Customer-Led Network Revolution

Insight Report:

Domestic Direct Control

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Contents

1 Trial Overview

1.1 Description

This report covers the work of the two domestic direct control test cells (TCs): 11a Wet White Goods (WWG) and 14. These test cells provide data on customers' acceptance of and responsiveness to direct control of washing machines and Air-Source Heat Pumps (AHSPs), and the technical performance of the solutions involved.

- **TC11aWWG** involved direct control and monitoring of 96 customers' washing machines. During the trial, data was collected during interruptions which were all called during weekday peak times. Each event lasted for four hours, from 4pm to 8pm.
- **TC 14** involved direct control of eight customers' ASHPs which were installed alongside a large thermal storage unit to allow interruptions to occur without a loss of heating. During the trial, 14 interruptions were called. Four lasted half an hour and ten lasted an hour.

1.2 Purpose

These trials were designed to support Learning Outcome 2. Specifically, they provide the data needed to understand:

- the degree to which customers accept direct control proposition for flexibility;[1] and
- the degree to which customers who have formally accepted a direct control proposition actually respond.

This report focuses on the second of these aims

It is also the case that the technologies used in these test cells have not previously been trialled in the UK. For example, the addition of a thermal storage unit to the ASHP and the addition of the control devices with the smart washing machines had not been used together before. Further, the way in which they have been used is unique: the heat pump DSR events involved interactions between a DNO, supplier and technical providers to automatically call interruptions during times of network stress (through the use of the "GUS" active network management control system – we understand this is the first time within the UK such a system has been used to call domestic DSR). Therefore, these test cells should be seen as much as a technical trial as a social trial.

We now discuss in more detail how each test cell aimed to support this learning.

[1] This is reported in "Project lessons learnt from trial recruitment: CLNR trials", Phillips, Owen, Ward (24 July 2013).

1.2.1 Test cell 11aWWG

Test cell 11aWWG provides detailed consumption profiles for the washing machines that formed a part of the direct control proposition. This data has allowed us to assess the effect of the direct control proposition on the households' actual consumption profiles. The key aims of the 11aWWG trial are summarised below.

- **Determine customers' responsiveness to an interruption** – For each interruption the customer's response to the interruption is determined, by looking at the extent to which they ran their washing machines during the interruption, or used the 'delay' function on their washing machine.
- **Determine the average effect of the direct control proposition on households' consumption profiles** – To assess the direct control proposition's effectiveness in shifting load from periods of system stress, households' consumption profiles on days in which there was an interruption event are compared with consumption profiles on similar days without an interruption, as well as TC2a participants, who act as a control group for this trial.

1.2.2 Test cell 14

Test cell 14 provides detailed consumption profiles for the ASHPs that formed a part of the direct control proposition. This data has allowed us to assess the effect of the proposition on the households' actual consumption profiles. The key aims of the 14 trial are summarised below.

- **Determine the average effect of the direct control proposition on households' consumption profiles** – Comparing the households' consumption profiles on days in which there was an interruption event with consumption profiles on similar days without an interruption event allows assessment of the direct control proposition's effectiveness in shifting load from periods of system stress.
- **Assess the impact of any 'payback' after the direct control event.** The data also allows assessment of the extent to which electricity demand from the heat pump spikes, to bring heat levels back to the required levels in the property, once the storage is exhausted and it is switched back on. Understanding the incidence of payback spikes will be very important in terms of how DNOs can use direct control on heat pumps in the future.

2 Trial Design

2.1 Test cell 11aWWG

2.1.1 Participation and recruitment

Test cell 11aWWG comprised 96 domestic British Gas customers. No out of region customers were included. Participants were offered a subsidy of £50-worth of vouchers on joining the trial, and a further £50-worth of vouchers at the end of the trial. They also received the smart washing machines that were the subject of the trial. These goods were worth approximately £1000 and were installed for free.

Given the large incentive customers received for joining this trial (the vouchers and the washing machine), results relating to their overall experience of the trial should be interpreted with this in mind.

2.1.2 Equipment and tariff

Four key pieces of equipment were installed as part of the trial.

- A smart meter – Where not already fitted, a smart meter was installed to provide the necessary ability to monitor consumption.
- A smart appliance – The washing machines incorporate sophisticated delayed start functionality. Specifically, the customer can specify a 'finish by' time, by when the cycle must have been completed. The device itself then selects a run-time based on this constraint, and any pre-announced interruptions from the suppliers (described in more detail below). The device also displays advisory messages, such as the announcement of a future interruption.
- A gateway – A device to collect and store data on and manage the smart appliance's use.
- A repeater – Where necessary a repeater was installed to boost signal strength between the internet modem and the smart appliance.

There was no specific tariff related to the operation of the device and no financial incentive to avoid using the appliance, or to lower consumption, during an interruption event.

2.1.3 Monitoring and interruptions

Customer demand was monitored during a period which included the DSR events (which occurred during March 2014) and a period before and after this.

Three main types of data were collected:

- half hourly data on the electricity consumption of the washing machine;
- the status of the link between the GreenCom cloud and the router, and between the router and the gateway (to determine whether the machine could see DSR signals); and

- status signals from the machine, indicating the mode it was in.

Under the terms of the direct control proposition, up to a maximum of 15 interruption events could be called in any one year, between 4-8pm on weekdays.

In the event that an interruption event is announced, the smart appliance displayed a message of the form 'Load reduction requested 4pm-8pm please avoid this time.' During the trial, interruption signals were sent 30 minutes prior to the scheduled start of the interruption, providing limited forewarning.

The effect of the interruption on the smart appliance is as follows:

- If the appliance has already stared to run, then the device displayed a message inviting them to stop the cycle in progress. The cycle could be deferred or restarted later if desired. However, the device did not automatically defer the load.
- If the appliance had been set to run, but had not yet started, then the start time was set until after the load control period, subject to ensure the cycle was finished by the user's 'finish by' time. If this required the machine to operate during the interruption event, the user was invited by the advisory messages to stop the cycle in-progress, as above.

As noted above, there was no financial incentive to avoid using the appliance during an interruption event and the appliance will only alter its run-time subject to the 'finish by' time specified by the user. Consequently, very little control was exerted over the participant.

During the trial, 11 events were called between 11/3/14 and 31/3/14. Each of these events lasted for four hours, from 4pm-8pm.

2.2 Test cell 14

2.2.1 Participation and recruitment

Within test cell 14 data was collected for eight domestic customers, including some non-British Gas and out of region customers. Participants were offered a subsidy of £50-worth of vouchers on joining the trial, and a further £50-worth of vouchers at the end of the trial. They also received a DECC-subsidised ASHP installation, worth an average of £3,500, and a year's free broadband, worth £277.

Given the small size of this trial, the high level of the subsidy received on joining and the fact that recruitment for this trial was not random, the learning that can be drawn from this test cell is mainly qualitative in nature.

2.2.2 Equipment and tariff

All participants were supplied with a 'smart grid capable' Neura Nano ASHP, which included integrated direct control functionality and ten-minute load monitoring. The ASHP draws a maximum of 2.7kW of power for the compressor itself, with smaller power usage for other components such as the fan.

A thermal store was also installed, to provide heat when the heat pump was switched off during 'direct control' mode. The unit installed was either a 300ltr or 500ltr Gledhill Stratified Thermal Store. This was supplemented by additional heat meters and temperature sensors. It should be noted that it is currently unusual for UK heat pump installations to include a thermal store, which is a sizable device in itself (one of the 300ltr models has a height of 1.85m and a diameter of 0.71m).

No change was made to customers' existing tariffs. Once again, there was no specific tariff related to the operation of the device and no financial incentive to avoid using the appliance, or to lower consumption, during an interruption event.

Again, under the terms of the direct control proposition, up to a maximum of 15 interruption events could be called in any one year. Each event could last for up to 4 hours. The event started by sending a signal to the heat pump requesting load control. If this communication was successful, load control occurred unless a user refused it (by adjusting their thermostat) or forced a restart of the heat pump. While the load was being controlled, the thermal store was used in preference to the ASHP. When this store was insufficient to keep the ASHP off for the whole interruption, the heat pump could run on a reduced duty cycle until the interruption event concluded.

2.2.3 Monitoring and interruptions

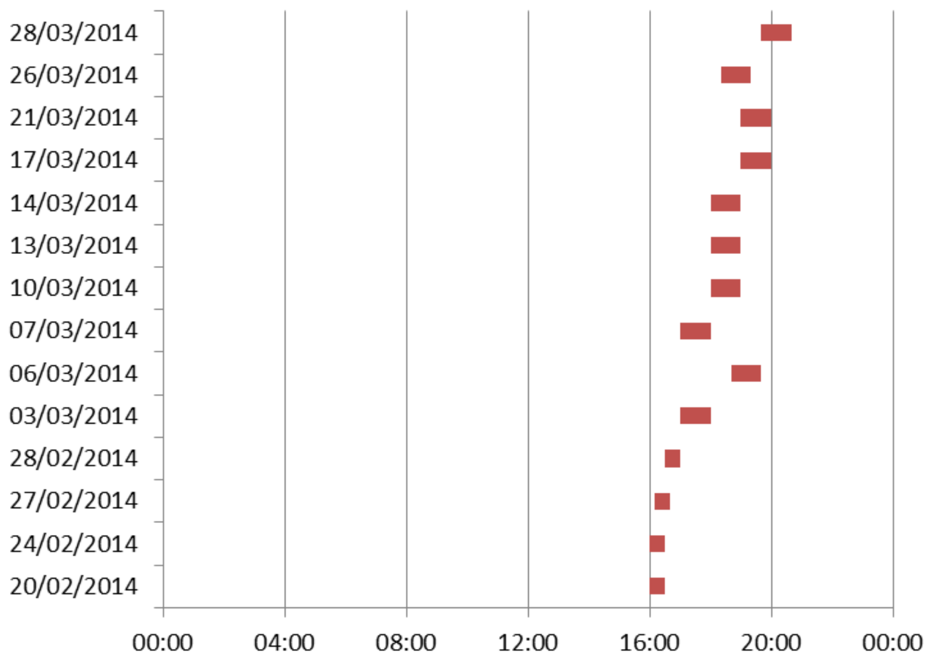
Customer demand was monitored for the period December 2013 to April 2014, which includes all DSR events that took place. Two main types of data were collected:

- half hourly data on the electricity consumption of the heat pump; and
- status signals from the heat pump – in particular whether the DSR was cancelled.

14 interruptions were called over a 36 day period during the peak heating season in February and March 2014. The first four interruptions lasted half an hour. Thereafter the interruptions lasted an hour. Four events were called between 16.00-16.59, two events were called between 17.00 and 17.59 and eight events were called between 18.00-19.00. All interruptions were called on week days.

This is illustrated in Figure 1.

Figure 1 Times, duration and dates of heat pump interruptions



Source: Event data received from British Gas

The majority of the DSR events were called manually by Northern Powergrid sending a text message to a dedicated number at British Gas. However, the last two events were called via the "Grand Unified Scheme" ("GUS") active network management system developed for this project. Every ten minutes, GUS checked the status of the network to determine if a transformer was forecast to be overloaded (the Rise Carr primary substation was monitored for the purpose of this project). Real-time thermal ratings were calculated to determine how close the transformer was to breaching acceptable headroom (artificially low headroom values were inputted to GUS to enable the system to deploy DSR without risk to the network). If this occurred, the system called a sufficient number of providers of DSR,[2] starting with the least expensive, to remedy the problem. GUS had access to more resources than would be required to fix network issues, and therefore would not call resources that were listed lower in its merit order. For the two events described above, it was ensured that heat pumps were priced low enough to be called.

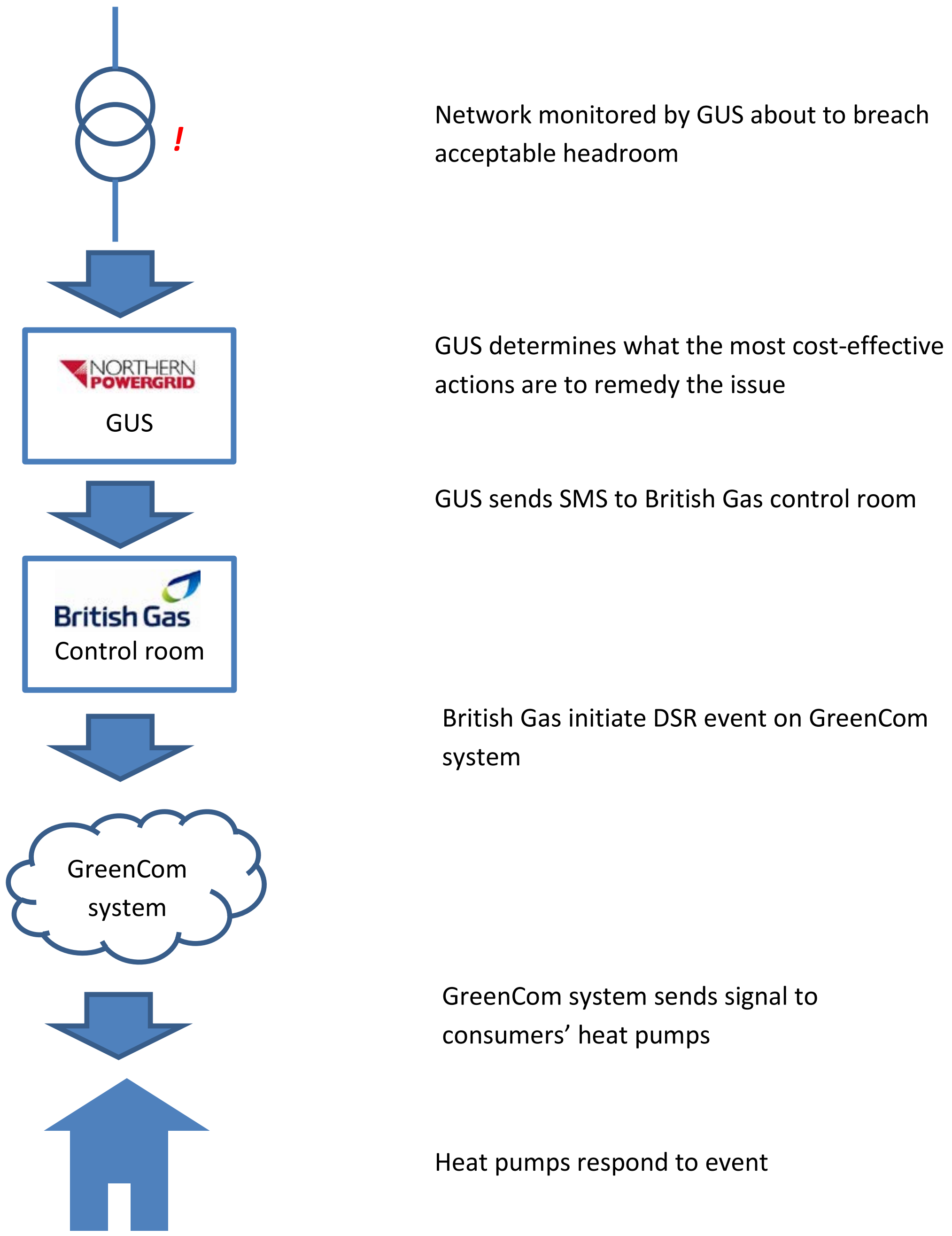
When GUS determined that an action by the directly controlled heat pumps was required, it automatically sent an SMS message to British Gas, who would then initiate the event.

