Customer-Led Network Revolution

Durham University Social Science Research

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Executive Summary

Research Project, Design and Methods

The Customer-Led Network Revolution (CLNR) Project is the UK's biggest smart grid project and at the forefront of the move towards a low-carbon economy. The £54 million scheme is collaboration between academia and business led by Northern Powergrid, the electricity distribution network operator for the North East and Yorkshire. The project is part-funded by the Office of the Gas and Electricity Markets' (OFGEM) Low Carbon Networks Fund (LCNF). The other lead business partners in the project are British Gas and EA Technology. Durham University and Newcastle University provide an interdisciplinary team of researchers to bring academic rigour and insight to the project.

The transition to a low-carbon economy will present both opportunities and challenges for the electricity industry and its customers. The CLNR project seeks to develop cost-effective solutions that will ensure the UK electricity network is fit for the future and able to cope with mass uptake of electricity dependent, low-carbon technologies, such as solar panels, electric vehicles and heat pumps.

This report provides a synopsis of the research findings produced by the social science team at Durham University in collaboration with the engineering research team at Durham and Newcastle Universities.

The electricity use data used for the analyses in this paper are provisional data and as a result this document should not be considered a final report.

We have adopted a broadly socio-technical approach to research and analysis of smart grids, where we seek to take account of the ways in which energy demand and its flexibility are shaped by social and material factors. In this report, we use a practice-based approach to inform our understanding of how and why energy is used in households and businesses. The conceptual approach developed through this project and the analysis we have conducted across the various test cells suggests that energy use is shaped by the interaction of five core elements or 'cogs' (see Figure 1: The CCRES Model of Energy Use), which we describe as the CCRES Model: where Capacities, Conventions, Rhythms, Economies, Structures shape the use of electricity and its flexibility.

Methodology

This report draws on research conducted across the 5 test cells within the CLNR project for which data was available at the time of writing. Data available for analysis at the time of writing this report are summarised in Table ES1.

In addition to the collection of consumption data through a range of monitoring and metering arrangements, Durham University's social science team recorded 250 face to face interviews as summarised table ES2. Each of these interviews was conducted on the participant's premises and involved a semi-structured interview about electricity use and flexibility as well as a tour of the premises to record discussions of how different rooms and appliances were used as part of everyday life.

Table ES1 – Consumption data used in this report.

Test Cell	Description	Number of participants from whom data was available for analysis for this report
1	Control Group	8649
3	Heat Pump Users	92
5	Solar PV	98
9	Time of Use Tariff	599
20a	PV used to automatically heat hot water	96
20m	PV users given an import / export IHD	101

Table ES2 – Qualitative research summary

Total Number of Domestic Participants	131
Total Number of SME Participants	57
Total Number of Unique Participants	186
Total Number of Qualitative Research Interviews including follow ups	250

As well as this qualitative research the social science team designed and analysed the results of an online survey of domestic customers administered by British Gas. The data used in this report come from the first survey of domestic participants to which there were 730 reliable responses.

Research Findings: Learning Outcome 1

Domestic electricity demand: Analysis of consumption data

- In Test Cells 1 and 9 demographic attributes collected by the CLNR project were available for each participant enabling analysis of the relationships between these and electricity consumption (these data were available for 7999 participants from Test Cell 1 and 591 participants from Test Cell 9). Analysis of consumption data for these participants confirms that total electricity demand differs considerably between households and that this variance increases in the winter months. Furthermore, evening (4pm - 8pm) domestic electricity demand increases relative to demand at other times of day and night in winter months (October – March). Consumption is on average 1.69 times higher per hour in the 4pm – 8pm period compared to other times of the day during these months.
- The rate of electricity consumption in this early evening period relative to other times of day and night varies widely between households. While the mean average peak to off-peak consumption ratio is 1.36 the distribution ranges from a maximum of 4.86 to a minimum of 0.5 and displays an interquartile range of 0.61.
- For those participants in Test Cells 1 and 9 where analysis of associations between demographic attributes and consumption has been possible, electricity demand has been found to differ by tenure, with owner-occupiers exhibiting, on average, higher demand than renters. Renters also consume a lower proportion of their total electricity use during the

evening peak hours, whereas owners' tend to consume more during this period. Owners also exhibit greater variation in the proportion of total electricity consumption that happens during the evening period.

- Households in rural off-gas areas have a substantially increased demand for electricity throughout the year compared to gas-connected households. As well as having the greatest average daily demand, rural off gas households who tend to use electricity for heating and hot water also consume a higher proportion of their total electricity in the evening period. The potential that new technologies will increase electricity demand in the early evening will need to be considered carefully if plans to shift away from gas to electricity as a source of energy for domestic heating move ahead.
- Households with young children (under 5) or older people (over 65) have a lower than average daily electricity demand. Existing research suggests that such households tend to consumer more energy than average, so this finding points to important social differences in the use of gas and electricity by households. These households also consistently consume a lower proportion of their total electricity during the peak period of 4-8 pm.
- Of all the socio-demographic attributes we have analysed to date, income has the strongest association with electricity demand with higher income households (combined household income of more than £30,000) consuming on average 2.9 kWh per day in June and July and 4.7kWh per day in December more than lower income households (combined household income of less than £14,999).
- The proportion of electricity consumption concentrated in the evening period was also highest and most variable amongst high-income households and lowest and least varied amongst low-income households. Because of their overall contribution to demand in the peak period and the variability in their demand high-income households appear to be a key target group for future DSR.
- We found relatively little difference between the average electricity demand of households living in homes with high, middle and low thermal efficiency (in this study age of property was used as a proxy for thermal efficiency).
- Statistical analysis of relationships between responses to the online survey and consumption data found no link between attitudes expressed and the electricity demand of the respondents (n = 383).
- Other than income and tenure, differences in domestic electricity consumption do not appear to be related to socio-demographic factors or to individual attitudes.
- Further analysis of the electricity consumption data is underway to test for association with additional customer attributes, their Experian categorisation and geographical area.

Electricity use and everyday practices in households

- The practices that are most associated with the bulk of electricity consumption in the home are cooking, heating and hot water, lighting, bathing, chores, entertainment, and standby and 24 hour loads.

- The everyday household practices most directly relevant to demand side management are: those with a likelihood of being performed during the 4pm – 8pm period; those which include appliances owned by many households; and those which have a high electrical load. On this basis, we focus on: household chores, cooking and dining, laundry and dish washing.

Test Cell 3: Heat pumps

- Successful heat pump installation and their ongoing effective use was greatly affected by the previous history of heating systems that households had experienced and the way in which the transition was communicated and managed. Those moving from individual night storage systems were much more positive about the new systems than those who had lived with district heating systems.
- Evidence from Test Cell 3 highlights both the positive potential of heat pumps to improve heat services while reducing bills as well as the potential risks to customer experience and well-being.
- Key benefits were found to be: (a) the quality of the heat provided and its use as a source of drying clothes as well as providing comfort; (b) reduced bills; and (c) the hot water service provided.
- Key concerns included: (a) whether running the system all day, which technically provides the most efficient service, would incur additional costs (see also Owen et al. 2012); and (b) the perceived complexity of the technology, with participants fearing their interventions would cause the system to breakdown.
- The research also suggests that energy suppliers are unsure about which tariffs and / or services they could and should offer to customers with heat pumps indicating that further research is need to better understand and engage with supplier approaches to heat pumps.

Test Cell 5: Solar PV

- Our research found that PV ownership leads to more active ways of relating to energy, whereby individuals engage in the calculation of their own energy use and production, as well as in monitoring and managing their use to a greater extent than in other households.
- We find that the uptake and use of PV is being shaped by a new conventions focused on investment and the potential financial returns that PV can bring based on a logic of 'exporting' electricity to earn a return from the feed-in tariff. As a result, on-site use of power is not widely recognised as a way to maximise financial benefits for PV owners. This creates a considerable opportunity for network operators to engage with consumers to identify the potential and value of using PV power on site and attenuate the flow of PV generated power into low voltage networks.

Emerging trends in electricity use and household practices

- We used qualitative research methods in Test Cells 1, 3, 5, 9, 20 to identify emerging trends in how electricity is being used at home in relation to different practices.

- For some 55% of participant households interviewed from all test cells (n = 131) the use of new entertainment and Internet enabled devices – including for managing the home in the case of PCs and laptops, socialising through social media, playing games and smart TV services – is perceived to be of great importance. The number of devices being used in home is growing. This offers opportunities for flexibility as mobile devices such as laptops, smartphones and tablets can continue to provide connectivity without a power connection for extended periods of time.
- Increased sensitivity to the cost of energy has led 49% of participant households (n = 131) to change their use of energy. While there is no single new approach, we found that domestic customers judge that managing energy to keep costs down has become an increasingly significant feature of mainstream home energy use.
- The emergence of new ways of working result in impacts on domestic energy use. For 59% of all households visited (n = 131) we found evidence that time and space boundaries between home and work are becoming blurred, enabled by the widespread adoption of smartphones and flexible working arrangements. These changes have the effect of creating a need for electrical equipment at home including printers, monitors and desktop PCs as well as mobile devices. These shifts also suggest opportunities for new routines for electricity use associated with practices traditionally done when returning 'home' from 'work'.

Smart Meters and In-Home Displays

- Smart Meters and IHDs have been overwhelmingly welcomed within the households included in the qualitative research (n = 131) and the survey (n = 730). We found that no concerns about security or privacy were expressed by the participants. We hypothesise that this is a function of the trust placed in the partners working together on the CLNR trial. We will investigate this further in focus group work in 2014.
- IHDs are a valued part of interventions for managing energy within the home. IHDs were positively received, easily understood and actively enrolled into managing the home, budgets and household life.
- Participants reported thinking of smart meters and IHDs to be the 'same thing', or at least two parts of a whole. For the vast majority the IHD is the smart meter because it is the means through which they are provided with information, and it looks 'smart' because of its digital display, its real time information and the way it physically resembles other devices associated with domestic ICT (smart phones, portable consoles).
- It was found that people used the IHD in at least three distinct ways: (a) to manage the household economy; (b) to provide oversight on what families are doing; and (c) to challenge themselves to save energy – each of these lead to the identification of energy saving potential.
- Our analysis reveals evidence of the impact of wider social trends relating to economic downturn, housing shortage, unemployment and the incidence of divorce on energy use and

patterns of consumption. Social trends reported by the Office for National Statistics support the notion that family structures are becoming more complex. The fastest growing household type in the UK is the household containing two or more families while more than one in three marriages are now remarriages. Stepfamilies are the fastest growing family form in Britain accounting for one in ten of all families. Households are thus often in flux; their composition amalgamating and re-amalgamating according to the comings and goings of members. Our evidence suggests that the extent of mobility within and between households shapes energy practices in ways that are difficult to capture, because of their variety and sometimes temporary nature and that this emerging situation presents opportunities and challenges for the management of electricity systems.

- Taken together, we conclude that interventions such as heat pumps, IHDs and Solar PV represent very different facets of a transition to electrification of low carbon energy services. While IHDs were almost universally welcomed and were often integrated into domestic life, heat pumps were found to be more challenging for end users and their successful domestication was more sensitive to context. Participants' and installers' lack of 'know how' with regard to optimal heat pump configuration and use also resonates with householders' lack of understanding about the workings of PV panels and the possibilities for on-site use of power in a Feed in Tariff (FiT) investment package.
- Overcoming forms of disengagement from the workings of energy systems such as those mentioned is an area of considerable potential for synergistic interventions that might benefit communities as well as those involved in the provision of energy and housing services.

SME electricity demand: Analysis of consumption data for Test Cell 1b

- SMEs have much more highly varied demand for electricity than households. Average daily demand is highest for Commercial & Office enterprises and lowest for those in the Public Sector & Other Industry classification. In terms of business size, organisations with 10-49 employees had the highest demand, suggesting that the relationship between number of employees and electricity demand is not linear.
- The proportion of total electricity consumption concentrated in the early evening period varies between businesses, with much greater diversity than in households. Many businesses (41% or 723 of the sample of 1762) consume less electricity per hour during the early evening peak than during the rest of the day or night (a ratio of less than 1:1). In contrast, this was rare (2%) amongst households.
- Smaller businesses (1-9 employees) tend to consume a higher proportion of their total electricity in the early evening peak period and limited consumption overnight (such as those in leisure, and hospitality industries). Larger businesses consume electricity more evenly across a 24 hour period, though may have larger total consumption and power demand per hour during the peak.

- This suggests that in terms of DSR larger businesses may offer more potential to be flexible by shifting demand to other times of day/night whereas smaller businesses may have relatively fixed electricity demand in the peak period.
- The proportion of total electricity consumption concentrated in the evening peak varies by sector with Industrial businesses tending to consume a lower proportion of electricity in this period throughout the year while businesses in Agriculture, Hunting & Forestry, Fishing sector consuming the most.

Practices giving rise to energy use in SMEs

- Key practices associated with electricity use across SMEs are: lighting, heating and cooling, refrigeration, and ICT. We also identified a range of business specific practices that create specific load profiles for certain businesses. Some business specific loads involve intermittent demand for high power, and these were found to be less fixed in time than lower power, day in day out processes and practices. These 'high power' practices could be flexible and therefore amenable to DSR interventions.
- Connectedness is seen as a vital service that energy use provides, with servers and mobile devices often reported as being among the most critical appliances to business continuity. Ensuring connectivity between employees and data and between staff and customers should be recognised as an important feature of communications surrounding DSR, and here alternative forms of storage (e.g. batteries for computers) may provide a means of interesting the SME community in DSR approaches.

Research Findings: Learning Outcome 2

Variability and flexibility in domestic electricity demand

- Flexibility can be seen as a property of everyday practices and takes four forms: shifting the time at which a practice is done, its location, how it is done (e.g. heating food by gas or in the microwave), or by stopping the practice altogether.
- Our analysis focused on the flexibility of practices in the early evening period, reflecting the fact that the peak demand for electricity in the UK occurs between 4 and 8 pm.
- Variability is the degree to which current demand for electricity in the peak evening period is fixed or varies over time for households. Our analysis shows that households have diverse degrees of variability in different test cells. For households in Test Cell 1 (n = 8649), analysis of electricity consumption data shows that evening demand varies by 51% on average. This indicates that evening demand varies considerably for each household on a daily basis.
- We found no evidence that the proportion of electricity consumed in the evening peak period was more or less varied amongst households in terms of their tenure, thermal efficiency or urban or rural location.
- Within the early evening peak period, dish washing, laundry and household chores were the least fixed of the practices studied amongst participants in the qualitative research (n=131),

Depending on the task, these could be completed either within 24 hours or within the week. In particular, we found that laundry is an activity that some groups of respondents (most typically working families) felt could be shifted within a 24 hour time-frame, or even between days, in relation to convenience, weather and the weekly rhythm of working patterns.

- Cooking and dining were reported to be less flexible by participants in the qualitative study.

Test Cell 9 – Time of Use Tariff[1]

- Our research suggests that the TOU tariff is effective in moving some practices outside of the 4pm – 8pm period. Our qualitative research with 32 participants in Test Cell 9 suggests that laundry and dish washing practices are most responsive. For example, householders report using the tumble dryer, dish washer and washing machine outside of the high tariff period, or at weekends. However, the evidence indicates that the TOU tariff is not effective in moving cooking times outside the 4pm – 8pm period in a sustained or widespread way, particularly for households with children.
- For some households not working around a conventional weekday work pattern, there was some movement of cooking practices in response to the TOU tariff, with participants cooking at a different time and or/by using a different method to avoid peak electricity prices.
- Where practices do not respond to the time of use tariff, this appears to relate to: (a) conventions in terms of how practices are conducted; (b) rhythms of day to day life, including leisure time at home in the evening; and (c) activities that connect householders to external structures or social groups. Examples are working hours, social activities and school life. This finding suggests that the degree of alignment between a TOU tariff and other schedules and structures will be important in shaping how flexibility is realised.
- Participants in TC9 are likely to consume less of their total electricity in the peak evening period (22%, n=599) in comparison to TC1 (25%, n-8649) suggesting that the tariff may have been effective in reducing evening consumption.
- In addition, we find that participants in TC 9 consume on average less in total than in TC1 (mean daily consumption for Test Cell 9 is 8.66kWh compared to 9.68 kWh for Test Cell 1) The reduction in evening demand alone does not explain the reduced total demand however.
- In a study of the electricity demand of Test Cell 9 participants for six like for like months (May to October 2011 compared to May to October 2012) total daily electricity demand was lower in 2012 (post intervention) in each month. On average, total daily electricity demand was 0.3 kWh lower but this figure grew to 0.77kWh in October. This suggests that as well as reducing peak rate consumption, the tariff trialists also reduced their total consumption.

[1] Test Cell 9, n = 32 participants were visited as part of the qualitative research, with 30 of these being visited twice in order to assess longevity of any impacts.

- Analysis shows that the total daily demand reduction observed in months 4, 5 and 6 (August, September and October) of the tariff took place across the week and was not confined to the evening high price period. Indeed, in these three months reduced consumption in the 4pm -8pm period accounts for less than half of the total reduction in electricity use observed; a finding which resonates with other recent research (Darby et al. 2013: p.729). This is of particular interest and will require further scrutiny as new data become available. There are several feasible interpretations including the possibility that the tariff has considerable spill-over effects and that participants have not responded to the TOU only as a price signal (where we would expect only the most expensive electricity to be reduced, and cheap electricity to be consumed), but rather that it has served to reshape everyday practices in a sustained manner.
- Evening demand reduction among households with the new tariff living in dwellings with different thermal efficiency varied considerably, with those in low efficiency homes able to reduce consumption between 4pm – 8pm more than other groups. This suggests that households in dwellings with poor thermal performance are delivering greater flexibility than those in more efficient homes. Further analysis is required of the types of households in these dwellings in order to better understand what is driving this pattern.
- Flexibility also varies with the rural location of households. Off-gas participants are the least flexible; rural gas connected participants displayed moderate flexibility in the summer but this diminished markedly over the period of 6 months we are able to observe. Urban and suburban household's display more flexibility than their rural counterparts and this flexibility is sustained indeed becomes more pronounced, over the period.
- Higher income groups are more flexible than lower income groups – with high-income groups consistently reducing evening peak consumption more than medium-income groups and in turn, medium groups reducing their peak consumption by more than low-income groups. The greater reduction made by higher income groups brought their consumption closer to the post-intervention consumption of lower income groups. The result is that in the post-intervention period, there appears to be a less clear relationship between income and the consumption of electricity in the early evening peak period.

Test Cell 20

- We interviewed 18 participants in Test Cell 20 and conducted follow up visits with 13 respondents, giving a total of 31 qualitative research visits in TC20. TC20 featured 2 groups of participants each trialling an intervention associated with Solar PV panels; these are referred to as Test Cell 20a and Test Cell 20m.

Test Cell 20m (Manual)

- In this test cell participants with PV panels were recruited and equipped with an IHD which indicated whether they were currently exporting or importing power.
- For many of the participants to whom we spoke (n = 10) investment logics are still invoked to describe and explain the ways in which practices have been modified to make more use of

solar power. However, participants referred to the use of colour coding in the IHD display as being particularly powerful in reshaping practices such as dish washing, showering and laundry such that they are undertaken when power is being generated on-site.

- Often changes to electricity use had been made as a result of the original PV installation, but the IHD is associated with undertaking further changes that participants are aware could be beneficial but which had not been fully realized before its introduction. For others the IHD identified new optimal alignments between PV power and their practices which they had not previously recognized. Overall, we find that the IHD is able to shift practices in ways that support the consumption of more electricity on site. Further analysis of the electricity consumption data is required to verify how widespread such shifts were across this test cell.

Test Cell 20a (Automatic)

- In this test cell participants with PV panels were recruited and equipped with a system that automatically heats a hot water tank using a 3kW heating element whenever the PV panels generate power that would otherwise be exported to the grid. Most of the 8 we visited households reported only modest changes to practices as a result of the automated hot water system intervention and not all participants in this group attributed changes to the intervention.
- The small changes reported were mostly related to times when showers were taken. However, more participants are motivated to use the power for use of appliances to a greater extent than they are motivated to use it to fill the hot water tank. Further analysis of the electricity consumption data is required to verify how widespread such shifts were across this test cell and their implications for demand.

Variability and flexibility in SMEs electricity demand

- Qualitative research was conducted with 52 SMEs who were asked what would affect their ability to be flexible about their electricity demand. Analysis of the data generated in this research suggests that variability and flexibility in electricity use among SMEs is related to diurnal (e.g. opening hours), weekly (e.g. shift schedules) or seasonal patterns of activities in pursuit of business goals with periods of flexibility and inflexibility being distinct for each SME. Seasonal patterns were more multi-faceted than the seasonal variation in household consumption - with different SME having different levels of ‘business’ and intensity throughout the year.
- While there is much less homogeneity to the rhythms of business life than is the case with households we find that the ways in which SMEs may be variable and flexible in their energy use is derived primarily from:
    - hours of operation
    - modes of interacting with customers (on premises or remotely)
    - operating requirements of business processes
    - tenure arrangements

- For SMEs, the potential to provide valuable demand flexibility centres on the scheduling, and interruptibility of practices. For example, some processes were described as being re-schedulable if they could be done at any time in the day or week without inconvenience but might be less interruptible if they cannot easily or cheaply be shut down once started (wasted materials or heat for example).

Conclusions

Domestic

- Initial analysis suggests that both total electricity consumption and the proportion of electricity consumption used in the early evening peak vary in relation to income and household composition. Higher income households and those without children under the age of 5 or adults over the age of 65 tend to consume more electricity in total, and to have a higher proportion of this electricity consumed during the evening peak period. Electricity consumption is not associated with any of the other socio-demographic variables available at the time of analysis and does not vary in relation to individuals' attitudes.
- The amount of electricity consumed in the 4pm – 8pm period exhibits high levels of variability within households, so that the actual amount consumed on any one day can be up to 50% different from the annual average for that household. This level of variation is highest for higher income households and those without children under the age of 5 or adults over the age of 65.
- The household practices that contribute most significantly to electricity use in the evening peak period are those which have the most load and which are most commonly undertaken at this time. From our research we suggest that the practices of most direct interest in terms of their potential ability to play a part in demand side management of the electricity distribution network are household chores, cooking and dining, laundry and dish washing. Electronic entertainment and cooking, although often undertaken in the evening peak period either have low electrical intensity (entertainment), or are perceived by respondents to be less flexible (both).
- Social trends that may affect future electricity consumption include: the growing use of mobile technology and IT at home; increasing levels of home work; the changing structure of households; and the rising price of energy.
- We find the presence of low carbon technologies also has significant potential to change energy practices, with smart meters, IHDs, and solar panels in particular having a strong influence on how households think about and manage their electricity use.
- Households involved in the CLNR project have shown that they can be flexible in their electricity use. Participants who have trailed a time of use tariff have shown sustained shift in their electricity use in the early evening peak period together with an overall reduction in electricity use. Participants with solar PV who were provided with an Import/Export meter

also showed a shift in their electricity use, though this was smaller/larger than those with automated hot water storage.

- Our findings suggest that these shifts occur as a result of changes in everyday practices – particularly laundry, dishwashing and chores, with a more limited shift in cooking and showering practices. These practices are shifted as households discover the 'capacities' of their appliances to work on timers and more economical cycles, change the 'rhythms' of their day in relation to their resource (e.g. PV produced by the sun) its cost (e.g. the TOU tariff), and their evening routines, and adopt new 'conventions' concerning how, when and by whom household work is undertaken.
- We find that some households are able to be more flexible than others, particularly those with fewer or less rigid commitments to work and family and those with a higher degree of know-how about appliances are more able to be flexible about their energy use. This has important implications for how the electricity supply industry might seek to engage with households and communities in order to realise flexibility in energy demand and reduce peak loads. If new business models were to be developed to tap into this flexibility, care should be taken to consider the social impacts on those who are excluded from participating and benefiting from such schemes, particularly given our work suggests that a lack of flexibility is created through wider social 'structures' and household economies over which individual households may have little control.

SMEs

- In contrast with the seasonal variation of domestic electricity consumption, which rises to a peak in December, for all sectors of SMEs electricity demand is greatest in January/February, after which there is a steep decline to April consumption levels.
- Our research shows that medium sized businesses (those with 10 – 49 employees) have the highest demand, suggesting that the relationship between number of employees and energy demand is not straightforward.
- As well as diversity in total demand, the evening intensity of SME demand varies more widely than in households with many businesses consuming less energy in the 4pm- 8pm period than at other times of day. The research indicates that smaller businesses (1-9 employees) tend to have more evening intensive loads, which suggests that larger businesses have demand that continues throughout the day and night. The smaller businesses in our sample are more likely to involve evening leisure and cooking activities which will close down over night, making their 24hr load profile more evening intensive compared to a factory that may be active throughout the night, for example.
- SME participants identify heating, cooling and ventilation amongst their most electricity intensive uses. Where there is a reliable alternative heating supply interviewees indicate their preparedness to view heating loads as interruptible in exceptional circumstances by using alternatives like gas or biomass.
- For those SMEs involved in food production such as pubs, hotels, B&Bs and child care facilities/activity centres, evening practices were most heavily influenced by socially

extensive routines, with flexibility limited by advertised times of food service or children's' meal times. Initial indications suggest however that there is some flexibility around how food services are delivered, through use of gas or by offering cold food in exceptional circumstances.

- Qualitative analysis suggests some businesses have high power but intermittent loads associated with specific business processes. There are several accounts of machinery with relatively high power ratings being used for short periods of time. Although referred to as 'necessary', these activities are not fixed in time and could be moved outside of 4pm – 8pm period.

Contents

Figures

Tables

Abbreviations

ASHP	Air source heat pump
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BG	British Gas
CLNR	Customer-Led Network Revolution
DECC	Department of Energy & Climate Change
DEI	Durham Energy Institute
DSM	Demand side management
DSP	Demand side participation
DSR	Demand side response
FIT	Feed-in tariff
IHD	In-home display
kWh	kilowatt hour
NEA	National Energy Action
Ofgem	Office of the gas and electricity markets
ECM	Evening Consumption Multiplier
TOU	Time of use (pricing)
PV	Photo-voltaic
SIC	Standard Industry Classification
SMEs	Small and medium enterprises

1. Introduction

The Customer-Led Network Revolution (CLNR) Project is the UK's biggest smart grid project and at the forefront of the move towards a low-carbon economy. The £54 million scheme is collaboration between academia and business led by Northern Powergrid, the electricity distribution network operator for the North East and Yorkshire. The project is part-funded by the Office of the Gas and Electricity Markets' (OFGEM) Low Carbon Networks Fund (LCNF). The other lead business partners in the project are British Gas and EA Technology. Durham University and Newcastle University provide an interdisciplinary team of researchers to bring academic rigour and insight to the project.

The transition to a low-carbon economy will present both opportunities and challenges for the electricity industry and its customers. The CLNR project seeks to develop cost-effective solutions that will ensure the UK electricity network is fit for the future and able to cope with mass uptake of electricity dependent, low-carbon technologies, such as solar panels, electric vehicles and heat pumps.

The core objectives of Durham University's social science team's contribution to the CLNR project are to provide insight into the nature of energy demand amongst households (domestic) and small and medium enterprises (SMEs) and to consider how, why and with what implications such demand might be 'flexible'.

Understanding energy demand has become a complex and contested matter within the social sciences, with contending perspectives suggesting that psychological, sociological, economic, material and practice based accounts are best able to offer an explanation of the ways in which energy is used. The approach taken in the CLNR project is explicitly multi-disciplinary, is informed by relevant work in several disciplines and engages with a range of conceptual approaches.

Section 1 of this report sets out the learning outcomes of the CLNR project and the research questions developed by the social science team to provide insights for each learning outcome. Section 2 provides an account of our research methodology and analytical framework. Section 3 presents the findings related to current energy demand and its potential future trajectories (LO1) and Section 4 examines how, why and for whom demand might be flexible and the outcomes that particular interventions have had on energy use in the domestic context.

The electricity use data used for the analyses in this paper are provisional data and as a result this document should not be considered a final report.

1.1. Learning Outcomes and Research Questions

The social science team have focussed their research activities on Learning Outcomes 1 and 2 through responding to the following research questions:

LO1.1 - What are today's domestic and SME demand (load and generation) profiles, and how do they vary or group?

1. Which practices are currently giving rise to electricity use in domestic/SME contexts?
2. Which of these practices are the most intensive in terms of electricity use?
3. What are the factors that shape the use of electricity for these practices?
4. What are the factors that are shaping the generation of electricity in domestic/SME contexts?
5. How do energy practices and generation vary in socio-demographic and socio-technical terms?

LO1.2 - How are load and generation profiles likely to change for all customer types? And what are the drivers for change in terms of load and generation?

1. How and why does energy use/practice change over time? What evidence is there that energy use/practice and generation within households or SMEs are currently shifting?
2. How does the emergence of new forms of energy use/practice/generation vary in socio-demographic and socio-technical terms?
3. What are the factors that are shaping the emergence of new forms of energy use/practice?
4. How do these factors vary in socio-demographic and socio-technical terms?
5. How are changing household dynamics likely to shape current and future energy use?
6. How are changing economic conditions likely to shape current and future energy use?
7. How might the financing, policy and regulation of Low Carbon Technologies (LCTs) shape future generation profiles?

LO2.1 - What does flexibility in energy use mean in a domestic and SME context?

1. What does flexibility in energy use mean in a domestic and SME context?
2. In what ways and why are customers currently fixed or variable in their use of electricity in the 4-8 period?
3. How and why does fixity or variability change temporally – on a daily, weekly, seasonal basis, special occasion – and geographically?
4. Which kinds of energy use and energy practice are the most and least flexible and why?

LO2.2 - What are the most effective interventions to deliver this flexibility?

1. What evidence is there of change per test cell (TC), per attribute?
2. What are the factors that have driven the changes?
3. Are there daily, weekly, seasonal variations in the nature and types of flexibility that interventions can achieve?
4. What do the results suggest in terms of from whom, when and where flexibility might be forthcoming?

LO2.2.1 - What is the most effective form of engagement to achieve sustained customer participation?

1. What are the factors that shape the degree to which customers are prepared to engage with demand side response (DSR) (i.e. specific requests for response to change or shift demand)? How/why does this vary (e.g. TCs, socio-demographic, geographical)?
2. What are the factors that shape the degree of demand side participation (DSP) (i.e. sense of commitment and engagement with reducing or shifting demand)? How/why does this vary (e.g. TCs, socio-demographic, geographical)?
3. How did the customer engagement used in the trial shape participation and response? How does this compare to other trials, and what lessons can be learnt from this experience?

2. Research Methodology

The social science team at Durham have developed two methodologies to help us understand the social dimensions of the CLNR trial: surveys (two instruments, one deployed with SMEs one with domestic customers); and qualitative face-to-face research visits. These methods are used in conjunction with the analysis of energy consumption data to provide insights into how and why energy use takes particular patterns for groups and individuals within the population included in the CLNR trial. We have drawn on the existing literature to design research instruments and methodology which, as well as making a contribution to the existing academic knowledge base, can produce sufficient dataset and deliver the learning outcomes required by project partners.

2.1. Qualitative Face-to-Face Research

2.1.1. Choice of Technique

In order to develop the qualitative methodology, the social science team undertook reviews of qualitative methodologies previously and currently being used to study energy use practices, and produced documents summarising the state of art.[2]

In addition, the social science team set up an expert advisory group to facilitate in-project peer review. The first meeting of the group focussed on methodological issues and provided a very useful sounding board and forum though which to sense check and refine the methodologies to be deployed. Having undertaken these review processes it was decided that face-to-face visits to premises would be the principle qualitative research technique.

2 See DEI's CLNR Researching Practices Working Paper for further detail.

2.1.2. Instrument Design

The qualitative research instrument involved three parts:

- Initial semi-structured interview focussing on LO1 learning
- Tour of the participant's premise
- Further semi structured interview, this time focussing on LO2 and linking the practices and materialities emerging in the first two parts of the visit.

Dedicated voice recorders and cameras were used to collect voice recordings, photos, basic categorical information about the participants (e.g. their heating and lighting technologies), as well as diagrams drawn by participants (participants were asked to sketch the property's floor plans and load profiles).

The semi-structured interviews focused on building rapport with the participant while discussing their energy use in general terms. These conversations include information about occupancy, major electrical loads, heating regimes, washing and cooking practices, thoughts and feelings about electricity use, seasonality and other temporal factors as well as experiences of and attitudes to new and existing tariffs and technologies.

During the tour of the premises led by the participant, they were prompted by the researcher to talk about all aspects of their electricity use using electrical equipment as catalyst for conversation. Furthermore, multimedia data was collected by the researcher, with permission, to further enrich analysis. The participant led approach is reflected in the instrument design which does not constrain the respondent or presuppose the factors which are most relevant to the participant.

The third part of the visit enabled a discussion of the principal issues with which the project is concerned as they relate to the participant's context and focuses on the topics of flexibility, peak consumption, key practices with potential for DSP and engagement.

Some participants were involved in a follow-up visit, and in this case a fourth part of the research instrument was used to interview participants about their experience of the particular interventions they had engaged with through the CLNR project.

2.1.3. Research Conducted

Participants were recruited to take part in the face-to-face visits by telephone. BG provided lists of customers who had explicitly consented to being contacted by Durham to take part in further research. The research analysed in this report took place in three phases between May – September 2012, November – March 2013, and August – September 2013.

Each interview has been assigned an anonymous interview number for future reference that is linked to the anonymous CLNR ID number used to identify the customers in all other project activities. The social science team recorded 250 face-to-face interviews, with CLNR participants interviews distributed across the test cells as shown in Table 1.

Table 1: Completed Qualitative Research

Test Cell	Interviews complete May - Sep 2012	Interviews complete Nov 2012 - Mar 2013	Aug - Sep 2013	Unique Participants
TC1a	18	10		18
TC1b	0	0		0
TC2a	0	16		16
TC2b	17	5		17
TC3	0	18		14
TC4	0	1		1
TC5	14	6		14
TC6			17	17
TC9a	32	30		32
TC9b	12	0		12
TC10a	0	0		0
TC10b	9	0		9
TC11a	0	0		0
TC11b	9	0		9
TC20	18	13		18
Learning Outcome 15. Informal SME Participants	5			
Sub-totals	**134**	**99**	**17**	
Total number of domestic participants				**131**
Total number of SME participants				**57**
Total number of unique participants				**186**
Total number of qualitative research interviews				**250**

2.2. Qualitative Analysis Methodology

The material captured in the face-to-face interviews produced a wide range of data: audio interviews, photographs, interviewers' reflections and scanned notes pages that include load curves and in some cases floor plans. The data were analysed using the data analysis software package

NVivo that supports qualitative and mixed method research, which also acts as a database for all the data. NVivo enables researchers to collect both the text-based (transcripts of interview, sheets used to record technology ownership and household details, notes and reflections) and multimedia information (audio files, photographs, drawings) and organises it around 'nodes'. A node, consisting of a collection of references around a specific theme, was created for each interview. A node associates the data generated at each visit with a unique interview ID.

The research team then collaboratively developed a set of themes to structure analysis of the qualitative data. These themes were developed through repeated discussions of the qualitative research process and literature reviews.

To further analyse the data we constructed queries in NVivo (see Appendix 1) that interrogate the data in structured ways to identify data that relate to particular questions of interest. These include practices that take place in the 4pm – 8 pm peak period, what participants regard as their most and least flexible practices, their responses to the interventions in Test Cell 9 and Test Cell 20, their interaction with IHDs and several wider themes that became significant in the development of our research.

NVivo queries can be viewed as similar to queries run in a conventional SQL database – they are repeatable structured searches for data (segments of audio, photos, scanned documents) that have been tagged (coded) by the social science researchers as related to Participant IDs and one or more themes. This process has enabled us to navigate and attune to the data and to extract data relating to particular research questions.

2.3. Survey Design

The online surveys were developed following consultation with several sources. National Energy Action's (NEAs) experience of conducting different types of household surveys informed the initial set of questions, while feedback from our external advisory group was instrumental for revising the attitudinal questions in the domestic survey. Reviewing examples of energy focussed surveys from different research projects helped in the preliminary selection of questions. The final set of questions for both the domestic and SME surveys was agreed in consultation with British Gas (BG) and Northern Powergrid.

The surveys are designed to produce quantitative data that directly addresses the two overarching learning outcomes (LO1 and LO2) of the CLNR project. To that end, the questions included in the survey address issues of current and future energy use and flexibility of energy use in both domestic and small to medium enterprise contexts.[3] The First Interim Survey Report (November 2012, Appendix 2 and 3) lists the survey questions and provides a more detailed account of the rationale for inclusion. Where appropriate the provisional hypothesis that it is designed to test is attached to each question. There have been a total of 152 responses to the SME survey and 1285 responses to

[3] See survey design rationale documents DEI-CLNR-RE028 (domestic) and DEI-CLNR-RE030 (SME) for a detailed description of the rationale for question selection.

the domestic survey. To our knowledge, this is one of the largest social science surveys of energy use conducted in the UK to date.

2.4. Analysis of Consumption Metrics

Analysis of the full consumption data sets from each test cell is beyond the scope of this report but we have included analysis of banded consumption metrics where the data is available. Specifically, we have used participants' electrical demand in each of the following three time bands to analyse their total demand and in particular, their evening peak demand and the peak intensity of their demand:

- Band 1: 8pm – 7am
- Band 2: 7am – 4pm
- Band 3: 4pm – 8pm

2.4.1. Evening Consumption Multiplier Analysis

As a means of analysing the extent to which a household or a group of households' electricity demand is more intensive during the hours of 4pm – 8pm, we have developed the Evening Consumption Multiplier (ECM) statistic to represent the rate of energy consumption per hour in the 4 – 8 evening period relative to the rate at which energy is consumed per hour at other times. It is calculated using the following mathematical formula:

$$\boldsymbol{ECM = (APT/4)/((ANT + ADT)/20)}$$

ECM= Evening Consumption Multiplier
APT = average peak time electricity use (4pm – 8pm)
ANT = average night-time electricity use (8pm – 7am)
ADR = average day time electricity use (7am – 4pm).

This ECM statistic is used in this report as a proxy for 'peak intensity' of demand and as a way to identify the degree to which peak electricity demand is associated with groups of households or interventions. We use the ECM statistic as it normalizes peak demand by the household or group's total demand.

2.5. Social Science and Academic Dissemination

The Social Science team has attended and presented CLNR related papers at the following academic meetings:

Table 2: Social Science Dissemination

Date	Conference	Title
Q1 2012	Association of American Geographers	Diagrams of Power: Politics and the Co-Production of the Smart Grid
Q3 2012	Royal Geographic Society incorporating the Institute of British	The Emergence of Smart Grids from Energy Markets

	Geographers	
Q3 2013	Beyond Behaviour change Symposium, Melbourne	Systems of electricity provision and the constitution of 'smart' energy practices
Q3 2012	European Association of Social Anthropologists	Smart grids: evolving relations between suppliers and consumers
January, 2013	Society for Anthropological Sciences	Presentation of Durham Anthropology research
Los Angeles April 2013	Association of American Geographers (http://www.aag.org/annualmeeting)	Enrolment and Exclusion – Flexibility Capital and The Politics of Smart Electricity Demand Management
Graz July 2013	Institute for advanced studies of science, technology and society (http://www.sts.tugraz.at/)	Paper 1: Fostering Active Network Management Through SMEs Practices Paper 2: Smart Grids and the Flexibility of Everyday Life
Copenhagen June 2013	Nordic Environmental Social Science Conference 2013 (http://ness2013.ku.dk/)	Paper 1: Prospecting for Flexibility: Findings from a Collaborative Enquiry into Smart Electricity Systems Paper 2: The Co-evolution of Energy Provision and Everyday Practice: Rigidity, Disruptions and Systemic Challenges in the Installation of Air Source Heat Pumps in the North of England
Durham June 2013	Smart Urbanism International Workshop and Symposium	The Emergence of Smart Grids from Energy Markets
Karlsruhe, Germany, October 2013	Energy Systems in Transition Conference	FITting Solar into the Smart Grid: Systems of Provision and the Constitution of 'Smart' Electricity Conduct

The following academic journal papers and book chapters have been produced:

- **"Fostering active network management through SMEs practices"** (in submission to Energy Efficiency) draws on analysis of the SME "energy tours" conducted as part of CLNR and presents a social practice-oriented theoretical perspective which enables us to a) see how and where energy is used, b) examine practice commonality across SMEs, and c) pinpoint which practices harbour potential flexibility. The paper concludes that for SMEs there is 'no one size fits all' approach and different routes to flexibility for different activities across sectors are present. Implacability in existing structures and systems may counter attempts to introduce flexible practices within SMEs. Potential opportunities for flexibility in electricity management could be achieved by reshaping SMEs' practices provided that interventions are tailored to specific needs.
- **"The co-evolution of energy provision and everyday practice: rigidity, disruptions and systemic challenges in the installation of air source heat pumps in the North of England"** (in submission to Science & Technical Studies) presents a case-study of one of the CLNR clustered domestic heat pump installations and examines how the uptake of this new technology is shaped by energy services provision and everyday practices. The paper argues that we must understand the ways in which energy systems co-evolve through the habits

and expectations of households, their technologies and appliances, and alongside large-scale socio-technical infrastructure. The study demonstrates that while retrofitting ASHPs has enforced some reconfiguration of domestic practices, resistance remains. A proportion of householders are found to be disengaged from their ASHP and thus are less empowered to manage their energy practices; this at a time when providers and intermediaries imagine ASHP technology to be an innovation for enrolling the participation of users in the overall system of energy provision.

- **"Prospecting for Flexibility? Producing Socio-Technical Capital through Smart Electricity Demand Management Systems"** (in submission to Economic Geography) explores the economisation of demand flexibility, and argues that that thinking of flexibility as a form of capital rather than as a commodity may open up possibilities for other forms of economic relationships and more socially and economically sustainable future arrangements. The paper draws on the CLNR domestic demand side response and solar trials, and uses the results of the CLNR home visit programme alongside quantitative investigations to draw conclusions.
- **“Peak Demand and the Flexibility of Everyday Life”**, in submission to Geoforum, investigates customer experiences of the CLNR residential TOU trial, and draws exclusively on the qualitative data from 186 research visits (semi-structured interviews) to 123 domestic research participants who were visited in summer 2012 and / or winter and spring 2013. The paper suggests that not all energy practices are equal in their relevance to peak demand debates and that those of most relevance i.e. laundry and dish washing practices show most signs of being responsive to TOU pricing. In contrast, dining and cooking remain firmly rooted in the 4pm-– 8pm peak period, suggesting alternatives to financial incentives are required to reduce the electrical loads associated with the evening meal.
- **“Smart Grids and the Constitution of Solar Electricity Conduct”**, a chapter in an empirically diverse and conceptually rich themed book entitled 'Beyond Behaviour Change', addresses smart grid and the governing of energy use. It draws on the CLNR PV trials and examines the ways in which participants responded to the different interventions in test cell 20. The chapter argues that smart grids intervene not only at network scales but also by recomposing the ways in which everyday practices are conducted; and that in the case of PV generation, new forms of self-government are being created within the household, caused by the interaction with the new technology. We anticipate that this book will become a significant volume in the contemporary understanding of energy use. An accompanying journal paper, “Smart grids and the governing of energy use: reconfiguring practices?” is also being produced as part of this work.

As these papers go through the peer review process the social science team will work with partners to communicate the insights in an appropriate manner. In addition, the team has presented to the following industry and regulatory forums. Harriet Bulkeley who leads the social science team gave evidence to the Houses of Parliament Energy and Climate Change Committee on the smart meter roll out in which she drew heavily on the social science fieldwork and analysis.[4] The social science team has also disseminated the learning emerging from CLNR to Smart Grids GB, BEAMA, Consumer Futures, The British Science Festival, IBM, Ofgem, DECC, at a number of events both in Durham and as guest speakers and contributors as well as at CLNR's regional and national stakeholder events.

Both these activities as well as several internal discussions have led to the production of this report which includes empirical data analysis and some discussion of how these are being interpreted through analytic frameworks which draw on wider energy research in the social sciences.

2.6. Research Framework

The social science research conducted as part of CLNR has adopted a socio-technical approach to understanding the provision and use of energy services, in which energy systems are seen as constituted through the continual interaction of both social and technical entities and where demand for energy is produced through and essential to the workings of different practices in homes and businesses.

