Further Analysis of the Household Electricity Survey

Early Findings: Demand side management

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Jason Palmer, Nicola Terry, Tom Kane

CAMBRIDGE ARCHITECTURAL RESEARCH LIMITED

elementenergy

Loughborough University

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Overview

DECC and DEFRA asked Cambridge Architectural Research, Loughborough University and Element Energy to re-analyse the Household Electricity Survey – the most detailed monitoring of electricity use in UK homes ever undertaken. The Departments drew up a list of 30 lines of enquiry – topics that were not explored, or unexplored in detail, in the initial analysis.

This report brings together the early findings from this work. It presents and analyses the data in new ways, and begins to improve understanding of how and why electricity is used in the home. In particular, it tells us how much power is used in peak periods, and how much of this could be switched to periods of lower electrical demand.

It begins to unravel the mysteries of baseload power – where the electricity goes when householders are asleep – and standby power – when appliances are left on but not doing anything.

24-hour electricity profiles

■ Judging purely from the 24-hour load profiles there is considerable scope for peak load shifting. On average, the evening peak demand is more than three times higher than the baseload. The average load profiles suggest that cooking, lighting and audiovisual appliances use the largest share of peak power. However, washing appliances and cold appliances also account for a significant share of the peak load, and these probably offer more potential for changing the times of use.

■ Summer electricity use is markedly different from electricity use in winter or mid-season. In monitored households there were pronounced variations in the timing of electricity use during the warmest month, with greater use at night and lower use during the usual evening peak. The power is also used for different appliances in summer, with greater use for cold appliances, none for space heating, and greater use of electric showers in the evening.

■ Both household composition and dwelling type have an impact on average 24-hour profiles. Predictably, larger households and larger dwellings tend to use more electricity. However, the effect of both of these is dwarfed by the impact of very hot or very cold outdoor temperatures: very cold temperatures coinciding with greater use for space heating, lighting, audiovisual and washing appliances.

Peak power and demand shifting

■ Replacing inefficient appliances with the most efficient appliances has the potential to reduce peak power demand by at least as much as demand shifting per se.

■ If cold appliances had controls to avoid electricity use in the evening peak (6-7pm) it would be possible to suspend up to 10% of peak power for half-an-hour, or up to 70 W for each household that replaces its cold appliances. (Given current replacement cycles for white goods it would take more than 20 years to replace all cold appliances.)

■ If householders switched their use of washing machines, tumble driers and dishwashers from the evening peak to non-peak periods, this would transfer at least 8% of the peak demand for the monitored households, or an average of 57 W per home.

■ It may be worth targeting the 15% of households in the sample that use peak electricity for water heating in order to reduce peak electricity use, because these households use an average of 60 W during the evening peak.

Standby power

■ There is some uncertainty in the data because of limitations in the monitoring equipment for monitoring appliances in low power states, but our analysis suggests that standby power accounts for an average of 201 kWh per household per year, or 5.1% of total electricity use.

■ Modems and routers have highest 'standby' power use among ICT equipment – around double the next-highest device. They often run continuously, so there may be opportunities for using timers on these devices.

■ There is some evidence that newer appliances use less power in standby modes, but not all appliances have been successful in cutting standby electricity use. New hi-fi equipment, TVs, ovens and monitors appear to use less power in standby modes, but other new appliances – like combined fax/printers– may actually use more electricity in standby.

Baseload power

■ Baseload electricity demand (defined as the low-point in daily electricity demand) is similar in summer and winter. Increased electricity use for heating in winter is roughly offset by reduced use for cold appliances.

■ Fridges and freezers account for the largest share of baseload electricity use: at least 36% in summer and 25% in winter, but there are big variations between households. A third of these households use at least 40W for cold appliances during the baseload period in summer. This suggests initiatives aimed at reducing baseload demand should focus first on cold appliances.

■ Some households have many more fridges and freezers than average – one of these households has four cold appliances. These households could be specially targetted in attempts to reduce baseload power use.

■ Space and water heating are large contributors to baseload power use in winter – even though only a small proportion of the homes (7%) use electric space heating. If these households could be persuaded to use solar water heaters instead of immersion heaters, they could cut their baseload power use considerably.

Secondary electric heating

■ Persuading the 4.2 million English households with secondary electric heating to use another form of heating from 6-7pm could save 680-820 MW during the peak period. In very cold periods the saving could rise to 2 GW.

■ Most households with backup electric heating use it continuously day and night, although they could invest in storage heaters. This would shift their electric heating outside the peak period.

24/7 appliances

■ We examined the monitoring evidence about electricity use by fire alarms, burglar alarms and doorbells. Only a small number of these appliances were monitored in the survey, but this indicated that more energy than expected is used by these 24/7 appliances: an average of 72 kWh/year for alarms, and 53 kWh/year for doorbells.

Introduction

Background to the Household Electricity Survey

The Household Electricity Survey monitored a total of 250 owner-occupier households across England from 2010 to 2011. Twenty-six of these households were monitored for a full year. The remaining 224 were monitored for one month, on a rolling basis throughout the trial. There were no private rented homes or homes owned by registered social landlords or local authorities – to avoid the extra procedures necessary in getting agreement from tenants and landlords to participate.

The study had four broad objectives at the outset[1]:

1. To identify and catalogue the range and quantity of electrically powered appliances, products and gadgets found in the typical home.
2. To understand their frequency and patterns of usage - in particular, their impact on peak electricity demand.
3. To monitor total electricity consumption of the home as well as individually monitoring the majority of appliances in the household.
4. To collect 'user habit' data when using a range of appliances through the use of diaries.

Participants kept detailed diaries of how they used their main appliances, matched against actual energy use monitoring for their homes. They had between 13 and 85 appliances in their homes, with about a third of them owning between 30 and 40 appliances.

The sample of homes was not perfectly representative – partly because only homeowners were included and partly because questionnaires found them to be more energy-conscious than average households. There were also fewer than the average number of households with primary electric heating (3.5% against an average across the population of 8%[2]), flats were under-represented (4% against 18% nationally[2]), and the average floor area was 5.5% larger. The average (mean) electricity use across homes in the sample was 4,093 kWh/year, against a mean of 4,154 kWh across all UK homes for 2011, see table[3,4].

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[1] DECC/EST/DEFRA (2012) Powering the Nation. London: DECC/EST/DEFRA.
[2] Palmer J, Cooper I (2012) UK Housing Energy Fact File 2012. London: DECC.
[3] A draft of this report cited a lower average annual consumption, before data cleaning was complete. We have now completed data cleaning for the new figure, validated against meter readings for 200 of the households.
[4] DECC (2012) Energy Consumption in the UK. London: DECC. (Tables 3.1 and 3.3.)

Seasonal adjustments

Most of the households in the survey were only monitored for a month, and these figures were unduly affected by the time of year when they were monitored. As a result, for some of the Departments' questions we had to adjust the data for these homes to account for seasonal differences. For example, fridges and freezers use more energy in the summer, but lighting is used more in the winter.

