Customer-Led Network Revolution

Insight Report: Enhanced Domestic Monitoring

Disaggregated Load, Hot Water and Storage Heating

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1 Trial Overview

1.1 Description

This report covers the work of the three enhanced profiling test cells (2a, 10a(HW) and 11a(SH)), which provide detailed consumption profiles by appliance or circuit for a range of domestic customers.

- **Test cell 2a** involved enhanced monitoring of customers' disaggregated domestic loads and overall consumption. The domestic loads monitored included: lighting, consumer electronics, the cooker, kitchen appliances, washing appliances and refrigeration. The trial duration was 12 months and included all seasons.
- **Test cell 10a(HW)**[1] involved enhanced monitoring of customers with immersion hot water heating and an Economy 7/10 tariff. The data gathered includes both the temperature and power consumption of the immersion heater.
- **Test cell 11a(SH)**[1] involved enhanced monitoring of customers with both immersion hot water heating and electric storage heating on an Economy 7/10 tariff. The data gathered includes power consumption for both the immersion heater and storage heaters.

1.2 Purpose

These trials were designed to support Learning Outcomes 1 and 2. Specifically, they provide the data needed to develop:

- a greater understanding of how future economic, social and technological trends are likely to affect the patterns of the various components of load and generation;
- an improved set of load profiles; and
- a greater understanding of the degree to which customers who have accepted a proposition for flexibility then respond.

1.2.1 Test cell 2a

Test cell 2a provides detailed consumption data by appliance. This data has allowed us to analyse different appliances' contribution to total consumption, as well as these appliances' potential contribution to demand side response (DSR). The key aims of the 2a trial are summarised below:

- **Determine detailed appliance-level consumption profiles** – The granularity of the data available from the test cell enables us to look at each appliance's contribution to energy consumption and to total electricity costs.
- **Determine how trends in consumption patterns and appliance efficiency will influence future consumption profiles** – Combining the test cell data with trends in appliance efficiencies and for forecasting of future consumption profiles.

- **Determine the potential contribution of different appliances to DSR** – Consideration of the timing of appliance use and the flexibility of different forms of consumption allows for a granular assessment of different appliances' potential contribution to DSR.

1.2.2 Test cells 10a(HW) and 11a(SH)[1]

These two test cells provide profile data for Economy 7 households with different heating technologies. This data can be used to examine how consumers behave when using a time of use (ToU) tariff. The key aims of these trials are summarised below.

- **Determine average consumption profiles for an Economy 7 customer** – Aggregating the detailed trial consumption data allows the construction of consumption profiles for homes with and without electric storage heating. We are also able to analyse the variability of consumption patterns among different customers.
- **Determine customer responsiveness to the tariff profile** – Analysing whether customers typically follow the incentives set by the profile demonstrates the extent to which E7 and E10 static time of use tariffs are successful in shifting demand.
- **Determine the technical feasibility of alternative (dynamic) tariff structures** – Analysing whether consumers override their storage heater timers on particularly cold days indicates whether technical factors may limit the use of this type of DSR on the days when it is needed most.

[1] **In this document the hot water and hot water plus storage heating trials are referred to as test cells 10a(HW) and 11a(SH) respectively. It should be noted that these two trials are also referred to as test cell 2a HW and 2a HW+SH and may be referenced in other CLNR outputs as such.**

2 Trial Design

2.1 Test cell 2a

2.1.1 Participation and recruitment

Test cell 2a comprised data on around 81[2] domestic customers, including non-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. All participants were recruited from among the staff of the trial partners[3], due to the intrusive nature of the monitoring installation. Therefore the participants are therefore unlikely to be representative of the wider population, both as a result of their relationship to the energy industry and the trials, and by the fact that at least one household member was in employment. However, there is no obvious incentive for the households that we observed to alter their consumption behaviour, so while these households may be different from the UK average, the data should be a reasonably accurate reflection of their typical consumption patterns.

2.1.2 Equipment and tariff

In order to gather the data required, two forms of monitoring were used.

- Circuit monitoring was installed for all circuits at the consumer unit, as well as for the household as a whole. This took the form of current clamps (small transformers) mounted on each circuit, connected to a monitoring unit which in turn connected to the households' broadband router. Late into the project, the whole house datasets were found to have an issue where a scaling factor (to account for differing sized current transformers) had been applied incorrectly. We have been able to apply a correction factor[4] which will lead to the averages we report being approximately correct. However, this will not be exact, and the whole house readings should be interpreted with this in mind.
- This was supplemented by the use of up to seven smart plugs on specified appliances. Installers were instructed to attempt to monitor one of each of the following types of device where they existed: Fan heater / bar heater / oil-filled radiator; washing machine; dishwasher; tumble dryer; refrigerator; freezer. If further smart plugs were available, the installers monitored other appliances (for example TVs and kettles). Consumption data was recorded every minute, transmitted via a ZigBee connection to a hub, and from there to the households' broadband router.

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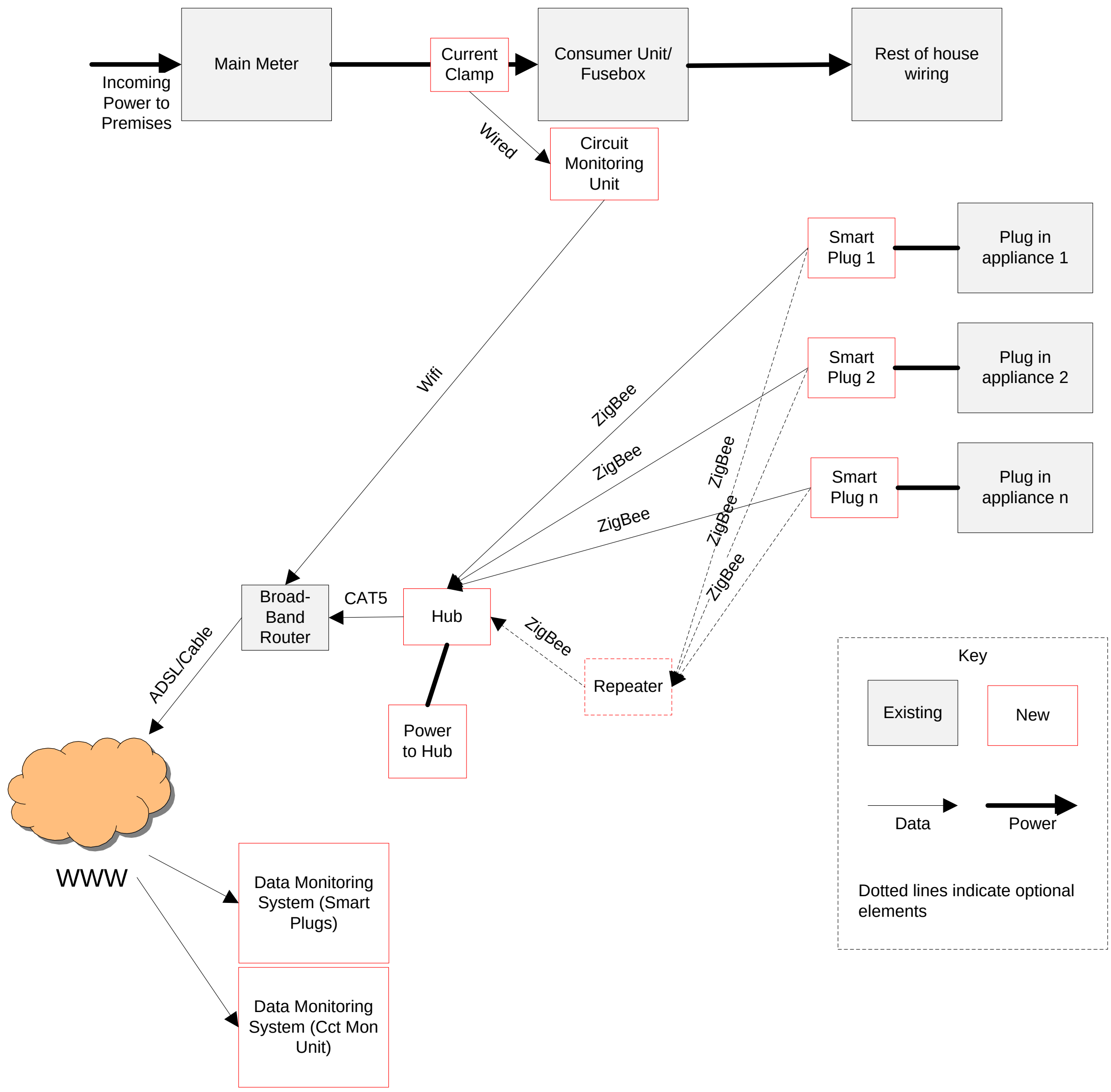
[2] The sample size varies by time and by monitored appliance – this figure relates to the maximum number of usable observations for a day within the whole house dataset.
[3] British Gas, Northern Powergrid, the Durham Energy Institute and EA Technology
[4] This was carried out by comparing the sum of circuit power (when data was present on all circuits) to the whole house power, to derive a scaling factor. This scaling factor varies slightly over time, since some earlier installations appear to have used different sized transformers. The scaling involved an uplift of 18% on the raw figures for the peak weekday.

The methodology for installing smart plugs means that, in many cases, the total load will be underestimated. For example, this would occur if a consumer had two refrigeration appliances and only one was monitored. This is explained further below.

Figure 1. shows the main components involved in this trial.

Figure 1 Main components for TC2a trial



Source: British Gas

No change was made to customers' existing tariffs.

2.2 Test cell 10a (HW) and 11a (SH)

2.2.1 Participation and recruitment

Both of these test cells comprised of consumers who already had E7 or E10 tariffs. 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. Customers were largely living in social housing, and spread nationally.

2.2.2 Equipment and tariff

To gather the data required for TC10a (HW), in-line monitors were installed on both the immersion heater and the boost facility. Consumption data was recorded every ten minutes. A hot water sensor and temperature strings (5 sensors) were also installed to provide constant data on tank temperatures.

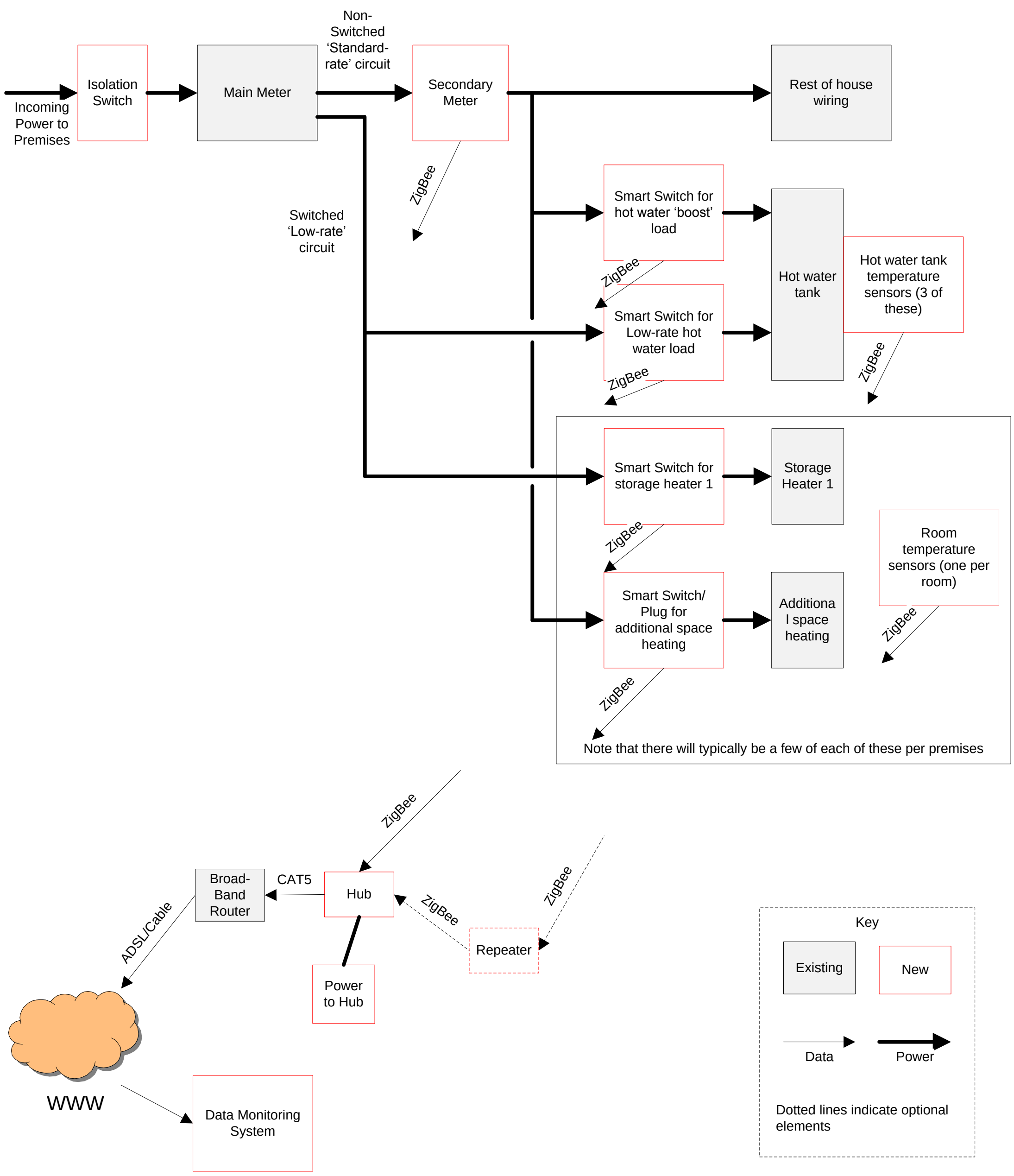
As part of the installation, the trial homes were also fitted with a mains isolation switch and a secondary meter on the main supply.

The equipment used in test cell 11a(SH) is identical to that in text cell 10a(HW) with the addition of monitoring equipment for the electric storage heating.

This additional equipment includes in-line monitors and temperature sensors for the radiators, as well as the use of room temperature sensors.

Figure 2 below summarises the main components of the TC11a(SH) trial (all items except those in the inset black box were also used for the TC10a(HW) trial).

Figure 2 Main components for TC11a (SH) trial



Source: British Gas

Due to a data scaling issue,[5] it was not possible to use the whole house data recorded for this test cell. Further, various data issues have led to extremely small sample sizes for the remaining datasets

[5] A variety of different sized current transformers (CTs) could potentially be used to measure whole house consumption: generating an output in kW required compensating for the varying number of windings. Late in the project, during the processing of TC2a (which included CTs on both the mains incomer and individual circuits), it was discovered that the data that had been provided was incorrectly scaled. It has been possible to work around this within TC2a since the individual

on power and temperature. For example, power data for the TC10a(HW) hot water tank is available for only four customers:

- 82 customers had power readings for their immersion heater, with 17 of these also having temperature readings.
- A comparison of temperature readings with power suggested that, in some cases, the power data was not referring to the same device (since power usage was not correlated with an increase in temperature). As a result, only the 17 customers with both power and temperature data were retained, since there was no way to cross-check power data for the other 65 customers.
- Of these 17 customers, ten were removed due to bad data quality (a very high proportion of missing values).
- Of the 7 customers that remained, 3 were removed due power data either being constantly zero (i.e. the heater was not in use), or not correlating with temperature data. This left a final sample size of 4 customers.

Similar issues affect the TC11a (SH) dataset.

All customers had an existing Economy 7/10 tariff and no change was made to the existing tariff.

circuits are known. However, this has not been possible for this test cell, as no other readings exist that could be used to reliably calibrate a scaling factor for the CTs.

3 Trial Results

3.1 Test cell 2a

In this section we analyse the data collected from test cell 2a to meet the following learning objectives.

- determine detailed appliance-level consumption profiles
- determine how trends in consumption patterns and appliance efficiency will influence future consumption profiles; and
- determine the potential contribution of different appliances to DSR.

3.1.1 Whole house consumption

A summary view of the results from test cell 2a is provided in Table 1 and Figures 3 and 4 below, which show typical energy use and cost across the year. More detailed analysis of the individual appliances types can be found in the relevant sections of the report. **The way in which appliances were monitored is likely to lead to an underestimate of certain types of load** because, as discussed above, the constraints of the trial meant that not all appliances were monitored. This is explained in greater detail in the sections on each appliance type.

It is worth noting here that these are average results. Individual consumption profiles can and do vary significantly between households and, even within a single household, consumption may not observe a constant pattern. Indeed, the CLNR's social science work has already shown that a household's consumption between 4-8pm can, on any one day, differ from its annual average by up to 50%.[6]

Average annual consumption among the group in the trial is 4,192kWh, between Ofgem's representative medium (3,200kWh) and high (4,900kWh) consumption figures. A significant element of this consumption is 'unaccounted' for. In other words, this consumption is not attributable to the devices that were monitored.

Some of this will be due to the issue highlighted above. However, to find out more, a short phone survey was carried out by British Gas to understand more about the trial participants and their use of different appliances. There were 31 responses to this survey. Putting these together, there are a number of appliances that will not have been picked up as part of the monitoring, which, most importantly, include the following large electric loads.

[6] This within-household variation is especially prevalent in higher income households, and in those without children under five or adults over 65. (CLNR Durham University Social Science April 2014 Report, p.11)

- **Electric showers.** Although these would typically be on their own circuit, only a very small number of circuits have been identified as such (too small a sample to analyse effectively). Nevertheless, when TC2a customers were surveyed, 17 respondents out of 31 indicated that they owned at least one such shower.
- **Electric heaters plugged into sockets**. Although the installers were asked to monitor these if found, too few data points exist to analyse. This is despite nine customers in the survey indicating they used such appliances (and yet none of these had heaters monitored as part of this trial). It may be that these appliances were stored out of view of the installer.