[2] Besides the domestic heat pumps, GUS had access to I&C DSR both directly and through third-party aggregators. The overall set of technologies available to GUS extended beyond DSR, also including real time thermal rating, electrical energy storage, and enhanced automatic voltage control.

For all DSR events (whether requested by GUS or manually), British Gas initiated the event through a web service (*Heat Pump Asset Manager*) provided by GreenCom. The service enabled British Gas personnel to select a subset of participants (whether individual heat pumps, or at higher levels of grouping such as postcode districts) and initiate a load control event. GreenCom's systems would then send the DSR event over the internet to the relevant heat pumps.

The overall chain of events is summarised (in simplified form) in Figure 1.

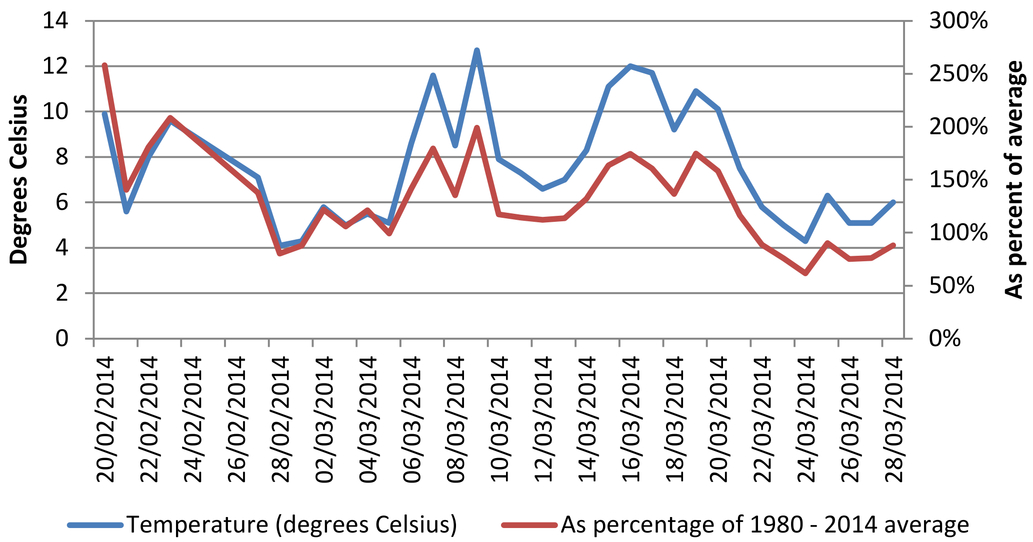
Figure 2 Summary of GUS-driven DSR event



2.2.4 Weather

As with all domestic space heating systems, heat pump usage will be strongly related to external temperature. As shown in Figure 2, temperatures during the trial period were milder than the historic average (the red line shows the temperature for that day as a percentage of the average between 1980 and 2014 and so a reading of 200% would imply that the temperature was twice as high during the trial period as the average).[3] It is to be expected that in milder weather, interruptions might be easier for customers to accept. The results presented below should be viewed in this light.

Figure 3 Average daily temperatures during trial period



Source: European Climate Assessment and Dataset

[3] Based on data from the European Climate Assessment and Dataset data (http://www.ecad.eu/), taken for Central England. Because some customers were out of region, we haven't used specific regional data for the North East.

3 Trial Results

3.1 Test cell 11aWWG

This test cell tests the ability to reschedule the time at which customers use their washing machine. Specifically, in this section we analyse the data collected from test cell 11aWWG to determine customers' responsiveness to the interruption, including how this response varied across the duration of the trial.

3.1.1 Categorising responses

Using the data provided by the smart washing machine, it is possible to categorise the response of consumers into the following groups.

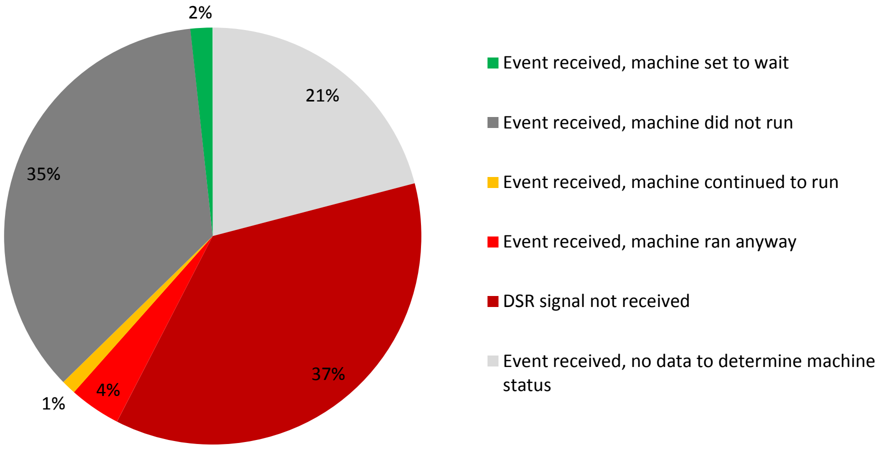
Table 1. Response types for TC11WWG

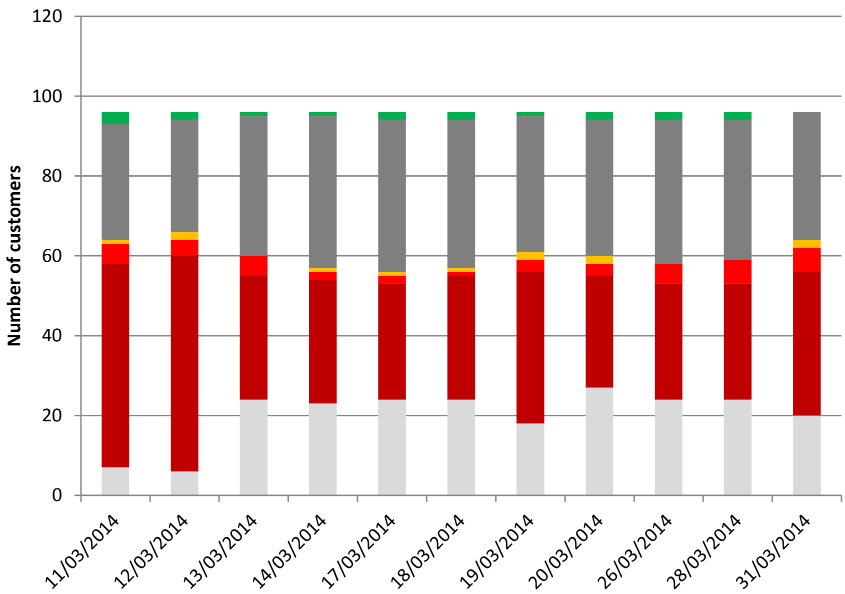
DSR definitely succeeded	DSR definitely failed	Inconclusive
The washing machine received the DSR signal. The consumer used the programmable delay feature of the machine to postpone the wash cycle until after the DSR event.	The washing machine (and therefore the consumer) never received the DSR signal due to a technical issue (either between the router and the gateway, or between the gateway and the washing machine). Despite receiving the DSR signal, the washing machine started a cycle during the DSR event. The washing machine had already started a cycle during the DSR event.[4]	No data is available on the status of the washing machine. The washing machine received the DSR signal. No cycle was carried out – however without further analysis it is not possible to say whether the consumer would have carried out a cycle in the absence of the DSR signal (i.e. whether this represents a true decrease in power).

The charts in Figure 3 below show the number of customers in each of these response categories (in aggregate in the pie chart, and separated by DSR event on the bar chart). Data was not available on a sizable number of customers. Furthermore, a very high proportion of customers never received the DSR notification due to a technical fault (this accounts for 37% of all customers on average).

[4] As described above, consumers were prompted to pause the cycle in these circumstances. However, the data indicates that none did.

Figure 4 Summary of responses to TC11aWWG DSR events





Source: Status reports from WWGs, delivered through GreenCom system

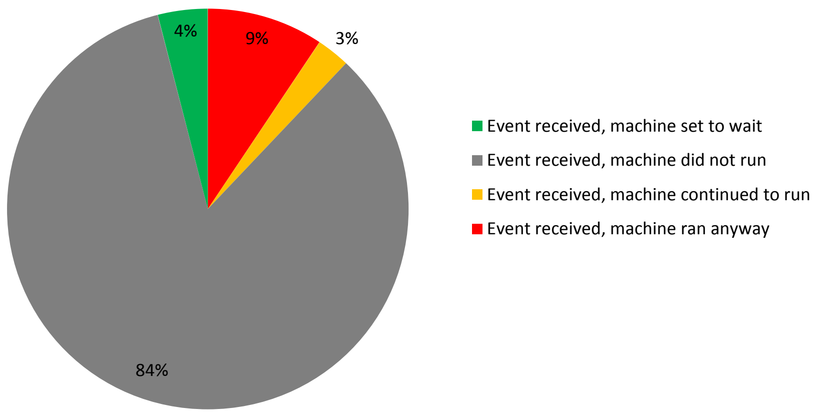
This clearly shows the difficulties in setting up a reliable DSR solution for WWGs using currently available technology. However, it is not unreasonable to assume that, in the future, the reliability of the technology would greatly improve.

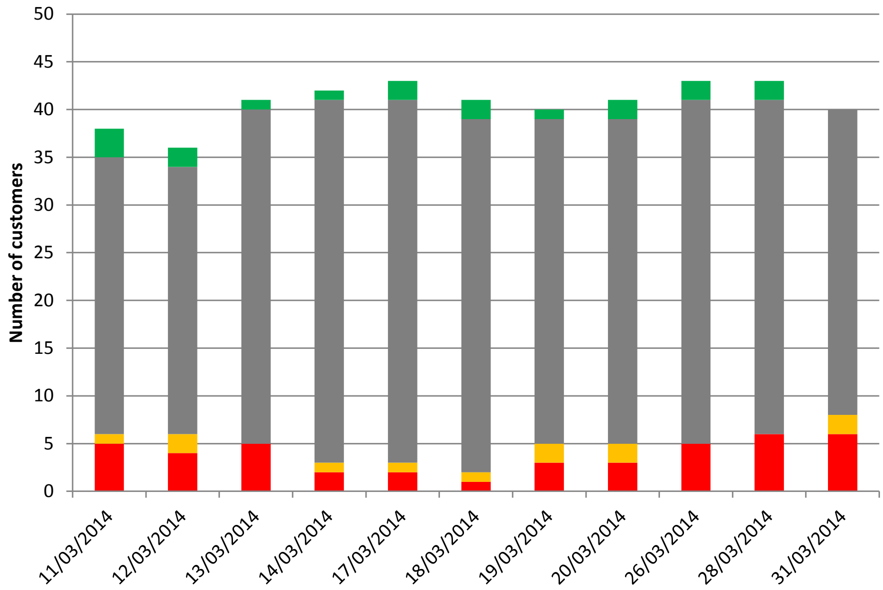
3.1.2 Response of customers to DSR events

For direct control of washing machines to be useful to networks, in addition to reliability of the technology, two conditions must hold: customers must be using their washing machine at the time of the interruption and they must not override the interruption.

To assess the impact of this intervention, we have excluded those customers that did not receive the signal, and those for whom no data is available. This analysis is shown Figure 4.

Figure 4 Summary of responses to TC11aWWG DSR events – excluding customers with no data or where the DSR signal did not arrive for a specific event





Source: Status reports from WWGs, delivered through GreenCom system

There are a number of insights that can be drawn from this analysis.

First, even excluding the customers that did not receive the signal, 12% of customers ran their washing machine during the event (in 3% of cases because it was already running and did not pause, and in 9% of cases by actively starting a new cycle despite the interruption). These cases represent an unambiguous failure of DSR to cause a reduction in WWG for certain customers on certain days.

4% of the time a signal was received, the customers delayed the cycle to occur after the peak window. Given that the customers could have simply started their washing machine during the peak window, it seems reasonable to assume that they would have done so if the DSR signal had not been sent. These events are therefore likely to represent a success of DSR in postponing wash cycles that would otherwise have occurred during the peak window.

Putting these statistics together, of the times when a user interacted with a washing machine that had received the event, they delayed the cycle on 30% of occasions.[5] This is consistent with DSR having an effect on behaviour: on almost a third of occasions when a user attempted to start a cycle on a machine displaying the interruption message, they delayed it.

Moreover, this is likely to understate the impact of DSR. In the vast majority (84%) of cases, the machine did not run during the event *and* was not delayed. The success of DSR is ambiguous in these cases.

- One possibility is that customers were not planning to run their appliance at that time anyway, in which case the DSR event would have no effect on their power consumption.
- However, it is possible that the consumers would have otherwise run the appliance, and avoided doing so in response to the DSR event.

As a result, it seems likely that the overall effect of the DSR trial will have been to decrease WWG power consumption further than the 30% reduction implied by the “delayed” and “started anyway” percentages.

To determine the overall fall in load that DSR may have caused, it is necessary to estimate what power consumption would have been in the absence of the events. This will help to resolve the ambiguity of whether any of the 84% of consumers who did not run their machines were in fact responding to the trial. The following section uses power data to carry out such an analysis.