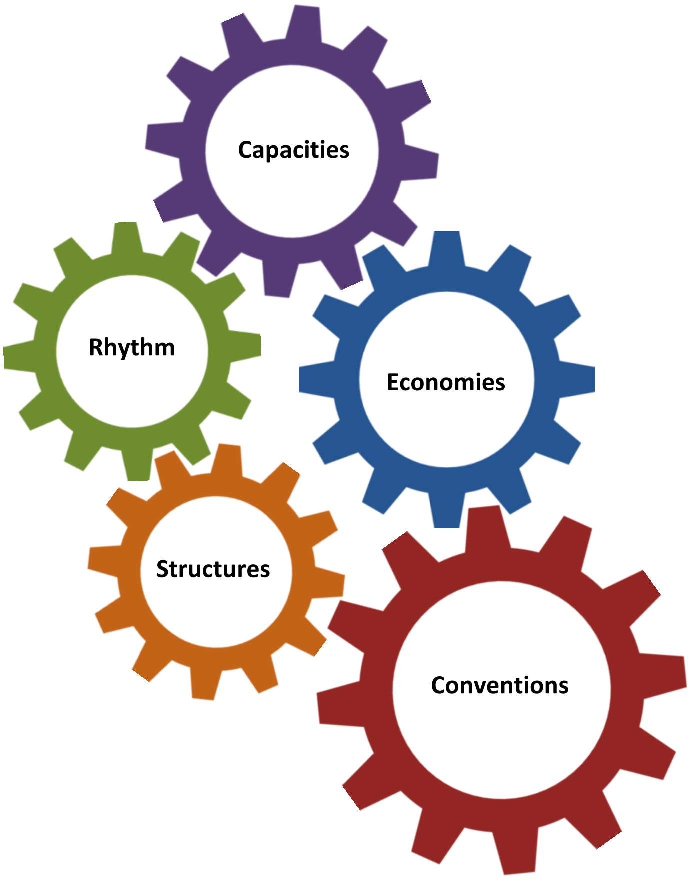
We conceptualize energy use as shaped through the interaction of five different core elements, which together work to constitute energy-related social practices and the ways they are organised and distributed across spaces and time. These core elements we identify as follows:

- Conventions: constitution of what is considered to be normal energy use, through for example standards, cultural expectations, design of appliances
- Capacities: the ability and potential for objects, artefacts, and techniques to use energy and provide energy services, constituted through their design, materiality, knowledge and craft
- Rhythms: the multiple temporalities operating at daily, weekly, monthly, annually through which activities are organised and patterned
- Economies: disposition towards and management of social, natural and financial resources and investments
- Structures: enduring features of the socio-material world, e.g. structures of employment, school hours, building structures, layouts and materials, systems of energy provision, family structures, household life-stages, social class

For shorthand, we can refer to this approach as the CCRES model of energy use. We find it useful to think of this model as a 'gear system' in which each element is a cog or gear which work together in different ways in different contexts to shape how energy is used. Relationships between the cogs are not fixed, neither is their relative 'size', or influence on any given scenario. The recurrent interaction of these cogs leads to the reproduction and patterning of social practices in particular contexts, and in turn serves to embed these elements within the socio-technical systems of which they are a part and to create the potential for alternatives.

[4] Further details at http://www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/news/smart-meter-2-3/

Figure 1: The CCRES Model of Energy Use



3. Research Findings: LO1

Learning Outcome 1 is concerned with the current loads on UK electricity distribution networks, and this report focuses specifically on domestic loads as reported by participants in test cells 1, 2, 3 and 5. The analysis is organized in order to address the different parts of Learning Outcome 1 (LO1.1 and LO1.2) and the specific research questions posed by the social science team to examine these issues.

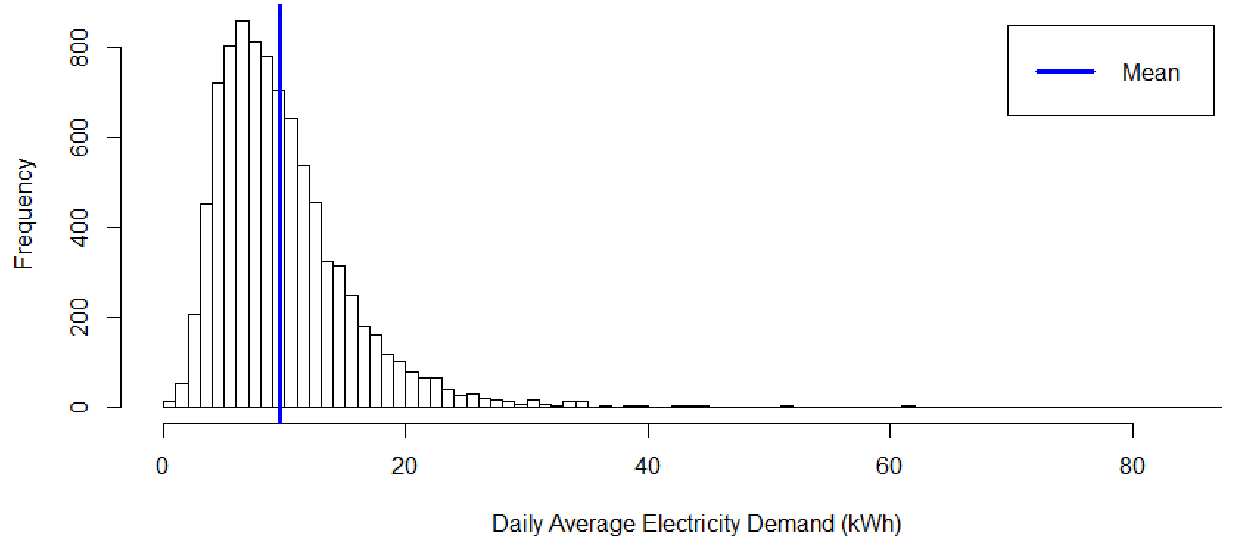
3.1. What are today's domestic demand (load and generation) profiles and how do they vary (LO1.1)?

Understanding the nature of today's electricity load requires the quantitative analysis of energy consumption data to reveal trends and patterns, and the use of social survey and qualitative data to examine why energy loads take the form that they do. In this report, we focus on the analysis of the qualitative data, but we provide some initial analysis from the energy consumption data to establish the context for these findings and to start the process of joining up the different data sets created through the trial.

3.1.1. Energy consumption and the intensity of energy use

The histogram in Figure 2 below shows the skewed distribution of daily average electricity demand: while the mean stands at 9.6kWh the most frequently observed average daily demand is lower than this, with a median value of 8.54 kWh. The presence of a relatively small number of high consumers has the effect of dragging the mean up, while the median consumer uses more than 1kWh per day less than this figure.

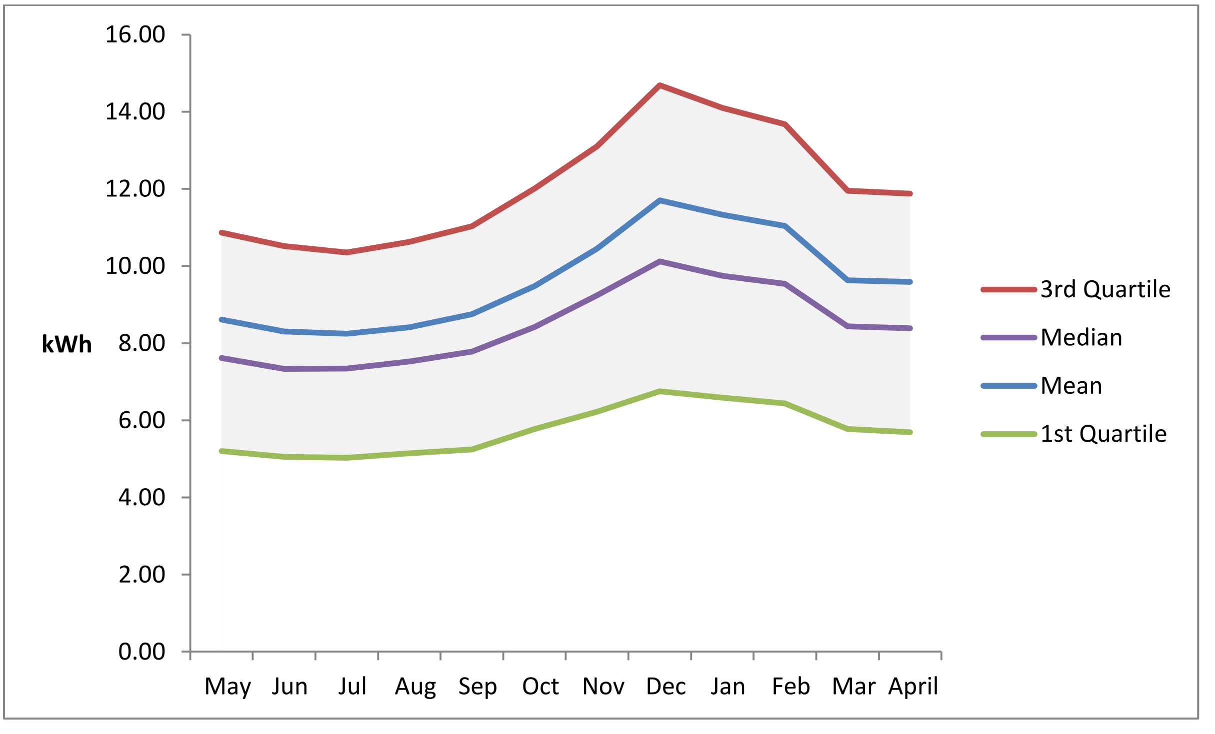
Figure 2: Daily average energy demand for all test cells



Looking across the year, Test Cell 1 provides an insight into the seasonal nature of electricity demand. It shows a 'curved' increase in consumption between summer and winter, which becomes steep in November before a peak in December, followed by a gradual reduction in January before a sharp decrease in February and March.

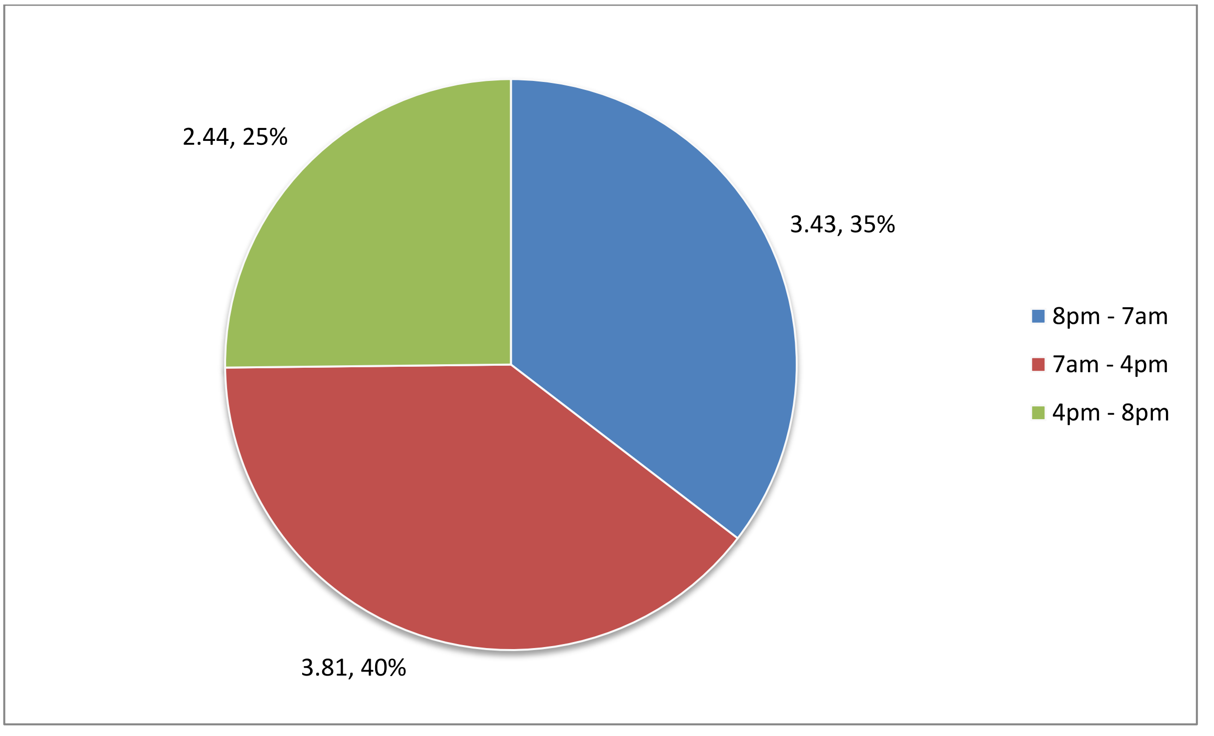
Diversity of levels of electricity consumption increases in the winter months. This can be seen as the interquartile range (the gap between the 25% percentile and the 75% percentile) increases when demand rises in winter, which has the effect of widening the gap between mean and median consumption.

Figure 3: Daily average electricity demand for Test Cell 1 for 12 months



Electricity use also has a daily pattern. Dividing the day into three time periods, we can see that although the four hour evening peak period (4pm – 8pm) appears to account for the smallest amount of energy consumption, this should be interpreted as being a period of higher energy intensity given that, on average, Test Cell 1 participants used 25% of their energy in just 17% (1/6) of the day. This translates to a demand for 1.69 times as much electricity in the peak period (4pm – 8pm) as at other times of the day.

Figure 4: Test Cell 1 - Average electricity demand per time period (kWh)



3.1.1.1. Peak Intensity Analysis

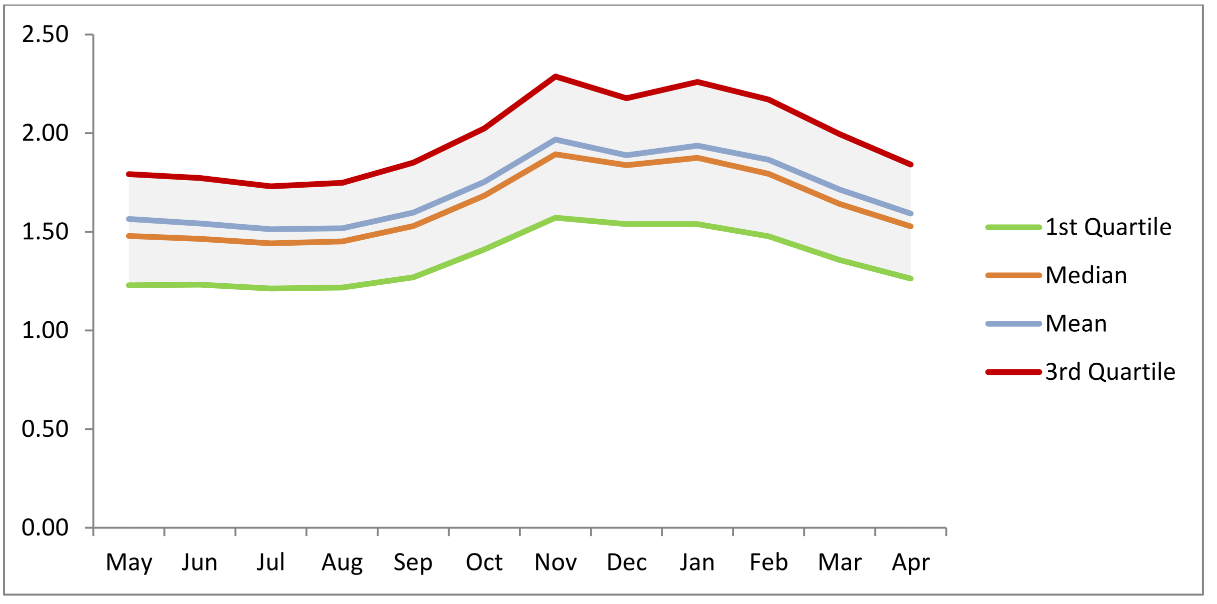
Using all records from all test cells where data has been available (1, 3, 5, 9, 20) we find that the intensity of electricity use varies considerably, with a maximum value of the Evening Consumption Multiplier as 4.863 and a minimum of 0.4951 (see Table 3).

Table 3: Evening Consumption Multiplier descriptive statistics

Minimum ECM	0.4951
1st Quartile	1.385
Median ECM	1.631
Mean ECM	1.69
3rd Quartile	1.938
Maximum ECM	4.863

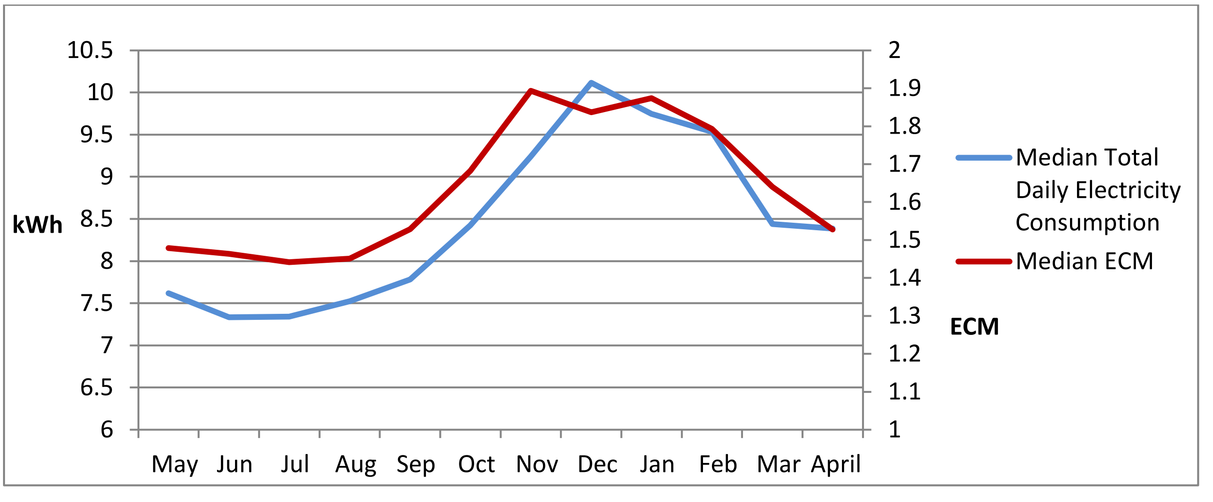
Demand not only rises in the winter (as indicated in Figure 3 above) but also becomes more intensive in the peak period. In Figure 5, which shows the Evening Consumption Multiplier (ECM) over 12 months, ECM varies between households as well as over time, with less peak intensive households ranging from a ECM of 1.2 in summer to a ECM of 1.6 in November; the more peak intensive households at the 3rd quartile of the distribution have a ECM of 1.7 to 1.8 in summer and rising to 2.2 in January and November.

Figure 5: Evening Consumption Multiplier over 12 months for Test Cell 1



Of particular interest is that December represents a slight attenuation of ECM. While average total domestic daily consumption peaks in December, ECM peaks in both November and January but falls slightly in December as daytime consumption rises relative to evening consumption in this period. This is visualised in Figure 6.

Figure 6: Daily average electricity demand and Evening Consumption Multiplier for Test Cell 1



The analysis also shows that research participants with a heat pump (Test Cell 3) also have lower than average ECMs as a result of their increased demand for electricity during off peak hours for heating (Figure 7, Table 4). Those households with PV (Test Cell 5) have slightly higher ECM than the control group in Test Cell 1, which may be a consequence of having higher incomes on average (associated with ownership of PV) than the control group, which makes them more likely to be out at work during the day, and using power in the evening peak.

It also suggests that they are presently not shifting practices into the daytime to make use of solar resources. This is a theme to which we return in Sections 3.8.3 and 4.6.3.

Figure 7: Distribution of peak intensity for LO1 test cells

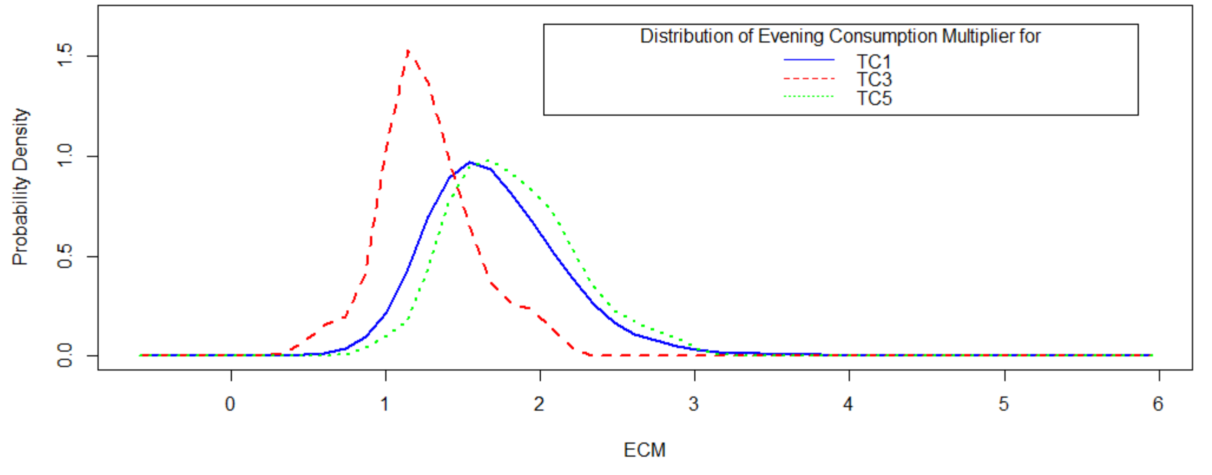


Table 4: Descriptive statistics relating to ECM of test cell populations

	n	Mean	Sd	Median	Min	Max	Range
TC1	7999	1.710961	0.439874	1.653829	0.495104	4.862993	4.367889
TC3	48	1.270098	0.3012	1.230245	0.580503	2.008656	1.428153
TC5	97	1.822026	0.394866	1.76854	1.014818	2.874303	1.859485

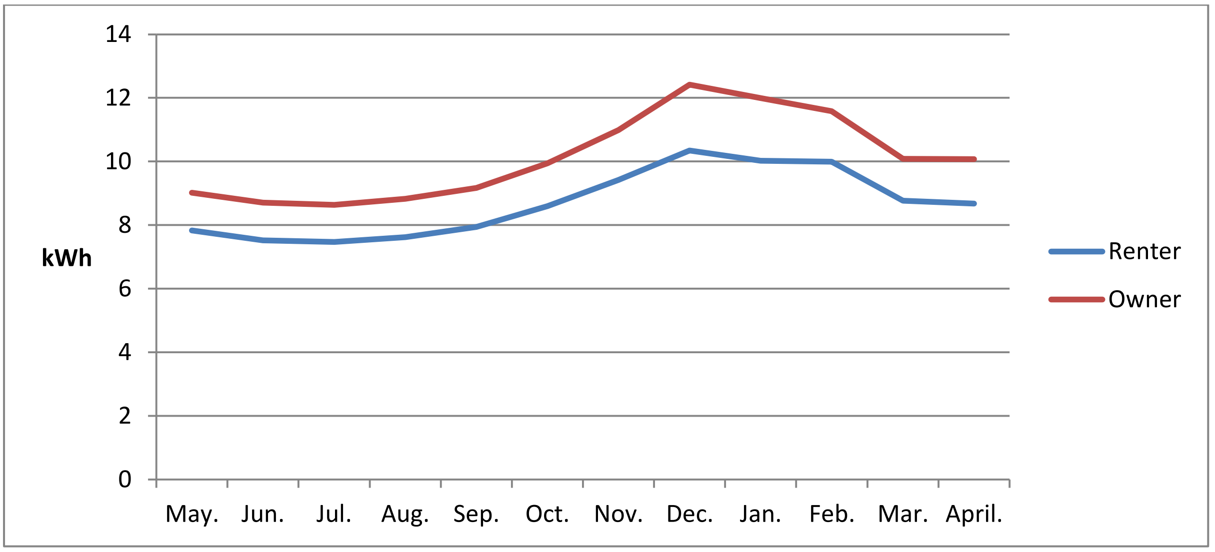
3.1.2. Explaining domestic demand

In this section, we use the data from Test Cell 1 to consider the extent to which variation in demand can be seen across different socio-demographic groups, in relation to the physical condition of housing stock, or in relation to the attitudes held by the sub-set of those participants who completed the survey. Further analysis on the significance of these variations, and more detailed consideration of these factors, will be developed in a future report analysing the energy consumption data.

3.1.2.1. Tenure

Figure 8 makes it clear that owner-occupiers have, on average, higher electricity demand than renters in the sample. This pattern is consistent throughout the year, and indeed becomes more pronounced in winter months when both renters and owners both demand more electricity, but owners do so to a greater extent, widening the gap between the annual demand profiles.

Figure 8: Average total daily electricity demand in Test Cell 1 over 12 months by tenure



Probability density plots of evening peak demand provide insight into the distribution of peak demand (kWh) across households. Figure 9 below shows that renters have a more consistent and lower, peak demand whereas owners' peak demand is slightly higher and more widely distributed.

Figure 9: Distribution of peak demand by tenure

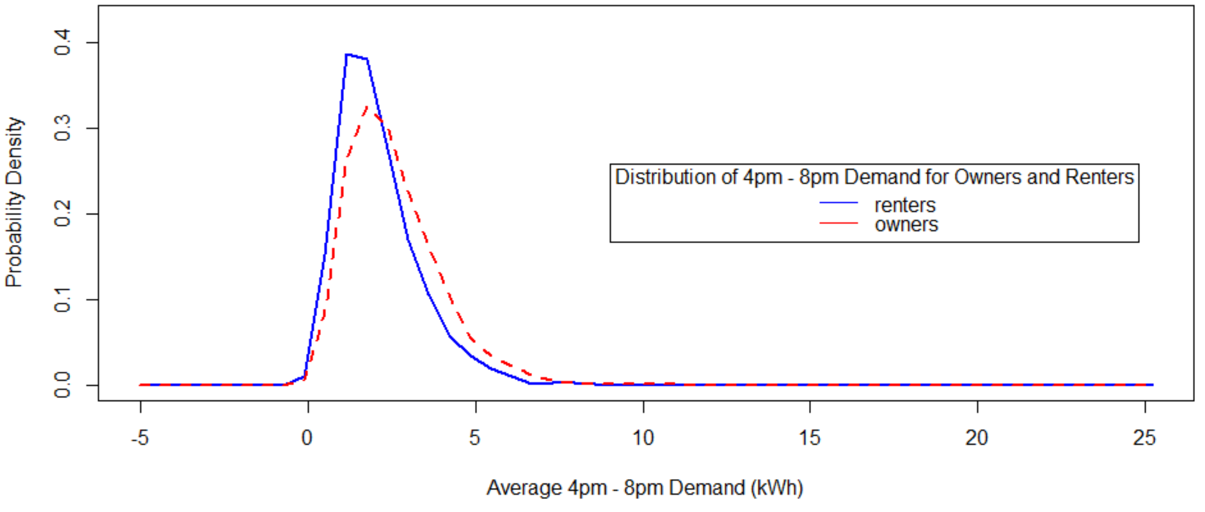
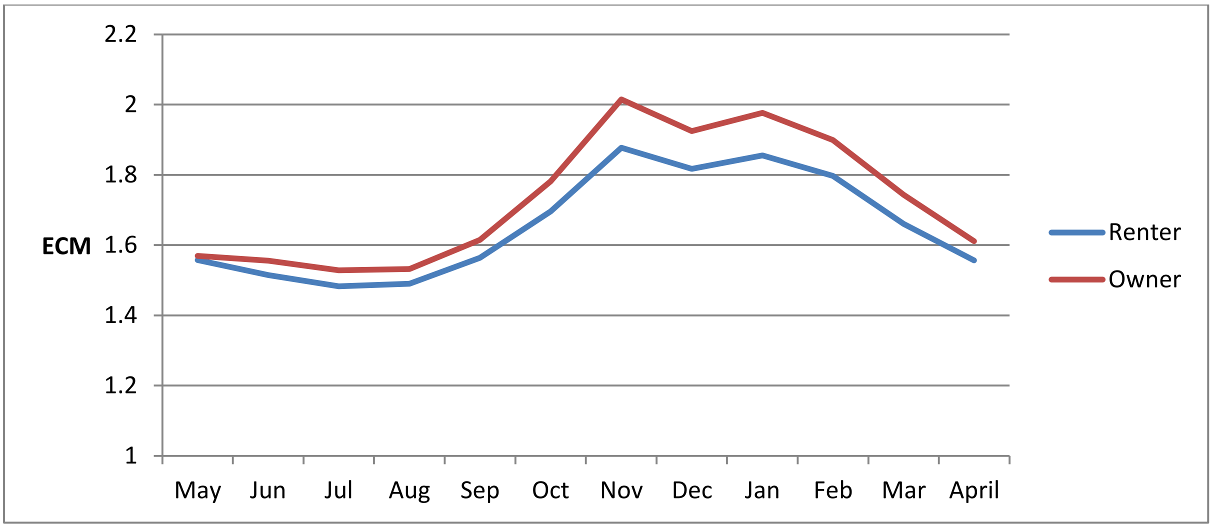


Figure 10 below shows average ECM for owners and renters in Test Cell 1, indicating that peak intensity of demand rises for both in winter; this is more pronounced for owners than for renters.

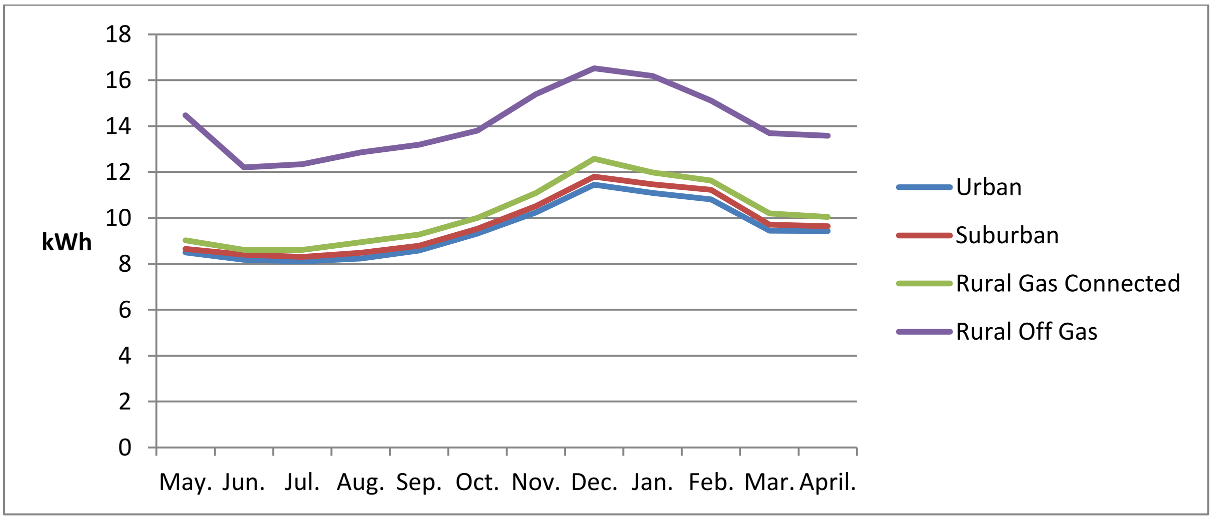
Figure 10: Evening Consumption Multiplier of owners and renters over 12 months



3.1.2.2. Rurality

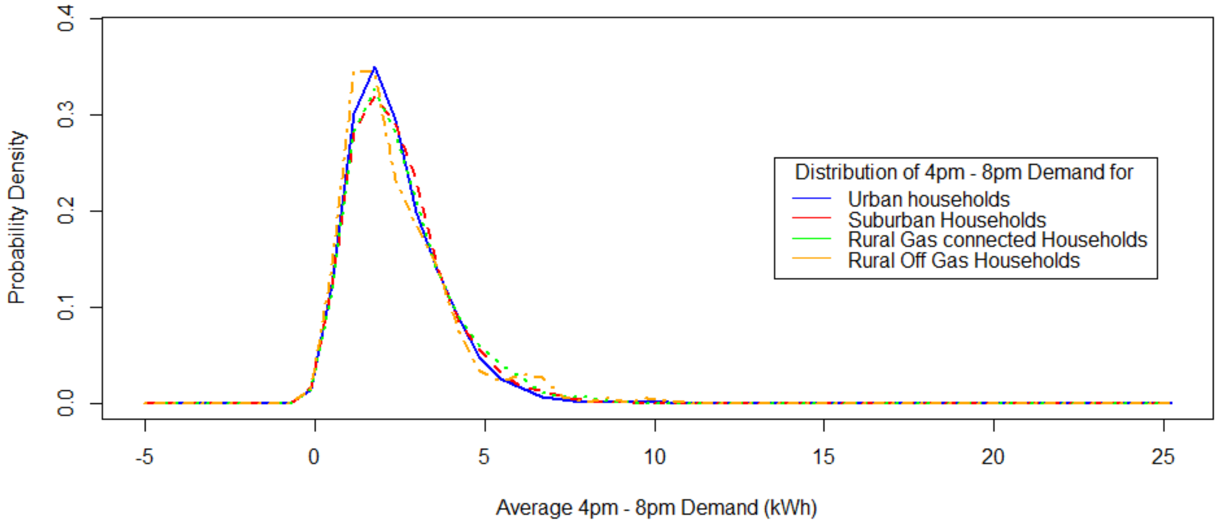
Analysing load profiles of those in urban suburban and rural areas shows that those in rural areas that are not connected to the gas network have a substantially increased demand for electricity throughout the year, as might be expected (Figure 11).

Figure 11: Average total daily electricity demand over 12 months by rurality



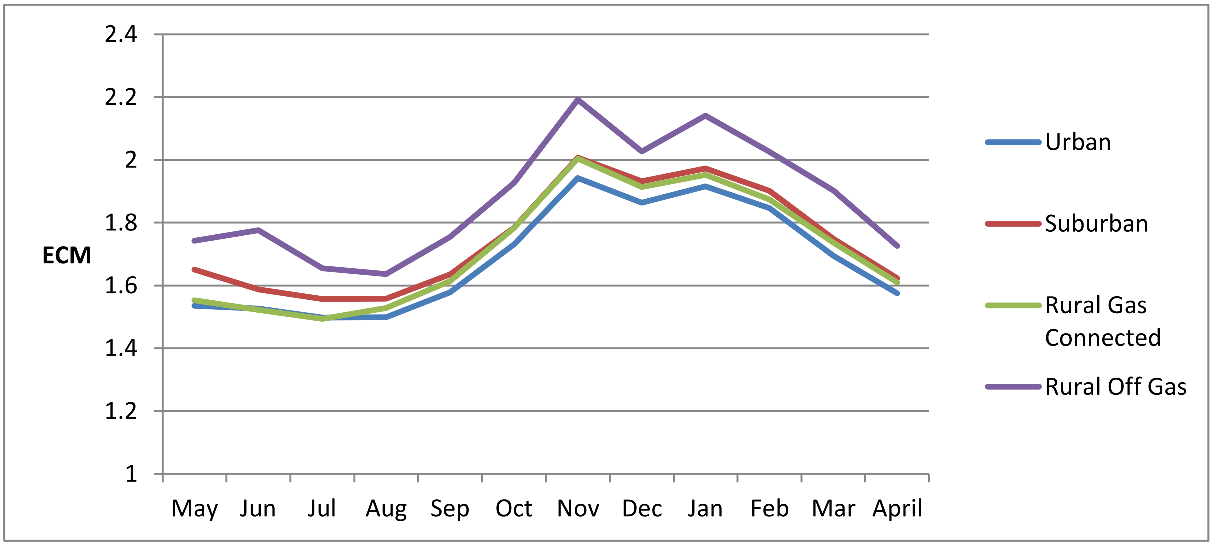
The distribution of peak demand across urban, suburban and rural households is shown below to be very similar to one another (Figure 12).

Figure 12: Distribution of 4pm - 8pm demand by rurality



As well as having the greatest average daily demand, Figures 12 and 13 also show rural off gas participants have substantially more peak intensive demand profiles despite having similar actual peak demand (kWh).

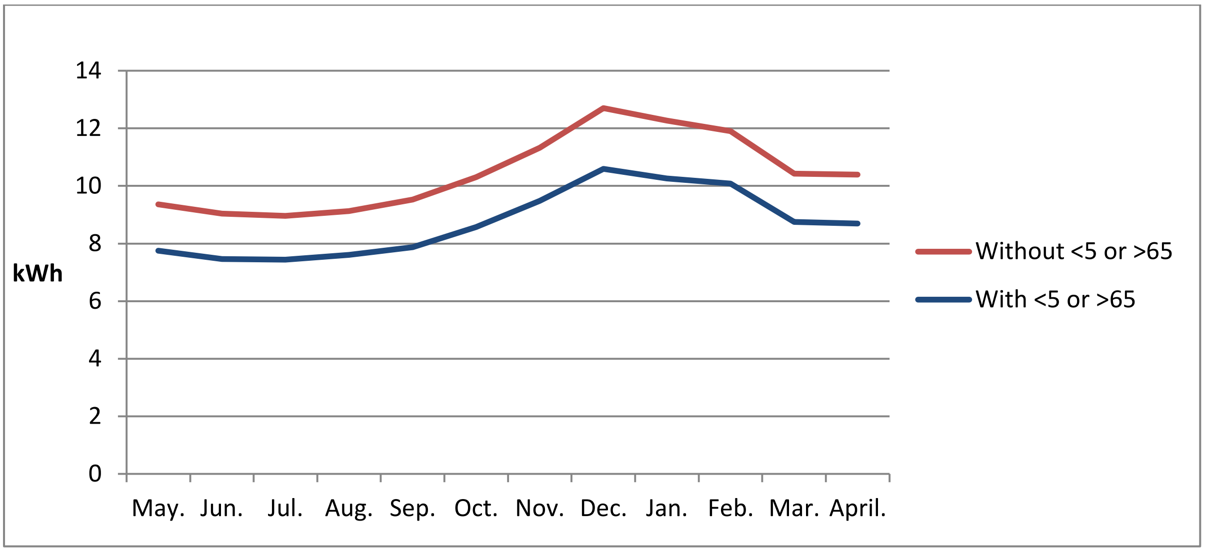
Figure 13: Evening Consumption Multiplier by rurality over 12 months



3.1.2.3. People under 5 or over 65 (U5/O65)

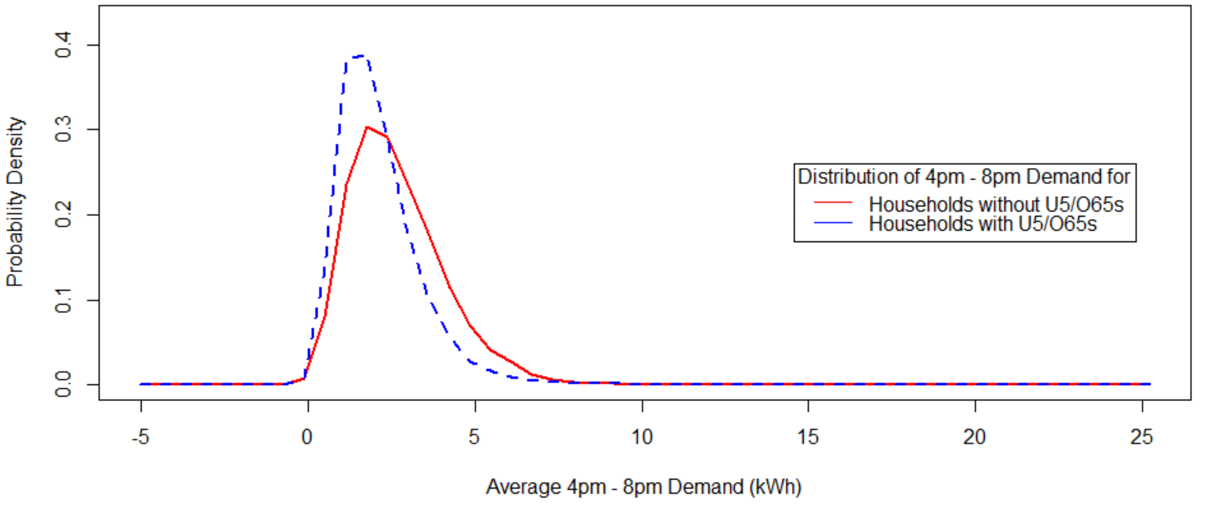
Households with people under the age of five or over sixty five are considered to have potentially greater energy use associated with spending more time in the home and requiring higher indoor temperatures. It is clear that there is consistently lower average daily demand throughout the year in homes without a U5/O65 present. This of particular interest as it goes against what has conventionally been found in relation to overall energy use, and suggests there to be important differences in the use of energy for heat or hot water and the use of electricity. Significance testing and analysis of interaction between this and other factors will be undertaken to investigate further.

Figure 14: Average total daily electricity demand over 12 months by presence or absence of over 65s or under 5s



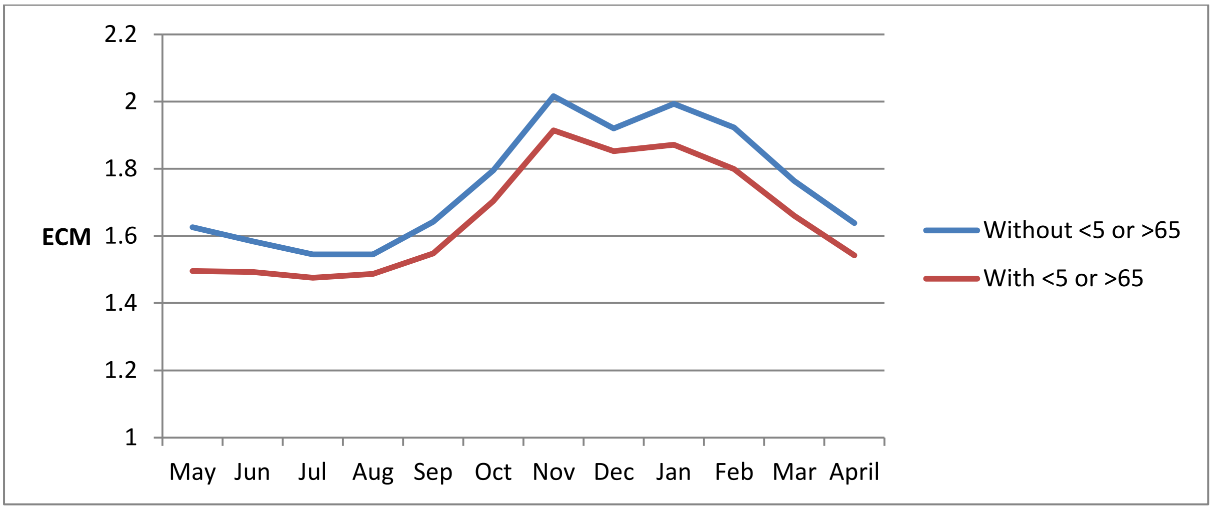
The distributions of peak demand for households with and without U5/O65s differ somewhat. Households with U5/O65 have a more uniform peak demand distribution at lower consumption levels than those without U5/O65 who have more variability and more likelihood of slightly higher evening peak demand. Median evening peak electricity consumption for households with U5/O65 is 1.86Kwh from 4pm – 8pm whereas for households without a U5/O65 the equivalent figure is 2.44kWh (Figure 15).

Figure 15: Distribution of 4pm – 8pm demand by presence of over 65s or under 5s



As well as having higher average total daily demand (as illustrated in Figure 14, above) households without U5/O65s are also more peak intensive than those without and that this is true for all 12 months of the study period (Figure 16).

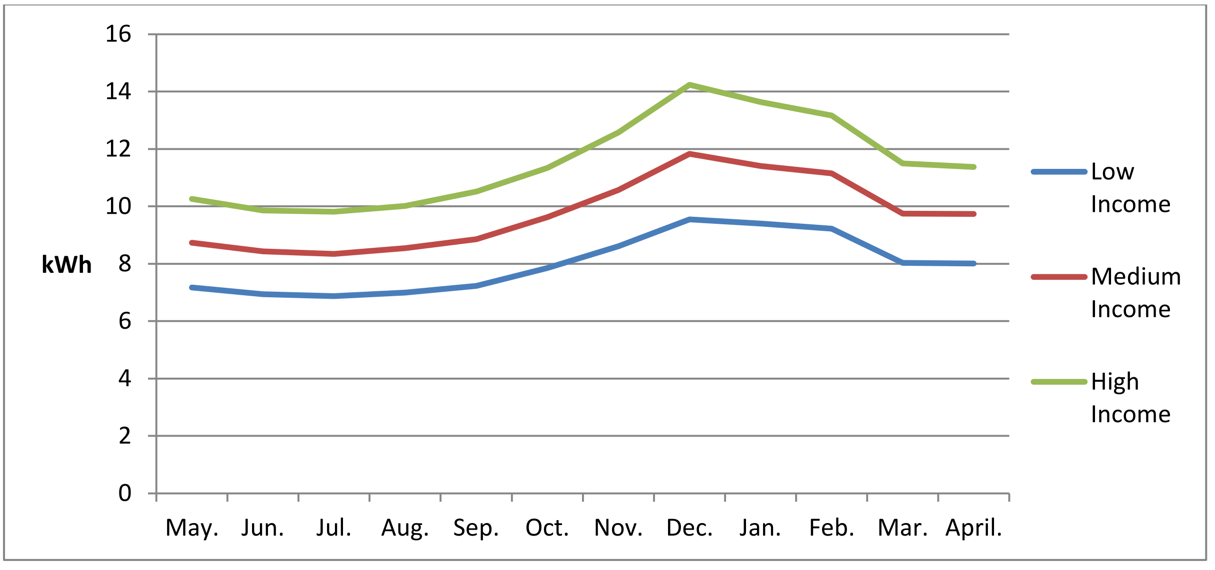
Figure 16: Evening Consumption Multiplier for those with and without under 5s or over 65s over 12 months



3.1.2.4. Income

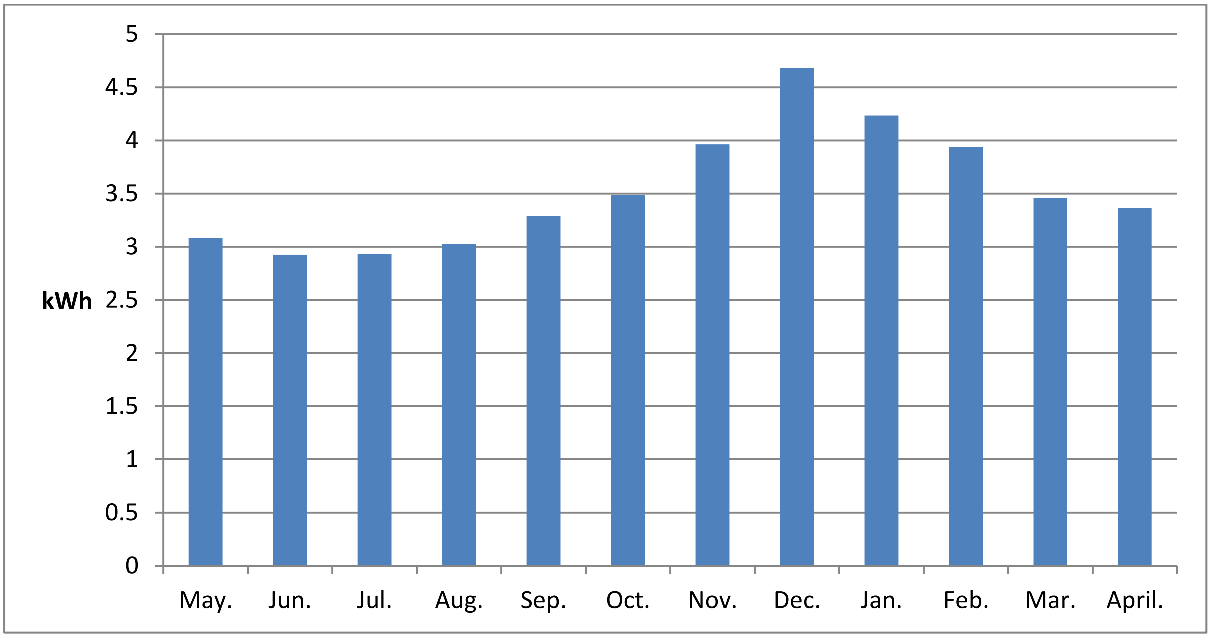
High income is associated with considerably higher demand. With the exception of rural off gas households in the rurality analysis, of the socio demographic variables recorded for Test Cell 1 it is income that is associated with the most divergent load profiles (Figure 17).