Table 1 Appliances' contribution to consumption and DSR and efficiency potential by appliance type

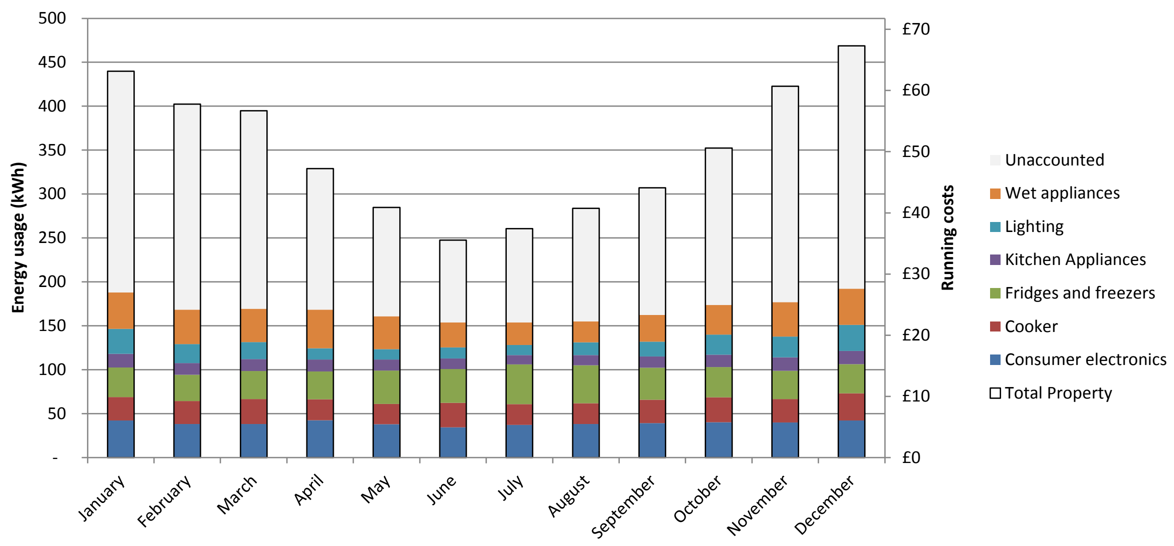
	Annual consumption		Share of household demand		DSR potential	Efficiency potential	YoY uptake of efficient appliances
	kWh	£	peak[7]	total		kWh	
Lighting*	225	32	7.6%	5.4%	Non-switchable	54	6%
Cooker[8]	317	45	13.8%	7.6%	Non-switchable	66	5%
Kitchen appliances*	161	23	2.9%	3.8%	Non-switchable	-	-
Space cooling	-	-	-	-	Partially switchable	-	-
Space heating	-	-	-	-	Partially switchable	-	-
Refrigeration*	427	61	4.9%	10.2%	Partially switchable	741	6.7%
Hot water	-	-	-	-	Switchable	-	-
Washing appliances	423	61	12.3%	10.1%	Switchable	222	7.5%
Consumer electronics*	470	67	7.2%	11.2%	Non-switchable[9]	274 (TV)	9% (TV)
Unexplained	2,170	311	-	51.8	-	-	-
Total household	4,192	602	100%	100%	-	1,357	-

Note: Efficiency potential shows potential savings from replacing equipment with the highest efficiency standard equivalent for an average 2013 household. Year-on-Year uptake is modelled based on consumers' willingness to pay for more efficient equipment

Sources: Element Energy analysis, 2014

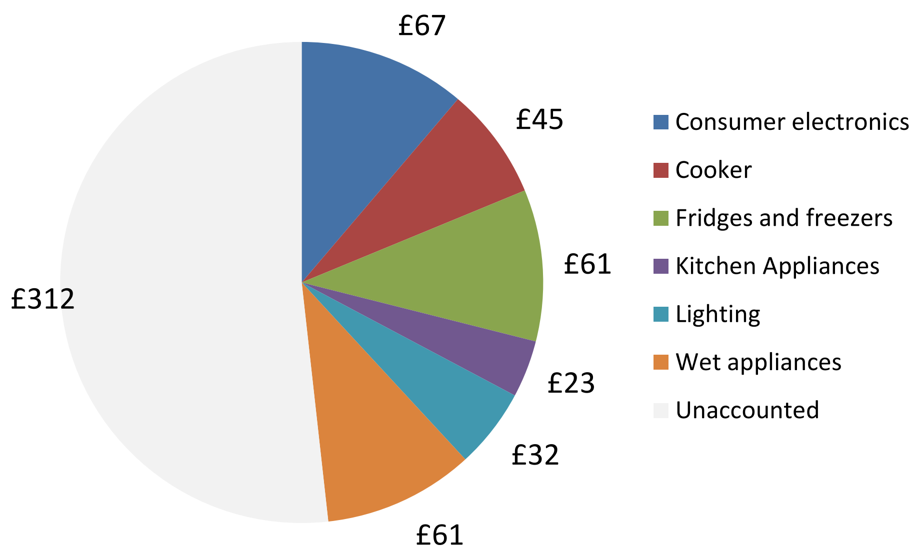
[7] Peak based on the peak recorded half-hour in the dataset. Total based on overall energy over a year.
* These power figures are highly likely to be understated due to the structure of the trial (not all appliances were monitored).
[8] Average electric cooker profile across all electric cooker circuits monitored. The average demand across all UK households would be lower, since many will use gas for cooking .
[9] There may be some potential to switch components of consumer electronics demand in the future, as discussed in section 3.1.11.

Figure 3 Average monthly energy usage and cost by appliance type



Source: Data collected for CLNR by Passiv and Microwatt

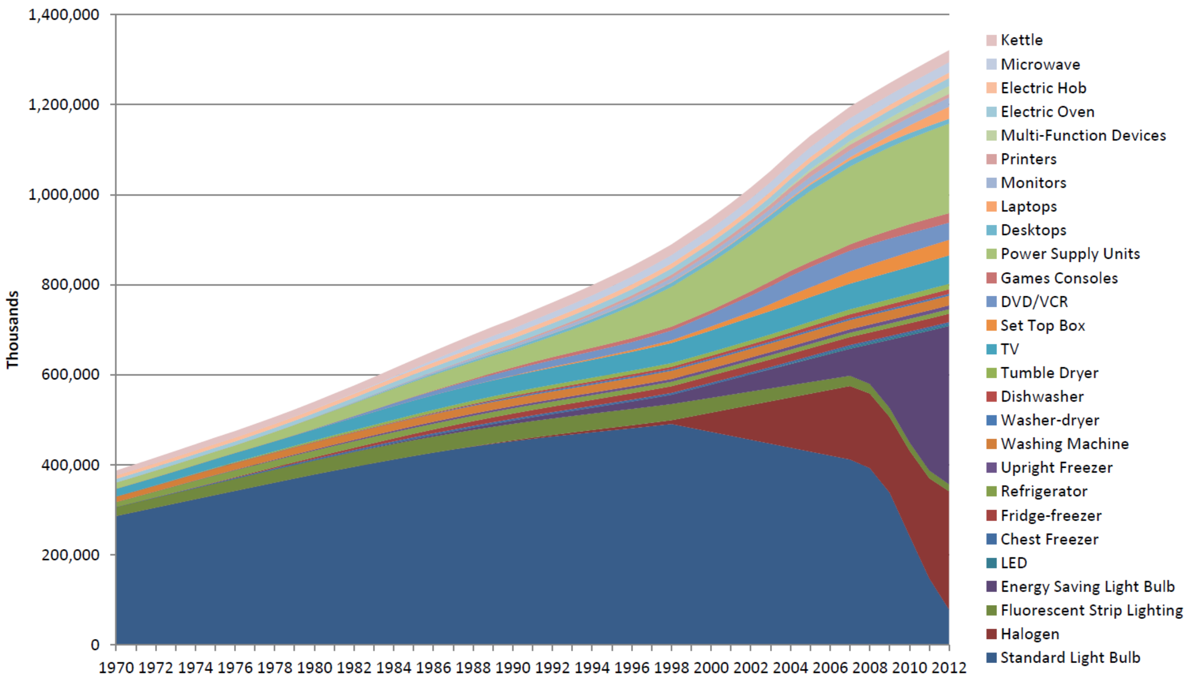
Figure 4 Average annual energy costs by appliance type



Source: Data collected for CLNR by Passiv and Microwatt

When considering how consumption will change over time, it is important to realise the significant influence of social and technological change in driving consumption patterns. Figure 5 below shows how appliance ownership has changed since 1970. Total appliance ownership has more than tripled in terms of the number of devices between 1970-2012, driven by greater affluence, a larger population, and a trend towards smaller households such that individual appliances are used by fewer and fewer individuals. The recent change in lighting technology is also visible, with standard light bulbs almost entirely replaced by more efficient lighting technologies over the space of a decade. As discussed further below, future changes in electrical heating technology have the potential to significantly alter the current consumption profiles detailed in the trial results.

Figure 5 Number of appliance owned by households in the UK 1970 to 2012



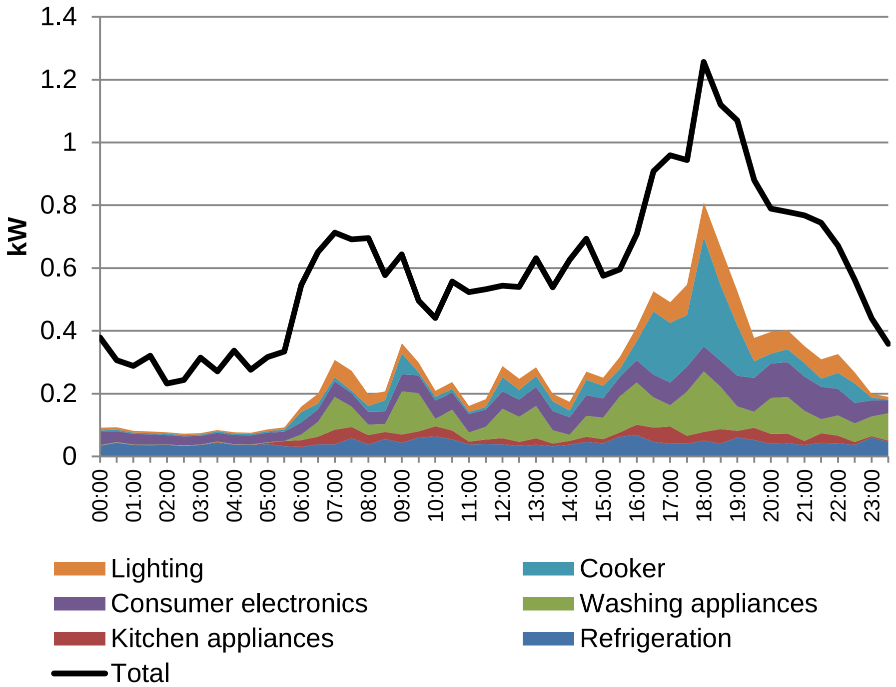
Source: CLNR Durham University Social Science April 2014 Report, Figure 38

Even where there are not fundamental technological changes, gradual improvements in design and production can result in rapid improvements in energy efficiency. Table 1 above also shows how much energy could be saved in a typical UK household if all of the relevant equipment were replaced by equipment with the highest efficiency rating currently available. It shows the significant scope for demand reduction using existing technology, irrespective of attempts to forgo or shift demand. The final column also shows the estimated rate of uptake of new, efficient devices based consumers' modelled 'willingness to pay'. Note however that historically, gradually improving efficiency gains have been overwhelmed by countervailing trends in product size, plus increased use and ownership.

3.1.2 Peak consumption

Figures 6-8 below show the average daily profile from the TC2a data, disaggregated by appliance type for the peak day in 2014[10], as selected from the whole house data in this test cell 2a (for which sufficient data on the appliance types is available). The relevant profiles for 2012 and 2013 have not been shown given the low sample sizes on the relevant days (n<20), however the data available suggests that the peak in 2014 may have been lower than previous years.

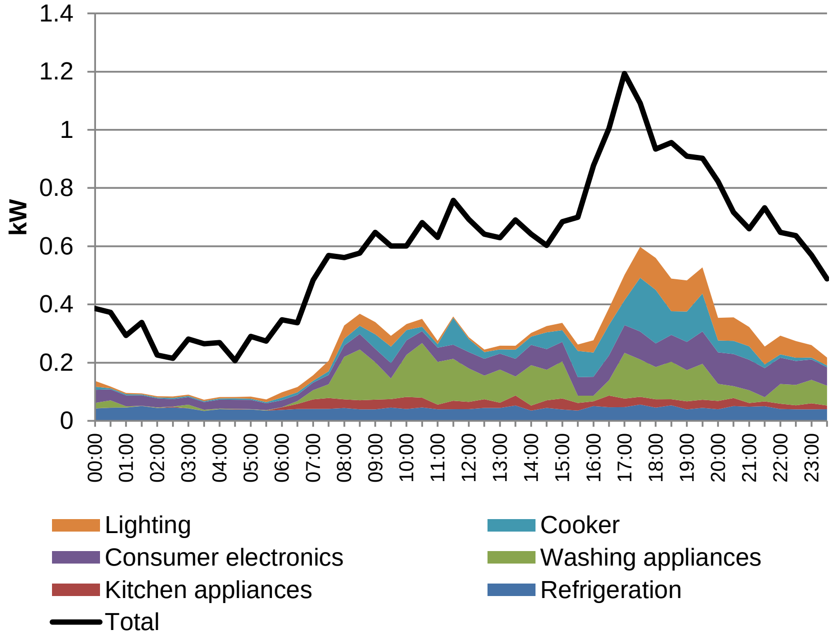
Figure 6 Electricity consumption by appliance type on a peak weekday[11]



Source: Data collected for CLNR by Passiv and Microwatt

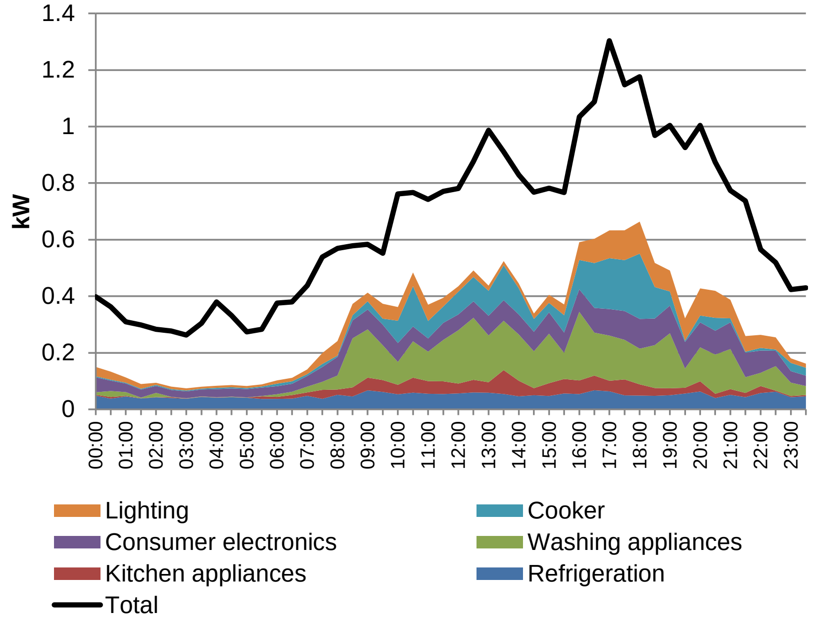
[10] These days are 5th February 2014 (weekday), 11th January 2014 (Saturday) and 19th January 2014 (Sunday)
[11] Sample sizes: Lighting 33, Cooker 41, Consumer electronics 47, Washing appliances 62, Kitchen appliances 118, Refrigeration 76, Total consumption 62

Figure 7 Electricity consumption by appliance type on a peak Saturday[12]



Source: Data collected for CLNR by Passiv and Microwatt

Figure 8 Electricity consumption by appliance type on a peak Sunday[13]



Source: Data collected for CLNR by Passiv and Microwatt

[12] Sample sizes: Lighting 35, Cooker 48, Consumer electronics 46, Washing appliances 60, Kitchen appliances 119, Refrigeration 74, Total consumption 65
[13] Sample sizes: Lighting 34, Cooker 45, Consumer electronics 48, Washing appliances 63, Kitchen appliances 118, Refrigeration 77, Total consumption 64

All of the peak day profiles exhibit a pronounced evening peak. The highest level of total consumption is realised on the Sunday, when average consumption over a half-hour period exceeds 1.2kW. As noted previously, even higher average peak loads are observed for earlier years, albeit for a small sample of households. Increased cooker consumption appears to explain a lot of the weekday peak, but there is also a marked increase in consumption by 'unaccounted' appliances, which may include plug-in electric heaters or electric showers.

3.1.3 Comparison with the Household Electricity Survey

Where analogous consumption groupings exist in both sets of data, we have compared the test cell 2a data with equivalent summary data from the Household Electricity Survey (HES). HES monitored appliance level consumption data in 250 owner-occupied households across England from 2010 to 2011[14] and, at the time, was the most detailed monitoring of electricity use conducted in the UK. As such, it represents an appropriate point of comparison for the appliance level monitoring conducted as part of this test cell.

Table **2** shows how we have mapped the HES consumption categories on to the test cell 2a appliances. Figures 9-18 below show the daily consumption profiles for the comparable consumption groupings for both workdays and non-working days. Note that the HES data tends to appear more volatile only because data is available with a 10-minute frequency, whereas the TC2a has a frequency of 30 minutes.

The patterns of consumption observed in test cell 2a tend to closely match those from HES. There is, however, a particular discrepancy in lighting demand, with HES consumption profiles exhibiting a far larger spike in lighting demand in the evening relative to the test cell 2a data. This is explored further in section 3.1.4.

In general, the HES data shows higher levels of consumption. This is likely to be due to differences in the sample populations. For example, the HES households may typically be larger or more affluent than those in test cell 2a. In particular, the HES data set exclusively looked at owner-occupied households.

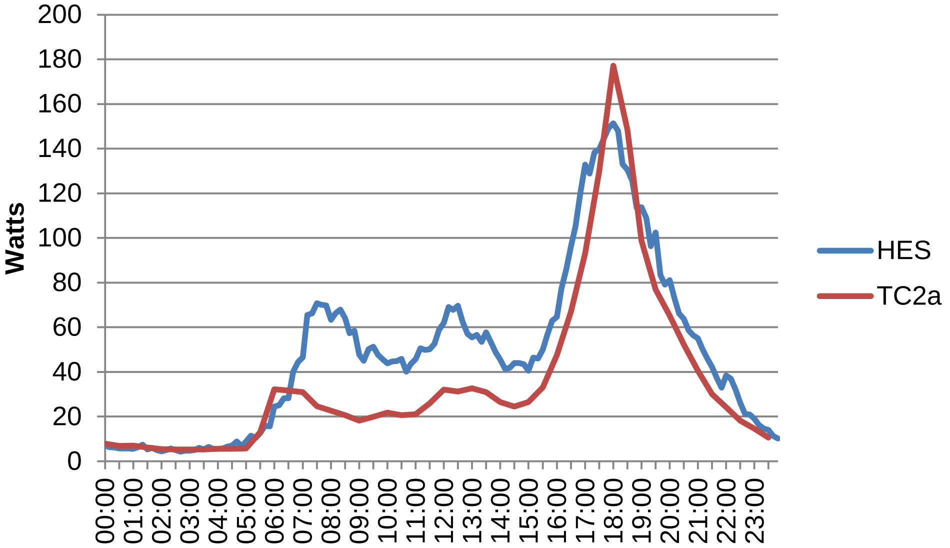
Table 2 Consumption category mapping between test cell 2a and HES

Test cell 2a	Household Electricity Survey
Cooker	Cooking
Lighting	Lighting
Refrigeration	Cold appliances
Washing appliances	Washers/dryers/dishwashers

[14] Note that most households within the study were only monitored for a month, after which monitoring equipment was moved to another household.