[5] This is derived by considering the 4% of customers who delayed the machine as a proportion of the total of 4% plus 9% who either delayed it, or actively started a cycle. These percentages are taken from Figure 3.

3.1.3 Analysis of WWG power profiles

To understand the extent to which the trial has delivered DSR, we need to investigate how much of the low usage of washing machines during peak time (84% in Figure 4 above) was driven by the use of DSR within the trial.

Power profiles are available for the washing machines in TC11aWWG, on days with and without a DSR trial. Furthermore, data is available from TC2a on WWG power consumption for consumers that were not on the trial altogether. Using these data, we can test a number of related hypotheses:

1. Did successfully receiving a DSR signal lead to consumers changing their load profile?
2. Did the DSR event days lead to an overall change in average load profiles, despite the relatively high rate of technical failure (as described above, 37% of all DSR events were never received by the appliance)?
3. On non-event days, did the presence of the trial lead consumers to change their washing machine usage? This would occur if, for example, the mere possibility of a DSR signal (or the greater awareness of network issues) caused people to change their usual wash time.

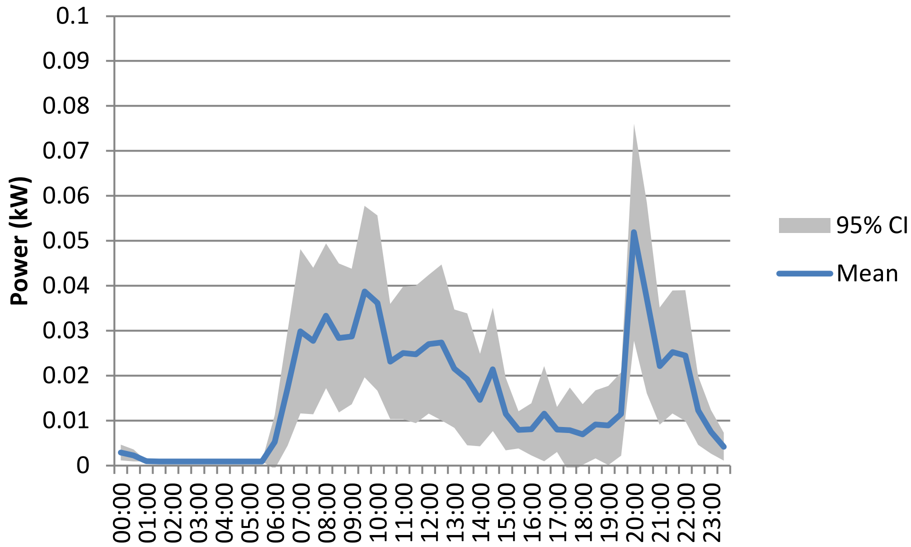
In the following sections, we answer these questions using statistical analysis (T-tests to determine whether the average demand at each point in the day is the same or different to a control).

3.1.3.1 Effect of DSR events, given event received

First, we wish to understand whether successfully receiving a DSR signal may have led to customers changing their load profile. This gives an indication of how successful this form of DSR could be in the future, if smart enabled washing machines were in commercial production and the associated comms were reliable.

Figure 5 below shows the mean and 95% confidence interval for WWG power consumption for those customers in TC11aWWG that received a DSR event. Average WWG power usage is relatively low during the 4pm-8pm peak window (consistent with demand reduction), and there is a significant spike from 8pm to 8:30pm (consistent with a payback spike for deferred cycles).

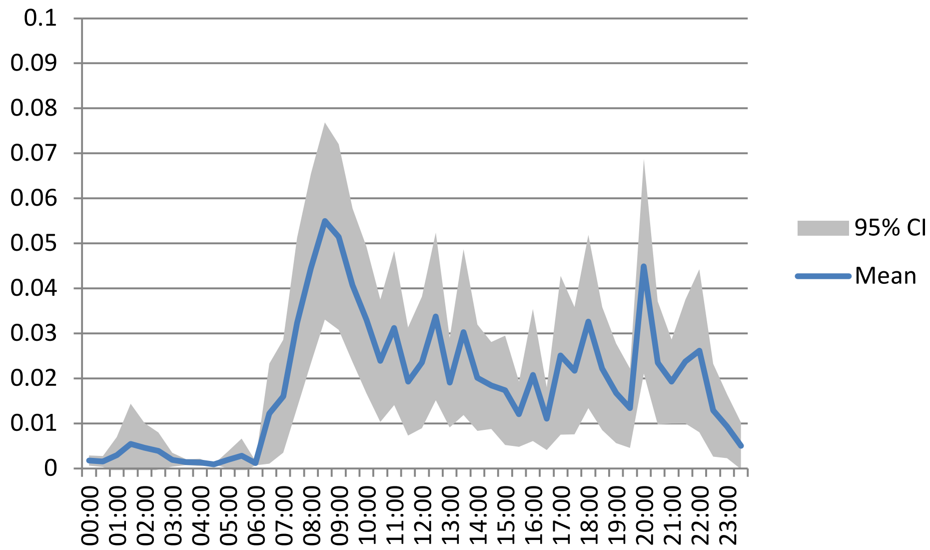
Figure 5: Mean and 95% confidence interval for washing machine power consumption for those customers in TC11aWWG that received a DSR event



Source: WWG status reports

Figure 6 shows the mean and 95% confidence interval for customers in TC11aWWG across a set of days in which DSR events did not occur (data has been drawn from the same set of customers as the graph above, to help ensure this is a valid control). Although the 8pm spike is still present (if lower), average power consumption during the peak window appears to be higher.

Figure 5: The mean and confidence interval for customers in TC11aWWG, on non-event days only, excluding customers that never received events

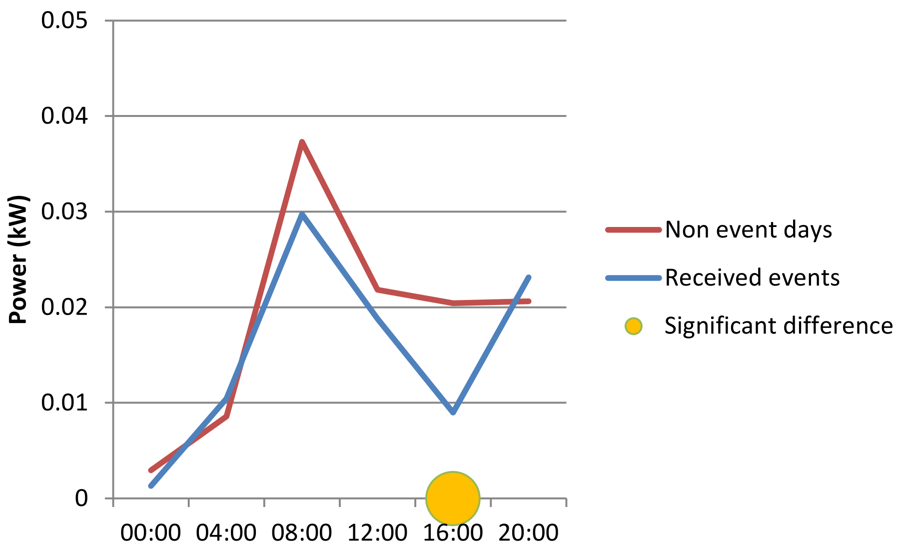


Source: WWG status reports

We have carried out individual T-tests for each half-hourly power reading, to compare the two profiles. However, the confidence intervals around the estimates are sufficiently wide that no conclusive results could generally be obtained (given the use of Bonferroni-corrected critical values[6] and a 5% significance level). Therefore, for this and the remaining tests in this section, we have carried out tests using average power consumption over four-hour windows.

The results are shown in Figure 7 below. This chart shows the mean power consumption for each four-hour window starting at the indicated time. Statistically significant differences are marked with a yellow circle. It can be seen that peak-time consumption is significantly lower than for the control days.

Figure 6: Mean power consumption for TC11aWWG received events compared to non-event days within TC11aWWG



Source: WWG status reports

As a further test, we compared the average TC11aWWG profiles for received events with average profiles from TC2a consumers with monitored WWG appliances (described in the separate report on the enhanced domestic monitoring test cells). We have calculated an average load profile for these customers, pooling across the same days used for the TC11aWWG sample.[7] The resultant load

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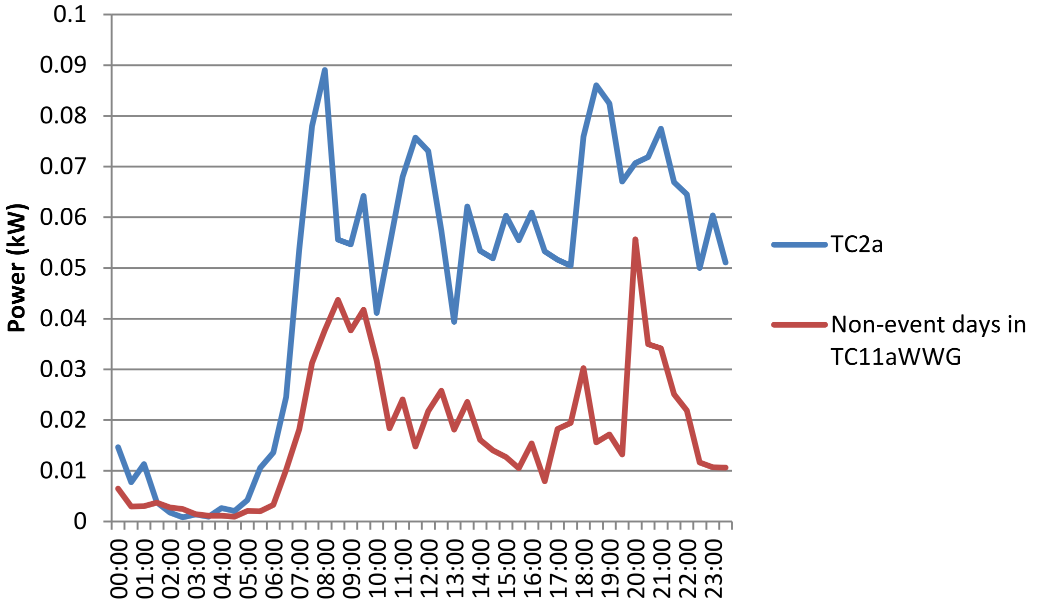
[6] This is one method of reducing the sensitivity of testing when a large number of related tests are carried out (in this case, 48 tests over a load profile). Without this correction, it is likely that we would conclude changes in load profile had occurred when they were just due to chance.

[7] Note that all analysis in this section uses data pooled across multiple weekdays. This is since individual washing machine power profiles are highly volatile, with relatively short (a couple of hours) periods of high power usage, separated by long periods (perhaps days) with no power usage. Without pooling days to

profiles appear higher than in TC11aWWG - Figure 8 below shows the average WWG power for TC2a compared to TC11aWWG customers on non-event days.

Figure 8: Average power for customers in TC2a and for customers in TC11aWWG, on non-event days only



Source: Passiv smart plug data for TC2a, WWG status reports for TC11aWWG

There are a number of factors which will lead to such a bias, but in particular these include:

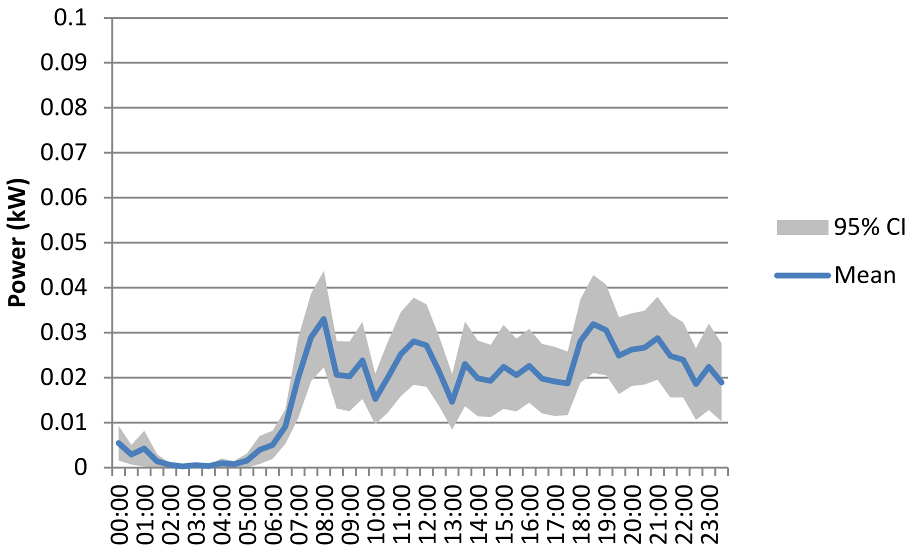
- The figures in TC2a aggregate all wet appliances (dishwashers, tumble dryers and washing machines), while the TC11aWWG figures only relate to washing machines. Approximately 50% of the WWGs monitored in TC2a are labelled as washing machines, however it has not been possible to accurately distinguish between these appliances in the data.
- The TC11aWWG washing machine was a highly efficient new washing machine which is likely to have a much lower power consumption than the average appliance in TC2a.

To partially correct for this for this, we have scaled the TC2a figures so that the average daily energy consumption is equal to the customers in TC11aWWG during non-event days. However, this will not control for any systematic difference in load *profile* (caused, for example, by the presence of dishwashers and tumble dryers in the TC2a data). **Any comparison between TC2a and TC11aWWG should therefore be treated with a high degree of caution.**

increase sample sizes, the confidence intervals around the estimate of mean power usage would be too high to carry out effective statistical tests.