Figure 17: Average total daily electricity demand over 12 months by income



Of particular interest here is that the difference between high and low income groups varies substantially over the year. The 'income gap' – the difference between average demand of high and low income households – ranges from 2.9 kWh per day in the months of June and July to 4.7kWh per day in December (Figure 18).

Figure 18: Difference between average daily electricity demand for high and low income groups over 12 months



Looking at typical peak demand of different income levels shows distinct difference between the three groups (Figure 20). Low income groups have the most uniform distribution and greatest likelihood of having lower peak demand, and high income households have the least convergent peak demand and the greatest likelihood of having higher peak demand.

Figure 19: Distribution of peak demand by income

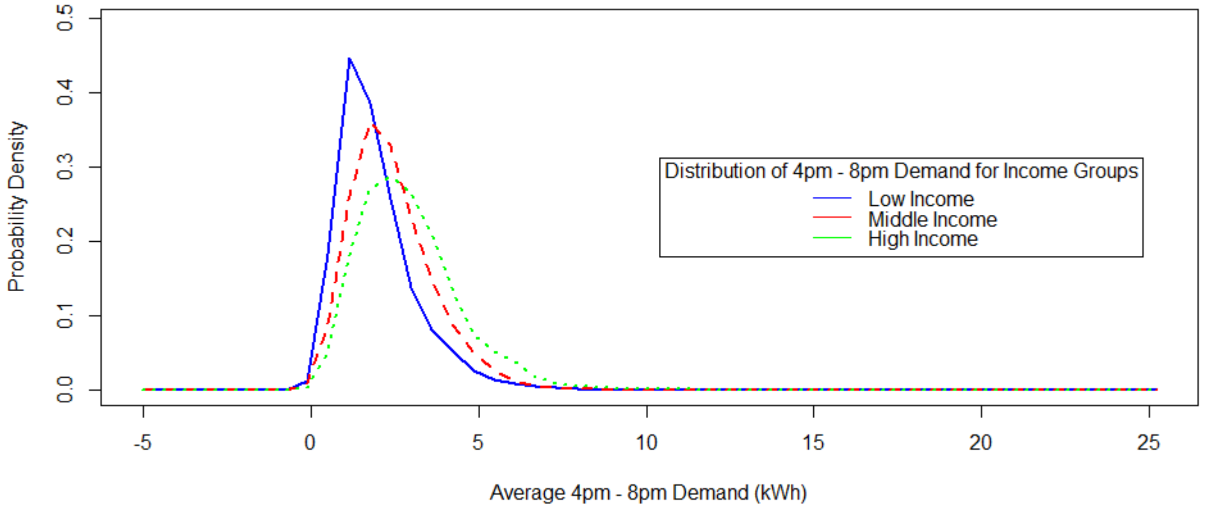
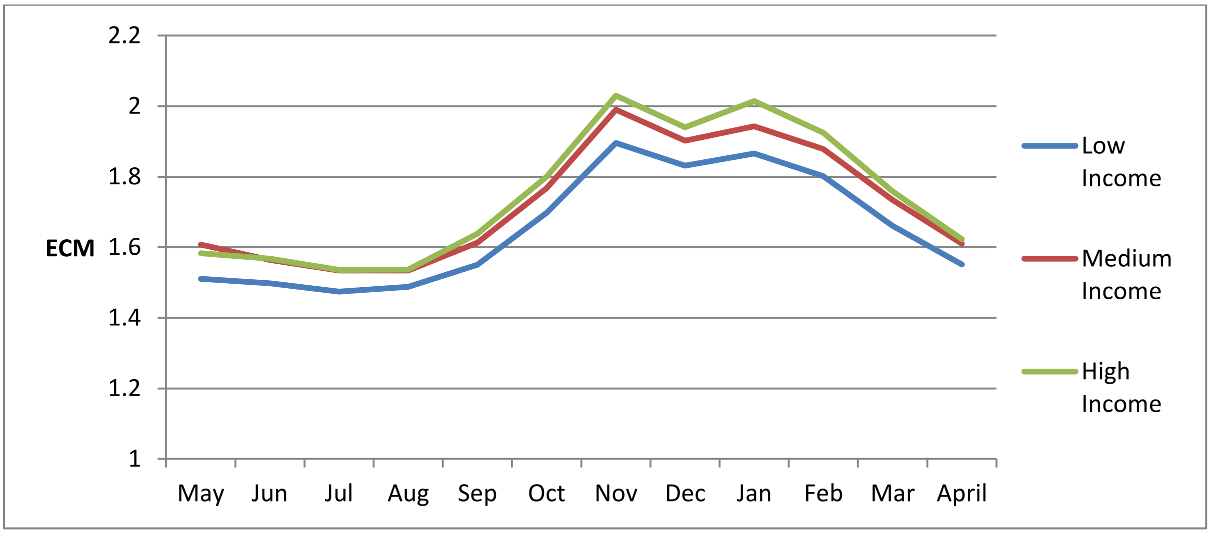


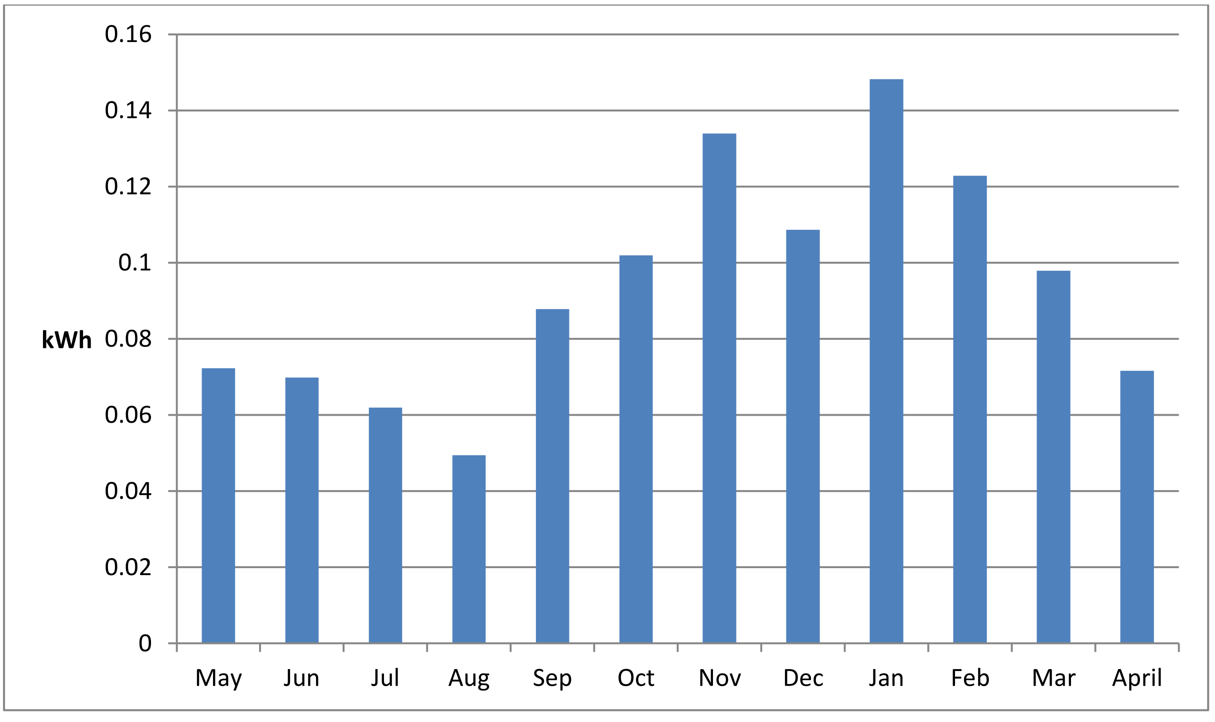
Figure 20 (below) shows average ECM for households in Test Cell 1 in high, middle and low income groups.

Figure 20: Evening Consumption Multiplier for high, middle and low income households over 12 months



High income groups had more peak intensive loads than lower income groups; this is true for almost all comparisons in all months (the exception is that high income groups have lower ECM than medium income groups in May). The difference between income groups becomes more pronounced as months become colder and darker, other than in December (Figure 21).

Figure 21: Difference between high and low income households' average Evening Consumption Multiplier over 12 months



3.1.2.5. Thermal efficiency of the home

Turning to analysis of the house itself, there is relatively little difference between the average electricity demand of households living in homes with high, middle and low thermal efficiency, although there is a slight increase in demand from those in low efficiency properties in winter months (Figure 22). As with all of the analysis conducted in this report, the extent to which this is compounded by other factors (e.g. age or income) has not yet been tested and will be examined in our further work on the energy consumption data.

Figure 22: Average total daily electricity demand over 12 months by thermal efficiency

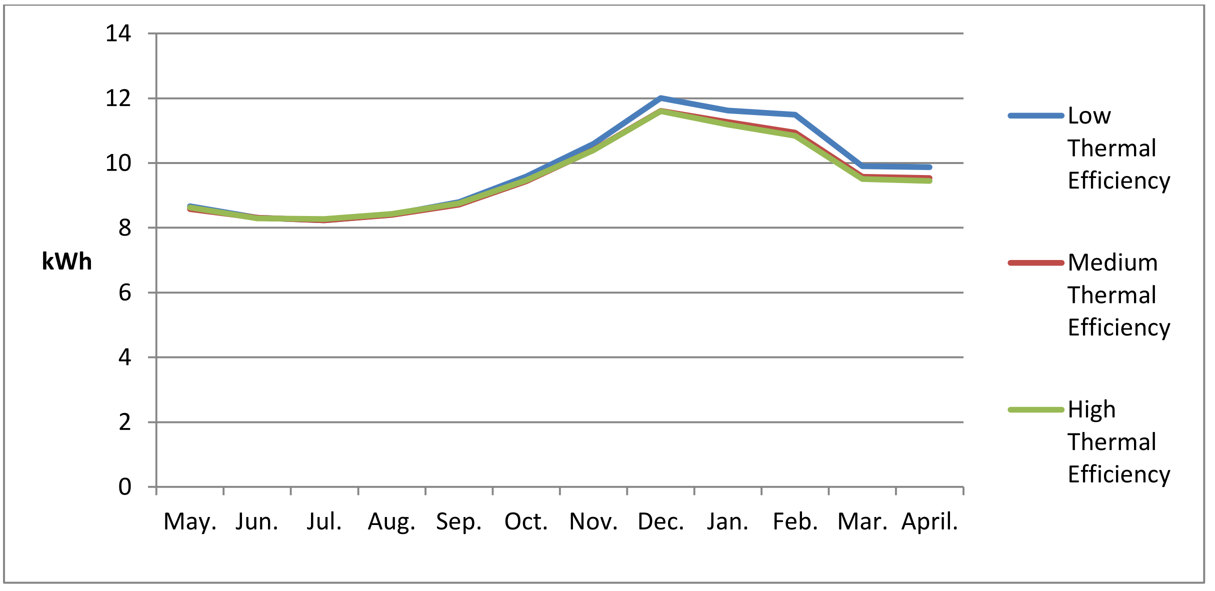
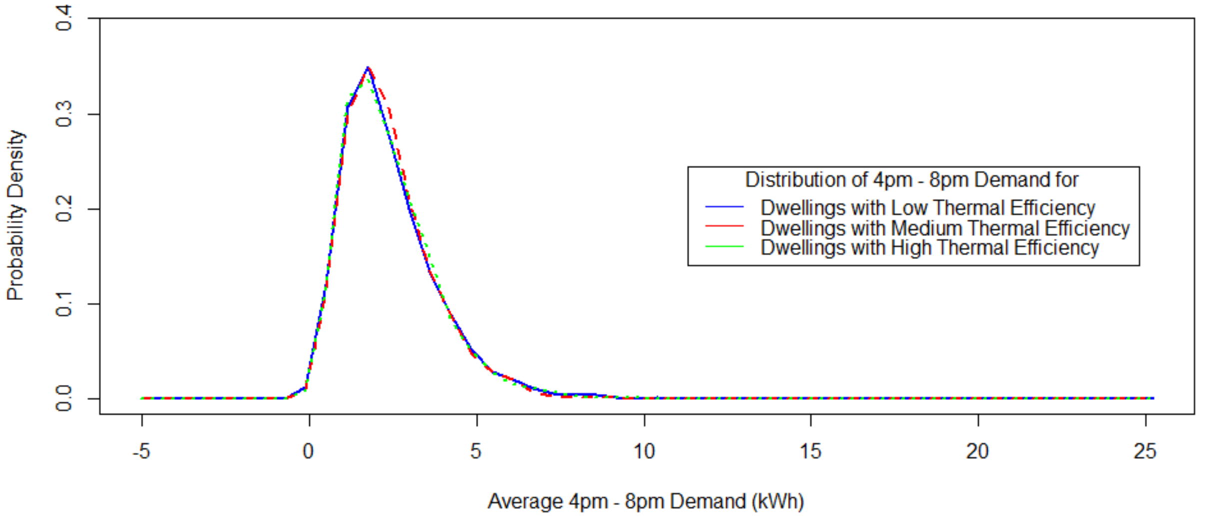


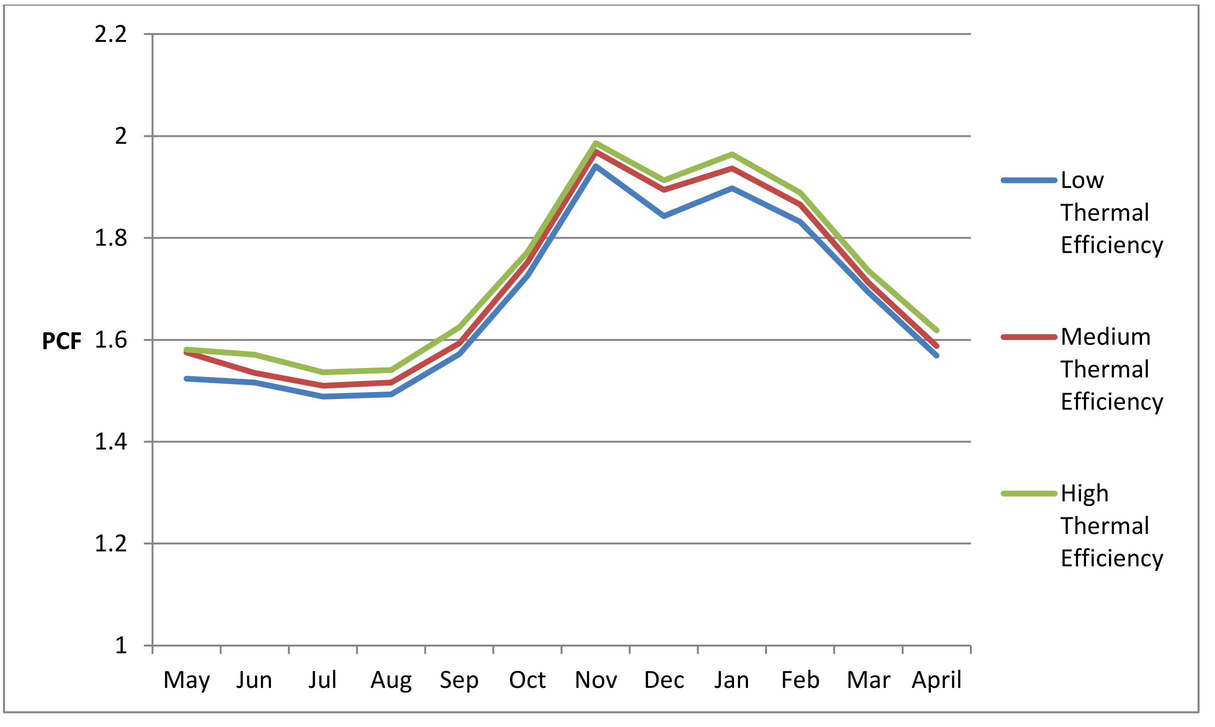
Figure 23 shows a probability density plot of evening peak demand for homes of different thermal efficiencies which indicates that distribution of peak demand is similar across all thermal efficiency groups.

Figure 23: Distribution of peak demand by thermal efficiency



While the previous figure shows that those in homes with low thermal efficiency have greater average daily demand, they also have the least peak intensive demand. As indicated in Figure 24 which shows the average ECM for households living in dwellings of high, medium and low thermal efficiency, those in better performing dwellings have more peak intensive demand.

Figure 24: Evening Consumption Multiplier by thermal efficiency over 12 Months



3.1.2.6. Attitudes

Attitudes towards energy use are often thought to guide the behaviour and choices of individuals. Despite strong critiques within the social sciences, this approach persists within policy and industry circles as a means of accounting for differences in energy use. We sought to test these assumptions through the social survey analysis conducted for CLNR using 383 responses to the online survey which could be linked to complete records of consumption data.

The final sample contained 231 male identified participants, 146 female identified participants and 6 participants who did not disclose a gender. Respondent age ranged from 23 to 89 years with a mean of 57.52 years (sd = 12.32). Household size ranged from 1 to 6 persons, with a mean of 2.32 (sd = 0.93). Average ages of all household occupants ranged from 17.25 to 89, with a mean of 52.69 (sd = 16.74). Twenty respondents reported the presence of at least one child under 5 years old in their household; 118 reported the presence of an adult over 65 years old.

In order to expose the underlying structure of attitudes towards energy use and the extent to which interventions should take place to manage energy use, all 29 attitudinal questions were entered into a Principal Components Analysis (PCA) which produced four significant factors explaining a total of 41.47% of the whole sample variance in responses to the attitudinal questions. These represent groups of attitudinal questions where responses tend to cluster, and are suggestive of four 'meta-attitudes' that householders report holding to a greater or lesser extent. Each factor is then created as a new variable in the data set, enabling simpler, robust analysis of attitudes. In order to interpret these new variables, their relationship to the original 29 questions was investigated. On the basis of this, the four components appear to relate to:

1. Attitudes toward government action.
2. Attitudes toward households' responsibilities.
3. Attitudes toward day to day activities.
4. Attitude towards the clarity of energy efficiency information.

Each of the four new attitude variables were entered as predictor variables into multiple linear regression models to test whether they are related to electricity use.

Average daily electricity use: Where the outcome variable was mean total electricity usage per day none of the attitudinal variables had any relationship with mean daily usage, as detailed in Appendix 3.

Mean daily consumption midnight - 7am and 8pm - midnight: Where the outcome variable was mean night-time electricity usage none of the attitudinal variables had any relationship with mean daily usage, as detailed in Appendix 3.

Mean daytime consumption 7am - 4pm: Where the outcome variable was mean day time electricity usage. None of the attitudinal variables had any relationship with mean daytime usage, as detailed in Appendix 3.

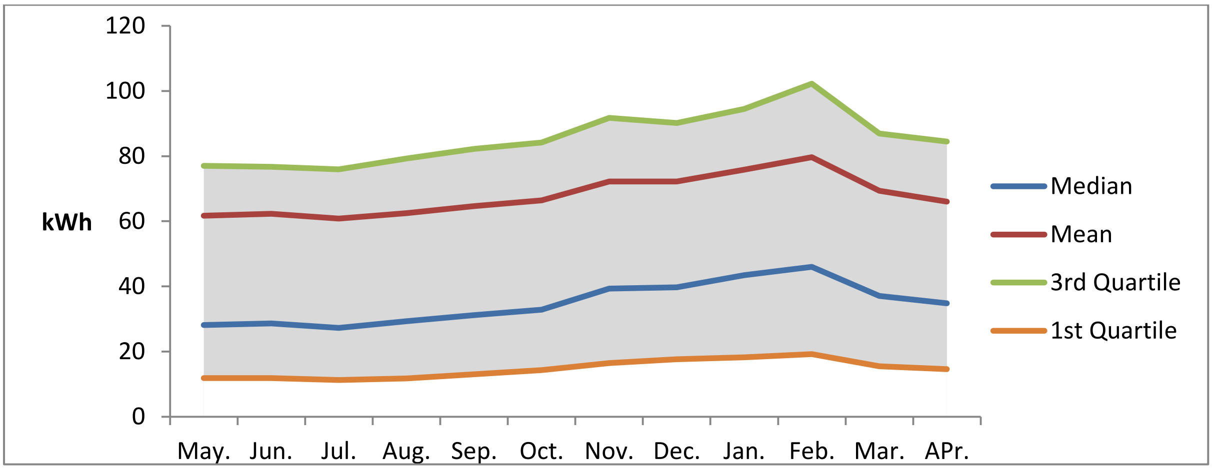
Mean daytime consumption 4pm - 8pm: Where the outcome variable was mean evening electricity usage none of the attitudinal variables had any relationship with mean daytime usage, as detailed in Appendix 3.

In summary, analysis across all time bands reveals that attitudinal data has no relationship with energy consumption.

3.1.3. Understanding SME Demand

Test Cell 1b provides an insight into typical demand profiles of SMEs. Figure 25 gives high level view how electricity demand varies over the sample of 1,795 businesses over one year. The chart illustrates the wide diversity of demand profiles for SMEs and the skewed-normal distribution (indicated by the substantial gap between mean and median). It also highlights that the consumption of electricity within any one SME is an order of magnitude higher than any domestic consumption, making these energy users of particular importance for understanding both current and future demand.

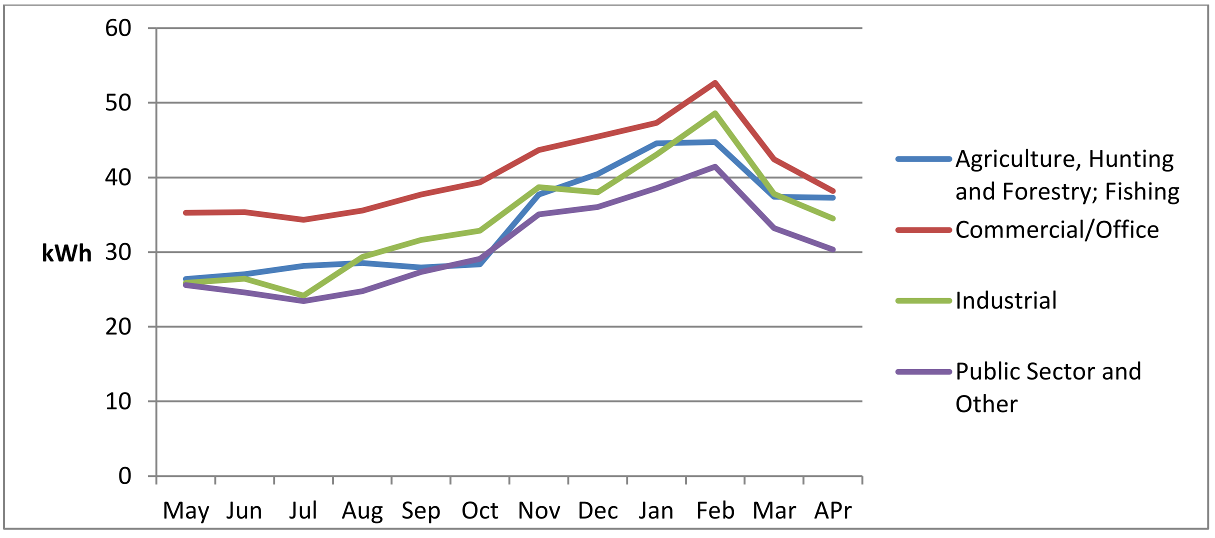
Figure 25: Average daily SME electricity demand over 12 Months



3.1.3.1. SMEs characteristics and energy demand

Looking in more detail at Test Cell 1b provides an insight into levels of electricity demand in association with organisation of different characteristics (Figure 26). In contrast with the seasonal variation of domestic electricity consumption, which rises to a peak in December, SME peak demand for all sectors is in January - February, after which there is a very steep decline to April consumption levels.

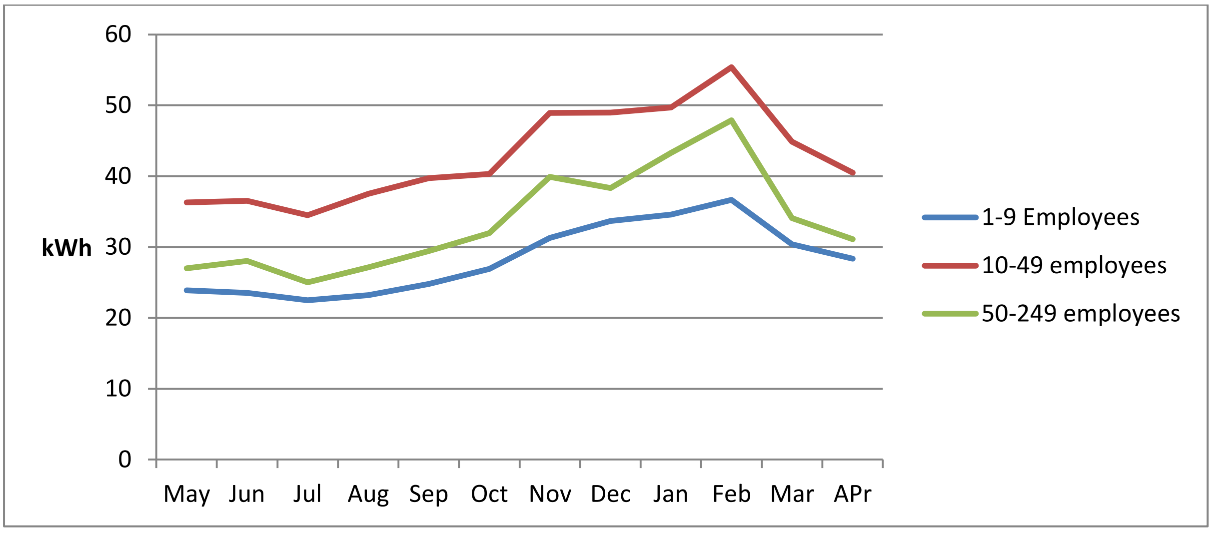
Figure 26: Average daily SME demand by sector for 12 months



Average daily demand is clearly highest for Commercial & Office enterprises and lowest for those in the 'Public Sector & Other' group. These groups were constructed by aggregating sectors in the top level of the 2007 Standard Industrial Classification of economic activities (SIC). Businesses in the highest consuming group could include those involved in wholesale and retail trade, hotels and restaurants transport, storage and communication financial intermediation real estate, renting and business activities while lowest consuming group includes education, health and social, work other community, social and personal service activities.

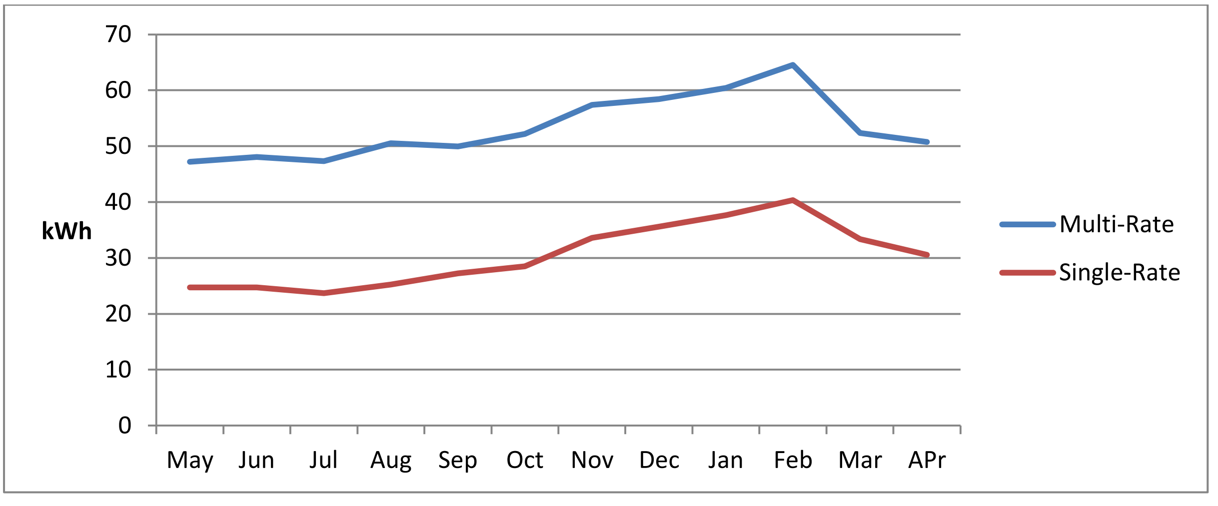
Medium sized businesses have the highest demand (Figure 27) suggesting that the relationship between number of employees and energy demand is not linear.

Figure 27: Average daily SME demand by number of employees for 12 months



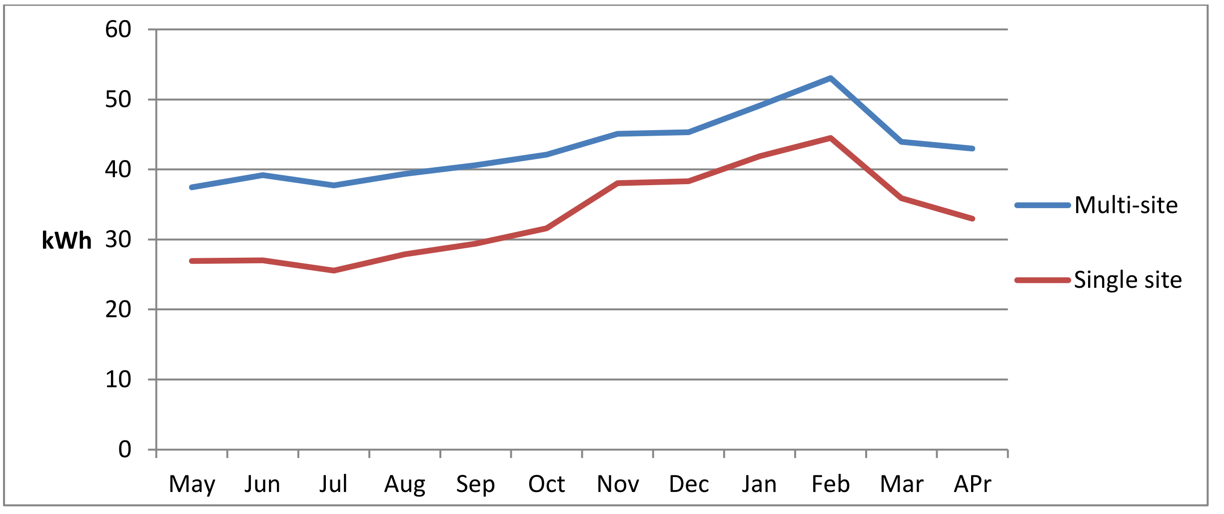
Organisations that have negotiated a multi-rate tariff have significantly higher demand than other businesses throughout the year (Figure 28), as might be expected.

Figure 28: Average daily SME demand by tariff type



Durham's initial evidence review revealed that energy use and the capacity to change energy use patterns in SMEs is partly determined by whether the SME is a single site organisation or part of a larger chain or group of organisations. These multi-site organisations have substantially higher demand than other organisations, particularly in summer months when single site businesses' consumption drops further than multi-site organisations (Figure 29).

Figure 29: Average daily SME demand by number of sites

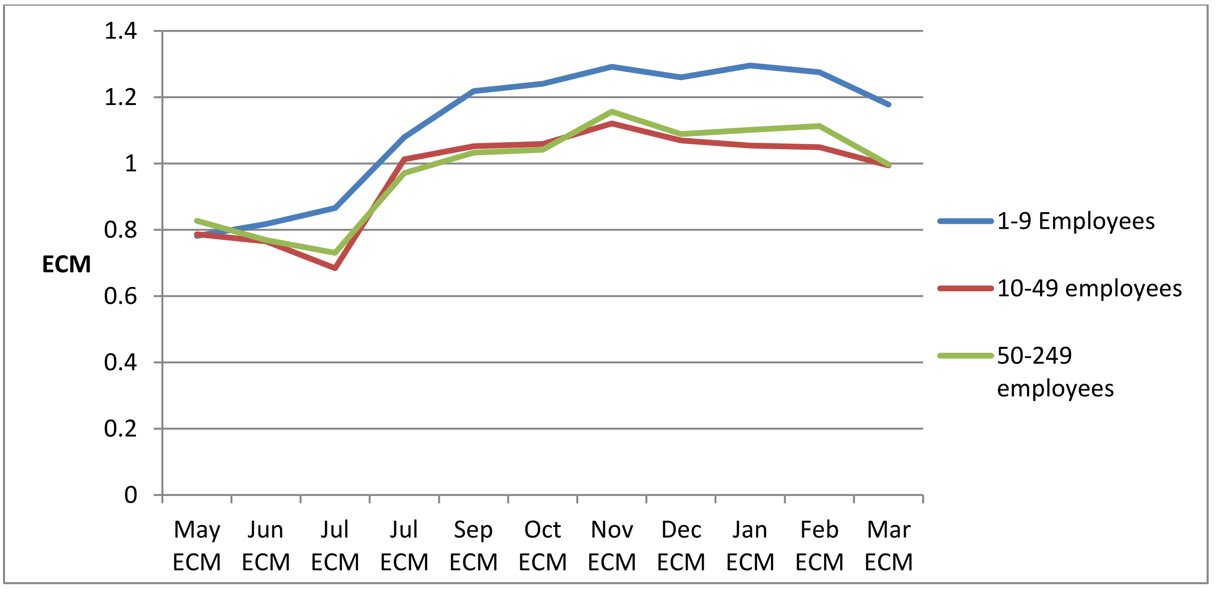


3.1.3.2. SME peak intensity

The previous section showed that businesses and other organisations in Test Cell 1b have highly varied energy use. We focus next on highlighting the difference between the peak intensity of the power demanded by businesses, and see that here too there is far greater diversity than in households; many businesses have a ECM of less than 1, meaning that on average these business consume less energy in the evening peak period than at other times of day.

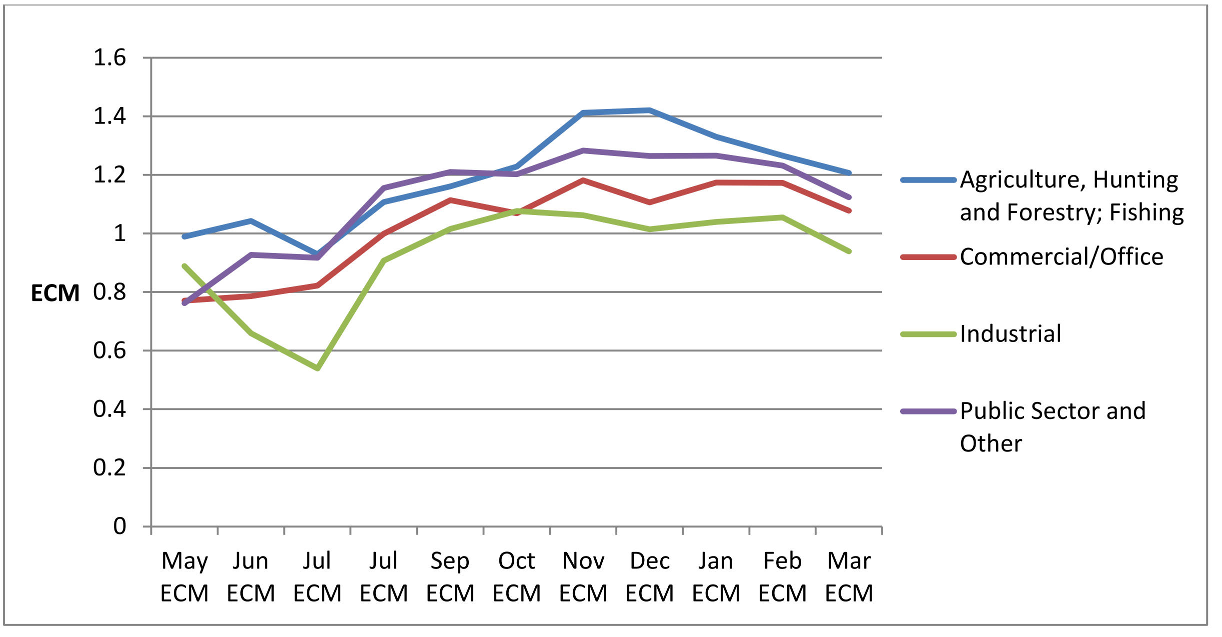
Smaller businesses tend to have more peak intensive loads (Figure 30), which suggests that larger businesses have demand that continues throughout the day and night whereas the smaller businesses in our sample are more likely to involve evening leisure and cooking activities, which will close down overnight.

Figure 30: Peak intensity of SME s with different numbers of employees



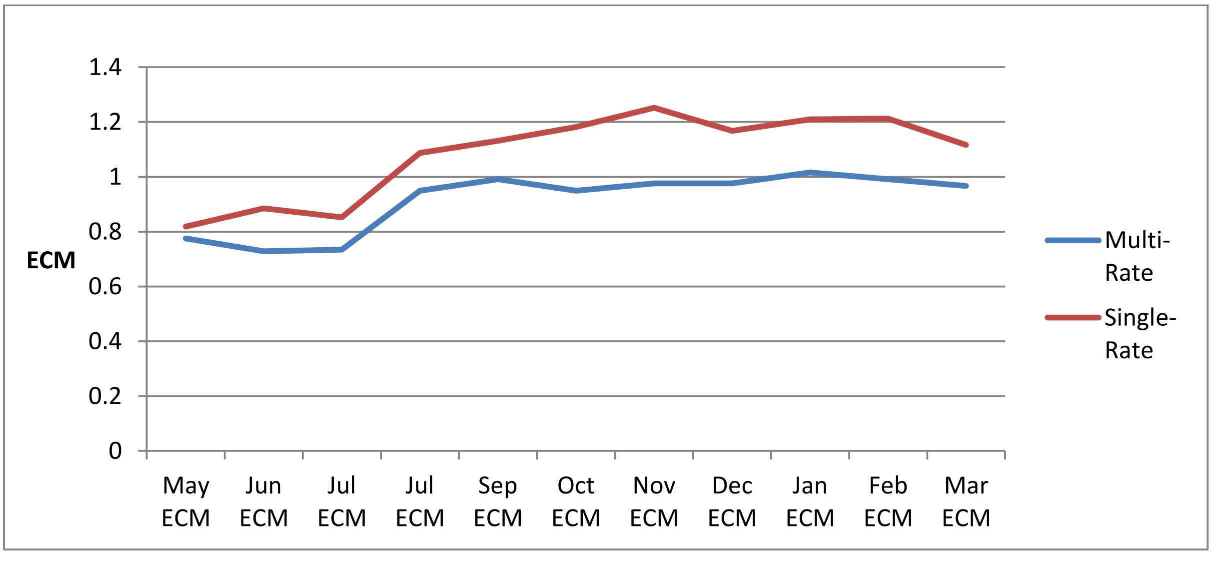
Peak intensity is shown to vary by sector: Figure 31, below, shows that industrial consumption profiles are least peak intensive while businesses in the combined Agriculture, Hunting and Forestry; Fishing sector are most peak intensive.

Figure 31: Peak intensity of SMEs in different sectors



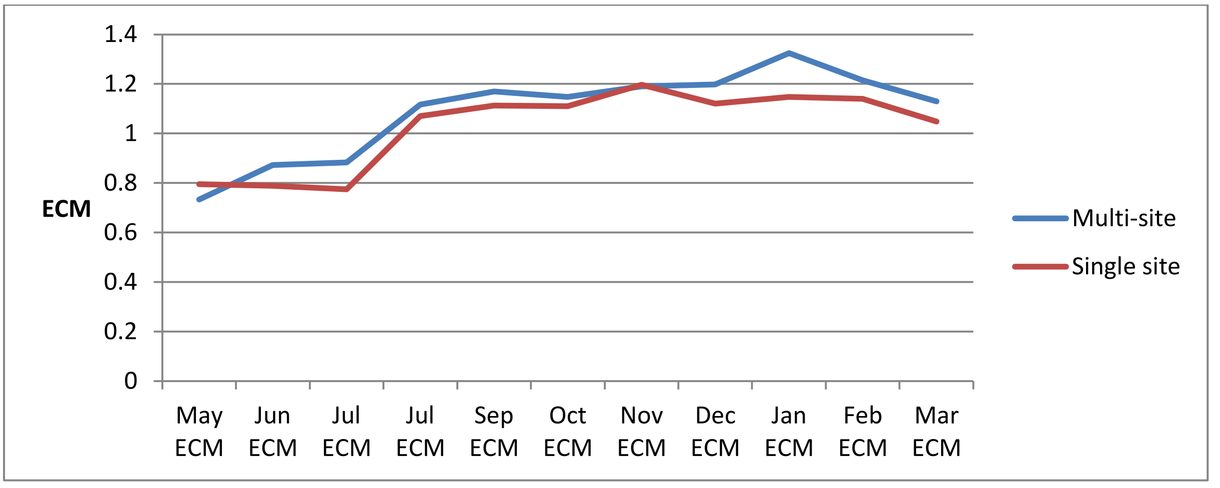
In comparing businesses with multi and single rates tariffs, it is clear that throughout the year single rate businesses are most peak intensive while multi-rate tariff businesses have an ECM close to 1 throughout the year (Figure 32). This is to be expected and reflects the factors that lead businesses to negotiate multi-rate tariffs – most notably that such businesses are operational through the night and can take advantage of off peak electricity. This night-time activity leads to an ECM close to 1.

Figure 32: Peak intensity of SMEs with different tariff types



Peak Intensity for multi- and single site enterprises is less clearly divergent, although in winter multi-site organisations become more peak intensive than their single site counterparts (Figure 33).

