elementenergy

Further Analysis of Data from the Household Electricity Usage Study:

Electricity Price Signals and Demand Response

Final report for

Department of Energy and Climate Change

and

Department for the Environment Food and Rural Affairs

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1 Executive Summary

1.1 Objective

Between 2010 and 2011, the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust (EST) conducted the Household Electricity Usage Study (HEUS), which examined the electricity usage behaviour of 250 owner-occupier households in England. In previous reports we have examined the technical potential that exists within these households for shifting electricity usage out of the evening peak demand period. The technical load shifting potentials calculated in these reports were based on the appliances that were used by each of the 250 HEUS households during the evening peak, how much electricity they consumed during that period, and the ease of shifting those loads without significantly impacting household lifestyles.

In this report, we use additional data from a number of UK domestic time-of-use tariff (ToUT) trials (conducted between 2003 and 2014) to examine how much actual household demand is shifted out of the evening peak period for various ToUT structures relative to the technical potentials determined in the previous reports. We also explore the key findings from the ToUT trials that relate to UK household electricity usage and the insights these provide for UK domestic demand response to ToUT price signals.

1.2 Findings and Recommendations

- The majority of domestic UK time-of-use tariffs trials surveyed have been successful in shifting household electricity consumption away from the peak periods. At the same time, most trials witnessed a concurrent reduction in total electricity demand. We have shown how these changes would impact on the HEUS load profiles for each of the UK ToUT trials. We have also used the HEUS data to scale-up the ToUT results to the national level, revealing UK domestic peak shift potentials of up to 2.7GW during the 6-7pm evening peak period (see Figure 1).

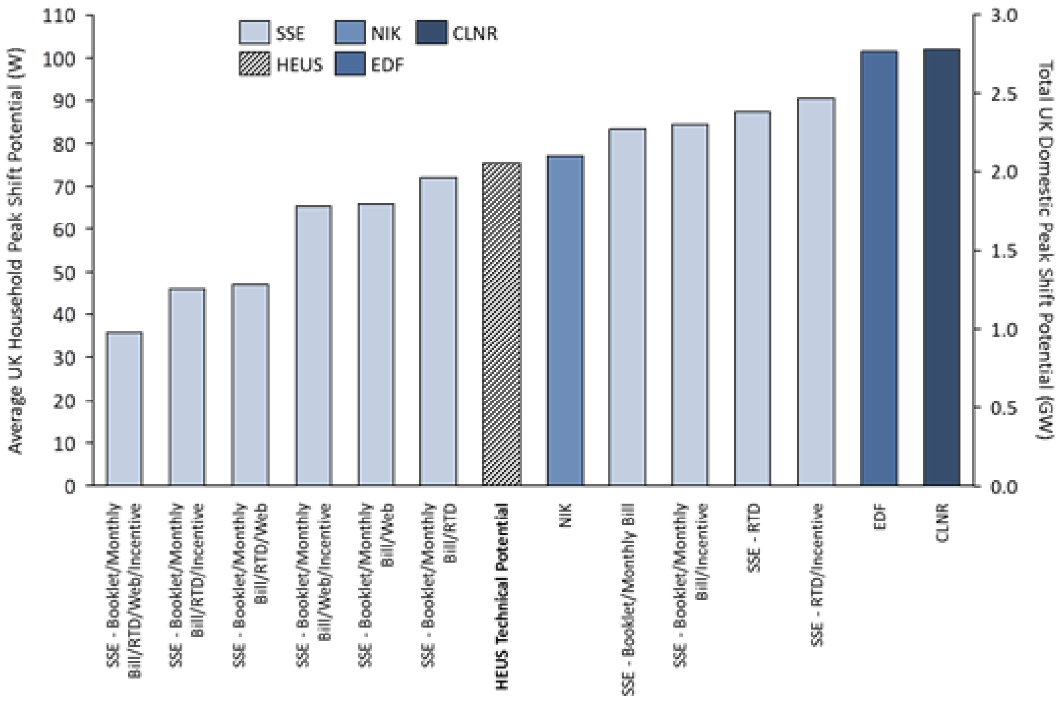

Figure 1: UK peak shift potential implied by each of the four UK ToUT trials along with the appliance based estimate of technical peak shifting potential from the HEUS.

- Comparing the actual amount of demand shifted in the four ToUT trials to the maximum technical potentials determined from HEUS appliance usage data reveals that, in most cases, UK households engage well with ToUTs and are even willing to shift loads that involve some element of lifestyle change. That is to say, in addition to washing, drying and water heating loads (which can be shifted with minimal lifestyle impact via timers etc.) there is emerging evidence that some cooking consumption and other loads closely linked to lifestyle patterns are being shifted in response to ToUTs[1]. This is a promising finding pointing to high levels of efficacy for this type of domestic demand side response intervention in the UK.

  Recommendation: Gather further data on the types of lifestyle changes, particularly around cooking appliances (which contribute approximately 20% of evening peak loads), that UK consumers are willing to adopt under modern ToUT interventions.

[1] To date, this evidence is limited to qualitative data only, based on participant interviews from the Customer-Led Network Revolution trial: Durham University, "Customer-Led Network Revolution: Social Science Interim Report 2", for Ofgem.

- The Energy Demand Research Project SSE trials revealed that the number of interventions implemented in conjunction with a ToUT (e.g. energy advice booklets, monthly consumption reports, real-time displays, online consumption data and complementary financial incentives) can have a strong bearing on the level of demand shifting achieved. Cases in which more than two interventions were implemented, in addition to the ToUT, were observed to negatively impact peak shifting – possibly due to an interference effect in which consumers were overwhelmed by an abundance of information. In the SSE trials, the optimal effect was observed for two interventions in support of the ToUT.

  Recommendation: Limit the number of demand shifting interventions implemented alongside ToUTs (e.g. energy advice booklets, monthly consumption reports, real-time displays, online consumption data and complementary financial incentives) to around two per household.

- The Energy Demand Research Project EDF trials showed that the peak demand shifting effect of a ToUT was, on average, negligible for households with more than three occupants (aged 16-64). This may be due to demand shifting constraints specific to large households, or perhaps it is linked to a "dilution" of actively participating household members – i.e. the household member(s) who signed up to the trial.

  Recommendation: Further research is required into the drivers behind poor ToUT response in high occupancy households and to better understand the load shifting constraints specific to these households.

- Both the SSE and EDF Energy Demand Research Project trials revealed a generally superior demand shifting response to ToUTs on weekends relative to weekdays. While it is not possible to determine the causes of this difference from the data available, it is conceivable that many households have an increased degree of demand flexibility on weekends when daytime constraints from work and school are typically lower.

  Recommendation: Further studies into the drivers behind the higher levels of demand shifting observed on weekends relative to weekdays could provide valuable insights for the optimisation of domestic demand side response interventions in the UK.

- The Customer-Led Network Revolution trial results exhibit, in addition to a strong shift in peak demand, a distinct demand peak at the beginning of the night-time tariff rate following the evening high-tariff period. This behaviour points to a significant challenge for network operators and policy makers identified in our earlier HEUS report, *Correlation of Consumption with Low Carbon Technologies*[2], which relates to large new loads from emerging low carbon technologies (such as heat pumps and electric vehicles). As these technologies are adopted in greater volumes by UK households and automated to preferentially operate during low-tariff periods, the peak observed in the CLNR trials at the beginning of low-tariff periods will be greatly accentuated. This is a problem related to consumption diversity and can be addressed as such – i.e. by staggering time-of-use tariff periods at the local and national level or implementing a range of demand side response mechanisms.

  Recommendation: Further research the effect of locally staggering time-of-use tariff bandings on network loads and consumption diversity. Similarly, further testing is required to understand the effectiveness of applying multiple demand side response interventions to maintain consumption diversity while reducing peak time loads in the UK domestic sector.

- The Northern Ireland Keypad Meters study, which encompassed a high proportion of low-income households (since it was a pre-paid meter trial), showed the highest demand shifting response of all the trials examined in this report. This raises important questions regarding the role of demographic factors in demand response, particularly in the context of the fuel poor.

  Recommendation: Further studies are required to explore the significance of household demographics (particularly household income and fuel poverty) in responsiveness to load shifting interventions such as time-of-use tariffs.

- Significant variation exists in the structure and level of detail associated with the published outputs from each of the four UK time-of-use tariff trials examined in this report. In building up a detailed view of UK demand side response behaviour, it is important to ensure that future studies extract the learning and best practices of these valuable past studies while also adhering to a minimum level

[2] Element Energy (2014), "Further Analysis of Data from the Household Electricity Usage Study: Correlation of Consumption with Low Carbon Technologies" for DECC and Defra.

of reporting detail to assist future research. For example, publication of average diurnal profiles (as in the CLNR trial reports) reveals important information for future studies that cannot be extracted in their absence. It is encouraging to see that recent trials are now adopting this standard reporting format alongside the high-level summary tables typically used in earlier reports.