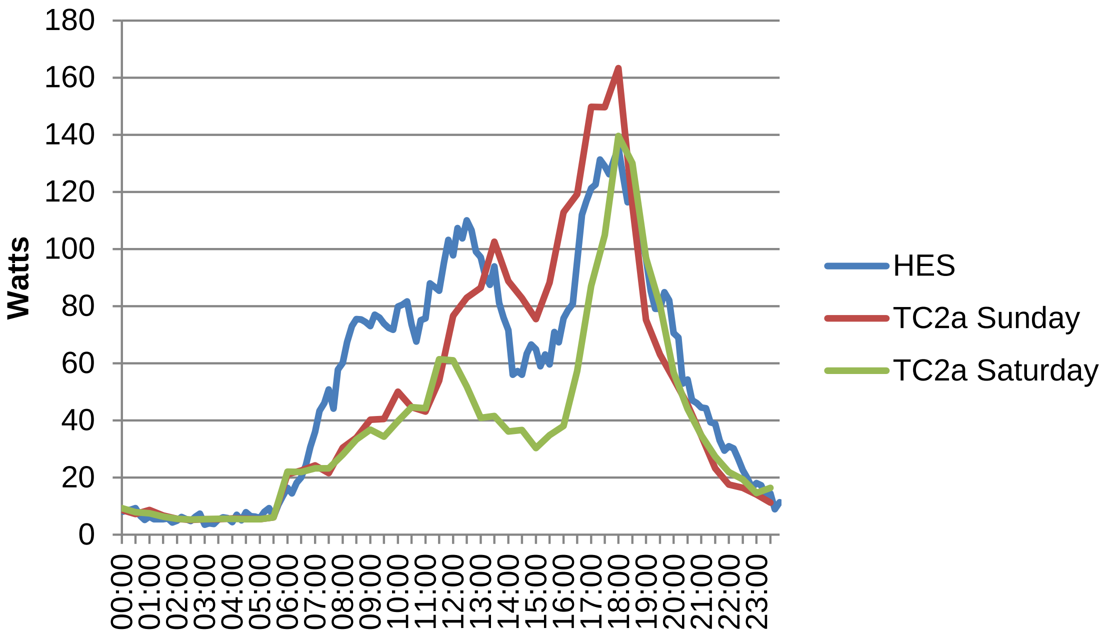
Consumer electronics	ICT and audio-visual

Figure 9 Workday cooking, average TC2a and HES profiles compared



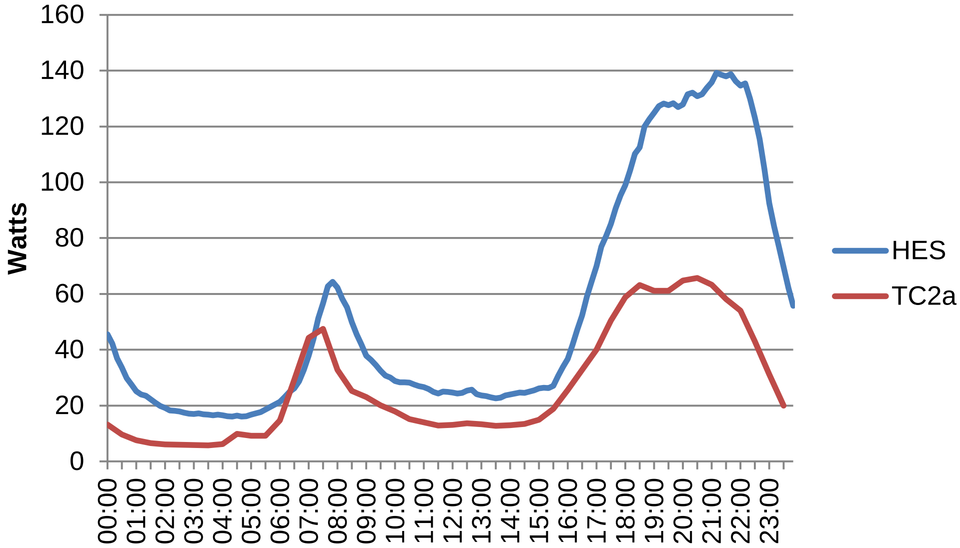
Source: Data collected for CLNR by Microwatt, HES data

Figure 10 Non-workday cooking, average TC2a and HES profiles compared



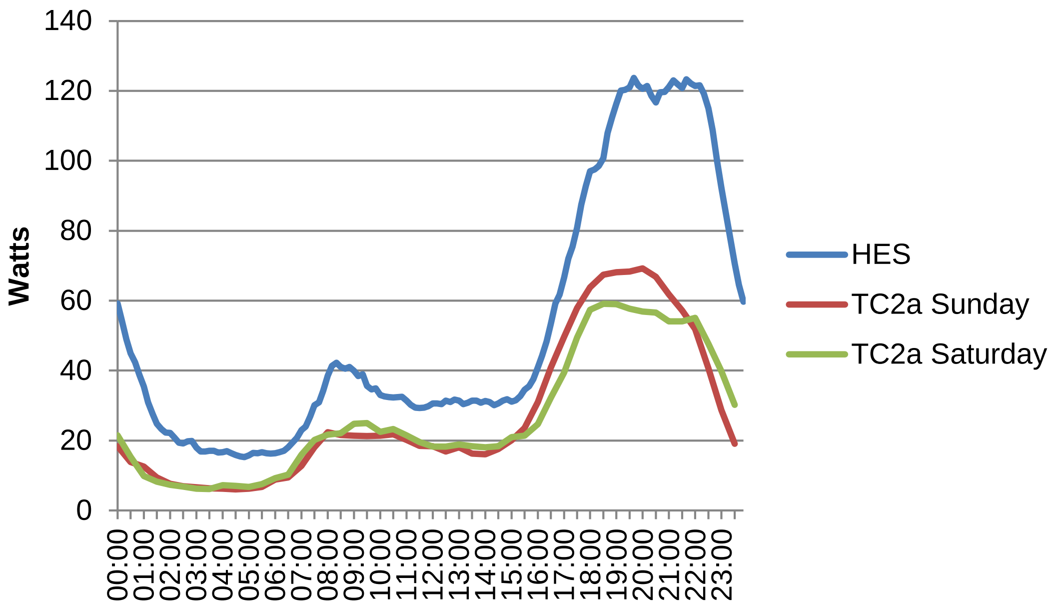
Source: Data collected for CLNR by Microwatt, HES data

Figure 11 Workday lighting, average TC2a and HES profiles compared[15]



Source: Data collected for CLNR by Microwatt, HES data

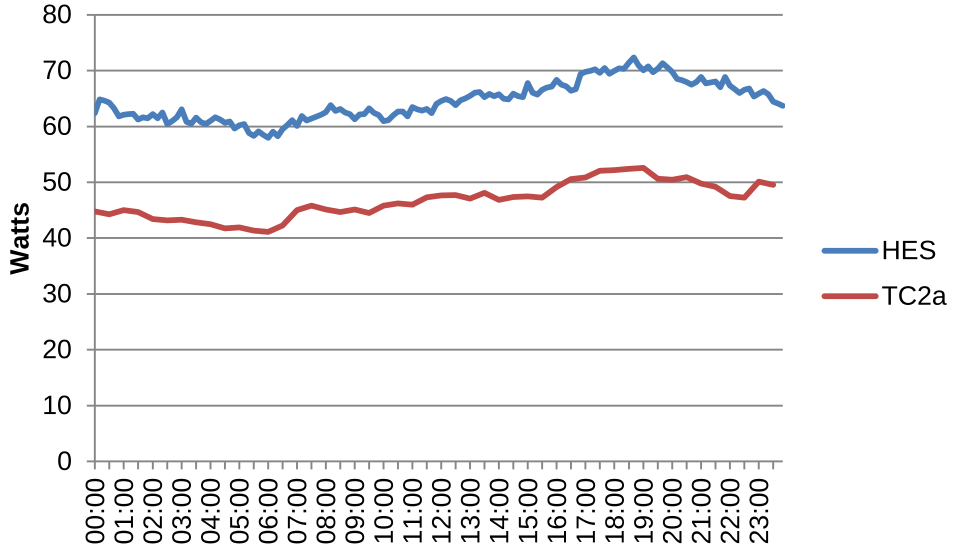
Figure 12 Non-workday lighting, average TC2a and HES profiles compared



Source: Data collected for CLNR by Microwatt, HES data

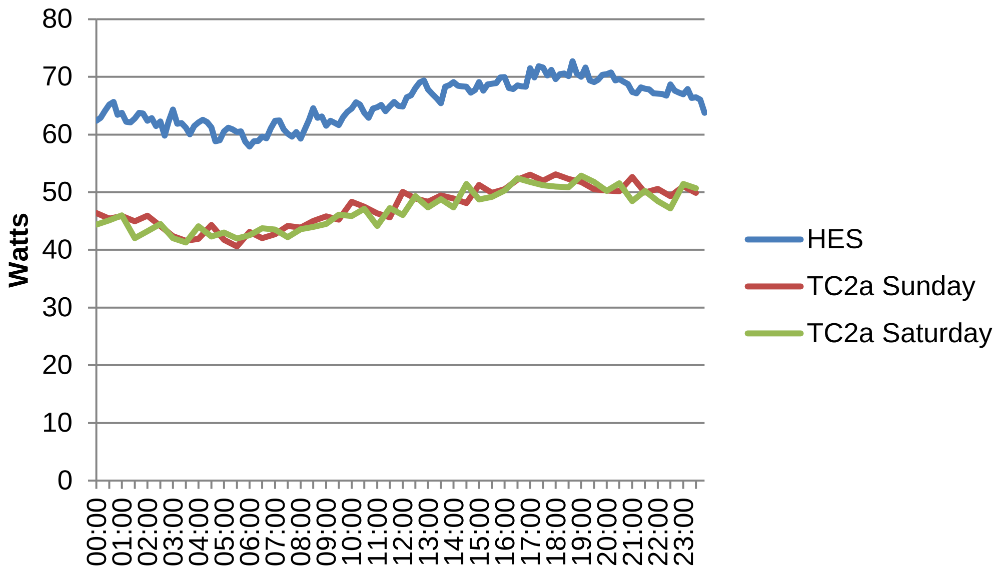
[15] The substantial discrepancy between the two datasets is explored in section 3.1.4.

Figure 13 Workday refrigeration, average TC2a and HES profiles compared[16]



Source: Data collected for CLNR by Passiv, HES data

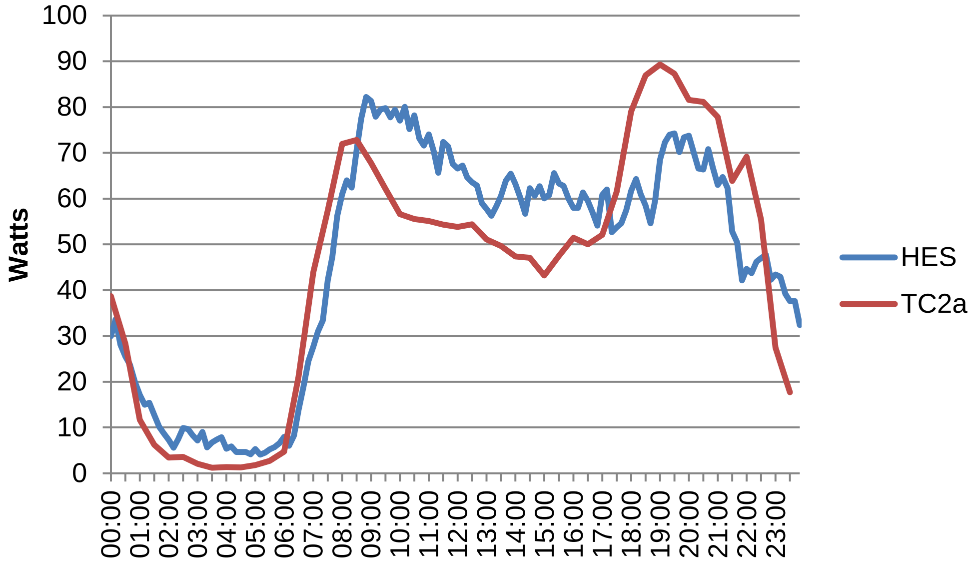
Figure 14 Non-workday refrigeration, average TC2a and HES profiles compared



Source: Data collected for CLNR by Passiv, HES data

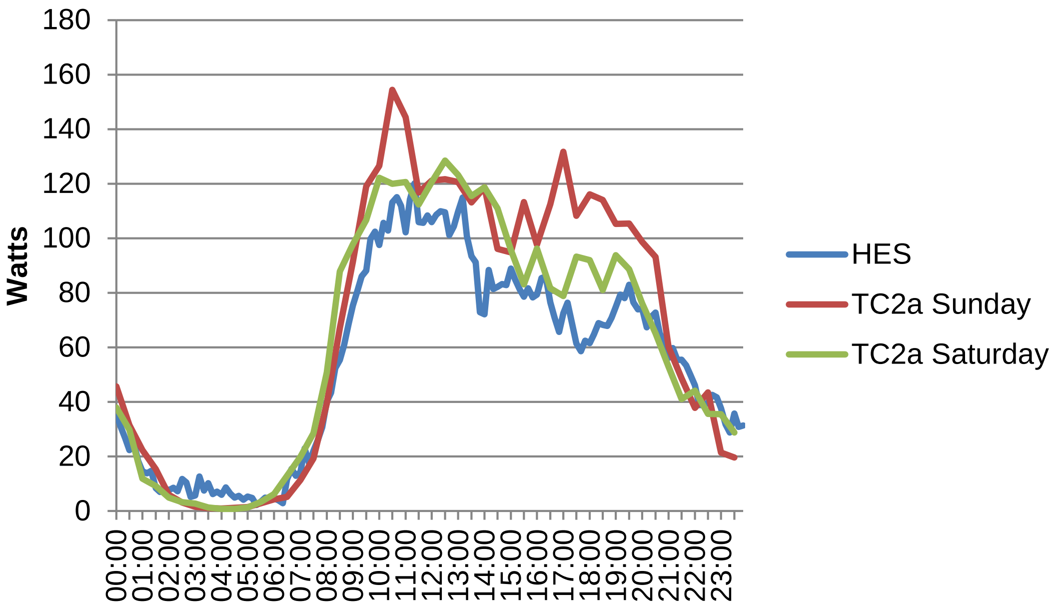
[16] See section 3.1.8 for possible explanations for the discrepancy.

Figure 15 Workday washing appliances, average TC2a and HES profiles compared



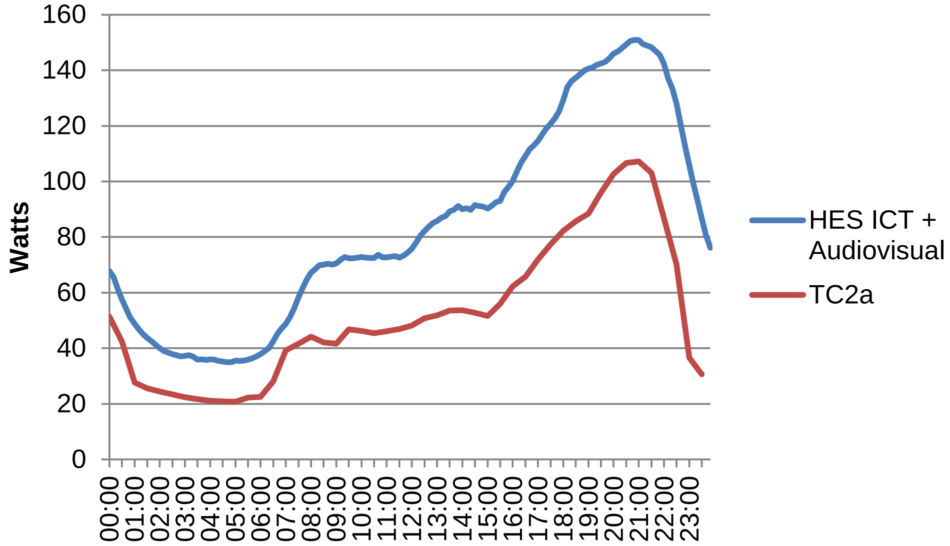
Source: Data collected for CLNR by Passiv, HES data

Figure 16 Non-workday washing appliances, average TC2a and HES profiles compared



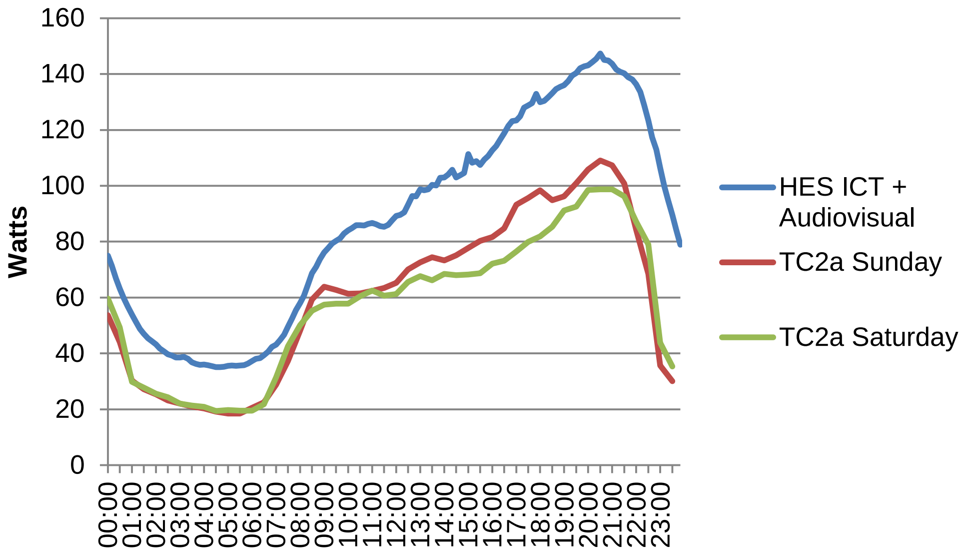
Source: Data collected for CLNR by Passiv, HES data

Figure 17 Workday consumer electronics, average TC2a and HES profiles compared[17]



Source: Data collected for CLNR by Passiv, HES data

Figure 18 Non-workday consumer electronics, average TC2a and HES profiles compared



Source: Data collected for CLNR by Passiv, HES data

In the sections that follow, we explore each consumption category in more detail, using data from our trial. We also provide more detail on their DSR potential as summarised in Table 1. In doing so, we use the framework for considering DSR potential established in the CLNR social science work.

[17] Reasons for this differential are explored in section 3.1.11.

Four potential consumer responses are distinguished that have the potential to contribute to load management. Specifically, a household can either shift:

- the time of the load;
- its location (e.g. to a place of work);
- how a practice is done (e.g. using an alternative means of cooking);
- or else it can forgo the practice entirely.