We used data from the 26 households monitored over a whole year to generate 'seasonality factors' for each appliance type – cold appliances, electric cooking, lighting, washing, AV, ICT, water heating and space heating. (For water heating there was no significant difference between the seasons.)

We calculated the electricity use on each day for each appliance type, averaging over the total usage for the 26 households. Then we normalised this by dividing by the total use over the year, times 365, to get a factor for each day.

The results were very noisy, so we used regression analysis and least squares to find a best fit curve, based on sine and cosine functions. We generated a separate adjustment curve for each of the eight appliance types where there was a link between energy use and the time of year.

The adjustments result in increased uncertainty, which is hard to quantify, particularly for heating due to the small sample. (None of the households monitored for a year used electricity for their main heating.) For heating we avoid using the adjusted figures where possible.

This data offers an unparalleled source of very detailed electricity profiles. It has already provided unmatched insights into the way electricity is used in English homes. However, there remains considerable potential for doing more with the data – notably in understanding the scope for demand shifting, baseload electricity demand, changes in the size and efficiency of appliances, and how different socio-economic groups and ages use electricity. It also provides a rich seam of data we can mine to inform the way smart meters are used to support or challenge DECC's existing understanding of power use, and to support or challenge the Department's current statistics and modelling of electricity use in homes.

Household type	Sample size	Mean electricity use per year
All HES homes	250	4,093 kWh
Homes with primary electric heating	9	7,318 kWh
Homes without primary electric heating	241	3,973 kWh
ECUK estimate for all UK homes[4]	(27 million)	4,154 kWh

The opportunity to glean more from this data could hardly be more timely. We are at a critical juncture in planning electricity generation, where the UK must invest £110bn in energy infrastructure[5] – partly to replace the power stations built in the 1960s and 70s, now reaching the

[5] See www.gov.uk/government/policies/maintaining-uk-energy-security--2/supporting-pages/electricity-market-reform

end of their useful lives. We must meet the Government's target of an 80% reduction in greenhouse gas emissions by 2050, and at the same time balance the necessities of maintaining the country's fuel security and allocating resources wisely for the long-term. We cannot make informed decisions about electricity generation without also understanding the potential for efficiencies and savings from households (and other sectors). This relies on robust data and analysis.

At the same time, the UK Government is committed to the most complex smart metering and consumer engagement project in the world - the vision of a smart grid, where data becomes the prime commodity to manage consumption and demand. The Green Deal, probably the most radical set of policies aimed at household energy use for 40 years, is also changing the landscape for cutting energy use in homes.

We have to make the most of this opportunity to understand more about power usage.

Limitations of the data

Studies like the Household Electricity Survey are unusual because they are complex to organise, and very expensive. Inevitably, there are some compromises in assembling such a rich set of data – largely linked to the modest sample size. Ideally, there would have been thousands, or perhaps tens of thousands of households participating in the study, including both rented and privately-owned homes. Ideally, all homes would have been monitored for the full 12 months rather than having some of them monitored for just one month. Some commentators hold that gender is an important determinant of energy use at home, and ideally we would have data on the gender makeup of households and/or individual participants, but this data was not collected.

It is possible that people living in rented property use electric appliances differently from owner occupiers, although we know of no empirical work in the UK that demonstrates this.

The Departments asked us to draw out policy recommendations from the work where possible. They and we recognise that policy recommendations would be more robust if based on a larger sample – especially for work focused on subsets of the homes in the study (e.g. homes with electric heating, or pensioners). The small sample makes it impossible to extrapolate reliably to all homes, but it is a starting point, and where possible we combine with other sources of empirical data.

In many parts of this work we see associations (or the absence of associations) between demographic profiles and patterns of energy use. We suggest explanations for these patterns where we think it is appropriate, with caveats, but we would not claim that our interpretations are categorical or definitive, and it is very seldom possible to infer unambiguous causality from the correlations.

This report

This report is the first in a series of reports to be written by **Cambridge Architectural Research**, **Element Energy**, and **Loughborough University**. Working closely together, the partners are scrutinising and analysing the data in a variety of different ways to explore specific questions drawn up by DECC and DEFRA. We have established a secure database for the data, and set up files that can be interrogated using Access, Excel and SQL (structured query language). Where necessary we have used programming for functions that are not supported in either Access or Excel.

We currently propose to write six detailed reports over the 13 months of this project:

- This Early Findings report, focusing on ‘Demand side management’
- ‘Electrical appliances at home: tuning in to energy saving’
- The ‘Scoping study for a National Monitoring Survey using Smart Meters’
- One report on ‘Models, labels and unusual appliances’
- One report on ‘Social studies and Policy’, and
- The Final Report – giving an overview of the whole project and summarising the main findings to emerge.

This report presents findings from our preliminary analysis of the data, including presenting 24-hour demand profiles for the 250 households, examining peak power and demand shifting, standby power, baseload power, secondary electric heating, and 24/7 appliances.

As a complement to this report we have developed an interactive spreadsheet that allows Departmental staff to work with the data easily themselves. The spreadsheet allows users to generate daily load profiles for different households selected from the sample of 250 households. We have made this spreadsheet available for scrutiny by the wider energy research community – which adds value to the study and helps to share the insights. Readers can download the spreadsheet here:

