaporator temperature; (vii) compressor states; (viii) overall RLA; (ix) measured grid frequency; (x) trigger frequency; and (xi) response of the DD algorithm. Therefore, compared to Phase 1, the data sets of Phase II contained also the state of the appliance in terms of response of the DD algorithm (1 – the appliance is giving response; 0 – the appliance is not giving any response) for each minute considered.

4.1.2 Assessment Criteria

The criteria used to assess the data are the same as the ones used in Phase 1, except for criteria A. Moreover, a more qualitative analysis, based on possible difference between periods and types of fridges (as mentioned above), has been conducted.

A: Distribution of Fridge Responses

The first criterion used to assess the data is the distribution of the number of individual fridge responses over the period the two weeks.

*It was expected that: **(A.1)** the number of fridges in service is consistent with the number supplied by Open Energi (approximately 100) **(A.2)** that the population should be responding (not providing data, but giving response services)[1] at a roughly similar rate during the period of interest.*

B: Trend in Frequency

The general measured frequency trend should be a relatively slow variation around the nominal value of 50 Hz. Any sharp increases or outlying data should be minimal and ideally attributable to a single or small number of fridges responding to a localised transient.

[1] In Phase 1 the definition of Response for this Criterion was different. It referred to the time the appliance was providing data to the READm device, not the time the appliance was giving response services.

*It was expected that: **(B.1)** the frequency will be a relatively slow variation around the nominal value of 50 Hz.*

C: Rate of Change of Frequency

To assess the overall realism of frequency measurements, the Rate of Change of Frequency (ROCOF) was calculated over a moving window of six measured frequency values. This particular window length was selected to view the ROCOF values due to the system frequency and should in general be less than 0.2 Hz/s. If a shorter window was used, higher short term ROCOF values due to the differences that could occur between individual fridges calculating frequencies at different points within their permitted tolerance band, could distort the results.

*It was expected that: **(C.1)** the calculated ROCOF values over the period would be less than 0.2 Hz/s.*

D: Response Level Availability

The RLA calculated for each fridge should ideally be an approximately triangular waveform ranging from 0 – 100 %. It is DNV KEMA's understanding that this RLA corresponds to a fridges ability to turn its compressor either on or off whilst the internal temperatures are within the permitted tolerance band. The positive gradient section corresponds to a rising internal temperature within the tolerance band with the option to turn on, whilst the opposite is the case for the negative gradient section. A deviation from this pattern (e.g. jumps to zero or other discontinuities) can be caused by a number of different events:

- the internal temperatures moving outside of the tolerance band and thus forcing the compressor control to take precedence over the algorithm,
- loss of communication, or
- due to the action of the algorithm turning the compressor on or off.

*It was expected that: **(D.1)** the RLA would follow an approximately triangular characteristic and **(D.2)** discontinuities would be attributable to defined events.*

E: Trigger Frequencies

Trigger frequencies of the fridges will be distributed across the range between 49.5 Hz and 50.5 Hz (a random number generator is present within the Open Energi algorithm).

*It was expected that: **(E.1)** the distribution of fridge trigger frequencies at an instant in time will have a roughly uniform spread across the range 49.5 to 50.5 Hz.*

4.2 Data Audit

4.2.1 A – Distribution of Fridges Responses

The distribution of fridges responses for the two weeks is shown in the graphs in the next page. As mentioned above, the definition of Fridges responses in this Phase was different compared to Phase 1.

As can be seen, the average for both types (static and upright) for both weeks is around 800 responses per day.

The main difference between the static fridges and the upright freezer is the deviation from the average for each single device. For the static fridges there is a considerable difference between fridges. Fridge number 1394 gave, for example, around 20% more response than fridge 1420 in the first week. In the second week that difference was not so high.

On the other hand, the upright freezers showed less deviation from the average. If the freezer 1226 is excluded from the analysis (the green line in the figure 2) because some missing data[2], the deviation from the average for each day of the two weeks is considerably smaller than the one estimated for the static fridges.

The data set available (which goes from November to March) doesn't allow for a complete seasonality effect analysis. The only conclusion that can be made is that no seasonal effect was noticed between autumn and winter periods. Moreover, no particular correlations could be noticed between working days and weekends.

Finally, two conclusions can be made considering the assessment criteria described in the previous section:

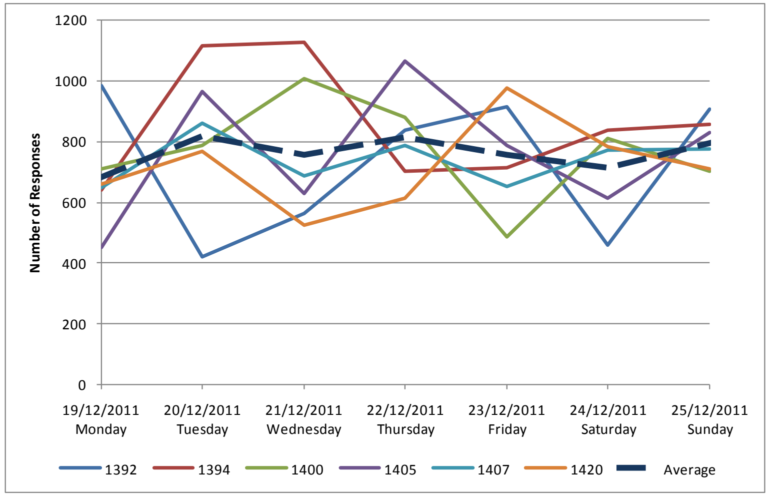
A.1: Can be omitted, since this characteristic was already tested in Phase 1. Moreover, as already mentioned, the analysis in this phase has been concentrated in a smaller group of devices.

A.2: This criterion is satisfied., The population responded at a roughly similar rate during the period of interest.

Criterion A: Satisfied

[2] For this device, 248 observations (around 4 hours) are missing for a single day (30/11/2011)

Figure 1 Distribution of Static Fridge Responses in the Two Weeks Considered



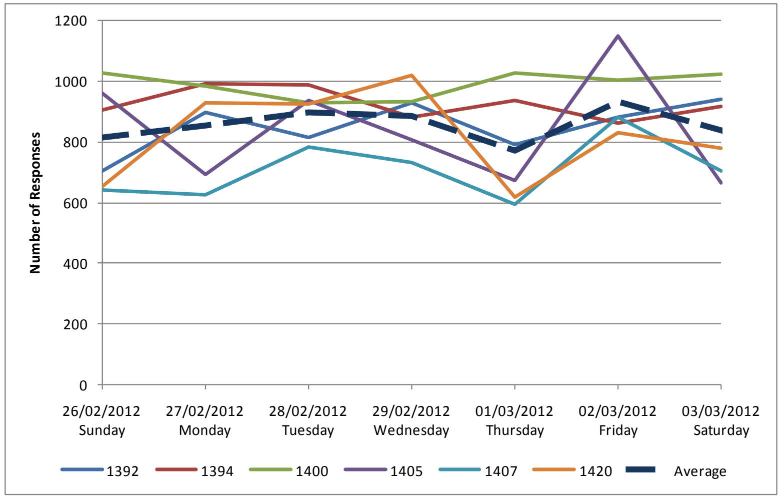
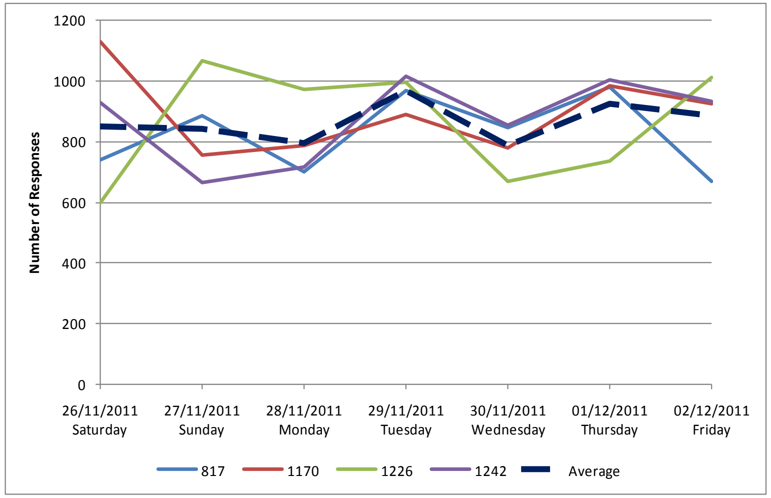
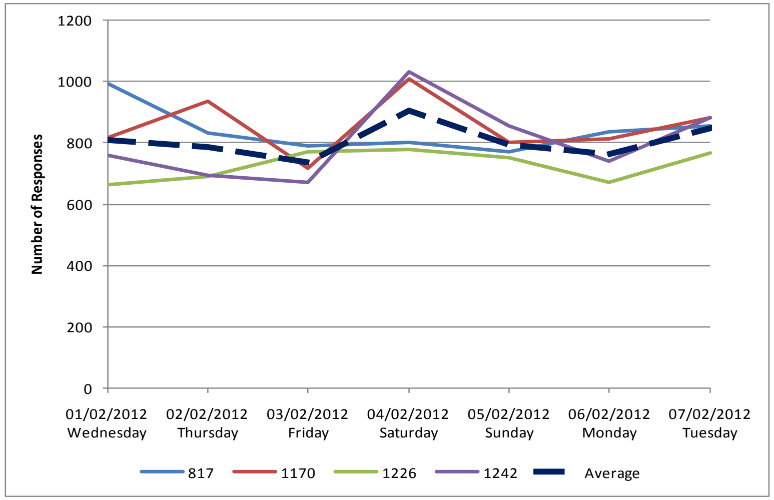


Figure 2 Distribution of Upright Freezer Responses in the Two Weeks Considered





4.2.2 B – Trend in Frequency

A graphical representation of the trend in frequency for the two devices types is shown in the next page.

Particular dates have been chosen to build these graphs. They are the days (within the two weeks which constitute the initial dataset) which have the greatest variation in the number of responses given by the two different types of devices. For the static fridges the dates are 21/12/2011 for the first week and 01/03/2012 for the second week. For the upright freezer the two dates are 26/11/2011 and 01/02/2012.

As can be seen, there is relatively slow variation around the nominal value of 50 Hz (**B.1**), rather than for some periods circled in red which correspond to data missing for some devices (1400 in the first week and 1394 in the second week for the static fridges and 817 in the first week for the upright freezers).