Figure 33: Peak intensity of SMEs with different numbers of sites



3.2. Which practices are currently giving rise to electricity use in domestic contexts? (LO1.1.1)

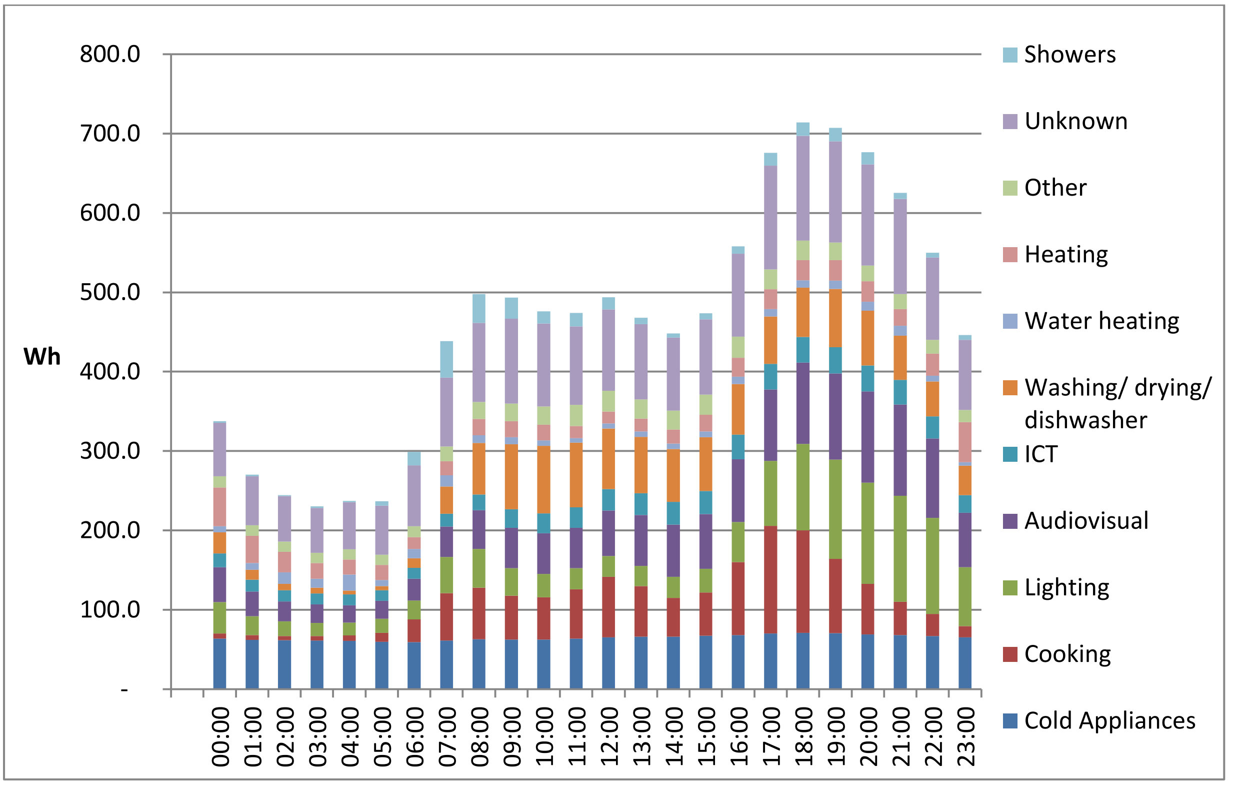
The previous analysis suggests that socio-demographic and housing variables offer some indications of how energy demand varies across different social groups in the domestic sector. However, there is limited evidence that these factors can explain the significant variance in demand and peak intensity. Furthermore, recent research in the social sciences suggests that rather than being driven by attitudes and behaviour, energy use can be understood in relation to the practices that people undertake. Practice-based approaches seek to understand how the everyday activities of domestic life, e.g. cooking, washing, entertaining, might influence the ways that energy is used, and in particular when and by whom it used. Importantly, practice-based approaches bring to the forefront of analysis not only individuals and their actions, but the 'things' through which energy use is mediated – cookers, lights, TVs, portable heaters and so on. In this report, we examine how a practice-based approach can inform our understanding of how and why energy is currently used.

A practice based approach means that rather than focusing on whether people or groups of people do or do not use energy or are more or less flexible, we focus instead on the extent to which different practices give rise to electricity use and their current and potential flexibility. This is in line with current research and thinking in the social sciences on the energy consumption and loads associated with everyday life (see Bulkeley et al. 2012; Gram-Hanssen 2010a; Gram-Hanssen 2010b; Halkier et al. 2011; Hinton et al. 2011; Pink 2005; Shove & Pantzar 2005).

The practices that are of most direct interest to this study, and associated with the bulk of energy consumption in the home, are cooking, heat and hot water, lighting, bathing, chores, entertainment, and standby and 24hour loads as identified in the first interim report from the social science team at

Durham.[5] Data available from DECC[6] provides a breakdown of average daily energy consumption per hour by major appliance groups. These data come from average electricity use profiles from 250 households, monitored over 12 months using meters on total electricity use and most appliances as part of the Household Electricity Use Survey 2010-11. Figure 34, based on this survey, shows that cooking, lighting, audio-visual and unknown appliances are most associated with increased energy use in the evening peak period. We will seek to develop our understanding of the appliances and practices that contribute to peak demand through the analysis of data from Test Cell 2 as it becomes available.

Figure 34: Household average daily electrical use per appliance by hour



3.3. Which of these practices are the most intensive in terms of electricity use? (LO1.1.2)

The practices which might be most directly relevant to demand side management debates are those with a likelihood of being performed during the 4pm – 8pm period and with a high electrical load. We conducted an analysis of these factors using the qualitative data collected as part of CLNR project and through reference to the CREST model of domestic electricity consumption (Richardson, et al. 2010)[7] (Table 5).

[5] DEI CLNR Social Science Interim Report 1
[6] https://www.gov.uk/government/publications/energy-consumption-in-the-uk
[7] http://homepages.lboro.ac.uk/~eliwr/

Customer-Led Network Revolution

Table 5: Practices associated with the 4pm - 8pm peak period

Practices	Employed Electrical Appliances	4-8 Peak Likelihood[8]	Typical Electrical Load[9]	Electrical Load Band[10] Mean Duration (mins)*	Proportion of Dwellings with Appliance*[11]	Ownership Band[12]	Peak / Load / Ownership	Rational for possible DSM Contribution
Other Household Chores	Iron	Middle	1.00kW	High 30 min	90%	Very High	M/H/VH	Load intensity, possibly in peak
	Vacuum	Middle	2.00 kW	High 20 min	93.7%	Very High	M/H/VH	
Electronic Entertainment and Work	PC / Console	High	0.14 kW	Low 300 min	70.8%	High	H/L/H	Mass participation in peak
	TV	Very High	0.12 kW	Low 73 min	97.7%	Very High	VH/L/VH	
	TV Receiver box	Very High	0.03 kW	Very Low 73 min	93.4%	Very High	VH/VL/VH	
Cooking and Washing Up	Hob	Very High	2.40 kW	High16 min	46.3%	Middle	VH/H/M	Load intensity, mass participation in peak
	Oven	Very High	2.13 kW	High 27 min	61.6%	Middle	VH/H/M	
	Microwave	Very High	1.25 kW	High 30 min	85.9%	High	VH/H/H	
	Kettle	Very High	2.00 kW	High 3 min	97.5%	Very High	VH/H/VH	
	Dish washer	Middle	1.13 kW	High 60 min	33.5%	Low	M/H/L	
Laundry	Tumble dryer	Middle	2.50 kW	Very High 60 min	41.6%	Middle	M/VH/M	Load intensity, possibly in peak
	Washing machine	Middle	0.41 kW	Middle138 min	78.1%	High	M/M/H	
	Washer dryer	Middle	0.79 kW	Middle198 min	15.3%	Low	M/M	
Bathing	Electric shower	Low	9.00 kW	Very High 5 min	67%	Middle	L/VH/M	Split: Load intensity for electric showering and mass participation of child bathing
	Central Heating Pump	Middle	0.6kW	Middle	90%	Very High	M/M/VH	
Refrigeration	Chest freezer	High	0.19kW	Low	16%	Low	H/L/L	Mass ownership, reliable peak load
	Fridge freezer	High	0.19kW	Low	65%	Middle	H/L/M	

[8] Likelihood based on CLNR qualitative data analysis
[9] All figures (kW, kWh, minutes and % of dwellings are taken from CREST model of domestic electricity consumption other than Central Heating Pump. See http://homepages.lboro.ac.uk/~eliwr/
[10] Load Band Definition: Very Low = <0.99kW, Low = 0.1 – 0.2.99, Middle = 0.3 – 0.99kW, High = 1kw – 2.49kW Very High = >2.5kW
[11] The % of households with an appliance is taken from the CREST model but in future work we will integrate the findings from the social science survey regarding technology ownership.
[12] Ownership Band Definition; Very Low = <10%, Low = 10 - 29%, Middle = 30 – 69%, High = 70 – 89%, Very High = >90% or more

This analysis suggests that the practices of most direct interest in terms of their potential ability to play a part in demand side management of the electricity distribution network are laundry, dish washing, and other household chores, cooking and dining. Electronic entertainment and showering, although listed in Table 5 either have low electrical intensity (entertainment), or are perceived by respondents to be less flexible (both bathing and entertainment). Nonetheless, we retain evidence of the nature of these practices and how they are important in the 'peak hour', not least because our research suggests that the peak is produced by the interaction of multiple practices being conducted at the same time – many of which are dependent on one another (e.g. putting the kettle on to make hot drinks to consume while watch evening scheduled; soap operas on television).

3.4. What are the factors that shape the use of electricity for these practices? (LO1.1.2)

In this section we consider what factors are affecting the use of electricity. The conceptual approach developed through this project and the analysis we have conducted across the test cells reveals that energy use is shaped by the interaction of five 'cogs' or core elements, which we describe in the CCRES Model (Capacities, Conventions, Rhythms, Economies, Structures, referred to in Section 2.6).

3.4.1. Structures

Structures take different forms, and may include employment schedules, school hours, building structures, layouts and materials, systems of energy provision, family structures, household life-stages and social classification.

3.4.1.1. Work

Interview data indicates that work regimes significantly influence when and how household practices are carried out, shaping patterns of energy use. Participants work patterns fall into three broad categories: conventional working hours (Monday to Friday); shift working (including weekend working); ad-hoc or flexible working. Those working typically Monday to Friday, 9 to 5:30pm express being squeezed for time, and find it challenging to fit domestic duties around their working hours – with dish washing done in the mornings before work, and cooking, cleaning and laundry done mainly in the evenings after arrival from work. Sometimes these tasks are shifted to weekends – but informants prefer to leave the weekend free for family time or leisure activities. These households employ various technologies and other 'devices' to assist in juggling the different demands, including using automatic timers (for dish washing and laundry), and employing a cleaner:

> *In an ideal world where we didn't have so many time pressures and we could choose when to do things like the washing or the cooking, and there were cheaper or more efficient times to use energy then we probably would. Not with a family and two jobs at the moment. (EPJ017)*

> *I tend to wash and dry on a Saturday. Habit. I'm not working so that's when the washing gets done. … I don't know how I could change the way I cook. … No 'cause work. (DL13)*

> *I am [cooking a meal] for my wife coming home from work. (GP2702)*

Friday I would come in from work ... the hoover would be on. The washer would be going. Right the way through probably 'til 10 o'clock that washer will go. (EPJ014)

It would be very awkward for us … we work days (GDP049)

I come home from work and I would put a wash in. .... I work in a fish shop so it's a bit smelly. (DL08)

[Laundry] is mainly done on my wife's day off. She's off like every Monday and Friday. So tends to do the ironing and washing. (EPJ020)

Usually on a Thursday … that's my day off. And throughout the weekend … I get the whole weekend off. … Big washing gets done on Saturday, bed sheets that sort of stuff. Saturday or Sunday. (GDP051)

[Dish washing] Every day. Once a day … It's probably either first thing in the morning or teatime when we're in. It can be during the day though. … it just depends who's in. My stepdaughter works … she's got mid-week days off so she starts at 5am and finishes at 3pm. … Predominantly it's in the morning before we go to work or when we come back from work but there are other times … in middle of the day when it gets used as well. (EPJ019)

We're out early on a morning. On the days my wife isn't off, we're out the house half past 7- 8 o'clock. … (EPJ020)

Kids' activities, football, daughter's horse riding so Saturdays we're out between 10am and 3pm anyway. (EPJ020)

Those who work shifts also talk about fitting household routines around their working hours but have more opportunity to shower, or to accommodate cooking and household chores outside of the morning or evening peak periods.

We don't work Monday to Friday, so it's not that we have to do things during that time [4pm – 8pm] (GDP028)

Although those not in full time paid employment, including those who do casual work, have greater freedom in household management and organising household practices, this may not follow because practices are arranged around the needs of other household members, for example children's activities. Retired people or those not in work report being able to exercise greater freedom around when they carry out household practices. Even so, household practices often scheduled by doing chores at a specific time of day or certain day of the week, or fitting around other activities, such as going out or watching a favourite TV programme. Indeed, we found these rhythms to be very important for these households (as illustrated below).

I only watch one soap and that's Emmerdale. I make the dinner, watch Emmerdale then do what I've got to do. If I'm in that's what I do. (GP0026)

Well, I'm up at 6'oclock in the morning so I like to tidy up in the morning so that's me finished for the day. (MJRTL012)

[Vacuum] three times a week … That would be in the mornings, definitely. (EPJ008)

I'll use the hoover [vacuum] on the morning. I use that every morning. (GP0025)

Hoovering [vacuuming] in the morning… normally washing, now that I've got all day (GP042)

I plan in advance always. But not today – I was going out shopping today but I won't go out when there's bad weather but yes, I plan my weeks. (MJRTL13)

For some, mealtimes are often routinised, a practice carried over from family, or previous employment patterns:

Start it [dinner] about 7 o'clock. … Habit we got into when we were both working. (ML23)

I can't see us changing our eating habits – which is what uses most power... So firmly ingrained that we have our main meal in the evening. (ML23)

As a family, we've always had our meals early evening, and if you go past 8 o'clock at night you're getting late, and I'm starting to want to go to bed earlier, so it's difficult to get out of that of using the oven at that time. (DL0602)

However, there is evidence of alteration in practices following retirement, and definite change in structures, through having more time to reflect and re-organise:

I am retired now so time to think about things (DL010)

You come in from work and think I have to do the washing, got to do this, got to do that, got to do the other, 'cause you have to do it while you were there. … I think it's entirely because of being retired. I don't think we would have done some of these things had we had still been at work. (HS001)

Hoovering [vacuuming] in the morning. Normally washing, now that I've got all day – at one time I used to wash at night coming home from work but not anymore. (GP042)

Most of my meals are cooked before 4 o'clock comes around. It's a case of it's just heating it up … Mostly it's been done through the day anyway … (GP0022)

> *Female: I don't think I can wait until 9 o'clock for my dinner. I couldn't eat at 9 o'clock then go to bed.*
> *Male: What you'd have to do is have [our] dinner at 4 o'clock.*
> *Female: And that's alright for us 'cause we're not working (GP0025)*

Employment patterns also relate to the material elements of practices and how certain technologies, such as tumble dryers are used within the home; this is discussed later in section 3.4.5 Capacities.

3.4.1.2. Household structure

Analysis demonstrates that practices and how they are performed relate to household structure, composition and life-stage. For families with young children, everyday practices such as cooking/eating, cleaning, laundry and bathing are organised around their needs, school and other routines. In families with older children, routines may be more fluid with events such as mealtimes less structured, and people eating at different times, so that there are various 'parallel electricity lives' being lived in the same household:

> *With a 16 and 19 year old … they're out all the time. … we cook when people are wanting food. (DL13)*

> *I don't cook a lot anymore, with being on my own. … usually use the microwave on the teatime. It got the stage years ago where they all wanted different things but now they just all do their own. And usually it's, if it's a pizza they use the oven, but it's mostly microwave stuff. … He (son) doesn't eat 'til really late. Sometimes I'll be going to bed at half ten and he might say "I'm going to have a meal now". I think "How can you do it?", but that's what he does. (GP021)*

A further aspect of household composition and age is a connection to health and wellbeing. Welfare is prioritised in some participants' explanations of their energy use; concerns over poor health in particular lead to increased need for reliable, controllable heat. While for now, this aspect mostly affects gas consumption, however, if heating is to be electrified in the coming decades via heat pumps, as per DECC's Carbon Plan (Department for Energy and Climate Change 2011) and Heat Strategy (Department of Energy and Climate Change 2013), as the population ages, health and well-being will become increasingly powerful drivers of domestic electricity consumption.

> *I grill things rather than fry them because I've got high blood pressure, and my husband had heart trouble so I was always taught to grill. My mother also used to grill rather than fry. (ML06)*

> *[Interviewer: Could you cook your tea earlier or later than you do at the minute?]*

> *Respondent: No. I wouldn't do it. I couldn't do it. Na, Na. Me' grandson comes for his dinner, says I'll be here 5:45 so I couldn't. I'm set in my ways now, I never used to be but since I had all this done [medical treatments] I don't even go out at night." (GPML004)*

> *The heating is on a lot more now because I've got to keep warm, but that radiator's not on because I get too hot. I've been washing more, I'm washing every day now, and ironing more obviously. The district nurse says she can't believe how well I'm doing. (MRJTL03)*

> *If I get too hot I turn it off completely rather than turn the radiators down. And I have the windows open because I like to get some air through the flat. The doctors tell me to try to keep my fingers and toes warm. (MRJTL06)*

3.4.1.3. Building structures

There is evidence to suggest that spatial constraints within dwellings influence people's selection of appliances or systems, leading to sustained effects on energy demand:

> *[I needed] a cooker that would fit into this station here. I always wanted a range cooker but I couldn't get it in here. I had to do with this one. It's got 4 rings, 2 ovens. (ML07)*

> *That one [fridge freezer] is fairly new…It's alright - don't think it's top of the range [energy rating]. … It was a decent size, you know and we had to fit it into that slot. (EPJ013)*

Many of the owner-occupiers interviewed have extended their dwellings to create additional space. Commonly, this is to provide a larger kitchen/family area, utility/laundry room, additional bedrooms and bathrooms, with associated new, often larger appliances such as fridges/freezers, cookers as well as dishwashers, tumble dryers, electric showers and additional lighting – which have implications for energy use.

> *There was just one [bathroom] but there is one en-suite now. So there's an additional [electric] shower gone [fitted] in the bathroom. (GDP052)*

> *The dryer – that's on more than it should be. But it's just too easy to go from the washer and [into the] dryer in the same room. (EPJ020)*

3.4.2. Rhythms

Rhythms are the multiple time patterns that operate daily, weekly, monthly, annually through which activities are more or less organised. Rhythms affect the workings of habits, how they are paced and located in time and place as well as how people are able to exhibit freedom or constraint in their activities. Rhythms can have starting points, triggers, which lead to certain practices, such as a TV show finishing and a kettle being boiled , and also set the pace for periods of activity and periods of rest between the performance of practices. These rhythms are both related to wider social structures (e.g. work, school, family composition) but also take on their own form depending on personal histories and expectations.

I tend to wash and dry on a Saturday. Habit. I'm not working so that's when the washing gets done. (DL13)

I usually put it on [washing machine] on a Tuesday night – overnight… just a habit I've got into. ... Used to be cheaper on a night, don't know if it still is. Habit. (EPJ003)

[Interviewer: When do you do your laundry?]
Once a week. All day on a Monday. I go right through the house. I'm in on my own so I can get on with it. Washing and ironing as well. All at the same time. … Beginning of the week and the end of the week, when there's enough to go in the washing machine, that's what I like to do. (EPJ018)
I don't hang it outside (laundry), I just chuck it in the dryer – it's easier. I have always done that … since I've been divorced. … It's convenient, that's all. […] I don't go out on a night-time. So all you do is watching the telly, so put washing in and when it finishes, you chuck it in the dryer. (ML12)
I have to wash them straight away. If leave these on the bench it makes my kitchen look untidy, it's so small. So I'm always washing up. … It's what I've been used to. (EPJ009)
I can't see us changing our eating habits – which is what uses most power. ... So firmly ingrained that we have our main meal in the evening. (ML23)

3.4.3. Economies

The term 'economics' is usually used in relation to energy to signify the costs of fuel and the attitudes and responses of households to these costs. At the same time, it is evident that people do not respond in rational or utility maximizing ways to the cost of electricity – with significant elasticity in the demand for electricity (and other forms of energy) even in the face of considerable public debate about energy costs. In this light, it is important to recognize that, as practice theory suggests, energy use is not a 'choice' in the conventional terms of market economics. People do not usually make a choice as to whether to use electricity, unless facing extreme hardship. Rather, the decision to use electricity is bound up with lots of other decisions – Is it time for tea? What do the children want to do now? Is it going to stay dry enough to put the washing out? etc.

A practice-based perspective therefore requires that we acknowledge that households do not respond in a 'rational' or simple way to prices. At the same time, we find that ways of managing the home economy, attempts to re-align practices around new incentive structures (such as tariffs) and various forms of financial calculation are a critical part of everyday life. The origins of the term 'economy' in ancient Greece point specifically to this meaning – the term 'economy' as oikonomia is derived from the terms for 'house' and 'rules', translated into 'household management'.

Our analysis suggests that in this sense, economies are vital to the ways in which practices are configured and undertaken. Managing the home economy plays an important part in shaping electricity use as people undertake various forms of calculation about resources (both financial and natural), the distribution of these resources (over time, between members of a household), and investments (of finance, time, emotion) in their homes.

The qualitative data provides a rich set of examples which illustrate the ways in which people think about the home economy and how the day to day performances of cooking, cleaning, bathing, laundry and so on are folded into and in some cases overflow out of such calculations. One illustration of this is in the choice of fuel, where this is an option, as part of everyday practices:

> *Participant: I think it's cheaper to run an electric cooker than a gas one. … A gas boiler costs 56p an hour to run, and a gas oven costs about the same. The electric cooker doesn't cost that because it's not on all the time.*
> *[Interviewer: How do you know?]*
> *Participant: The smart meter. (ML24)*
> *Yesterday my daughter put soup in the microwave, I said "What you putting soup in the microwave for!? It takes just as long on the gas and it costs less." (GP023)*

A further example of participants' management of resources is to re-schedule certain practices, for example postponing laundry until the weekend when the tariff is lower, unless other factors intervene:

> *My washing I definitely do over the weekend when it's cheaper, unless it's absolute necessity. I might have it on twice. (MRJTL06)*

We observed that cost is not the only factor, with management of natural and other resources playing a part in the home economy:

> *If it's raining or whatever, I just get it in the tumble dryer. I do use the tumble dryer a lot. … Yesterday, I didn't 'cause it was so windy I got stuff dry on the line. … When you're at work and you need the uniform for the next day. It's easier … I do use the tumble dryer a lot. (GP0037)*

We see the home economy as a constantly adaptive socio-technical process in which technologies, tariffs and activities - both internal and external to the home - are aligned to the continuity of everyday life within loosely defined parameters and the logics of particular domestic settings. We also notice that a minority of households are prepared to pay for what they perceive to be a better quality of life:

> *I changed from cooking in the evening to lunchtime but I couldn't get my head around that so we've gone back to cooking in the evening. So now we realise if we're using the oven in the evening we have to pay for it. … I didn't enjoy it. I didn't enjoy it I'm so used to it. If I was working away I would have my dinner in the evening and if we were at home I would come in, have a drink and then we'd have our dinner in the evening and I enjoy that. The thing is it's gone on for years and years and I'm eighty odd now and I suppose if my wife dug her heels in we could do it but for now I don't mind the cost. (MRJTL10)*

3.4.4. Conventions

The term ‘conventions’ refers to patterns of meanings that motivate and regulate people's energy practices through the creation of assumptions, standards and expectations i.e. notions of comfort, cleanliness and convenience. Conventions, or the way that something is done, occur at multiple scales, for individuals, within households, across social groups, and society at large.

Norms and habits are related in that they combine to create conventions, but we distinguish between them here to consider the different ways in which social factors shape the contemporary and emerging future performance of practices. Participants often explain their day to day lives by invoking the notion of ‘normality’, and thus making a practice or activity seem self-evident, or not needing explanation. Norms are socially reproduced and come to be more or less widely accepted in social groups. In many interviews respondents present their behaviour as being normal, and therefore beyond analysis or reflection. Assertions that certain practices exist beyond justification or reflection pose questions about why this has come to be the case.

Following from analysis of the components of practices is the necessity to explain how some things come to be considered normal, while others remain open to reflection. Here we present examples of aspects of daily life that people deem as self-explanatory by drawing on examples concerning hot meals and hygiene that seem heavily influenced by notions of norms and received wisdom:

> [*Interviewer: How often do you vacuum?]*
> *Not every day. I think you should, shouldn’t you. There’s only me here. … Maybe every other day. (EPJ006)*
> *I’ve got clean clothes on every day. That [the iron] would be on for about 20 minutes. Every day. (EPJ007)*

> *[Interviewer: Do you iron very often?]*
> *No. No, not if I can help it, just my pyjamas. Because them you’ve got to.*
> *The point is though, at what time are you going to start making your tea? 8 or 9 o’clock is too late, and 3 or 4 o’clock it’s an afternoon snack. It’s not your tea for most people’s programing.*
> *I mean we have to have a dinner, we have a hot dinner every day. (Customer with an in home display only)*
> *Microwave? We don't really use it much, I never cook in it, I would never dream. I mean don't get me wrong, I always keep a couple of ready meals in the freezer, sometimes our son will come home, “I'm hungry mum you got anything?”, I bung him one in, or whatever. But I never, I won’t make a cake or a casserole in it, or anything like that.*
> *[Interviewer: Why would you say that I would never use it?]*
> *Participants: It's not proper cooking is it? It's just not, proper. (EPJ004)*

Another aspect of energy practices that is influenced by convention is lighting. Most households had some low energy light bulbs within the home but adoption was selective.

> *Our bedroom has got the only energy saving lamp in. (EPJ019)*

> *Most of our [light] fittings don't take them [low energy light bulbs] (GP028)*

This is because energy efficient bulbs did not 'fit' with a householder's ideas of how lighting should look, or did not provide appropriate quality of light (Crosbie & Baker 2010). Due to shape or size, which differs from an incandescent bulb, compact fluorescent light bulbs were often deemed not suited to existing fittings.

3.4.5. Capacities

The ability and potential of objects, artefacts to use energy and provide energy services, including techniques required for people to interact with them, is referred to as 'capacities'. These capacities are constituted through design, materiality, knowledge and craft. The socio-technical capacities of a household involve a number of appliances, how they are clustered and put to use. As part of the statistical analysis of the survey data a principal components analysis (PCA) has been conducted on the electrical appliances/technologies that households report as owning. Counts of all 34 electrical goods prompted in the survey were entered into a PCA. This produced 3 components that accounted for 50.19% of the sample variance in technology ownership. These three components are groups of technology ownership questions which have been named post-hoc and around which technology ownership responses tend to cluster. These three components can be thought of as technology ownership tendencies, in which ownership of one or more technologies indicates that ownership of the others is more likely.

1. Common Household Equipment
2. Luxury Items
3. Digital +

The technologies present in each group are shown in Table 6, below.

Table 6: Electrical goods Principal Components Analysis

	Component		
	1: Common Household Equipment	2: Luxury items	3: Digital +
% Variance explained	31.51	11.93	6.76
Microwave	.90		
Washing Machine	.89		
Tumble Dryer	.77		
WiFi	.74		.42
Electric Kettle (Regular)	.73		
Electric Cooker	.71		
Electric Shower	.70		

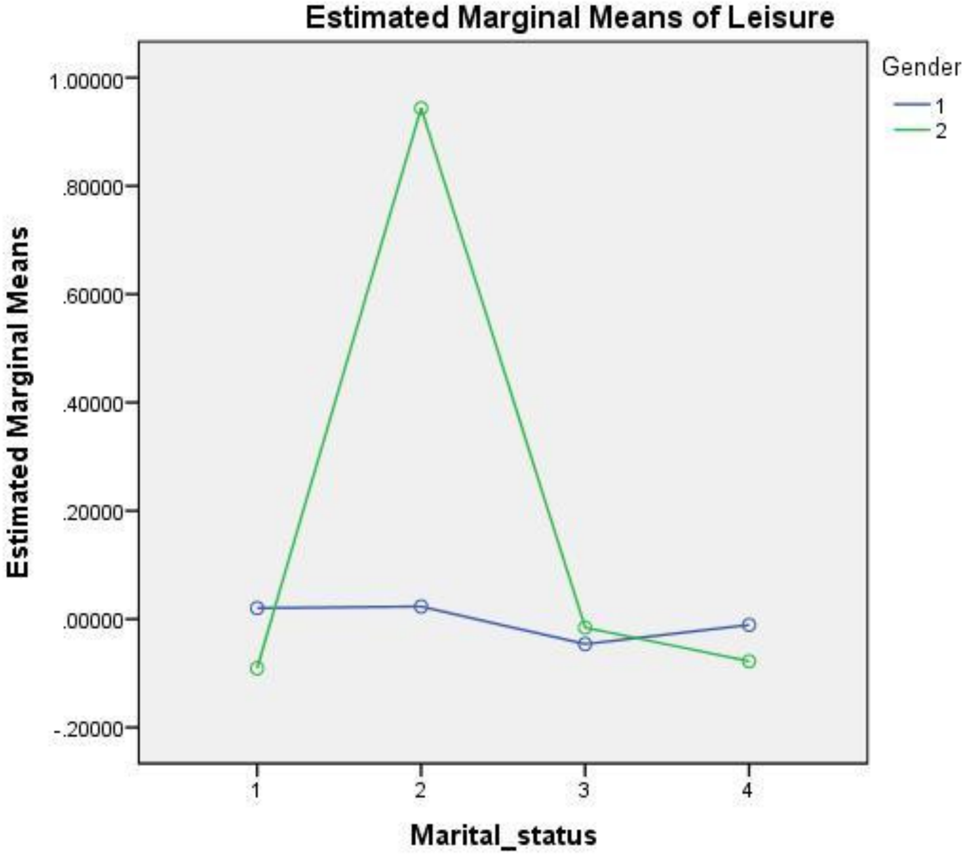
Chest Freezer	.61		
Printer	.60		.48
Heated Pool		.90	
Sunbed		.86	
Patio Heater		.80	
Washer / Dryer		.73	
Energy Saving Kettle		.65	
Musical Instrument		.47	
Greenhouse Heaters		.44	
TV			.70
Digital Receiver			.65
Laptop			.61
Phone Chargers			.57
Jacuzzi			
Aquarium			
Dishwasher	.42		
Hair Straighteners			
Games Console			
Desktop Computer			
Garden Tools			.41
Refrigerators	.43		
Fridge / Freezer	.56		
Tablet			
Photocopier		.53	

Further analysis suggests that respondent age was found to correlate positively with the ‘scores’ in the new variables Common Household Equipment and Luxury Items, suggesting that older respondents possess more of each. Analysis of variance revealed that gender has a significant relationship with common household items, such that men report owning fewer common household items (component one) than women.

Neither of the other components had a significant relationship with gender. Marital status had a significant relationship with component 3 (Digital +). Pairwise comparison revealed that single respondents reported possessing more items in the Digital + group than either cohabiting or married respondents; and that divorced/widowed respondents have fewer of these items than married respondents. No other comparisons were significant.

There was a further significant effect of marital status on the Luxury Items group, which we suspect is the result of the significant interaction between the independent variables for this factor. The interaction can be seen in Figure 35 which shows that married women report owning more luxury goods than any other group.

Figure 35: The significant interaction between gender and marital status (1 = single, 2 = cohabiting, 3 = married, 4 = divorced/widowed).



Women (represented by the green line) who describe themselves as married (Marital status 2) are much more likely to own items in the Luxury Goods group (the vertical axis represents the likelihood of doing so) than any other gender or marital status.

Within the survey and interview data we observed the accumulation of cold appliances in households over time, with more established households having multiple fridges and freezers. Older appliances tend to be relocated in a garage or utility room, but kept switched on – used as an overspill or the storage of food for special occasions. Older models are not disposed of if they are still in working order, even where these are energy inefficient. Energy efficiency may not be the principal factor in selection of appliances; this is a trade-off against other material factors such as capacity, size and space with multiple fridge freezers often linked to other household practices such as growing food, cooking, managing a household, and catering for visitors:

That one [fridge freezer] is fairly new. …It's alright - don't think it's top of the range [energy rating]. … It was a decent size, you know and we had to fit it into that slot. (EPJ013)

When we had the kitchen done, that [fridge freezer] came as part of the kitchen. But I like that one better so we kept that one. I do cook a lot so tend to freeze things a lot. We have a big garden so we freeze vegetables and fruit. … The one in the garage, someone gave us that. (GDP053)

That's the other freezer – which is a chest freezer. [Interviewer: Why do you need a second freezer?] Capacity. Being retired, having an allotment next door, we produce a lot of vegetables which don't last. They go in there. We also produce a lot of our own fruit … I've got huge surpluses. (DL15)

I've got two big bloody fridges, one in there, one in the other room so if we need any meat [for visitors] just pull it out. (GDP045)

One of the biggest things we should get rid of is freezers and fridges. We have 3 fridges and 3 freezers. … Our granddaughter she's vegetarian so all her vegetarian stuff goes out there … We've got a little bar … we've got a fridge in there to keep the drinks cool, you know. ... (GP03002)

We've got a chest freezer, an under counter freezer, and an under counter fridge. (GDP049)

The data suggest that a large fridge freezer and/or multiple fridges/freezers are commonplace where space permits. Such 'over-sizing' points to 'social loading' (Wilhite & Lutzenhiser 1999) where feedback loops between appliance manufacturers and suppliers of food, detergents and so on create a momentum which leads to appliances getting bigger and more common over time.

3.4.5.1. Socio-technical interactions

Energy practices are shaped by the interaction of these five core elements: structures, rhythms, economies, conventions, and capacities. The relationship between energy-consuming technologies, structural and other factors is evident in the participant responses, for example, the connection between working patterns, rhythms, and use of household appliances.

When you're at work and you need the uniform for the next day. It's easier … I do use the tumble dryer a lot. (GP0037)

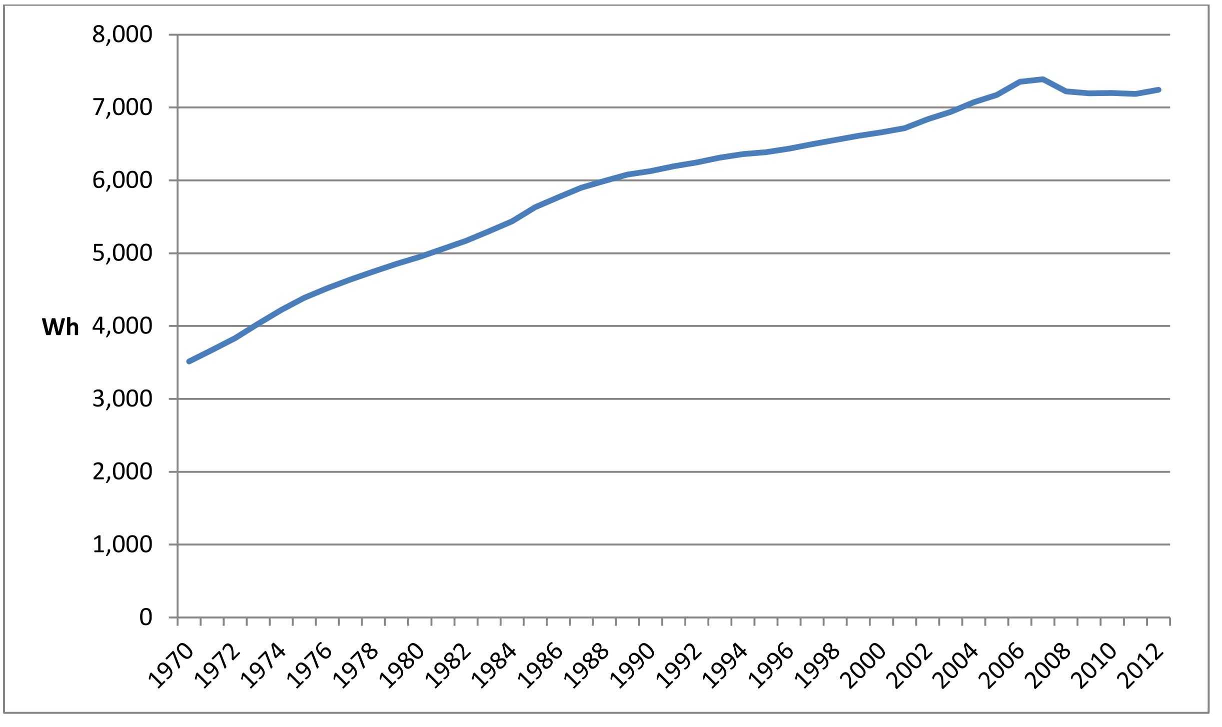
We've always had a big fridge – a relatively big fridge, because we tried to do one big shop a week when we were working so we got used to having a big fridge. (ML23)

The analytical work we have conducted in the various research papers submitted for publication to date considers these interactions in more detail, and we will also undertake case studies of specific households where we have qualitative and quantitative insights in order to generate more in-depth analysis of these interactions.

3.5. How are load and generation profiles likely to change (LO1.2)?

While LO 1.1 has examined current loads and practices, LO1.2 considers the emergence of trends in energy consumption and practices. First we consider the long term trends that can be seen in public data sets.

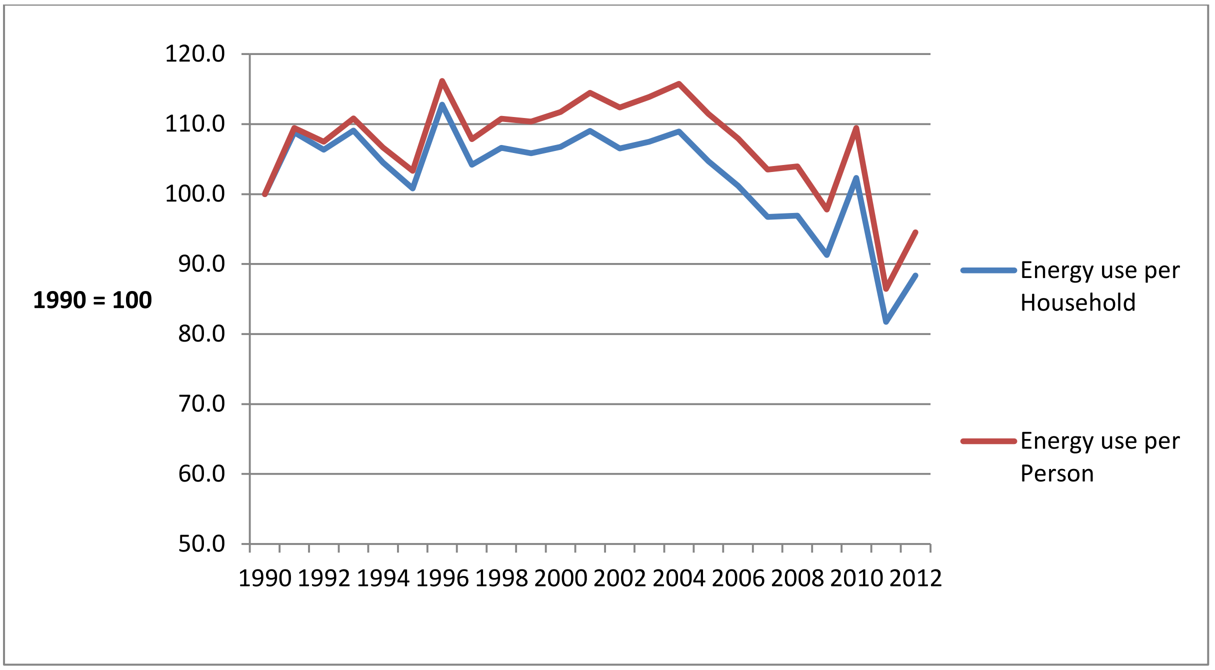
Figure 36: Average UK daily domestic electricity consumption



The upward trend in electricity consumption can be seen to have peaked in 2007 at 7,387Wh per day. Since then demand has fallen slightly, with average daily demand in 2012 standing at 7,242Wh.

We can contrast this overall rise in energy electricity demand with demand for energy. Energy use per household is now lower than it was in 1990 (88% of the 1990 level) while energy use per person has also fallen, albeit not by as much (94.5% of 1990 levels) suggesting that the UK's increased demand for **electricity** is driven by different factors than those affecting overall **energy demand** (gas and electricity combined). Indeed, it was not until 2008-2009 when average energy use per person fell below 1990 levels that electricity demand began to flatten out (Figure 37) – suggesting that gas demand had been falling further and for longer even as electricity use continued to rise.

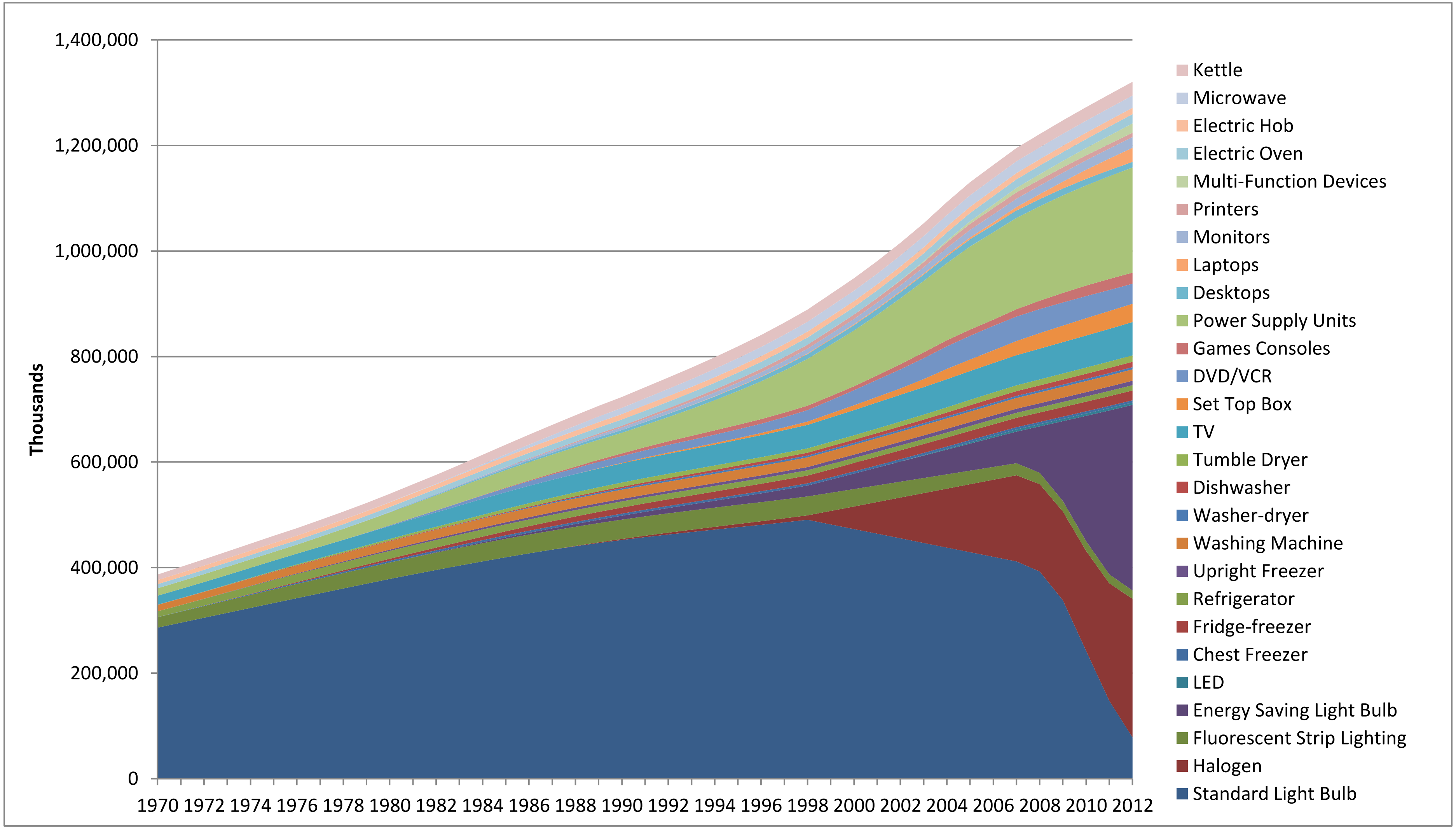
Figure 37: UK domestic energy demand, indexed at 1990



As well as looking at total energy use, it is also useful to consider how everyday life in UK households has changed over time in order to think about the socio-technical processes driving total electricity demand. Figure 38 uses data from the UK's Market Transformation Programme and other UK government sources to chart the ownership of major domestic appliances in UK homes since 1975, revealing substantial shifts in the fabric and materiality of UK domestic life.[13]

[13] https://www.gov.uk/government/publications/energy-consumption-in-the-uk

Figure 38: Number of appliances owned by households in the UK 1970 to 2012



3.6. What evidence is there that energy use/practice and generation within households are currently shifting (LO1.2.1)?

Several aspects of the face-to-face research suggest that there are a number of novel, or emergent features of everyday life that have an impact on how energy is used. These were identified in the analysis of qualitative data and captured by a query that retrieved associated data. The major features of these emerging shifts are listed below, with example data provided for illustration. The focus of this analysis is on domestic energy users. Further analysis of levels of SME's engagement with energy will be part of the work of the social science team in 2014.

3.6.1. Smart home and the presence of multiple internet connected devices

Seventy three out of the 131 unique households visited (55%) were tagged by the research team as actively talking about their use of new entertainment and internet devices – including using them for managing the home in the case of PCs and laptops, socialising through social media, playing games and also using smart TV services.[14] These devices are described as being of great perceived importance to participants. Although the number of devices being used in home and requiring a data connection is growing, not all require constant power. Indeed in the case of mobile devices such as laptops, smartphones and tablets the battery enables them to provide continued connectivity without a power connection for extended periods of time.