www.tinyurl.com\24-Hour-Chooser

Demand-side management

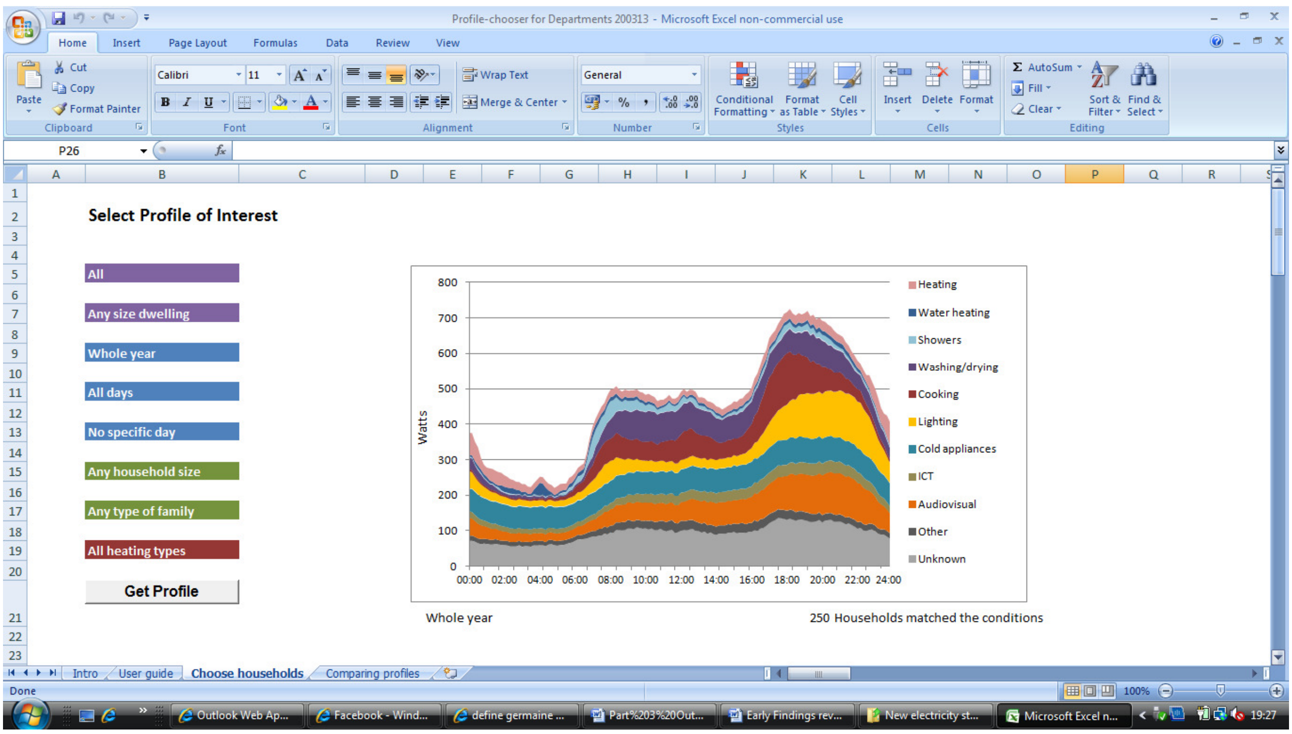
Provide daily demand profiles

The original analysis of the Household Electricity Study included 24-hour demand profiles in 10-minute intervals for an average day and for the coldest day. Power demand was broken down by category (lighting, cooking, cold appliances, washing/drying, space heating, water heating, showers, audio-visual, ICT, other, and not known), and profiles were prepared for specific household types. However, the Departments wish to look at more complex combinations of household and dwelling types, including demand profiles for an average day for each month, and for the warmest day of the year. This is partly motivated by modelling tasks CAR will carry out for the Departments later in the project.

Approach

Rather than delivering an unwieldy paper document with hundreds of charts, which would make it very difficult to find the combinations of households, dwelling types and periods that interest the Departments, we have prepared a simple interactive tool allowing them to generate daily electricity-use profiles for specific criteria very easily. The tool, called the 24-Hour Profile Chooser, runs in Excel and has a database of average monthly consumption data at a 10-minute resolution. All 250 homes are included, and it takes just a few seconds to select criteria and generate a profile.

The tool also includes a comparison worksheet that allows users to compare daily profiles for different types of households, different dwelling types, and/or different periods. The profiles below were all created using the 24-Hour Profile Chooser. This section serves as an illustration of what the tool can do, and in fact hundreds of combinations of the various parameters are possible.



This screenshot from the tool shows all households' average daily profile over a whole year. It is clear that baseload power over night is significant at just over 200 Watts, or about a third of peak power use between 6pm and 8pm.

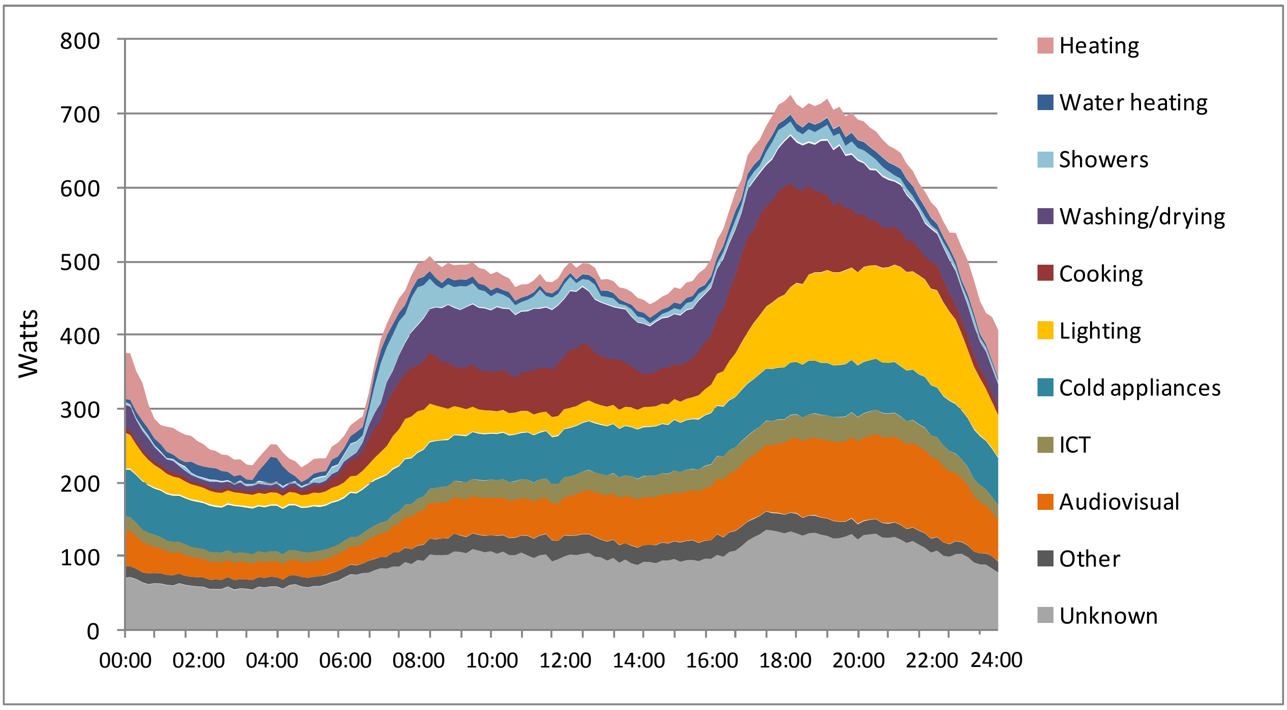
Data analysis

In this section we look first across all households, for the whole year. Then we pick out a few different sub-groups of households: first single pensioners and other single-person households (because single person households raised some unexpected findings in the initial study), and second we examine electricity use in flats and detached houses (because these dwelling types are at opposite ends of the scale and occupancy spectrums). Finally we compare the electricity profiles for all homes monitored during the coldest and the warmest months. The figures do not match similar figures presented in the original analysis of the Household Electricity Study because of improved data cleaning. The original analysis also excluded households where more than 10% of the energy use was unknown. In contrast, we have opted to include all households, in order to keep sample sizes as large as possible.

This analysis uses raw data, unadjusted for seasonal effects. This means the sample sizes for short periods of the year are rather small, since the analysis includes only the dwellings monitored over the period selected.