3.1.4 Lighting

Figure 11 and Figure 12 showed a substantial difference between the lighting profiles recorded as part of this trial, and those reported within the HES survey. Notably, weekday evening peak average power consumption recorded from the circuit monitoring is approximately half that seen in HES. We have therefore explored a number of possible reasons for the discrepancy.[18]

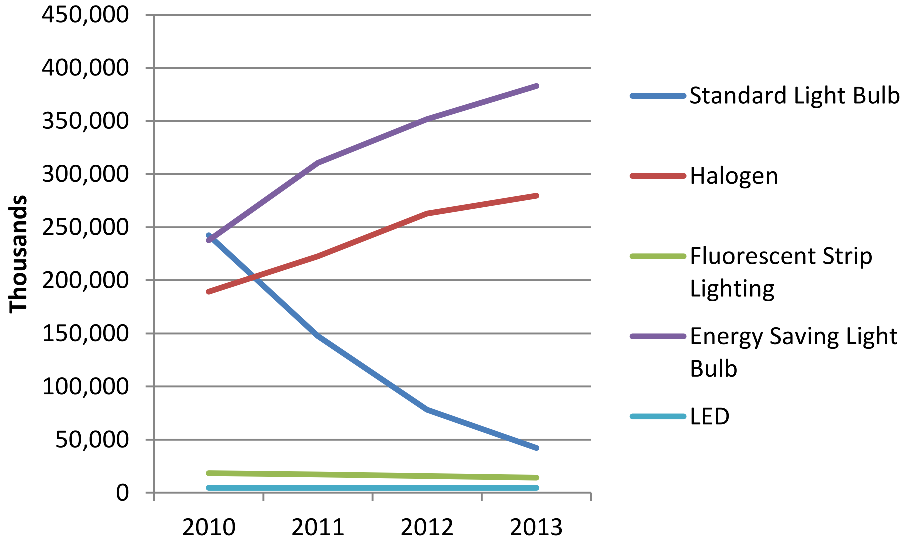
- First, in addition to lights mounted to the ceiling or wall (which will typically be picked up in the circuit monitoring), many homes have lamps which plug into sockets. These will not have been captured in the figures above. To roughly quantify the magnitude of this effect, the short survey referenced above, also asked about lighting use on a winter weekday. Across the 31 responses received, customers reported having an average of 3.7 ceiling- or wall-mounted lights on at 7pm on a winter weekday, and 1.6 socket-connected lights. If all bulbs were of the same power,[19] this suggests that the TC2a lighting profile should peak at around 86W, rather than 60W. **This represents a systematic tendency for the TC2a lighting data to underestimate total lighting power.**
- Second, as shown in Figure 5, the average domestic light bulb has become considerably more efficient since 2010, as more efficient CFLs (and, to a lesser extent, halogen bulbs) have replaced tungsten bulbs. Figure 19 shows the underlying figures from this graph. Based on average power figures from Which,[20] this suggests that the average power of UK domestic lightbulbs fell by around 30% between 2010 and 2013. Applying a further uplift of 30% to the 86W figure yields 112W, which is close to the peak consumption obtained in the HES study. **This effect is not a bias in the data, but reflects actual trends in energy usage.**

[18] It is also possible that some lighting circuits were not monitored. We have no evidence that this is the case (the majority of houses have both an upstairs and downstairs lighting circuit, as would be expected) but cannot rule this out.

[19] In reality, this assumption is unlikely to hold. For example, socket-connected lights could be lower power on average, but might also tend to use less efficient bulbs.

[20] Figures for a bulb equivalent to a 60W tungsten bulb were taken from http://www.which.co.uk/energy/energy-saving-products/guides/how-to-buy-led-cfl-and-halogen-bulbs/five-tips-for-choosing-the-right-light-bulb/, accessed on 11/12/2014.

Figure 19 Domestic installed base of light bulbs by type



Source: DECC[21]

This analysis suggests that:

- Socket-connected lighting may form a substantial proportion of overall UK domestic lighting load, at least during peak time. This is not included within the data monitored as part of this project, and may be an area for future research.
- The rapidly increasing efficiency of the stock of UK domestic lightbulbs means that load profiles are likely to be very different to what they were only five years ago.

The data below should be interpreted with the first point in mind – both the level and profile of average power will not be representative of the full UK domestic lighting demand and is instead only reflecting mains-connected lighting.

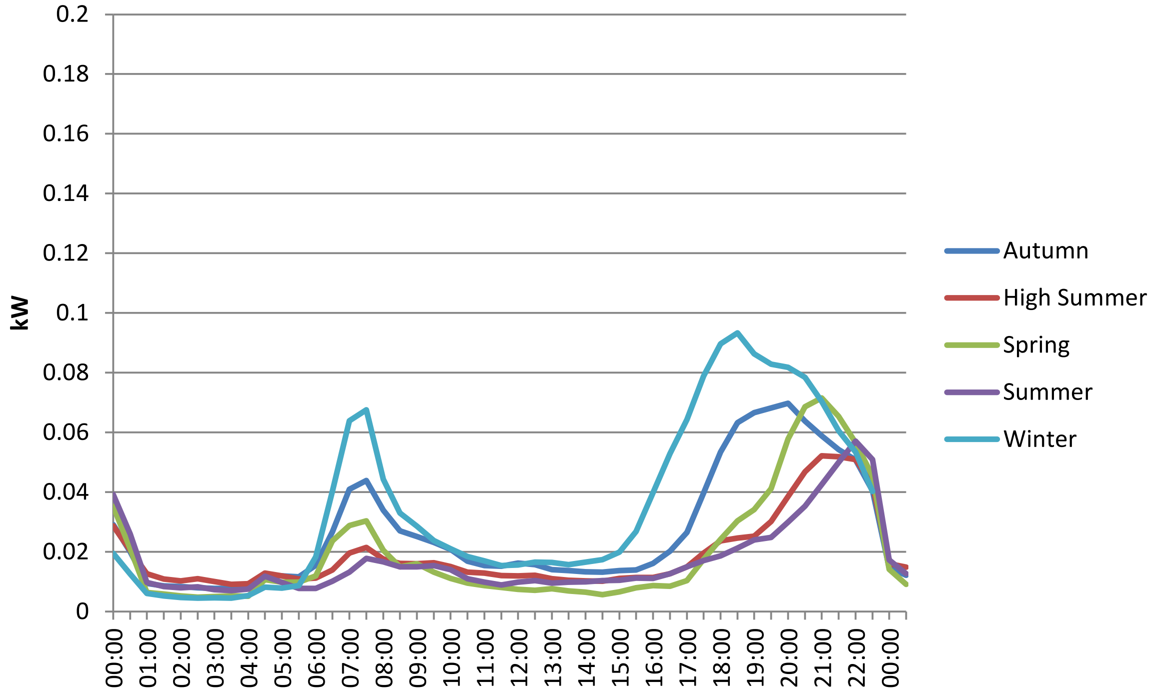
Figures 20-22 below show the average daily lighting consumption profile across the Elexon seasons for weekdays and for Saturday and Sunday.

Unsurprisingly, consumption is significantly larger in winter and autumn than during the summer; however this increase in demand seems only to affect the peaks. If anything, baseload lighting demand appears to be lower during the winter than in the summer months. Winter demand also ramps up earlier in the day as it gets dark earlier.

The morning peak during winter is markedly different between workdays and weekends. Whereas half-hourly average demand exceeds 30W on weekday mornings, it barely gets above 15W on the weekend. This is presumably the result of people opting to start their days later on the weekends during the dark winter months, and more variation in the timing of morning routines across households.

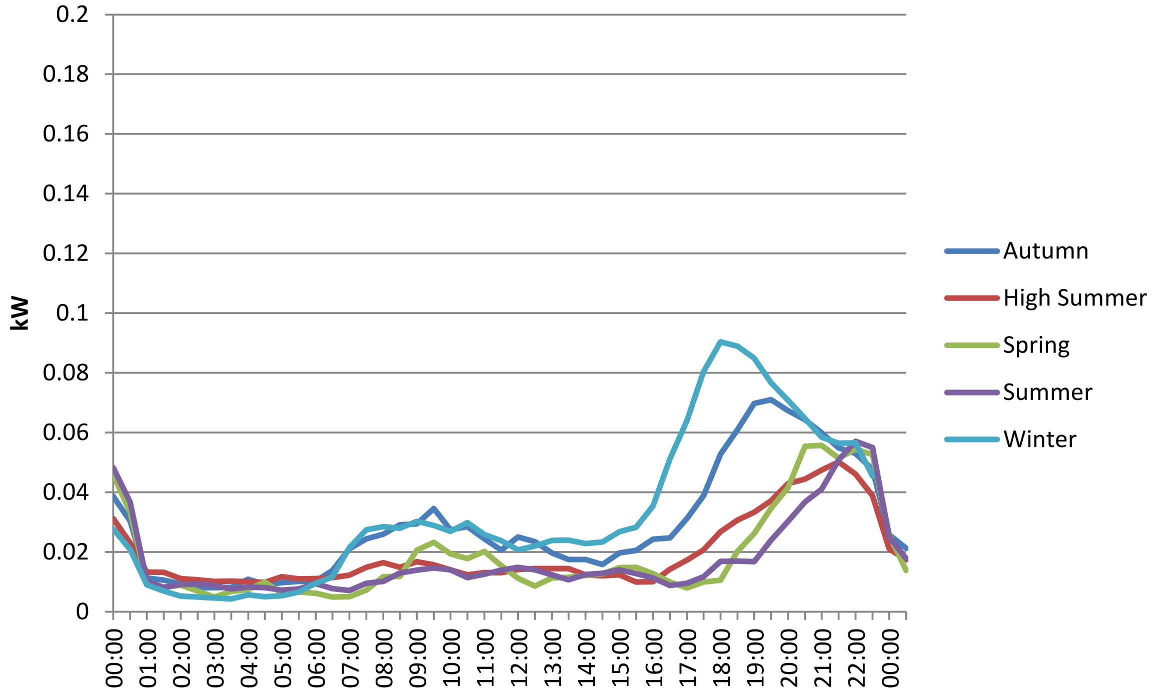
[21] DECC (2014) *Energy Consumption in the UK*, Table 3.12

Figure 20 Average weekday lighting appliance profiles by season



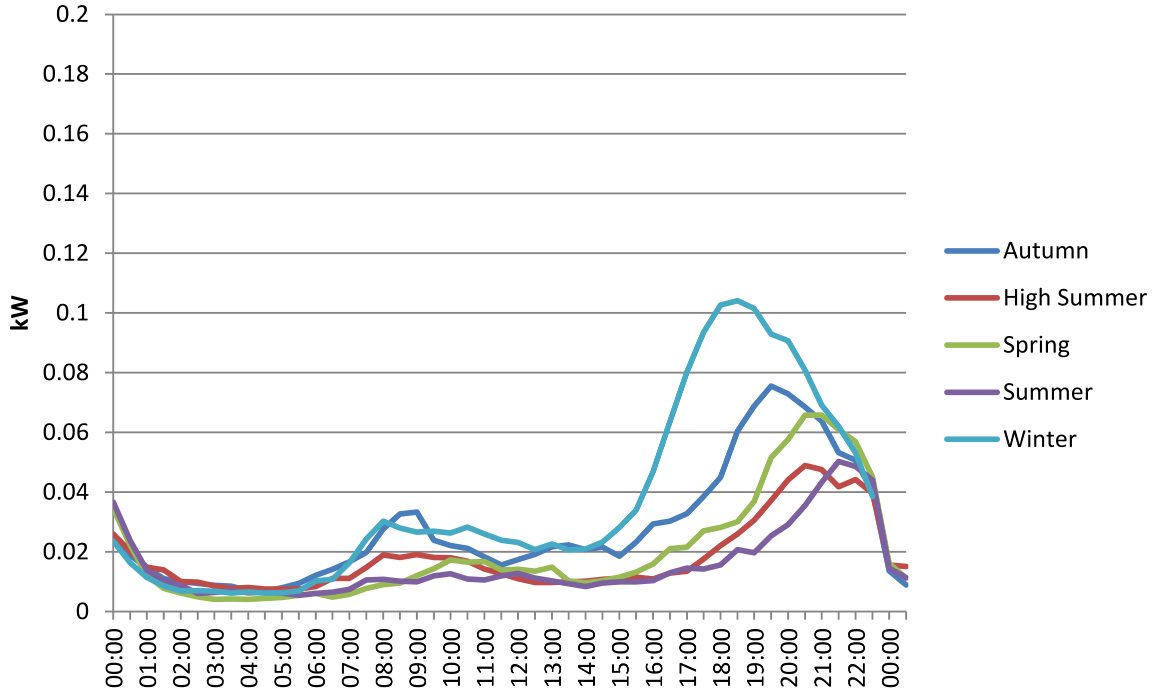
Source: Data collected for CLNR by Microwatt

Figure 21 Average Saturday lighting appliance profiles by season



Source: Data collected for CLNR by Microwatt

Figure 22 Average Sunday lighting appliance profiles by season



Source: Data collected for CLNR by Microwatt

In terms of DSR potential, lighting is considered non-switchable, as there is no scope to re-schedule or relocate its use. Forgoing the use of electric lighting is generally not an option outside of daylight hours, although there will be limited marginal cases around dusk and dawn. Similarly, non-electrical forms of lighting are generally impracticable. For all of these reasons, lighting has possibly the least scope for use in DSR of all the forms of consumption considered. However, as has already been seen in the period between the HES research and now, further efficiency improvements in lighting consumption could well prove far more effective in lowering peak demand in future. Understanding the remaining potential for increasing the efficiency of the remaining lighting stock, and providing ways to accelerate this, should be an avenue for further research.

3.1.5 Cooking

The peak day cooking profile shown in Figure 9 was relatively similar in magnitude to the profile produced under the HES study. Indeed, it would be unlikely that the cooker profile has been underestimated in the same way that profiles such as lighting and refrigeration have been, given that most households would only have one electric cooker, which will have been monitored as it is on a separate circuit.[22]

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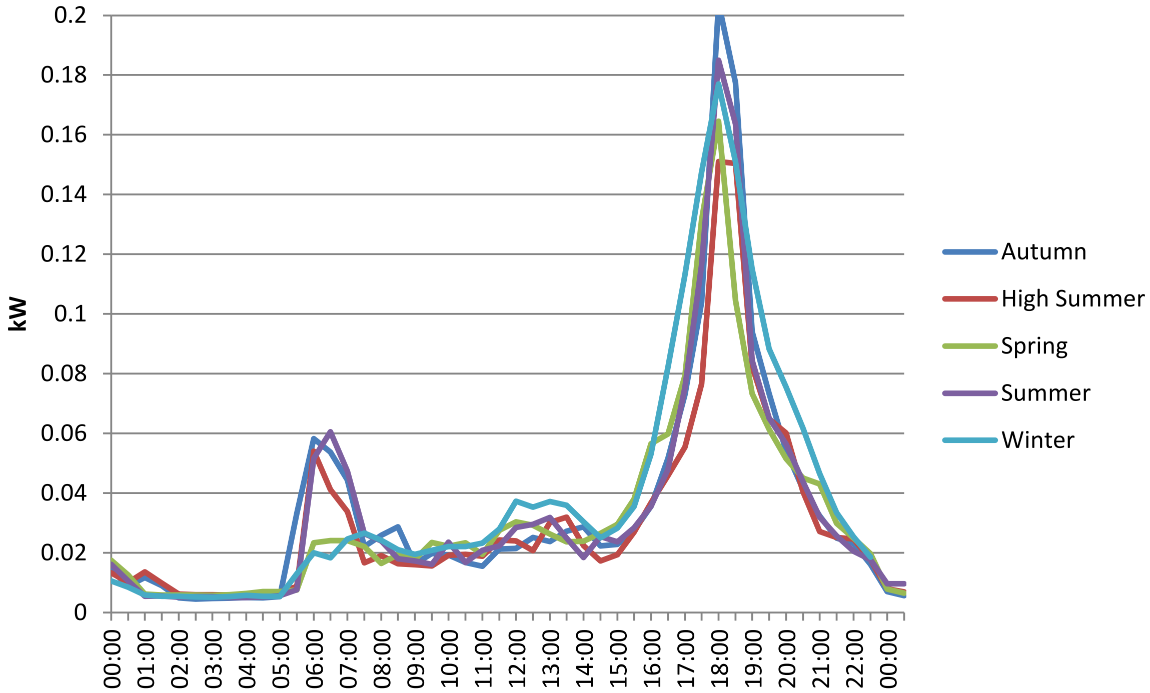
[22] Any cookers not on an identified circuit will have been excluded from the analysis altogether, rather than assumed to have a zero consumption.

The load profiles below display a substantial variation between weekdays and weekends. On weekdays, there is a substantial evening peak at approximately 18:00, with comparatively little activity throughout the rest of the day – this is consistent with a large proportion of the sampled households being at work during the day, and preparing dinner during the evening. Load profiles on Saturday have a similar evening peak, but also exhibit a lunchtime peak (just over half the size of the evening peak). The lunchtime peak is higher on a Sunday, while the evening peak moves back closer to 17:00. This may reflect cultural traditions, such as the preparation of a roast dinner.

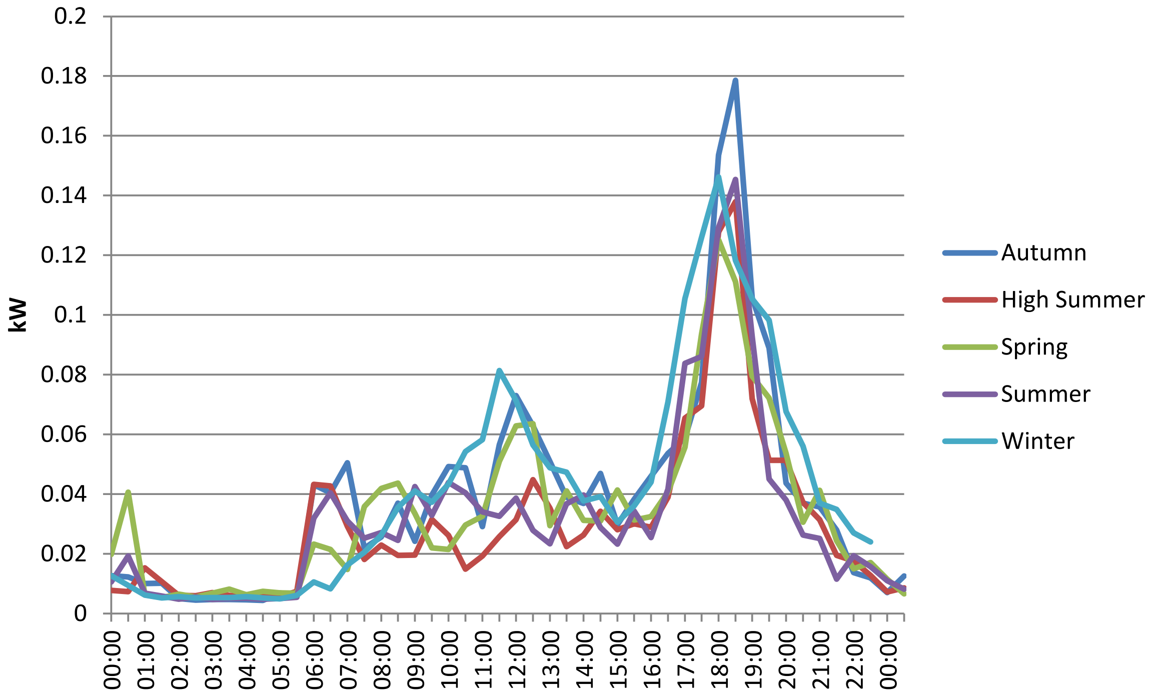
There is also a seasonal trend: in general, cooker loads are lower during warmer seasons.