Criterion B: Satisfied

Figure 3. Frequency Measurements – Static Fridges

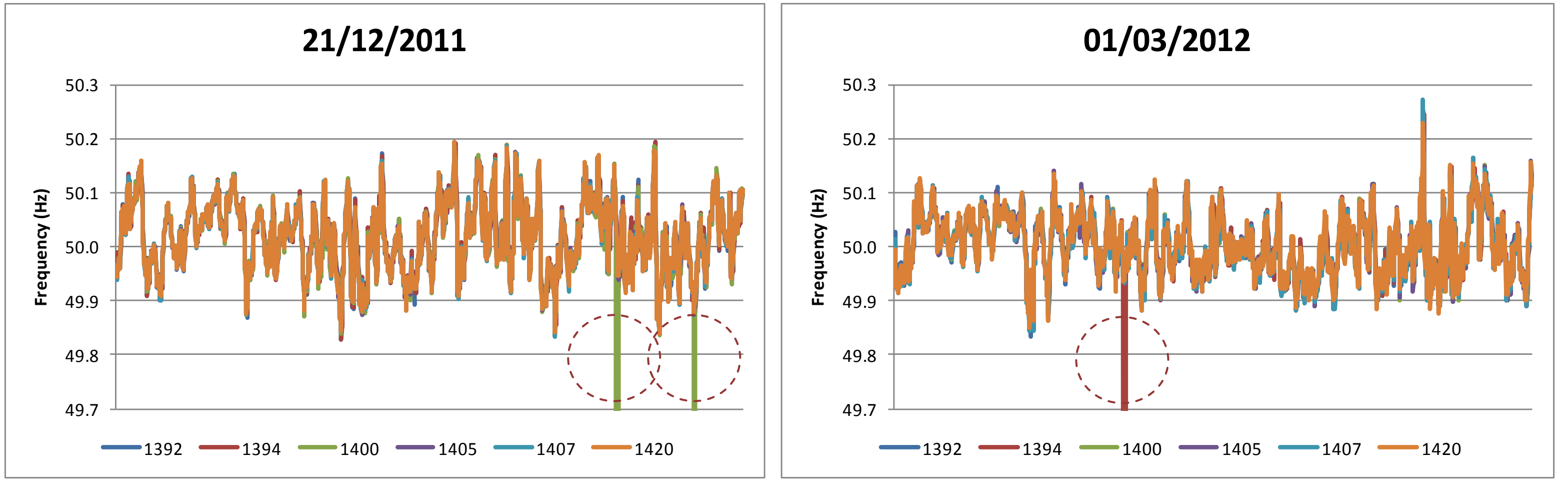
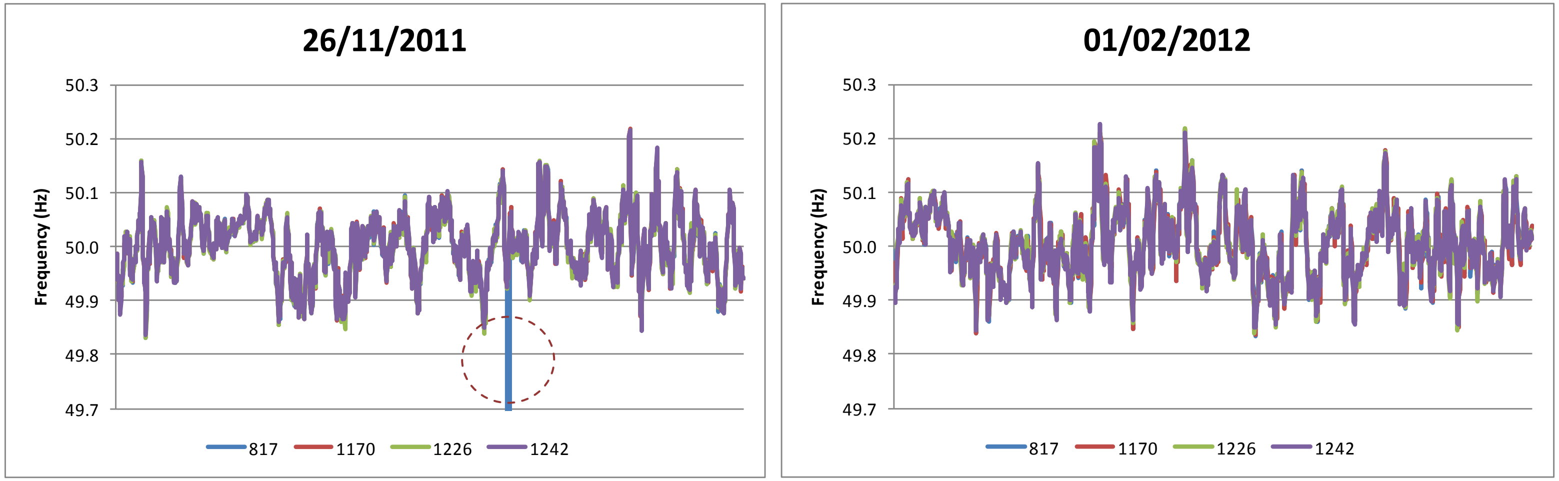


Figure 4. Frequency Measurements – Upright Freezer



4.2.3 C – Rate of Change of Frequency (ROCOF)

The calculated ROCOF values associated with the measured grid frequency trend are all well below 0.2 Hz/s for all of the fridges types and days examined (see Figure 5, Figure 6, Figure 7 and Figure 8 in the next pages).

As can be seen, there is some data missing for devices 1392, 1394 and 1400 for the static fridges and devices 817, 1226 and 1242 for the upright freezers.

Finally, analysing these data series the team discovered that, for the upright fridge 817, there are some duplicate values in the date 02/12/2012[3] which would need some further analysis.

Criterion C: Satisfied

[3] For this date, at the time 6:19, 19:17 and 23:17 there are two corresponding values instead of one (as for the rest of the observations).

Figure 5 ROCOF for Static Fridges – Week 1 (19/12/2011 – 25/12/2011)

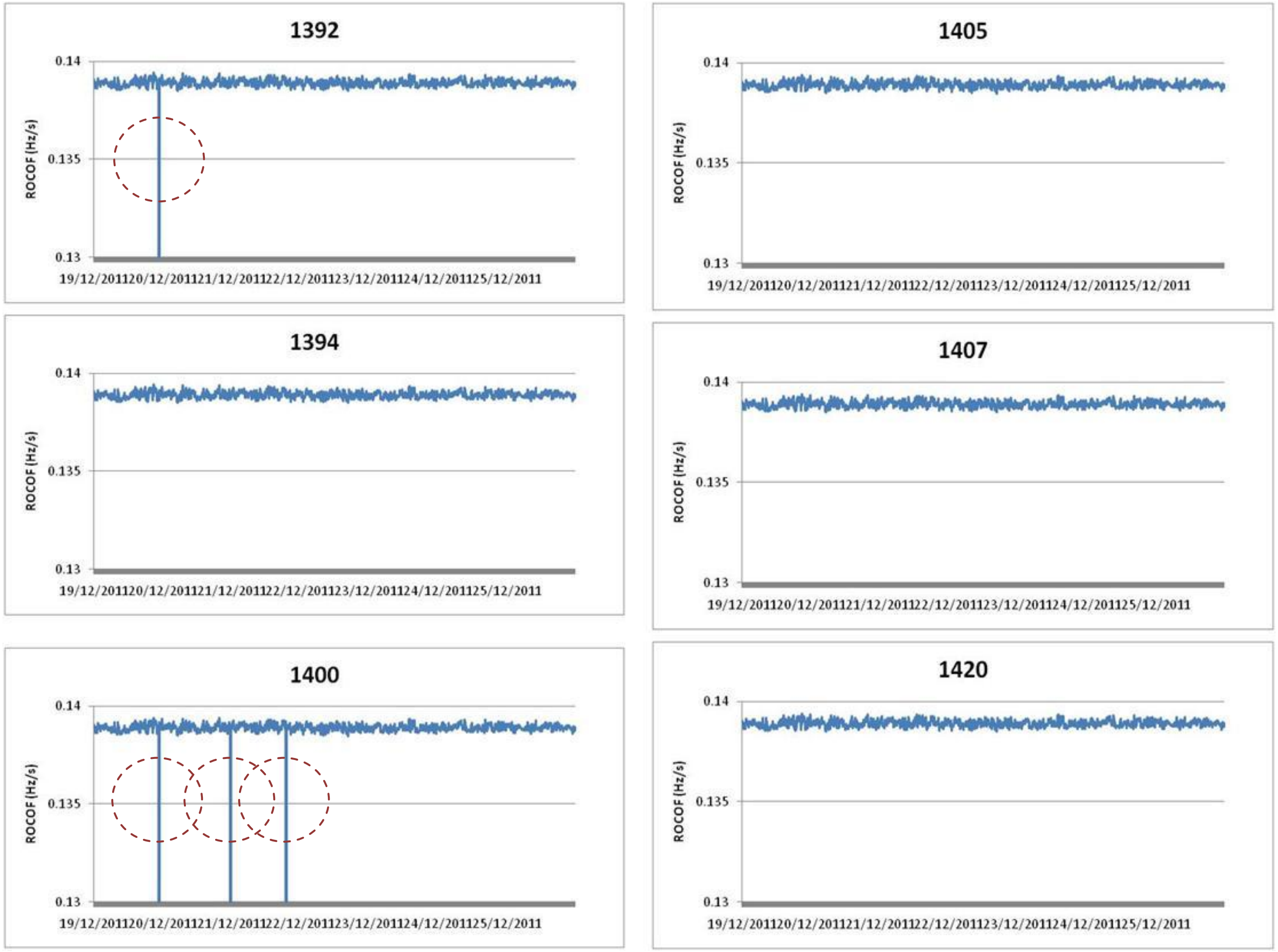


Figure 6 ROCOF for Static Fridges – Week 2 (26/02/2012 – 03/03/2012)