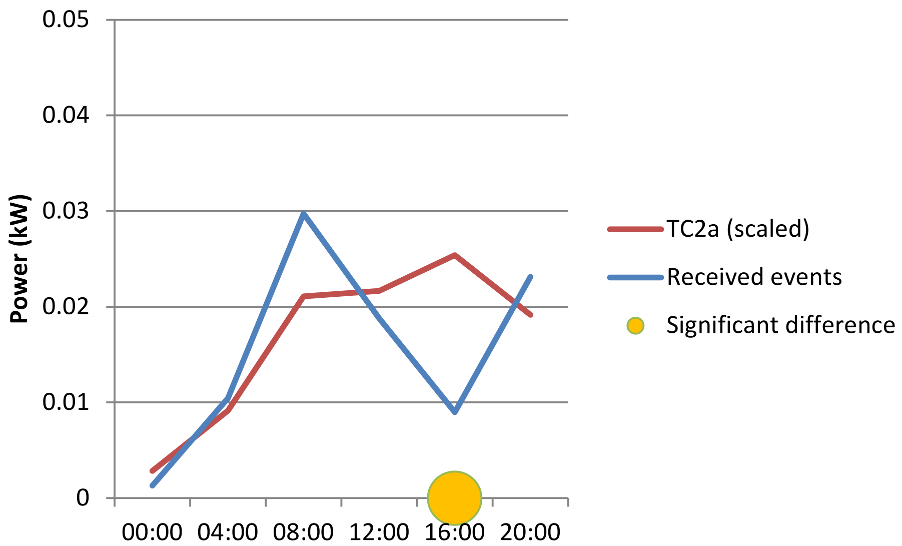
The resulting scaled TC2a average load profile is shown in Figure 9, while Figure 10 shows the comparison to TC11aWWG received events. Once again, average power consumption during the peak window is significantly lower than within the control dataset.

Figure 9: The mean and confidence interval for customers in TC2a (control group), after scaling



Source: Passiv smart plug data

Figure 10: Mean power consumption for TC11aWWG received events compared to TC2a



Source: Passiv smart plug data for TC2a, WWG status reports for TC11aWWG

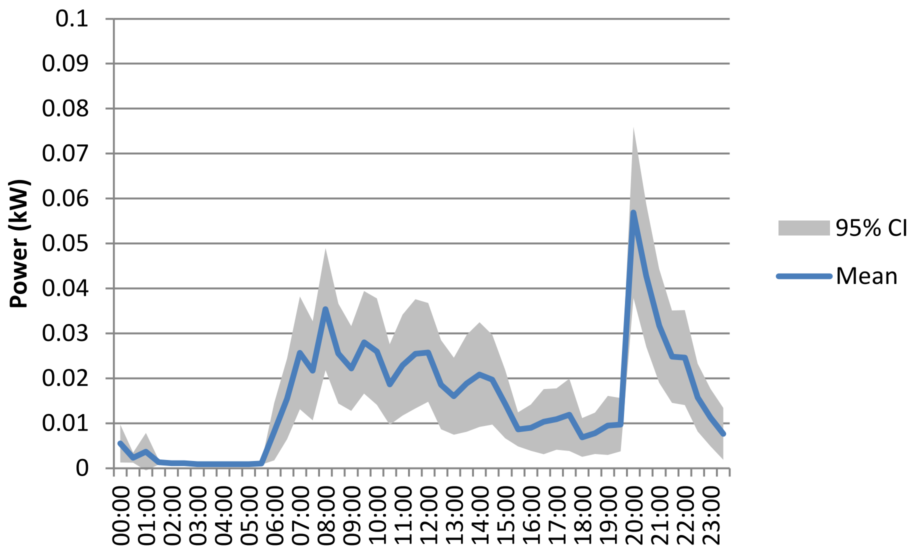
Both of these tests suggest that the DSR intervention did have an effect on customers' demand at peak time.

3.1.3.2 Overall effect of DSR events, allowing for communication failures

We now turn to the analysis of the event days, to determine whether the DSR event days led to an overall change in average load profiles, despite the relatively high rate of technical failure preventing the DSR signal from being received.

Figure 11 below shows the mean and 95% confidence interval for TC11aWWG consumers on DSR event days, regardless of whether or not they received the event.

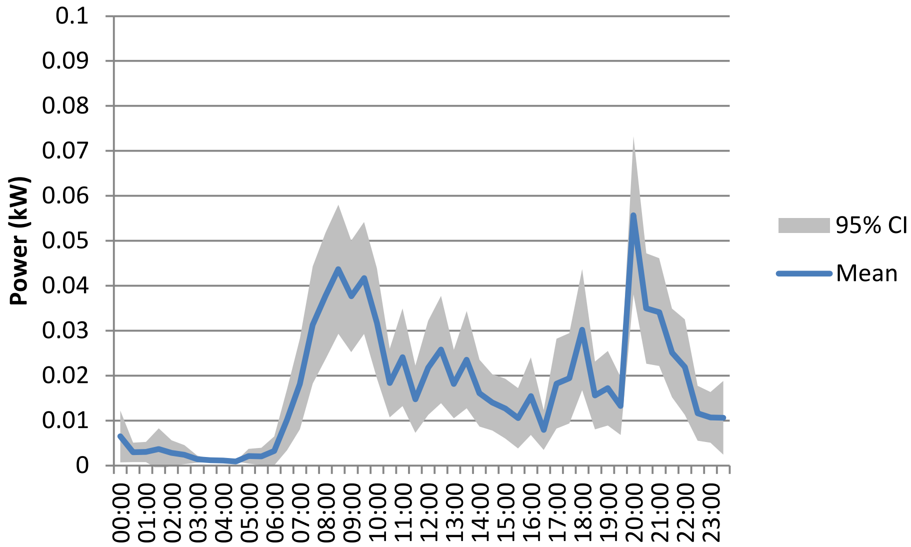
Figure 11: The mean and confidence interval for customers in TC11aWWG, on event days, including customers that never received events



Source: WWG status reports

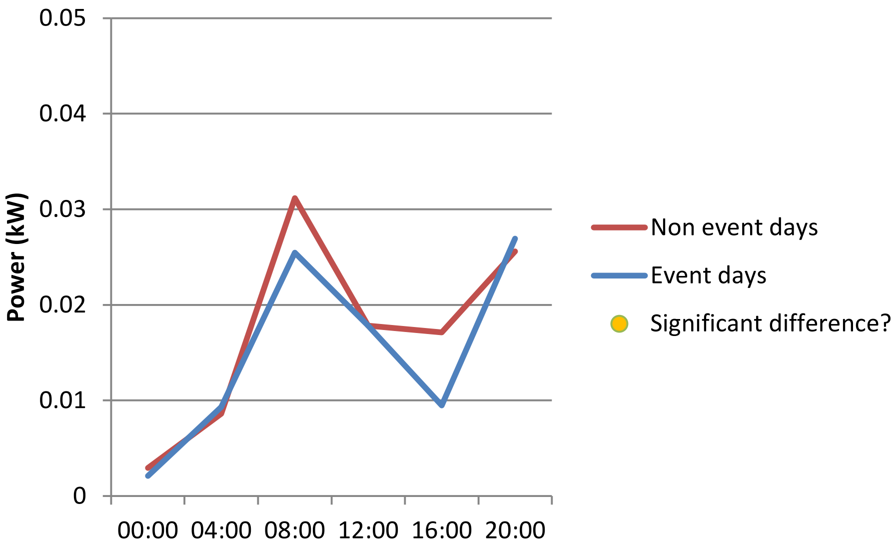
We have carried out two comparisons (again, at the four-hour resolution). The first is against the same group of TC11aWWG customers on non-event days. This avoids using the TC2a data which, as described above, is not fully comparable with TC11aWWG. The resulting load profile is shown in Figure 12. As shown in Figure 13, the effect on peak-time load is not statistically significant at the 5% level – however this is an extremely borderline result (the test statistic is 2.62, compared to a critical value of 2.65 after Bonferroni correction). This suggests that, even when a large proportion of DSR events fail due to technical reasons, a DSR event is still likely to be associated with some peak-time consumption levels below those seen on non- event days (although we are not able to confirm this as statistically significant at the 5% level).

Figure 7: The mean and confidence interval for customers in TC11aWWG, on non-event days only, including customers that never received events



Source: WWG status reports

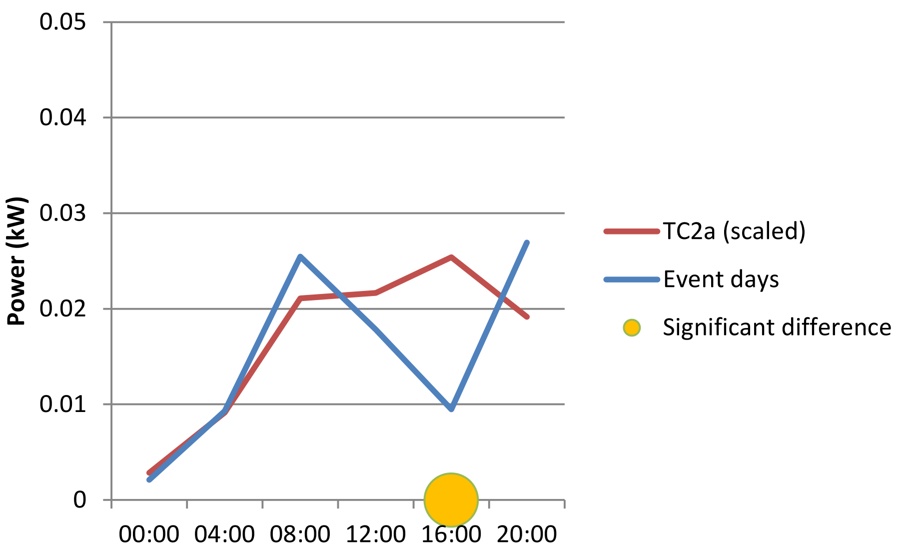
Figure 8: Mean power consumption for TC11aWWG on event days and TC11aWWG on non-event days (control)



Source: Passiv smart plug data for TC2a, WWG status reports for TC11aWWG

We have also compared the profile against the scaled TC2a control data. Figure 14 shows that power during the peak window is statistically significantly lower for the TC11aWWG event days, and higher (but not significantly so) immediately before and after the window. Both of these results suggest that the combination of being in the trial, and some customers receiving DSR signals, is enough to lead to lower load during the peak window.

Figure 14: Mean power consumption for TC11WWG on event days and TC2a (control)



Source: Passiv smart plug data for TC2a, WWG status reports for TC11aWWG

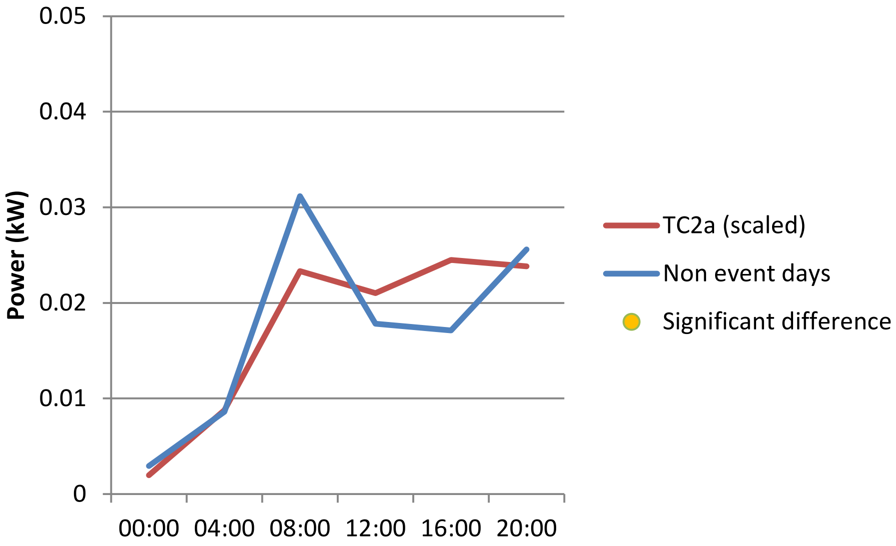
3.1.3.3 Effect of the trial on non-event days

The mere possibility of direct control may have caused consumers to adjust their washing machine usage. This can be tested for by comparing the non-event days of the trial (when DSR was not called) to the TC2a control group that was not part of this trial.

Looking at the comparison chart (Figure 15), consumption under the non-event days does appear to be lower than in the control (TC2a) during the 16:00-20:00 window. However, at the 5% significance level, we are unable to reject the null hypothesis of equality for any of the time windows.[8] Therefore we cannot conclude that demand on the non-event days was lower than in the control group. While the presence of the trial itself may have lowered peak-time consumption even without DSR events, we are unable to state this with confidence based on this particular comparison. However, this result should be interpreted cautiously due to the problems associated with using TC2a as a control group for TC11aWWG.

[8] At the 10% significance level, we would find significant differences for both the 8:00-12:00 and 16:00-20:00 windows. All T-tests on four-hour windows have had Bonferroni correction applied.

Figure 15: Mean power consumption for TC11WWG on non-event days and TC2a (control)



Source: Passiv smart plug data for TC2a, WWG status reports for TC11aWWG

3.1.4 Overview of results

Table 2 summarises the results from these tests. It shows there is generally a small but significant impact of the intervention on washing machine electricity consumption during the peak period. Rows in italics use scaled WWG power profiles from TC2a as a control group, and should therefore be interpreted with caution given the presence of dishwashers and tumble driers in the data.