Figure 23 Average weekday cooker profiles by season



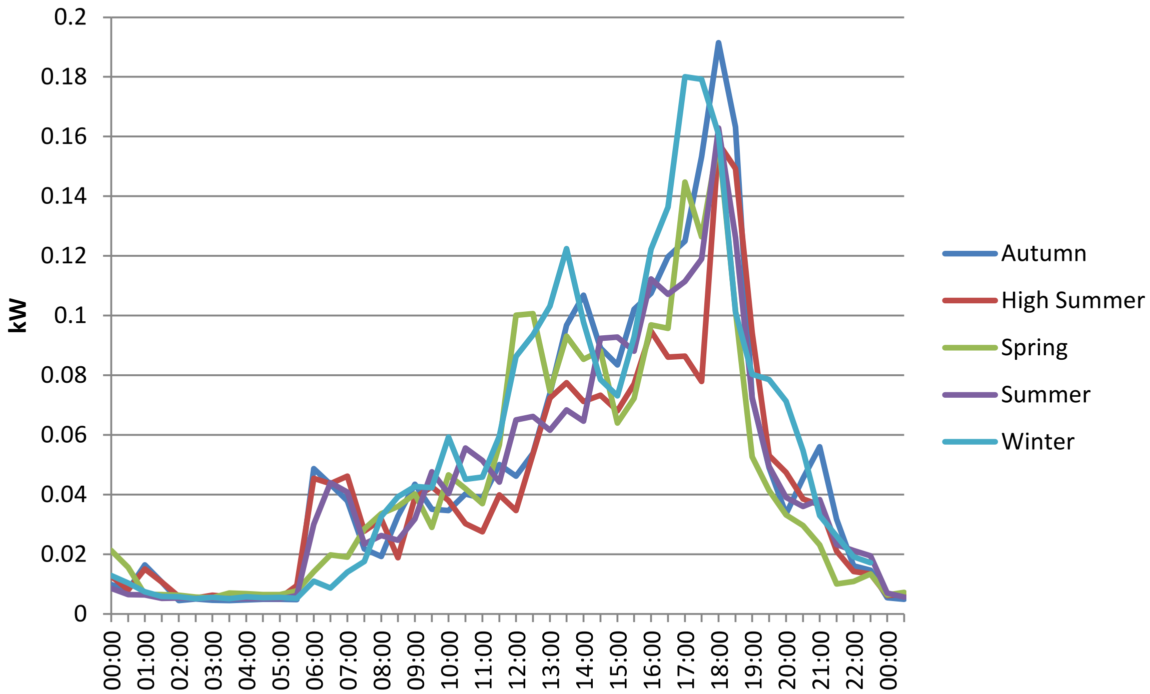
Source: Data collected for CLNR by Microwatt

Figure 24 Average Saturday cooker profiles by season



Source: Data collected for CLNR by Microwatt

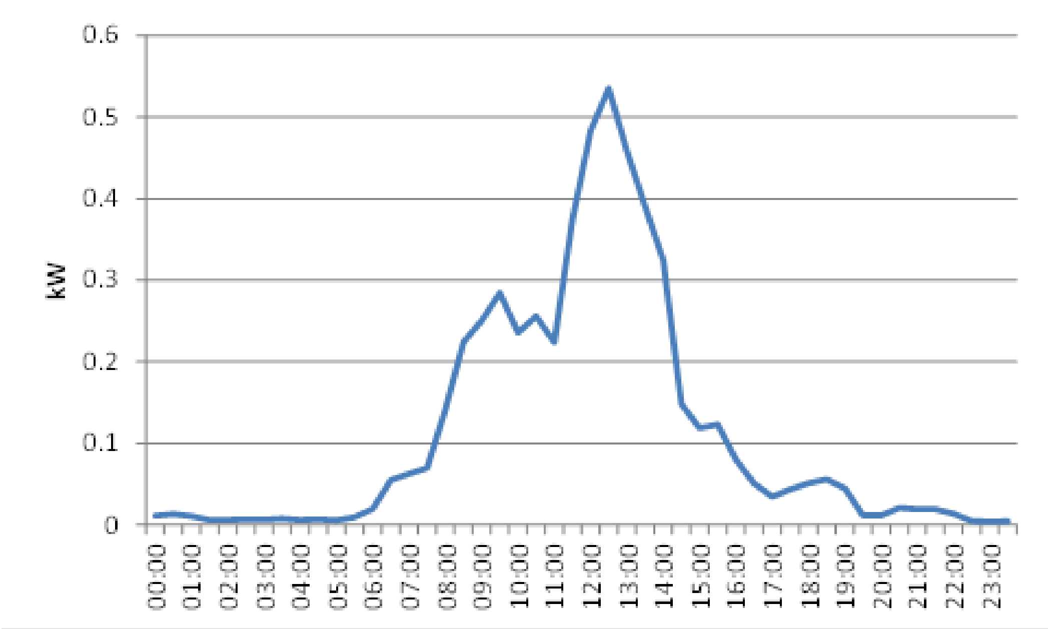
Figure 25 Average Sunday cooker profiles by season



Source: Data collected for CLNR by Microwatt

Although not shown in the seasonal averages, there can be significant deviations from these figures. The most notable is the extremely high cooker usage (peaking at an average of over 500W) on Christmas Day. This is shown below for 2013.

Figure 26 Average 25/12/2013 cooker profile



Source: Data collected for CLNR by Microwatt

Figures 27-29 below show the electricity consumption attributed to kitchen appliances, which covers both microwaves and kettles. It should be noted that installers were asked to place a smart socket on one microwave, but only placed sockets on other devices (notably kettles) at their discretion. **It is therefore likely that these figures underestimate total kitchen appliance consumption.**

The weekday profiles show three distinct consumption spikes, coinciding with meal times. These spikes are tightly focused, particularly the morning spike, with use of these devices constrained by households' working patterns. Interestingly, the morning spike is taller than the evening spike, which is spread over a longer period.

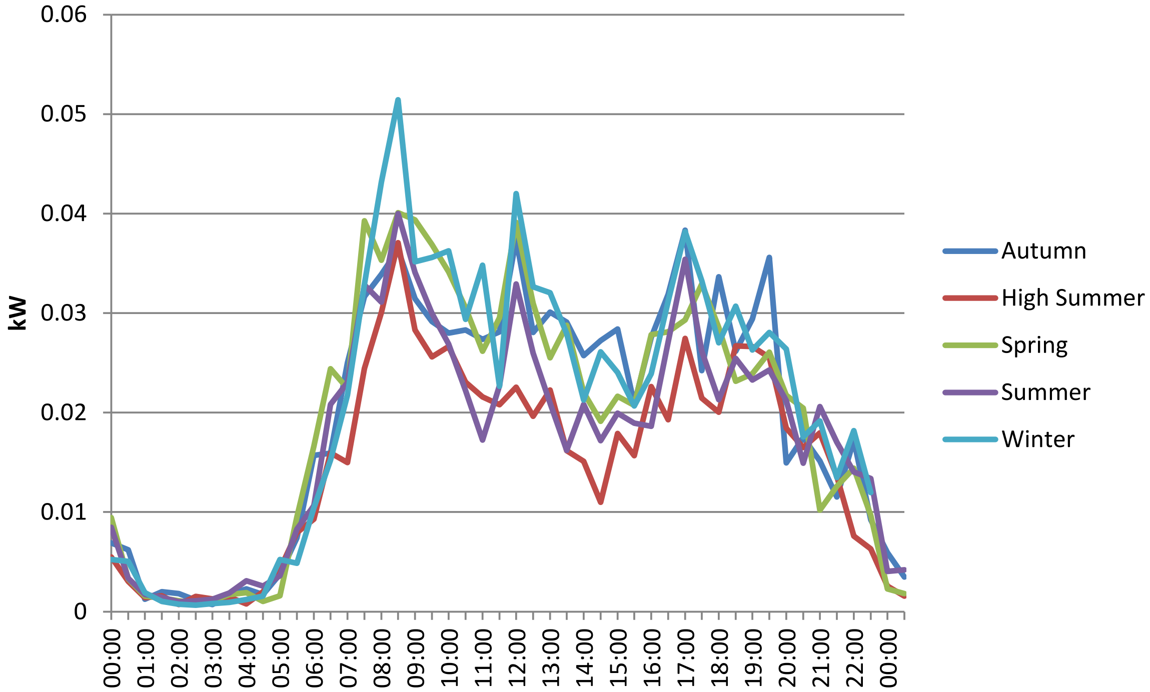
On the weekends, consumption from kitchen appliances is much more evenly spread throughout the day, although not significantly below the maximum consumption levels observed on the weekday. The profiles suggest that working patterns are constraining kitchen appliance during the day on workdays, presumably as people are absent from the home. Without the constraint of work, consumption is flatter but exhibits a pronounced pick-up in the morning.

The consumption profiles suggest limited seasonal variation across the use of kitchen appliances, although high summer use is notably lower, presumably as people consume less tea and coffee and/or fewer microwaved meals or because they are on vacation and therefore absent from the property.

Figure 27 Average weekday kitchen appliance profiles by season

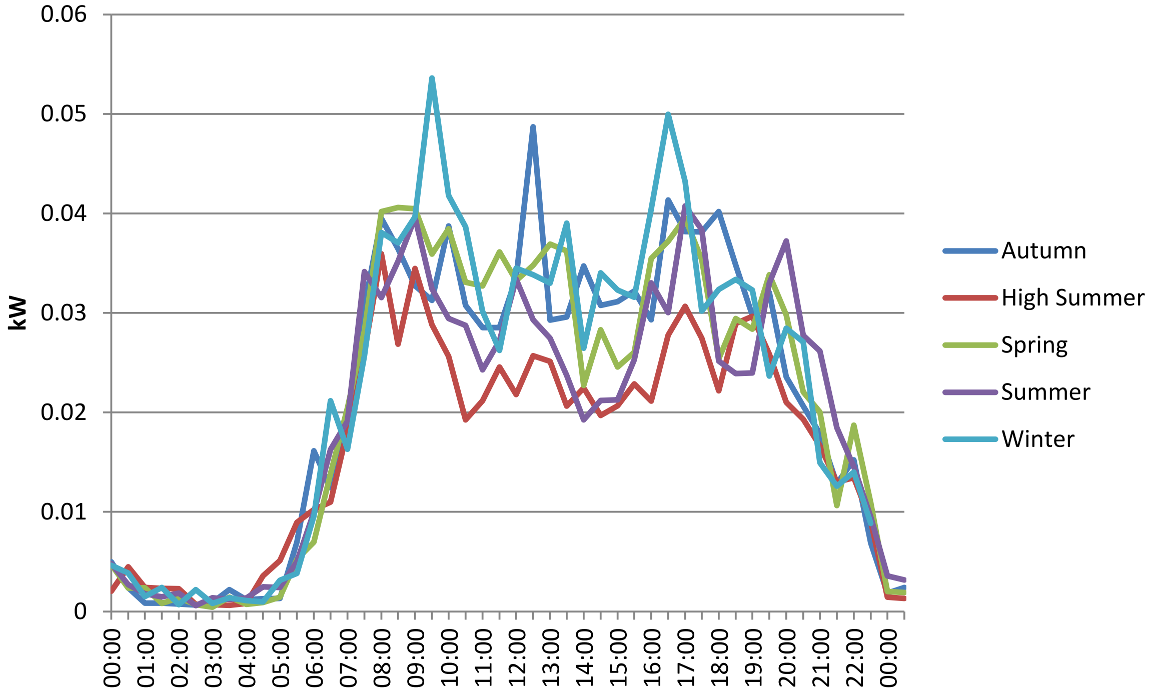
Source: Data collected for CLNR by Passiv

Figure 28 Average Saturday kitchen appliance profiles by season



Source: Data collected for CLNR by Passiv

Figure 29 Average Sunday kitchen appliance profiles by season



Source: Data collected for CLNR by Passiv

As already noted, cooker demand makes up 20.4% of peak demand within the test cell, implying that even relatively modest demand side response could be potentially useful. The importance of cooking is corroborated by the Government's HES study of 150 households, in which, cooking appliances also made up 20% of peak demand,[23] and by Defra's analysis of product ownership, which suggests that, in 2013, 64% of households had electric ovens, and 44% had electric hobs.[24]

However, willingness to alter cooking behaviour is typically low. Responses to an Electricity Policy Research Group Public Opinion survey in 2010 showed that less than 20% of people who cook between 7-9 PM would consider postponing their cooking until after 9PM under a hypothetical ToU tariff scenario. This was the lowest share of any of the categories of demand that were asked about, including watching the TV. Acceptance was also low for hypothetical proposals to limit cooking use to thirty minutes during peak hours.[25]

This conclusion is echoed by the social science work conducted as part of the CLNR, which indicates that mealtimes are relatively inflexible. In particular, family mealtimes may be firmly fixed by the

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[23] Element Energy, Further Analysis of Data from the Household Electricity Usage Study: Electricity Price Signals and Demand Response (2014), p.27
[24] Household Electricity Survey, Early Findings: Demand side management (2013), p.19
[25] Sustainability First, What demand side services could household customers offer?, pp.39-40

need to accommodate the daily schedules of multiple individuals. Similarly, some people have set daily rhythms that largely define the timing of meals.[26]

Although there is some technical flexibility to alter the electrical consumption associated with eating, for example by ordering take-away, or by using a microwave instead of an oven, we consider cooking demand to be 'non-switchable' given the low willingness of people to alter their dining behaviour.

3.1.6 Space cooling

Air conditioning is potentially a movable source of demand, since an air conditioning unit can potentially be turned off for short periods without a loss of comfort. For example, the LIPA Edge trial in the US (described in the CLNR report on TC14) successfully applied DSR to domestic air conditioners.

At present, UK uptake of domestic air conditioning is relatively low, greatly limiting the potential of this form of DSR, although some projections indicate that uptake may increase in the future.[27] Air conditioning is a considerably more prevalent technology within UK businesses, and the CLNR report on TC2b and TC10b provides some insights into the use of air conditioning within SMEs for DSR.

While one smart plug for this test cell was connected to an air conditioning unit, this is an insufficient amount of data to analyse here.

3.1.7 Space heating

Space heating is potentially a highly movable source of demand. Around 10% of GB households use electricity as the primary energy source for heat,[28] and 80% of these already have storage heaters, which have some flexibility in terms of when they are dispatched. Even for systems without a specific storage unit, the fabric of the building will store a substantial amount of heat (particularly if the building is well insulated), enabling heating to be turned off for a period without a loss of comfort. On the basis of current technology, and the likelihood of significant behaviour change, we consider space heating to be 'partially switchable'.

It should be noted that DSR potential is not limited to homes with electric primary heating. In addition to time-shifting heating loads, some homes may have the option of using alternative heating systems. Approximately 4.2 million homes in England use electric backup heating,[29] and collectively contribute significantly to total demand on cold days. On the coldest day in 2010, the 24 homes within the HES study that supplemented their gas or oil main heating system with electric

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[26] CLNR-L052: Durham University Social Science April 2014 Report, p.101

[27] For example, Pathan, A., Young, A. and Oreszczyn, T., 2008. UK Domestic Air Conditioning: A study of occupant use and energy efficiency. *Air Conditioning and the Low Carbon Cooling Challenge*. Windsor, UK, Network for Comfort and Energy Use in Buildings (NCEUB)

[28] Sustainability First, What demand side services could household customers offer?, pp.13-14.

[29] Household Electricity Survey, Powering the Nation 2: Electricity use in homes, and how to reduce it (2014), p.20

heating used an average of 570W for back-up heating during the peak hour, making up 84% of their electricity consumption at the time.[30] The potential to substitute between multiple heating systems represents a potential source of demand side flexibility within such households that is distinct from time-shifting noted above.

In future, greater heat pump penetration will alter the shape and size of the profile of electric heating demand. Improved efficiency will result in less electricity consumption overall and the profile of demand would be smoother, reflecting the operating characteristics of the pump. Should the pump be installed in conjunction with a sizeable thermal store, space heating profiles could even be used to help counterbalance increased demand by other appliances. The CLNR report on domestic direct control trials describes how such a heat pump and thermal store was successfully used in conjunction with direct control signals. The extent to which households' heating technology will change over the next decade represents one of the key uncertainties over future electricity consumption profiles.

3-3.5m households are on Economy 7 tariff[31] (with further households on Economy 10 tariffs). These households are examined in greater detail in TC10a(HW). There is an insufficient sample size of electric space heating in the TC2a data[32] to carry out a robust analysis of load profiles for houses with electric space heating on standard tariffs.

3.1.8 Refrigeration

Figure 13 shows that the peak weekday refrigeration load obtained under this study was approximately 30% below that obtained from the HES study. Possible reasons for this include:

- Fridges and freezers have increased in efficiency over time. Figure 30 shows how the fleet of UK domestic fridge-freezers has changed between 2010 and 2013. However, the improving efficiency in refrigeration appliances has been undermined by their growing size. The cold appliances purchased by the Household Electricity Study households between 1985 and 2011 suggest that fridges got two-fifths bigger on average over the period, while freezers and fridge-freezers grew by one fifth.
- Therefore the most likely explanation for the difference is that the smart plugs used in this study did not record every refrigeration device owned by the household. In most cases only one appliance (a fridge, freezer, or fridge/freezer) was monitored, whereas many households will have multiple such appliances. This was verified in a survey of TC2a consumers: out of the 31 respondents, the vast majority indicated that they had a refrigeration appliance that was not on the list of monitored appliances.[33]

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[30] Ibid., p.19

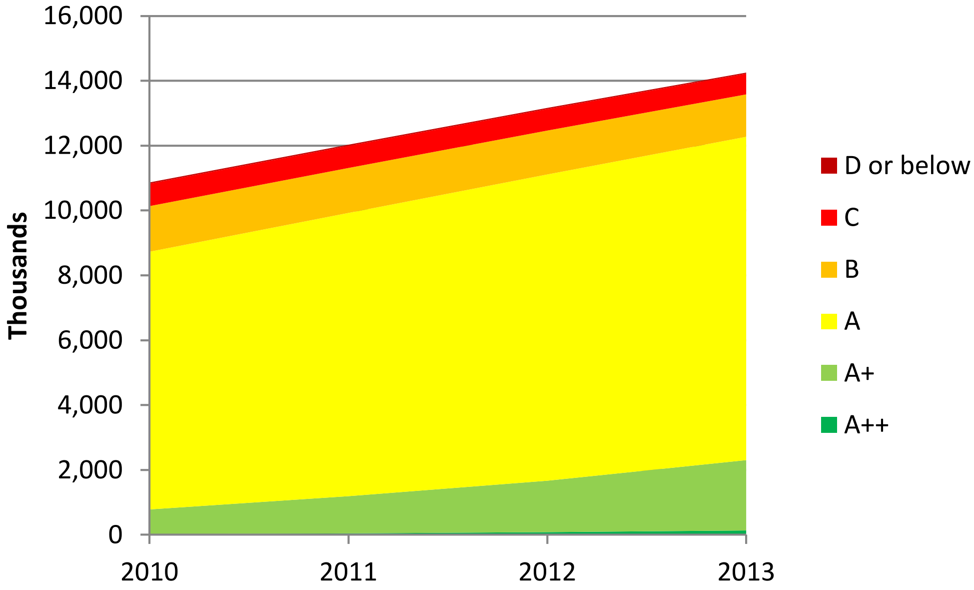
[31] Sustainability First, What demand side services could household customers offer?,pp.13-14.