All households, whole year

The mean daily profile for all homes included in the study across the whole year indicates that on average cold appliances draw very similar power from the grid throughout the day, see chart below. Conversely, audiovisual, lighting, electric cooking and 'washing/drying' (which also includes dishwashing) vary quite significantly through the day. In fact the averaging across homes and times of year reduces the variability of these components of the profile, and in reality they fluctuate much more than the graph suggests for specific household groups and/or periods.



The evening peak is very pronounced, and made up largely of electricity used for cooking in the early evening, transferring to lighting and audiovisual later in the evening.

The evening peak is much more pronounced than the morning peak, and accounts for 50% higher peak load when averaged across all homes and periods. Overall, although there is an identifiable morning peak at about 7.30am, lower demand for lighting, space heating and cooking are almost completely offset by increased energy use for washing, drying and dishwashing.

The average baseload through the night is about 220 Watts/household. The small peak at 4am is due to an electric water heater in a single household, used mainly between 3.30 and 4.30am. Very few households use significant electricity for water heating: only twenty use more than 0.5 kWh/day. Even among the nine households using electricity for primary heating, only six record energy use for water heating separately. The table below shows the pattern of water heating by space heating type.

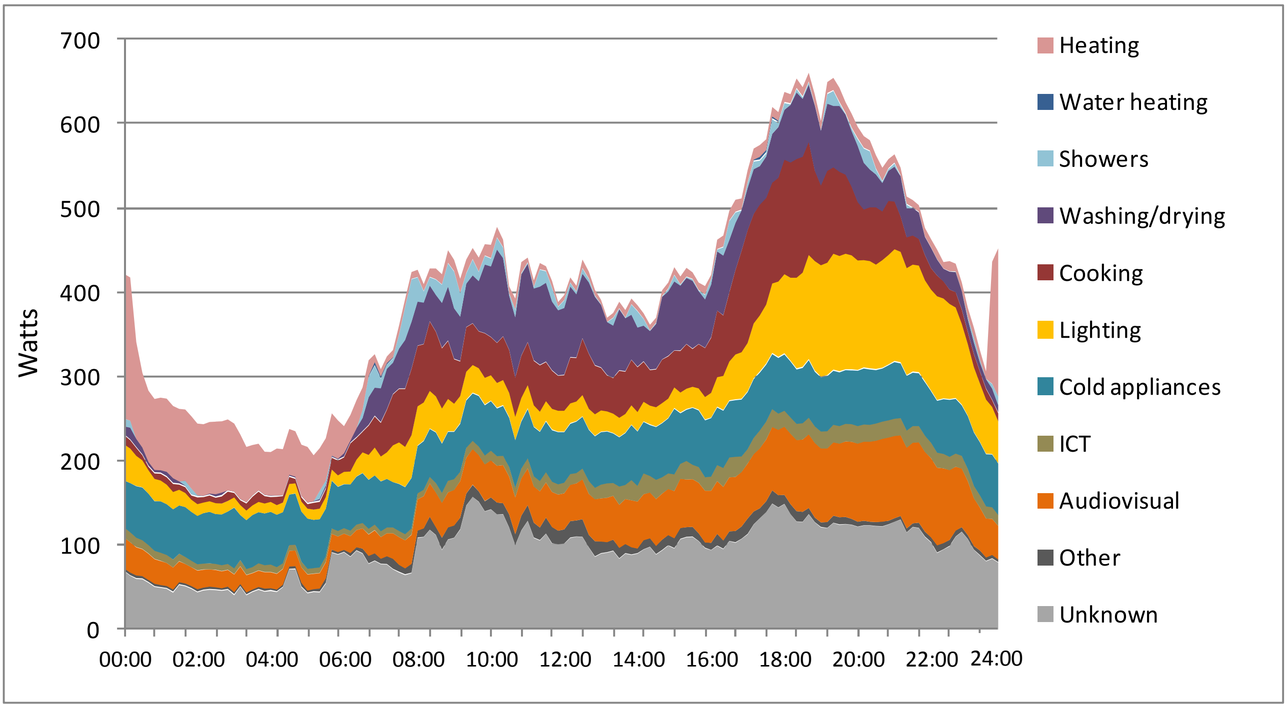
Space heating type	% using some electricity for water heating (count)	Mean kWh/day for water heating
Gas or oil	19% (39)	1.0
Electric top-up heating	19% (7)	0.4
Primary electric heating	66% (6)	2.4

Apart from the space heating type there is no particular pattern to the types of homes or households that use electricity for water heating. The top twenty water users include single person households, two, three person and larger households, dwelling sizes from 60 m^2 to 150 m^2, and include detached, semi-detached and terraced houses, bungalows and a flat.

Single pensioners, whole year

Thirty-four of the households in the survey were pensioners living alone. Their 24-hour profile (below) looks quite different from the average profile for all homes. First, it is peakier – partly an artefact of a smaller sample. Second, night-time electricity use is dominated by space heating (pink). Of the single pensioners, six (18%) use some electricity for heating, the same proportion as in all households, but only one of them uses electricity for primary heating. This one dwelling (a flat) is responsible for the spike in space heating around midnight. This pensioner uses an average of 2.5 kW between midnight and 5am. (During February-March).

Electricity consumption is lower at nearly all times of day than the average of all households. (The midnight spike in space heating energy is the only exception.) They also use less electricity for hot water, and for 'other' appliances (typically small plug-in devices like hair-driers, vacuum cleaners, phones and hair-straighteners).



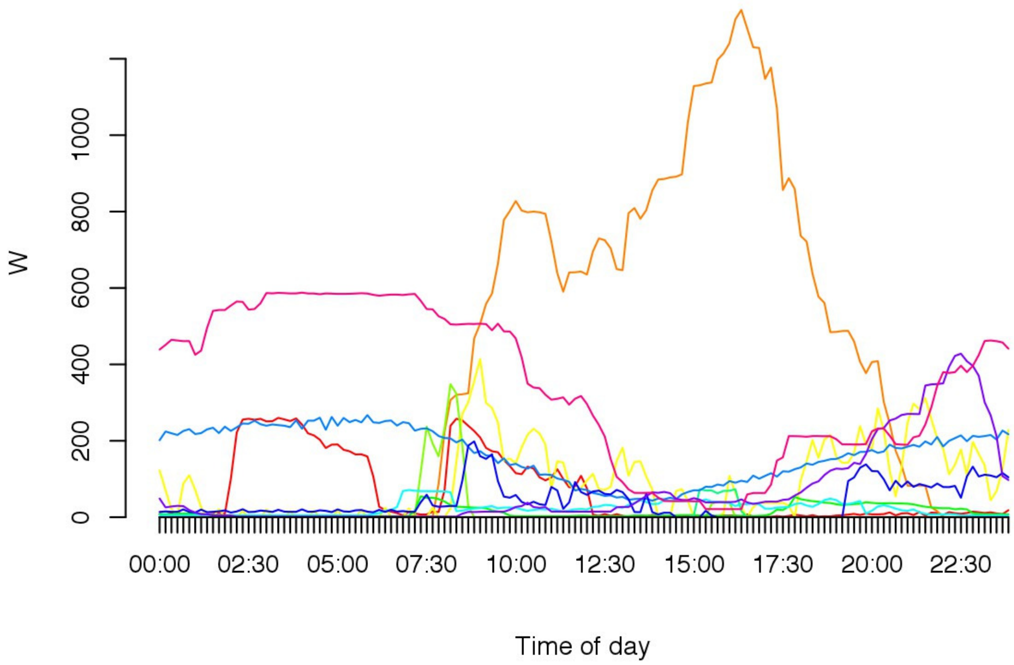
The 34 single pensioners have similar consumption patterns for lighting and audiovisual appliances, but tend to use less electricity for water heating and washing appliances.