> *We've got electric guitar, play station, phones… but it is all turned off in the morning. ... laptop's constantly plugged in. (DL07)*

> *RES(f): So there is three printers but only two that we use [describing the home office]. There is a router and the modem and [...] we've got a shredder. In this office we have all the computers, here we have four computers [five across whole house]. We have three towers [note: tower is a slang word for pc case] and two laptops. One of the towers doesn't get used but the other four are on all the time. Two laptops, so both laptops are always on and two tower computers. Two of them used all the time. (DL13)*
> *We've got are 3 printers, 2 videos, the router and 2 splitters which are powered, a shredder, 5 computers, 3 towers and 2 laptops. One doesn't get used but the others get used all the time. And an iPad. We're both insurance surveyors. My son, he's got a TV and a computer and his laptop and he has them both on all the time.*
> *You charge the ipad through the day … and the laptop.*
> *There are 3 laptops, 2 tablets, and 3 cameras. There's a TV in each room, I've or printers up there too. There's either the radio on in here or the TV through there. There's always one or the other, always something on. The grandchildren come in the holidays for a week and then our consumption goes zoom! They're doing all of the above, charging their phones, playstations, … it's not like when they were at uni and they brought their washing home now they bring all their technology. There's a*

[14] Quotations identified by the Smart homes and Flexible entertainment queries identified data from 73 households.

lot more washing with a 2 year old, and cooking as well. I read the paper on the iPad, I get The Guardian. You can charge the iPad through the day and use it in the evening. We do the same with the laptops. It's the same with the electric toothbrush. (HS01)

RES(m): We use it much more in the winter during the day. In the summer it would be in the evening.
RES(m): I carry on stand-by if the power goes off [...] Or trying to get new results or ... So this is what I'd do either on the laptop or ... looking at plans, instructing team and that kind of things. [working from home]
No Wii, just phones and computers. Its ipad and portables, they're all portable.
I might be on the computer or the ipad- we use the ipad a lot because it saves firing the computer up and we don't have to go upstairs now. It's convenience. It allows you to do more things at once. But if I've got proper work to do like anything with spreadsheets I'll fire the computer up but for surfing, and maps …We used to have it on a few hours a day but now, it's never off. (EPJ15)

3.6.2. The evolving home economy

The other major trend identified in the data is the increased awareness of the cost of energy. We find that 65 of the 131 unique households we visited (49%) report that they have an increased sensitivity to the cost of energy and that this has led them to change their use of energy in order to find ways to cope with increased costs and decreased incomes in the post-2008 period.[15] This is accompanied by participants talking about energy companies' rationales and ways of setting prices, which often includes speculation and guesswork. While there is no single 'new approach' to energy cost management, and indeed some households report no change at all, we do find none the less that domestic customers feel that managing energy to keep costs down has become a more significant feature of mainstream domestic energy use.

RES(f): You know, even a slight saving. 'Cause we spent so much on energy that even if it's like one per cent less [%] than the other companies you know ...RES(m): British Gas has already said, I think it's last week, that they gonna put the bills up this winter. And I think it's EDF or somebody or EON that said they gonna freeze it. [...]

RES(m): I used to have the heating on in the morning and leave it on continuously well you can't possibly do that anymore. It's just sitting cold most of the time and then put it on when everybody's in.

RES(m): I've realised that I'm more careful about what I spend my money on, not just spending money on things that I would spend money before.

[15] Quotations identified by the New economies query data from 65 households.

RES(m): [motivation for becoming part of the project] When bills are going up and going up and going up you've got to try [do] something. I'm only on pension ...

RES(m): Yes the recession has impact on the way I look at energy. All kinds of energy, not only the fuel in the car and things like that. [...] It's the same through the household energy as well.

RES(f): You just have to save, you have to look for bargains. You've got to look around. You know one time you just used to go and say I'll get this and I'll get that but now you don't. Now you just look around all the other shops, maybe you just used to go into one and get everything. You just can't do that, you've got to go around where it's cheaper.

In addition this management of the home economy is not limited to energy, instead other forms of resources are being worked into the home economy in new ways which seem to make changes in the way practices like cooking and heat are being conducted. Examples given below include the weather and food as being used differently – with an emphasis on making more use of resources that would otherwise not be considered part of the home economy.

RES(m): I was quite interesting with the cold weather [talking politics, especially the 'big society']. All the local shops had a huge increase in customers because people couldn't drive to the supermarket. And I think it changes a lot of people attitudes towards buying things ... because we do throw away and we set as a target basically not to waste food. We go two days a week, do a little shop rather than big shop. And we've also started doing some Internet shopping. And again, you pay for your delivery but really now the cost of fuel it's ... and a shared van coming out delivering that really is more environment aware. So yes, that sort of things has changed.

RES(f): [recession] Food, food has definitely gone up. I don't throw as much away. I wouldn't like to buy a lot of stuff that would be wasted in fridge. But I don't think you should either, waste. Trying to make things, do something with them. Like I brought me daughter plums to make a plum crumble but she won't do it. That kind of thing.

RES(m): I've realised that I'm more careful about what I spend my money on, not just spending money on things that I would spend money before.

3.6.3. Ways of working

The third feature of the qualitative data that suggests a longitudinal change in everyday domestic life of is the emergence of new ways of working. For 59% of all households visited there was evidence of elements of a work style which features flexible hours, blurred lines between home and work and the use of portable computers to enable work to creep into the home, and for evening and weekend times to be structured by and organised around the need to complete work.[16] In this sense work seems to be overflowing out of conventional spatial and temporal 'containers' and is appearing in times and places that would have been unusual before the mass adoption of smartphones and flexible working legislation. This has the effect of creating a need for electrical equipment at home including printers, monitors and desktop PCs as well as mobile devices.

> *RES(f): Because I work from home, I'd do some work and I work on the computer so I need some break anyway. But I'd just get it done, get it in and then go to work. …*
> *RES(f): So there is three printers but only two that we use [describing the home office]. There is a router and the modem and [...] we've got a shredder. In this office we have all the computers, here we have four computers [five across all house]. We have three towers [note: tower is a slang word for pc case] and two laptops. One of the towers doesn't get used but the other four are on all the time. Two laptops, so both laptops are always on and two tower computers. Two of them used all the time. (DL13)*

> *RES(f): See, I'm more flexible because of the times we work. So I work five to nine [05:00 to 21:00] so I'm out of the house for sixteen hours. But me daughter usually works evening anyway. So it just leaves the two. And one goes to bed at nine [21:00], the other at ten [22:00] so the house is shut down basically at ten o'clock [22:00]. [...] See, that's me. I'm more flexible than other families, the nine to five families if there's any of them about. But nine to five families [09:00 to 17:00], I think they'd find it harder. (GP23)*

> *RES(f): I'm there all day all night, twelve hour shifts. I'm out of the house from half six [06:30] and I don't get in until after [...] Me husband works different shifts. Me mum would probably cook for the kids. ….: You see, we all work shifts so and me mum would have to look after me daughter. So I work three/twelve hour shifts. Me husband works different shifts. It's probably used quite a lot isn't it [this room], there is mostly somebody in the house. (GP28)*

> *RES(f): Well, I'm using the computer, to make some notes. We use it every day, it's a fair bit. We both use computer every day, laptops and tablets. ... I'm a governor of a college. I do preparations for the meetings at home. All we use computer all the time, don't we. I shop online. Lot of technology used here: printer, graphic printer for high quality photographs. (HS01)*

> *RES(f): I'm the church council secretary. I do the minutes, and I do those from home. Or sometimes I go to Age UK, and do them there 'cause I have a bit of company and easy to photocopy there as well. (HS11)*

[16] Quotations identified by the Ways of Working Query identified data from 77 households.

RES(m): From time to time. My wife does it more than I do. She certainly prefers to work from home, I don't especially like but there are occasions when I do it. But she would do it a lot more. Certainly nine to five [09:00 to 17:00] but there is an element of doing things on the weekends. [work related activities at home] (GP46)

RES(m): I do voluntary work for the local golf club, I'm a secretary. To be honest the work load for the golf club is very consistent throughout the year. It's just the type of work that changes. So like at the moment it's preparation for the season and then once you get in the season then you're managing various things. [...] It's probably more in the winter because I'd try and do more here that means I'd have to spend less time up there. So for example it's doings of document type work that I do on my computer and then just email it to the club. [use of the computer at home]. (HS04)

RES(f): I do accounts, works email but it's been mainly social. [...] Energy bills, banking, accounts, all of that is done on there. [home management & Internet] (EPJ14)

In addition to these three emerging features of energy use, it was noted that households with solar PV panels exhibited new forms of planning to take advantage of the solar resource. This is discussed in more detail in those sections that address how practices connect with PV panels (Test Cell 5, Section 3.8.3) and solar intervention trials (Test Cell 20, Section 4.6.3). In addition, Section 3.6.4. covers the other significantly emergent feature of domestic household consumption – household dynamism and change.

3.6.4. How are changing household dynamics likely to shape current and future energy use?

Our findings reveal evidence of the impact of wider social trends relating to economic downturn, housing shortage, unemployment and the incidence of divorce on energy use and patterns of consumption. Most evident are the effects relating to increase in the numbers of adult offspring – sometimes referred to as the "boomerang generation" – returning to live in the parental home, while others are unable to leave.

Over 3.3 million people aged between 20 to 34 years of age were living with their parents in 2011 (ONS 2014). The figures represent a 25% increase on comparable figures from 1996. Some of these adult children are parents themselves, creating three generation households. Households are thus often in flux; their composition amalgamating and re-amalgamating according to the comings and goings of members. Our evidence suggests that the extent of mobility within and between households shape energy practices in ways that are difficult to capture, because of their variety and sometimes temporary nature.

The clearest picture of households in flux emerges from findings surrounding the "boomerang generation". The term was initially coined by journalists in the USA and subsequently adopted and refined by academics studying increases in adult offspring cohabiting with their parents (cf. Dey and Morris 1999; Kaplan 2009). It is a broad analytical concept describing an 'ideal type', but provides a starting point for thinking about complex patterns of familial mobility as they impinge on household energy resources.

3.6.4.1. What are the consequences of parent/adult offspring co-habitation on household energy practices?

Analysis indicates similar responses to household energy use in circumstances where adult sons and daughters remain rooted to their natal home as occur when they leave and return. The key difference between households where adult offspring return and those where they simply remain is that greater degrees of disruption are likely be experienced in the former.

Common to all these households, however, is a tendency for tensions to cohere around how people use and consume energy. Our qualitative data represents perspectives from provider parents, as opposed to adult offspring, as interviewees were recruited from customers and bill payers. It reveals, from this vantage point at least, that energy practices can be a source of conflict, with parents characterising their adult offspring as unreasonably profligate.

> *RES(m): On the top of energy usage is daughter. As soon as she goes upstairs, she puts television on. As she's getting changed, television is on. When she was off Tuesday Wednesday and I think she's got through the whole series of Friends, one, two, three (DL12)*

> *Yesterday my daughter put soup in the microwave, I said what you putting soup in the microwave for!? It takes just as long on the gas and it costs less. (GP23)*

> *[H]e's on it [computer] all the time. He's got one in his bedroom … he (son) pays for that, the internet, but he doesn't pay for anything else! No board, or gas or electric and I wonder why he doesn't move out! (ML02)*

> *RES(f): Now at the moment I know it is on but I turn it off before I go to bed. He [son] wouldn't, he'd just put the DVD and the telly and not think about it, just leave the box on. (GP21)*

> *We had the internet cut off, I can't afford the bills anymore. So I only have the TV and Sky. I can't afford 60 odd pound a month, it's just crippling me. I know my son watched DVDs before he goes to sleep, because I think he puts the TV on timer. … (GP21)*

Some people attempt to diminish or resolve the potential for conflict over energy by creating structured routines around household chores in order to better align with the flow of work patterns that complicate mobility in their household. One household in this situation tried to impose order and reduce tension that had built up around household chores through the formality of a cleaning rote; while another negotiated new shower routines to accommodate mobility patterns:

> *It normally would be a weekend. ... if it's one of the [adult] kids then it would be through the week, during the day. Chores organised around various working*

patterns. [There is a cleaning rota hanging in the kitchen, arranged on a person/task basis]. (EPJ19)

We observed during interviews that whilst adult children living at home may make a financial contribution to cover accommodation or other costs, often referred to as 'board', this may be a nominal sum towards general household costs, and may not reflect actual costs of energy use. Adult children living with parent/s may not be the account-holder and, therefore, not directly involved in payment of the electricity bill.

3.6.4.2. Work patterns and planning

The difference between members' work patterns is the major variable that influences sociality, and hence energy practices, in boomerang households. They dictate the timings and extent of footfall within the home making it difficult for members to rationalise and harmonise their energy use.

Some people reduce the potential for tension by negotiating routines that fit around the mosaic of household mobility:

RES(f): No [no shower in the morning], shower in the mid-day 'cause me daughter works shifts as well, so mid-day when she goes out 'cause she works in the restaurant. (GP29)

Practices such as meal times, entertaining, showering and laundry are difficult to order because they are subject to the effects of routines extraneous to the home.

We just eat when we're hungry … (Daughter) will eat about half five, six-ish, and I'll have mine any time after 3 o'clock. … I probably have a sandwich before I go to bed. (DL08)

RES(m): It just depends who is in [about the washing]. Because me stepdaughter works at Marks & Spencer's so she's got midweek days off, she starts at five o'clock [05:00] and finishes at three [15:00] so that kind of random pattern. (EPJ19)

RES(f): Microwave and toaster there. Microwave, we don't really use it much, I never cook in it, I would never dream. I mean don't get me wrong, I always keep a couple of ready meals in the freezer, sometimes our son will come home, I'm hungry mum you got anything? (MJRTL14)

3.6.4.3. Interim return

Even when maintaining separate households, family homes can remain open to adult sons, daughters and grandchildren to return regularly to receive hospitality; ranging from Sunday lunches to regular meals and periodic stays. Some parents respond to the needs of their adult children often at short notice.

RES(f): We have friends over for a weekend sometimes. And we have a son who lives down in [city] and when he comes up, that's him with his wife and two little children *as well. They all come for the Sunday lunch if they're up here, everybody comes (MJRTL09)*

RES(m): Couple of months ago, our daughter who lives in [town name] decided to have a new kitchen fitted. And she said if we could look after the kids; two girls, sixteen and fourteen. And also do the washing for them. This was supposed to take a week but...(MJRTL09)

[INT: Could you cook your tea earlier or later than you do at the minute?] No. I wouldn't do it. I couldn't do it. Na, Na. Me' grandson comes for his dinner, says "I'll be here 5:45" so I couldn't. I'm set in my ways now, I never used to be but since I had all this. (GPML04)

3.6.4.4. Household zones

Analysis demonstrates that when adult sons or daughters co-reside with parents on a permanent or semi-permanent basis they spend limited time together and tend to operate in separate well defined zones within the home; sometimes to the point of meeting only occasionally during the course of a day, as these zones are constructed temporally as well as spatially.

RES(m): The daughter (thirties) is upstairs. Me and my wife down here. My wife works four days a week so ... daughter works five. But when she's at home I never see her. She comes down, have her breakfast, go up, have a shower, get changed and that's it. (DL12)

These temporal zones are largely determined by the contrasting work patterns mentioned above but also occur where grandparents are looking after grandchild.

When my other grandkids come they'll play on that stuff (consoles).At the moment we're living in the back room (because grandchildren are living there). The xbox, wii …when they get their own place that'll all go. The little one is only allowed on it for now. (MJRTL04)

3.6.4.5. Repositioning

At the points when adult offspring leave the parental home a transition occurs as the household reconsiders and reorders its energy practices to a new phase.

RES(f): When [daughter] was at home she had the heating on almost all day, sat in front of the computer, freezing. Now the heating is off. I may put it on for couple of hours at night when it gets cold. At winter it would have gone on for me about six o'clock. (GPML01)

Since she's [daughter] been gone it is taking a lot longer to fill up the wash machine. (DL08)

3.7. How does the emergence of new forms of energy use/practice/generation vary in socio-demographic and socio-technical terms (LO1.2.2)?

The trends identified in LO1.2.1 have been cross analysed against both socio-demographic and socio-technical participant attributes to identify patterns in how these trends may be associated with any of these characteristics. This was done by examining the characteristics of participants involved in the face-to-face research and testing for correlations between the way their qualitative data was interpreted by the research team and the attribute data held about them.[17]

Almost all correlations between emerging trends and major socio-demographic variables are weak (less than + / - 0.1). The only correlation that was found to be greater than 0.1 is that between Planning and Income – which suggests that the research team more often interpreted planning (which could include planning the week, the day or planning to conduct practices in line with things such as weather forecasts and shift work) as being an emerging or established feature of energy use in higher income homes than lower income homes. This could be seen as a result of busier working lives in high income homes requiring more planning in order to fit practices into less time spent at home: as well as these homes being more likely to have installed solar PV and as a result planning to make use of solar resource.

In addition to this, it is clear that Smart Homes and the introduction of digital technology correlate with younger people and higher incomes. Families with two working adults and teenage or young adult children were, in our face-to-face research, more likely to be digitizing everyday life through smartphones and other internet devices while also more likely to be participating in reconfigurations of work and education that blur boundaries between previously demarcated time-spaces. However, these trends are not restricted to this demographic. The presence of large internet connected TVs was a noticeable feature of living spaces of retired people, so much so that we found no linear correlation between 'age' and 'smart' in the analysis of qualitative data. What we suggest is that these new forms of connectivity and flexible consumption – whether being able to work from anywhere, or being able to watch favourite TV shows at any time – are widespread, widely accepted and easily integrated into the other longer standing features of daily lives.

3.8. What are the factors that are shaping the emergence of new forms of energy use/practice (LO1.2.3)?

According to the latest strategy of the UK government, achieving significant decarbonisation of the UK's energy system requires a significant shift in domestic energy provision for heating and hot water (DECC 2009). Achieving this goal has involved incentivising micro-generation technologies and mandating a smart meter roll out to cover all UK properties.

Uptake of PV has increased markedly since the introduction of the Feed-in Tariffs (FITs) and although uptake of heat pump technologies in the UK is considered 'dismal' when compared with the volume of installations reported in mainland Europe and North America (Singh et al. 2010:876), this may

[17] How quotations were tagged in Nvivo 9, as detailed in Section 3.2.

change in the coming years. By 2010 an estimated 30,000 air source heat pumps were installed in the UK; the majority being located in residential buildings (Fritsch 2011) and in situations where dwellings are without mains gas (Energy Saving Trust 2010).

In this section we consider what comparing the energy use of Test Cell 1 (a sample of British Gas's smart meter population), Test Cell 3 (a heat pump study group) and Test Cell 5 (a PV study group) can reveal about emerging trends associated with these technologies. There is a need to consider how the provision of energy services and the everyday practices within which these are enrolled are related and how they co-produce one another in order to understand how such interventions are domesticated, either to be embraced, side-lined or contested within the home. Importantly, the insertion, uptake and effect of new technologies will be shaped just as much by the ways they are consumed as the ways they are provided.

3.8.1. The role of smart meters

We found that smart meters are viewed positively, with few concerns expressed by participants about security or health. Furthermore, they understand smart meters and IHDs to be the same thing, or at least two parts of a whole. All households in our study have both a smart meter and an IHD and for the vast majority the IHD is the smart meter – it is the means through which they are provided with information, and it looks 'smart' because of its digital display, its real time information and the way it physically resembles other devices associated with domestic ICT (such as smart phones, portable consoles).

3.8.1.1. Using the IHD

We find that people use the IHD in at least three distinct ways; to manage the household economy, to provide oversight on what families are doing, and to challenge themselves to save energy – each of these leads to the identification of energy saving potential.

First, in terms of managing the household economy, the IHD provides feedback and contributes to understanding what specific devices use energy, how much energy is being used at different times of the day/week, and overall spending. This is about 'good housekeeping' – knowing what is coming in/going out and managing the household economy and finances. For some people, this feedback is used to reduce the most easily adjusted items in terms of expenditure, but for most it is about keeping track of bills/understanding the overall family finances.

> *We've had it [IHD] just over a month about 6 weeks … since the husband left. It's brilliant. I do check it on a daily basis. Yesterday cost 54p, and 1.11 [gas], last 7 days 5.84. (DL07)*

Second, especially for families with teenage children, the smart meter provides a means of understanding what other family members are doing at different times of the day.

> *When we got it he was like, "What you got on!? What you got on!?" He was in a panic! (DL802)*

My husband keeps going "Get it off! Get the kettle off!" (GP028)

There's nothing to dislike about it. It's quite useful, it tells you what's going on, it changes colour. (ML06)

Third, for a sizeable minority, the smart meter offers the opportunity for households to try to optimise their energy use in terms of overall consumption, the extent to which energy is being used at different times of the day and so on. This is sometimes related to the home economy but is also often seen as something to do for its own sake with some loose rationalising references to saving energy, saving money or the inevitability of energy transitions.

I mean you can see the peaks … If someone's used summat' you can see it goes, I mean it's like a skyscraper. On a rare occasion it goes red. [If] [t]here's be 2 high voltage things on at a time it goes red. If the kettle and deep fat fryer's on together … I think they're better than not having anything at all. … I think we try to use less because they're showing you how much you're using. (DL402)

3.8.1.2. Domesticating IHDs

Sociologists (Berker et al. 2005; Mansell 1996) have studied the domestication of technologies in order to understand how they are brought into alignment with specific domestic processes that may or may not match the designer's envisaged optimal usage. IHDs typically find their way onto kitchen benches where they become part of the central electrical hub of the home – adjacent to or at least within viewing range of white goods, kettles, toasters, coffee machines. There is a sense in which the kitchen is the cock-pit of the home from where practices, family life and the home economy are managed, with the IHD fitting into this space as an additional source of feedback and information to complement postal communication with energy suppliers, smart phones, and personal interaction which contribute to these management activities.

It's not caused any bother... I am aware of it because it's in the pantry. I know if I've left something on so I can go back and then the light will go off. So it reminds you that you left something on that shouldn't be on. (ML03)

… I look at it daily; it's in the kitchen on the bench so you can see it. (DL802)

Whilst the majority of participants are positive about their IHDs, a sizeable minority are indifferent with one participant having opted out by unplugging their IHD. The 'traffic light' system is seen as intuitive and easy to understand and little communication/information is needed for people to know that 'green' is a positive level of consumption and that 'red' is a warning about high electricity use/high costs. This is the most widely used feature of the IHDs and is not thought of as complex or difficult to engage with by any of the respondents, even those in demographic groups that might typically be thought to be less likely to engage with IHDs and other smart devices.

Must admit that I just go by the colours. If I haven't got me glasses on I can't see the rest of it. If the red comes on the alarm bells go. … I look at it daily; it's in the kitchen on the bench so you can see it. (DL802)

I keep a track of it [(energy use)] by using the graphs because it can go red when the shower's on, or the kettle. But if the washer is on, which is supposed to take the most, it's only orange. But it's about when you use it and for how long. (GP2602)

Much more could be made of the built in messaging functionality – while this hasn't happened as part of the trial many participants commented that messaging through the meter would be an effective means of communicating DSR messages. In addition, however, householders were open to receiving messages via regular SMS to mobile phones and in a small number of cases suggested messaging to their smart TV or an appliance that is in the living room.

3.8.1.3. Frustrations

While the IHD itself is easy to read and understand in the main, with the vast majority of participants choosing to use the price based readings (rather than units of energy or CO2), many commented that it caused them confusion because the readings were hard to explain in reference to their own activities. We suggest that this is both a potential problem (it may lead to disengagement, or reduced trust in the device, if not increased frustration at the 'energy company') and an opportunity to increase awareness and knowledge of the energy consumption associated with different activities and appliances.

[Interviewer: Do you have faith in the meter?]
Well sometimes but not always. Like Sunday I wasn't in at all and it was £1.73, then the next [day] I was in and it more or less the same. Sometimes like it's £3 'summat and other days it's £1 'summat and I don't know why. (DL302)

While the interviewees we spoke to were mostly very positive about the IHDs a common theme in the data is that engaging the entire household or family with the device is a challenge. The data includes discussions of archetypal characters who do not positively engage with the IHD and for these characters the IHD is at best a toy or folly. Among these, teenage or adult children are least engaged with the IHDs which is perhaps surprising given that this generation is often thought to be most attuned to smart / digital devices.

I 'tek notice. I'll flick up the price and there's about a 10p difference. Me' daughter that's a different story… (DL902)

The only other thing is the bloody computer, he's on it all the time. He's got one in his bedroom … he (son) pays for that, the internet, but he doesn't pay for anything else! No board, or gas or electric and I wonder why he doesn't move out! (ML02)

3.8.2. Engaging with heat pumps

3.8.2.1. Structures

The removal of one socio-technical structure (heating technology and payment arrangement) and its replacement by another was found to be key to how users relate to ASHPs. Discussions with participants reveal the importance of the legacy of existing heating systems in shaping how they relate to the introduction of the ASHP. Those participants with experience of a previous communal system of heating and hot water reported that it was 'tip top' (DC031) and they had 'never had any problems' (DC035). In contrast, participants who had previously lived with electricity storage heating systems, regarded the ASHPs as a considerable improvement to a regime in which they once depended on various and expensive forms of electrically produced heat:

> *You had no heat. They [storage heaters] were supposed to stay warm all day but they were cold by 11 o'clock so you were freezing. I had to use the electric fire all the time… but now I hardly ever use it… Well, I was putting £35 to £40 a week on with the storage radiators but now I'm putting £20 on now. I couldn't have afforded the other. It was terrible. (EPJ004)*

> *You had no control over them … when I come in in the evening, the place was cold. They only have bricks with a heating element, so once they switch off at 7 o'clock [07:00hrs] they start cooling down, so by the time I'm getting here in at 7-8 o'clock [19:00-20:00hrs] or whatever, the place was cold and I can't do anything. I can't turn the heating on 'cause they won't switch on again until midnight, and I've got no control.' … I mean, there was controls on it, and they said that if you closed the vents when it switched on at 7 o'clock in the morning and kept them shut, then when you came in at night if you opened them that would let the heat out. Then at midnight you close them—but it doesn't work like that. (EPJ011)*

Users, and their expectations and practices, are critical in shaping how the system is operated. For some, existing daily routines over-ride the system imperatives, and users are active in reshaping the technology to their needs:

> *When I'm working shifts what I normally do when I go out first thing in the morning I'll switch it off completely. … so then put it on auto for 5 o'clock, or if it gets too cold, like the last few weeks, I'll just come in and put it on. (EPJ011)*

3.8.2.2. Capacities

While some participants reported a smooth transition and felt that they had the capacity to use and control the new system, for many the demands of participating in the provision of energy services seemed too great. Some had tried and failed to ensure that the ASHP provided the kinds of energy services they required. Several had concerns about whether running the system all day, which technically provides the most efficient service, would in fact incur additional costs (see also Owen et al. 2012). Others sought to distance themselves from the technology, which is regarded as complicated to operate, fearing that their actions may lead to the breakdown of the system:

I don't know whether its there's a fault on the system or what. Sometimes I'll switch it on the On setting… it doesn't come on. So if I go and switch it on the All Day setting it'll come on sometimes. Or if I put it on All Day first and it doesn't come and I put it on the On, it'll come on. But sometimes it'll only come on All Day or On for a couple of hours and it'll switch itself off and the radiators cool down again. The only time I can get it to work properly is when I put it on Auto. (EPJ011)

That's the control which I do not touch. I operate it from the thermostat.' (EPJ005)

I don't let anybody touch anything. I don't want to know. As long as it's working, I don't want to know. (EPJ009)

In these cases, co-provision of energy services is not something celebrated or enjoyed, but rather the emergence of new consumer roles is resisted, ignored or feared. This may very well reflect the social and demographic make-up of the sample of participants, and their position as tenants in social housing over which they may traditionally have held little sway. At the same time, they also reflect the process of installation and instruction that participants experienced. Many participants found the instructions concerning how to operate the system, and the controls through which this was supposed to be achieved, made little sense. Recounting the advice received from the social housing provider on re-setting the system, householders remained confused:

If it goes off and needs reset… Switch it off from the inside, then switch it off from the outside. Give it a couple of minutes then switch it back on from the outside first, then come in and switch it on from the inside. And that should re-set it. … The people I am asking information off I don't think they are fully aware with it being a new system and that. … I'm not sure whether they know that much about it. Like I say, I am getting contrasting solutions to the same problems. (EPJ011)

However, at the time of the interviews, most householders had reached a point where they were able to operate the system at a basic level (using the up and down arrows on the thermostat), but they stuck to the programme set initially on installation:

They just put it in and I've left it as it was … I wouldn't know what to do. That's the only trouble. They didn't really tell you much about anything. (EPJ004)

A few more technically literate had changed the programme settings to suit their own preferences or understandings, however, even the more competent had some difficulty with the technical information supplied, as illustrated by the comments from a recently retired electrical engineer:

I wasn't happy with the times they had set. So I tried to set the timer myself. So eventually I got there. Eventually. Reading the book over and over and over again. (EPJ008)

Others found they had little to go on by way of understanding how the system operated and what they should be doing with it, particularly outside of normal operating conditions:

> *The red light starts flashing and I just do not know why. And I think" Oh God there's something wrong!" Nobody told me that the light would go flashing red, you know. When you don't know, naturally I am the age that I worry. (EPJ009)*

3.8.2.3. Changes in heating practices: mixed outcomes

Householders shifting from storage heaters (with or without supplementary heating) and electric hot water systems make adjustments that sometimes result in a lowered awareness of their energy use and lead to high rates of electricity consumption.

> *The booster is brilliant. … if we've let the water get too cold. It takes less than an hour. (EPJ010)*

The potential for ASHP to actually increase energy consumption has led some researchers to conclude that depending on context, installation procedures and demographic factors, as well as variations in dwellings and the purposes they serve, a heat pump can be viewed as 'a wolf in sheep's clothing' (Christensen et al. 2011). However one potential counteraction to increased electricity consumption following installation of heat pumps in dwellings previously fitted with electric night storage heating are changes to the use of supplementary heating. Some householders forsook supplementary heating altogether - 'I don't use that [electric fire] now… I used to when I had the storage heaters though' (EPJ011). In this case, a once desirable resource is dispensed with and another practice – that of relying on ASHP for thermal comfort – is configured. However, this energy saving effect is not universal as others prove more reluctant to depend solely on AHSP:

> *I was thinking about getting one of those gas ones, just in case … I used to have a one but got rid of it. I wish I'd never have done now (DC032).*

In this case an old resource and associated practice is resurrected out of apprehension about the new technology.

Table 7: Test Cell 3 Heat Pump Summary Box

Successful heat pump installation and their ongoing effective use was greatly affected by the previous history of heating systems that households had experienced and the way in which the transition was communicated and managed. Those moving from individual night storage systems were much more positive about the new systems than those who had lived with district heating systems. Evidence from Test Cell 3 highlights both the positive potential of heat pumps to improve heat services while reducing bills as well as the potential risks to customer experience and well-being. Key benefits were found to be: (a) the quality of the heat provided and its use as a source of drying clothes as well as providing comfort; (b) reduced bills; and (c) the hot water service provided. Key concerns included: (a) whether running the system all day, which technically provides the most efficient service, would incur additional costs (see also Owen et al. 2012); and (b) the perceived complexity of the technology, with participants fearing their interventions would cause the system to breakdown. The research also suggests that energy suppliers are unsure about which tariffs and / or services they could and should offer to customers with heat pumps indicating that further research is need to better understand and engage with supplier approaches to heat pumps.

3.8.3. Solar Gain

Drawing on interviews with participants in Test Cell 5 we are able to make some initial observations about the ways that electricity generation and use practices are co-evolving with PV installations. Research that we have undertaken to date with owners of PV panels suggests that PV ownership leads to more active ways of relating to energy, whereby individuals engage in the calculation of their own energy use and production, as well as in monitoring and managing their use to a greater extent than in other households:[18]

> *We keep a record of what we generate, [husband] normally does it, now we've got that thing, he'll [record] how much we sent back and how much we've used. He likes things like that! … That's how much we use in the day, that's how much we used yesterday – we only used 3 but we exported 11. (DL14)*

[18] 164 qualitative energy research visits have been conducted with households as part of the CLNR project to date. The total number of household research visits continues to rise as new parts of the project become active. Of these, the 46 visits detailed in Table 1 represent only those households with Solar PV. Other interventions studied include various combinations of time of use pricing, air source heat pumps, smart washing machines, enhanced monitoring as well as a large control group.

I check it every day. I've got all the stats since we got it, the monthly stats. ... When the number goes round, that's how many units we've brought in, and shoved out to the grid. (DL20)

What also emerges here are the ways in which the uptake and use of PV is being shaped by a particular set of new conventions organised around logics of investment and returns:

The line that I'm going down for energy saving has changed … I was looking at heat pumps but they're not economical. I wouldn't get a return in my lifetime. Instead I'm very interested in energy storage, batteries. If I get all my electricity on Economy 7 and run it through the invertor that the solar panels feed into [explains the financial benefits] … I would be reducing my costs by approximately a third but it's the wrong way of looking at it; I wouldn't be using any less electricity. (DL15)

At the time it was after the crash of '08 and I came out of the health service. I was looking for somewhere to put my lump sum on retirement and instead of putting it in stocks and shares I put it on the roof! And I got the maximum tariff. (DL19)

I don't know 'nowt about the technology, but it's nice to get that amount for your electricity. Every pensioner should have it as standard. (DL21)

The FIT, it weren't for the FIT it wouldn't make sense to put PV panels up. You've got to have something, as well as feeling good, you've got to have some financial incentive. (DL17)

It's the fact that it's given us that bit extra towards us pensions. (DL14)

I got an income of £1600 and an outlay of around £1000 so I was getting £600 more than I was using. In terms of what I paid and what I'm getting back from it there's nowhere I would get the same income with security. For 25 years … and I think 25 years will probably see me out! (DL15)

The UK's feed-in tariff, particularly in the presence of low interest rates and insecurity about housing and financial markets, led to PV being regarded as one of the most secure and profitable forms of investment during 2010 – 2011, as can be seen in their appearance in financial advice media primarily as an investment technology than an energy technology (Which 2013; Louth 2013). The result of this is that electricity generated through a FIT system is often used in accordance with logics of investment, particularly for those consumers who were early to adopt PV and as a result receive the higher per kWh generation tariffs.

Crucially, the investment logic does not ask individuals to modify everyday practices. This situation is changing however. While the emphasis of the FIT, as is reflected in its name, has been to feed power back into the grid since its launch the guaranteed floor price paid for PV generated power has fallen from 43.3p/kWh to 14p/kWh between 2010 and 2013; while the price paid for exported energy is index–linked to the UK's retail price index, making it static in real terms. As well as these changes to the price itself, the duration of the guarantee has also fallen from 25 years to 20 years. The effect of this re-configuration is that the guaranteed income generated by PV panels is diminishing over time and as a result the financial viability of new PV installations will come to rely on the money saved by using power on-site. For households with only a PV panel and no other intervention, money saved on energy bills will rise with energy prices (in the UK electricity prices have consistently risen in both real and actual terms since 2004 (Bolton 2013). This re-calibration of the investment landscape may on its own lead PV owners to modify their practices to use more power on-site rather than export. We consider the effects of the solar intervention in detail as part of the report on LO2 trials.

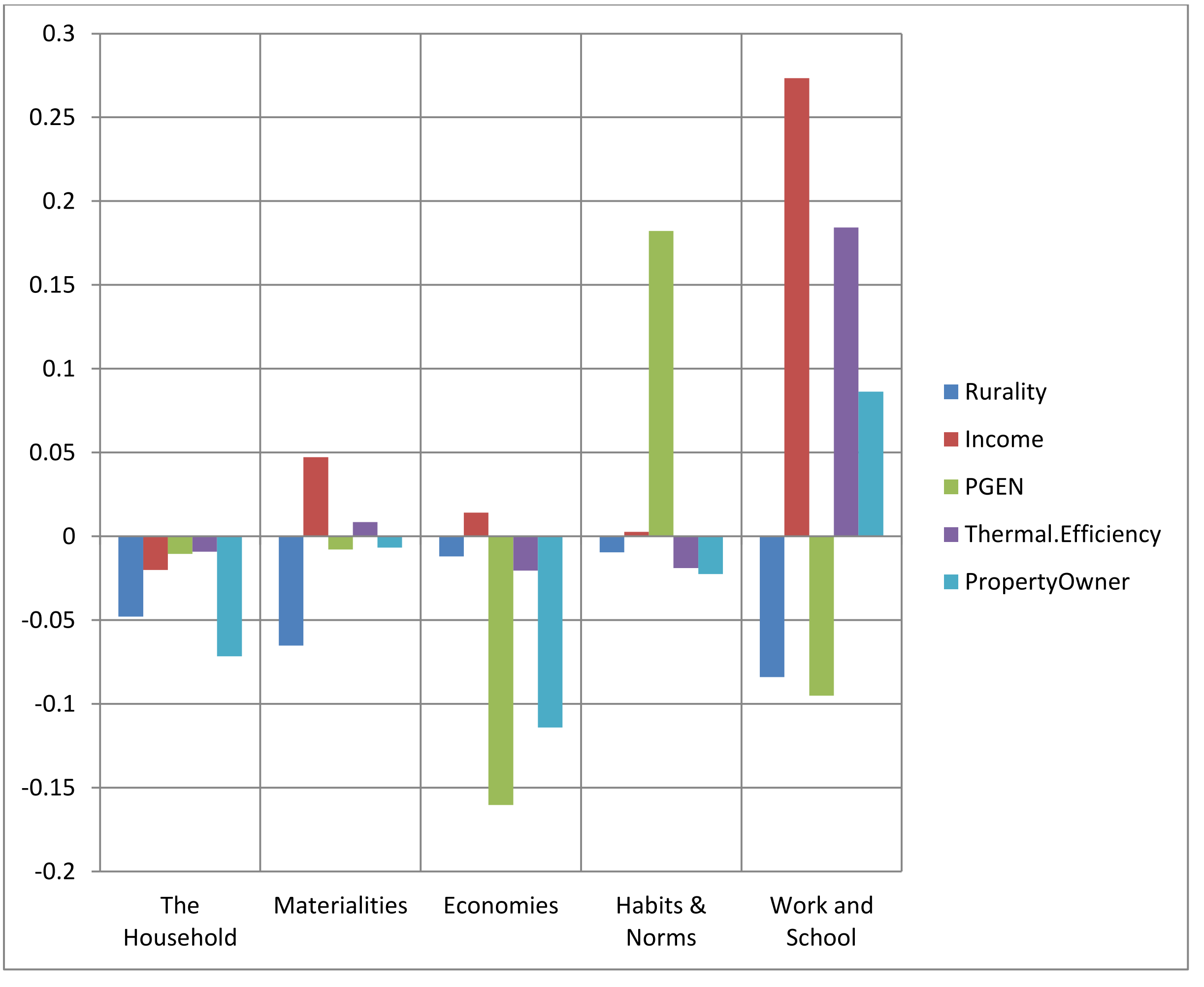
Table 8: Test Cell 5 Solar Summary Box

Our research found that PV ownership leads to more active ways of relating to energy, whereby individuals engage in the calculation of their own energy use and production, as well as in monitoring and managing their use to a greater extent than in other households. We find that the uptake and use of PV is being shaped by a new conventions focused on investment and the potential financial returns that PV can bring. On-site use of power is not widely recognised as a way to maximise financial benefits for PV owners. This creates a considerable opportunity for network operators to engage with consumers to identify the potential and value of using PV power on site and attenuate the flow of PV generated power into low voltage networks.

3.9. How do the factors shaping the energy use and the emergence of new forms of energy use vary in socio-demographic and socio-technical terms (LO1.2.4)?

Figure 39 below shows the relationships between the major factors identified as affecting energy use and the principal socio-demographic attributes held for participants. In interpreting the graph it is important to note that while most correlations are weak, there are six correlations greater than 0.1. This was achieved by producing a correlation matrix to relate instances of a quotation being tagged with one of the factors and the attributes of the household from which the quotation came.

Figure 39: Correlations between factors affecting energy use and major socio-demographic attributes



The first two factors have no correlations greater than 0.1 suggesting they are not strongly related to the major socio-demographic attributes.

The third factor, Economies, has two correlations greater than 0.1. These are both negative and suggest that managing the home economy is a more powerful factor in determining energy use for renters (property ownership is negatively correlated with economies, -0.11) and households *without* U5/O65s (this variable is negatively correlated with economies, -0.16).

The fourth factor, habits and norms, is positively correlated with U5/O65s (0.18) suggesting that habits and norms have a greater influence on energy use in households with.U5/O65s.

Finally, work and school schedules and ways of working are most strongly correlated with income (0.27) and thermal efficiency (0.18). This suggests that these factors are more likely to be reported as influencing energy use in higher income homes and in homes with greater thermal efficiency.

3.10. LO1 Summary

3.10.1. Domestic Electricity Demand: Analysis of consumption data

Total electricity demand differs considerably between households and this variance increases in the winter months.

The rate of electricity consumption in the 4pm – 8pm period relative to other times of day and night varies widely between households. While the mean average peak to off-peak consumption ratio is 1.36 the distribution ranges from a maximum of 4.86 to a minimum of 0.5 and displays an interquartile range of 0.61.

Consumption is on average 1.69 times higher per hour in the 4pm – 8pm period compared to other times of the day during winter months.

Evening electricity demand has been found to differ by tenure, renters also consume a lower proportion of their total electricity use during the evening peak hours, whereas owners' tend to consume more during this period. Owners also exhibit greater variation in the proportion of total electricity consumption that happens during the evening period.

As well as having the greatest average daily demand, rural off gas households also consume a higher proportion of their total electricity in the evening period, possibly as a result of cooking practices.

Of all the socio-demographic attributes we have analysed to date, income has the strongest association with total and 4pm -8pm electricity demand with higher income households (combined household income of more than £30,000) consuming on average 2.9 kWh per day in June and July and 4.7kWh per day in December more than lower income households (combined household income of less than £14,999).

Because of their overall contribution to demand in the peak period and the variability in their demand high-income households appear to be a key target group for future DSR.

The household practices most directly relevant to demand side management those which include appliances owned by many households; and those which have a high electrical load. On this basis these are heating, bathing, cooking,, laundry and dish washing.

3.10.2. SME Electricity Demand Summary

SMEs have much more highly varied demand for electricity than households.

The proportion of total electricity consumption concentrated in the early evening period varies between businesses, with much greater diversity than in households. Many businesses (41%, or 723 of the sample of 1762) consume less electricity per hour during the early evening peak than during the rest of the day or night (a ratio of less than 1:1). In contrast, this was rare (2%) amongst households.

Smaller businesses (1-9 employees) tend to consume a higher proportion of their total electricity in the early evening peak period and limited consumption overnight (such as those in leisure, and hospitality industries). Larger businesses consume electricity more evenly across a 24 hour period.

This may suggest that in terms of DSR larger businesses may offer more potential to be flexible by shifting demand to other times of day/night whereas smaller businesses may have relatively fixed electricity demand in the peak period.

3.10.3. SME Practices

Key practices associated with electricity use across SMEs are: lighting, heating and cooling, refrigeration, and ITC. We also identified a range of business specific practices that create specific load profiles for certain businesses.

Some business specific loads involve intermittent demand for high power, and these were found to be less fixed in time than lower power, day in day out processes and practices. These 'high power' practices could be flexible and therefore amenable to DSR interventions.

Connectedness is seen as a vital service that energy use provides, with servers and mobile devices often reported as being among the most critical appliances to business continuity. Ensuring connectivity between employees and data and between staff and customers should be recognised as an important feature of communications surrounding DSR, and here alternative forms of storage (e.g. batteries for computers) may provide a means of interesting the SME community in DSR approach

4. Research Findings: LO2

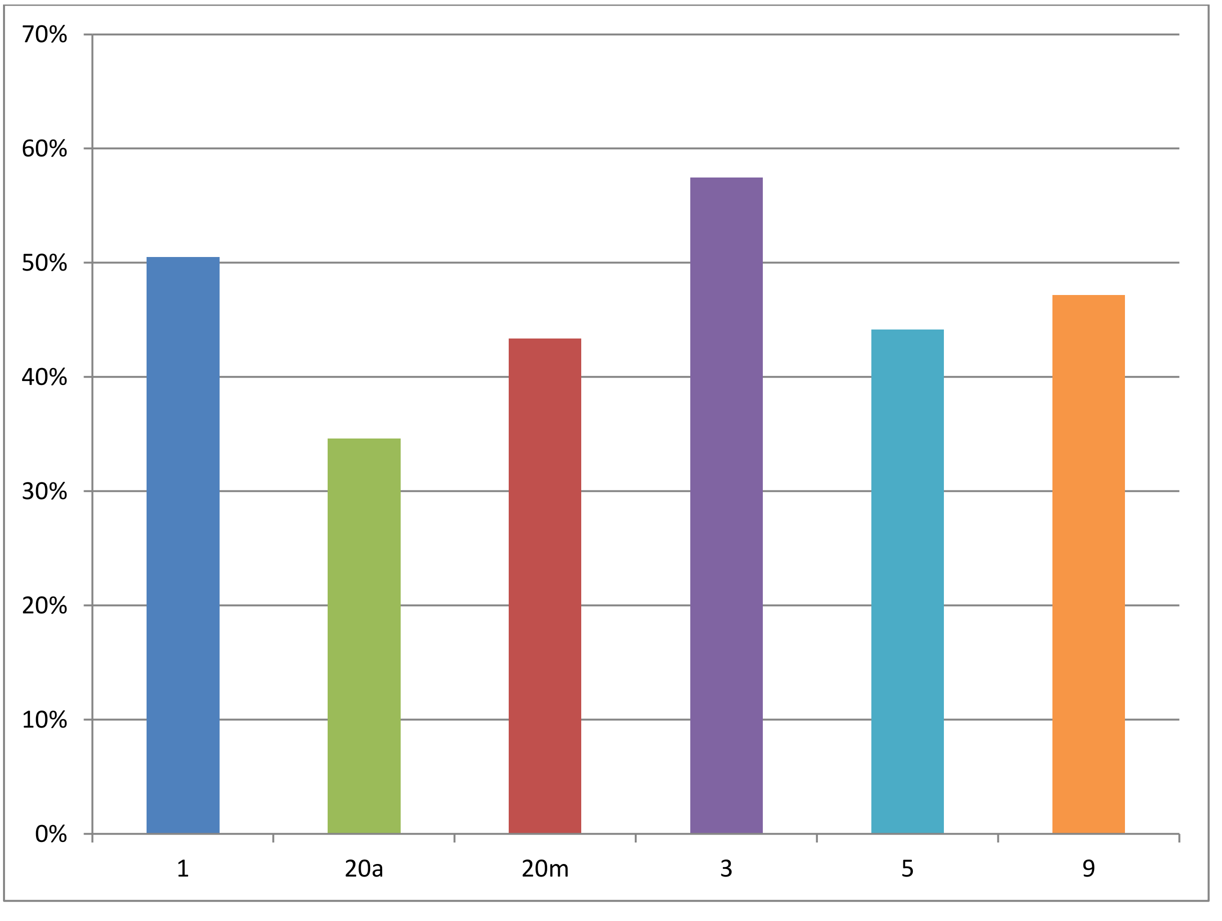
Learning Outcome 2 is concerned with the ways in which customers may engage with a new system and interventions for the demand side management of the electricity distribution network. While historically the power system has been a demand led system and distribution networks built to serve any foreseeable demand scenario there is increasing interest in and incentives to manage rather than meet certain demand scenarios in order to reduce the costs or defer decisions around network reinforcement. Under LO2 we present emerging analysis from the experimental test cells, and reflect on which practices are most and least flexible and where possible, how this flexibility varies.