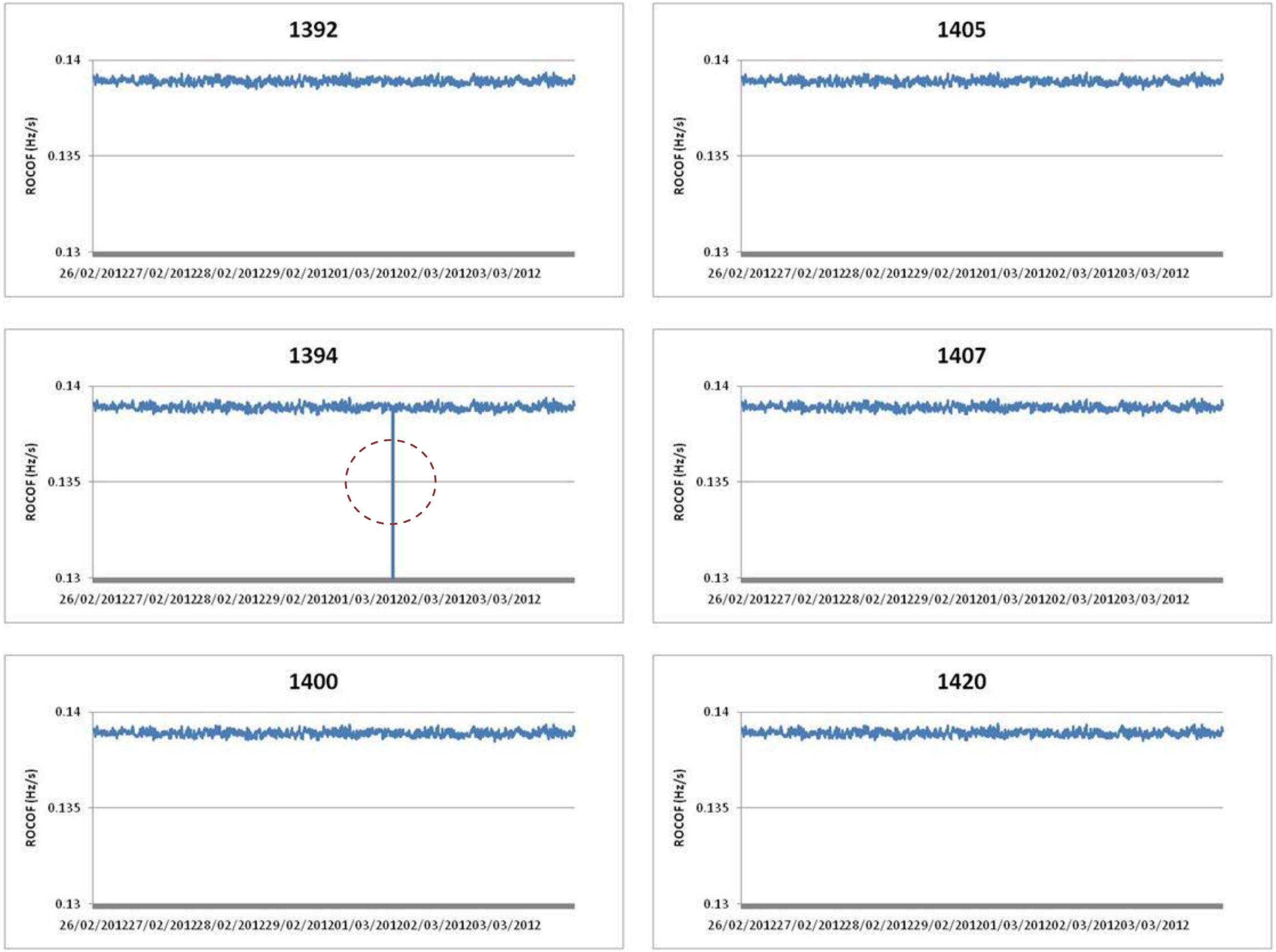


Figure 7 ROCOF for Upright Freezers – Week 1 (26/11/2011 – 02/12/2011)

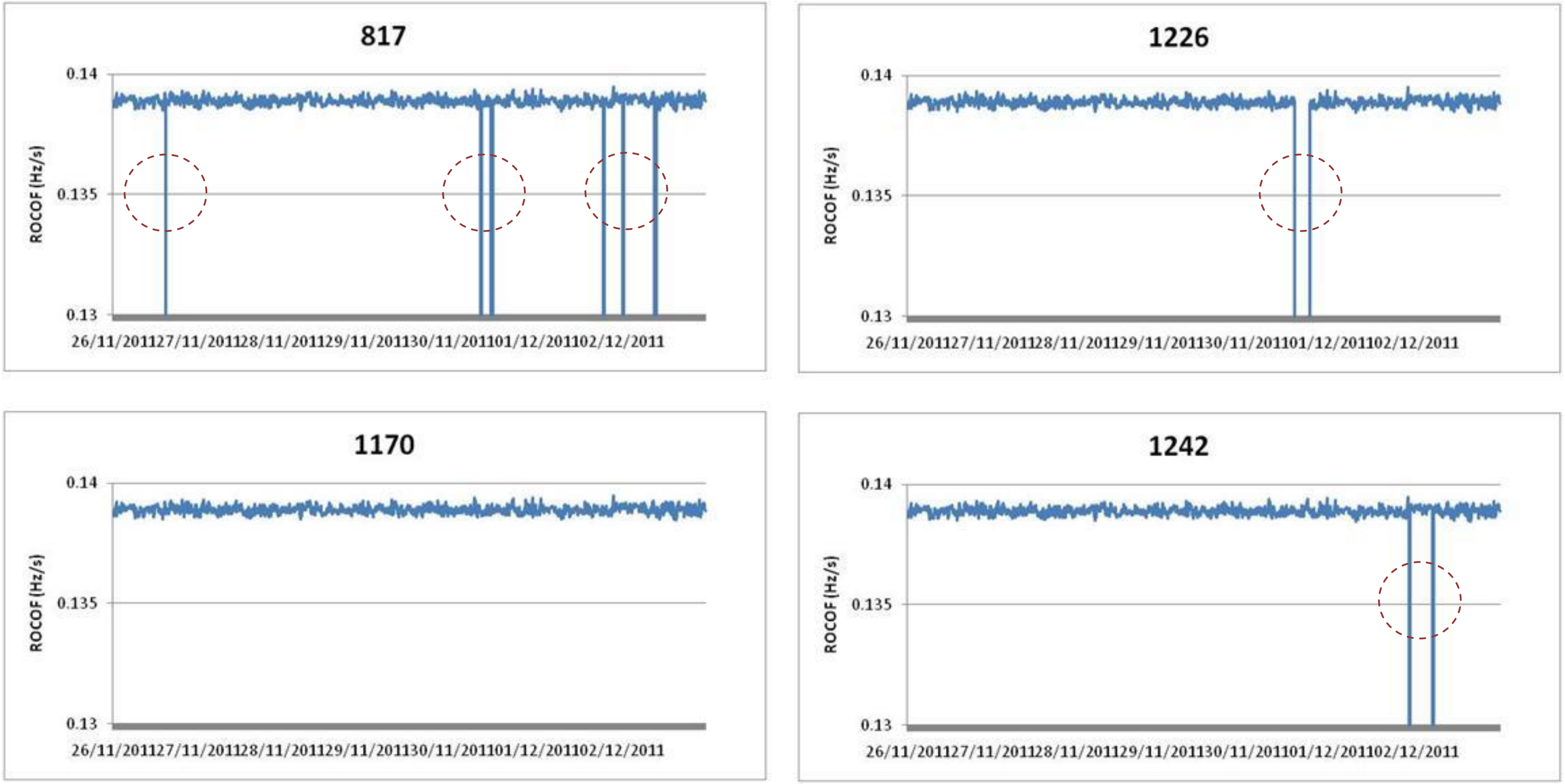
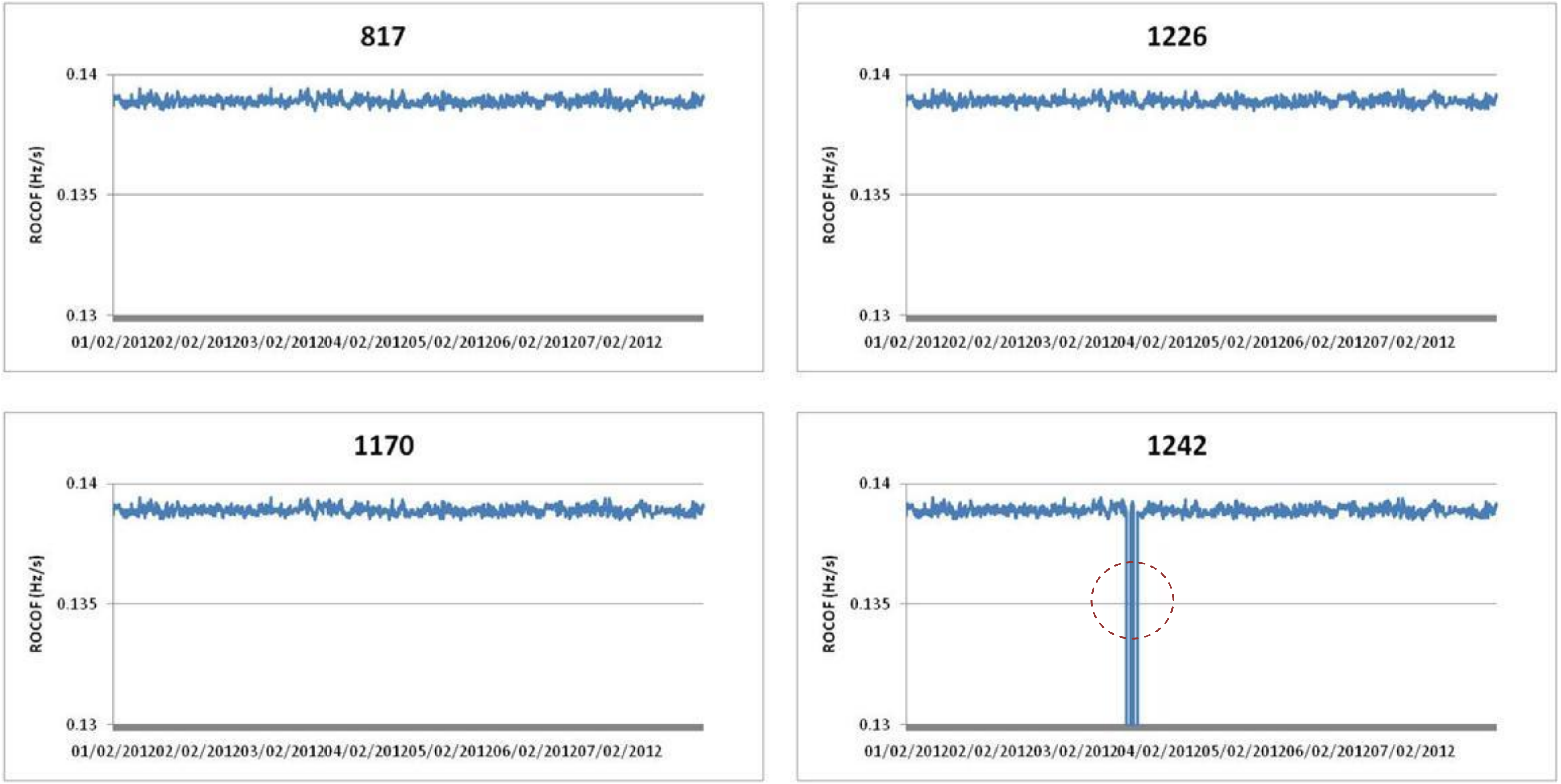


Figure 8 ROCOF for Upright Freezers – Week 2 (01/02/2012 – 07/02/2012)



4.2.4 D – Response Level Availability

The graphs in the next pages (from Figure 9 to Figure 13) show the RLA trends of the 10 fridges for the two days analysed in 4.2.2, along with fridge cavity temperature, freezer cavity temperature and compressor state.

The close relationship between these measures can be easily seen from the graphs, and this strong correlation has been also studied in more detail through an econometric analysis. DNV KEMA built a simple OLS regression model, setting RLA as a dependent variable and the other three variables (cavity temperature, freezer cavity temperature and compressor state) as explanatory variables. The estimation of the regressions conducted for each of the fridges gave robust results, confirming the strong correlation between RLA and these three measures (See Appendix A for more details).