Single non-pensioners, whole year

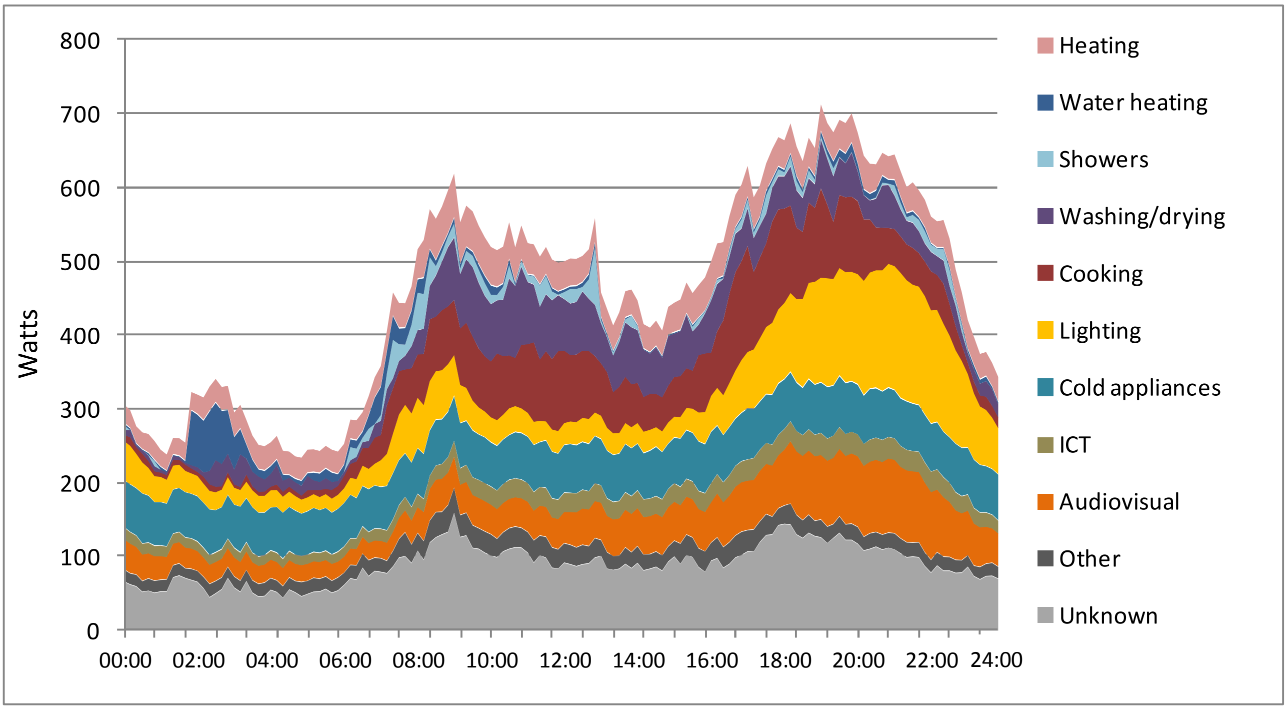
Thirty-five of the households were non-pensioners living on their own. Their average electricity use profile is shown in the chart below. These households have a more pronounced twin-peak pattern of use, with higher use from 8am to 1pm, and an even higher use from 5pm to 10.30pm. Presumably the pattern is linked to people being more likely to be working or doing other activities outside the home from 1pm to 5pm.

The high power for water heating between 2 and 4am is due to a single household, using an immersion heater overnight. This household is in the top five for water heating use, averaging 4.6 kWh/day energy, and they also use electricity for primary electric heating. They have an Economy 7 meter for cheaper overnight electricity.

Although the pattern for space heating looks even through the day, this is misleading because while most of the households use little through the afternoon, there is one with very high use, which drags up the average for the group. The graph below shows the daily pattern for space heating for single non-pensioners.



The daily pattern of energy use for electric space heating in pensioner households shows the variety in how pensioners in the survey use electric heating, with some peak-tariff heating.

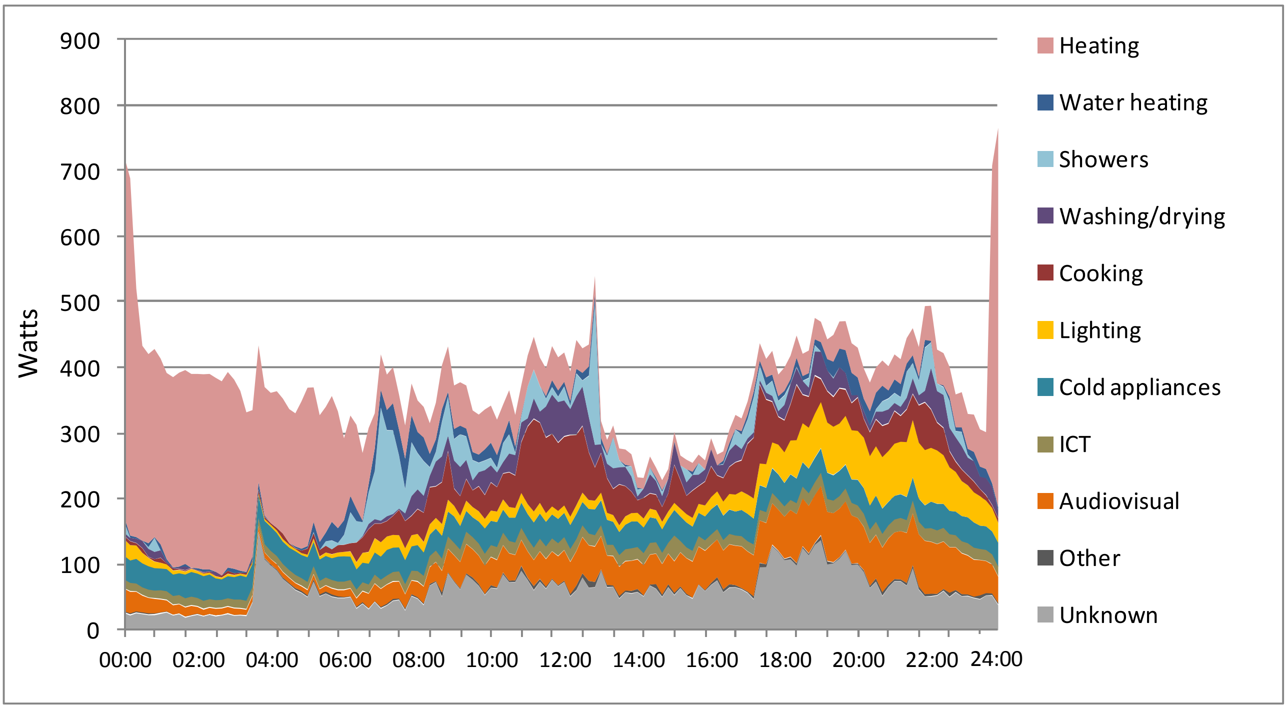


The 35 single non-pensioners use more electricity for space heating, on average, and have two pronounced peak periods separated by lower use from 1pm to 5pm.