4.1. In what ways and why are customers currently fixed or variable in their use of electricity in the 4-8 period? (LO2.1)

4.1.1. Domestic

Domestic customers display a range of energy consumption profiles. Analysing the variance of the average 4pm – 8pm evening consumption of groups of households, we can see that households in different test cells have differing degrees of variability in their peak demand.

Figure 40: Average coefficient of variance (CoV) of 4pm – 8pm demand for each test cell



The chart shows average coefficient of variance (normalised deviation from the mean) of demand in the 4pm – 8pm period for each test cell over 1 year. It shows that households in all test cells exhibit substantial variance. As a reference point, the control group (Test Cell 1) has considerably variable evening consumption, and for households in this group the average difference between the actual evening demand on a given day and their mean evening demand is, on average, slightly more than half of the mean evening demand (51%).

The chart suggests that solar test cells (Test Cells 5, 20a) have less varied evening consumption relative to Test Cell 1 and that heat pump users have most variance in their peak evening demand. Those on the time of use tariff in Test Cell 9 have slightly less variance in their evening consumption than the control group. These figures are tabulated below.

Table 9: Average coefficient of variance (CoV) across test cells

Test Cell	n	Average CoV
1	7999	51%
20a	93	35%
20m	101	43%
3	48	57%
5	97	44%
9	591	47%

Looking more closely in Test Cell 1 at the variability of households' evening consumption reveals that different socio-demographic groups have differing degrees of variability, although in most cases variability in peak demand between socio-demographic groups in Test Cell 1 is less than the variability in peak demand between test cells (Figures 41-45).

Figure 41: Coefficient of variance (CoV) of peak electricity demand by tenure

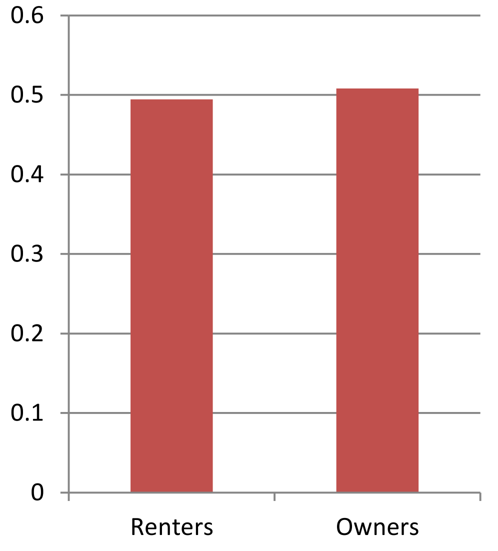


Figure 42: Coefficient of variance (CoV) of peak electricity demand by thermal efficiency

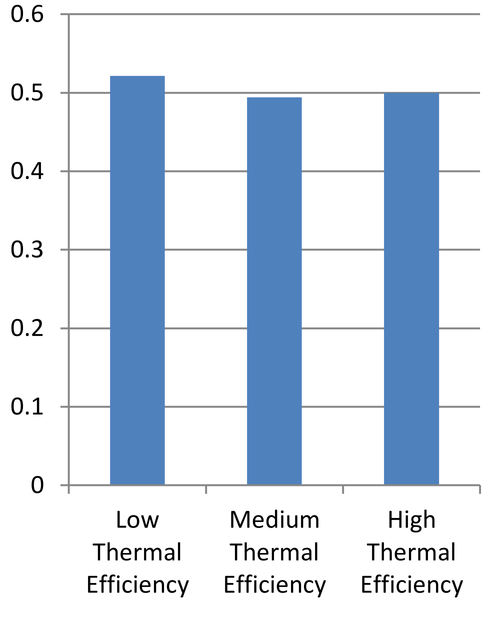


Figure 43: Coefficient of variance (CoV) of peak electricity demand by rurality

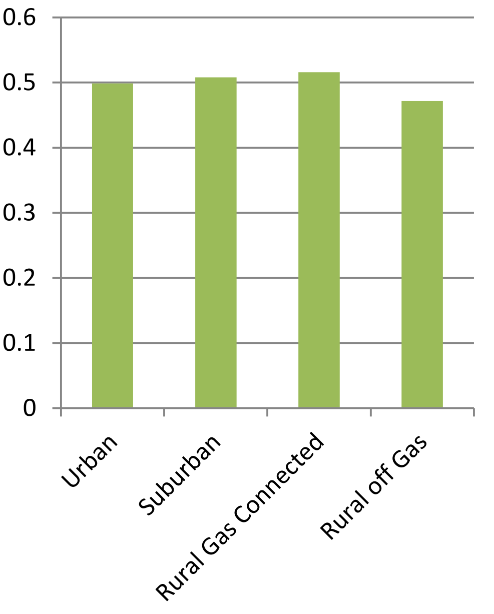


Figure 44: Coefficient of variance (CoV) of peak electricity demand by income

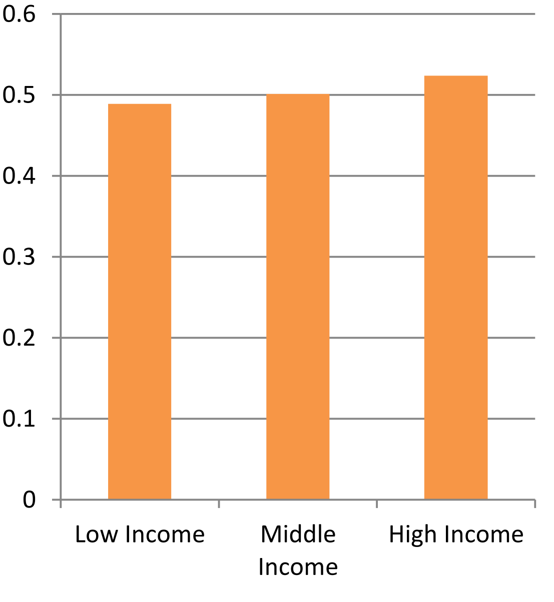
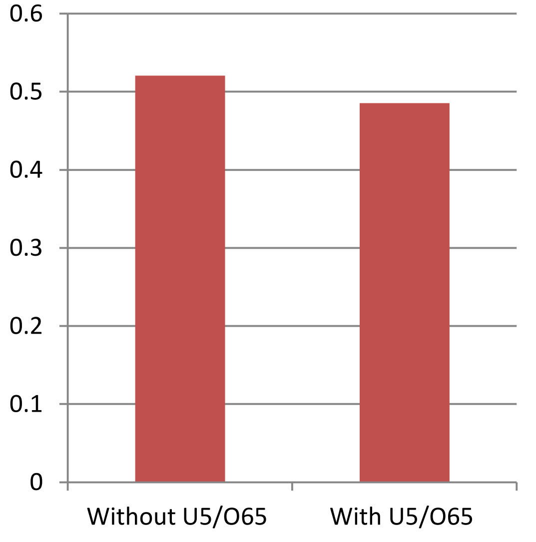


Figure 45: Coefficient of variance (CoV) of peak electricity demand by presence or absence of under 5s or over 65s



Socio-demographic variables associated with noticeably different average variability in evening peak demand are Income – where lower income is associated with less variability in peak demand – and the presence of U5/O65 s, which is also associated with less variable peak demand.

4.1.2. SMEs

Analysis shows that for SMEs flexibility is limited by material structures, temporal rhythms, economies, conventions such as standards and expectations, and capacities in the form of knowledge and competencies.

4.1.2.1. Material structures

Material structures refers to the location of the business and its access to power supply, as well as the constellation of services, such as lighting, heating, cooling and ventilation, and the various types of electrically powered equipment required for the business to operate. Services, like lighting or heating, are common to all businesses. For some SMEs, service provision imposes what is construed as a non-negotiable load, mainly lighting, heating and/or cooling. Examples of non-negotiable loads include using floodlights for all night security, extra heating required for clients undergoing health treatments, illuminating window displays out of opening hours to project a presence in the locality, or refrigerating food in accordance with externally imposed protocols to meet food hygiene regulations.

Certain types of equipment are also common across the sample. All SMEs in the study used at least one computer. However, many businesses feature specialized, energy intensive machinery essential to their product or service. These range from hot wax heaters to ventilation systems, and industrial production equipment. Cooling practices such as refrigerating food and drink, processing foodstuffs in production contexts, animal welfare concerns and machinery requirements are affected by material conditions and the characteristics of ‘non-humans’ rather than by users’ choices, for example:

> *When you're working in a lab, working with gases and such like, you've got to make sure they're extracted … (Bio-technology/R&D company manager)*

> *The milk cooling system has a timer that runs on for 2 or 3 minutes every hour – like a thermostat. It has to keep it below 4 degrees. And that’s the water heater, that’s for going through the milk units to sanitize them. (Dairy farmer)*

The range of these examples provides a sense of the diversity of socio-technical situations that are perceived to ‘need’ cooling or ventilation as a result of the interplay between natural conditions (biological/chemical/physical properties) and socio-technical conditions (regulation, technology design, building design, building maintenance).

In terms of material structures, location, types of equipment and types of service provision heavily influence electricity practices and seriously – if not fatally – constrain flexibility in practices.

4.1.2.2. Rhythms

SME’s variability and flexibility in energy use is related to diurnal, weekly, monthly or seasonal patterns of activities in pursuit of business goals. These patterns might cohere around regular routines such as opening hours, meal times, weekend clients, food production, holiday periods and the like, when energy consumption is unavoidably high in relation to other lighter periods.

For some SMEs in the UK patterns of energy use is determined by connections with businesses in different time zones:

> *We start early in the morning … at 6 or 6.30am because the factories are all in the East and at 3pm we're done for the day (Textile manufacturer).*

But not all business activities have temporal predictability, for example, when manufacturers have to work overtime to meet unusually large orders. In other cases the materiality of equipment and the purpose to which it is put coincide with temporal factors:

> *They have to heat up, digital printers have to be at operating temperature so they need to be more or less left on … (Digital print factory manager)*

> *The wax pot needs to be on all day – it keeps the wax warm and soft for doing legs or eyebrows. It takes 20 minutes to warm up so if we need it on we can't wait for it, so it stays on all day (Beauty salon manager)*

> *For all the optics, the pumps, there's a big unit with a coil in it, that's on 24/7. If you turn it off the ice block inside will melt and you've got to start again and it takes 24 hours to cool down. (Publican)*

These arrangements of spatio-temporal ordering are implicit to the functioning of businesses, sometimes as a consistent centre of action or otherwise intermittent practices that are equally essential to production, as illustrated by the following example:

> *That's quite high power, taking about 6.5kW, and it's in use, in a good day about 20 minutes a day. [Digital print factory]*

A limitation on flexibility related to conventions is temporal factors attached to production and service regimes, which are closely connected to customer and supplier's expectations:

> *We work longer hours during busy times because we have to accommodate [clients]. (Hair and beauty salon manager)*

> *I have clients until seven, seven-thirty. (Architect)*

> *The customers that we deal with want us to be open late. (Estate agent)*

> *We normally operate from nine to five [09:00 to 17:00], there are quite frequently exceptions to that. For instance the reason why we have got a rush this morning was because a customer runs short on a certain item for production … that would*

> *normally take three days to finish and we have about three hours. (Panel manufacturer)*

SMEs argue that they must accommodate the requirements of their customers, even though this affects the ability to plan production efficiently or modify ways of working to reduce energy within the 4 to 8 period, to safeguard their reputation, and to ensure the continued viability of their business.

> *They [customers] always are putting time pressure on us. …. They would be on the phone the following day saying you haven't delivered. … they start looking for other vendors. (Panel manufacturer)*

Analysis of data indicates that the ways in which SMEs may be variable and flexible in their energy use is derived primarily from the nature of the business but also the wider networks of which it is a part.

4.1.2.3. Capacities: Knowledge and competencies, business arrangements and networks

Further limitations on flexibility are imposed through knowledge and competencies. Some participants exhibited a very low level of awareness (i.e. not knowing what tariff they are on), whilst those with the highest degree of knowledge were unsure about how to further adapt their practices to optimise electricity consumption.

Knowledge refers not only to technical know-how and skills, but includes the owner-managers' ideas about how systems of provision are operated. Such knowledge is dynamic and shifting, obtained from a variety of sources, and sometimes deployed as an instrument of authority. Managers, as opposed to owners, often passively await instructions from bosses:

> *There's no culture of switching computers off, the company hasn't really gone down that road yet. (Electronic equipment repairer)*

> *We have a test area when we have twenty or thirty machines on; we do need to power them for a long time. We don't necessarily need to power them constantly twenty-four hours a day. …The PCs are on twenty-four hours, most of them. [...] Printers would be left on stand-by. Yes, I'd end up leaving this lighting on upstairs. […] The current way we are working, there is no guidance from the company, I don't think we have any sort of policies on switching these PCs off or anything like that throughout the company. (Panel manufacturer)*

Many of those SMEs taking part in the survey have undertaken well-publicised measures, the most common being improved insulation, double glazing, and training employees to switch off unused lights and equipment. Even with these measures, implacability of existing structures and systems may counter attempts to introduce flexible practices. Some firmly believe they cannot make further changes because they are locked into to certain unavoidable practices by the nature of their business arrangements. In some circumstances people are resigned to circumstances they view beyond their control, due to dependency on the landlord, suppliers, or because a business is run under franchise. They are aware of energy being wasted, but stand outside the problem as exemplified by this publican:

> *The cooler is meant to be on 12 hours a day but it's on about 18 or more hours a day, because it's a rubbish system but unfortunately it's not my system it's the brewery's and trying to convince them to replace it is hard work. So there's a massive fan down there trying to keep the place cool. (Publican)*

Most of those who took part in the research state that they would like to use less electricity or are willing to be financially rewarded for using less at certain times of the day or week, while uncertainty remains about how either of these outcomes can be achieved. They maintain that energy measures like lower temperatures and reduced lighting will make their business less attractive to customers. Others inhabit rented premises that their landlord refuses to upgrade or retrofit. This group in our sample represents what might be termed the 'stuck majority' who desire change but cannot envisage further alteration to the way they operate. These owner-managers can imagine the possibility of new and more sustainable practices but are daunted at the prospect of realizing them (Shove and Spurling 2013: 1) because of the changes in work practices and business relations they might entail.

Partly guided by ingrained habitual routines that interact and are consequently influenced by other people's practices and underlying assumptions, people may be unable to articulate the full range and implications of their work practices: owner-managers' reading of, and response to, the expectations of customers being one example. Owner-managers retain an overarching view of their business procedures and can evaluate how changes to one way of doing things will have a knock-on effect upon others. Change may be resisted out of a firm grasp of the interdependencies, rendering owner-managers suspicious that change could unravel complex threads of altered practices with inadvertent consequences, leading to inertia.

4.1.2.4. Economies

Those interviewed described measures they had already taken to reduce energy and costs. In assessing whether to modify business operations or invest in equipment that could enable variability and flexibility, SME owner-managers weighed up advantages against consequences to evaluate potential risk to viability of their business.

> *We have to make sure it doesn't impact the business, whatever changes we are making. So like turning lights off and looking closed when we need to be looking busy and open. (Estate Agent)*

> *I'd tend to wait until it reaches its ... apart from the light fittings ... but any other equipment I would tend to replace that only when it comes to [end of] its use and buy more energy efficient one. (Electronics company manager)*

> *You can't be replacing equipment on the promise that you may get work to pay for it. So you don't. … [W]e'll be running that [machine] until it drops 'cause we can't*

> *afford buying a replacement for it. If there was some sort of scheme that would allow us to upgrade to a more efficient unit quite easily, then we'd work it. (Panel manufacturer)*

> *[W]e were thinking about getting a row of solar panels on the back. [...] Well it is a bit expensive so it's something that we'd consider in the future but obviously not right at this moment in time. (Beauty salon manager)*

> *[T]he price then went down for the equipment [solar panels] and it looked like it was worthwhile. [...] And three grand [£3,000] [investment] and it didn't seem as if it was worthwhile for us … financially to get a return in seven years … (Community music centre manager)*

> *This is one of the biggest problems you've got with saving energy: it's the payback time. Small companies like mine, you'd want your money back in no less than three - five years 'cause you can't see that further ahead. (Electronics company manager)*

4.1.2.5. Conventions

One aspect that emerges as particularly significant in producing inflexibility in electricity practices is a perceived requirement to maintain connectivity with customers and suppliers on a 24 hour basis. This is taken to be a given in running a business; to be open and contactable. ICT practices are important to all businesses in our study, with the use of ICT affected by material considerations pertaining to the design and age of the equipment. Temporal factors also intervene. Our interviewees want fast and reliable access; while the desire to maintain connectivity with customers and stay 'open for business' leads to continuous loads (see also Gram-Hanssen 2010):

> *We have a computer that gets left on overnight, because we do get customers placing orders through the night (Panel manufacturer)*

Lack of knowledge of alternative means for continuous online presence without local power load informs owner-managers' decisions to maintain uninterrupted power on-site. Even when a business' computing load is relatively small, it is nevertheless frequently deemed to be uninterruptible. Moreover, dependence on ICT can generate proliferation "as new features are added to a practice or a complex of practices" (Røpke and Christensen 2013: 56) creating puzzling and overly complicated forms of use:

> *There are constantly two PCs running upstairs. There's a laptop I try to turn off. But the main PC is always picking up emails any time of night. (Publican)*

There is scope for reconfiguring ICT systems and practices. There is evidence of changes to some SMEs ITC energy practices through changes in employment structures, such as working from home, and increased use of mobile internet devices and cloud-based services.

4.2. LO2.1.1 - How and why does fixity or variability change?

Section 3.2 of this report identified groups of practices that are most directly relevant to peak demand management debates as a result of the combination of several factors pertaining to the likelihood of being performed during the 4pm – 8pm period, electrical load, and the popularity of technology ownership. This section is concerned with fixity or variability in those practices identified, and the mechanisms underlying this.

Analysis of the qualitative data indicates that practices are organised on a daily or weekly basis, and may be adjusted seasonally depending on the particular practice. In many households routines related to personal hygiene or cleanliness are performed on a daily basis, for example bathing, showering, or dish washing. Others, such as washing and drying laundry and vacuuming tend to be carried out daily, inter-day or weekly, depending on the number of people in the household and 'virtues' of housekeeping held. Laundering is practiced frequently by busy families, as illustrated in the excerpts below:

> *RES(f): [W]e all put our clothes in the basket; the washer is on every day without fail, even Christmas day, at least once a day. (ML14)*

> *RES(f):Two to three [wash loads] a day. … Well, if I missed a day I'd probably do 5 loads the next day (EPJ12)*

Practices may vary seasonally, such as those associated with heating regimes or drying laundry, which are weather-contingent. This seasonality is reflected in the daily electricity load profiles, which show lower average consumption during the summer months, and this is discussed further based on qualitative interviews later in this section.

4.2.1. Daily or inter-day variation

Some changes are observed to the timing of daily practices as households seek to make greater use of electricity generated by PV on-site in the middle of the day. Such practices range from charging small household appliances, from power drills and electronic devices, to batch cooking, laundry, and heating internal spaces:

> *RES(f): What I do now, because on the washing machine and the dishwasher I have got the time delay switched on. So often I load it at night and put the time delay on so it comes on early in the morning when it [PV] starts generating. (HS02)*

> *I certainly concentrate the washing when the solar panel is working … through the day. (HS10)*

> *RES(m): I try and I'll even cook things when the sun shines or get a shower when the sun's shining if I can. (DL17)*

In the following example, this householder uses battery storage to provide lighting in the evening, and heating to make most use of electricity generated on-site:

> *RES(m): The LED lights run off batteries that are in the attic which is charged by a little ten Watt solar panel which I've attached to the brackets that the original solar panels were put up with and that is set on a timer which is in the computer room. I've got it set to come on at eight o'clock and go off at midnight [20:00 to 24:00]. (HS10)*

> *RES(m): I do have two twelve-hundred Watt heaters that I use. … they only get used when I'm generating more than four-hundred Watts. … when I'm generating more than I can put on. I'd use them in the summer because if it's cooler during the night I'd put them on at night providing I've got more energy coming in than I'm using. (HS10)*

Participants reported changes to the time that rechargeable appliances are charged; those with PV charge electronic appliances during the day where previously they were charged at night:

> *RES(m): You charge the ipad through the day … and the laptop. (HS001)*

In contrast, a different approach is observed by those on a time of use tariff who charge appliances at night:

> *RES(m): I use a lot of batteries, rechargeable items, power tools, my scanner … I try and charge them after 8 o'clock or overnight. … some of these things take 16 hours to charge so I'll charge them overnight. (GP19)*

Although these householders are seeking to optimise energy consumption through aligning their practices with the system of provision or electricity tariff where possible, there are limitations to such flexibility – inferred from participants' explanation of their own experience of using the technology, and how it fits with their routines and expectations. This is further exemplified in daily showering practices, and the provision of hot water:

> *RES(m): Obviously if I am at work I'll get a shower in the evenings now. I just try and make full use of the solar panels. (DL17)*

> *RES(m): That does not heat water if there is no sunshine. I'm only getting one immersion heater operational in dull weather. And that has a consequence. If it was really dull all day we [wife and myself] could not each have a shower without putting additional electricity into the system, on peak. It's really a matter that we look at the weather forecasts, we look at the weather during the day. And I've got the solar powered immersion heater set at seventy degrees, which is very, very hot. The result is that if neither of us had a shower on that particular day and it happened to be sunny, that amount of hot water would still be available the next day. We've got to take into consideration the weather conditions. (DL1502)*

Only modest changes to showering practices were reported by participants with automatic water heating from PV: these were related to variability in when showers are taken, either on the same day, or inter-day, depending on favourable weather conditions and availability of hot water from solar electricity, as illustrated in the excerpt above.

Variability in showering practice amongst participants is more likely to occur where practices can fit with existing structures and routines, notably working hours or social activities. Bathing practices are strongly related to norms around cleanliness: as part of their usual routine, most people interviewed take a shower or bath once or twice a day, in the morning and/or evening.

More widespread evidence exists within the data of variability in doing household chores, in particular use of the dishwasher, washing machine, tumble dryer, and iron. Variability in clothes washing and drying is affected by several factors – most notably, the weather, habit and routine, extent of planning and contingency (for example, having an alternative means of drying laundry) and the householder's own understandings of home management:

> *RES(m): We have changed our habits. You know the letter that BG sent me showing what rates were highest, after four o'clock [16:00]. So my wife has changed her habits of housekeeping. So at the weekend she does most of the things you know hoovering [vacuuming], washing at the weekend if she can or in the morning if she can. Off-peak in effect. (MJRTL01)*

> *RES(m): This morning … just emptied it [dishwasher] and put the dishes away. … I'm quite happy for it to sit there overnight, it's perfectly normal. Whereas before it would be on instantly when we'd finish the meal. (MJRTL09)*

> *RES(f): I like to hang my washing out, I don't like to use the tumble dryer. So I select days when it's dry so for example I did two loads on Wednesday because the weather forecast said it was going to be dry on Wednesday. So there is one load waiting … but I didn't switch it [washing machine] on today because it did rain. (ML23)*

> *RES(f): If it's raining I think oh I'm not gonna do the washing today and I would put the washing when the weather is nice. [...] When it's [a] sunny lovely day I tend to go looking for washing. You tend to do a bit more extra washing when the weather is nice, which I would do. (ML13)*

> *RES(f): I'd do the washing definitely in the morning. If I know it's not gonna be fine I'd do it at night and put them on clothes horse. I'd look at weather forecast [laughs]. I do prefer to hang them out, I was brought up like that. I just think it's better for them. It is isn't it! It's natural to be outside and dried. And then when I brought them in I iron them. (ML25)*

RES(f): I wouldn't do that [do the laundry in different time]. If they'd change the tariff – yes, I'd probably do it. I prefer to do the washing through the day because it's not in the washing machine all night. (DL03)

RES(f): I'd normally wait, have a look outside and if it doesn't look bad, switch it [washing machine] on. If I do make a mistake, I have got a small tumble dryer in the garage but it doesn't get used very often. I don't like to pay for electricity for something that I don't need to. It also dries better outside and smells fresher in my opinion. And on a good day you can peg it all out together and bring it in a bit at a time and iron it as it's ready. It's much better than getting the whole load into the tumble dryer, having to put it all onto clothes airer until you can iron it. It's just the way I was brought up really. It's just the way my mum did it. (ML23-28.06.12_TC20)

RES(m): Wednesday we do the bedding wash, and there's no room to dry them anywhere else. [rationale for using tumble dryer] (EPJ17)

Participants identify tumble drying as having high load intensity and certain groups report medium likelihood of use in peak. Fifty six per cent of households in the North East have a tumble dryer (ONS, 2013), and how these are used varies between households. Tumble drying during the peak is less likely to occur where households are not in employment, and where space and ideas about home management allows for hanging laundry indoors or outdoors to dry. However, convenience is paramount for those who are working and/or busy families:

If it's raining or whatever, I just get it in the tumble dryer. I do use the tumble dryer a lot. … Yesterday, I didn't 'cause it was so windy I got stuff dry on the line. … When you're at work and you need the uniform for the next day. It's easier … I do use the tumble dryer a lot. (GP37)

RES(f): I tend to wash and dry on a Saturday, that's habit. It's when I'm not working and that's when my washing gets done. I use the dryer; I don't do the washing line. [INT: any reason for using the dryer?] I'm lazy! [laughs] I don't know, I suppose because I work full-time, I just can't be bothered to put washing out, to come back to wet washing on a line. (DL13)

RES(m): The dryer – that's on more than it should be. But it's just too easy to go from the washer and dryer in the same room. … We've got no sort of set routine … but I think over a week you're talking probably about 3 or 4 loads over a week so about an hour and a half each, 6-8 hours a week it'll be on. (EPJ20)

4.2.2. Seasonal variation

The qualitative data reveals some evidence of changes in how practices are performed relating to the seasons, most notably, laundering and heating (thermal comfort) practices:

Through the summer months it can be 7 o'clock in the morning put it [washing machine] on, quite early so I can get them out. Usually maybe two loads. (ML20)

Obviously, in the summer I never, ever use my tumble dryer. I always put them out on the line. 'Cause I prefer it, they smell's nicer when it comes in from the air. […] Winter –obviously, I do put the tumble dryer on. (MJRTL07)

RES(f): We tend to use dryer during the winter, but once it gets Spring we wouldn't use the dryer. Even in the winter I only use the dryer for towels and sheets 'cause I've got airers for the clothes. But then in the summer we don't really use the dryer at all really … we've got a couple of outside lines. Also, 'cause it's a washer-dryer you find its tied up doing the washing. (EPJ012)

RES(m): Yes, we'd have different settings [spring, autumn, winter], we'd change it very often. Well, we don't change the start time and the finish time but during the day we'd change it when it comes on so depending on sunshine basically. (ML23)

4.3. LO2.1.2 - What does flexibility in energy use mean in a domestic context?

In the first Social Science Interim report we presented a flexibility framework that has been revised in subsequent work and presented again here for completeness. It represents a framework for further analysis and discussion on flexibility as a property of practices that is of value to DSM initiatives.

1) Time Flexibility:
   a) Same-day flexibility: changing the time of day a practice is conducted, moving it within a 24 hour period
   b) Inter-day flexibility: changing the day on which a practice is conducted, or moving it by more than 24hrs.
2) Location flexibility: changing where a practice takes place, such as showering at a family member's home or at work.
3) Process flexibility: changing how a practice is performed and as a result changing the electrical characteristic of the practice. For example, cooking on a gas hob rather than using a microwave.
4) Practice abstention or curtailment: doing a practice less often or for shorter periods of time. For example doing less cooking altogether, or taking shorter showers.

This part of the report now turns to consider the flexibility of dining and cooking practices, laundry and household chores, refrigeration, and bathing/showering.

4.4. LO2.1.3 - Which kinds of energy use and energy practice are the most and least flexible and why?

This section is concerned with the extent to which energy-intensive practices performed within the 4pm – 8pm period may be flexible, and the mechanisms for this.

4.4.1. Dining as fixed in the early evening

For the most part, dining still takes place at conventional meal times, between 4pm and 7pm, and for most households this is firmly fixed in time. It is worth noting however, that this does not cover all situations. Where there are mixed households – with adult children living with parents or grandparents, or where shift patterns vary, some cooking does take place after the evening peak and this tends to be microwave cooking.

> *When I was at work I used to come in and have dinner in the evening, Now, that means if we're using the cooker that's one of the most expensive times … We did have a situation and we talk about it and we did change a bit and we had our main meal at lunch time but I couldn't get my head around it, I didn't like it. Now we've gone back to having our main meal in the evening, being full aware that that cooker is going to use a bit more electricity. … I was so used to having my dinner of an evening, and I enjoyed that and it's gone on for years and years. (Customer on a time of use tariff) (MRJTL10)*

> *I probably cook my tea at about 5 o'clock, I know it's probably the wrong time, but I mean, what time are you supposed to have your tea?! You sort of programme yourself for it, don't you. By tea time I want filling up again. (GP32)*

While the data clearly tells us that dining is fixed for most households, we feel it is worth exploring cooking-dining practices further for two reasons. First, for some households (those not in a typical work or school schedule) cooking, if not dining, is something that participants feel could be experimented with, as is picked up in the LO2 sections of the report, below. Second, there are large loads associated with cooking that offer potential value for DSM.

4.4.1.1. Inflexibility: rhythms, structures, conventions

Mealtimes are considered to be relatively inflexible because of how they are influenced by conventions about when to eat, established social structures and rhythms:

> *RES(m): It depend whether I'm working or not. [...] I can't actually give a specific times because some weeks I work all week or couple of days, whatever. [...] I'd have my evening meal. … Generally whenever we came home from school, we'd have our tea ready. So quarter past, half past four every day [16:15; 16:30] we sat down, every day, always around about this time. (ML26)*

RES(m): For forty years I'd got up at seven o'clock [07:00] and leave the house at half past seven [07:30], I've gone to work [...]. That's the trouble now [to change the routine], I'm so settled, you know I've been doing this for forty-three years! (EPJ18

RES(m): The main meal is always in the evening. [long list of who eats what & when; varied household] [...]They [adult children] have different working patterns than ours. The main meal of the day is probably around seven o'clock [19:00] when [wife/partner] and I and my stepdaughter will have a meal. (EPJ019)

Despite being at home and flexible about when laundry is done, this householder is unable to be flexible in meal times:

RES(m): Well, I think that meal times are as a whole fairly inflexible. But since I'm at home pretty much all the time I actually can be a lot more flexible in things like washing. (GPML03)

Understandings about personal health and risks to wellbeing, such as the need for regular meals due to medical conditions (in this case, diabetes), influences routines:

RES(f): No, I didn't change [any of the cooking during the week]. I'm very strict, I have breakfast at nine [09:00], dinner at twelve [12:00] and tea at five o'clock [17:00]. (GP22)

4.4.2. Time flexibilities of dish washing, laundry and household chores

The analysis suggests that chores are an interesting collection of linked practices in that they are affected by a wide range of factors, and are practices that large groups of householders perceive to be least fixed. That is, these activities are not fixed to particular times of day for many household groups, but are activities that participants want to happen in certain time-frames. For example;

Dishes: Having dishes cleaned by a dishwasher appliance is reported as being something that should happen within a 24 hour time-frame. However, within 24 hours there is flexibility; dishwashers should be activated most days but the timing is not tightly fixed.

Every day. Once a day … It’s probably either first thing in the morning or teatime when we’re in. It can be during the day though. … it just depends who’s in. My stepdaughter works … she got mid-week days off so she starts at 5am and finishes at 3pm. … Predominantly it’s in the morning before we go to work or when we come back from work but there are other times in the middle of the day when it gets used as well. (EPJ19)

Laundry: Having clothes cleaned and dried is not always talked about as being fixed to particular hours in the week (although some household do retain the custom of having set days for laundry). Laundry is an activity that some groups of respondents (most typically working families) felt could be moved around within a 24 hour time-frame, or even between days, in ways that would be driven by convenience, weather and the weekly rhythm of working patterns. People talk about laundry as happening within a weekly time-boundary, which can be contrasted with daily time-frames for practices like dining, or entertainment.

> *The dryer – that's on more than it should be. But it's just too easy to go from the washer and dryer in the same room. … We've got no sort of set routine … but I think over a week you're talking probably about 3 of 4 loads over a week so about an hour and a half each, 6-8 hours a week it'll be on. (EPJ20)*

Cleaning: Having the home dusted, vacuumed is most often thought of as needing to happen within either daily or weekly time-tables, but is not always fixed to particular times: although this is not the case for all households, as is discussed below. Working couples and families particularly are open to this being done at a different time, or in the case of an exceptional interruption, being prepared to reduce, rather than reschedule these chores.

4.4.2.1. Flexible chores: capacities

To assist with shifting laundry practices, households must have the socio-technical capacities for drying laundry in alternative ways including an alternative to using the tumble drier which includes physical capability as well as material resources:

> *RES(f): If it's a nice day I'd put some things outside. I haven't got so many facilities for drying outside so I tend to fold them and put them on a piece of plastic on there and then when they're dry bring those in and put those others out. So it works well. [...] If it's windy and it's warmish it soon dries out there. Usually I'd put the washing out at eight o'clock in the morning [08:00], by the lunch time they're virtually all dry. That's not heavy towel or bed sheets, they take longer. (ML06)*

> *RES(f): After it's finished I'd mostly put it [laundry] outside if it's a good day like this one. Or it would go inside [at the heater] and let it just dry like that [...] I'd put it outside as soon as it finishes, before twelve o'clock [12:00]. (ML16)*

> *RES(f): If it's not raining I'd put it out on the line. If it's raining, the big clothes I'd put on the clothes horse but underwear and socks sometimes I put them on the radiator, depending on how cold it is I would stick them in tumble dryer but it's not often… (ML22)*

> *RES(m): If it's like this or sunny we'd put that on the line. If it's raining, there is a tumble dryer in shed or on the radiator. Or we have got a drying screen in the conservatory and it's like a greenhouse in there. (ML19)*

> *RES(f): Sometimes I put this up, which opens out to a big square and I'm getting lots of things on that and then have a little one [hangers]. If it was really pouring down I wouldn't wash. Or I might wash them and leave them to see if it was fine the next*

day or I'd put over that [hangers] and they would just dry here overnight. I very rarely use the tumble dryer. I used to use it a lot because I couldn't take the clothes out, could I? I was quite ill. So I used to use it a lot but now that things are a lot better I don't' use it. I usually put the towels out and let them sort of get some of the wet out and I finish them off in here for about fifteen minutes. (ML11)

Many householders who eschewed the tumble dryer had a room or hanging space that they could use for drying laundry:

RES(m): It depends on the weather if I take it straight out and hang it up. If it's inclement weather I'd just leave it there until things brighten up a bit. If it's still there when my wife comes in and the weather hasn't changed then it's a case of hanging this in the conservatory on the stand and place it right next to the radiator. (ML05)

RES(m): We'd always hang out all things: if the weather is not good enough we'd bring it in here either put it in the dryer or in the conservatory. (ML28)

RES(f): I peg the washing now rather than use the dryer. I only put the dryer on now to sort of finish the towels off so they're soft. Or in the really bad winter then I might have to put them in the dryer, but even then … I have the clothes horse. (ML11)

This appears to be more of a problem for families with children, or where space is limited. For some participants drying laundry indoors conflicts with ideas about good housekeeping and propriety:

RES(f): We've changed the beds today because it's a nice day and we can get the bedding dry. But if you pass a week without the washing and [...] it's pouring with rain, where do you dry everything? We have a [...] cupboard in [name, son] bedroom which has got some rails in it and we can hang things up in that but there is only so much you can put in there. And I don't like it all on radiators, I'd put a tea towel on there just to dry off but I don't put clothes on the radiators around the house because I don't like to see it like that. (ML14)

RES(m): Wednesday we do the bedding wash, and there's no room to dry them anywhere else. [rationale for using tumble dryer] (EPJ17)

RES(m): If it was raining outside I'd put it on either there or I'd put it on there or I've got a stand so I can use that one if I need to. Any heavy things I wouldn't put in the tumble dryer anyway, I'd only be socks, underwear, and the tea towels. I wouldn't put jeans in there even if I'd want them that day, I'd put them in there or outside but not in the tumble dryer. It's not needed. And the only reason why I'd put in socks and underwear, it doesn't look nice if people come in and you've got socks and underwear and bra's and knickers and underpants all over ... oh no! Maybe if it's a jumper but not underwear. But it's just me, I think. (ML07)

None of the householders interviewed mentioned using a launderette or outsourcing washing, drying or ironing, although it is likely that some elderly or disabled participants may rely on family members and carers to provide assistance with this service.

4.4.2.2. Structures and rhythms

For some households, the rhythm of household chores is fixed due to not only patterns of working, but other routines and social or leisure activities:

> *RES(f): We're going out today [Saturday] so no, I'm not putting washing in today. But tomorrow we're in 'cause he's on standby so I'll put the washing in then and get it dried for Monday. (EPJ18)*

> *RES(f): Friday I would come in from work ... the hoover would be on. The washer would be going. Right the way through probably 'til 10 o'clock that washer will go. (EPJ14)*

> *RES(m): Well, I'm up at 6'oclock in the morning so I like to tidy up in the morning so that's me finished for the day. (MJRTL12)*

There is a clear pattern in the data to indicate a relationship between the meanings attached to laundry practices and the time of day they are routinely performed. Participants who had few other time-structures had often created their own wash day and time, to which they attached great importance. However, laundry was considered to be a chore for those performing laundry in the peak period, to be squeezed in between other activities, as indicated in this example:

> *RES(m): In an ideal world where we didn't have so many time pressures, and we could choose when to do things like the washing or the cooking, and there were cheaper or more efficient times to use energy then we probably would. Not with a family and two jobs at the moment. (EPJ17)*

This is of importance to the peak demand debate as it suggests that to the extent laundry contributes to the network peak it is relatively flexible, and where it is inflexible it is done in the morning or weekend day time and as a result does not contribute to the network peak problem.

4.4.2.3. Structured and unstructured laundry and chores: regimes and rhythms

There is evidence to suggest two main approaches to laundry reported by participants. One is the unstructured 'when it piles up' approach which is not restricted to a particular time in the week and is more flexible. In these reactive regimes chores can be done at almost any time of day in working households. Another manifestation of this reactive approach to chores is that laundry is a practice that can be triggered by weather conditions. If there is a particularly sunny or windy day these natural resources are taken advantage of and enrolled into the management of the home by increasing textile washing (clothes, curtains, bed linens, towels etc.) while tumble drying is reduced.

If there is anything that needs doing you've just got to do it. I can't wait for that. (GDP45)

I just do things as they are convenient to me. I do the laundry sometimes in the evening, if the clothes are there I'll do them. (GP26)

If the clothes are there and I think it's going to be a fine day, I'll do it then. (GP26)

[Interviewer: When do you use the washing machine and dishwasher?]
Participant: Anytime. If we need something doing [washing] we'll do it. (ML28)

The second type of chores regime is a more structured, timetabled approach with a particular washing day being a fixture in the week. Counter intuitively this is more typical of retired people or those not in typical (roughly 9am-5pm, Monday to Friday) working arrangements. These participants tend to create a timetable in which to locate chores – in order to 'get them out of the way', or contain them away from other activities reserved for the rest of the week.

Oh, I couldn't stand it. No. Monday is washing when I get up to wash. It's folded ready to go out or in. I go along to get my pension. … I go to the paper shop and pay gas, electric, rent, garage, lotto – all on a Monday morning … all at the paper shop and then back home. … No, that would knock me to bits. (GPML004)

I tend to wash and dry on a Saturday. Habit. I'm not working so that's when the washing gets done. (DL13)

Friday I would come in from work ... the hoover would be on. The washer would be going. Friday night is my washing night. I don't use the washer though the week. …. [from 5:30-6pm after coming in from work] Right the way through probably 'til 10 o'clock that washer will go. (EPJ14)

4.4.3. The case of refrigeration

Electricity consumption associated with cold appliances varies seasonally, with the highest consumption in the summer months, linked to ambient temperature (Defra, 2012).

In the North East of England 97% of households have a fridge freezer or freezer (ONS, 2013) which is consistent with the national average.[19] It was observed during interviews that households participating in the CLNR commonly have multiple fridges and freezers; a recent survey (Defra, 2012) found a mean average of 1.7 cold appliances per household in England. Although energy efficiency of new cold appliances has improved (DECC 2012), the qualitative data indicates that where new appliances are acquired, older models are often retained as a second or third refrigerator/freezer

[19] Fridge freezer is attributed to both 'refrigerator' and 'deep freezer' (ONS).

where these are still in working order, as overflow from the main appliance, for extra capacity for special occasions or to cater for visitors, leading to accumulation of appliances with the older appliances likely to consume more energy compared to newer ones as a result of component degradation and dated design.

Whilst electrical load associated with refrigeration is low (Table 5), mass ownership combined with consistent peak load means that refrigeration practices are of interest in the 4pm – 8pm period. Although consumption for refrigerators and fridge freezers remains very constant during the whole day, the maximum peak is between 17:00 and 20:00 corresponding to evening meal times and the presence of people in the household (Defra 2012) as a result of people opening and closing the doors as part of food preparation which results in internal temperatures dropping and thus having to be returned to the set temperature.

In general, participants do not envision refrigeration as offering scope for flexibility because of a perceived risk to food safety, but if this can be safeguarded against then there is potential for flexible refrigeration without any time flexibility in practices being required:

> *RES(m):I think the only thing I would be concerned about turning off would be the fridge freezer … I wouldn't particularly have any problems switching it off for four hours, more than that I'd start getting a bit concerned. (GDP51)*

Viewed from a socio-technical perspective, refrigeration and freezing is closely linked to food provisioning and cooking practices (Garnett 2007; Hand & Shove 2007; Wilhite 2008); households shopping, food preparation and consumption is nowadays predicated on the existence of the fridge and freezer. However, as various accounts show, associated consumption practices and processes are varied, unstable and subject to change (Hand & Shove 2007). As such, flexibility around refrigeration and freezing practices need to be considered alongside food provisioning and dependency on electrically-powered cooling.