[32] As noted above, participants who indicated in a survey that they used such heating during the winter did not have it monitored as part of the trial – this may be due to appliances being hidden from the view of installers.

[33] It is not possible to exactly quantify this, as there appear to be inconsistencies in the labelling used by the installers – e.g. installers calling an appliance a "fridge/freezer", when the consumer indicated there were discrete appliances.

The analysis below should be interpreted with this in mind.

Figure 30 Efficiency of UK installed base of fridge-freezers



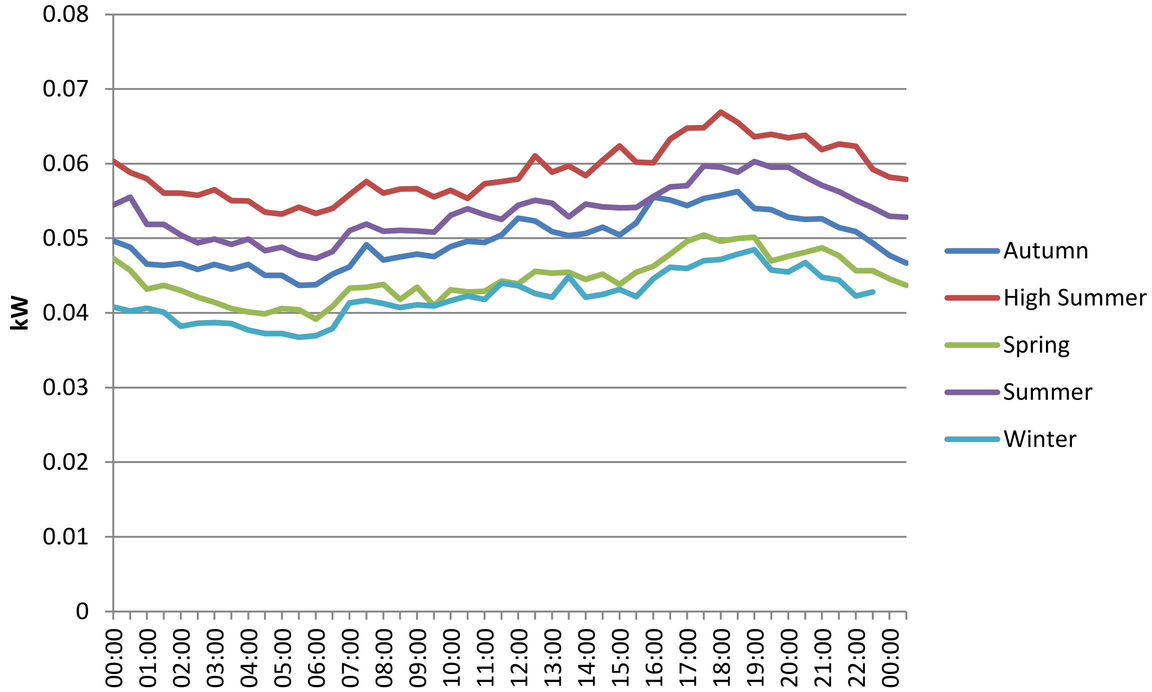
Source: DECC[34]

As can be seen in charts 31-33 below, refrigeration demand is remarkable in that it is extremely stable over the time frames shown. The frequent cycle of individual units results in a steady base load demand for power. There is a slight, but noticeable increase in the evening, probably associated with opening of the unit's door for dinner.

Although there is little variation among days, there is pronounced seasonal change, almost certainly driven by changes in the ambient temperature. As a result, refrigeration demand is consistently higher in the summer than in the winter or spring.

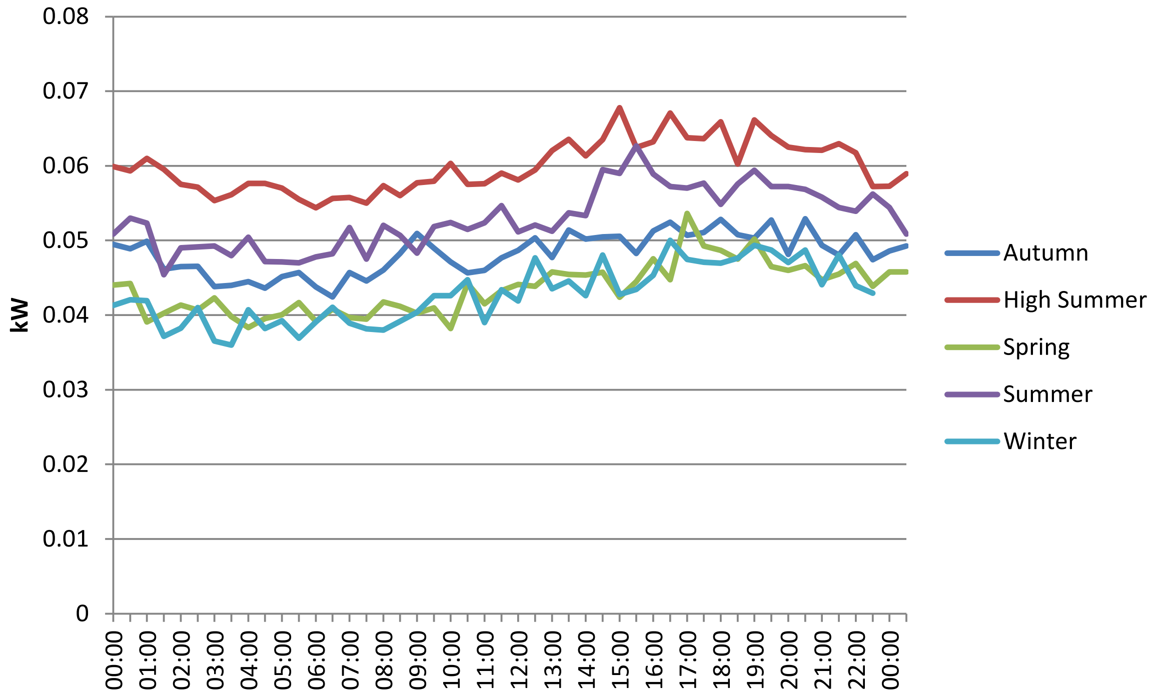
[34] DECC (2014) *Energy Consumption in the UK*, Table 3.12

Figure 31 Average weekday refrigeration profiles by season



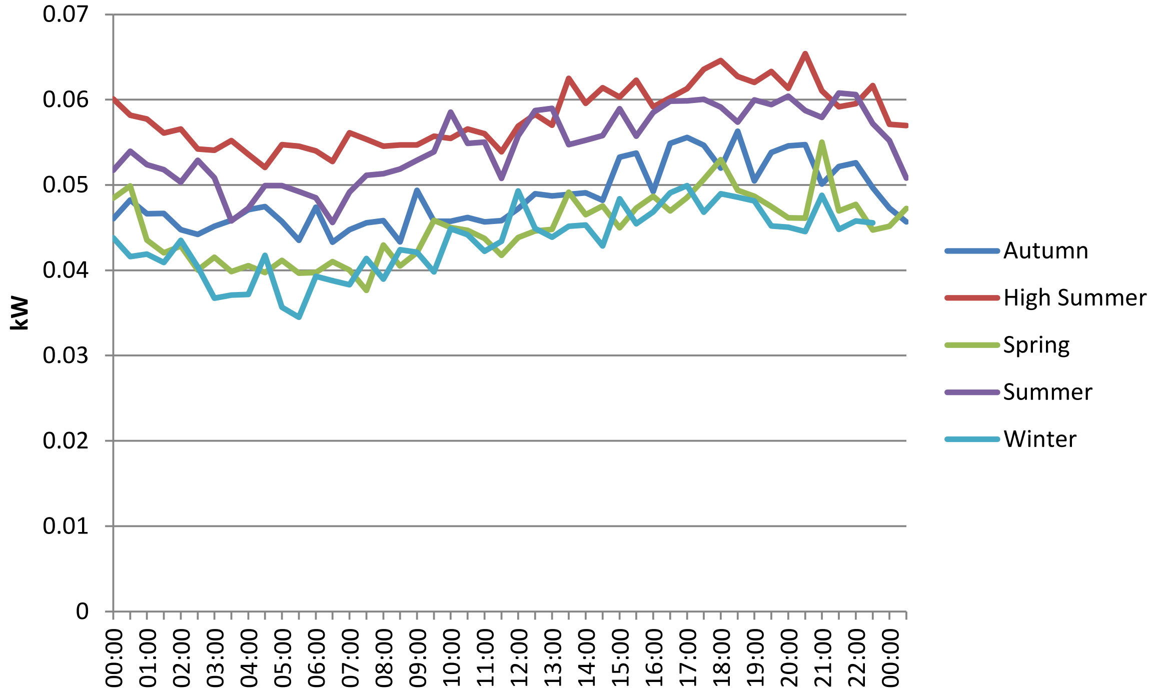
Source: Data collected for CLNR by Passiv

Figure 32 Average Saturday refrigeration profiles by season



Source: Data collected for CLNR by Passiv

Figure 33 Average Sunday refrigeration profiles by season



Source: Data collected for CLNR by Passiv

Although refrigeration loads are not especially high during peak hours, the potential for time-shifting the load means that that could be 'partially switchable'.

As noted in the CLNR social science work, households generally do not envision any scope for changes in refrigeration behaviour owing to the perceived risk to food safety. Consumption and food provisioning practices are generally predicated on the existence of electrically-powered cooling.[35] As a result, any demand side response from refrigeration appliances will be especially reliant on automation to provide households with confidence that any changes in consumption are kept within safe bounds.

There are, however, a number of technical challenges that limit refrigeration's ability to play a more significant role in demand response. The need to maintain a reasonably tight temperature range makes it unlikely that demand could be safely deferred for a whole hour. This is particularly true of fridges, where the scope for pre-cooling is limited by the need to avoid freezing and potentially damaging the fridge's contents. The scope for delay is similarly restricted by opening of the door, which often occurs during the evening peak owing to the timing of meals. And, given the relatively short time spans over which it is possible to safely defer demand, it will also be more challenging to stagger the return of refrigeration demand such that it does not result in sudden demand changes at the end of the formal peak.[36]

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[35] CLNR-L052: Durham University Social Science April 2014 Report, p.107

[36] Household Electricity Survey, Early Findings: Demand side management (2013), pp.20-21

Instead a more effective way of reducing peak demand may come from scrappage schemes that remove the old refrigeration unit from the home and replace it with one of lower consumption.

3.1.9 Water heating

Water heating is among the most switchable of consumption categories due to the prevalence of hot-water cylinders, as opposed to on-demand heating, particularly where water is heated electrically. The cylinders provide an existing thermal heat store and, provided the cylinder is suitably large and well insulated, allow hot water use to be separated from the associated electrical load.

Looking beyond households with electrically heated hot water however, there has been a trend decline in the number of hot water tanks as older gas boilers have been replaced by more efficient combination boilers. Between 1995 and 2009, the number of dwellings in England with hot water cylinders fell from 16.7m to 12.5m.[37] Should electric heating of hot water become more prevalent in future, we might expect the stock of cylinders to grow. However, space constraints may mean that the cylinders are too small to fully separate the timing of hot water use and demand for electricity, resulting in more peaky hot water profiles.

Many houses with electric water heating are likely to be on Economy 7 or Economy 10 tariffs. These households are examined in greater detail in TC10a(HW). There is an insufficient sample size of hot water heaters in the TC2a data to carry out a robust analysis of load profiles for houses with electric water heating on standard tariffs.

3.1.10 Washing appliances

Figure 15 showed that the average washing appliance load obtained in this study was similar to that obtained from the HES study. In general, we have less reason to believe that the power in these results is being understated. This is since the installation engineers were instructed to place a smart plug on one each of tumble dryers, washing machines, and dishwashers.[38] Given relatively few household will have multiple appliances of the same type, it is more likely that all washing appliances will have been measured – although it is still possible that some have been omitted, and the results below should be interpreted in this light.

Figures 34-36 below show that washing appliance use varies significantly between workdays and weekdays, as well as across seasons. Weekday demand is relatively low, rarely exceeding 10W, but

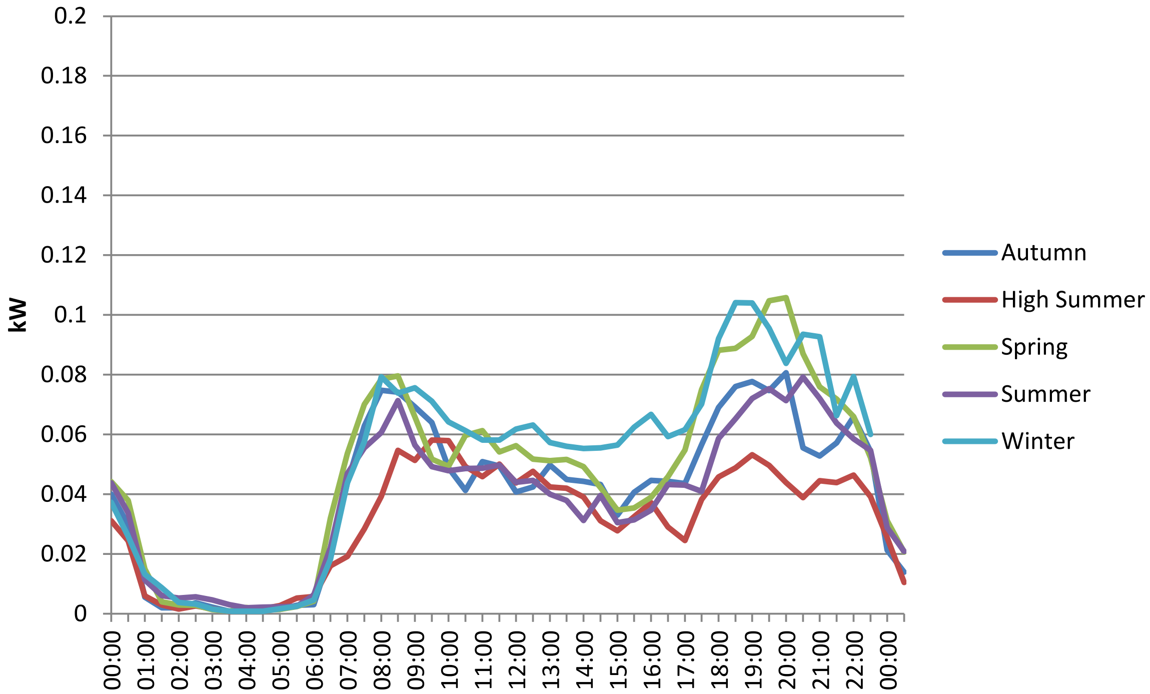
[37] Sustainability First, What demand side services could household customers offer?, p.20

[38] Despite the presence of separately labelled smart plugs, it has not been possible to split out these appliances for this analysis (as with kettles and microwaves). This is since it is known that some consumers switched smart plugs between appliances. To correct for this, we have applied filters that consider factors such as average power, maximum power, average time on per day, and average number of on/off switches per day, to determine when an appliance has likely been mislabelled. This is only possible for appliances with different load characteristics, and washing appliances (as with kettles and microwaves) are too similar to each other to separate out reliably.

does exhibit a marked post-work peak, presumably as people activate washing appliances after having returned home. As shown in Figure 15, this is more apparent than in the HES data, potentially as the sample of individuals for this study all worked. Weekend demand is significantly larger and more evenly spread across waking hours. This is consistent with households carrying out weekly laundry cycles on the weekend as alluded to in the social science work discussed below. Night-time demand is very low on all days, suggesting that few if any households use a time delay to run these appliances during the night.

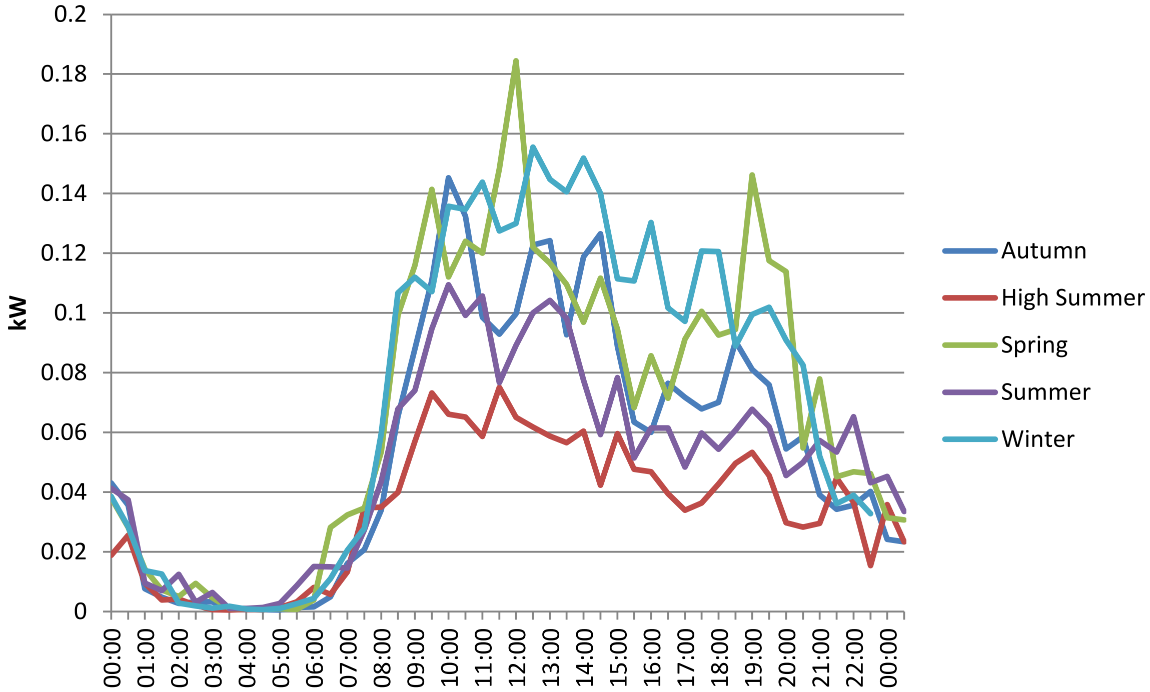
High summer demand is markedly lower than demand during the colder months. This probably reflects less use of drying machines and more line drying as people take advantage of the warm weather and seek to avoid inadvertently heating their homes beyond comfortable levels. It may also reflect that this period is likely to involve more people being away on holiday.