Flats

Only 11 of the households in the survey were flats, so we cannot draw too much from the average daily profile for flats, shown below. The pattern may be skewed by one or two very unusual consumption patterns that are not representative of the wider population of flats. The 11 flats included here have below-average electricity use overall, with hardly any discernible morning or evening peak use. Most of the night time space heating – and all of the big spike at midnight – is due to the same household we saw in the section on Single Pensioners above. This time it is one of 11 instead of 34, so it has a greater effect on the overall profile.

The relatively low-use pattern – apart from heating – is probably linked partly to flats being smaller than houses, on average, with fewer occupants. The Profile Chooser allows users to select households by floor area and/or occupants if they wish to explore this further.

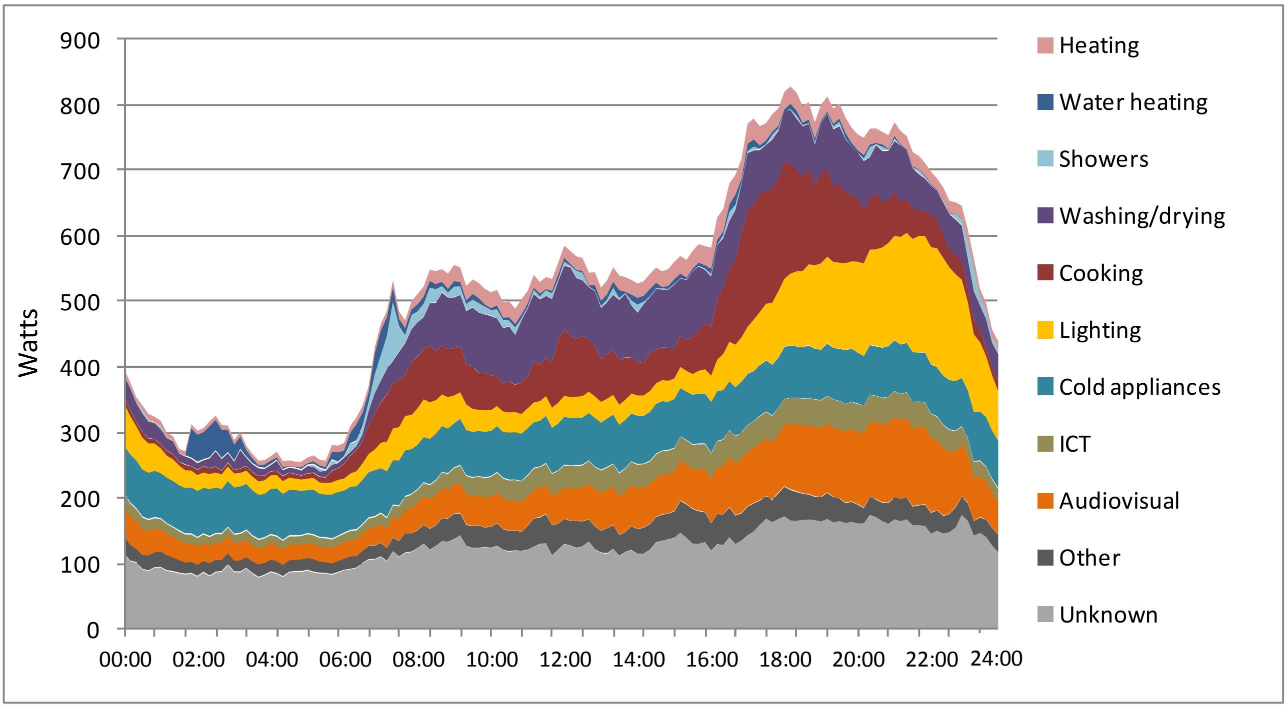


The 11 flats in the sample show profiles dominated by overnight space heating (pink). Other aspects of electricity use are lower than average for all homes in the sample.

Detached houses

There were 57 detached houses in the study. Average electricity drawn from the grid by these homes is somewhat higher than the average across all households in the sample: about 50 W higher for the period from 7am to 4pm, then about 80 W higher during the evening peak. The detached homes use a little more electricity than average for ICT, and for lighting between 9pm and 11pm (again, probably linked to house- and household-size).

However, detached houses use less electricity for water heating, on average. This may be because they are less likely to use immersion heaters. Overall, although the accepted wisdom is that income and floor area effects increase energy use (in this survey detached dwellings averaged 134 m^2, compared to 93 m^2 for the others), in fact the difference between detached homes and the whole sample is only about 10%.