4.4.4. Transition: Turning the cogs

Whilst fixity and variability is shaped by habit and routines such as work or other patterns – with the rush of everyday life and increasing use of technologies supporting energy intensive practices – our analysis also indicates that participants transitioning from full-time working to retirement and having 'looser', less regimented structures, were able to reflect on and shift practices. We see this as being an example of the re-arrangement of the five 'cogs'; a changed home economy, a slower and more open daily rhythm, and new structures that afford an opportunity to establish new practices, as observed in the following examples:

> *Hoovering [vacuuming] in the morning. Normally washing, now that I've got all day – at one time I used to wash at night coming home from work but not anymore. (GP42)*

> *RES(m): [W]e shower in the morning which we would have done before work anyway but then we'd have probably showered after work, five or six o'clock [17:00*

or 18:00] whereas now we don't. We shower in the morning and that's it, once a day. (ML14)

RES(f): We'd always be sitting in the dining room and have a TV on in there, or the radio [during the day]. [...] We always eat together but different times, we eat earlier. [...] Yes, it's the lifestyle change.
…
RES(m): When we were working, we would be eating in the evening about half past eight [20:30]; now it's in the evening around half past five, six o'clock [17:30, 18:00]. But it is the lifestyle change. (HS01)

Ways of doing the laundry are passed from parents to children, and incorporate ideas about efficiency, and norms around cleanliness/freshness, which then become embedded as part of household management, as illustrated by the following quotations:

RES(f): My mum told me [how to do laundry]. It's just the women thing. If it's not raining I'd put it out on the line. If it's raining, the big clothes I'd put on the clothes horse but underwear and socks sometimes I put them on the radiator; depending on how cold it is, I would stick them in tumble dryer but it's not often … (ML22)

RES(f): [O]n a good day you can peg it all out together and bring it in a bit at a time and iron it as it's ready. It's much better than getting the whole load into the tumble dryer, having to put it all onto clothes airer until you can iron it. It's just the way I was brought up really. It's just the way my mum did it. (ML23)

RES(f): I do prefer to hang them out, I was brought up like that. I just think it's better for them. It is, isn't it! It's natural to be outside and dried. And then when I brought them in I iron them. (ML25)

I always put them out on the line. 'Cause I prefer it, the smell is nicer when it comes in from the air. (MJRTL07)

These attributes may or may not be persuasive in recruiting householders into more flexible ways of laundering.

4.5. SME Flexibility

4.5.1. SMEs – most flexible practices

In addressing the scope for flexibility amongst SMEs in this study a practice-led approach reveals some practices offer more scope for flexibility than others. In the cluster of practices that represent a business's electricity-related activities, heating strategies are one of the most likely sites for increased flexibility.

Participants identify heating, cooling and ventilation amongst their most electricity-intensive uses. Where there is a reliable alternative heating supply interviewees indicate their preparedness to view heating loads as interruptible in exceptional circumstances by using alternatives like gas or biomass. Some SMEs agree that heating practices could be altered to reduce loads or interrupt supply without detrimental effects:

> *As long as we were notified about it, we wouldn't have a problem. I'd gladly turn the thermostat down and put the big fire on. (Publican)*

Flexibility is a dynamic phenomenon: heating practices are in some respects inflexible – in that heating is heavily structured by long-lasting material conditions (building envelope, current appliances/systems, gas connectivity, etc.) – and in other respects flexible, as it is perceived as capable of being compromised without undue impact. This interplay between structured heating practices and day to day trade-offs in control is an area for future attention, as heating is best suited of the major load types to on-site storage of energy, as in thermal tanks.

Among our interviewees air conditioning (AC) is not universally regarded as a basic requirement. SMEs are prepared to cope with high ambient temperatures. Others value AC through two main modes of operation: first, as background cooling where AC practices are seasonal, and where attention can be focussed on timing; and second, where AC is linked to a particular purpose and can be thought of as a form of business-specific equipment or an integrated feature of a business' production/service delivery.

Our findings suggest that cooling practices such as refrigerating food and drink, processing food stuffs in production contexts, animal welfare concerns and machinery requirements are affected by material conditions and the characteristics of 'non-human' agents rather than by customer choices. The range of examples provides a sense of the diversity of socio-technical situations perceived to 'need' cooling or ventilation as a result of the interplay between natural conditions and socio-technical conditions.

For those SMEs involved in food production such as pubs, hotels, B&Bs and child care facilities/activity centres, practices were most heavily influenced by temporal structures, with flexibility limited by advertised times of food service or children's meal times. Initial indications suggest there is some flexibility around how food services are delivered, through modifying operations:

> *We could very easily say hot food is no longer available and just serve sandwiches … that's an option for us … but if I've got a hot food party then I'm contracted to provide hot food in that period. (Childrens' activity centre manager)*

> *We've got an oven and a hob, but we don't use it because we serve continental breakfast. (Bed & breakfast owner)*

> *I always ask if they need both [deep fat fryers] on. Realistically, we could get away with just one on. There are certain foods you can't fry together … but I always question them. … Oil takes a while to heat up so once they're on they stay on all day. (Restaurant manager)*

Load reduction is particularly problematic for interviewees whose business requires electricity for machinery and equipment that may be called upon at any time during working hours. Some business-specific processes, are perceived to be beyond the control of people in the SMEs, and are driven by the requirements emanating from materials or equipment that has to be supervised on a 24 hour basis. Aside from the 24 hour loads and common office loads, qualitative analysis implies that certain business specific loads can be 'spikier' than others i.e. high power but intermittent. There are several accounts of machinery with relatively high power ratings being used for short periods of time. Although referred to as 'necessary', these activities are not immovably fixed in time implying some 'spikiness' may lend itself to flexibility by moving intermittent practices to times outside of peak load (4pm – 8pm). The use of intermittent machinery comes out as offering likely sites for increased flexibility.

Some businesses with strict temporal constraints are not anyway operating during times of peak load. Processing schedules with the least implications for temporal fixity are the most open to change if the SME owner receives the right kind of advice and support, as illustrated in this example:

> *Our production facility shuts down at 4.30pm … we could probably re-schedule certain things that are done, for example … we manufacture to stock not to order … some of the planning could be brought forward from the next working period … there's always ways to re-schedule what you do if it is advantageous from a cost point of view … so we could look to do things like that. (Printer cartridge re-manufacturer and supplier)*

Even among owner-managers who declare inflexibility in most other respects there are indications of potential for load reduction:

> *I can't turn my cellar off....it would ruin my beer.[...] we do have timers on the fridges and the ice machine so we do turn them off at midnight and it comes on again in the morning. So we are looking at things like that but we can't turn the kitchen off between 4 and 8 because we do services. (Hotel manager)*

Computing practices are important to almost all businesses, even where it is not highly visible. The use of IT is affected most by the design and age of the equipment, and the desire for fast access and reliability. There is a significant 24 hour load associated with servers, routers, and back-up devices. As observed in section 5.1.2.5, the need to maintain connectivity with customers and stay 'open for business' leads to continuous loads. Some SMEs display a requirement for uninterrupted power on-site, despite there being alternative ways to maintain online presence without a local power load. Although the computing load is often relatively small, it is frequently regarded by the owners/managers in our sample as uninterruptible. To enable flexibility from a network point of view involves finding other ways to ensure connectivity.

Increasing use of mobile devices – whether battery operated laptops, tablets or smart phones – offers scope for mobility and flexibility in working practices but also greater tolerance of power interruption where core activities like email, diary, and data access can be sustained for several hours without a fixed power connection. A few interviewees suggest they are alert to these possibilities, which may be among the most potentially fruitful areas for the dissemination of education and information interventions. Although reduced load reduction at work might transfer to increases at home:

> *We could switch to laptops, or mobile devices, so that they run off battery … we could do that when we switch them but we couldn't afford to do that all at once. (Estate agent)*

> *The people who move between here and head office, they use laptops ... They would be using a battery … we should get them to charge them at home! (Contracts manager)*

4.5.2. SMEs – least flexible practices

Reduction in lighting is less acceptable among SME owner-managers interviewed because they believe the effects are more noticeable and impactful than reduction in heating. Lighting is associated with security, the correct environment for working, or for customers. In some SME settings such as retail or where employees need 'the right light', as in lab work, there is very little perceived flexibility in reducing lighting.

> *There is one security light at the front which would be left on generally speaking all night during the winter. (ATM repairer)*

> *The air-conditioning unit in one lab and the server, phone systems would be on twenty-four hours. The security systems are actually [on] out of hours. I have a camera system watching the building as well. (Commercial print lab manager)*

> *Because of the work that we're doing they need to have good light. …we've got desk lights for the repair guys right down on their desk; it's not just quite bright enough and it's delicate repair work. (Electronic equipment repairer)*

> *Lighting we wouldn't be able to turn off because obviously there has to be signs to draw in. (Beauty salon manager)*

> *I don't know how I can use less in my shop opening hours. […] if you're a shop you don't know when you've got a customer and it has to be lit. (Gift shop manager)*

In terms of flexibility, as well as changing to more efficient lighting technology, there is evidence of use of timers and sensors for switching off lights when spaces are not being used.

> *All the outside lights they're on timers. (Publican)*

> *The lights here are all on sensors. (Stone mason)*

The lights just came on automatically, they're on a sensor. (Furniture shop manager)

However, lighting, and power for equipment that enables owner-managers to meet externally imposed regulations represent the least flexible practices, according to SME owner-managers interviewed.

RES(f): I'm a shop so I open ten till five [10:00 to 17:00]. I have the spot-lights on. As soon as I come in, what you see down here, permanently on, all day. Ten until five or if I stay a little bit later to half past [17:30] or on a Sunday maybe eleven o'clock [11:00], … But generally I'd say ten to five [10:00 to 17:00], seven days a week. And upstairs I've got spotlights. For this time of year I don't really have them on yet, I don't actually put them on. But in the winter, you can imagine that I just need more lighting. The staircase lights, they are on. (Gift shop manager)

RES(m): At eight [08:00] the lights are on; I'd put the air cleaner on every hour, if it's not windy we use it more. (Stone mason)

Public health and safety obligations and those applying to animal welfare often overrule flexibility, as illustrated by the following examples:

You've got to keep the cellar at constant temperature. … It has got to be kept at the right temperature to keep it; it's food at the end of the day and that's how you have to keep it. (Publican)

We couldn't change [milking time] really, cows need as long an interval between them as possible, it's animal welfare. […] The welfare of the animals is paramount, and regular milking routine is … non-negotiable really. (Dairy farmer)

Analysing a cross-sectoral range of SMEs and their practices has identified a number of challenges and potential opportunities in seeking to engage SMEs in flexibility. First, for SMEs, there are different routes of flexibility for different activities across the sectors, and 'no one size fits all'. Second, implacability of existing structures and systems may counter attempts to introduce flexible practices: with investment often considered unaffordable, and frequently dependent on the co-operation of others, this presents a serious stumbling block for some SMEs.

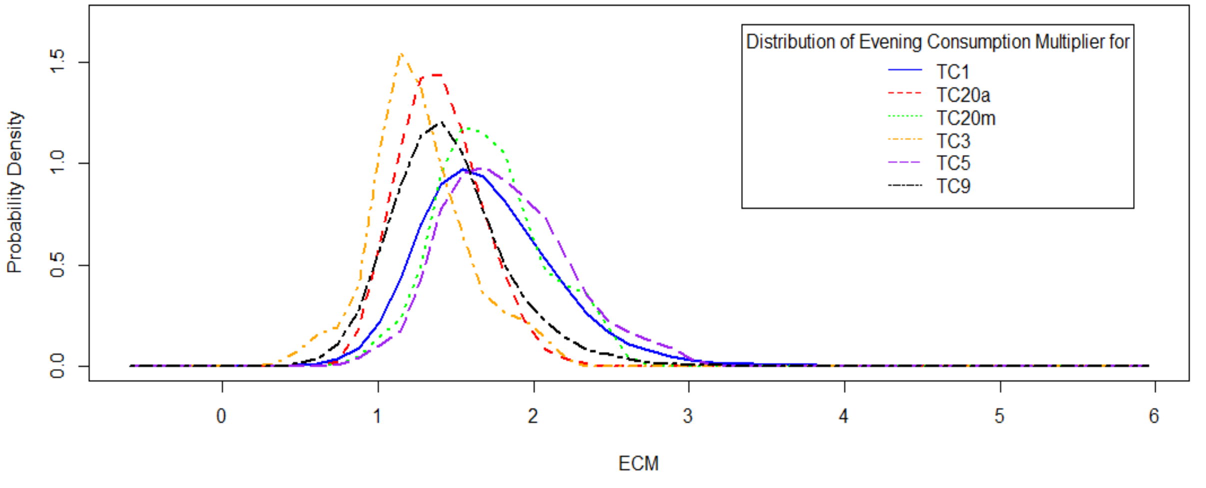
The research indicates potential opportunities for flexibility in electricity management could be achieved through re-shaping SMEs practices, provided that interventions are tailored to specific needs. SMEs are open to modifying practices provided that it does not significantly impinge on their business viability. For SMEs, the dynamics of flexibility centre on degrees of acceptability of interruption of supply and potential for the re-scheduling of practices.

4.6. LO2.2 - What are the most effective interventions to deliver this flexibility?

LO2.2 considers the various interventions used in the CLNR project and assesses the extent to which these have been effective in creating flexibility in domestic electricity use via changes to everyday practices. The interventions we have been able to study at this stage are the three rate time of use tariff in Test Cell 9 and two PV related interventions in Test Cell 20. These are set out in detail in project documents available in the project's learning library.

Figure 46 below shows the distribution of ECM statistics for each test cell, showing that participants in both Test Cell 20 and Test Cell 9 were likely to have less peak intensive demand profiles than those in Test Cell 1. Of particular interest is the extent of the shift for Test Cell 20a.

Figure 46: ECM for LO1 and LO2 test cells



4.6.1. Analysis of peak consumption in Test Cell 9

Six hundred and twenty eight participants in Test Cell 9 volunteered to undertake a 12 month trial of a three rate time of use tariff and were equipped with an in-home display which provided an instantaneous traffic light system for current loads and retrospective visualisations of gas and electricity consumption. These are the same as the units used in Test Cell 1 (participants in Test Cell 1 did not have a time of use tariff). The rates and time bands of the tariff are shown in Table 8.

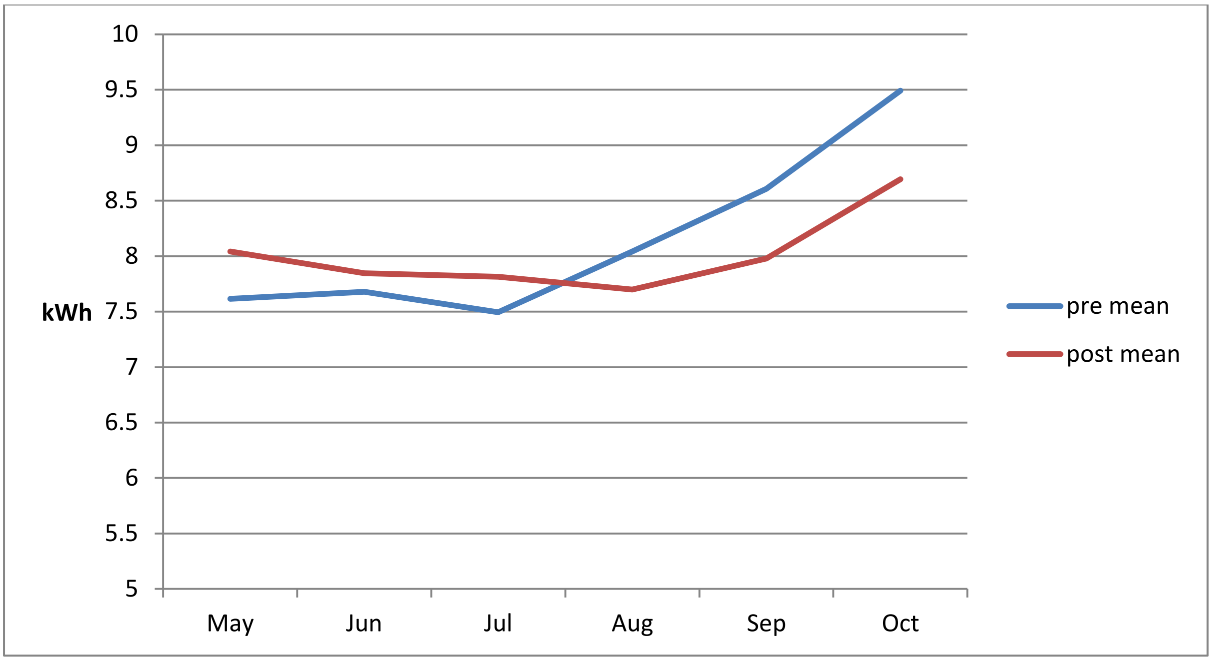
Table 10: Time of use tariff details

Time Period	Description	Rate
07.00 – 16.00	Day	4% below standard rate
16.00 – 20.00	Peak	99% above standard rate
20.00 – 07.00	Night	31% below standard rate

Notes:
The Night rate applies all weekend (Saturday / Sunday)
A standing charge is applied in addition to the per-unit costs

Electricity demand is seen to be higher for TOU participants post intervention in the first three comparison months before falling below pre-intervention levels in the following three months.

Figure 47: Average total electricity demand pre- and post- tariff intervention over 6 months



This change happened in the context of evening peak demand, and remained lower in all months post-intervention.

Figure 48: Average 4pm – 8pm electricity demand pre- and post- intervention over 6 months

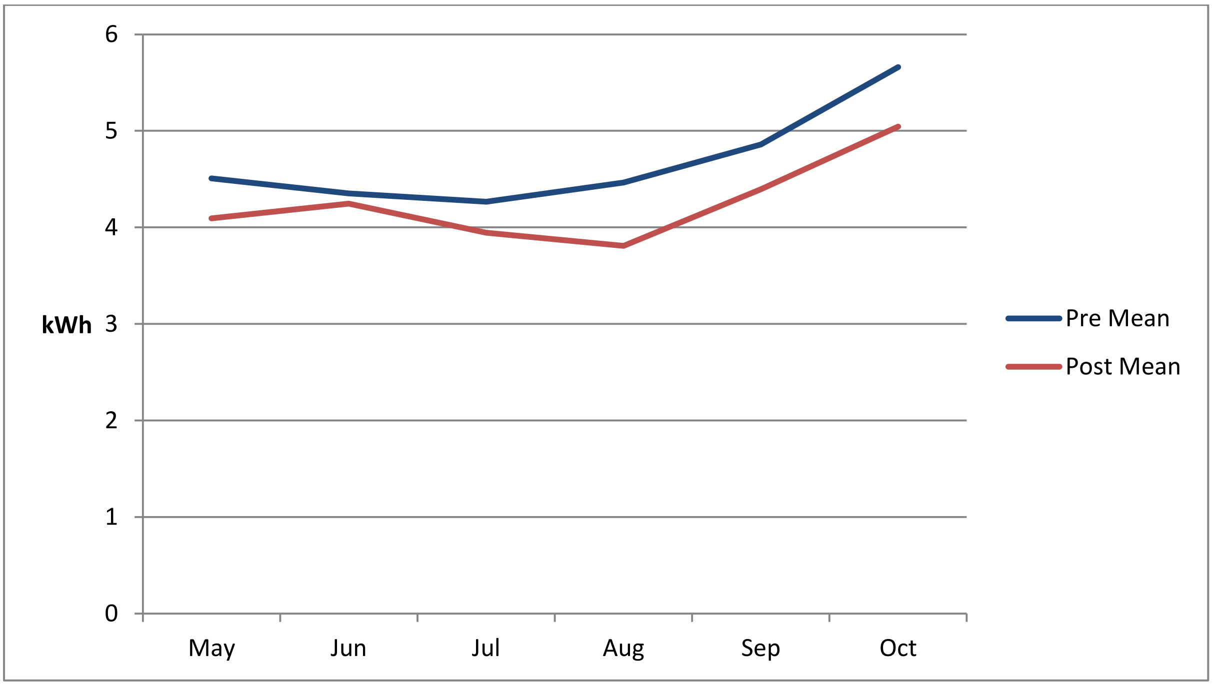
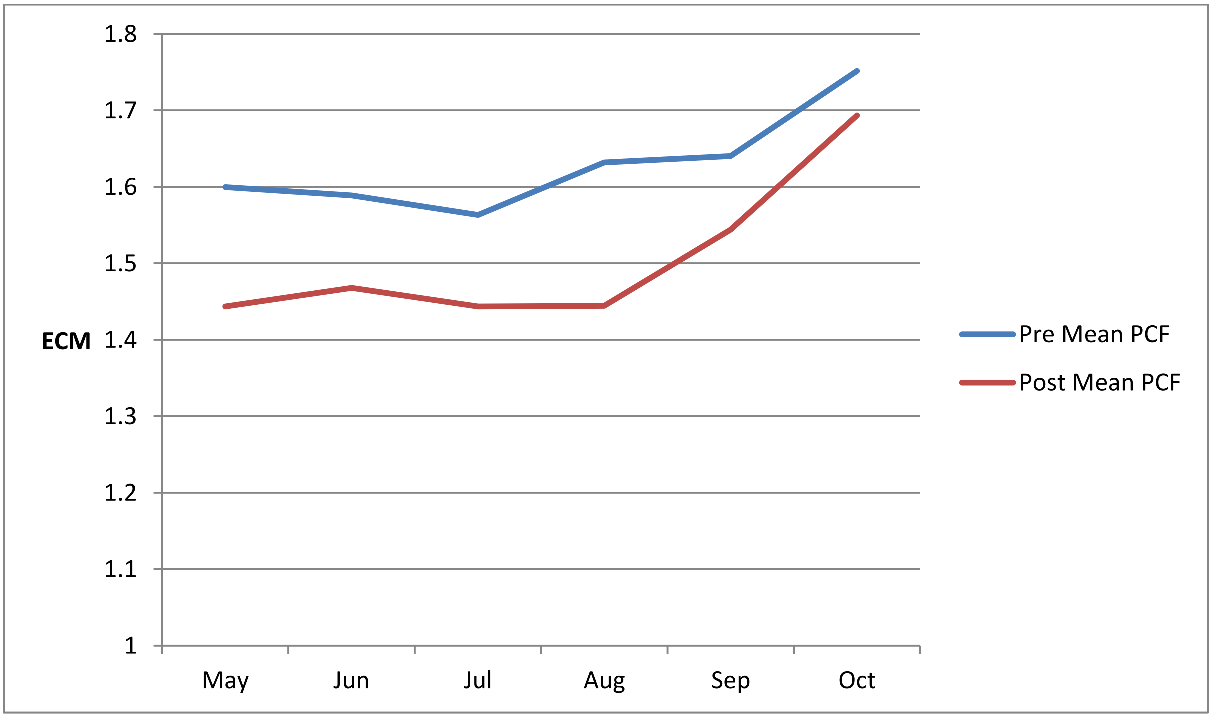


Figure 49: Average Evening Consumption Multiplier for 6 months pre- and post- intervention

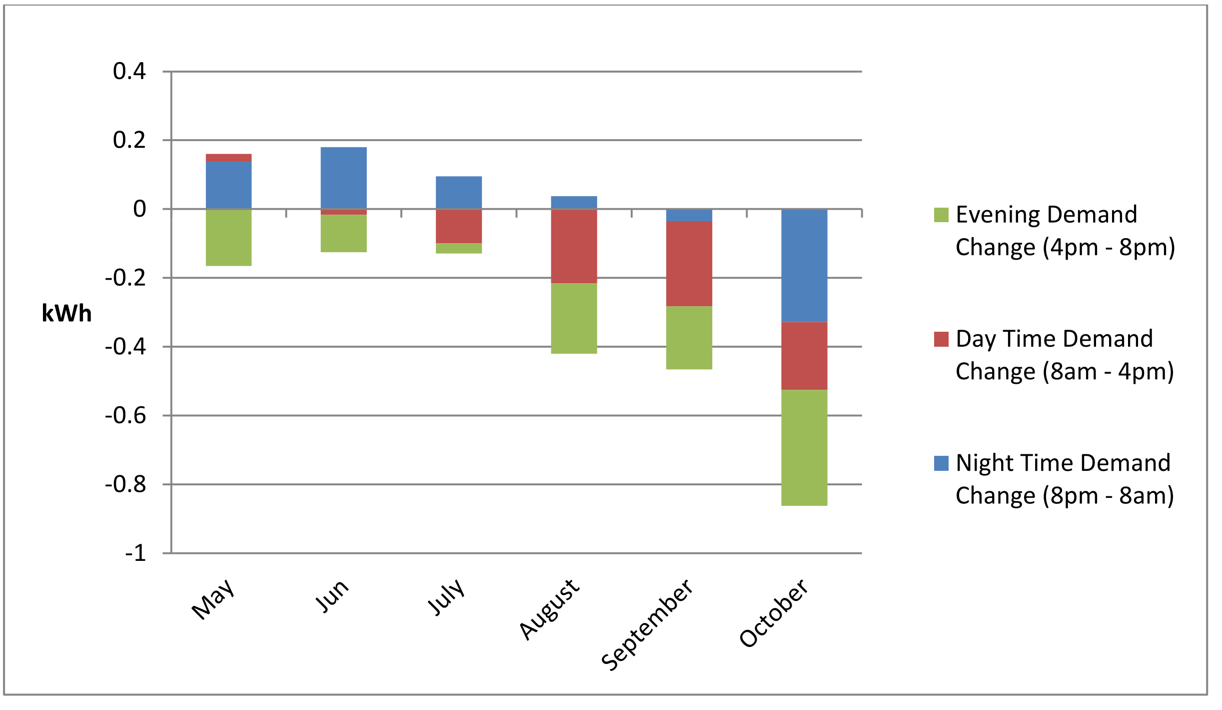


While it is clear that the ECM of TOU participants – a measure of the peak intensity of their demand – is lower post-intervention, as in Figure 48 above, the difference between pre- and post-intervention ECM narrows over the course of the 6 month period we are able to study. Furthermore the reduction in evening peak demand alone does not explain the reduced total demand in the later months as the difference between pre- and post- intervention average total daily demand is greater than the difference between pre- and post- peak demand peak demand.

Analysis shows that the total demand reduction observed in August, September and October post-intervention is made up of demand reduction across all three tariff band periods, as shown below in Figure 50. Indeed, in these three months evening peak demand accounts for less than half of the total energy reduction observed.

This finding is of particular interest and will require further scrutiny as new data is made available; it suggests several possible interpretations including the possibility that the tariff has considerable spill-over effects and that participants have not followed price signals rationally – as they have reduced their demand while prices were also reduced for 20 hours of the average day and this has been more pronounced than their 'rational' action.

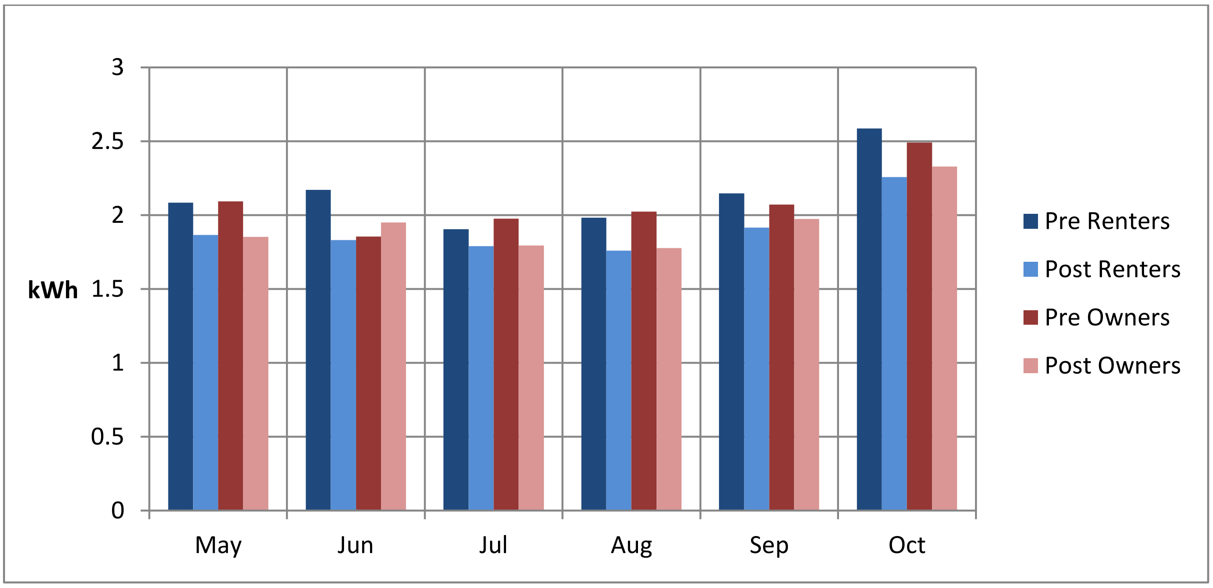
Figure 50: Energy demand change pre- and post- intervention split by time period



4.6.1.1. Socio-demographic analysis of time of use (TOU) trial data

Analysing the response of different socio-demographic groups to the time of use intervention reveals a range of patterns.

Figure 51: 4pm – 8pm demand pre- and post- intervention for renters and owners



Analysis by tenure indicates that both owners and renters reduced peak demand in all months except for June, when owners actually used more electricity in the 4pm – 8pm period than pre-intervention. The difference in savings varies between the groups each month and no clear pattern can be seen in the 6 months we are currently able to report on.

In terms of thermal efficiency, peak demand reduction among households living in dwellings with different thermal efficiency varies considerably, with those in low efficiency homes able to reduce consumption between 4pm – 8pm more than other groups. This suggests that households in dwellings with poor thermal performance are delivering more flexibility than those in more efficient homes. There may be several explanations for this, which we will investigate in future work that focuses on understanding the types of households in these homes in order to better understand what is driving this pattern.

Figure 52: 4pm – 8pm demand pre- and post- intervention by thermal efficiency

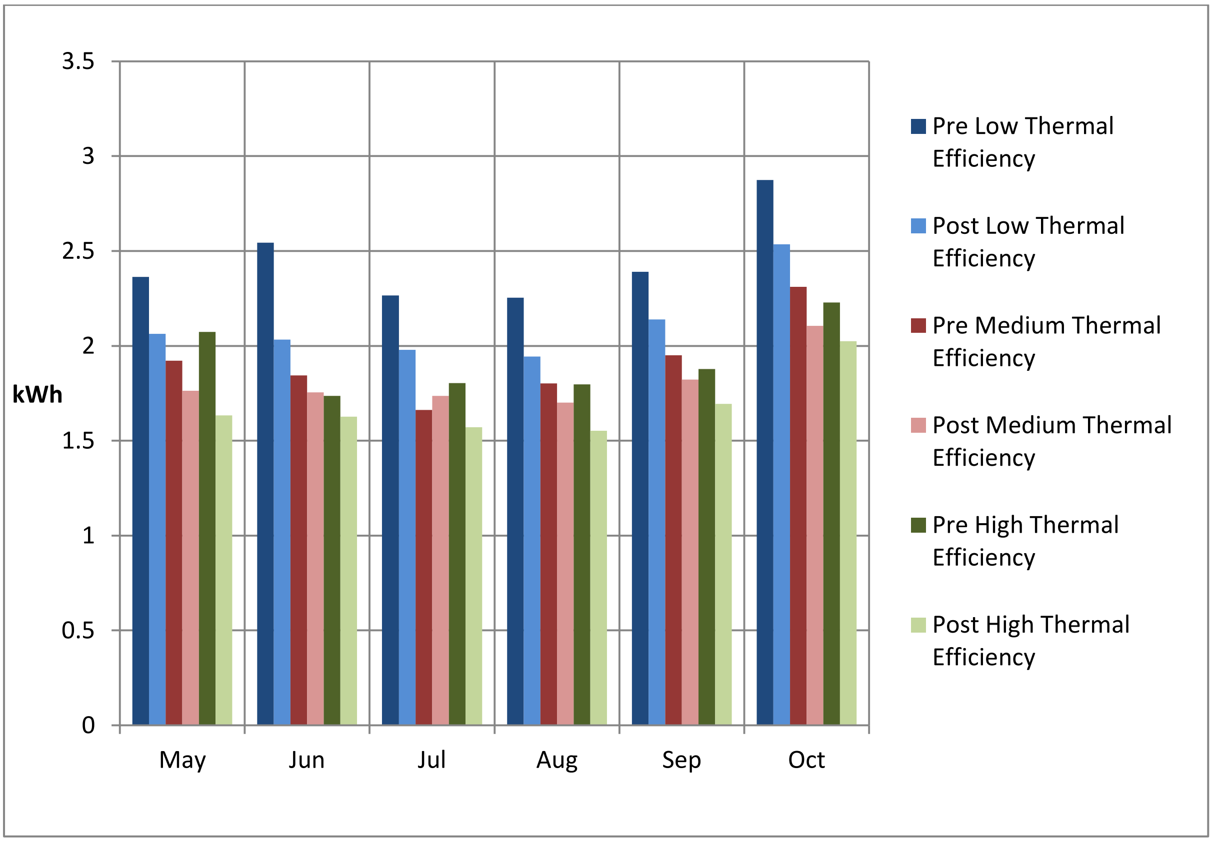
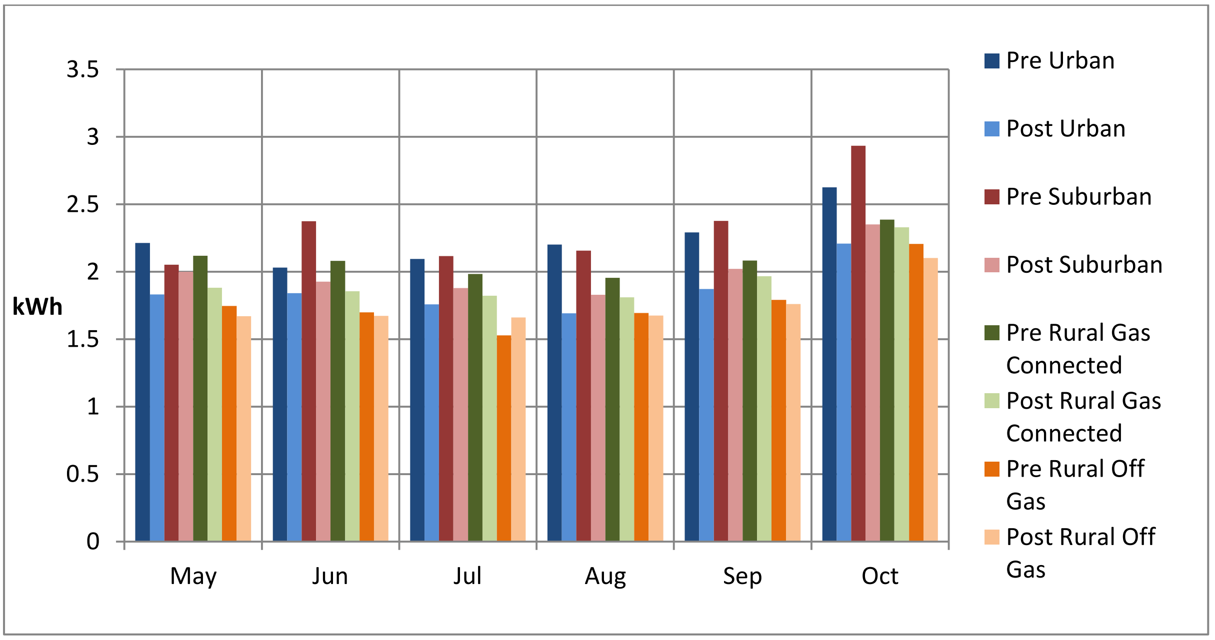


Figure 53, below, shows several interesting patterns. First, off-gas participants are the least flexible and their relative inflexibility is consistent across the six months for which we have data. Second, rural gas connected participants displayed moderate flexibility in the summer but this diminished markedly over the period of 6 months.

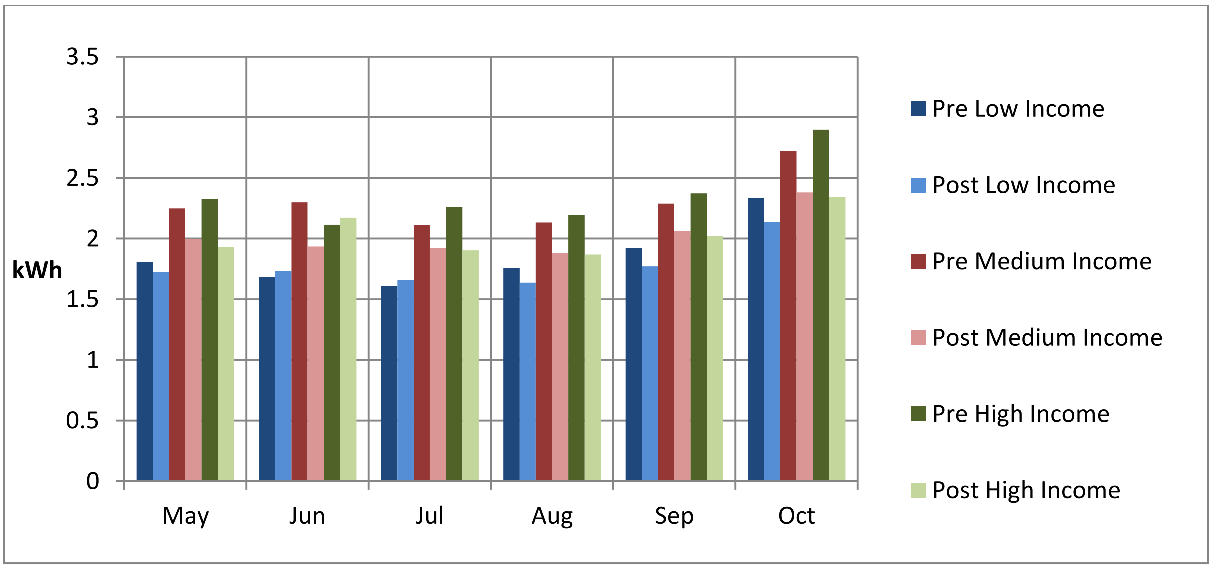
Until we are able to observe their performance over a longer period of time we are unable to determine whether this can be attributed to a seasonal effect or to the effect of the intervention ‘wearing off’. Third, and the most strikingly of these patterns, urban and suburban households display more flexibility than their rural counterparts and this flexibility is sustained, indeed became more pronounced, over the 6 month period we are able to observe.

Figure 53: 4pm – 8pm demand pre- and post- intervention by rurality



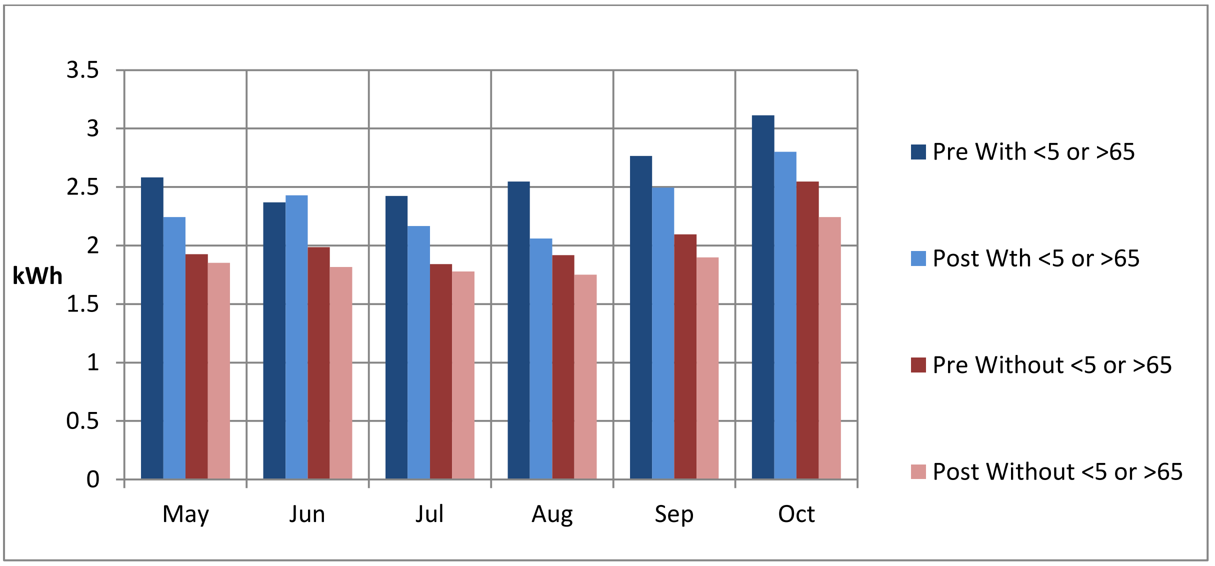
As Figure 54 below shows, higher income groups are more flexible than lower income groups – with high income groups consistently reducing evening peak demand more than medium income groups and in turn, medium income groups reducing their peak demand by more than low income groups. As a result, there is considerably less variation in demand levels between income groups post-intervention as the greater reduction made by higher income groups brings their consumption closer to the post-Intervention consumption of lower income groups. It follows that in the post-intervention period, there is a less clear relationship between income and peak demand, with middle income groups having the highest demand in four out of the six post-intervention months.

Figure 54: 4pm – 8pm demand pre- and post- intervention by income group



Both those with and without household members who were under 5 or over 65 reduced peak demand in all months except for June, when those with a U5/O65 present actually used more electricity in the 4pm – 8pm period than pre-intervention. The difference in savings varies between the groups each month and no clear pattern can be seen in the 6 months we are currently able to report on.

Figure 55: 4pm – 8pm demand pre- and post- intervention for households with and without under 5s or over 65s



4.6.2. Qualitative insight into peak practice flexibility for time of use participants

There is evidence that participants in Test Cell 9 are avoiding laundry, chores, dish washing and in some cases, cooking differently within and around the 4pm – 8pm period, suggesting that the tariff is having an effect on these practices:

> *I think maybe on a Friday, without thinking … I'd probably shove them [work clothes] in the washer … and just start it without thinking. … Yeah. I would probably avoid that now [using the washing machine]. I can't afford to pay more. (GP0021)*

> *The washer, dryer and dishwasher we haven't been putting on between 4 and 8. (GP1802)*

> *We're doing after 8 o'clock on a night and over t'weekend. Washing, most of t'laundry gets done on a weekend unless we have something that actually crops up. (DL0602)*

> *My washing I definitely do over the weekend when it's cheaper, unless it's [an] absolute necessity. (MJRTL06)*

> *She'll do washing after 8 o'clock at night when it goes onto the night-time tariff, the lower tariff. (GP2702)*

The tumble dryer will be used at night-time … Even if I have to stop up later or something. I would rather use it at night-time than on the peak [tariff] … (GP0025)

Things like the dryer and the washing we'll put on during the day, then if at 4 o'clock if we haven't finished drying then we stop then and pile it up on usually just put it on the back of the chair and wait 'til 8'oclock and then we'll finish it then because the dryer's expensive to run… (MJRTL14)

We try and do washing on a weekend or after 8. … The dishwasher doesn't go on 'til after 8 now either … before we got the [IHD/tariff] we would just put it on when it needed to go on … Couple (GP1902)

The results also suggest that the degree of alignment between the tariff and other schedules is important in shaping how flexibility is realised. Although the use of electrical appliances for dish washing, washing and drying laundry is reported as having moved outside the 4pm – 8pm mid-week period or to the weekend for many participants, one couple (above) persist in showering any time of day, and within the 4pm – 8pm period, which suggests that for some people certain practices are non-negotiable. This is connected to established habits and perceived pleasures, and links with other activities that connect householders to external practices or social groups making them more difficult to change. Examples are aspects of work, social and school life. Of particular interest is the way in which flexibility presents difficulty for some groups due to potential misalignment of the tariff time bands and existing timings and schedules around which life is already organised. Our findings suggest that these factors could be external to the home, such as work hours, or as a result of internal routines around eating times:

[Interviewer: When do you shower?]
Male: Me – half past 7 every night.
Female: You'll have to change. I told you you're going to have to adapt.
Male: I go to the pub at 8 – it can't be after 8. Couple (DL12)

Female: I don't think I can wait until 9 o'clock for my dinner. I couldn't eat at 9 o'clock then go to bed.
Male: What you'd have to do is have [our] dinner at 4 o'clock.
Female: And that's alright for us 'cause we're not working but what about people that are working? They've got to come home and they're going to do it [cooking] in the busy time, aren't they? Couple (GP0025)

4.6.2.1. Fixed dining routines

Resonating with the finding reported elsewhere in this report, mealtimes are often fixed and this evidence indicates that the tariff is not effective in moving meals outside the 4pm – 8pm period in a sustained or widespread way. This analysis leads to the conclusion that a financial incentive does not lead to a shift in this practice, whereas it does create flexibility in laundry, chores and dish washing:

Obviously, not our tea … but [I] wouldn't put the dishwasher on [between 4-8], or the washing machine or dryer. (GP28)

With two kids they have to be fed before they do homework. They tend to be doing homework while I'm cooking. … If I waited it'd be too late for them … (DL07)

Everything else, or nearly everything we can work around it [tariff] and in a way some of the things we have changed … putting the dishwasher on – we used to put it on after tea. Now, it will be left 'til the next morning, or after 8 o'clock. (GP19)

To maintain the standard of living if we had to pay a little bit more we would pay a little bit more. …The only thing we do between 4 and 8 that would cause a hassle if we couldn't cook. Everything else we could move around or reprogram. (ML09)

Of particular interest are those households not working around a 9 to 5 pattern, where there has been some movement of cooking practices in response to a time of use tariff, which we interpret as same-day flexibility enabled by process flexibility where there are new or different cooking methods used to prepare and cook food.