Recommendation: To extract maximum value from future time-of-use tariff studies, we recommend the following:

- Monitor pre-trial and in-trial consumption data for the same households, ensuring statistically significant sample sizes where possible.
- Monitor and report key demographic characteristics (anonymised appropriately) such as the number of household occupants, household income and geodemographic segment (e.g. Experian Mosaic group, Acorn segment or Output Area Classification).
- Publish full diurnal profiles to reveal the distribution of shifted loads.
- Make the full dataset from each trial available, resolved to the level of each participating household (suitably anonymised).
- Monitor appliance level data (as in the HEUS), where possible, to better reveal the types of appliance demand that contribute most significantly to UK domestic demand shifting under modern time-of-use tariff schemes. Where this level of monitoring is not possible, even minimal information on which of the monitored households make use of primary electric heating would be beneficial.

2 Introduction

Between 2010 and 2011, the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust (EST) conducted the Household Electricity Usage Study (HEUS), which examined the electricity usage behaviour of 250 owner-occupier households in England. In previous reports we have examined the technical potential that exists within these households for shifting electricity usage out of the evening peak demand period[3,4]. The technical load shifting potentials calculated in these reports were based on the appliances that were used by each of the 250 HEUS households during the evening peak, how much electricity they consumed during that period, and the ease of shifting those loads without significantly impacting household lifestyles.

In this report, we use additional data from a number of UK domestic time-of-use tariff (ToUT) trials (conducted between 2003 and 2014) to examine how much actual household demand is shifted out of the evening peak period for various ToUT structures relative to the technical potentials determined in the previous reports. In each of the ToUT trials examined, demand side response (DSR) – i.e. load shifting out of peak demand periods – was encouraged by the implementation of significantly higher electricity tariffs during fixed periods in which domestic demand is typically high (e.g. early evening), offset by reduced tariff periods when domestic demand is generally lower (e.g. overnight).

The objective of this project is to apply the demand-shifting findings of UK ToUT trials to the Household Electricity Usage Study (HEUS) and explore how real UK households respond to ToUTs relative to their technical ability to move appliance loads.

Specifically, this report provides:

- A comparison of the results from four UK ToUT trials, highlighting the effectiveness of each trial in shifting peak demand and reducing overall consumption.
- Insight into factors that influence the demand shift achieved by the ToUTs, including household occupancy and complementary intervention steps implemented alongside the ToUT.

[3] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Consumer Archetypes" for DECC and Defra.
[4] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability" for DECC and Defra.

- Application of the ToUT trial results to the HEUS dataset showing how the average HEUS profile would be expected to change under each of the four ToUT trials.
- A comparison of the UK ToUT response to the technical potential identified from the HEUS appliance and household data.

In this report, four studies are analysed:

1. Energy Demand Research Project: SSE Trials[5] (abbreviated to SSE)
2. Energy Demand Research Project: EDF Trials[5] (abbreviated to EDF)
3. Customer-Led Network Revolution[6] (abbreviated to CLNR)
4. Northern Ireland Keypad Meters[7] (abbreviated to NIK)

The trials in these studies tested time-of-use tariffs ToUT with fixed low, medium and high price periods throughout the day (see Figure 4 for more details). Some studies further differentiated by offering different tariff rates for weekdays and weekends. All studies complemented the ToUT with information booklets and a basic real-time display of the electricity used with the objective of creating awareness among the household occupants of the trial structure, their electricity use and the economic benefits of lowering their peak time electricity use.

[5] AECOM (2011), "Energy Demand Research Project: Final Analysis"
[6] Customer-Led Network Revolution (2013), "Initial Time of use Tariff Trial Analysis"
[7] Sustainability First (2007), "Smart Meters in Great Britain – The Next Steps? Paper 6: Case Studies - Northern Ireland keypad meters case study"

3 Methodology and Assumptions

Across the four UK ToUT trials used in this report, there was considerable variability in the way the trial results were reported. In several instances, the change in peak demand in absolute units was not published, limiting the conclusions that can be drawn in absolute terms. However, the change in the proportion of total electricity demand occurring in the peak period was available for all trials and is listed in Appendix B. So too were data on the proportional change in total demand over the trial period (also shown in Appendix B). These two sets of data were used to characterise the effectiveness of each trial in reducing electricity consumption during the peak period as well as over the entire period of the trial. These two metrics were also used to apply the outcomes of each ToUT trial to the HEUS data.

The annual average electricity demand profile for the 250 HEUS households, with 10-minute resolution, is shown in Figure 2. Across all months, the HEUS average household profiles exhibited peak demand during the late afternoon and early evening hours, between 4-7pm. The proportion of total electricity demand occurring during the 4-7pm period was highest in the winter months, as shown in Figure 3.

For ToUT trials in which full profile data was not available, the change in proportion of total electricity demand occurring in the peak period was noted in each trial, and we added/subtracted this value directly to/from the proportion of total electricity demand occurring during the same period in the annual average HEUS profile. Demand at off-peak and night-time rates was adjusted according to their weighting in the original HEUS data. When no profile information was provided by a given trial (which was the case for all trials except the Customer-Led Network Revolution), it was also assumed that the reduction in total electricity demand occurred uniformly over the course of a day. In instances where profile information was available, the time-dependency of demand reduction was captured directly. The full technical details of this process are given in Appendix A.

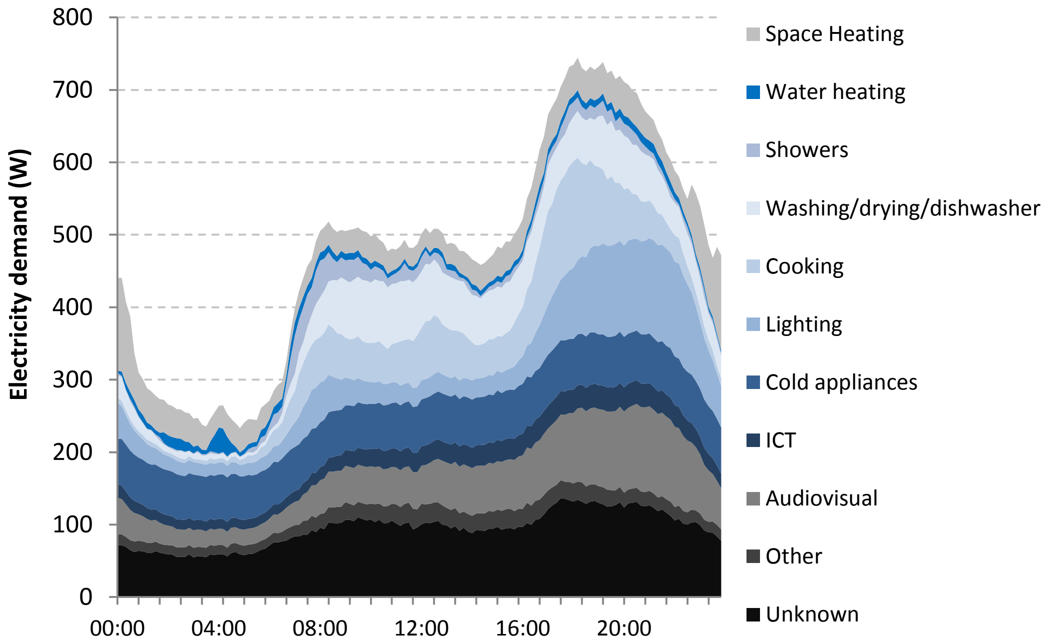

Figure 2: Annual average diurnal electricity demand profile of the 250 HEUS households.

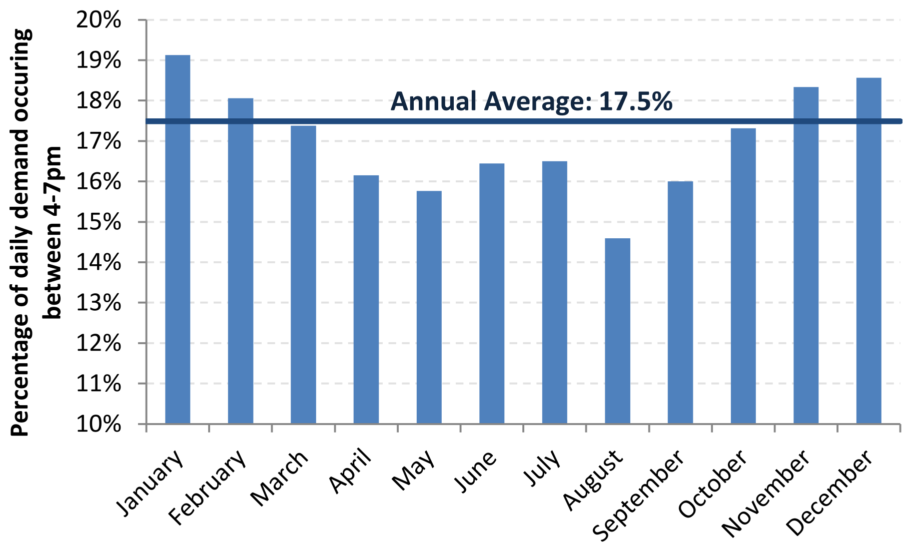

Figure 3: Percentage of diurnal average electricity demand occurring between 4-7pm for the 250 HEUS households[8].