The static fridges (see Figure 9, Figure 10, and Figure 11) do not show major differences between the two weeks and exhibit the expected response with the broadly triangular characteristic observable over the two days taken into consideration (excluding some data missing issues that can be seen for fridge 1394 and 1400 in Figure 9 and Figure 10 - the red-dotted circles). An interesting outcome for this type of fridges can be seen by analysing the trend of fridge 1407. It shows a completely different pattern compared to the other fridges. The frequency of changes in RLA and the State (ON/OFF) status was dramatically higher than the one registered for the other fridges. Considering that the six fridges are of the same type, this difference can be explained either by different geographical location or the different usage of the fridge compared to the others.

Upright freezers (see Figure 12 and Figure 13), like static fridges, do not show any major differences between the two weeks. They also show frequency of changes in RLA and the State Status similar to the static fridge 1407. For this type of fridge, rather than having some data missing issues (fridge 817 in Figure 12), there are also some transitions where the temperature moved outside the tolerance band which are reflected in the RLA (fridge 1170 in Figure 12, fridges 1226 and 1242 in Figure 13 – the red dotted rectangles).

Finally, comparing the two types of fridges, difference in the cooler cavity temperature (on average, 8 for static fridges and 35 for upright freezer) and in freezer cavity temperature (on average, -30 for static fridges and 22 for upright freezer) is clear.

Criterion D: Satisfied

Figure 9 RLA, Cooler Cavity temperature, Freezer Cavity Temperature and Compressor State for Static Fridges 1392 and 1394

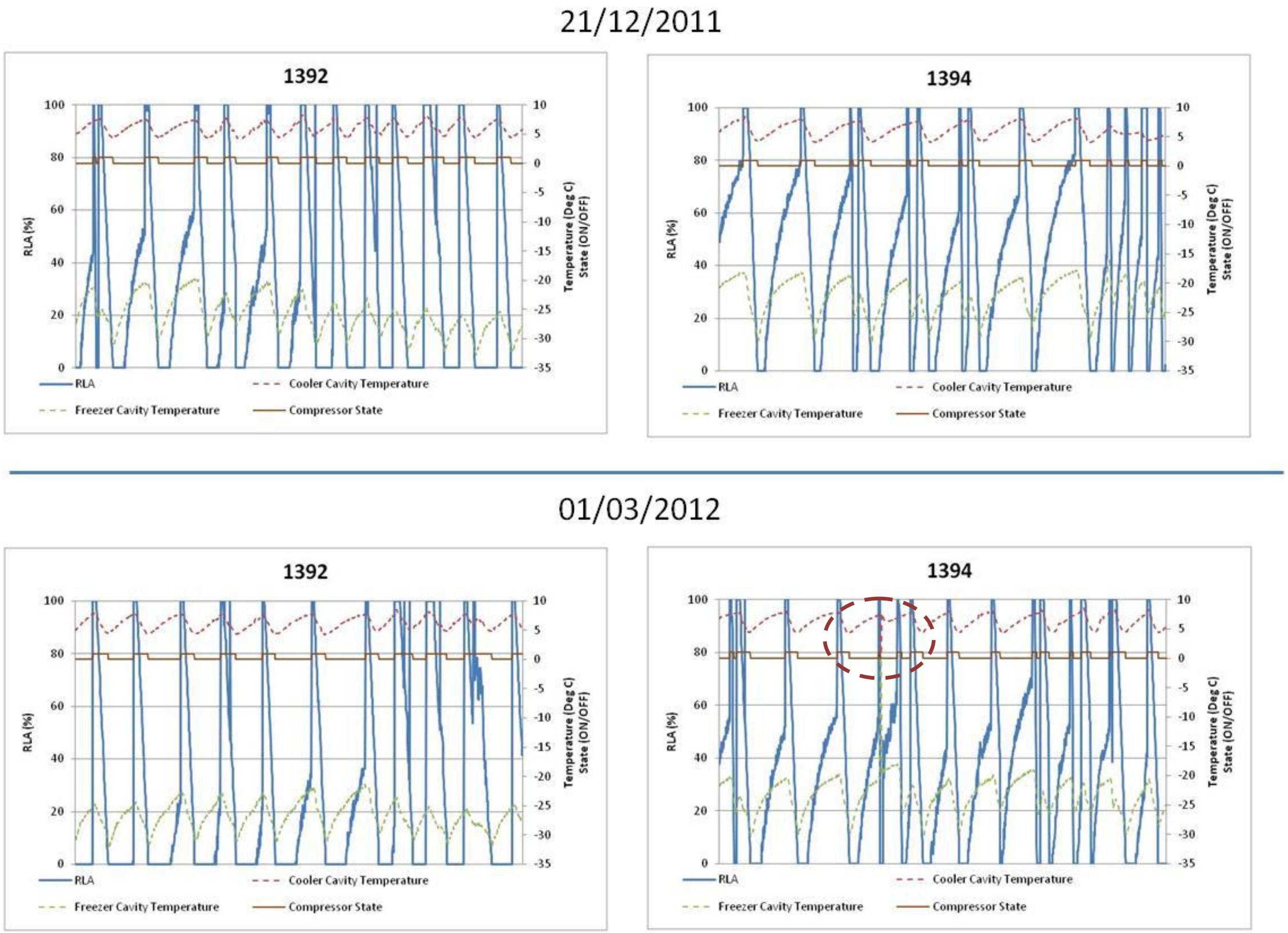


Figure 10 RLA, Cooler Cavity temperature, Freezer Cavity Temperature and Compressor State for Static Fridges 1400 and 1405

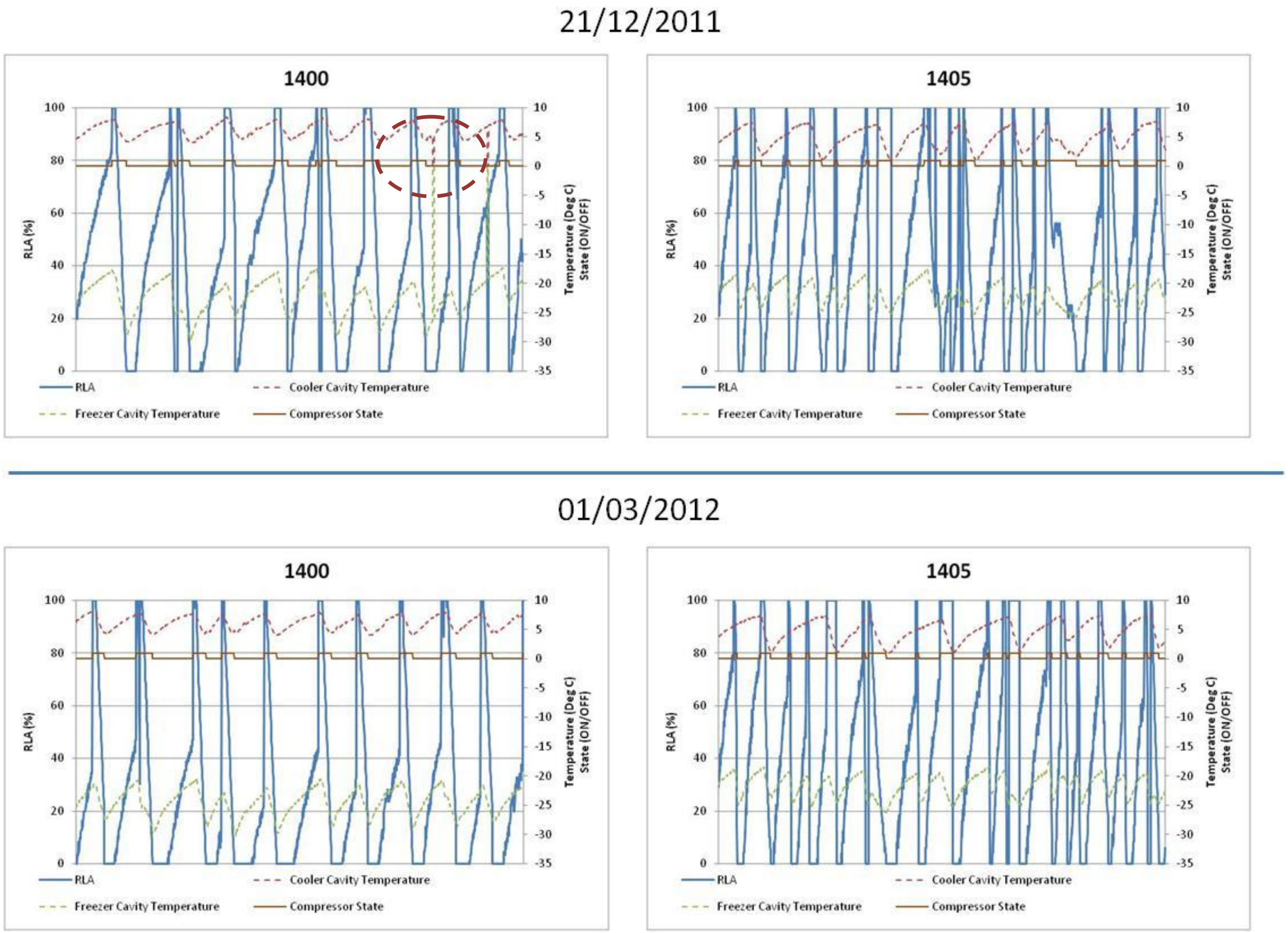


Figure 11 RLA, Cooler Cavity temperature, Freezer Cavity Temperature and Compressor State for Static Fridges 1407 and 1420