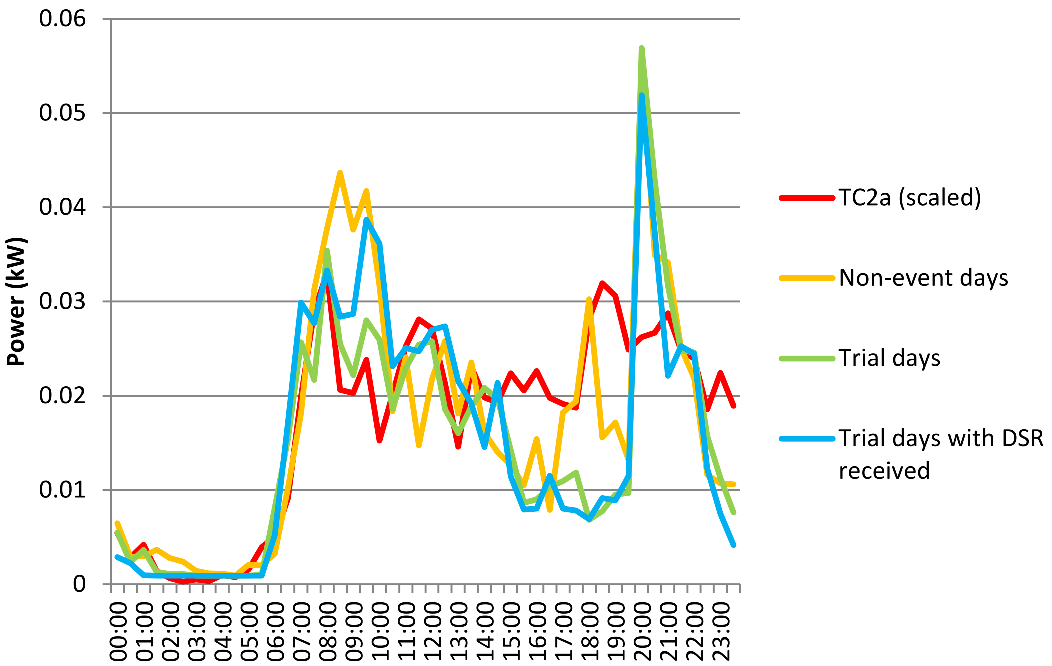
Table 2: Summary of results for 11aWWG

Test	Control group	Treatment group	Change in average power used during peak window	Change in average power used during peak half-hour[9]	Interpretation
1a	TC11aWWG Non-event days during trial	TC11aWWG Event days during trial, only customers receiving event	**-11W**	-26W	***Significant*** When only considering customers receiving an event, events appear to lead to significantly lower peak-time WWG usage
1b	*TC2a (scaled)*	*TC11aWWG* *Event days during trial, only customers receiving event*	***-16W***	***-25W***	***Significant*** *When only considering customers receiving an event, events appear to lead to significantly lower peak-time WWG usage*
2a	TC11aWWG Non-event days during trial	TC11aWWG Event days during trial	-8W	-23W	***Almost significant*** There is an almost significant decrease in peak load for event days in the trial compared to non-event days – even accounting for communication failures
2b	*TC2a (scaled)*	*TC11aWWG* *Event days during trial*	***-16W***[10]	***-25W***	***Significant*** *There is a significant decrease in peak load for event days in the trial compared to customers outside the trial – even accounting for communication failures*
3	*TC2a (scaled)*	*TC11aWWG* *Non-event days during trial*	*-7W*	*-2W*	***Not significant*** *Being in the trial but not receiving an event might have a weak negative effect on peak power*

[9] This was the peak half-hour period for the peak winter day (05/02/2014) used in the analysis of TC2a.
[10] Bold entries are significant at the 5% level, after Bonferroni correction (for 4 simultaneous tests for 4-window periods, or 48 simultaneous tests for half-hourly profiles).

Figure 16 summarises the half-hourly power consumption across each of the groups described above.

Figure 9: Power consumption compared across groups



Source: Passiv smart plug data for TC2a, WWG status reports for TC11aWWG

These results again highlight that peak-time WWG power consumption appears to be significantly lower on days when a DSR signal is sent – whether compared to days in TC11aWWG without a DSR event, or to TC2a.

Consumers' willingness to be flexible with their washing machine use is also evident from the wider literature. For example, the 2010 Electricity Policy Research Group Public (EPRG) opinion survey showed that more than half of respondents currently using washing machines between 7-9pm would be willing to shift their use until after 9pm if electricity were cheaper then. However, only a quarter of respondents currently used their washing machines between 7-9pm.

However, the magnitude of the decrease in power (perhaps an average 25W per consumer signed up to DSR at the 6pm peak) is relatively low compared to the overall peak figures seen in TC2a. This is potentially due to two factors:

- First, as shown above, washing machines are not on for the majority of the time, limiting the available scope for this form of DSR.
- In addition, the technology used for this trial was unreliable, leading to a large number of consumers not receiving DSR events.

Nonetheless, a sufficiently large proportion of consumers appeared to respond to events to lead to an overall effect on peak WWG power usage.

The results from the social science side of the project are not fully consistent with this picture. As part of the trial, four households (three families and one single-person household) were interviewed about their experiences:

- One respondent noted that her machine would occasionally delay its start during the trial, and said that, for her, "it's not really an issue". Such behaviour (an acceptance of DSR) is consistent with the aggregate effect observed above.
- However, none of these four households had any recollection of seeing a message or code on the machine informing them it was being controlled.

The social science research concluded that: "None of the interviewees believed the direct control element had any influence on decisions about when to do the laundry. With all four asserting that there has been no change to their previous washing regimes."[11] However, given the extremely small sample size, it may just reflect the behaviour of these individuals rather than being representative of all of the participants in the trial, or indeed the wider population.

Indeed, some of this apparent discrepancy could be accounted for by variations in WWG usage habits. As shown in the Enhanced Domestic Monitoring report on TC2a, average WWG power usage is higher on weekends than weekdays. This is consistent with a proportion of the population tending to carry out washing activities at the weekend, in which case they would not see DSR messages sent as part of this trial. Section 3.1.5 below attempts to determine whether we observe such "clustering" of consumer behaviour, however the results are inconclusive.

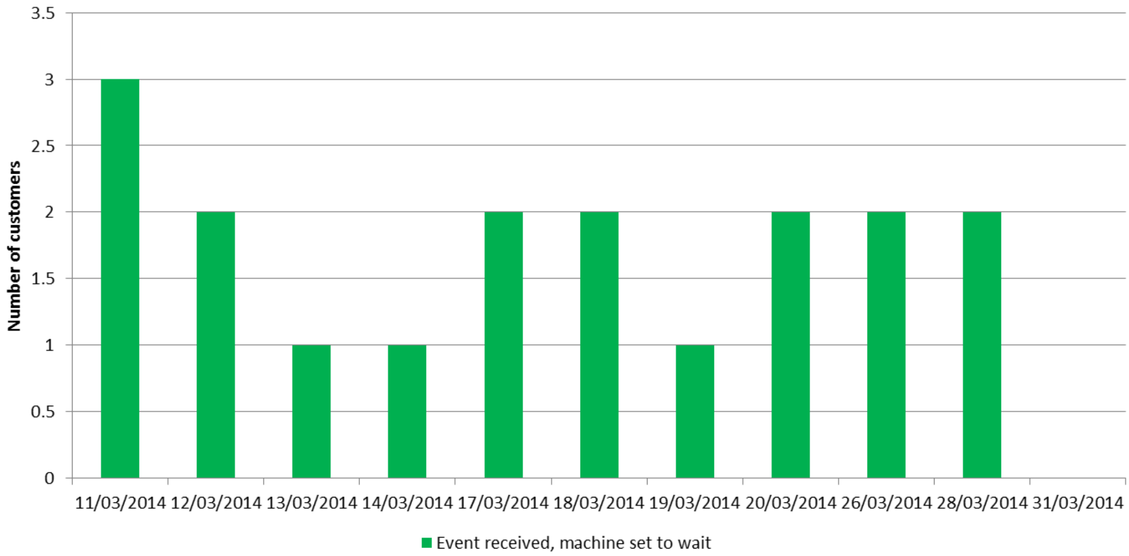
3.1.5 Understand whether behavioural change was temporary or permanent

There is no evidence that consumers' responses changed in a systematic way, though this may be driven by the short time period covered by this trial.

Figure 17 shows the positive responses (those who delayed their washing machine use) to the interruptions over time. No clear pattern is observable.

[12] CLNR(2014), Demand Side Response (White Goods) – October 2014 Social Science Team Report p4

Figure 17 Positive response to the 11aWWG interruption over time



Source: WWG status reports

We have also considered whether it is systematically the same customers acting with or against the DSR signal. Of the eighteen times during the trial when a customer delayed the start of the cycle:

- Eight are accounted for by two customers, who each delayed the washing machine start on four occasions;
- two are accounted for by a customer who delayed the cycle twice; and
- the remaining eight are accounted for by eight customers each delaying the cycle once.

These figures alone do not give a good impression of whether delays are particularly concentrated among certain customers. This is since, even if each customer had the same chance of delaying in response to a given event, natural variability would lead to some customers delaying more events than others. To determine whether delays are concentrated among customers, it is necessary to simulate what these figures would look like if every customer had an identical probability of delaying an event. We have done so using a binomial distribution,[12] and the resulting simulated customer numbers are plotted below in Figure 18, alongside the actual numbers observed. Although we have not carried out a statistical test, it is clear that the observed clustering is not substantially different to what would occur if all customers had the same chance of delaying the cycle.

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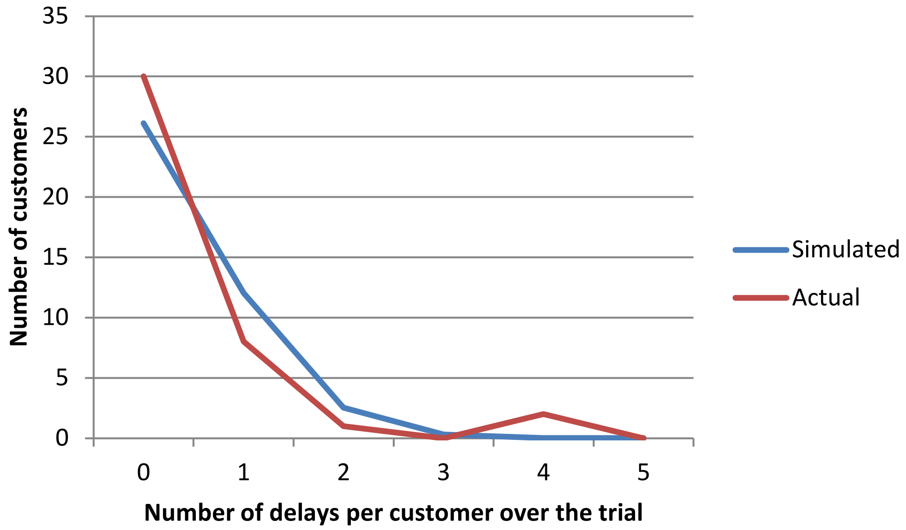
[12] We considered only customers that successfully received DSR events – this assumes that the DSR technical failures were typically confined to the same customers. As shown in Figure 3, 4% of the time DSR events led to a delay, while 9% of the time they led to a "ignore" (the machine was started anyway). There were 11 DSR event days. If customers always had the same probability of delaying, the probability of a given customer carrying out X delays would be distributed in the form X ~ B(11,0.04). Similarly, the probability of a given customer carrying out X ignores would be distributed in the form X ~ B(11,0.09). The resultant probabilities were carried out and multiplied by 41, the average number of customers that successfully received DSR events.

Figure 18 Comparison of observed and simulated frequency of DSR-induced delays



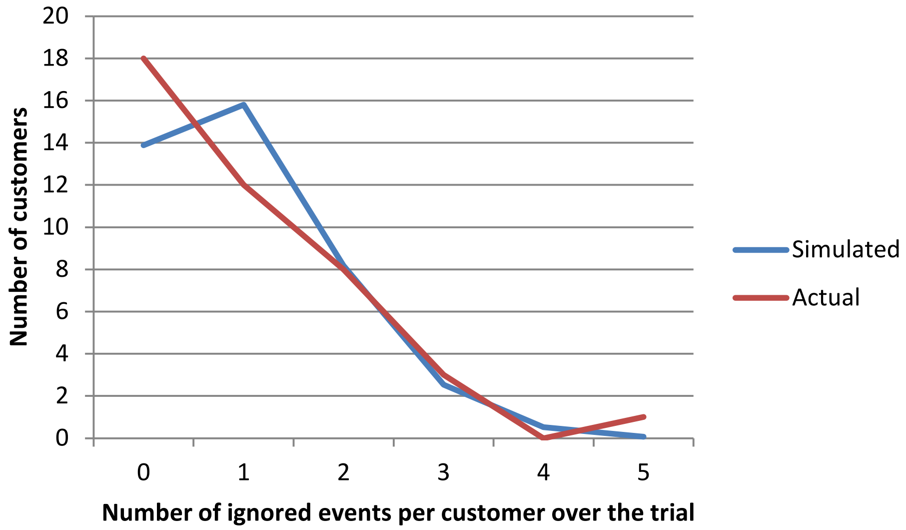
Source: WWG status reports

Of the 42 times during the trial when a customer initiated a cycle during a DSR signal (i.e. ignored the event):

- Five are accounted for by one customer who did so five times;
- nine are accounted for by three customers who did so three times each;
- sixteen are accounted for by eight customers who did so twice;
- and twelve are accounted for by twelve customers with one such event each.

Figure 19 compares these values to the simulated distribution – again, there is no obvious discrepancy from what would be expected if there were no clustering.