8 The high proportion of peak demand in June and July relative to the adjacent months is related to a significant increase in peak period demand from showers, cold appliances and unknown appliances during these hot summer months.

4 Trial Outcomes and Application to Household Electricity Usage Study

In this chapter, a summary of the demand shifts observed for each trial is given, along with an analysis of other relevant factors that influence programme efficacy. A summary of the tariff structure used in each of the four trials is provided below in Figure 4.

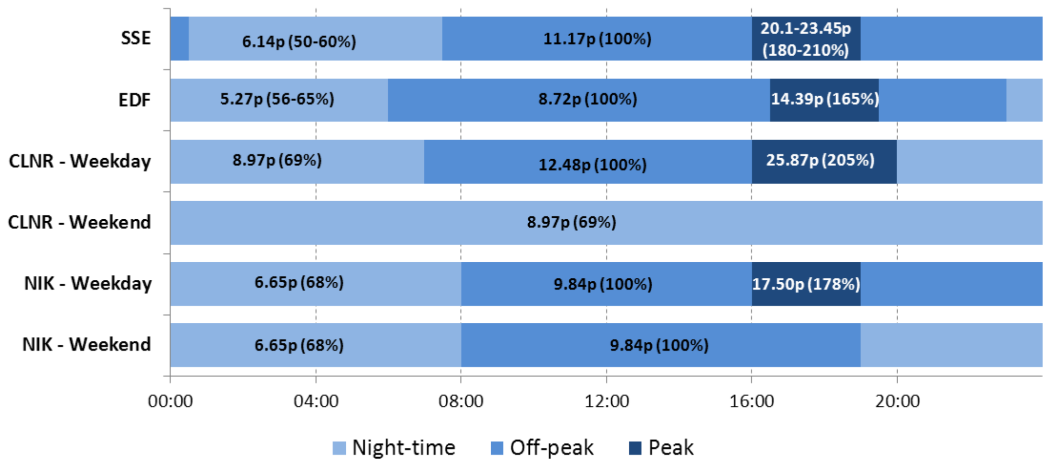

Figure 4: Tariff structures of the four UK trials – the percentage values for each time period reflect the electricity price as a proportion of the off-peak tariff.

4.1 Overview of the Trials

In Figure 5, an overview of the effectiveness of each trial is presented in terms of the change in percentage of demand during the evening peak period, and the reduction in annual (or the total trial period) electricity demand. The first metric provides a measure of the load shifting achieved during peak periods, while the second is a representation of the overall reduction in demand (i.e. the amount of demand that is curtailed rather than simply shifted) for the entire trial period.

Figure 5 indicates that the UK time-of-use tariff trials were, for the most part, successful in reducing peak-time demand, which in most cases was also accompanied by a reduction in overall demand. There exist a small number of trials where this was not the case, and the possible explanations for these instances are explored in the specific analyses for each trial covered in the following sections of the report. Of particular note, is the Northern Ireland Keypad Meters trial (NIK), which exhibited the greatest reduction in peak demand along with an increase in total demand (NIK was the only trial to report an increase in total demand). This implies a significant increase in off-peak demand in the NIK trial. The outlier behaviour of this group (of 100 households) may be linked to the high proportion of low-income households participating in the NIK trial and has important implications for low-income and fuel poor households which warrants further investigation. A summary of the key result metrics for each trial are provided in Appendix B.

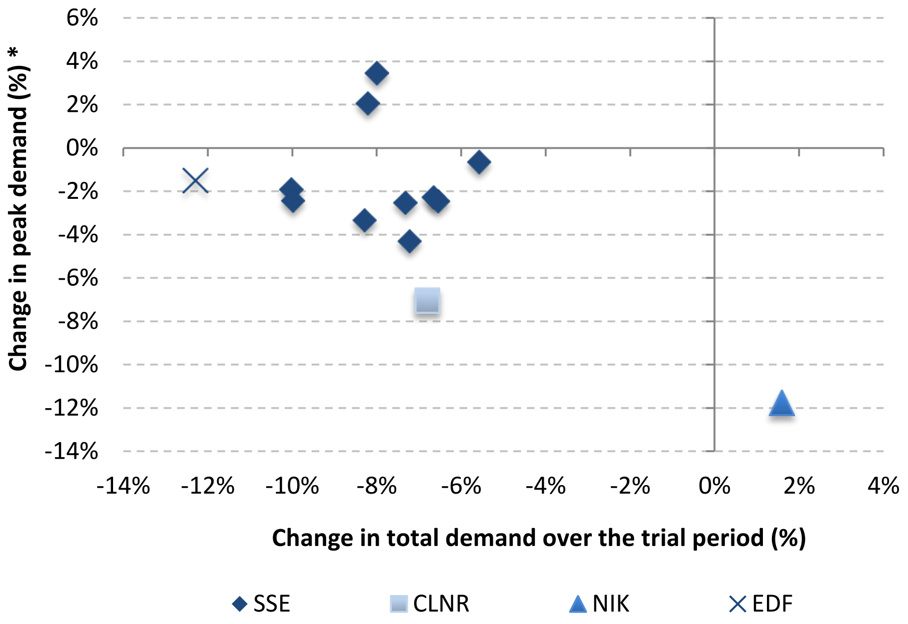

Figure 5: The change in electricity demand during the peak period versus the change in total electricity demand over the whole trial period.[9]

The pricing signals for the trials surveyed were broadly similar – the peak prices were in the range of 165% - 210% of the off-peak rate, and the night-time prices were 50-69% of the off-peak rate. The plot of tariff peak price (as a percentage of the off-peak rate) versus the change in peak period demand is shown in Figure 6. With the limited number of trials currently available, it is not possible to accurately determine the relationship between tariff peak price and the change in peak period demand. However, this could be an interesting area of investigation for future trials.

It is worth noting that the tariffs in all four studies were designed to be cost neutral. In other words, users that did not change their consumption habits over the trial period would not see a change in their monthly bills. However, considerable savings were available to households that could shift consumption out of peak hours.

[9] ***** This refers to the percentage change in the proportion of daily demand occurring in the peak period. Change in the total consumption over the trial period is captured on the x-axis.

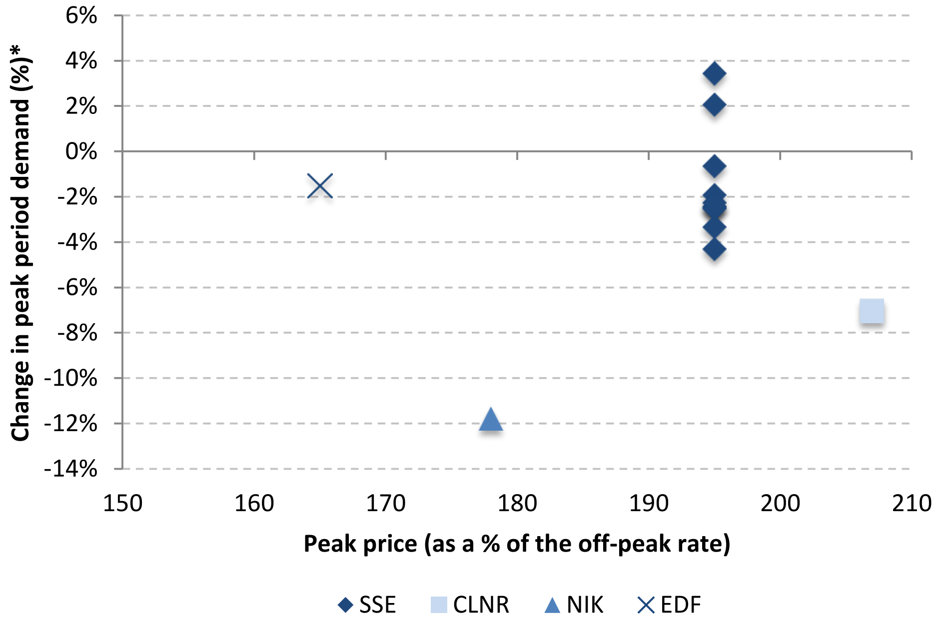

Figure 6: Change in peak period demand[10] as a function of the peak period electricity price (expressed as a percentage of the off-peak rate).

Aside from some of the intervention variations tested in the Energy Demand Research Project (EDRP) SSE trials, there were no major differences in the basic approach undertaken in each trial – interventions generally consisted of a real-time display and a booklet (with tariff information and energy saving advice), in addition to the necessary smart meter installation and time-of-use tariff implementation.

None of the ToUT trials examined here reported any information on the proportion of monitored homes utilising primary and/or secondary electric heating. Given the significant contribution of electric heating towards total household electricity use, further information on this specific household characteristic, and its impact on the trial outcomes, would be useful in future trials.

4.2 Energy Demand Research Project – SSE

The SSE trial tested a number of variations in the type and number of interventions that accompanied the ToUT.