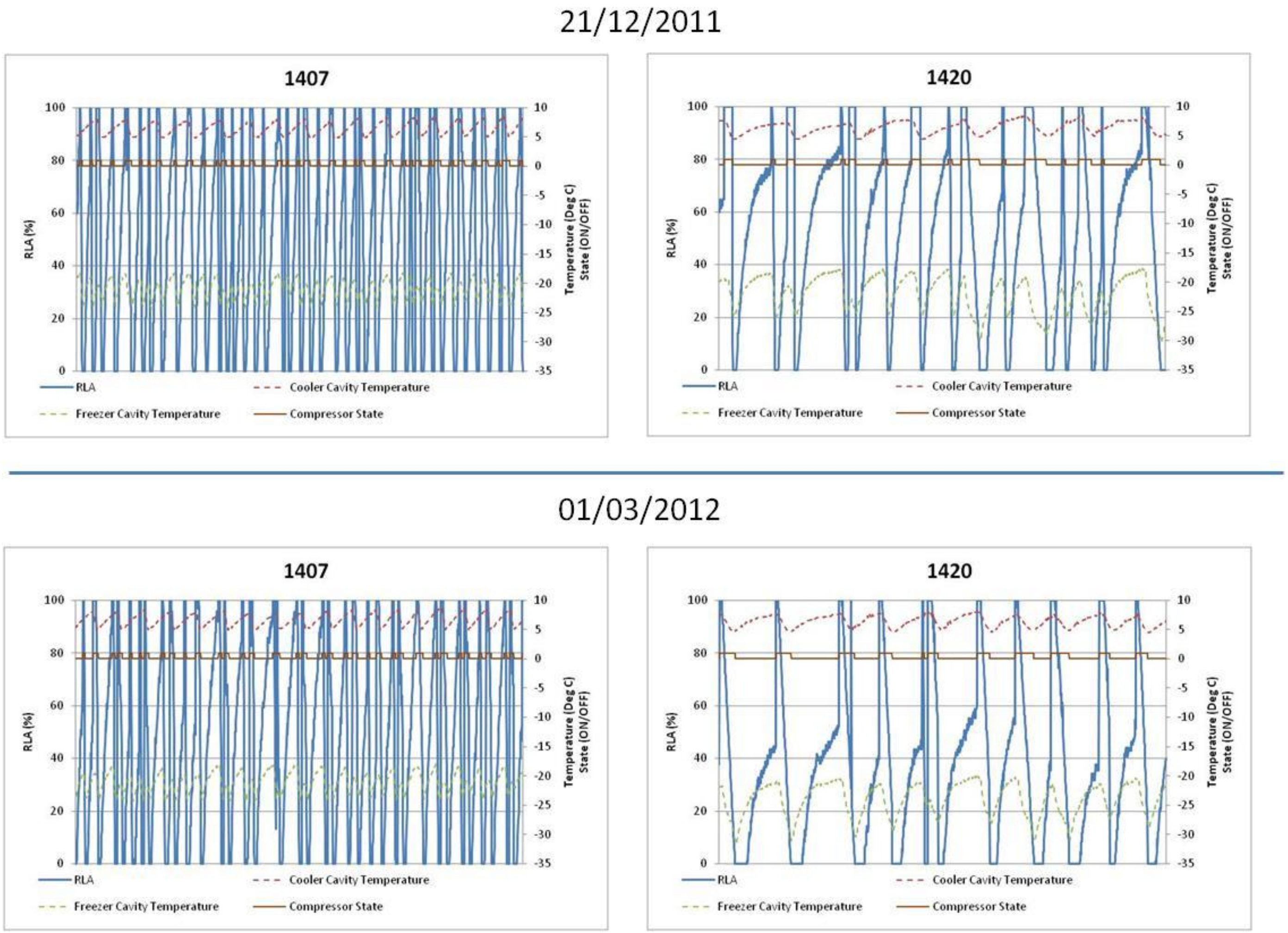


Figure 12 RLA, Cooler Cavity temperature, Freezer Cavity Temperature and Compressor State for Upright-Freezers 817 and 1170

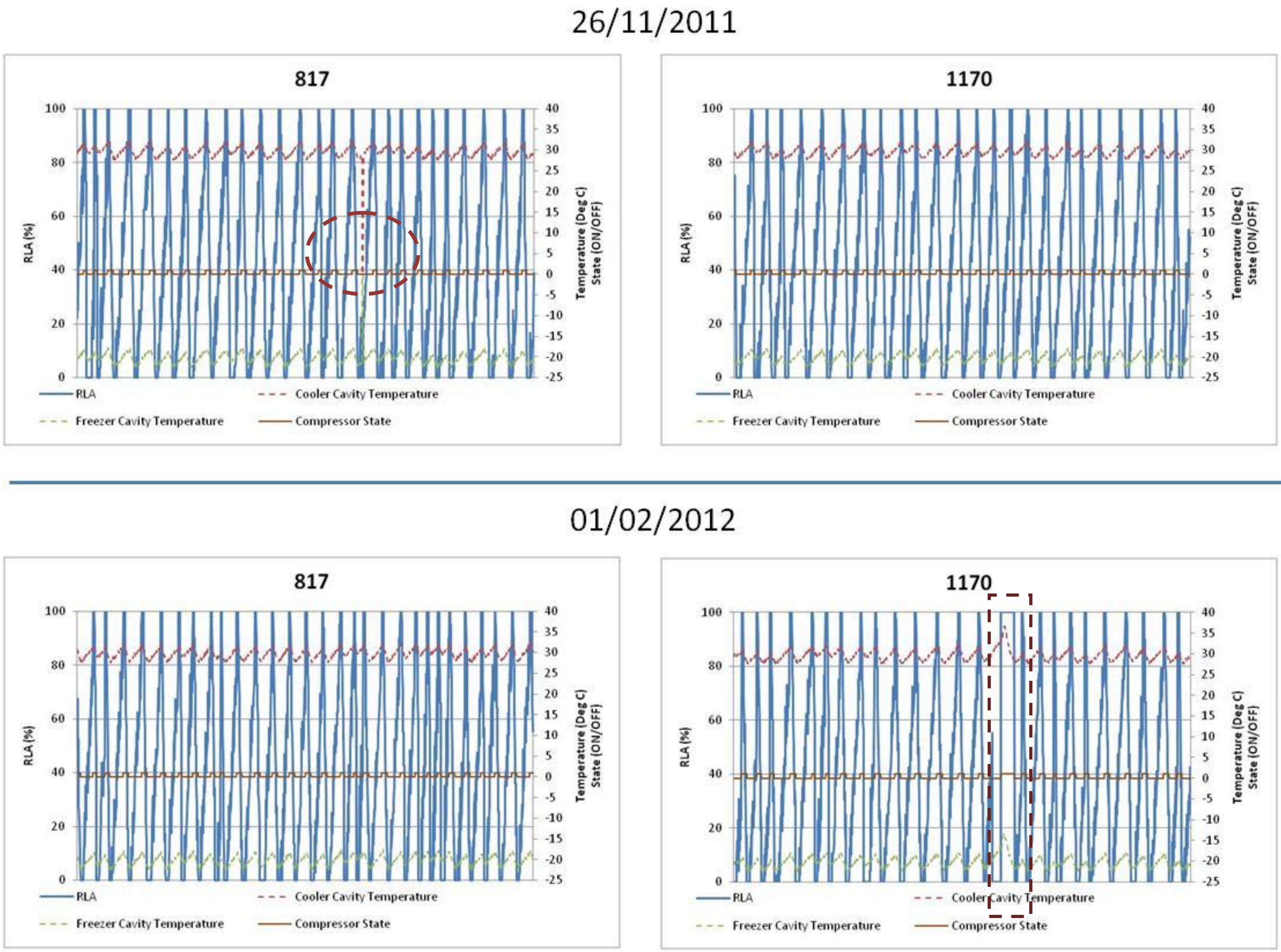
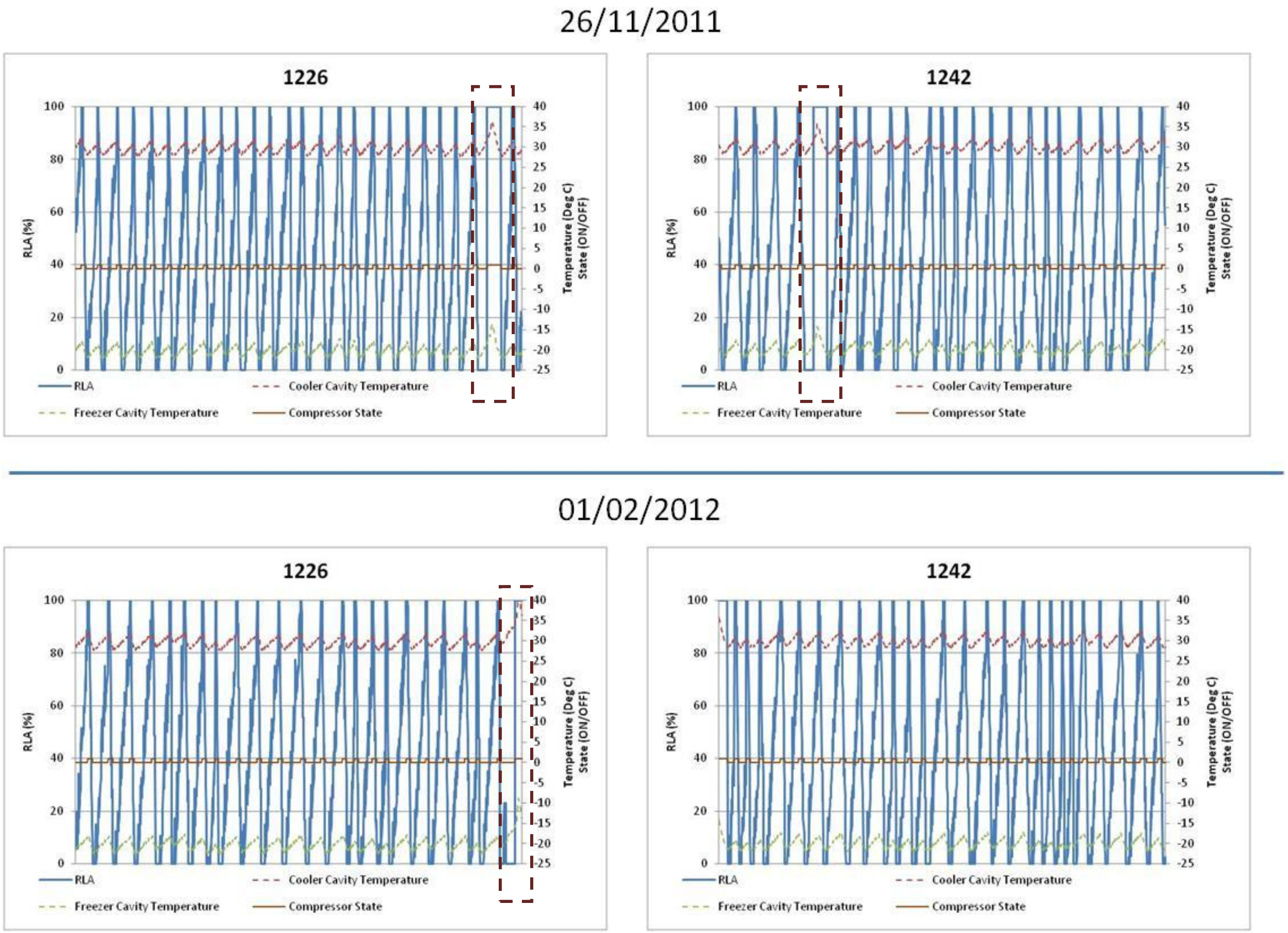


Figure 13 RLA, Cooler Cavity temperature, Freezer Cavity Temperature and Compressor State for Upright-Freezers 1226 and 1242



4.2.5 E – Trigger Frequencies

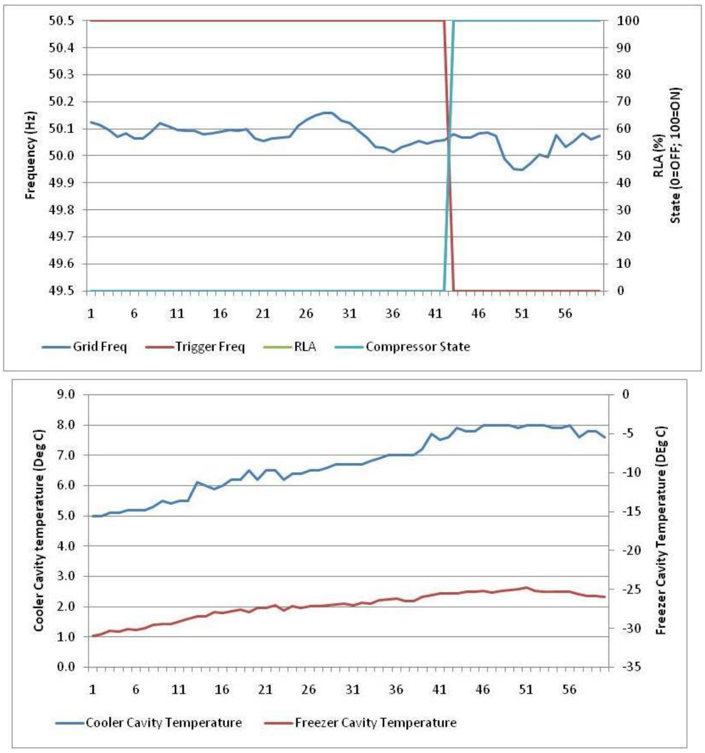
Considering the same two days analysed above, the next pages show trigger frequencies for the 10 devices (from Figure 15 to Figure 19). A more extensive analysis has been also conducted, taking into consideration the entire two weeks. However, the trends are in line with the ones showed below.