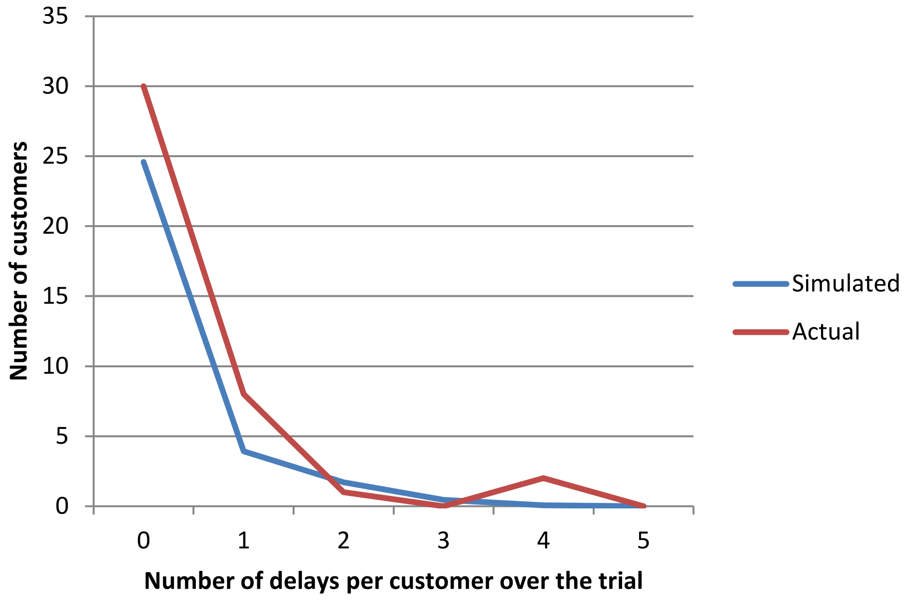
Figure 19 Comparison of observed and simulated frequency of DSR "ignore" events



Source: WWG status reports

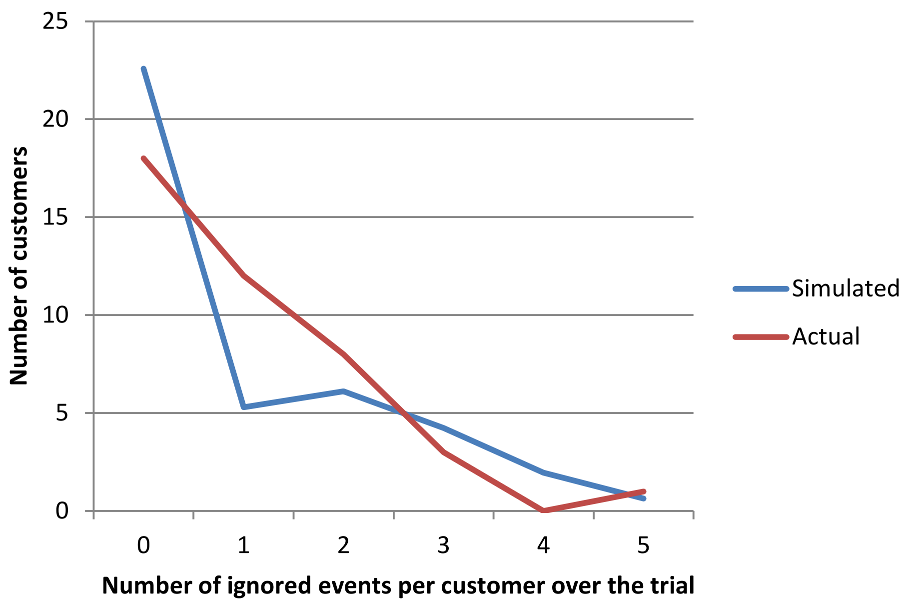
These results show that it is possible that all participants receiving DSR signals were equally likely to delay or start a washing cycle in response to a given DSR event. However, the results would also be consistent with a certain level of clustering. For example, if 50% of individuals never considered washing during a weekday peak (and so would never delay or start a cycle during the DSR period), the remaining individuals would have an 8% and an 18% chance of delaying or ignoring respectively. The simulated frequencies would then look as shown in Figure 20 and Figure 21.

Figure 20 Comparison of observed and simulated frequency of DSR-induced delays, with 50% of consumers assumed to not wash on weekday peaks



Source: WWG status reports

Figure 21 Comparison of observed and simulated frequency of DSR "ignore" events, with 50% of consumers assumed to not wash on weekday peaks



Source: WWG status reports

It is therefore not possible to come to a definitive conclusion on whether behaviour in response to DSR events was clustered among consumers.

3.2 Test cell 14

In this section we analyse the data collected from test cell 14 to meet the following learning objectives.

- Determine average consumption profiles for heat pumps;
- Determine customer responsiveness to the direct control interruption; and
- Determine the technical feasibility of alternative (dynamic) tariff structures.

3.2.1 Consumption profiles for consumers with heat pumps

Data collected suggests that heat pump electricity consumption in this trial has two distinct peaks – one in the morning, and then a smaller one in the evening.

Figure 22 shows the heat pump electricity demand profiles on days without interruptions. This covers a set of 16 weekdays, for the same eight customers and over the same period as the interruptions were called in late February and March 2014[13]. These days also had a similar average temperature to the trial days (around 7 degrees Celsius, compared to 8 degrees Celsius for the trial days).

A clear consumption pattern emerges from this data. The largest peak (around 2kW) is in the morning between 6am-8am.[14] There is then another peak (around 1.5kW) in the early evening, between 18.00-20.00. Total electricity consumption from heat pumps on the control days was 15.4kWh on average. This data forms the control group for the rest of our analysis.

Caution should be applied when interpreting these results, since all eight customers involved in the trial have the same model of heat pump, with the same thermal store. Greater diversity would be expected where customers have different heat pump models. Further, the use of a large thermal store is highly unusual within the UK – these results are therefore unlikely to be representative of the existing UK domestic heat pump fleet.

Indeed, this profile is different to the sample profiles published in DECC's heat pump trials[15]. In the first phase of DECC's trials, heat pump electricity consumption showed a marked variation between

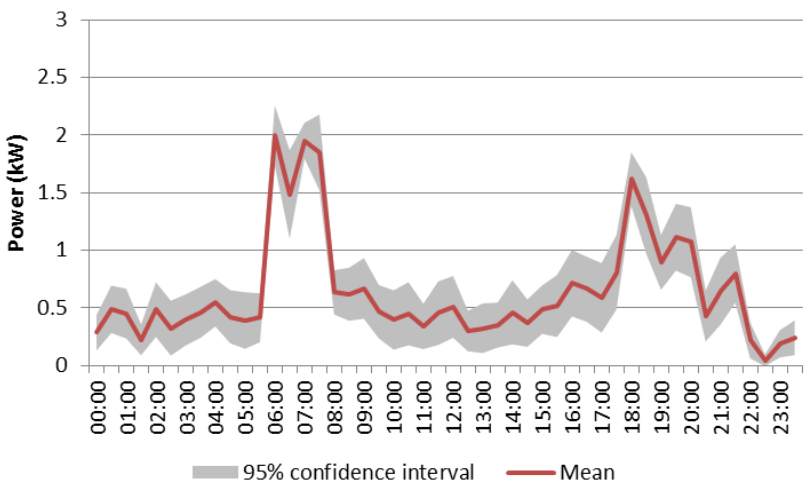
[13] The interruptions were called between 20/2/14 and the 28/3/14. The control days are taken from the period between 17/2/14 and 27/3/14.

[14] For the avoidance of doubt, where we refer to peak power demand in this report, we mean the average peak power in the half hour with the highest overall consumption (measured in kW and numerically equal to twice the consumption measured in kWh in that half hour).

[15] DECC (May 2013) Detailed analysis from the second phase of the Energy Saving Trust's heat pump field

day and night, with consumption cycling around 2kW in each period during the day, and close to zero overnight. In the second phase of the trials, the heat pumps were set to continuous daily operation. As a result, the sample profiles suggest that electricity consumption was flatter (cycling around 1kW) for the second phase of trials. It is worth noting that setting the heat pumps to run constantly in the second phase of trials, resulted in both an increase in internal temperature in the homes, and a reduction in overall electricity use. This suggests that there is likely to be a cost in terms of energy efficiency, when DSR is applied to heat pumps.

Figure 22 Heat pump electricity demand profiles on days without interruptions



Source: HP status reports

3.2.2 The impact of the interruption on electricity consumption

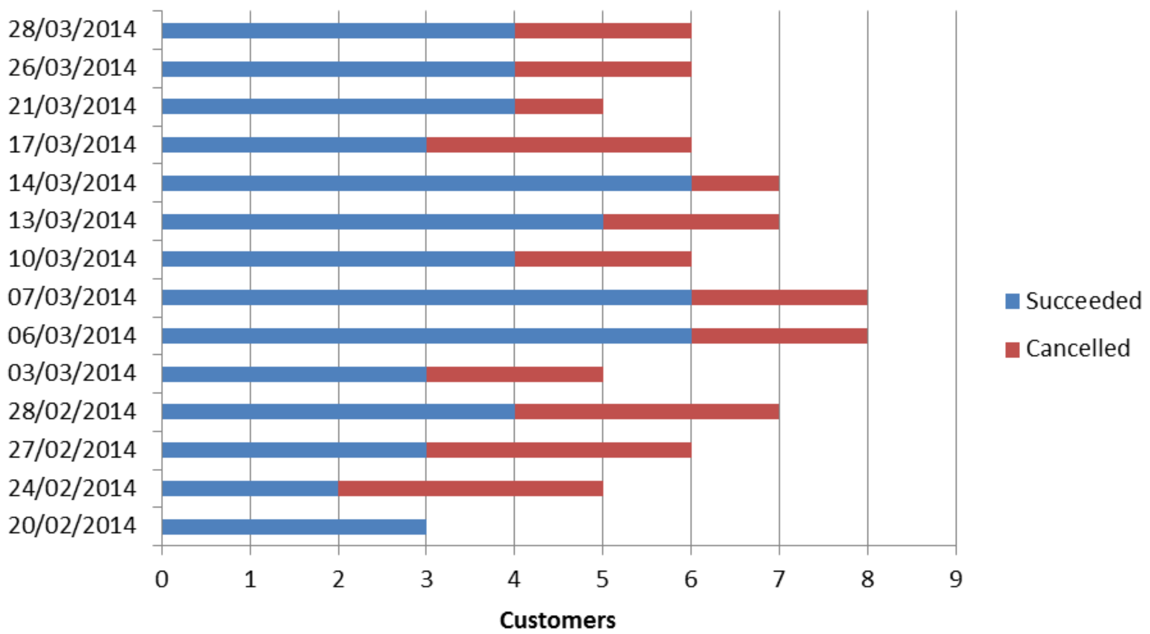
Interruptions were successful the majority (67%) of the time in this trial.

Figure 23 shows for each interruption, the number of successful direct control incidences against the number of times the consumer cancelled the direct control. To cancel the interruption, customers needed to adjust the thermostat, either in the hour before,[16] or during the interruption. It is possible that consumers did not mean to override the interruption, and were simply adjusting their thermostat for other reasons. However, where the interruption succeeded, we can be sure that they did not intend to override it.

Trial, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225825/analysis_data_second_phase_est_heat_pump_field_trials.pdf

[16] This was due to a technical issue with the control software, which resulted in the DSR events always being delayed by one hour.

Figure 23 Overall responses to the interruptions



Source: HP status reports

Not all customers were called at each event (for example on 20/02/14, only three customers were called).

To carry out statistical tests to determine the effect of the DSR events, it is beneficial to pool as many events as possible for the analysis. However, since we are comparing consumption to consumption in the control group at a certain point in time, it only makes sense to pool together interruptions that were called at the same time. We have therefore pooled the three DSR events that occurred between 18:00 and 19:00 (on the 10th, 13th, and 14th of March).[17]

For those customers that did not cancel the interruption during these three events, electricity consumption fell close to zero during the time of the intervention. Total electricity consumption from heat pumps on the control days was 1.5kW on average. This can be seen for the example of interruptions called at 18.00 in Figure 24, where the yellow shading marks the period where the intervention occurs.

It is also noticeable from Figure 24 that there is a strong payback spike directly after the intervention. We discuss the implications of these payback spikes further below.

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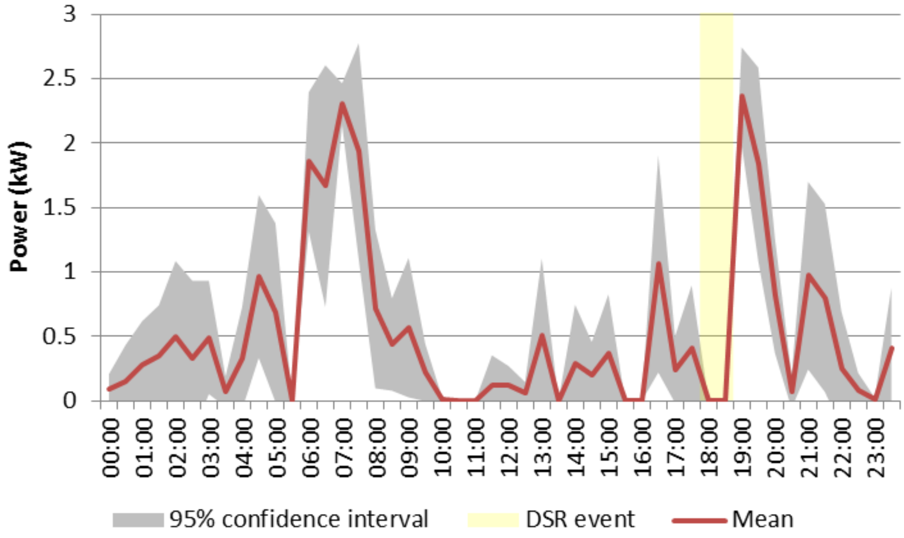
[17] Broadly similar results were also obtained for the two DSR events occurring between 17:00 and 18:00.

Figure 24 Electricity consumption for customers who did not cancel intervention (for events called at 18.00)

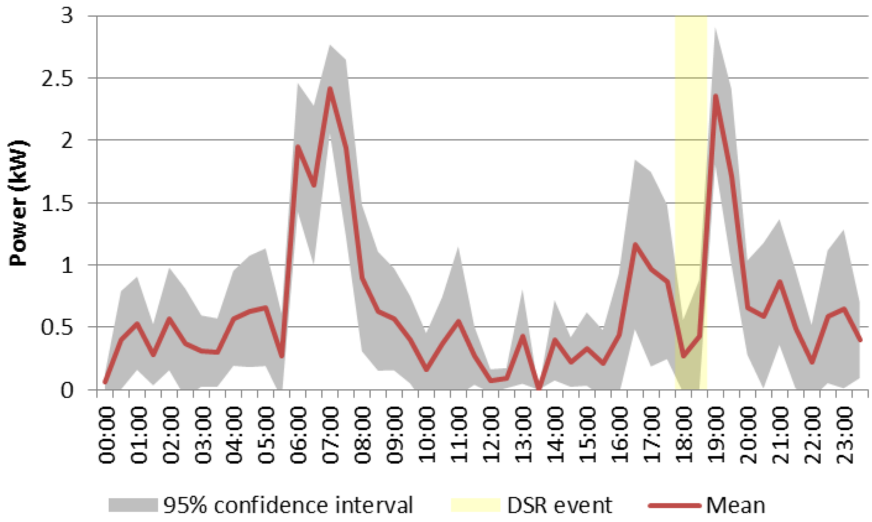


Source: HP status reports

Though it is useful to see that the interruption is effective where consumers do not cancel it, of more interest to networks is the average response of customers when an interruption was sent – regardless of whether the consumer cancelled it.

For the interruptions called at 18.00, there was a statistically significant difference between electricity consumption of those receiving the intervention and the control group. Figure 25 illustrates the average load profile for the full set of customers for whom DSR was called between 18:00 and 19:00. Even after including consumers that cancelled the event, there is a clear drop in average power for the hour of the interruption, followed by a payback.