In addition to the time-of-use tariff, the other interventions (designed to further promote shifting of load away from peak periods and/or reduce total electricity consumption) included:

[10] * This refers to the percentage change in the proportion of daily demand occurring in the peak period.

- An energy advice booklet.
- Monthly billing with graphs showing historic and half-hourly consumption.
- A real-time display (RTD) of electricity consumption, cost, CO_2 emissions and historical data, plus a “traffic light” indicator of current consumption.
- Web information providing a personalised consumption history available online.
- A financial incentive (an additional 5% bill reduction) to reduce total electricity consumption by 10%.

The full list of intervention combinations and their effectiveness in reducing the peak period demand is shown below in Table 1.

Table 1: The various interventions tested in the SSE trials and their impact on peak demand and total electricity use.

Trial Group Code	Number of households	ToUT	Booklet	Monthly bills with graphs	Incentive to reduce	Real-time display	Web information	Change in peak period demand with ToUT (high season)	Change in peak period demand with ToUT (low season)	Change in total electricity demand with ToUT
27	233					✓		-1.28%	-2.23%	-10.0%
28	124	✓				✓				
29	121				✓	✓		-2.61%	-2.34%	-10.0%
30	127	✓			✓	✓				
11	305		✓	✓				-5.30%	-3.81%	-7.2%
12	162	✓	✓	✓						
13	153		✓	✓	✓			-4.01%	-3.01%	-8.3%
14	160	✓	✓	✓	✓					
23	206		✓	✓		✓		-2.16%	-2.70%	-7.3%
24	103	✓	✓	✓		✓				
25	126		✓	✓	✓	✓		-0.60%	-0.66%	-5.6%
26	121	✓	✓	✓	✓	✓				
10	283		✓	✓			✓	-2.11%	-2.65%	-6.6%
7	173	✓	✓	✓			✓			
8	162		✓	✓	✓		✓	-1.71%	-2.53%	-6.7%
9	177	✓	✓	✓	✓		✓			
22	210		✓	✓		✓	✓	0.83%	2.67%	-8.2%
19	131	✓	✓	✓		✓	✓			
20	137		✓	✓	✓	✓	✓	3.18%	3.59%	-8.0%
21	140	✓	✓	✓	✓	✓	✓			

In addition to the reduction in peak demand observed in the majority of these cases, there was also a reduction in total annual demand of between 5-10% in each instance. Interestingly, there were some cases in which the proportion of total electricity consumed during peak hours increased – which may be linked to the number of interventions implemented[11]. To further explore the impact of the number of interventions, we investigated the change in peak demand as a function of the number of interventions (shown in Figure 7).

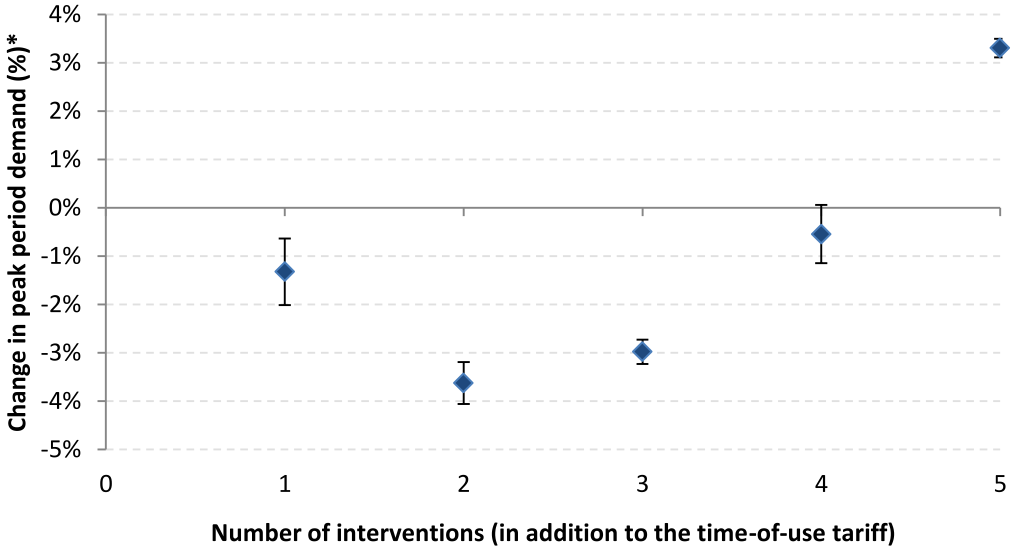

Figure 7: The average change in peak period demand[12] for different numbers of interventions in the SSE ToUT trails. The error bars indicate the standard error of the mean in each case (and include results differentiated by weekday/weekend and high/low season).

Figure 7 implies that peak shifting benefits decline when more than two interventions (in addition to the time-of-use tariff) are introduced. This observation may be linked to an interference effect observed in the original study[11], where an abundance of information is counterproductive to peak demand reduction.

Figure 8 shows how the annual average diurnal HEUS demand profile would be altered if subjected to the SSE trial results (for the interventions with the most extreme increase and decrease in peak demand[13].

[11] AECOM (2011), "Energy Demand Research Project: Final Analysis"
[12] * This refers to the change in the proportion of daily demand occurring in the 4-7pm peak period of the SSE trials.
[13] The SSE trial outputs do not provide specific information on the consumption during off-peak and night-time tariff hours; therefore, the load shifted from peak times is distributed in these two periods according to their weighting in the HEUS dataset.

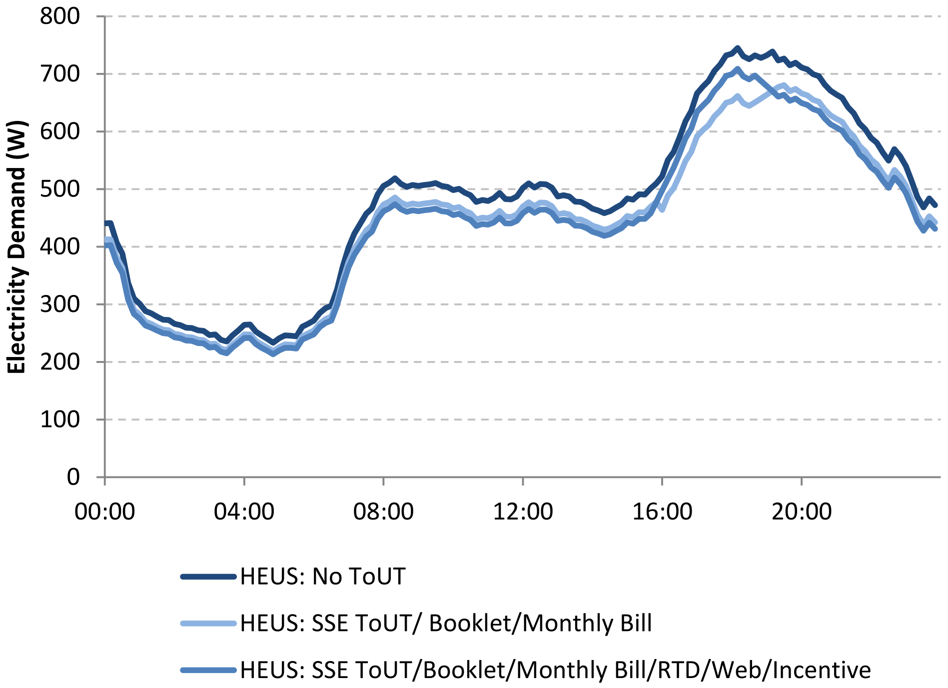

Figure 8: Annual average diurnal electricity demand, for the HEUS households, when subject to the ToUT trial findings from the SSE study[14]. Since the SSE study involved several trials of different intervention combinations (in addition to the ToUT), only the trials that offered the most and least favourable peak demand shift are shown.

While in absolute terms there was a significant difference between the amount of peak demand shifted in the high season (November-February) and the low season (March-October), there was little difference in the fraction of peak demand shifted by season for the SSE trials. Figure 9 below shows that, on the whole, the various SSE interventions showed no consistent differences between the fraction of peak demand shifted between the high and low seasons.

In most of the SSE trial interventions, weekends offered a better demand shift response than weekdays (see Figure 10). It is possible that this is linked to a greater degree of demand flexibility on weekends as less household occupants are at work during the day compared to weekdays[15]. However, further testing is required to investigate this observation in greater detail and to determine the drivers behind it.

[14] The impacts of both the change in peak demand as well as the change in total demand recorded from the SSE trial are included.
[15] This is consistent with the lower levels of 6-7pm peak period consumption (combined with higher levels of total daily consumption) observed in the HEUS dataset for weekends relative to weekdays.