In general, for both fridges types, the same conclusions made for RLA can be seen: trigger frequency trends do not show any significant differences between the two periods and they respect (except for the same data missing points saw in the previous sections) the range 49.5 to 50.5 Hz.

The static fridge 1407 shows, as for RLA, a different trend compared to the other static fridges.

The relationships between grid frequency, trigger frequency, RLA, compressor state and temperatures can easily be seen by analysing together the graphs from this and the previous sections. As an example, below there is a graph showing these measures for the static fridge 817 at 18:00 in the 21/12/2012.

Figure 14 Grid Frequency, RLA, Temperatures and State of Static Fridge at 18:00 on 21/12/2012



Criterion E: Satisfied

Figure 15 Trigger Frequency for Static Fridges 1392 and 1394

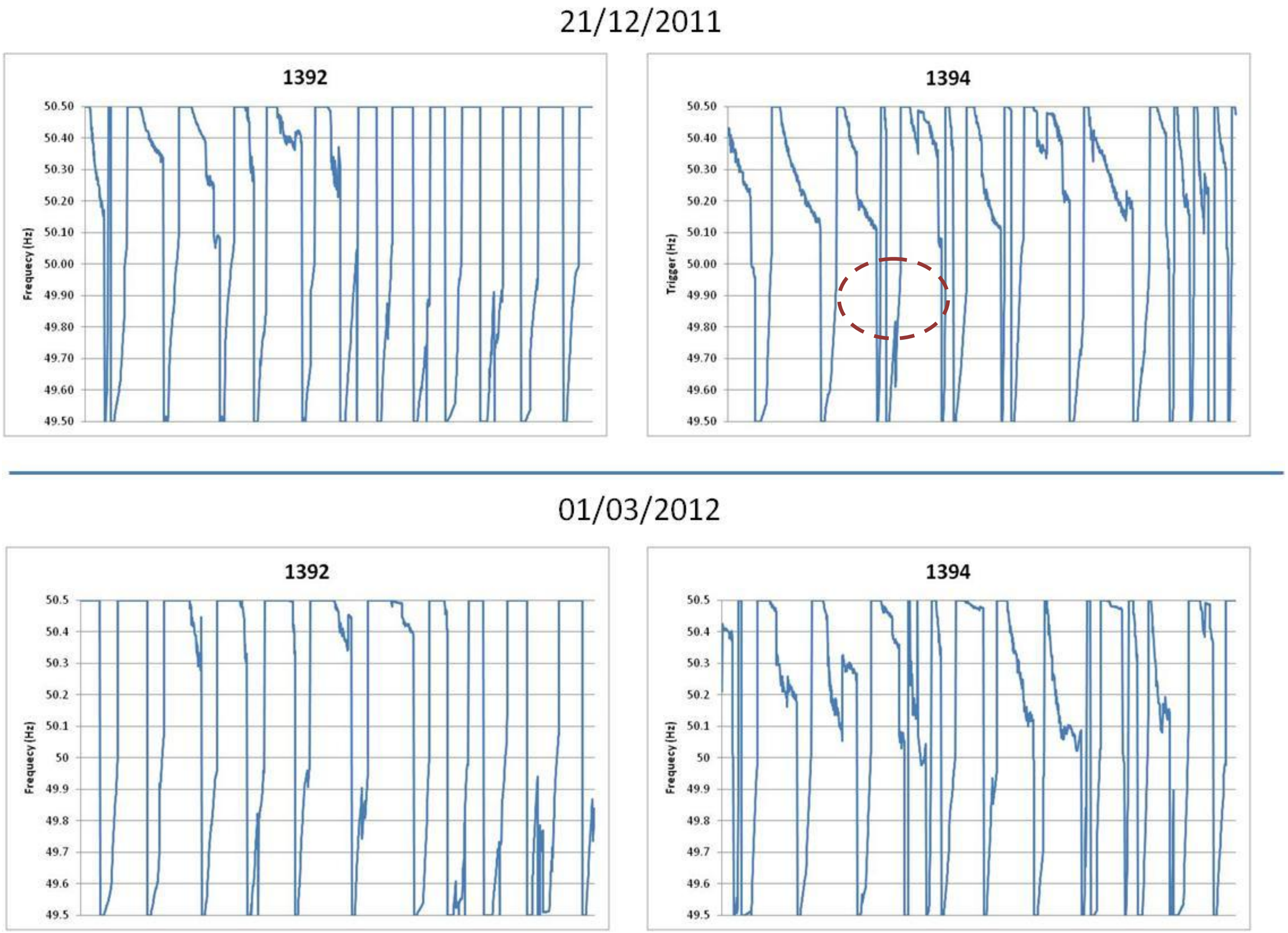


Figure 16 Trigger Frequency for Static Fridges 1400 and 1405

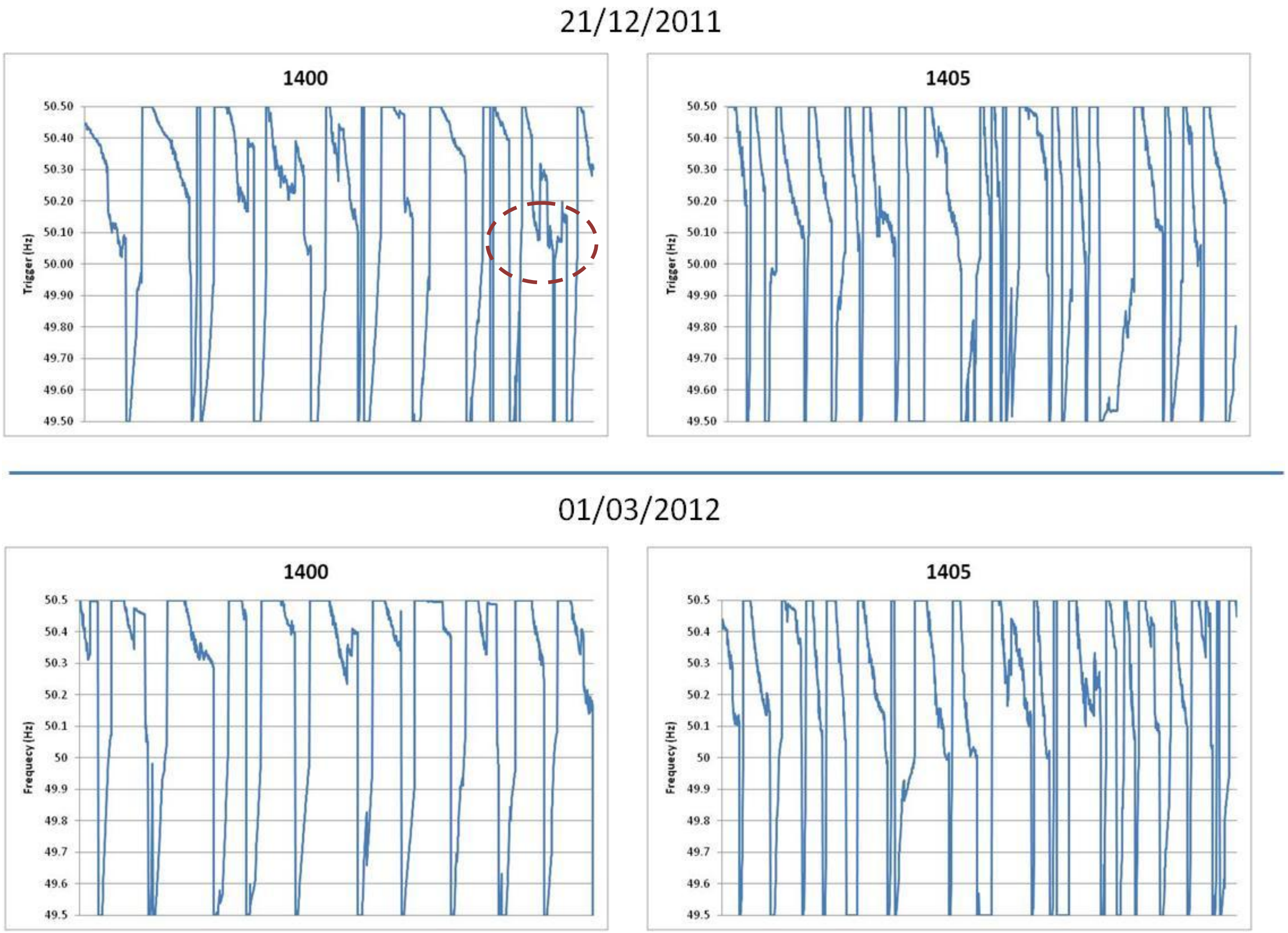


Figure 17 Trigger Frequency for Static Fridges 1407 and 1420

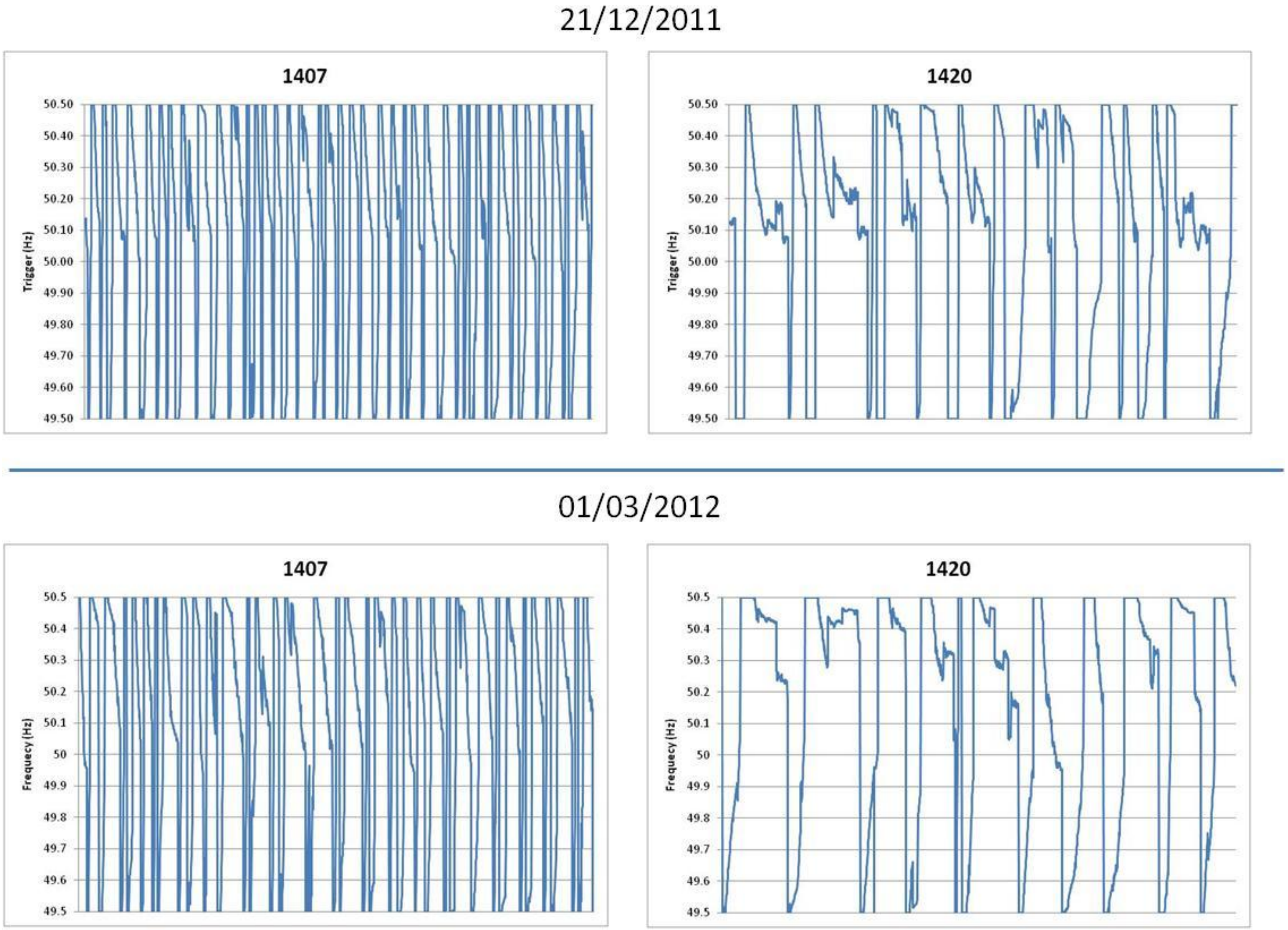


Figure 18 Trigger Frequency for Upright-Freezers 817 and 1170

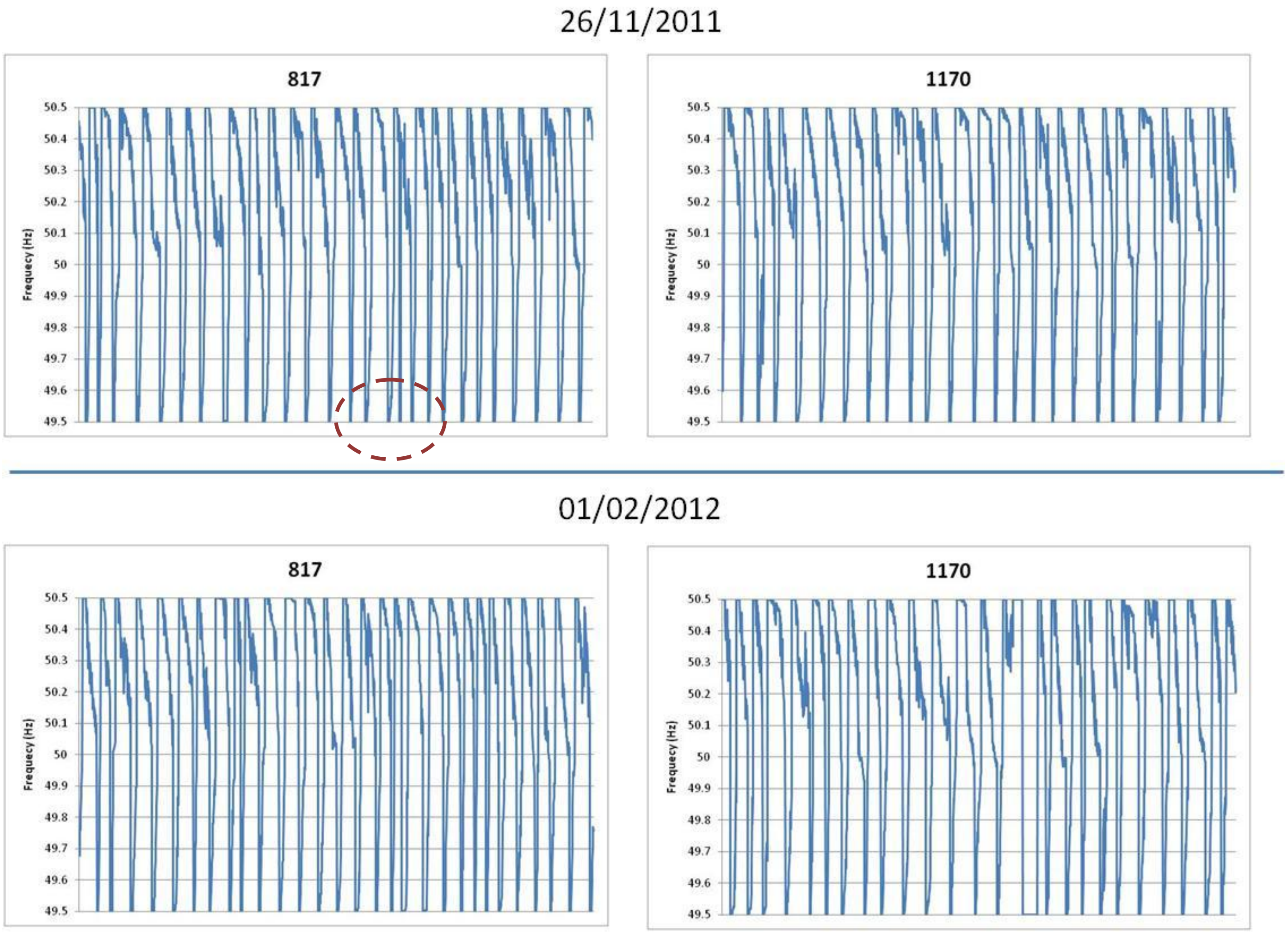
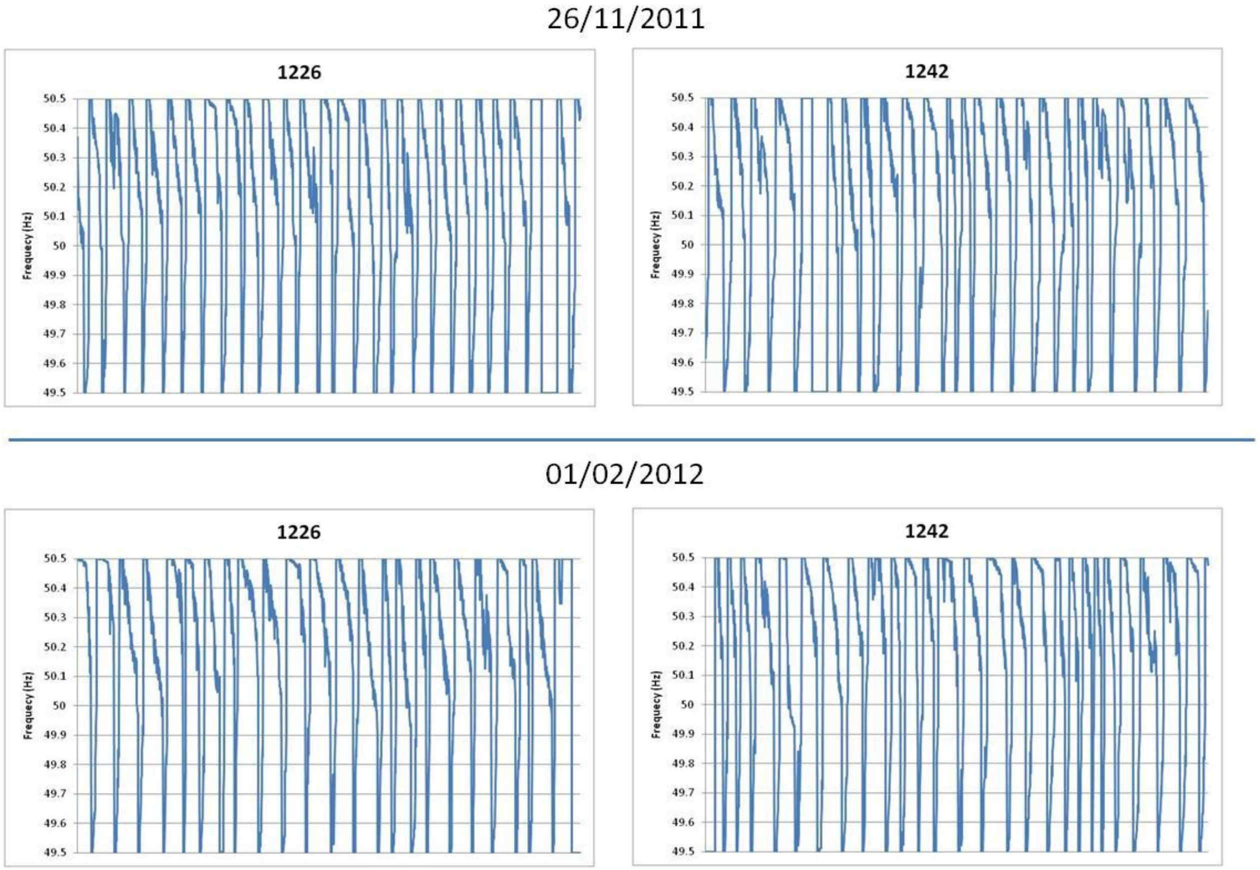


Figure 19 Trigger Frequency for Upright-Freezers 1226 and 1242



5 FUNCTIONAL VERIFICATION, CO_2 CALCULATIONS ANALYSIS

The Open Energi patented Open Dynamic Demand™ technology provides a potential CO_2 saving performance in addition to those achieved as a result of voluntary industry agreements.