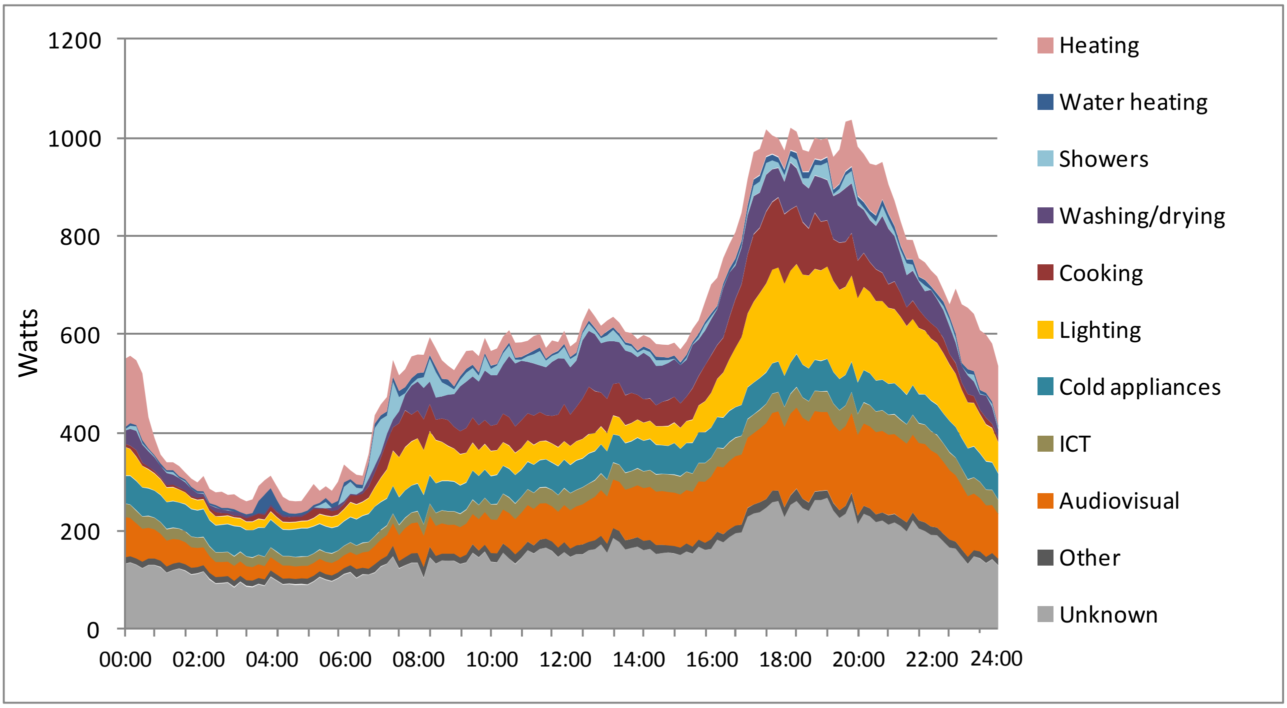


The 57 detached houses in the study used a little more electricity than average throughout the day, with more lighting energy late at night, and greater use of 'other' plug-in appliances.

Coldest month, all homes

Sixty-one households were monitored during the coldest month, January. Predictably, electricity use is much higher, and electric space heating (pink) is more prominent than at other times of the year. (Remember that most of these homes have gas heating, so electricity is only providing part of the heating load.)

Space heating is markedly higher from 10pm to 1am, possibly as a result of charging electric storage heaters. Unknown electricity use is around double the load for the average across the year, suggesting that heating is a significant part of the electrical load in January – probably electric fan and bar heaters that were not separately monitored.



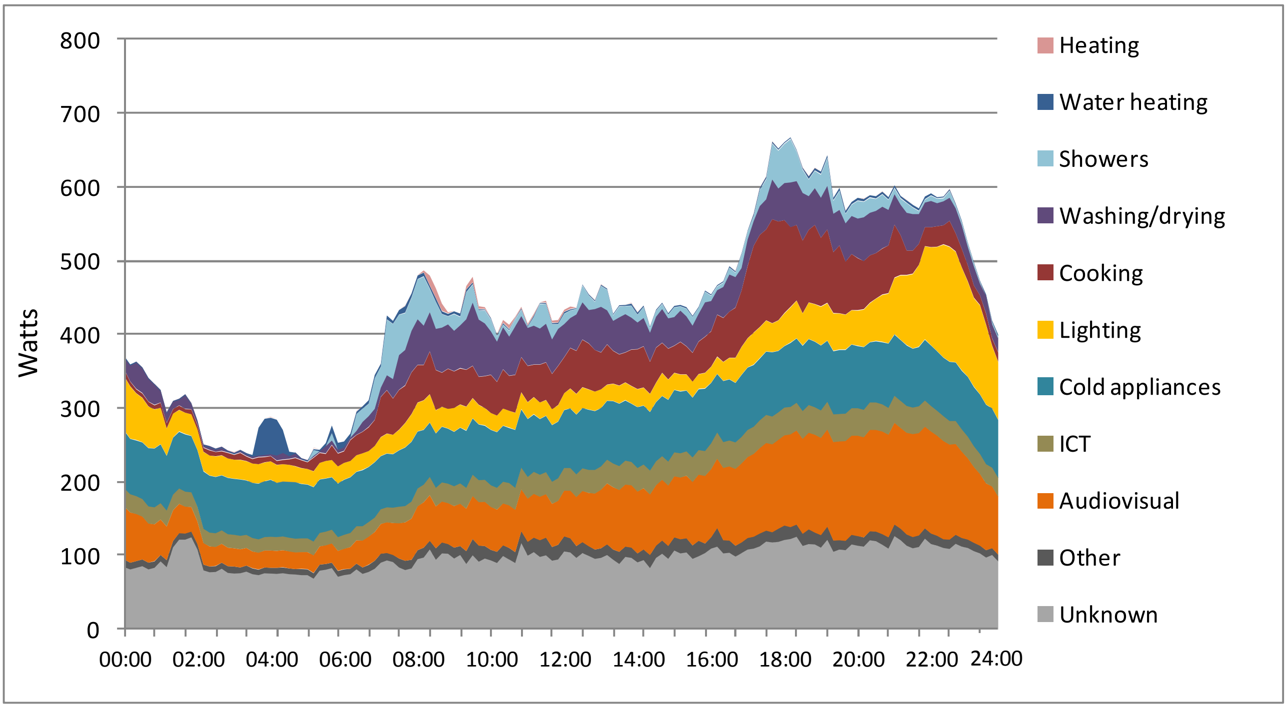
There appears to be proportionately more electricity use for lighting, audiovisual, washing appliances, and 'unknown' appliances – as well as the obvious increase in space heating – for the 61 homes monitored in January.

Around half as much electricity is used for cold appliances in January compared to the whole year. This partly offsets increased electricity use for space heating.

Warmest month, all homes

Sixty-four households were monitored during July 2010, the hottest month in England during the project. Again, the monthly profile is more erratic than the whole year profiles, because of the smoothing effect of averaging over a year. Overall electricity use is similar, but the pattern through the day is much less pronounced – with higher night-time electricity use (especially for lights, cold appliances and audiovisual appliances), and a lower, shorter period of peak energy use in the evening. This is likely to be linked to lighter evenings and warmer night-time temperatures, which could have two effects on householders. First they could encourage people to spend time outdoors (reducing electricity use), but second they could make it harder for some people to sleep (which may increase electricity use.

As you might expect, there is greater use of electric showers in the hottest month, which make a noticeable contribution to the evening peak. There is almost no use of electric space heating. However, cold appliances have to work harder in the warmest month, so electricity use is sustained at a higher level than other times of the year. Electricity use for lighting peaks later in the evening – 9-10pm, compared to 7-10pm when averaged across the whole year.



The warmest month profile shows that the 64 households monitored in July use a little less electricity than the average over the whole year, with a noticeably shorter evening peak. However, they use more power overnight.

Other Evidence on Hourly Profiles

Detailed electricity metering of 400 homes in Sweden suggested that electricity profiles there are very different – partly because electric heating is much more common. The average daily profile below for homes with electric heating shows that households there can draw much more power from the electricity grid – up to 2.7kW, on average, with nearly 2kW even at night.