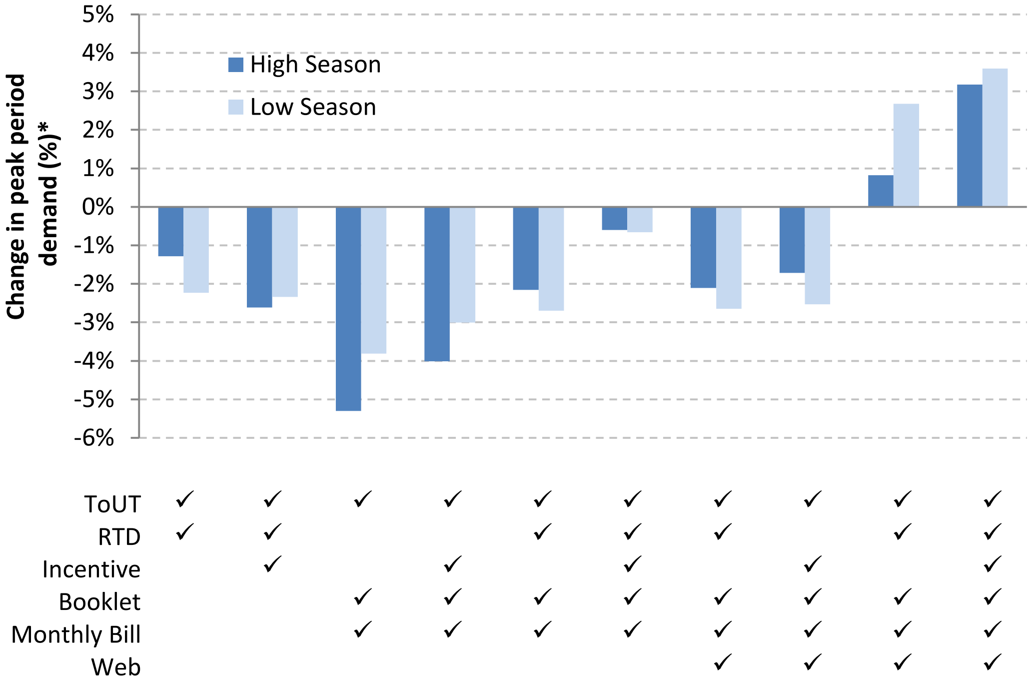

Figure 9: The change in peak period demand[16] for the various SSE trial intervention combinations differentiated by high and low seasons.

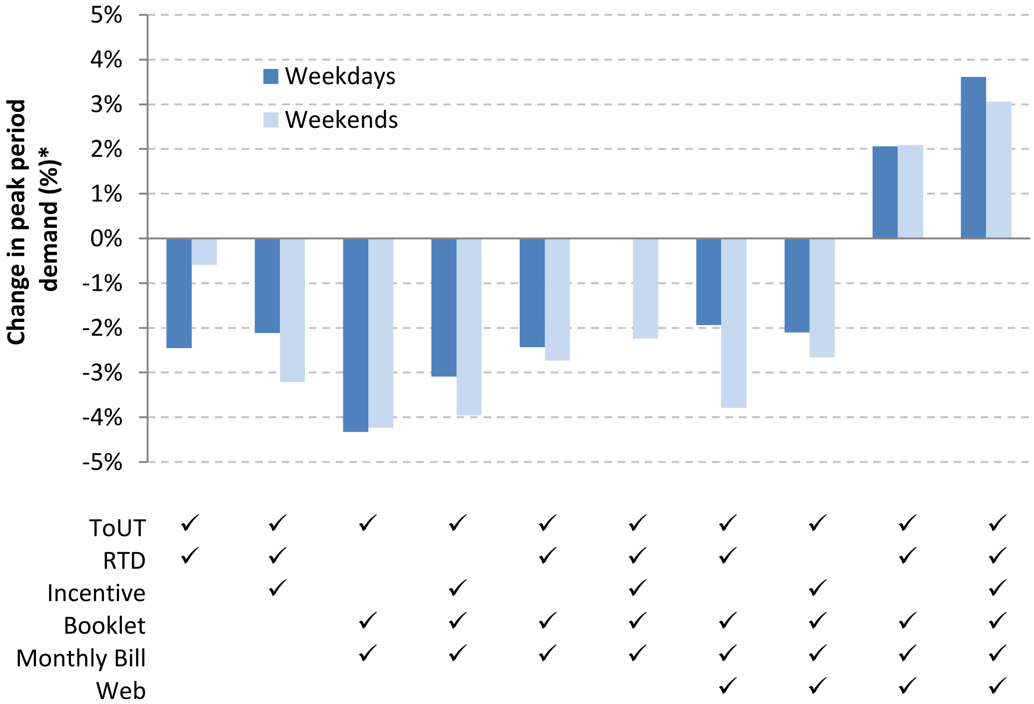

Figure 10: The change in peak period demand[16] for the various SSE trial intervention combinations differentiated by weekdays and weekends.

[16] * This refers to the percentage change in the proportion of daily demand occurring in the 4-7pm peak period of the SSE trials.

4.3 Energy Demand Research Project – EDF

The EDF trial made use of three trial groups:

1. A control group, with no interventions (135 households).
2. A group with a real-time display, but no time-of-use tariff (141 households).
3. A group with a real-time display and a time-of-use tariff (170 households).

All three groups received energy efficiency advice in the form of additional literature included in their monthly bill data. Group 1 (Control) and Group 2 (RTD only) consumed the same proportion of total electricity use during peak periods, suggesting the real-time display, in isolation, offers little improvement in peak load shifting.

Comparison of Group 1 (Control) and Group 3 (RTD and ToUT) revealed that the introduction of a time-of-use tariff did result in shifting of peak demand, however, this effect was observed to be strongly dependent on the number of household occupants (see Figure 11). Figure 11 shows that the peak demand shifting effect of the ToUT was negated for more than three household occupants (aged 16-64).

Though it is not possible to provide a conclusive explanation for this observation based on the evidence presented in the study, the following factors may have contributed:

- The household member that enrolled in the trial may be more aware of the incentives supplied to encourage demand shifting than other household members. This awareness and responsiveness may be "diluted" as the number of household members increase.
- Larger households may, on average, have different constraints on their electricity consumption which affect their flexibility in shifting peak demand.

Why peak demand in Group 3 (RTD and ToUT) actually increased relative to Group 1 (Control) for more than 3 household occupants is unknown, though the original trial report[17] points to limited samples sizes for these high occupancy levels. With this in mind, the findings for occupancy levels in excess of three may need to be validated in a larger trial.

[17] AECOM (2011), "Energy Demand Research Project: Final Analysis"

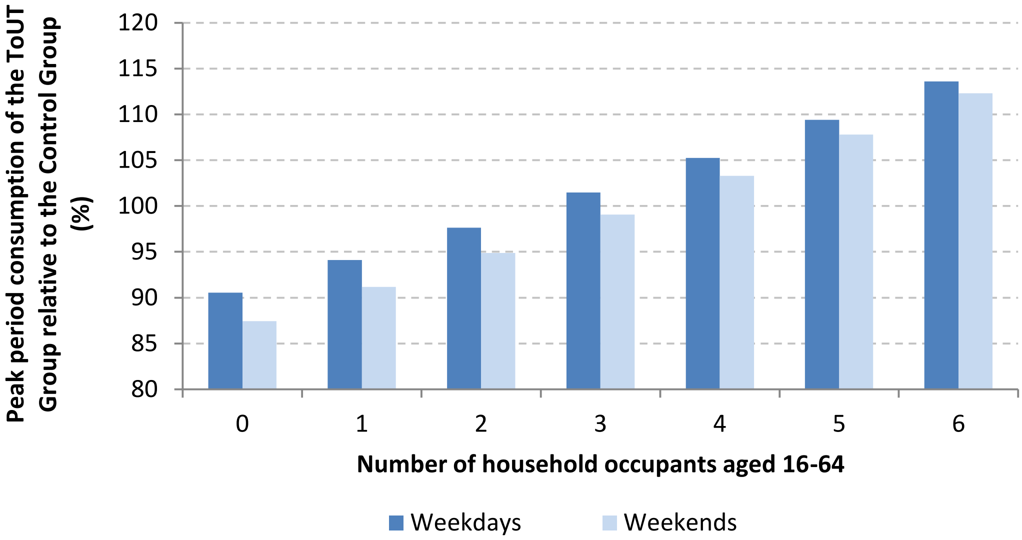

Figure 11: Average peak consumption of time-of-use-tariff households, relative to the consumption of the control group in the same period.

Figure 11 also shows that the peak shifting results on the weekend are better than those during the weekdays. As discussed in the previous section, this may be linked to greater levels of household demand flexibilibility on the weekends (e.g. it may be possible to operate loads during the weekend daytime that would normally occur during the evening peak when household occupants arive home from work and school on weekdays). However, it is not possible to determine the drivers behind this result from the data available and further work to investigate this finding is warrented.

The age of occupants exhibited a small impact on the change in peak demand. On average, each additional occupant aged 16-64 increased the proportion of consumption in the peak period (by between 4.3-4.8%) more than an additional occupant under age 16 (between 2.1-3.7%).