The Dynamic Demand technology for CO_2 emissions savings is based on the required reserve capacity in the UK (which is needed to supply flexible power for frequency response). According to National Grid, the total appropriate capacity range held for reserve in the UK should be between 1000 MW and 1320 MW. Currently discussion are taking place to raise this range between 1320 MW and 1800 MW. The reserve capacity, provided by the energy suppliers, is managed by National Grid (NG). Special contracts allow NG to "operate" an energy supplier's power station within certain limits. To be able to provide reserve capacity, power stations are operated at a lower capacity, which has a negative impact on the efficiency of the plant.

National grid calculated that each MWh of energy hold for reserve equals an additional CO_2 emission of 0.26 tonne. Therefore, technologies like the Open Dynamic Demand™ will help to reduce the reserve capacity needed at power station level; resulting in an emission reduction.

The Response Level Availability (RLA - the availability of the demand response service measured for each fridge in the trial) was used by DNV KEMA to calculate the contribution of the fridges in stabilising the grid frequency and the subsequent contribution of these appliances in CO_2 savings.

As already mentioned, three different fridge types were installed during Phase 2 of the trial. These models have different capacities and they have been considered accordingly in DNV KEMA calculations:

- The Combi Static Fridges have a capacity of 85 W;
- The Upright-Freezers have a capacity of 91 W ; and
- The Table-Top have a capacity of 55 W..

The tables below show the results for the first two fridges types. Both are consistent with the ones obtained in Phase 1: there is a *reduction of around 1 tonne of CO_2 over the appliances' lifetime*.

Another important conclusion can be made comparing the two fridges types: the difference in capacity between the upright freezers and the Combi static fridges (91W vs 85W) leads to a larger amount of CO_2 savings from the upright ones. In this respect, another aspect should be considered as well; the upright freezer will presumably consume more in the course of the year, due to the larger compressor. Therefore, the annual energy consumption for this type of device will be higher than the static fridges. This will lead to an increase of CO_2 emissions. The overall effect on CO_2 emissions will be then the sum of these two opposite actions.

Table 1 CO_2 Savings due to Service Availability using RLA Average: Static Fridges

Period: 19/12/2011 - 25/12/2011								
Power Cmprssr	Static fridge	RLA Average		Year	Life time fridge	Service availability	Emissions	Fridge DD savings
[W]	[ID]	[%]	[W]	[hours]	[Years]	[MWh]	[t CO2/MWh]	[t CO2/lifetime]
85	1392	30.50	25.92	8766	15	3.41	0.26	0.886
85	1394	42.86	36.43	8766	15	4.79	0.26	1.246
85	1400	40.02	34.02	8766	15	4.47	0.26	1.163
85	1405	41.21	35.03	8766	15	4.61	0.26	1.198
85	1407	47.70	40.55	8766	15	5.33	0.26	1.386
85	1420	43.58	37.04	8766	15	4.87	0.26	1.266
							Average	**1.191**

Period: 26/02/2012 - 03/03/2012								
Power Cmprssr	Static fridge	RLA Average		Year	Life time fridge	Service availability	Emissions	Fridge DD savings
[W]	[ID]	[%]	[W]	[hours]	[Years]	[MWh]	[t CO2/MWh]	[t CO2/lifetime]
85	1392	30.61	26.02	8766	15	3.42	0.26	0.889
85	1394	40.24	34.21	8766	15	4.50	0.26	1.169
85	1400	34.85	29.62	8766	15	3.89	0.26	1.013
85	1405	41.81	35.53	8766	15	4.67	0.26	1.215
85	1407	47.58	40.44	8766	15	5.32	0.26	1.383
85	1420	42.39	36.03	8766	15	4.74	0.26	1.232
							Average	**1.150**

Table 2 CO_2 Savings due to Service Availability using RLA Average: Upright Freezers

Period: 26/11/2011 - 02/12/2012								
Power Cmprssr [W]	Upright freezer [ID]	RLA Average [%]	RLA Average [W]	Year [hours]	Life time fridge [Years]	Service availability [MWh]	Emissions [t CO2/MWh]	Fridge DD savings [t CO2/lifetime]
91	817	40.78	37.11	8766	15	4.88	0.26	1.269
91	1170	40.92	37.24	8766	15	4.90	0.26	1.273
91	1226	40.75	37.08	8766	15	4.88	0.26	1.268
91	1242	41.36	37.64	8766	15	4.95	0.26	1.287
							Average	**1.274**

Period: 01/02/2012 - 07/02/2012								
Power Cmprssr [W]	Upright freezer [ID]	RLA Average [%]	RLA Average [W]	Year [hours]	Life time fridge [Years]	Service availability [MWh]	Emissions [t CO2/MWh]	Fridge DD savings [t CO2/lifetime]
91	817	41.07	37.38	8766	15	4.91	0.26	1.278
91	1170	40.24	36.62	8766	15	4.81	0.26	1.252
91	1226	39.43	35.88	8766	15	4.72	0.26	1.227
91	1242	41.25	37.54	8766	15	4.94	0.26	1.283
							Average	**1.260**

6 CONCLUSIONS

From this report the following conclusions can be made regarding Phase 2 of the Open Dynamic Demand™ technology trial.

- Based on Open Energi's definition and National Grid estimations regarding generated emissions from hold reserve capacity in the UK, DNV KEMA calculated CO_2 savings coming from the Open Dynamic Demand™ built into the appliances analysed in this phase. The results show an average of 1.17 and 1.26 tonne CO_2 savings over the lifetime for the static and upright fridges respectively. These numbers confirm the consistency of Open Energi's findings and the assumptions made in Phase 1 report.

- Five out of five technical data verification criteria (A. Distribution of Frequency Responses; B. Trend in Frequency; C. Rate of Change of Frequency; D. Response Level Availability; and E. Trigger Frequency) were completely satisfied and consistent with Phase 1 results.

- Criterion A (Distribution of Fridge Responses) in this Phase assumed a different definition to Phase 1. In Phase 1 it referred to the total number of minutes that the appliance was providing data to the READm device, while in Phase 2 (thanks to additional information made available by Open Energi) it referred to the total number of minutes that the appliances were giving response services.

- No seasonal influences were identified, due to the limited time frame considered. For the static fridges the two weeks considered were in late November and late February/early March. For the upright freezer the two analysed weeks were in late November/early December and early February. This period (from November to early March) can be considered in the UK as 'winter period'. To best assess the impact of seasonal changes, a more extreme time period analysis would be needed (November – June, for example).

- The Response Level Availability (RLA) behaviour of the static fridge 1407 was different to the other fridges of the same type. Different reasons could explain this: (i) the appliance was deployed in a different area; (ii) different user behaviour; (iii) the fridge was set in a different operational mode. Further investigation would be needed to explain these differences.

- A strong and expected relationship between RLA, trigger frequency, net frequency, temperature and compressor state was found.

APPENDIX A

Econometrics is based upon the development of statistical methods for estimating economic relationships, testing economic theories, and evaluating and implementing government and business policy.

Much of applied econometric analysis begins with the following premise: *y* and *x* are two variables, representing some population, and we are interested in "explaining *y* in terms of *x*," or in "studying how *y* varies with changes in *x*.

In writing down a model that will "explain *y* in terms of *x*," we must confront three issues.

(i) Since there is never an exact relationship between two variables, how do we allow for other factors to affect *y*?

(ii) What is the functional relationship between *y* and *x*?

(iii) How can we be sure we are capturing a *ceteris paribus* relationship between y and x (if that is a desired goal)?

We can resolve these ambiguities by writing down an equation relating *y* to *x*. In this case it is needed an equation which relates the Response Level Availability (RLA) with cavity temperature (CT), freezer cavity temperature (FCT) and compressor state (CS). The simple equation is:

$$RLA_t = \beta_1 CT_t + \beta_2 FCT_t + \beta_3 CS_t + U_t$$

That equation, which is assumed to hold in the population of interest (in this case the 10 devices taken into consideration), defines the linear regression model. It is also called the four-variable linear regression model or multivariate linear regression model because it relates the fours variables (RLA, CT, FCT and CS)

Analysing the linear equation more in details can be seen that:

- *U* is the error term
- β_1, β_2 and β_3 are the factors of the CT, FCT, and CS respect to RLA respectively.

These three last factors have, in the analysis, a central rule. They indicate, in fact, the possible correlations between the response level availability with cavity temperature, freezer cavity temperature and compressor state.

Data used

The econometric model is based on the data set given by Open Energi, which contains minute data for the 10 devices in the two weeks described in paragraph 4.1.1, for a total of 1440 observation for each variable.

Estimations

The estimations (conducted using the Ordinary Least Square Estimator (OLS), which has the objective to find the values of the betas which minimize the sum squared of the errors) performed for the four days considered in the analysis in section 4.2.4 are shown below.

Table 3 OLS Estimations for Static Fridges

	21/12/2012						**01/03/2012**					
	1392	*1394*	*1400*	*1405*	*1407*	*1420*	1392	1394	1400	1405	1407	1420
R square	0.92	0.93	0.94	0.79	0.81	0.88	0.91	0.92	0.94	0.79	0.82	0.96
β1	12.96	14.90	15.36	8.86	14.59	15.77	9.82	13.05	11.41	7.34	15.98	14.36
β2	2.56	2.49	2.62	0.75	2.98	2.79	2.11	2.52	2.30	0.37	3.44	2.88
β3	50.84	34.50	32.02	40.63	42.35	37.86	59.81	45.44	50.40	50.49	39.32	47.09
P-Value β1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-Value β2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-Value β3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4 OLS Estimations for Upright Freezers

	26/11/2011				**01/02/2012**			
	817	*1170*	*1226*	*1242*	*817*	*1170*	*1226*	*1242*
R square	0.95	0.96	0.92	0.93	0.95	0.88	0.84	0.94
β1	10.25	10.71	8.86	9.07	10.24	7.26	5.89	9.52
β2	13.23	13.90	11.27	12.10	13.33	9.06	6.98	12.58
β3	16.17	16.78	20.37	21.06	15.99	26.73	23.54	21.05
P-Value β1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-Value β2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-Value β3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The first measure in the table is the R squared (or R^2). This estimates the percentage of variation of the dependent variable (RLA in this case) which is explained by the explanatory variables (RLA, CT, FCT and CS in our case). In other words, it measures the goodness of fit of the linear regression. It ranges between 0 and 1 and higher values indicate that the model fits the data better and vice-versa. Therefore, R^2 estimations for the two types of fridges show the goodness of fit of all the regression conducted.

The other two measures are related to each other. The betas, as mentioned above, estimate the possible correlations between the variables. For the purposes of this project, the absolute value of these coefficients is not relevant; but rather the significance of them, which is expressed by the *P-Value*s. P-Values are associated with a statistic test called *t-statistic.* For this purposes it is enough to know that small values of the P-Value (mean that the variable taken into consideration is statistically significant in the explanation of the dependent variable. In this case, since all the p-value are really small (near to zero) we can conclude that, for every regression estimated, CT, FCT and CS are significant in the explanation of RLA. In other words, there is a significant correlation between RLA, CT, FCT and CS.