Figure 34 Average weekday washing appliance profiles by season



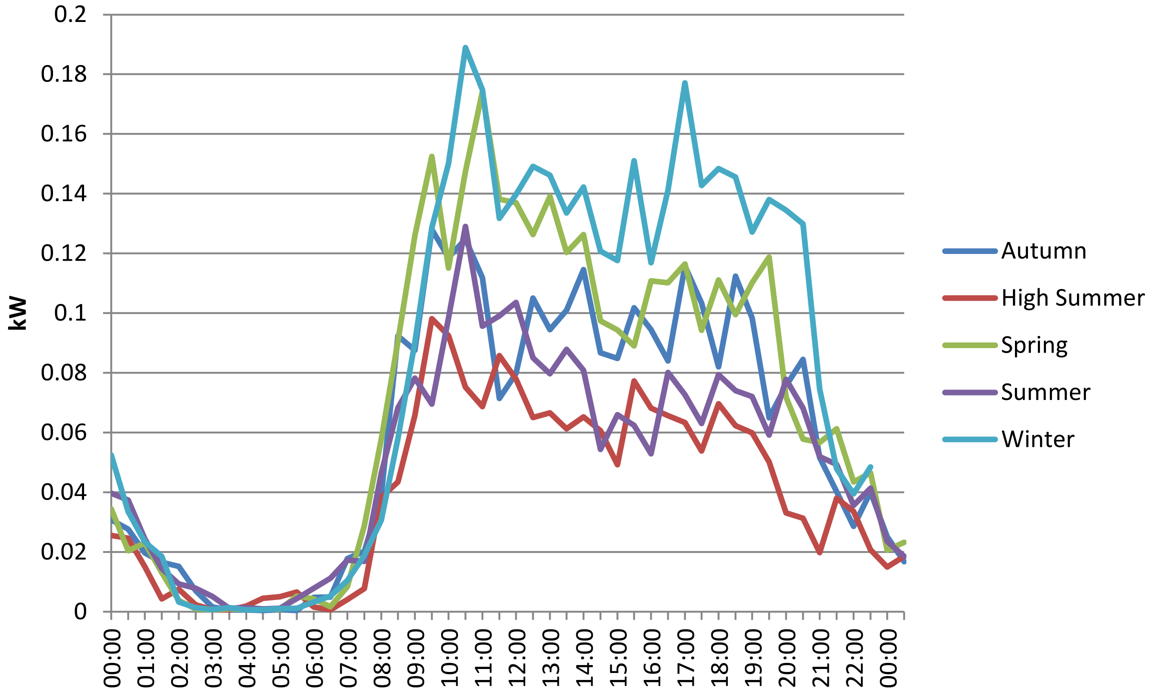
Source: Data collected for CLNR by Passiv

Figure 35 Average Saturday washing appliance profiles by season



Source: Data collected for CLNR by Passiv

Figure 36 Average Sunday washing appliance profiles by season



Source: Data collected for CLNR by Passiv

Work using the Household Electricity Survey data suggests that if households switched their use of washing machines, tumble driers and dishwashers from the evening peak to non-peak periods, peak load could be reduced by 8%.[39] As shown above, a substantial amount of washing activity occurs during the evening peak, making this an attractive target for DSR.

Several studies note that washing appliances are among the most flexible of sources of demand. The 2010 Electricity Policy Research Group Public (EPRG) opinion survey showed that more than half of respondents currently using dishwashers and 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. The equivalent figure for dishwashers was just 18%. There was also some willingness among respondents to give up the option of running these devices between 7-9pm, with 17% willing to have their washing appliances pre-set such that they would only operate after 9pm.[40]

The CLNR social science work corroborates these findings, suggesting that households will want chores completed within a limited time frame, but exhibit some flexibility as to the precise timing. Typically, dishes will need to be washed within 24 hours, but the timing won't be tightly fixed. The timing of laundry was typically even more flexible, needing to happen within a week, but with scope to change timing across the week based on convenience or the weather.[41]

Although not necessary to shift the timing of loads, this willingness to be flexible is generally not complimented by equipment design. Only 31% of UK households have a start delay function on their washing machine, and about 32% of dishwashers have a similar feature. These figures are low relative to some other European countries, for example France, where the equivalent figures are around 40% and more than 50% respectively.[42] The lack of such features may partly be explained by the fact that loads can be retimed manually, as well as the limited incentive to retime loads to begin while people are asleep or absent. Were future incentives to make such features more useful, one might well expect them to become more prevalent.

A more significant barrier therefore is likely to be safety concerns associated with running these appliances unattended. In particular, public safety organisations like the Chief Fire Officers Association advise against running these appliances while asleep or absent, given the risk of fire.[43] Given that electricity consumption is lowest during the night when people are asleep, there is a fundamental tension between shifting washing loads to coincide with baseload, and ensuring that washing appliance fires do not occur when everyone is asleep.

The CLNR test cell 11aWWG consisted of a trial of direct control for "smart" washing machines, and is documented in the report on the CLNR domestic direct control trials. This trial shows that such DSR of washing machines can be effective.

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[39] Household Electricity Survey, Early Findings: Demand side management (2013), p.2
[40] Ibid., p.39
[41] CLNR-L052: Durham University Social Science April 2014 Report, pp.102-3.
[42] Sustainability First, What demand side services could household customers offer?, pp.26-27
[43] Household Electricity Survey, Powering the Nation 2: Electricity use in homes, and how to reduce it (2014), p.20

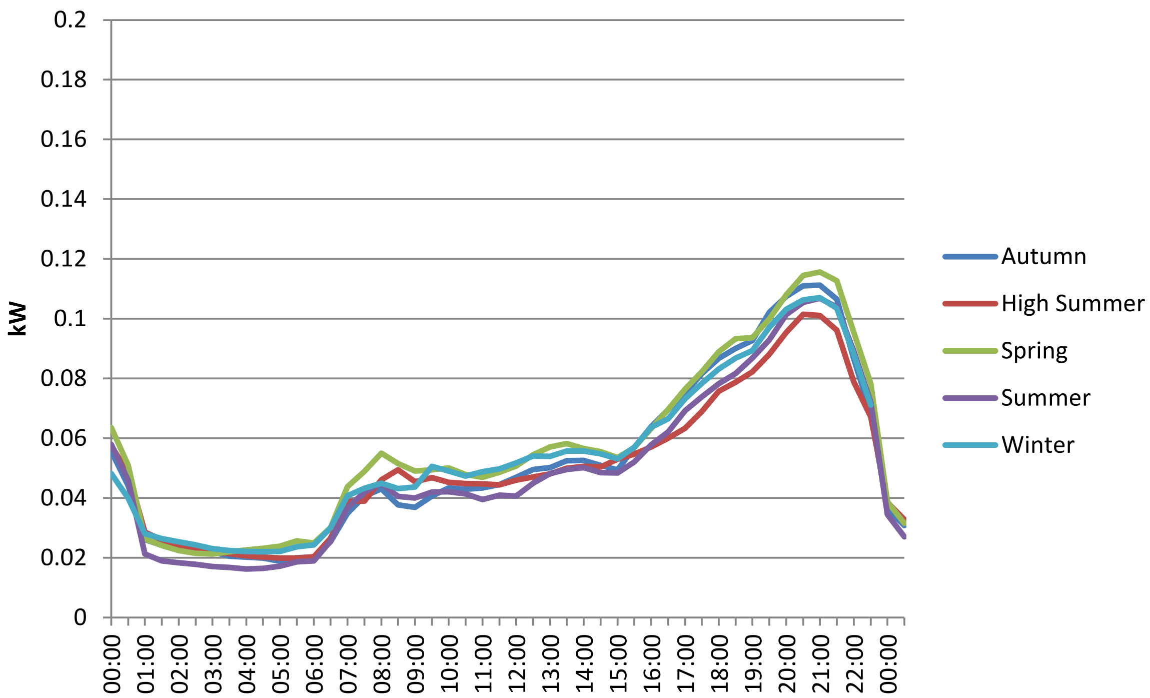
3.1.11 Consumer electronics

The comparison of the CLNR data with the HES study in Figure 17 showed peak weekday figures approximately 30% below those reported in HES. A likely reason for this is that many households will contain a variety of consumer electronic equipment, but CLNR installers only had seven smart plugs and were therefore likely to omit some items. To test this, TC2a customers were asked how many TVs they had in their house. The 31 respondents reported an average of 2.7 TVs per house. Even if some of these are in use for shorter periods, this does suggest that the methodology used for this trial will tend to systematically understate consumer electrics load. **The results below should be interpreted in this light.**

Consumption from consumer electronics, as shown in Figures 37-39 below, shows a very pronounced evening peak, which builds through the afternoon and falls away sharply in the late evening as people go to sleep. This evening peak is especially pronounced on weekdays, presumably because work patterns prevent earlier use, but is also clearly visible on weekends, when the peak builds more gradually throughout the day.

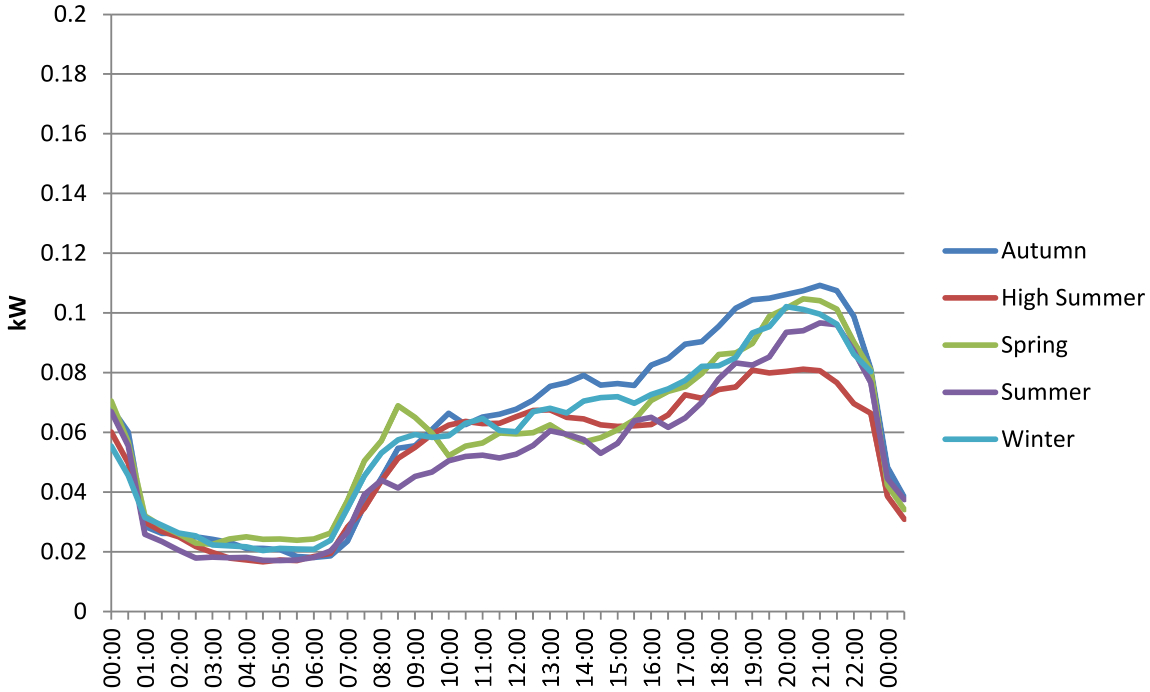
The profiles also exhibit some seasonal variation, with markedly lower peak consumption in the high summer, and to a lesser extent the summer. This may be the result of people spending more of their evenings outdoors during the summer months, and consequently reducing their use of home electronics.

Figure 37 Average weekday consumer electronics profiles by season



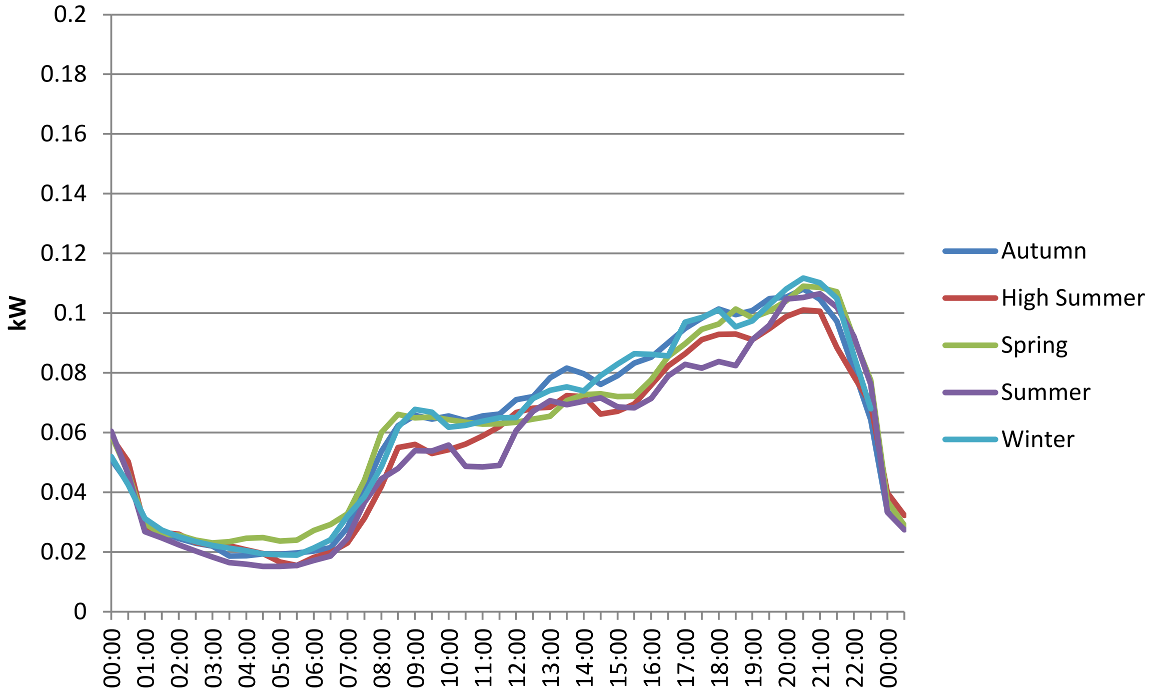
Source: Data collected for CLNR by Passiv

Figure 38 Average Saturday consumer electronics profiles by season



Source: Data collected for CLNR by Passiv

Figure 39 Average Sunday consumer electronics profiles by season



Source: Data collected for CLNR by Passiv

The CLNR social science work shows that the number of consumer electronics used in the home is growing, but that many of these new devices, such as laptops, smartphones, and tablets, are inherently flexible.

Seventy three of the one hundred and thirty-one CLNR customer households visited (55%) actively spoke about their use of new entertainment and internet devices, and there was evidence that IT was allowing the home to become a place of work, creating a need for additional equipment, including printers, monitors, and desktop PCs, in addition to mobile devices. [44]

These findings suggest that consumer electronics will become an increasingly important component of household electricity consumption. If these new devices are designed to be portable, and so have in-built batteries, they may also bring new options for households to shift their load.

The DSR potential of consumer electronics depends both on consumers' willingness to defer consumption and on the presence of a battery, which allows the time of use to differ from the timing of the electrical load.[45] We consider these two factors below as they relate to TV usage, a key component of consumer electronics load.

TVs cannot be charged. However, there is evidence that some of the viewing that would previously have been carried out on a TV is moving to devices such as smartphones and tablets with inbuilt batteries. A recent report by Ofcom[46] indicates that TV and video content will increasingly be consumed on such devices. If these devices would typically be charged during peak periods but could be moved, this would be a possible source of DSR. However, Ofcom also notes that these new forms of viewing are likely to supplement, not replace conventional linear broadcast TV platforms, which "…are likely to continue to represent the majority of consumer viewing for the foreseeable future."[47]

TVs are also subject to relatively inflexible patterns of use, suggesting low DSR potential. In the 2010 EPRG opinion survey, less than 20% of those people who watched TV between 7-9pm were willing to postpone their TV use until after 9pm.[48] If this reluctance is due at least partly to the broadcast schedule, the increased prevalence of on-demand TV services could feasibly increase flexibility over time. However, household consumption will ultimately still be constrained by its members' regular routines: even if consumers are capable of postponing their desired viewing times, it seems unlikely that this would be an attractive proposition.

In summary, technological developments mean that the amount of *potentially* shiftable consumer electronics load could increase in the future. Such DSR would be highly valuable, given the concentration of consumer electronics load during the evening peak. However, further trials would be needed to confirm whether this type of DSR could ever be acceptable to consumers.

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[44] CLNR-L052: Durham University Social Science April 2014 Report, pp.5, 66.
[45] Either of these factors in isolation can be sufficient for DSR – it is not necessary to have both consumer flexibility and storage potential.
[46] Ofcom (2014) *Infrastructure Report 2014* p108 onwards
[47] Ibit
[48] 2010 EPRG Public Opinion Survey: Policy Preferences and Energy Saving Measures, EPRG Working Paper 1122, p.38-39.

3.2 Test cells 10a(HW) and 11a(SH)

In this section we analyse the data collected from test cells 10a(HW) and 11a(SH) to help meet the following learning objectives.

First, we have determined the average heating power profiles for an Economy 7/10 customer in this dataset. This helps shed light on consumer responsiveness to the tariff profile: If customers systematically align their heating usage to the E7/E10 off-peak periods, it shows that this basic form of static time-of-use tariff is effective. This section also briefly considers the results of the study into hot water tank temperatures.

Second, we have looked at whether consumers may go against these consumption patterns during times of high network stress. If customers ignore the price signals provided by time of use tariffs under such conditions, this could undermine the feasibility of this form of time of use tariff for network purposes.

3.2.1 Average consumption profiles Economy 7/10 customers

The tariff structures and heating systems examined as part of these test cells reflect the current experience of a significant number of the British homes, and could be used in a larger number of homes in future. There are around five million homes in Great Britain with Economy 7 meters, and three to three-and-a-half million of these are currently on an Economy 7 time-of-use tariff.[49] The various national housing surveys suggest that around two million British homes, around 8%, use storage heaters, and the vast majority of these will be on time of use tariffs to benefit from the storage functionality of their heating system.[50] Around two-and-a-half million homes in Great Britain heat their water exclusively using electricity.[51]

Electric space and water heating is expected to make up a growing share of domestic heating needs as efforts to decarbonise the economy require fossil fuel alternatives, and their associated emissions, to be squeezed out. Although the electrification of domestic heating is expected to result predominantly from adoption of heat pumps, there will be instances where these are not viable. Consequently, resistive heaters, like hot water and storage heaters examined in this report are still likely to help meet domestic heating demand as part of a decarbonised domestic heating system.