4.6.2.2. Inflexibilities for those with conventional work or school hours

Interviewer: Could you cook your evening meal earlier or later than you do currently? Participant: With two kids they have to be fed before they do homework. They tend to be doing homework while I'm cooking. … If I waited it'd be too late for them … (DL07)

Interviewer: Could you cook your evening meal earlier or later than you do currently? Participant: I don't know how I could change the way I cook. … No, 'cause [because of] work. … we cook when people are wanting food. (DL13)

Interviewer: Could you cook your evening meal earlier or later than you do currently? Participant: No. I wouldn't do it. I couldn't do it. Na, Na. Me' grandson comes for his dinner, says I'll be here 5:45, so I couldn't. (GPML004)

Cooking? Well it's about 5 o'clock I'm making me tea. I know it's the wrong time to do it but what time am I supposed to have me tea!? You program yourself for it don't you. (GP32)

4.6.2.3. Same-day laundry flexibility

Informants talk about feedback from IHDs fed by smart meter data as having changed the way they achieve certain washing practices – in particular, water temperature and cycle duration are selected as ways to reduce power consumption prompted by the IHD changing colour to red, in the case of tumble dryers, or seeing the sustained peak created by some white goods' programmes. There is also some evidence to suggest that chores have moved more than other practices out of the 4pm – 8pm period, for those on a TOU tariff, and for those with PV there is evidence of efforts to use the PV generated power for laundry, although this is not always the case.

> *My washing I definitely do over the weekend when it's cheaper, unless it's absolute necessity. (MJRTL06)*

> *She'll do washing after 8 o'clock at night when it goes onto the night time tariff, the lower tariff. (GP2702)*

> *The tumble dryer will be used at night time … Even if I have to stop up later or something. I would rather use it at night time than on the peak [tariff] … (GP0025)*

While this timing flexibility is apparent, there is less reported flexibility when participants were asked about changing the days of the week associated with laundry. This is in part explained by the 24 hour rhythm of the tariff in the mid-week period, and the constraints of timers on white goods, which were found to be commonly used to facilitate the flexibility and often have a maximum delay of 9 or 12 hours. However, there is a notable lack of evidence to suggest that laundry or dish washing can have inter-day flexibility.

4.6.2.4. Responses to the idea of TOU pricing from other test cells

As well as studying how Test Cell 9 participants have responded to the tariff, we asked members of other test cells about how they might relate to a time of use tariff. Although many participants are amenable to the idea of moving some practices outside the 4pm – 8pm period, there are some ways in which household practices are not perceived to be flexible in response to a the price signal in the 4pm – 8pm period:

> *I couldn't alter things really. I just do things as they are convenient for me… I could put the dishwasher on I suppose after 8 o'clock instead of before. That would be the only thing I could alter. (GP26)*

> *You could put the washer on before you went out, could put the dishwasher on before I walked out the door to go to work in the morning. Yeah there would be things … (GDP50)*

However, this family could not envisage changing their cooking practice of using the electric oven to cook the evening meal:

> *It'd be hard. Even though I do put the oven on its not on for a great amount of time, I'd say it were only on for no more than an hour a night and some nights you're talking probably 20 minutes. (GP50)*

> *At the moment it [TOU tariff] probably wouldn't make much of a difference – not while we have a 4 year old and a 6 year old. Because time is scarce and precious and the washing machine goes on when you've got the opportunity. (EPJ17)*

Clearly, some practices are evaluated as essential and non-negotiable, while others appear to be more flexible:

> *When you want a cup of tea you'll put it [kettle] on. You can't avoid that … If there is anything that needs doing then I will do it. I can't wait for that [tariff]. Like I say if I've got to use my drill for something … I've got to do it that way … We'll put that [washing machine] on after 8 o'clock anyway or a weekend … (GP45)*

Interventions can prompt individuals to re-examine their use of existing technologies (washing machines and dishwashers, in particular) such that previously unused capacities and functions are utilised, to a greater or lesser extent, enabling the performance of practices in more optimal ways or at more optimal times. When available, householders are leveraging existing functions like timers or a delay function on white goods to enable certain practices to absorb more solar power thereby assisting in organising household chores to fit with routines and optimise on-site generation, or take advantage of lower cost electricity:

> *RES(f): Both this and the dishwasher have got a time delay so often I'll load it at night and put the time delay on so it comes on early in the morning when it [PV] starts generating. … It's only recently, in the last few months, I've used it [the timer] on that one [washing machine] and the dishwasher. (HS02)*

> *What I'll do if it's going to be a sunny day tomorrow, I'll fill the washer up tonight and in the morning. I'm up at 5 o'clock in the morning and put it on a timer [on the washing machine] … and it'll be timed to come on later in the day when the sun shines. … If the forecast is for a bright day that's what I'll do. (DL17)*

> *RES(m): We do our washing on Economy 7, which is midnight or 1 o'clock in the morning or something like that because that's when we get a financial incentive to do it. (DL1502)*

> *RES(m): I usually put it on [washing machine] on a Tuesday night – overnight … just a habit I've got into. ... Used to be cheaper on a night, don't know if it still is. (EPJ03)*

Our findings suggest that at least some practices are amenable to the introduction of new knowledge and things, and where this occurs, it serves to reconfigure the constellation of particular practices. However, in other instances, new smart things are not adopted, and practices remain unchanged.

> *I've never used it [delay timer]. I've got one but never used it. I used to use it – years ago, when I was working and that. I've never used it since we've had this washing machine. (GP0025)*

> *RES(f): Yes, yes, there is a delay, it's this one here [delay settings on the wash machine]. And then if I press that again it will go on, it will start the wash machine.*

I have never used that [the delay programme]. I only use it [the washing machine] when I'm in the house really. (ML07)

[Interviewer: Would you ever use that [delay start on washing machine]?
Participant: It just wouldn't make any sense at all. Just bung it in, press the [ON] button and that's it. (GP22)

4.6.3. Solar intervention: responses to within premises balancing intervention (Test Cell 20)

Test Cell 20 included two different interventions. First, a group of 99 participants who already had a PV installation agreed to have a system fitted to divert up to 5kWh of solar energy into an immersion tank to provide hot water. Second, 141 participants who also already had a PV installation agreed to have an in-home display system fitted that provides a green or red digital display to communicate whether they are exporting their PV generated power back to the grid (and in doing so collecting the feed-in tariff) or using it in the home to power electrical goods or appliances. These trials are being conducted because the use of the power on-site is of interest to network designers and could reduce potential voltage problems associated with increased penetration of micro-PV in the future.

As argued above, on-site consumption is increasingly aligned with the changing incentive landscape for PV investors but importantly these logics are now equipped to change the material components of energy consuming practices to enable individuals to recalibrate their use of technologies, often leveraging existing functions like timers on white goods to enable certain practices to absorb more solar.

For many participants, investment logics are still what are invoked to describe and explain the ways in which practices have been modified to make more use of solar power:

On a night anywhere between 8 and 9 o'clock depending on how much we're generating I switch the TV from main to batteries which I've got in the garage. They're completely different from the main panels. I put an extra 2 100w panels on the roof which are just on the top out here which are to charge the 4 batteries in the garage up. They're 125 Ah batteries and I charge them up through the day and at night I plug the TV and I usually plug the security monitor in and it costs me virtually nothing to watch TV. (HS10)

We don't want to export. We want to use. ... We are better off using it. That's why we then changed that habit because we're using what we generate. We could change our habits more really, if we thought about it. Probably. … We were generating and not really thinking about it - It was after we got that box [the IHD] that identified green, amber, and red that literally the next day our habits changed. It was quite drastic … That's only been recently that I thought about that one but it was just changing the habit from putting them on at night to putting them on through the day. Changing the habit of putting it on at night. (DL13)

> *Now that we're producing our own electricity, if it's a sunny day my wife will set the washing machine during the day. (DL12).*

> *I try and I'll even cook things when the sun shines or get a shower when the sun's shining if I can … I just try and make full use of the solar panels. … I'll fill the washer up tonight and in the morning …put it on a timer [on the washing machine] … and it'll be timed to come on later in the day when the sun shines. … If the forecast is for a bright day that's what I'll do. (DL06)*

Importantly, the combination of the 'governmental technologies' particularly the in-home display devices, and participants' more active role as co-managers of energy systems have established new ways of performing practices – with participants referring to the use of colour coding to indicate 'good conduct' and 'bad conduct' as being particularly powerful in conditioning practices such as dish washing, showering and laundry.

> *[When asked about leaving items on standby] Not after the solar panel, which went in … we were generating, we didn't really think about it. It was after we got that box, that identified to us green and the red, that literally next day changed our habits. (HS01)*

> *I'm in green which means I'm generating more than I'm using. … So whenever it's on green we stick a big appliance on and you are more or less getting that electricity free cause we're generating it. Then obviously at night … it's all red because we're not generating any power. When I went to bed I was putting a wash on and dishwasher on and then obviously realised that that wasn't generating any power at that point. (DL13)*

While the approach expressed in this quotation typifies that adopted by the majority of participants, for a minority the idea of being governed in this way is not welcome and conscious forms of resistance remain, particularly in winter when the PV panels are less effective:

> *I am still more or less the same. … During the winter it doesn't make any difference at all. (HS09)*

4.6.3.1. Test Cell 20a: Automatic hot water

Participants in Test Cell 20a (with automatic water heating from PV) reported only modest changes to practices as a result of the automated hot water system intervention and not all participants in this group attributed changes to the intervention. The small changes reported were mostly related to when showers were taken.

> *It has resulted in more showers being taken during the day. Our normal preference is a shower first thing in the morning. But with the [PV]… if it happens to be a nice bright sunny day and you haven't had a shower in the morning you can have one in*

the afternoon knowing you're not going to be short of hot water the next day (DL1502)

In summer I'll shower during the day, but in winter it won't provide enough power to let me have a shower and do everything else so I shower at night before bed, just on normal electricity. I prefer to have a shower before bed but like I say, in summer I'll do it in the afternoon. (DL17)

However, for more households the incentive to use the power for domestic appliances, which is associated with PV in general rather than the intervention, still dominates their thinking. In other words, the analysis of the data illustrates that participants are motivated to use the power for use of appliances more than they are motivated to use it to fill the hot water tank:

If it's a sunny day my wife will set the washing machine during the day. Before the solar panel 'were installed all the washing was done at night on Economy 7 … (DL15)

Respondents also reported that the tanks are unable to absorb all the surplus energy and demonstrate both positive and negative attitudes towards the system. This extended quotation provides a detailed account of how the system is interacting with showering and how the details of system design, specification and installation affect both the householder's experience and the eventual impact on energy demand.

The tank will only accept 4 – 6 kWh of energy and on a decent day I'm getting 10 – 15, so there's still about 5kWh going back into the grid. Of course I'm getting paid at about three and half pence per unit, which is neither here nor there. So the system does work, I'm getting additional hot water. I used to have two immersion heaters now I've only got one. … but that has a downside, … I've got one immersion heater on the E7 circuit. I've got another one on the solar panel circuit and that does not heat water if there's no sunshine, so I'm only getting one immersion heater operational in dull weather and that has a consequence in that (my wife) and myself couldn't both have a shower without putting day time electricity into the system. We look at the weather forecasts and look at the weather on the day and I've got the solar panel immersion heater set at 70 degrees which is very hot, so if we don't use it, it will still be available the next day, if that was dull. But it's something we have to careful of. We have to take into consideration the weather conditions. I'm anticipating that once it comes to the beginning of April until the beginning of October there's no problem at all. …It's strange, it's resulted in more showers being taken in the day. (DL1502)

Table 11: Test Cell 20a Summary Box

Most households reported only modest changes to practices as a result of the automated hot water system intervention and not all participants in this group attributed changes to the intervention. The small changes reported were mostly related to times when showers were taken. **Further analysis of the electricity consumption data is required to verify the effects of this intervention.**

4.6.3.2. Test Cell 20m: In-home displays

When looking more specifically at evidence of changing practices to take advantage of the Test Cell 20 IHD we find that households are responding to the traffic light system of the Test Cell 20 IHDs, as the quotations below testify, with households reporting that the device is easy to understand and has prompted them to make further changes to their practices. Often changes had been made as a result of the original PV installation. However, the IHD is associated with going further with changes that participants are aware could be beneficial, but which had not been fully realized. For others the IHD identified new optimal alignments between PV and their practices.

> *We don't want to export. We want to use. ... We are better off using it. That's why we then changed to that habit because we're using what we generate [on-site]. We could change our habits more really, if we thought about it. Probably.*

> *[Asked by the interviewer when they started to change their habits] We were generating and not really thinking about it – It was after we got that box [TC20 IHD] that identified green, amber, and red that literally the next day changed our habits. It was quite drastic …. (DL13)*

> *I'm in green, which means I'm generating more than I'm using. … So whenever it's on green we stick a big appliance on and you are more or less getting that electricity free 'cause we're generating it. Then obviously at night … it's all red because we're not generating any power. (HS001)*

Other respondents were less positive about the IHD, with one not using it at all. Another respondent complained that it was difficult to re-start the system after having previously disengaged it. Some householders in this group were already quite knowledgeable or already had meters, which they had worked into their home management regimes, so felt that the IHD offered little additional information:

> *I think the reason I don't use it is that I know how much a kettle uses, how much a TV uses. I'm quite knowledgeable about what I actually use. …I've got a meter which measures total power generated, which is in the garage not from the inverter. So that's good information. (DL1502)*

This suggests that the information provided by the IHD needs to be tailored to householders' requirements to continue to be relevant.

Table 12: Test Cell 20m Summary Box

For participants trialling a PV specific IHD (TC20m) participants referred to the use of colour coding in the IHD display as being particularly powerful in reshaping practices such as dish washing, showering and laundry such that they are undertaken when power is being generated on-site. Often changes to electricity use had been made as a result of the original PV installation, but the IHD is associated with undertaking further changes that participants are aware could be beneficial but which had not been fully realized before its introduction. For others the IHD identified new optimal alignments between PV power and their practices which they had not previously recognized. Overall, we find that the IHD was reported to be effective in making practices flexible in ways that support the use of more electricity on site.

4.7. *LO2 Summary*

4.7.1. Variability and flexibility in domestic electricity demand

Flexibility can be seen as a property of everyday practices and takes four forms: shifting the time at which a practice is done, its location, how it is done (e.g. heating food by gas or in the microwave), or by stopping the practice altogether.

Our analysis shows evening demand varies considerably for each household on a daily basis.

Within the early evening peak period, dish washing, laundry and household chores were the least fixed of the practices studied amongst participants in the qualitative research (n=131), Depending on the task, these could be completed either within 24 hours or within the week. In particular, we found that laundry is an activity that some groups of respondents (most typically working families) felt could be shifted within a 24 hour time-frame, or even between days, in relation to convenience, weather and the weekly rhythm of working patterns.

Cooking and dining were reported to be less flexible by participants in the qualitative study.

4.7.2. Test Cell 9 – Time of Use Tariff

Our research suggests that the TOU tariff is effective in moving some practices outside of the 4pm – 8pm period. Our qualitative research suggests that laundry and dish washing practices are most responsive.

The evidence indicates that the TOU tariff is not effective in moving cooking times outside the 4pm – 8pm period in a sustained or widespread way, particularly for households with children.

Where practices do not respond to the time of use tariff, this appears to relate to: (a) conventions in terms of how practices are conducted; (b) rhythms of day to day life, including leisure time at home in the evening; and (c) activities that connect householders to external structures or social groups. Examples are working hours, social activities and school life. This finding suggests that the degree of alignment between a TOU tariff and other schedules and structures will be important in shaping how flexibility is realised.

Participants in TC9 are likely to consume less of their total electricity in the peak evening period (22%, n=599) in comparison to TC1 (25%, n-8649) suggesting that the tariff may have been effective in reducing evening consumption.

On average, as well as reducing peak rate consumption the tariff trialists also reduced their total consumption.

Higher income groups are more flexible than lower income groups – with high-income groups consistently reducing evening peak consumption more than medium-income groups and in turn, medium groups reducing their peak consumption by more than low-income groups. The greater reduction made by higher income groups brought their consumption closer to the post-intervention consumption of lower income groups. The result is that in the post-intervention period, there appears to be a less clear relationship between income and the consumption of electricity in the early evening peak period.

4.7.3. Variability and flexibility in SMEs electricity demand

Analysis of the data generated in this research suggests that variability and flexibility in electricity use among SMEs is related to diurnal (e.g. opening hours), weekly (e.g. shift schedules) or seasonal patterns of activities in pursuit of business goals with periods of flexibility and inflexibility being distinct for each SME. Seasonal patterns were more multi-faceted than the seasonal variation in household consumption - with different SMEs having different levels of 'business' and therefore energy intensity throughout the year.

While there is much less homogeneity to the rhythms of business life than is the case with households we find that the ways in which SMEs may be variable and flexible in their energy use is derived primarily from:

- hours of operation
- modes of interacting with customers (on premises or remotely)
- operating requirements of business processes
- tenure arrangements

For SMEs, the potential to provide valuable demand flexibility centres on the scheduling, and interruptibility of practices. For example, some processes were described as being re-schedulable if they could be done at any time in the day or week without inconvenience but might be less interruptible if they cannot easily or cheaply be shut down once started (wasted materials or heat for example).

5. Appendices

5.1. Appendix 1: Overview of NVivo Queries

5.1.1. Domestic data (analysed July – October 2013)

Q1. Smart home / connectivity

Q2. Ways of working

Q3. Gender Roles

Q4. Electric Cooking and Food Prep as a long term trend

Q5. Economic Trends

Q6. Temporality of Fix / Flex

Q7. DSP - Engagement

Q8. DSR

5.1.2. SME data (analysed October – December 2013)

Q1. Ways of working

Q2. Major electrical loads and when they are used

Q3. Key practices for flexibility

Q4. Inflexible loads/practices

Q5. Factors affecting participation in DSR

Q5.1 Temporality

Q5.2 Customer service/reputation

Q5.3 Networks

Q5.4 Motivations, drivers

Q5.5 Premises/equipment/technology

Q5.6 Ownership/renting

Q5.7 Economies/financial

5.2. Appendix 2: Residential survey: preliminary statistical analysis

5.2.1. Attitude survey

All 29 attitudinal items were entered into a Principal Components Analysis, with varimax rotation. 4 components were retained which had eigenvalues >1, and fell before the point of inflexion on the scree plot (Figure 1.). These components explained a total of 41.47% of the variance. Inspection of factor loadings (Table 1) suggests that these factors represent 1: government action; 2: household action; 3: personal action and 4: confusion about options. Components were named accordingly.

Components were saved as variables using regression extraction and used as dependent variables in the following analyses.

5.2.2. Respondent attributes

Respondents who did not report a gender or marital status were excluded from analysis (this included the solitary respondent who identified as being in a civil partnership). The sample for the following is therefore $n = 730$ (see table 2 for descriptives).

Respondent age was found to correlate negatively with components 3 (personal action, $r=-.14$, $p<.001$) and 4(confusion about options, $r = -.23$, $p<.001$), suggesting that older respondents are more willing to take personal actions, but are more confused about how to obtain trustworthy information about energy efficiency.

All 4 principal components were entered as dependent variables into a 2x4 MANOVA, with participant gender (2 levels: man; woman) and marital status (4 levels; single; cohabiting; married; divorced or separated) as independent variables. Respondent age was entered as a covariate.

As expected, there was a significant main effect of age, $F(4,718)=18.03$, $p<0.001$. Controlling for this, there was a significant main effects of marital status, $F(12,2160) – 2.15$, $p < 0.05$ and a borderline effect of gender, $F(4,718)= 2.43$, $p = 0.05$. There was no significant interaction between the IV's. These effects were investigated using univariate analysis.

ANOVA revealed a significant effect of gender on component 2 (household action, such that men (mean = 0.07, sd = 0.97) scored higher on this variable than women (mean = -0.13, sd = 1.03, $F(1,721) = 4.66$, $p<0.05$); men place higher importance on household level changes than women. No other component related to gender ($p > 0.05$).

Marital status had a significant relationship with component 3 (personal action), $F(3,721) = 5.49$, $p =0.01$). No other component was significantly related to this variable ($p > 0.05$). Pairwise comparisons with Bonferonni adjustment revealed that respondents identifying as 'Divorced/widowed' (mean = -0.45, sd = 0.72) report taking less personal action than married (mean = 0.08, st = 0.98, $p<0.05$) respondents. No other comparisons were significant ($p > 0.05$).

5.2.3. House attributes

Before proceeding with this analysis, the 12 individuals who reported living in a flat or maisonette were excluded and "end terrace" and "mid terrace" were collapsed into a single category "terraced". Final sample size for the following was (n = 694). See Table 3 for frequencies.

All four attitudinal components were entered as DVs in a 2x4 MANOVA. The two IV's were ownership type (2 levels, owned; rented) and property type (4 levels, detached house; semidetached house; terraced house; bungalow). House period could not be included in this analysis since 601 individuals failed to answer this question. House period is analysed separately, below.

Results from the MANOVA revealed no significant effect of either house or ownership type on any of the 4 components (all $p > 0.05$).

A separate one way MANOVA was run for house period. Again, no significant effects were detected (all $p > 0.05$).

5.2.4. Electrical goods inventory house

Counts of all 34 electrical goods were entered into a Principal Components analysis with varimax rotation. 3 components were retained which had eigenvalues >1, and fell before the point of inflexion on the scree plot (Figure 2.). These components accounted for 50.19% of the sample variance. Inspection of the rotated factor loadings (see Table 4) suggest that these components can be named (1) Basic household items; (2) Luxury items; and (3) Technological items. Variables were extracted using regression technique.

5.2.5. Respondent attributes

Respondents who did not report a gender or marital status were excluded from analysis (this included the solitary respondent who identified as being in a civil partnership). The sample for the following is therefore n = 730 (see Table 2 for descriptives).

Respondent age was found to correlate positively with components 1 (basic items, $r=-0.09$, $p<0.05$) and 2(luxury items, $r = -0.19$, $p<0.05$), suggesting that older respondents possess more basic and luxury electrical items.

All 4 principal components were entered as dependent variables into a 2x4 MANOVA, with participant gender (2 levels: man; woman) and marital status (4 levels; single; cohabiting; married; divorced or separated) as independent variables. Respondent age was entered as a covariate.

As expected, there was a significant main effect of age, $F(3,719)=16.20$, $p<0.001$. Controlling for this, there was a significant main effects of marital status, $F(9,2163) = 6.99$, $p < 0.05$ and a significant main effect of gender, $F(3,719)= 3.56$, $p < 0.05$. There was also a significant interaction between the IV's, $F(9,2163) = 2.30$, $p<0.05$. These effects were investigated using univariate analysis.

ANOVA revealed that gender has a significant relationship with component 1 (basic items), such that men (mean = - 0.05, sd =0.75) report owning fewer basic items than women (mean = 0.09, sd = 1.30 , F(1,721)=6.96, p <0.05). Neither of the other components had a significant relationship with gender (p >0.05).

Marital status had a significant relationship with component 3, F(3,721) = 14.83, p<0.001. Pairwise comparison revealed that single respondents (mean = -0.53, sd =.63) reported possessing more technological items than either cohabiting (mean = -0.004, sd = 0.81) or married (mean = 0.14, sd = 1.06) respondents; and that divorced/widowed (mean = -0.32, sd = 0.87) respondents have fewer technological items than married respondents (all p<0.05). No other comparisons were significant (p>0.05).

There was a further significant effect of marital status on component 2 (luxury items, F(3,721) = 5.15, p<0.05) which is presumably the result of the significant interaction between the IVs for this factor, (interaction effect: F(3,721) = 4.46, p<0.001). The interaction can be seen in figure 1: married women appear to report owning more luxury goods than any other group.

Figure 56: Scree plot for PCA 1 (attitudes)

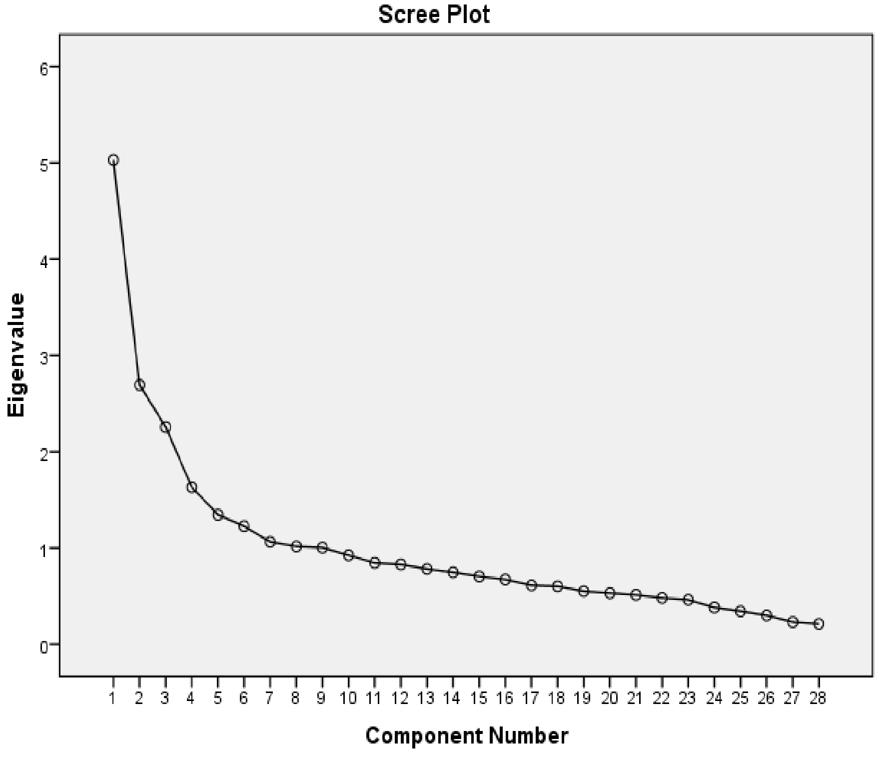


Figure 57: Scree plot for PCA 2 (Technologies)

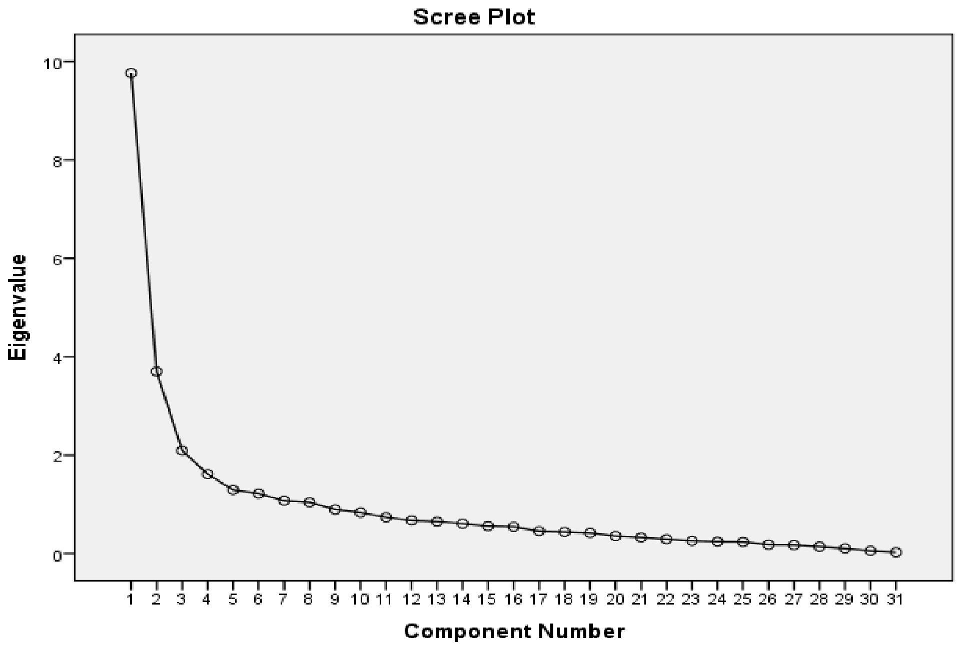


Table 13: PCA on Attitudes

			Component 1: Government Action		Component 2: Household Action		Component 3: Personal Action		Component 4: Confused by energy efficiency information	
		n	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Detached house	Owned	206	.09	1.04	-.01	1.00	.24	1.04	.08	.94
	Rented	4	1.14	.24	-.36	.78	.20	1.11	.08	.74
	All	210	.11	1.04	-.02	.99	.24	1.04	.08	.94
Semi detached house	Owned	232	.05	.98	-.01	.96	-.10	.92	-.02	.97
	Rented	31	-.16	.96	-.19	.89	-.28	1.14	-.36	1.20
	All	263	.02	.98	-.03	.95	-.12	.94	-.06	1.00
Terraced house	Owned	131	-.16	.96	-.04	1.02	-.17	.95	.14	1.08
	Rented	26	-.04	1.08	.19	1.25	.00	1.10	-.06	1.08
	All	157	-.14	.98	.00	1.06	-.14	.97	.11	1.08
Bungalow	Owned	55	-.10	.96	.10	.93	.06	.83	-.21	1.05
	Rented	9	-.16	.94	-.06	.73	.12	1.36	-.71	.65
	All	64	-.11	.95	.07	.90	.07	.91	-.28	1.02
All houses	Owned	624	.00	1.00	-.01	.98	.01	.97	.03	1.00
	Rented	70	-.04	1.01	-.04	1.02	-.10	1.14	-.27	1.08
	Whole sample	694	.00	1.00	-.01	.98	.00	.99	.00	1.01

Table 14: PCA on Technology Ownership

	Component		
	1: Basic items	2: Luxury items	3: Technological items
% Variance explained	31.51	11.93	6.76
microwave	.90		
washing machine	.89		
tumble dryer	.77		
wifi	.74		.42
electric kettle regular	.73		
electric cooker	.71		
electric shower	.70		
chest freezer	.61		
printer	.60		.48
heated pool		.90	
sunbed		.86	
patio heater		.80	
washerdryer		.73	
energy saving kettle		.65	
musical instrument		.47	
greenhouse heaters		.44	
TV			.70
digital receiver			.65
laptop			.61
phone chargers			.57
Jacuzzi			
aquarium			
dishwasher	.42		
hair straighteners			
games console			
desktop computer			
garden tolls			.41
Refrigerators	.43		
fridge-freezer	.56		
tablet			
photocopier		.53	

Table 15: PCA 2, Electrical Items

			Component 1: Basic Items		Component 2: Luxury items		Component 3: Technological items	
		N	Mean	Sd	Mean	Sd	Mean	Sd
Men	Single	47	-.12	.26	.04	.32	-.43	.60
	Cohabiting	42	-.18	.36	-.15	.24	.07	.64
	Married	337	-.03	.85	.01	.47	.14	1.03
	Divorced/widowed	20	-.05	.28	.00	.30	-.52	.81
	All men	446	-.05	.75	.00	.44	.04	.97
Women	Single	50	.08	1.26	-.06	.48	-.62	.65
	Cohabiting	26	.50	2.31	.78	4.88	-.12	1.03
	Married	173	.02	1.10	-.07	.40	.15	1.11
	Divorced/widowed	35	.10	1.28	-.11	.31	-.20	.89
	All women	284	.09	1.30	.01	1.52	-.06	1.05
Men and Women	Single	97	-.02	.93	-.01	.41	-.53	.63
	Cohabiting	68	.08	1.48	.21	3.02	.00	.81
	Married	510	-.01	.94	-.02	.45	.14	1.06
	Divorced/widowed	55	.05	1.03	-.07	.31	-.32	.87
	Whole sample	730	.00	1.01	.00	1.01	.00	1.00

Figure 58: The significant interaction between gender (1= male) and marital status (1 = single, 2 = cohabiting, 3 = married, 4 = divorced/widowed)

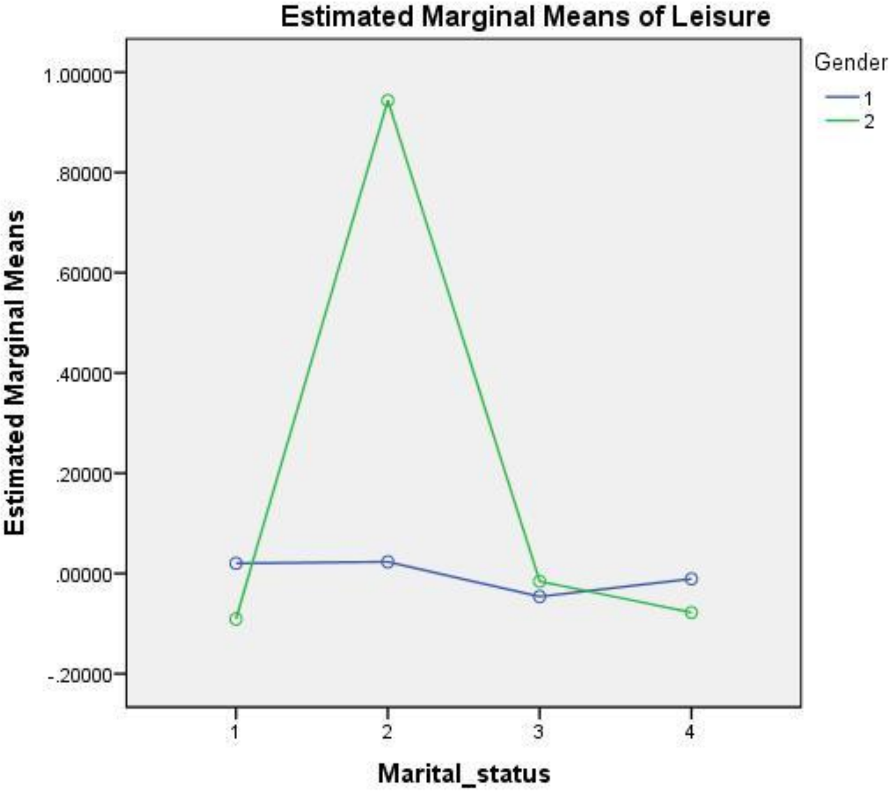
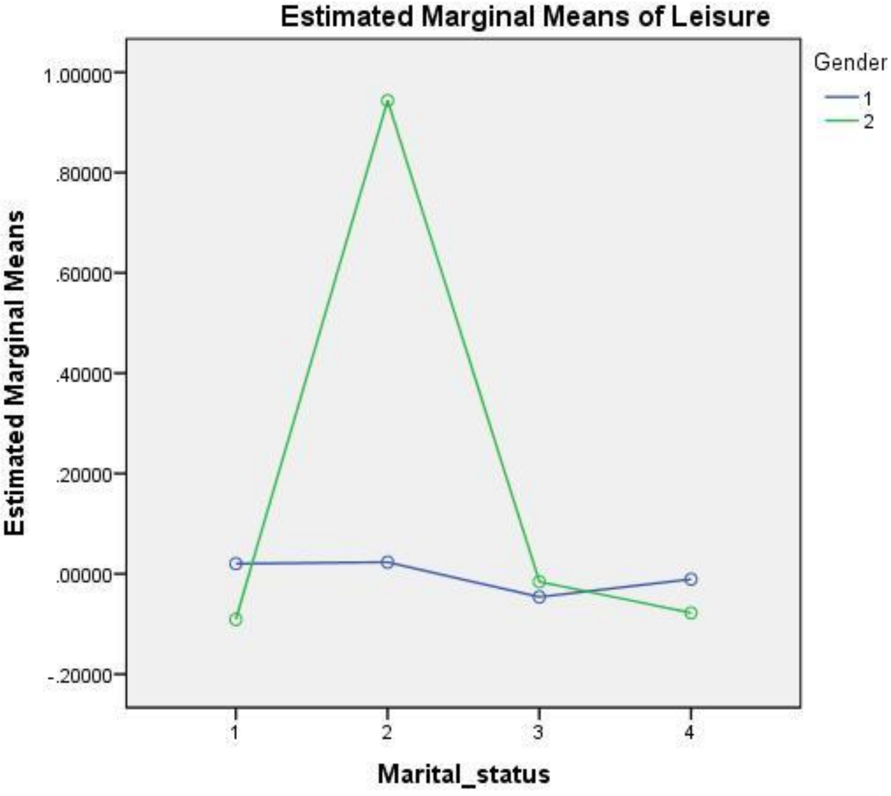


Figure 59: The significant interaction between gender (1= male) and marital status (1 = single, 2 = cohabiting, 3 = married, 4 = divorced/widowed)



5.3. Appendix 3: Energy consumption, attitudes and electrical goods report

Analysis conducted by Jamie F. Lawson

5.3.1. Processing and sample descriptives

5.3.2. Demographics

The complete sample contained 388 individuals, however inspection of the data revealed that a small group of respondents had reported unusually high numbers of electronic goods, e.g. reporting possessing 10 of all goods offered (the maximum allowed by the survey), or alternating between 10 and 0. In order to remove similar responses from the data (on the assumption that they represented individuals not engaging properly with the survey), the total number of electronic goods reported by each participant was calculated (mean = 20.93, sd = 24.46, ranging from 0 to 150), and participants who reported owning no electronic goods, or more than the mean + 2sd (i.e. more than 45.39 electronic goods) were excluded.[20] 5 people were removed by this method, reducing final sample size to 383.

The final sample contained 231 male identified participants, 146 female identified participants and 6 participants who did not disclose a gender. Respondent age ranged from 23 to 89 years with a mean of 57.52 years (sd = 12.32). Household size ranges from 1 individual to 6, with a mean of 2.32 (sd = 0.93). Average ages of all household occupants ranged from 17.25 to 89, with a mean of 52.69 (sd = 16.74). 20 respondents reported the presence of at least one under 5 year old in their household; 118 reported the presence of an over 65 year old.

5.3.2.1. Energy usage data

For the three time bands (1-3), mean consumption data was calculated by dividing the total consumption by the number of days for which data was recorded. A mean for band 0 (total energy consumption) was calculated in the same way. Descriptive statistics are available in Table 1.

5.3.3. Principal Components Analysis

In order to reduce the numbers of variables in both the attitudinal questionnaire and the electronic goods survey, and to identify underlying structure in each, variables were respectively entered into two Principal Component Analyses (PCA).

Principal Components Analysis uses whole sample variance to extract underlying components from a set of data. The resulting components correlate to a greater or lesser extent with the original set of variables. The way in which original variables cluster on resulting components can reveal information about each which can be used for interpretation. Components can be used as variables in subsequent analysis.

[20] It is possible that the individuals excluded by this method did indeed own an unusually high number of electronic goods, and that further data (e.g. face to face interviews) may bear this out. Participants excluded by this method are identified by random codes 114, 252, 448, 474 and 121, the latter of which reported possessing 0 electronic goods.

5.3.3.1. PCA 1: Attitudinal data

Responses from the attitudinal survey were entered into a PCA, using varimax rotation. This produced an array of components from which 3 were retained following inspection of the scree plot (fig 1.) These components explained 36.27% of the sample variance.

Rotated component loadings are displayed in Table 2 (loadings only reported for questionnaire items that correlated > 0.4 with any of the three components). Components were interpreted using these loadings as representing:

1) Attitude towards specific government action
2) Attitude towards specific household action
3) Attitude towards the clarity of energy efficiency information.

Variables were extracted using regression method.

5.3.3.2. PCA 2: Electrical goods survey

Responses from the electrical goods survey were entered into a PCA, using varimax rotation. This produced an array of components from which 4 were retained, following inspection of the scree plot (fig 2.) These components explained 29.84% of the sample variance.

Rotated component loadings are shown in table 3. Component 1 loads strongly on the number of phone chargers, televisions, laptops, games consoles, hair straighteners and digital recorders owned; Component 2 loads positively on the number of washing machines and tumble dryers owned, but negatively on the number of combined washer-dryers owned (i.e. people who own a combined washer-dryer unit are unlikely to also own separate washing machines and tumble dryers); Component 3 loads positively on the number of chest freezers and refrigerators owned, but negatively on combined fridge-freezers (see previous comment); Component 4 loads positively on numbers of electric kettles and microwaves owned, but negatively on the number of energy saving electric kettles.

Accordingly, we name the factors as follows:

1. Entertainment/leisure
2. Washing machines
3. Refrigeration
4. Kettles/microwaves

Variables were extracted using regression method.

All 8 variables extracted by PCA were entered into analyses as predictor variables in order to investigate the effect of attitude, electronic goods owned and household ages on energy consumption

5.3.4. Results

5.3.4.1. Relationships between predictor variables

All 8 factors were tested for correlation with average household age using spearman's rank order correlation (since KS tests revealed household age to be significantly non-normal, p<0.01). The

Entertainments/leisure component correlated negatively with average household age, rs=-0.63, p<0.001, (i.e. households with a younger average age possess fewer of these items). The Washing Machines component correlated positively with average household age, rs=0.13, p<0.05 (i.e. older households possess more washing machines and tumble driers, but fewer combined washer-driers). No other component correlated with average household age.

Further analysis revealed that household size correlated positively with the Entertainments/leisure component rs= 0.63, p<0.001 (i.e. larger households possess more of these items); positively with the Washing machines component, rs=-0.12, p<0.05, (i.e. larger households possess more washing machines and tumble driers but fewer combined washer-driers); and negatively with the Microwaves and kettles component, rs=-0.11, p<0.05 (i.e. larger households possess fewer microwaves and regular kettles, but more energy efficient kettles).

5.3.5. Energy consumption: regression analyses

For each of the following, all 8 factors were entered as predictor variables into multiple linear regression models (enter method) along with average household age and number of occupants. Two dummy variables, the presence or absence of >65 year olds or <5year olds (both scored as 1/0) were also entered.

5.3.5.1. Band 0 (Total mean daily usage)

The outcome variable was mean total energy usage per day (calculated as total energy usage over the study period, divided by days of study).

Analysis produced a significantly significant model, F(11, 371) = 9.37, p <0.001, R2 = 0.22. Four variables made significant contributions to the model: the Entertainment/leisure component, β = 0.22, p = 0.001; the Washing machines component, β = 0.10, p = 0.03; average household age, β = 0.28, p < 0.05; and number of occupants, β = 0.42, p < 0.001. Number of occupants was the most influential variable. None of the attitudinal variables had any relationship with mean daily usage, nor did the presence or absence of the two target age groups.

In summary, mean daily consumption is increased by the presence of more entertainments/leisure devices, by the number of (separate) washing machines and tumble driers and by the number of occupants of the household. In addition, households with a younger average age use more energy per day. Household size is the most influential variable here.

5.3.5.2. Band 1 (Mean daily consumption midnight – 7am and 8pm – midnight)

Analysis produced a significantly significant model, F(11, 371) = 5.78, p <0.001, R2 = 0.38. Two variables made significant contributions to the model: the Entertainment/leisure component, β = 0.13, p < 0.001; and number of occupants, β = 0.29, p < 0.001. None of the other variables had any relationship with mean energy usage during this timeband, and number of occupants is the most influential variable.

In summary, mean energy consumption between midnight and 7am and 8pm and midnight on the same day is increased by the presence of entertainments/leisure items and by the number of household occupants. Again, the latter is the most influential variable.

5.3.5.3. Band 1 (Mean Band 2 (Mean daily consumption 7am-4pm)

Analysis produced a significantly significant model, $F(11, 371) = 8.84$, $p < 0.001$, $R2 = 0.46$. Four variables made significant contributions to the model: the Entertainment/leisure component, $\beta = 0.23$, $p = 0.001$; the Washing machines component, $\beta = 0.11$, $p = 0.03$; average household age, $\beta = 0.42$, $p < 0.01$; and number of occupants, $\beta = 0.45$, $p < 0.001$. None of the other variables had any relationship with mean energy usage during this timeband.

These results are broadly identical to those from timeband 0, above.

5.3.5.4. Band 3 (Mean daily consumption 4pm-8pm)

Analysis produced a significantly significant model, $F(11, 371) = 14.22$, $p < 0.001$, $R2 = 0.30$. Three variables made significant contributions to the model: the Entertainment/leisure component, $\beta = 0.23$, $p < 0.001$; average household age, $\beta = 0.27$, $p < 0.01$; and number of occupants, $\beta = 0.50$, $p < 0.001$. None of the other variables had any relationship with mean energy usage during this timeband, and number of occupants is the most influential variable.

In summary, energy consumption during this time is increased by the number of the energy/leisure goods, by household size and by average household age. Household size is the most influential variable for energy consumption during this timeband.

5.3.6. General summary

Across all timebands, number of occupants is shown to be the most influential variable when predicting average energy use. Attitudinal data has no relationship with energy consumption. The number of entertainment/leisure items (phone chargers, televisions etc) are also shown to be important across all timebands. Household age ceases to predict energy use at night-time, and washing machines become influential between the hours of 7am and 4pm.

5.3.7. Cluster analysis

Owing to the importance of the two electrical goods components, Energy/leisure and Washing machines (and noting that they are the top two components in the PCA2 for variance explained), a two-step cluster analysis was run in order to investigate the potential for these variables to classify the sample. Analysis revealed a 3 cluster solution, which has been mapped onto a graph of the two components (figure 3). Clusters 1 and 3 seem to be differentiated from each other by PC1 (Entertainment/leisure), and Cluster 2 differentiated from both other clusters by PC2 (Washing machines).

A One Way ANOVA revealed that the clusters significantly differ from each other with respect to average household age, $F(2,380)= 66.58$, $p < 0.001$. Post hoc tests revealed that this is driven by cluster 3 (mean age = 38.57, sd = 11.92) which is significantly younger than clusters 1 (mean age = 58.05, sd = 15.17) and 2 (mean age = 56.76, sd = 15.66). Similarly, the clusters differ significantly in terms of mean energy consumption per day, $F(2,380) = 24.39$, $p < 0.001$. Again, post hoc tests reveal that this is due to cluster 3 (mean = 14.25, sd = 6.42), which consumes more energy on a daily basis than clusters 1 (mean = 10.46, sd = 4.82) and 2 (mean = 9.22, sd = 3.02).

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