In addition to peak shifting effects, a substantial change in total annual demand was seen for households taking up time-of-use tariffs in the EDF trials. The EDF trials noted, over two years, a median reduction of 12.3% in total load when compared to pre-trial consumption. This is in contrast to the other three studies, which report the mean reduction (and generally smaller reduction levels). With no further information available for this trial, we have used this figure in place of the mean demand reduction. It should also be noted that the EDF total reduction value was determined by comparing the total annual consumption of Group 3 (RTD and ToUT), which had a sample size of 170 households, with that of the pre-trial consumption levels of only 4 of these households. As such, this result should be treated with caution.

When the ToUT outcome of the EDF trial is applied to the HEUS demand profile, the HEUS diurnal demand is shifted as shown in Figure 12.

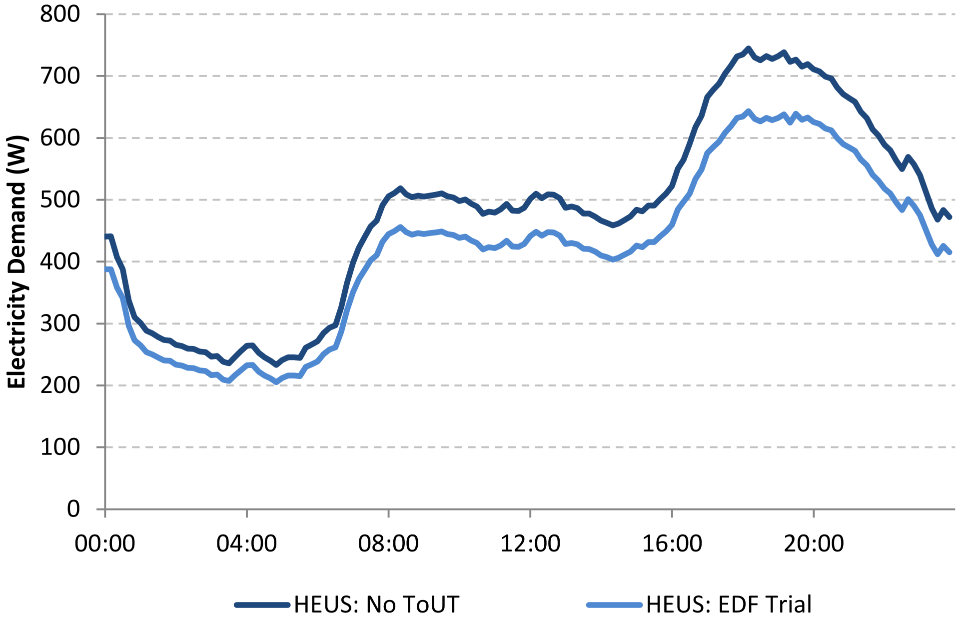

Figure 12: Annual average diurnal electricity demand, for the HEUS households, when subject to the ToUT trial findings from the EDF study[18].

4.4 Customer-Led Network Revolution

The Customer-Led Network Revolution (CLNR) is a large, on-going project funded by Ofgem's Low Carbon Networks Fund. To date, the project has released time-of-use tariff average half-hourly consumption profile data for April to November 2012 (interestingly, this coincides roughly with the "Low Season" SSE trial period). A real-time display and advice booklet were provided for each household taking up the trial, with telephone support for any technical issues that arose. The half-hourly electricity consumption profiles of the 112 participating households were monitored before (April to November 2011) and after (April to November 2012) introduction of the time-of-use tariff.

In this trial, substantial demand reduction during the 4-8pm peak period (14.3% reduction in absolute consumption) is achieved, together with a reduction in the average daily total demand (6.8% reduction in absolute

[18] The impacts of both the change in peak demand as well as the change in total demand recorded from the EDF trial are included.

consumption). These results are broadly in line with the results from the SSE trials over the same period.

In Figure 13, we apply the CLNR ToUT results, including the reduction in total demand, to the annual average diurnal consumption profile of the HEUS households. The peak period demand drops by 7%, in line with the most effective of the SSE trials.

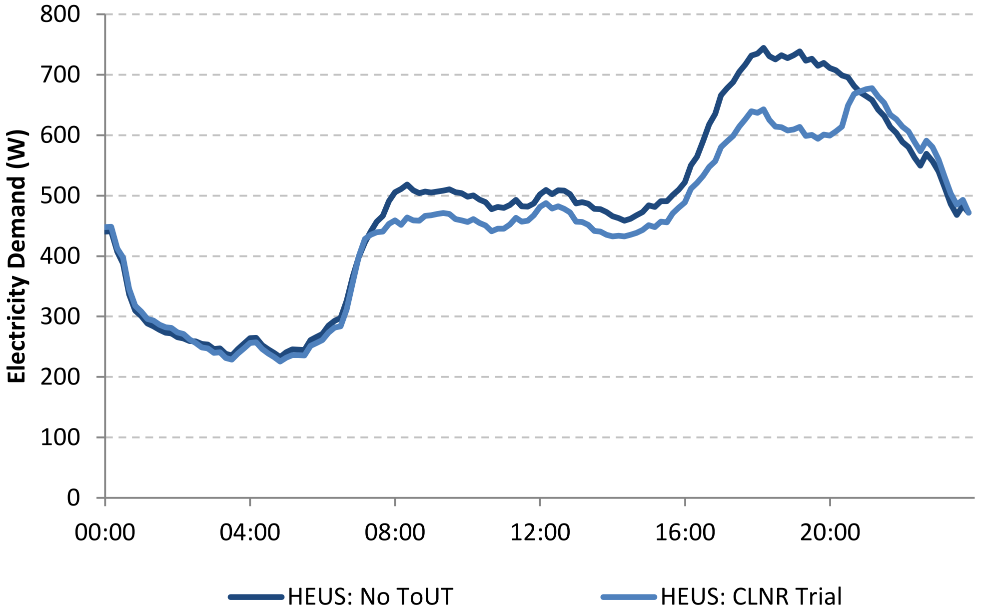

Figure 13: Annual average diurnal electricity demand, for the HEUS households, when subject to the ToUT trial findings from the CLNR study[19].

Figure 13 shows that while significant demand is shifted from the evening peak period, there is still a distinct peak produced where the high-tariff period ends and the night-time rate begins. As discussed in our earlier report on the *Correlation of Consumption with Low Carbon Technologies* in the HEUS dataset[20], this phenomenon has important ramifications for network loads as new low carbon technologies (such as heat pumps and electric vehicles) are taken up by UK households. If these new technologies are widely automated to preferentially operate during low-tariff periods, the peak at the beginning of low-tariff periods will be greatly accentuated, creating challenges for local and national electricity networks

[19] The impacts of both the change in peak demand as well as the change in total demand recorded from the CLNR trial are included.
[20] Element Energy (2014), "Further Analysis of Data from the Household Electricity Usage Study: Correlation of Consumption with Low Carbon Technologies" for DECC and Defra.

due to loss of consumption diversity. This phenomenon points towards the need to preserve consumption diversity (e.g. by using nationally and locally staggered tariff periods in conjunction with a variety of other DSR mechanisms)[21].

It is also worth noting in Figure 13 that there is no significant increase in demand for the night-time (12am – 7pm) period, despite lower electricity prices at this time. While there may currently be little load shifting into this period for the current appliance mix, this may increase substantially with uptake of electric vehicles and heat pumps in the UK domestic sector[21].

4.5 Northern Ireland Keypad Meters Study

In 2003-2004, a prepayment keypad meter, with a real-time display, was used to trial a time-of-use tariff in Northern Ireland. A leaflet containing energy and cost reduction advice was also provided.

The proportion of electricity consumed during peak hours was 12% lower for consumers in the time-of-use tariff group (100 households) relative to the control group (a different 100 households). However, the total annual demand of the ToUT group increased relative to the control group, in contrast to the majority of other trials.

The results for this study should be viewed in light of a possible selection bias in this study. In 2009, it was estimated that around 30% of domestic electricity meters in Northern Ireland were keypads, and a substantial proportion of the keypad consumers were classified as “low-income”[22]. For comparison, 3.8 million UK consumers relied on pre-payment meters[23] in the same year, representing approximately 15% of all households. It is unclear if the excellent demand shifting response from the trial participants in this study is linked to the high proportion of low-income households in this trial. However, this does highlight the importance of further work to investigate the impact of demographic factors, such as household income and fuel poverty, on responsiveness to DSR interventions such as time-of-use tariffs.

Figure 14 below shows how the HEUS average annual demand profile is impacted by the results from the Northern Ireland Keypad Meters Study.

[21] Element Energy (2014), “Further Analysis of Data from the Household Electricity Usage Study: Correlation of Consumption with Low Carbon Technologies” for DECC and Defra.
[22] Department of Energy and Climate Change (2012), “Demand Side Response in the domestic sector - a literature review of major trials”.
[23] OFGEM (2012), “Domestic suppliers’ social obligations: 2011 annual report”.