As explained in section 2.2.2, only a very small sample of data is available for these test cells. Average winter power profiles are available for a maximum of:

- 4 immersion heaters in TC10a(HW);
- 8 immersion heaters in TC11a(SH); and
- 13 homes with storage heaters in TC11a(SH).[52]

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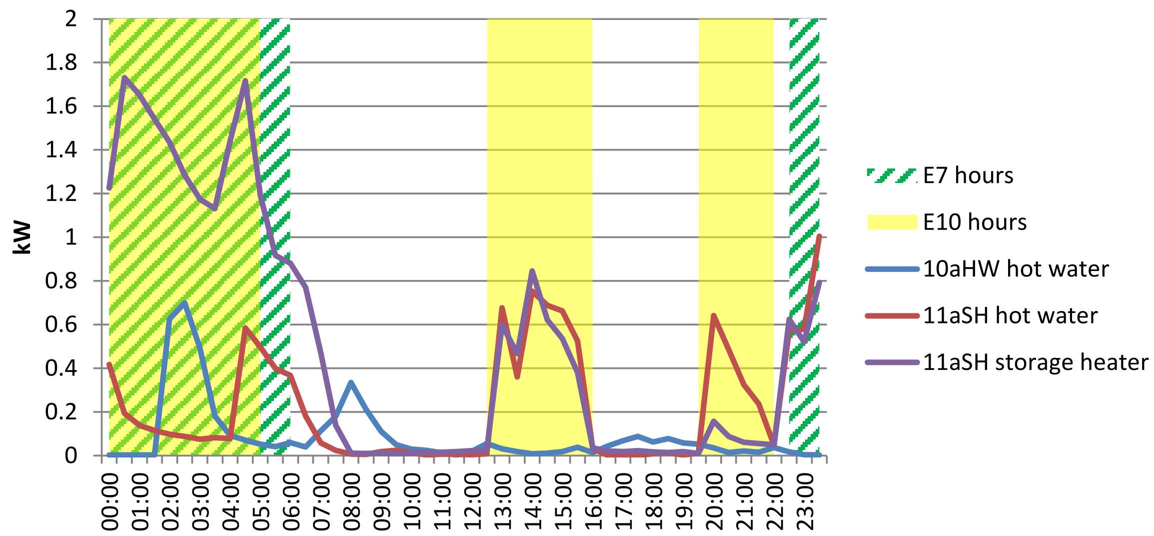
[49] Sustainability First, What demand side services could household customers offer?, pp.13-14.
[50] Sustainability First, What demand side services could household customers offer?, pp.13-14.
[51] *Ibid*., p.20.
[52] Data may not be present for all storage heaters within these homes.

As a result, **the average profiles presented here will not be representative of the UK E7/E10 population as a whole**. Instead, they should be interpreted as case studies, which can provide insights into the types of behaviour that individual consumers may exhibit.

Figure 40 shows the average mean power across consumers monitored during winter weekdays (where winter is defined as per the EXEXON definition – i.e. the period during which GMT rather than BST is in effect).

Although specific data is not held on which tariff each specific customer was on, the average power consumption profiles broadly match the profile of a typical E7 or E10 tariff, as indicated by the green and yellow shaded regions.[53] This is consistent with customers on these tariffs responding to the price incentives they provide. However, there is one possible exception to this: The average 10a(HW) immersion heater power profile displays a peak at 8am, continuing until 9am. Although 8am is within E7 times for some regions, the continued use of power at 9am may be consistent with at least one customer using hot water "on demand" for their morning routine – although, as described below, data for Saturday and Sunday indicate that this may not be the case.

Figure 40 Average winter weekday power profiles for TC10a(HW) and TC11a(SH)



Source: Data collected for CLNR by Passiv

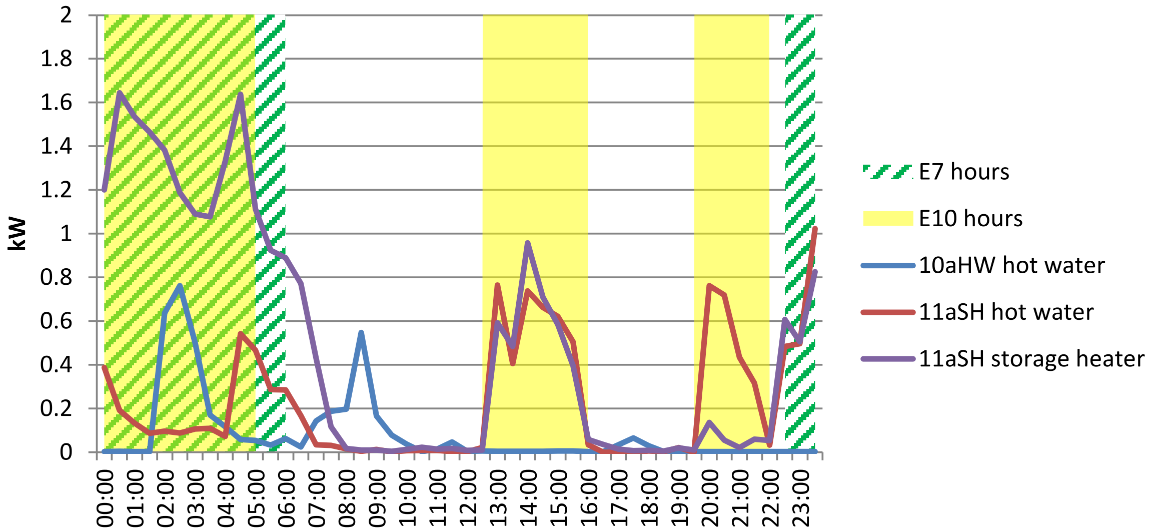
As shown in Figure 41 and Figure 42, these figures show almost no variation on Saturdays or Sundays. This suggests that the usage of these appliances is being driven by automated timers

[53] These relate to off-peak periods within Northern Powergrid's regions. Winter E7 off-peak hours within Northern Powergrid's region are from 23:00 to 06:00, while E10 hours are 00:00 to 05:00, 13:00 to 16:00, and 20:00 to 22:00. However, as these customers were recruited nationally, they may be on differing tariffs. For example, E7 off-peak hours can end as late as 08:30 in the south of Scotland.

rather than varying daily routines (by contrast, the whole-house load profiles in Figure 6, Figure 7, and Figure 8 clearly show a delayed morning peak at the weekend, consistent with consumers tending to wake up later on these days).

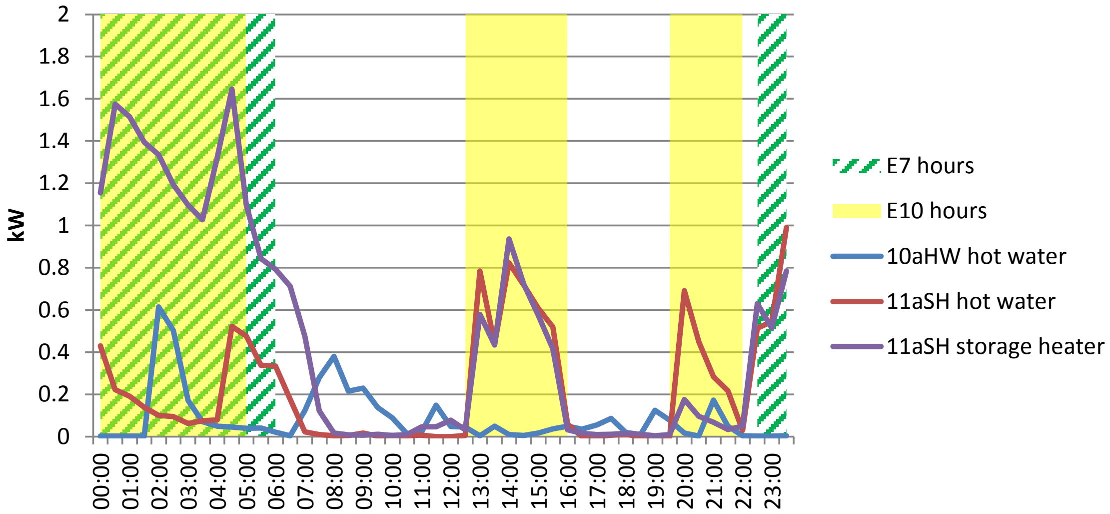
Since the 10a(HW) 8am peak continued to occur at the same time over the weekend, it's possible that this reflects automatic timers rather than "on-demand" water heating. Nevertheless, with a sample size of four, it is impossible to make any definitive conclusions: it is also possible that some of the individuals within the study have a morning routine that is constant across weekdays and weekends.

Figure 41 Average winter Saturday power profiles for TC10a(HW) and TC11a(SH)



Source: Data collected for CLNR by Passiv

Figure 42 Average winter Sunday power profiles for TC10a(HW) and TC11a(SH)



Source: Data collected for CLNR by Passiv

The project also collected data on the average temperature of hot water tanks within TC10a(HW). The average winter weekday figure is shown in Figure 43. There was no substantial variation in this between weekdays, Saturdays and Sundays.

The subset of customers for which this temperature data is available is different to the set for which power data is available. As such, these temperature profiles cannot be directly compared to the power profiles seen above. The average temperature profiles show a substantial increase in temperature (i.e. use of the immersion heater) between 7am and 8am, and a smaller increase from around 5pm. The former result would be consistent with customers choosing to use their immersion heaters right at the end of the off-peak period (as described above, the shaded regions only relate to off-peak periods within Northern Powergrid's region, therefore 7am may be an off-peak period for some customers). A gradual increase in temperature is visible within the highlighted afternoon E10 off-peak window, but not overnight. This is consistent with the hot water heater elements not running during the night-time off-peak windows. However, we do not have definitive data to state exactly what kind of tariff each consumer was on. Given this and the very small sample size, this data should be interpreted with caution.

Figure 43 Average weekday winter hot water tank temperature for TC10a(HW)

Source: Data collected for CLNR by Passiv

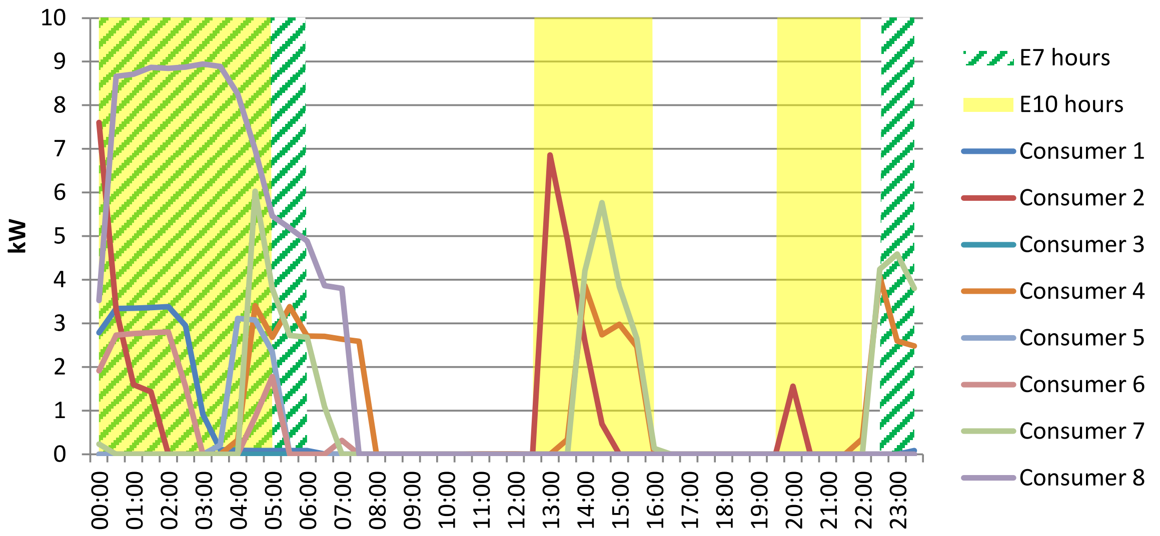
3.2.2 Customer responses to exceptional weather or demand conditions

In the preceding section, it was shown that the customers for which data is available typically followed the incentives set by an E7 or E10 tariff. However, there may be exceptional circumstances (for example, extreme temperatures) which are sufficient to outweigh the price signal and cause customers to run their heating appliances during the E7 or E10 peak periods. Such behaviour would have adverse consequences for using static time of use tariffs to avert network constraints.

To explore this issue, we have focussed on storage heater demand in TC11a(SH). This is since it is intuitively more likely that space heating needs could increase during a period of cold weather, while the effect on hot water requirements is more ambiguous.

Figure 44 shows storage heater power demand for the customers with available data on Thursday January 30th 2014. Based on a dataset of average UK temperatures, this was the coldest day for which we have data available.[54] It can be seen that storage heater power usage is still almost entirely concentrated within the E7 and E10 periods (the customers with power consumption between 6am and 8am may be in regions where the off-peak period extends further than the highlighted periods, which only apply to Northern Powergrid's region). It therefore appears that, at least for these customers, the cold weather did not require running storage heaters outside the set hours.

Figure 44 Storage heater profiles for 30/01/2014

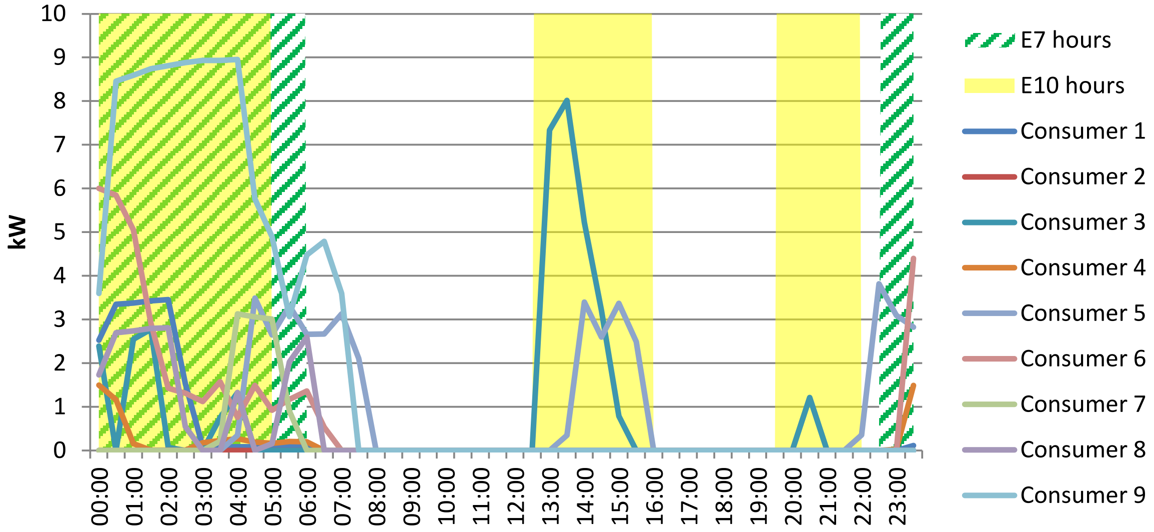


Source: Data collected for CLNR by Passiv

We also carried out this analysis for Wednesday February 5th, identified as the day of peak demand within the whole house dataset for TC2a (the average temperature on this day was much higher, at 6.8 degrees Celsius). The resulting profiles are shown in Figure 45 (note that the customer numbers are arbitrary and will not match those in the previous figure). Once again, storage heater usage is highly concentrated within the E7 and E10 off-peak periods.

[54] Based on data from the European Climate Assessment and Dataset data (http://www.ecad.eu/) – the specific weather station is in Central England. This day had an average temperature of 2 degrees, the coldest reported for 2014 (at least until October where the dataset ends). However, it is worth noting that 2014 was a relatively warm year. For example, the lowest temperature recorded in 2013 was -3.9 degrees, on the 16th January.

Figure 45 Storage heater profiles for 05/02/2014



Source: Data collected for CLNR by Passiv

4 Conclusions

The TC2a analysis considered the DSR potential of a number of different types of domestic load, based both on monitored power consumption and more qualitative information.

For some categories of consumption (for example, **lighting**, **cookers**, and **kitchen appliances**), it appears that there is very little DSR potential. However, efficiency improvements to these devices could still deliver savings to networks – sections 3.1.4 and 3.1.8 show the substantial increases in efficiency for lighting and refrigeration in recent years. This also helps illustrate the rapidity with which technological developments can date existing load profiles.

Fridges and freezers and **wet appliances** are two forms of load which are intuitively more capable of DSR (indeed, wet appliance DSR was successfully trialled as part of TC11aWWG). As shown in Figure 4, these appliances use a substantial amount of energy. However their load profiles differ, with fridges and freezers perhaps offering less potential for DSR at the evening peak than wet appliances.[55] However, as with lighting, there is still the potential for refrigeration scrappage schemes to reduce consumption of these appliances at peak times.

Consumer electronics, is the remaining category of appliances for which data has been presented. This represents the greatest element of total energy usage, *and* is highly correlated with peak demand. This would therefore be an ideal target for DSR, if technically and socially possible. Technological developments (in particular, the increased usage of battery-powered devices to watch content on-demand) might help facilitate this in the future, and this is an area where further research could be useful.

Potentially the most striking aspect of the TC2a results is the amount of **load which is unaccounted for by the appliances listed above**. Some of this will be due to limitations in the number of appliances which could be monitored within each household. However, it is likely that a portion of this is accounted for by the seasonal use of secondary electric heating. Further research could be undertaken to understand how and why consumers use such heaters, and whether they could be replaced with a technology more amenable to load-shifting, or with a lower overall consumption.

Domestic heating in general is recognised as a fertile area for DSR – particularly given the increased electrification of heat projected to meet carbon targets. In TC10a(HW) and TC11a(SH) we have attempted to understand to what extend consumers respond to existing DSR incentives around heat (E7 and E10 tariffs). The analysis has been based on an extremely small sample: the results therefore cannot be extrapolated to the UK as a whole, and there is scope for much further research in this area. Nonetheless, for the customers within the dataset, we can state the following.

- The customers tend to use power for hot water and heating within time periods that are consistent with E7 or E10 off-peak periods. The customers therefore appear to be broadly following the incentives provided by the tariff.

[55] While potentially less appropriate for a DNO seeking to reduce evening peaks, such profiles would be consistent with other requirements for DSR – e.g. a supplier seeking to reduce energy or imbalance payments.

- Even on the coldest day of the year and on the day of highest network demand (as measured by TC2a), consumers typically kept their storage heating power within the E7 and E10 off-peak periods. This suggests that a static time-of-use tariff is potentially enough to ensure power reductions occur reliably. However, it should be noted that 2014 was a relatively warm year – it is possible that more extreme conditions would lead to greater deviations from the tariff.

These results suggest that existing forms of DSR (static time-of-use tariffs) work when coupled to a technology (storage heaters or hot water tanks) which offers a substantial amount of energy storage and timers which consumers are content to leave running regularly. However, it is harder to generalise the results to other technologies (such as heat pumps) or forms of DSR (such as dynamic time-of-use tariffs or direct control). The CLNR project has also trialled direct control of both heat pumps and smart washing machines.[56]

[56] CLNR-L096: Insight Report Domestic Direct Control

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