Figure 25 Electricity consumption for all customers receiving DSR event, regardless of whether it was cancelled (for events called at 18,00)

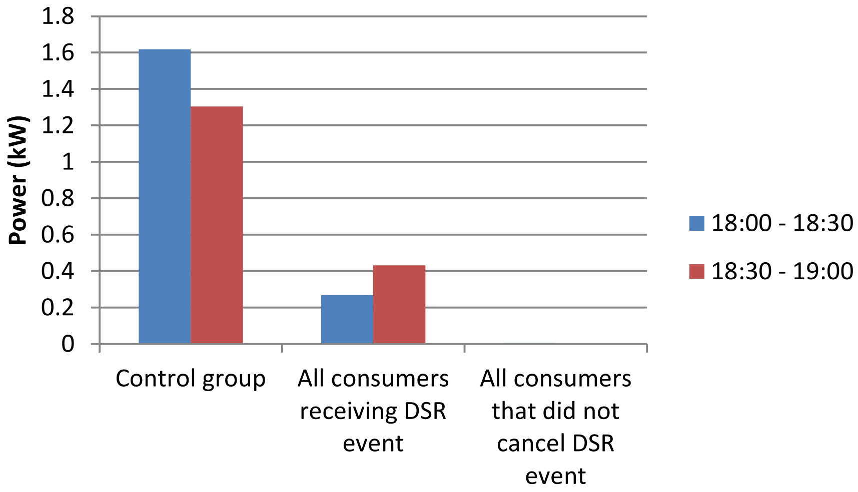


Source: HP status reports

The 18:00 – 19:00 average heat pump power consumption for all three groups (the control, all customers that received the event at 18:00, and all those that did not cancel it) is shown below in Figure 26. For both the group that received the event and the subset which did not cancel it, there was a statistically significant[18] fall in average power, compared to the control group, for both half-hour periods.

[18] Tested with a two-tailed T-test at the 5% significance level. Bonferroni correction was applied to compensate for carrying out two simultaneous tests.

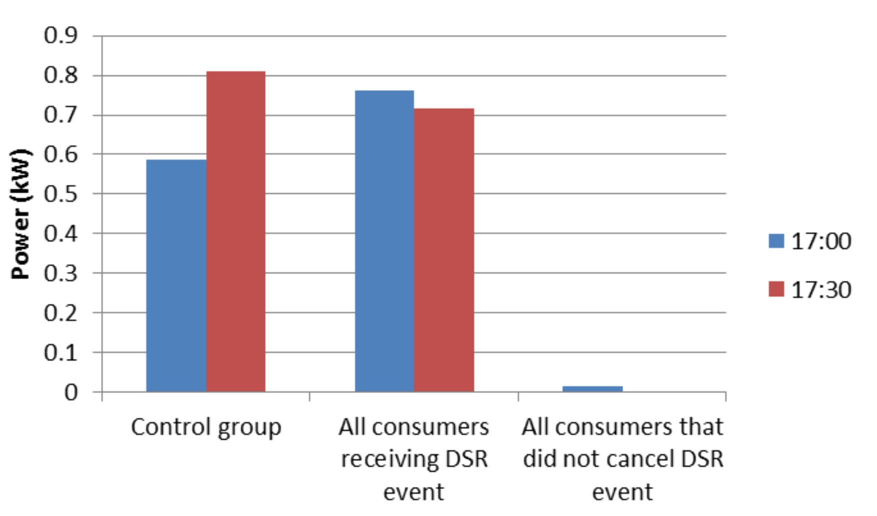
Figure 26 Power consumption during the 18:00 – 19:00 DSR trials



Source: HP status reports

However, not all interruptions produced a statistically significant result. For interruptions called at 17.00, the difference between the peak demand of the control group and the peak demand of all consumers who were sent the interruption signal was not significantly different (shown on the left and the middle of Figure 27). However, there *is* a significant difference between consumption in the control group and consumption of consumers that did not cancel the DSR event (shown in the left and right of the Figure 27). This disparity is driven by the relatively high proportion of customers (1/3) that cancelled these DSR events, and suggests that further work on the technical and social aspects of the intervention would be required to reduce cancellation rates.

Figure 27 Electricity consumption compared between the control group and all customers receiving the interruption for hour-long interruptions called at 17.00



Source: HP status reports

3.2.3 Payback spikes

Payback spikes can seriously limit the usefulness to networks of direct control of heat pumps.

To maintain a reduction in electricity consumption over a prolonged period (for example, four hours) in the presence of substantial payback spikes, increasing numbers of heat pumps would have to be called on as the period progressed. This is because after the first interruption (which could only last until the thermal storage was depleted), further interruptions would be needed to deliver both the required reduction in electricity consumption as compared to normal conditions, *and to compensate for the payback caused by heat pumps that had reduced their demand in the previous period*. It would not be possible to avoid a payback spike at the end of this process, though it could be timed to occur well into the off-peak period (e.g. overnight).

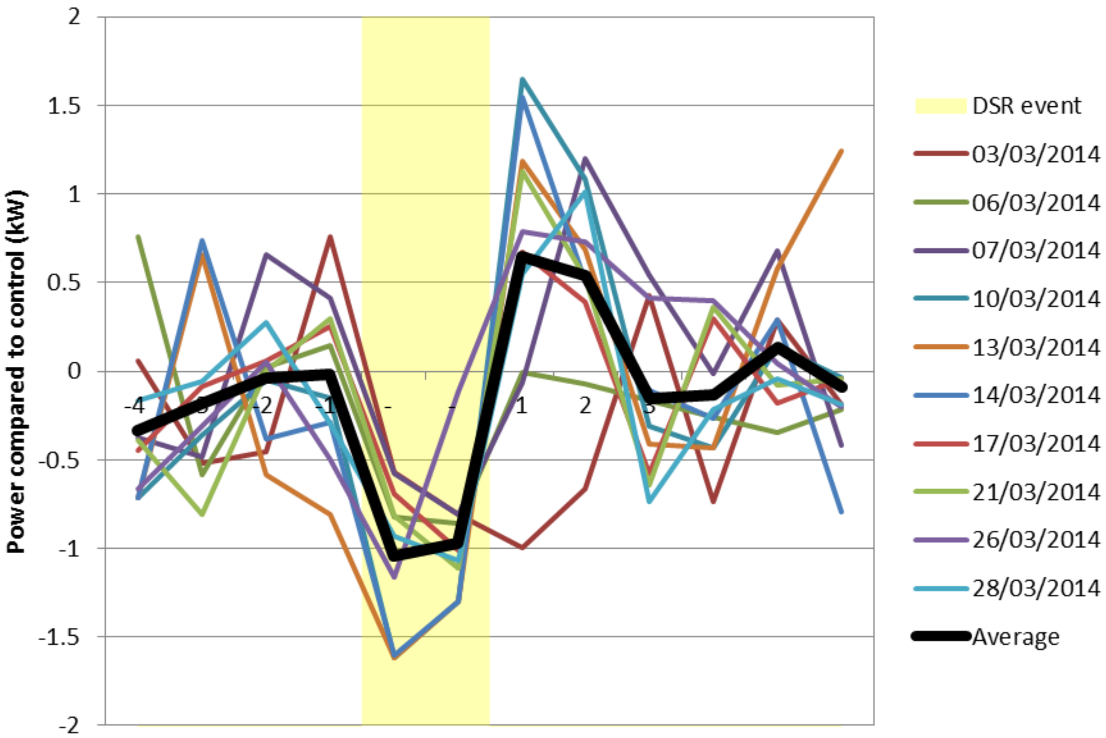
For the eight households included in this test cell, payback spikes are important, even though the heat pumps used had thermal storage attached.

Figure 28 shows the difference between the heat pump electricity consumption of the group who allowed interruptions to happen relative to the control group, for the four hours before and three hours after the interruption (shown as the yellow shaded hour).[19] While there is a lot of diversity around the different interruptions, a clear payback spike is evident in the hour subsequent to the interruption[20]. The thick black line shows the average variation against the control group, across all these events. On average, it appears that power consumption was reduced by approximately 1kW during the hour-long interruption, but then increased by just over 0.5kW for the hour-long period after the event.

[19] For each event, a half-hourly dataset was created of average power used by heat pumps in dwellings where the event was not cancelled. The average consumption of the control group was then subtracted, to determine how much higher or lower power was in each period compared to the control. Finally, the datasets for each event were aligned, so the hour-long interruption spans the yellow shaded box.

[20] A similar chart based on the half-hour interruptions is less clear. However it is not possible to tell whether this is due to the fact that less thermal energy will have been lost in a half hour than in an hour, or due to a small sample size.

Figure 28 Payback spikes for hour-long interruptions



Source: HP status reports

The presence of a payback spike suggests that direct control of heat pumps may only be useful to networks under the following conditions:

- where heat pumps are accompanied by very well insulated homes which may be capable of storing large quantities of heat within the fabric of the building;[21]
- where heat pumps are sufficiently numerous to allow diversification of the type to be applied; or
- where the network requires interruptions of shorter duration than those tested in this trial.

It is likely that this payback spike would also cause problems under different dynamic tariffs, such as Time of Use tariffs. However, smart technology which optimises the response of heat pumps to Time of Use tariffs may mitigate this. In particular, it is possible[22] that a conservative storage

[21] We cannot be more specific here as we do not have information on the level of insulation of these homes
[22] We do not have information on the specific algorithm used to dispatch the thermal storage units used in this trial.

dispatch algorithm would attempt to replenish the storage immediately after the DSR event finishes.[23] Ways of averting this could include:

- ensuring that the storage dispatch algorithm does not attempt to immediately refill the thermal storage after a DSR event (for example, the algorithm could take into account the fact known contractual restrictions that mean a DSR event could not be closely followed by another, allowing it to fill up during a time when overall electricity usage was low without risk of a further DSR event in the meantime); or
- if the storage dispatch algorithm is designed to aggressively refill the storage if it falls below a set level, a greater number of shorter DSR events could be called to ensure that this level is not reached.

3.2.4 What drives customers' response to the direct control event? Do they notice the direct control event?

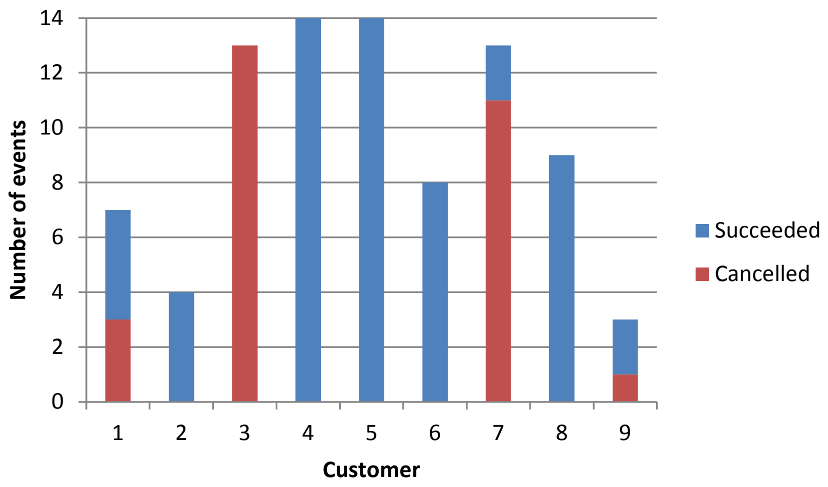
It is clear from the trial results that customers often did not override the direct control event, and allowed their heat pump to be powered down for the duration of the event. This in itself is strong evidence that consumers did not feel that the direct control led to a loss of comfort, particularly given that the override mechanism simply involved adjusting the thermostat.

Figure 29 shows that the cancellations that did occur were limited to a small number of customers (in particular, two customers who cancelled all or nearly all events).[24] It is not possible to determine whether these customers were deliberately adjusting the thermostat to cancel DSR, or were simply used to frequently adjusting the thermostat, cancelling DSR as a side-effect. Further research into consumer interactions with thermostats could help in the design of an interface that makes it less likely for customers to accidently cancel a DSR event.

[23] This is consistent with the temperature readings discussed below.

[24] Given the far smaller sample of customers, we have not presented a simulation comparison as was done for TC11aWWG. However, the clustering of customers is highly apparent from the figure alone – two customers accounted for over 85% of cancellations.

Figure 29 Cancellations by customer



Source: HP status reports

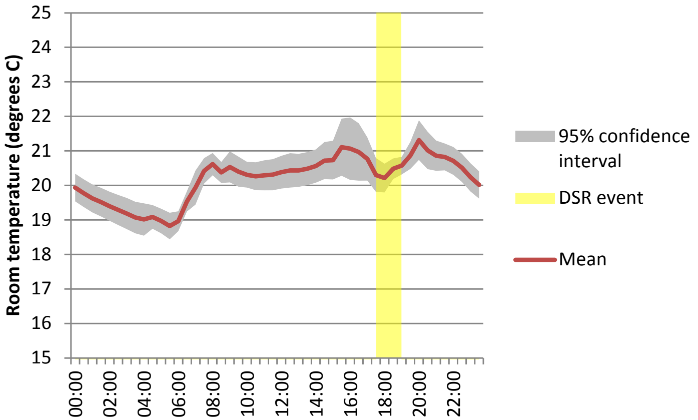
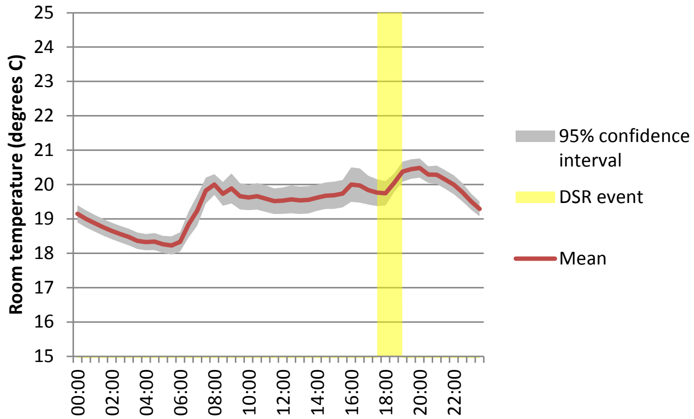
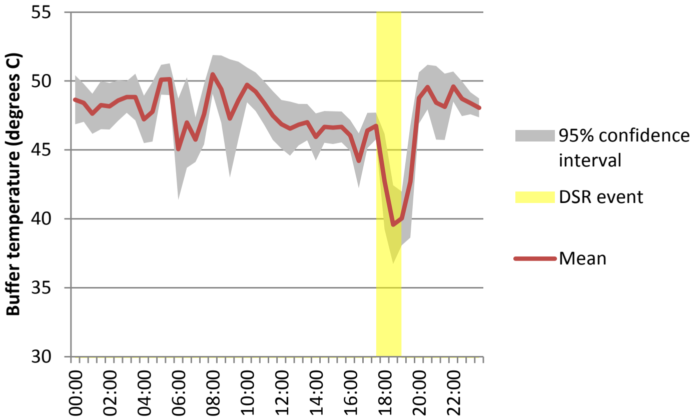
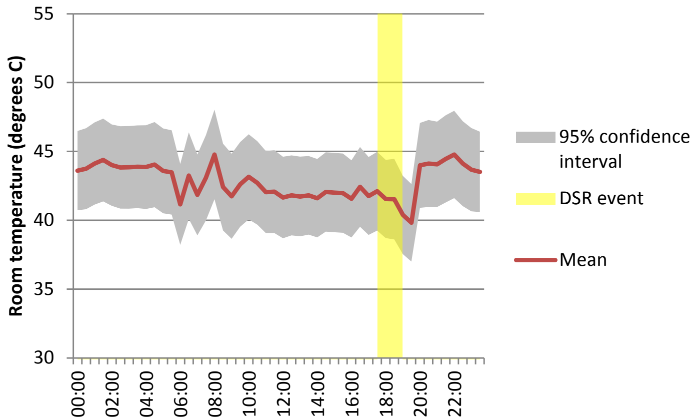
We can examine the possible impact of DSR on consumer comfort more directly through the use of temperature data. The heat pumps were installed alongside two temperature monitors: one at the thermostat location (typically this might be in a hallway), and the other within the thermal storage unit itself. Figure 30 shows the average temperature readings for customers that responded to the 6pm-7pm DSR events, and the control group of days where an event did not occur.