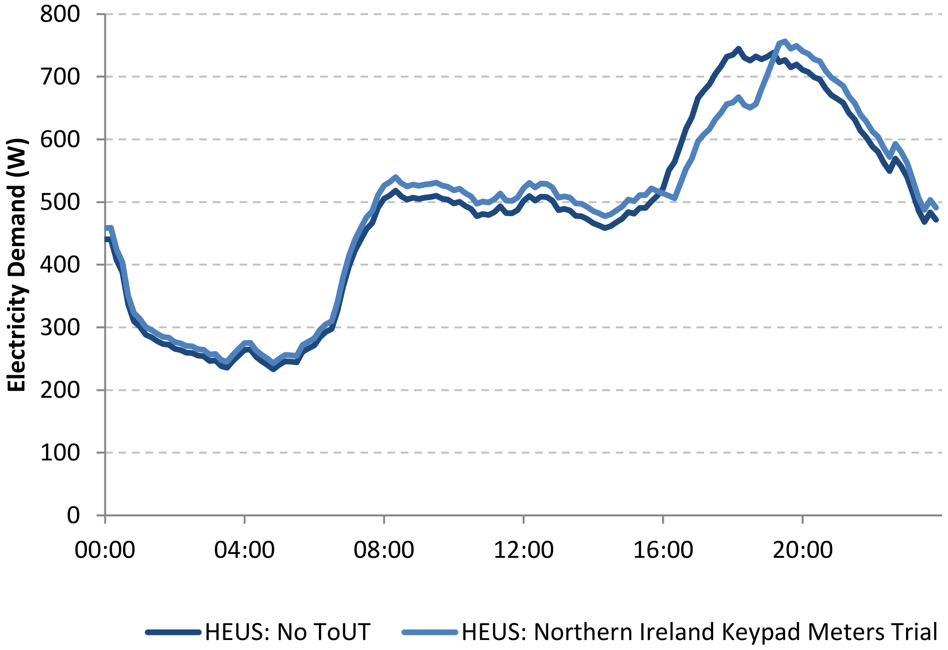

Figure 14: Annual average diurnal electricity demand, for the HEUS households, when subject to the ToUT trial findings from the Northern Ireland Keypad Meters trial[24].

4.6 National Peak Shift Potential

In this section, we compare the load shift observed for the four ToUT trials with the maximum technical potential for peak shifting determined from the HEUS appliance data in our previous work[25,26]. The maximum technical peak shifting potentials calculated in these earlier HEUS reports were determined from the peak period (6-7pm) loads for appliance types that could be shifted out of the evening peak without significantly impacting household lifestyles. In these calculations, we conservatively assumed that the appliance load types shown in Table 2 could be shifted out of the evening peak. It is feasible that the use of other appliance types (such as cooking appliances) could also be shifted out of the evening peak period, though these were not considered in the calculation of maximum technical potential owing to the likely lifestyle changes this would involve.

[24] The impacts of both the change in peak demand as well as the change in total demand recorded from the Northern Ireland Keypad Meters Study are included. The sharp rise in demand at 7pm is a result of substantially lower demand during the peak period relative to the following off-peak period. As there was no demand profile available from this trial, it was not possible to ascertain precisely the rate of change at the end of the peak period.

[25] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Consumer Archetypes" for DECC and Defra.

[26] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability" for DECC and Defra.

Table 2: The fraction of peak load that is assumed to be shiftable out of the evening peak load period (6-7pm) for various appliance types[27].

Appliance type	Fraction of appliance peak-time load that can be shifted
Washing appliances (washing machines, tumble dryers and dishwashers)	100%
Water heating appliances (household hot water and electric showers but not including kettles)	100%
Cold appliances (fridges and freezers) fitted with smart control systems	9%

In this section, we also extrapolate the findings of each ToUT trial, along with the HEUS maximum peak shift potentials, to estimate the load shifting capacity implied in each case for the UK domestic sector[28]. In doing so, we assume that the trial participants are broadly representative of the UK population[29] (an unavoidable simplifying assumption – particularly in the case of the Northern Ireland Keypad Meters Study which is known to contain a high proportion of low-income households). We also assume that peak-shifting occurs uniformly over the evening peak period.

Figure 15 shows the peak load shifting capacity for the four ToUT trials alongside the HEUS maximum technical peak shifting potential. While all studies indicate an effective peak shifting capacity, it is interesting to note that some of the trials (SSE, CLNR, EDF) reveal a shifting capacity substantially greater than the the maximum technical potential determined from the HEUS appliance usage data. This implies that, in many cases, UK households are willing to shift energy use from appliances in addition to those shown in Table 2 above, which typically involves some degree of lifestyle change.

This important finding is in line with the interview findings of the CLNR project which suggest that ToUT trial participants "are avoiding laundry, chores, and dish washing, and in some cases are cooking differently within

[27] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability" for DECC and Defra.
[28] These estimates are determined by applying the peak load shift and total demand reduction reported by each of the ToUT trials to the average 6-7pm domestic load profile determined from the HEUS. The calculation is performed in terms of power demand.
[29] UK load shifting capacity was determined by multiplying the average peak shift from each trial by the number of UK households (26.4 million, from: Office for National Statistics UK "Families and Households, 2012").

and around the 4pm-8pm period"[30]. Since cooking appliances account for a large portion of the evening peak demand (20% of demand between 6-7pm for the 250 HEUS households)[31], a small change in cooking behaviour can unlock significant additional peak demand shifting capacity.

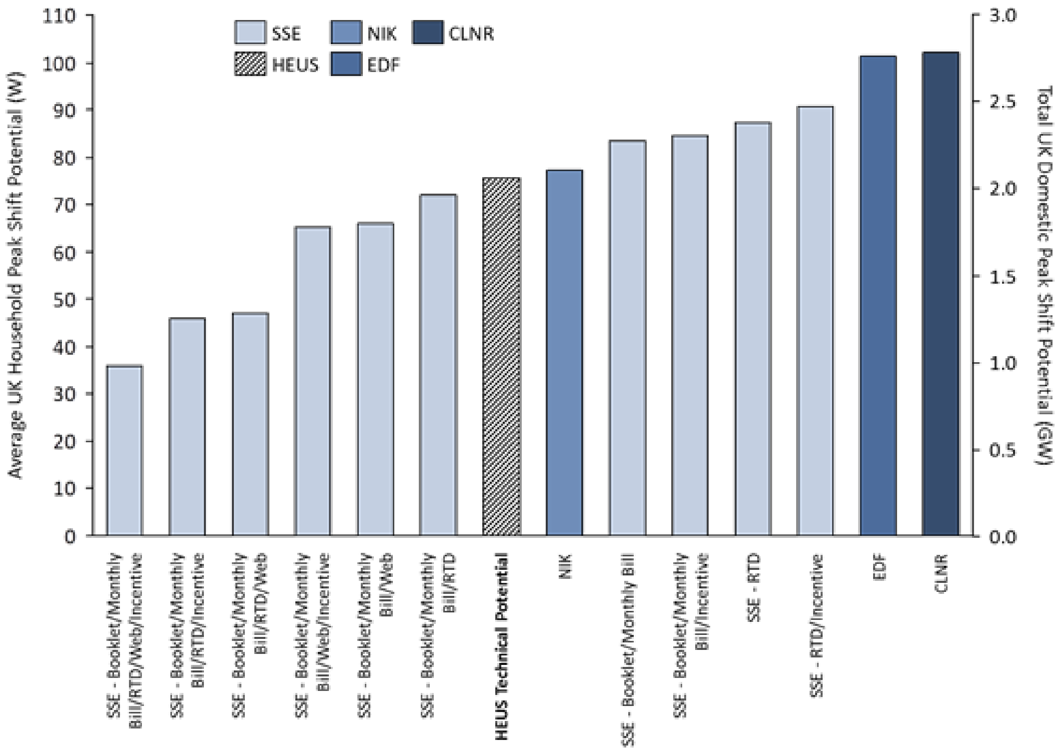

Figure 15: UK peak shift potential implied by each of the four ToUT trials along with the appliance based estimate of technical peak shifting potential from the HEUS[32].

[30] Durham University, "Customer-Led Network Revolution: Social Science Interim Report 2", for Ofgem.
[31] Cambridge Architectural Research, Element Energy and Loughborough University (2013), "Further Analysis of the Household Electricity Use Survey: Early Findings – Demand side Management", for DECC and Defra.
[32] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability" for DECC and Defra.

5 Conclusions and Recommendations

- The majority of domestic UK time-of-use tariffs trials surveyed have been successful in shifting household electricity consumption away from the peak periods. At the same time, most trials witnessed a concurrent reduction in total electricity demand. We have shown how these changes would impact on the HEUS load profiles for each of the UK ToUT trials. We have also used the HEUS data to scale-up the ToUT results to the national level, revealing UK domestic peak shift potentials of up to 2.7GW during the 6-7pm evening peak period.