From the control data (top-right graph), it can be seen that the average daytime temperature within the houses is just under 20 degrees Celsius. Between approximately 9pm and 6am this gradually drops to a low of just over 18 degrees, before rising again in the morning. There is also a small drop in average room temperature between approximately 5pm and 6pm. There is insufficient information to conclude what may be causing this – one possibility could be that individuals returning home from work open doors and windows which lead to a temporary fall in temperatures. Such behaviour could potentially lead to additional demand for heat during the evening peak, and may be worth further investigation.

The DSR event room temperature data (top-right graph) is typically higher than the control data. It is likely that this just reflects the very small sample size (temperature data was only available for four combinations of customer and day for 6pm DSR events). There does appear to be a fall in room temperature during the period of the trial which is not present in the control data. However, given the small sample size, it is not possible to conclude that the difference is statistically significant. Moreover, the average temperature remains around 20 degrees Celsius, which suggests that the comfort of the household is unlikely to have been materially affected.

The lower panels of Figure 30 show the mean recorded temperature of the thermal storage. During the control days, there is a decrease in the mean thermal store temperature after about 7pm, followed by an increase – it is unclear what is causing this. The event days appear to show a greater reduction in thermal store temperatures during the DSR event, which would be consistent with the thermal store correctly being used to maintain room temperatures, before it is recharged immediately after the DSR event. However, we cannot conclude that there is any statistically significant difference between the trial and control days. This is potentially due to the small sample size involved.

Figure 30 Heat pump temperature readings

<table>
<tr><td></td><td>DSR events received</td><td>Control days</td></tr>
<tr><td>Room temperature</td><td>
</td><td>
</td></tr>
<tr><td>Storage temperature</td><td>
</td><td>
</td></tr>
</table>

Source: HP status reports

It has not been possible to draw conclusions on the drivers of consumers' response to the interruptions through the qualitative interviews. Although DEI carried out 21 semi-structured interviews with domestic customers, these found that the negative experiences of overcoming a new technology made it impossible to explore the sociocultural dimension of heat pump technology and the household's energy practices. Evidence from these interviews suggest that users found the heat pumps to be unreliable - reporting issues with hot water supply, an increase in energy bills due to technology malfunction (one person had a 66% increase in bills) and noise.[25] It is not possible to determine any *additional* effect on comfort that DSR may have had. However, based on the experience from this trial, the project partners involved do not consider that heat pumps (with storage) are likely to be a mass-market retrofit option in the UK in the near term.

We note that other parts of the social science research found a much more positive reaction to heat pumps among consumers. For example, the Heat Pump Survey work (a telephone survey of 120 customers in Test Cell 3) found that 76% of participants were either satisfied or very satisfied.

Other trials of heat pumps (without DSR) have also tended to find greater levels of customer satisfaction. DECC's RHI evaluation (based on a survey of 3,056 responses from RHI applications accredited between May and August 2014) found that 87% of ASHP participants were "very" or "fairly" satisfied, with 55% of them reporting that the technology was better than they expected.[26] Similarly, in the second phase of the Energy Savings Trust heat pump trials,[27] 80% of users interviewed were either "satisfied" or "very satisfied" with the space heating supplied by their heat pump, 84% gave similar responses for hot water, and 77% said they would recommend a heat pump to a friend, mainly because of the efficiency and running costs of the system.

This test cell was designed to assess the feasibility of DSR for heat pumps, rather than heat pumps as a general technology. It is therefore difficult to conclude why users on this trial might have had worse experiences with heat pumps than consumers in the studies listed above. However, some possibilities are listed below.

- Many of those surveyed as part of the other trials quoted above may have chosen a heat pump to replace a less efficient system (e.g. an oil-fired boiler), while some of the TC14 participants may have been replacing gas-fired boilers.
- Consumers using the RHI actively chose to install a heat pump with their own money, and are therefore likely to have spent longer weighing up the costs and benefits than the consumers in TC14. For example, it is possible that RHI customers as a whole may be more influenced by the "green" benefits of heat pumps, compared to participants in TC14. In contrast, the CLNR participants did not choose the heat pump themselves, this was selected by the social housing provider.
- There may have been issues with installation of the heat pump. In the first phase of the Energy Savings Trust heat pump field trials where satisfaction levels were markedly lower

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[25] Demand Side Response (White Goods), Durham University, Social Science Interview Report 2014

[26] DECC (2014) *Evaluation of the Domestic Renewable Heat Incentive: Interim Report from Waves 1–4 of the domestic RHI census of accredited applicants*

[27] Energy Savings Trust (2013), *The Heat Is On: Phase 2 Heat Pump Field Trials*

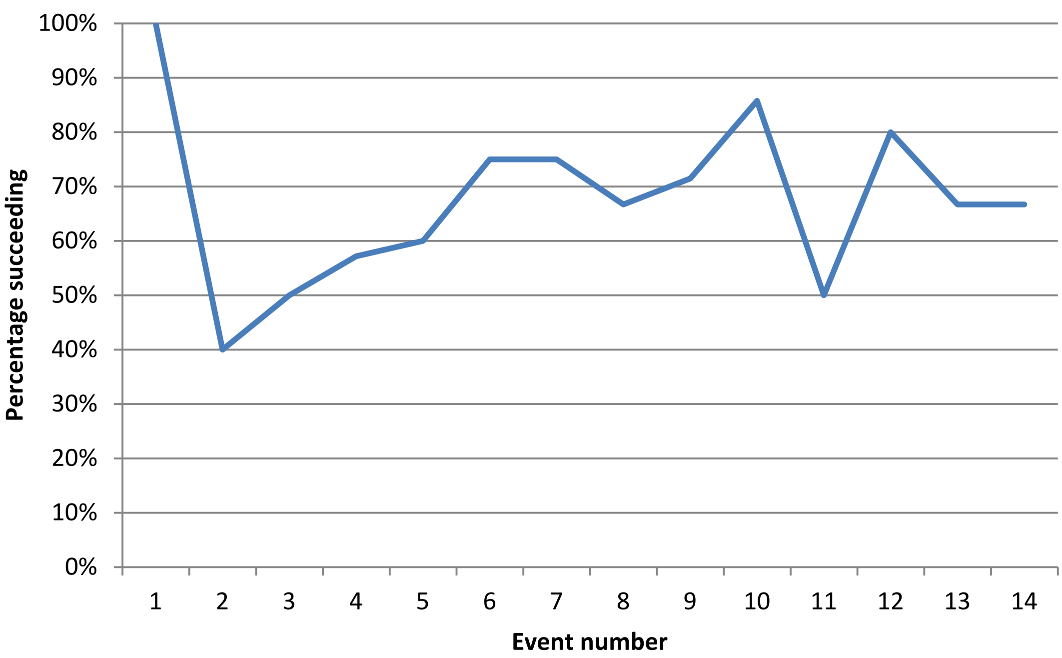
than in the second phase, many heat pumps were found to have been installed incorrectly. In addition, sometimes neither installers nor users understood proper control requirements. These types of problems may have arisen in the TC14 trial – particularly given the way in which large thermal stores are not typically installed alongside heat pumps in the UK.

3.2.5 Understand whether behavioural change was temporary or permanent

There is no evidence that consumers' responses changed in a systematic way across the duration of the trial.

Figure 31 illustrates that the proportion of interruptions succeeding (i.e. where customers did not cancel the interruption) fluctuates during the trial, but does not display a clear pattern.

Figure 10 Proportion of consumers for which each DSR event succeeded (was not cancelled)



Source: HP status reports

3.3 Comparison with previous studies

The CLNR direct control study brings new learning, as most previous studies of direct control:

- included a peak tariff element alongside the automated element; and
- focussed on customers with air conditioning (mainly in the US).

3.3.1 Automation with tariffs

The design of the CLNR direct control test cells differs from the test cells concerned with time of use tariffs, in that customers receive no financial incentive to shift load from the interruption periods. Instead, they receive additional compensation for agreeing to take up the direct control offering.

Previous studies have found that the use of automation alongside a peak tariff greatly increases the effectiveness of the tariff.[28] We found only one other study that looked at the application of automation (with override) *without* an additional peak tariff signal (Box 1). As with the trials in these test cells, the LIPA study found that automated signals could be effective in reducing consumer demand.

3.3.2 Technologies to automate

The focus of the CLNR trial on washing machines and heat pumps is also relatively new ground for this type of study.

Previous studies have also found that the technology to which the automation is applied is critical. Looking across 12 studies (10 in the USA, one in Australia, one in Norway), a DECC review of the use of automation for DSR[29] found that interventions to automate responses deliver the greatest and most sustained household shifts in demand. However, this finding was strongly driven by the technologies held by customers – and worked best where consumers have certain flexible loads such as air conditioners and electric heaters.

While the per unit load and flexibility of air conditioning units may be comparable to that of a heat pump in the UK, there is little evidence of payback spikes being an issue in the literature for air conditioners.

We did not find a study that relied upon intermittent loads such as washing machines for direct control.

Box 1: The LIPA Edge Trial, Long Island, USA

The LIPA Edge trial involved the direct control of 20,400 residents' air conditioners, with participants receiving free installation of a thermostat and a bonus payment of $25 for joining the trial. $20 was also given to existing members who successfully referred new members.

In exchange, LIPA could call curtailment events between 2-6pm on up to seven days during the summer season. During these events, LIPA could either increase the set point on the thermostat or

[28] For example, those covered in Vaasa ett, 2011, The Potential of Smart Meter Enabled Programs to Increase Energy and Systems Efficiency: A Mass Pilot Comparison; Short name: Empower Demand. Available at http://www.esmig.eu/press/filestor/empower-demand-report.pdf. Faruqui and Palmer, 2012, The Discovery of Price Responsiveness- A Survey of Experiments involving Dynamic Pricing of Electricity. Unpublished paper submitted to the EDI Quarterly

[29] Frontier Economics for DECC (2012), DSR in the domestic sector - a literature review of major trials

instruct the air conditioning compressors to cycle for a part of each hour. Participants could override these signals (although the supplier could prevent this in exceptional circumstances). Providing participants with the ability to override direct control was found to be important in gaining participants' acceptance.

On average, each controlled air conditioning unit reduced consumption by 1.03kW during a curtailment event, relative to an average capacity per unit of around 3.84kW. Compliance with the fell over the course of an event as an increasing share of households chose to override the constraints implied by LIPA.

There is some evidence that overriding rates were low, despite the lack of financial penalty. For example, during a curtailment event in August 2002, 20.8% of consumers had chosen to override the automated reduction in their air conditioning usage by the end of the peak period. Low rates of overriding could be due to the tendency of consumers not to opt out of schemes in which they have been included, even if they would not have actively opted in to these schemes.

Source: Frontier Economics for DECC (2012), DSR in the domestic sector - a literature review of major trials,

Crossley (Energy Futures Australia), 2010, International Best Practice In Using Energy Efficiency and Demand Management to Support Electricity Networks.

4 Conclusions

These trials have found that direct control of washing machines and heat pumps can have statistically significant impacts on peak demand for these appliances. This has even occurred despite the inevitable technical issues[30] associated with the first UK application of these technologies.

However, the results of the trials described in this paper do also highlight a number of challenges for these types of DSR:

- The response gained from **washing machines** may be limited in size, because they are only used intermittently at peak time. Therefore networks would need to engage with a substantial number of customers to gain the desired results.
- For **heat pumps**, payback spikes are likely to cause issues with their use by networks in direct control unless these can be mitigated – for example, through the use of different storage dispatch algorithms, or if more thermally efficient houses were capable of storing more heat in the building fabric.
- In this trial, problems with the DSR technology limited the size of the response, as a substantial proportion of customers did not receive a signal. Further development of this DSR technology would be required before the signal could be relied on.
- The design of the user interface also needs to be carefully considered, to prevent the possibility of accidental cancellation of DSR events. This appears to be concentrated among a small set of customers, so further research could be undertaken to determine the types of behaviour underlying this.[31] Both this and the previous point suggest that any future development of DSR for heat pumps may benefit from being tightly integrated with advances in domestic Home Energy Management products (such as the *Hive* system offered by British Gas).

[30] In particular, the way in which a large proportion of WWG DSR events were not received by the machines, and the way in which an issue in scheduling heat pump DSR meant that any thermostat adjustment carried out in the hour prior to the event would cancel it.
[31] For example, whether customers are making unnecessary thermostat adjustments, or have temperature requirements which genuinely vary over the day.

Customer-Led Network Revolution

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