- Comparing the actual amount of demand shifted in the four ToUT trials to the maximum technical potentials determined from HEUS appliance usage data reveals that, in most cases, UK households engage well with ToUTs and are even willing to shift loads that involve some element of lifestyle change. That is to say, in addition to washing, drying and water heating loads (which can be shifted with minimal lifestyle impact via timers etc.) there is emerging evidence that some cooking consumption and other loads closely linked to lifestyle patterns are being shifted in response to ToUTs[33]. This is a promising finding pointing to high levels of efficacy for this type of domestic demand side response intervention in the UK.

  Recommendation: Gather further data on the types of lifestyle changes, particularly around cooking appliances (which contribute approximately 20% of evening peak loads), that UK consumers are willing to adopt under modern ToUT interventions.

- The Energy Demand Research Project SSE trials revealed that the number of interventions implemented in conjunction with a ToUT (e.g. energy advice booklets, monthly consumption reports, real-time displays, online consumption data and complementary financial incentives) can have a strong bearing on the level of demand shifting achieved. Cases in which more than two interventions were implemented, in addition to the ToUT, were observed to negatively impact peak shifting – possibly due to an interference effect in which consumers were overwhelmed by an abundance of information. In the SSE trials, the optimal effect was observed for two interventions in support of the ToUT.

[33] To date, this evidence is limited to qualitative data only, based on participant interviews from the Customer-Led Network Revolution trial: Durham University, “Customer-Led Network Revolution: Social Science Interim Report 2”, for Ofgem.

Recommendation: Limit the number of demand shifting interventions implemented alongside ToUTs (e.g. energy advice booklets, monthly consumption reports, real-time displays, online consumption data and complementary financial incentives) to around two per household.

- The Energy Demand Research Project EDF trials showed that the peak demand shifting effect of a ToUT was, on average, negligible for households with more than three occupants (aged 16-64). This may be due to demand shifting constraints specific to large households, or perhaps it is linked to a “dilution” of actively participating household members – i.e. the household member(s) who signed up to the trial.

  Recommendation: Further research is required into the drivers behind poor ToUT response in high occupancy households and to better understand the load shifting constraints specific to these households.

- Both the SSE and EDF Energy Demand Research Project trials revealed a generally superior demand shifting response to ToUTs on weekends relative to weekdays. While it is not possible to determine the causes of this difference from the data available, it is conceivable that many households have an increased degree of demand flexibility on weekends when daytime constraints from work and school are typically lower.

  Recommendation: Further studies into the drivers behind the higher levels of demand shifting observed on weekends relative to weekdays could provide valuable insights for the optimisation of domestic demand side response interventions in the UK.

- The Customer-Led Network Revolution trial results exhibit, in addition to a strong shift in peak demand, a distinct demand peak at the beginning of the night-time tariff rate following the evening high-tariff period. This behaviour points to a significant challenge for network operators and policy makers identified in our earlier HEUS report, *Correlation of Consumption with Low Carbon Technologies*[34], which relates to large new loads from emerging low carbon technologies (such as heat pumps and electric vehicles). As these technologies are adopted in greater volumes by UK households and automated to preferentially operate during low-tariff periods, the

[34] Element Energy (2014), “Further Analysis of Data from the Household Electricity Usage Study: Correlation of Consumption with Low Carbon Technologies” for DECC and Defra.

peak observed in the CLNR trials at the beginning of low-tariff periods will be greatly accentuated. This is a problem related to consumption diversity and can be addressed as such – i.e. by staggering time-of-use tariff periods at the local and national level or implementing a range of demand side response mechanisms.

> **Recommendation**: Further research the effect of locally staggering time-of-use tariff bandings on network loads and consumption diversity. Similarly, further testing is required to understand the effectiveness of applying multiple demand side response interventions to maintain consumption diversity while reducing peak time loads in the UK domestic sector.

- The Northern Ireland Keypad Meters study, which encompassed a high proportion of low-income households (since it was a pre-paid meter trial), showed the highest demand shifting response of all the trials examined in this report. This raises important questions regarding the role of demographic factors in demand response, particularly in the context of the fuel poor.

> **Recommendation:** Further studies are required to explore the significance of household demographics (particularly household income and fuel poverty) in responsiveness to load shifting interventions such as time-of-use tariffs.

- Significant variation exists in the structure and level of detail associated with the published outputs from each of the four UK time-of-use tariff trials examined in this report. In building up a detailed view of UK demand side response behaviour, it is important to ensure that future studies extract the learning and best practices of these valuable past studies while also adhering to a minimum level of reporting detail to assist future research. For example, publication of average diurnal profiles (as in the CLNR trial reports) reveals important information for future studies that cannot be extracted in their absence. It is encouraging to see that recent trials are now adopting this standard reporting format alongside the high-level summary tables typically used in earlier reports.

> **Recommendation:** To extract maximum value from future time-of-use tariff studies, we recommend the following:
> - Monitor pre-trial and in-trial consumption data for the same households, ensuring statistically significant sample sizes where possible.

- Monitor and report key demographic characteristics (anonymised appropriately) such as the number of household occupants, household income and geodemographic segment (e.g. Experian Mosaic group, Acorn segment or Output Area Classification).
- Publish full diurnal profiles to reveal the distribution of shifted loads.
- Make the full dataset from each trial available, resolved to the level of each participating household (suitably anonymised).
- Monitor appliance level data (as in the HEUS), where possible, to better reveal the types of appliance demand that contribute most significantly to UK domestic demand shifting under modern time-of-use tariff schemes. Where this level of monitoring is not possible, even minimal information on which of the monitored households make use of primary electric heating would be beneficial.

6 Appendix A – Calculating Demand in Night-Time and Off-Peak Periods

Where diurnal profiles were not provided in the outputs of a given time-of-use tariff trial (i.e. all trials examined with the exception of the CLNR trial), the percentage of electricity used during the night-time and off-peak periods was calculated using the algorithms below:

$$Offpeak_{trial} = \frac{(100\% - Peak_{trial}) \times Offpeak_{HEUS}}{Night_{HEUS} + Offpeak_{HEUS}}$$

$$Night_{trial} = \frac{(100\% - Peak_{trial}) \times Night_{HEUS}}{Night_{HEUS} + Offpeak_{HEUS}}$$

Where $Peak_{trial}$ represents the proportion of electricity demanded during the peak period in the trial, and $Offpeak_{HEUS}$ and $Night_{HEUS}$ represent the proportions of electricity demanded during the off-peak and night time periods of the HEUS, respectively.

7 Appendix B – Summary of Trial Results

Table 3: Summary of change in total annual demand and peak period demand for all trials examined in this report.

Trial		Without ToUT, total demand (kWh/yr)	With ToUT, total demand (kWh/yr)	Change in total mean demand (%)	Without ToUT, percentage of consumption in peak period (high season)	Without ToUT, percentage of consumption in peak period (low season)	Change in percentage of consumption in peak period (high season)	Change in percentage of consumption in peak period (low season)
SSE - RTD	SSE - TG 27/28	4,271	3,843	-10.0%	19.90%	18.4%	-1.28%	-2.23%
SSE - RTD/Incentive	SSE - TG 29/30	3,994	3,595	-10.0%	19.70%	18.4%	-2.61%	-2.34%
SSE - Booklet/Monthly Bill	SSE - TG 11/12	3,942	3,657	-7.2%	19.70%	18.4%	-5.30%	-3.81%
SSE - Booklet/Monthly Bill/Incentive	SSE - TG 13/14	3,874	3,553	-8.3%	19.90%	18.6%	-4.01%	-3.01%
SSE - Booklet/Monthly Bill/RTD	SSE - TG 23/24	3,971	3,680	-7.3%	19.90%	18.6%	-2.16%	-2.70%
SSE - Booklet/Monthly Bill/RTD/Incentive	SSE - TG 25/26	4,014	3,790	-5.6%	19.20%	17.9%	-0.60%	-0.66%
SSE - Booklet/Monthly Bill/Web	SSE - TG 10/7	4,168	3,895	-6.6%	19.60%	18.5%	-2.11%	-2.65%
SSE - Booklet/Monthly Bill/Web/Incentive	SSE - TG 8/9	3,907	3,647	-6.7%	20.00%	18.6%	-1.71%	-2.53%
SSE - Booklet/Monthly Bill/RTD/Web	SSE - TG 22/19	4,078	3,743	-8.2%	19.10%	17.6%	0.83%	2.67%
SSE - Booklet/Monthly Bill/RTD/Web/Incentive	SSE - TG 20/21	3,949	3,633	-8.0%	18.90%	17.8%	3.18%	3.59%
EDF[35]		3,695	3,241	-12.3%	19.7%		-1.50%	
Northern Ireland Keypad Meters		4,098	4,163	+1.6%	17.0%		-11.76%	
CLNR[36]		3,351	3,123	-6.8%	N/A	17.38%	N/A	-7.04%

[35] The EDF data reports only the median total demand (which has been used in the absence of a mean value). It is also worth noting that the pre-trial sample in the EDF study is comprised of a small sample size of only 4 households.

[36] The CLNR data has been extracted from a single average half-hourly diurnal profile, recorded over April – November 2012. Annual demand is, therefore, an approximation based on scaling up the data from the average diurnal profile provided – no seasonal weighting was applied.