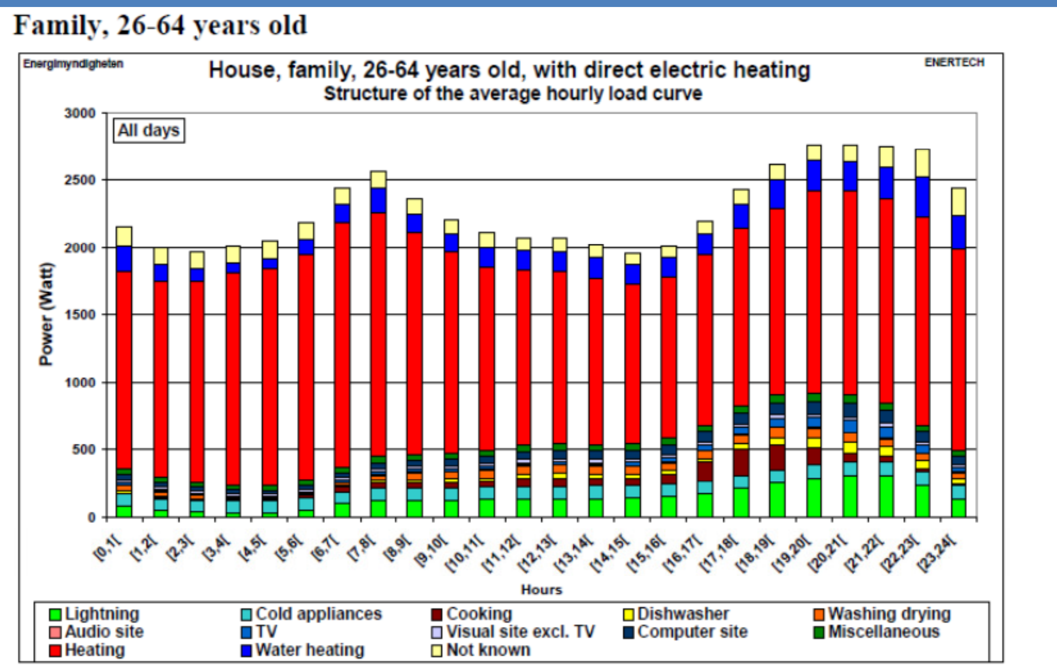


Figure 2.56: Structure of the average hourly load curve – Houses with direct electric heating - All days

[4] Zimmermann JP (2009) End Use Metering Campaign in 400 Households in Sweden: Assessment of the potential electricity savings. Eskilstuna, Sweden: Swedish Energy Agency.

Recommendations

■ Judging purely from the 24-hour load profiles there is considerable scope for peak load shifting. On average, the evening peak demand is more than three times higher than the baseload. This data suggests that electric cooking, lighting and audiovisual appliances use the largest share of peak load power. However, washing appliances and cold appliances also account for a significant share of the peak load, and these probably offer more potential for changing the times of use.

■ We cannot assume that summer electricity use is the same as electricity use in winter or mid-season. In monitored households there were marked variations in electricity use between summer and winter months, and what the electricity is used for.

■ Different household compositions may have a bigger impact on 24-hour profiles than dwelling types. However, the effect of both of these is dwarfed by the impact of very hot or very cold outdoor temperatures.

Assess the potential for demand shifting

The Departments wish to find out whether it is possible to shift electricity use from periods of high demand to periods when less electricity is drawn from the grid. If possible, they want to quantify the potential for shifting demand – to move towards more even demand for energy, which is easier to meet using low carbon power generation. The Departments also want to understand more about how to encourage households to change the time of use of appliances, to reduce peak electricity demand.

Approach

Some appliances are by their nature less time-sensitive than others. For example, households clearly need some form of electric lighting when it is dark outside and occupants are active: they cannot choose to use electric lighting at some other time. Conversely, households have more discretion about when they choose to run their washing machines or tumble-driers. Given the right incentive, householders might be persuaded to use such appliances overnight, or at other periods of low electricity demand.

We distinguished between three types of appliances: switchable, non-switchable, and 'partially switchable'. (The latter covers things like ovens, where it may be possible to change the time of use of some oven use – say when baking bread or cakes for later consumption – but not others.)

Switchable	Partially switchable	Non-switchable
Washing machine	Ovens	Lights
Tumble Drier	Space heating	TV
Dishwasher	Cold appliances	Audio equipment
Water heating		Computers
		Hobs
		Microwave

We examined electricity use over the period studied for all four switchable appliances, and cold appliances from the 'partially switchable' list. (We will examine space heating and ovens in our next report.)

In total the Switchable Appliances account for 19% of the electrical load in the households monitored, see table below.

Switchable	Mean Electricity Use over 12 months	Mean Percentage of Known Electricity Demand
Washing machine/ tumble drier/ dishwasher	437 kWh	13.1%
Water heating	197 kWh	5.9%

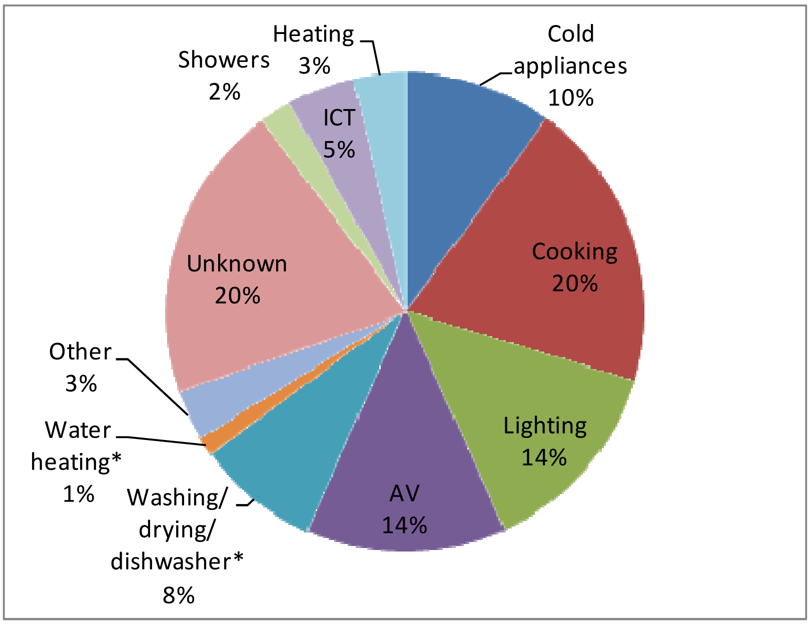
Analysis: Focus on Peak Load Period

We also looked in detail at electricity use during the peak load period from 6-7pm. During this evening peak (much more pronounced than the morning peak) the mean power drawn from the grid for households in the survey was around 720 Watts averaged across the year (see page 8 above). This rises to an average of 1600 Watts for the 38 households monitored on the coldest day.

If the sample were perfectly representative of all English homes, this would factor up to a peak load of 17 GW (720 W x 23 million dwellings) averaged across the year, or 37 GW (1600 x 23) on the coldest day of 2010 (20th December). This compares to National Grid's record[6] of the average UK demand of 58 GW for 6-7pm for this date, or the annual UK average from July 2010 to June 2011, 6-7pm, of 43 GW. The National Grid figures include non-domestic users (public sector, commerce and industry) as well as household energy use.

The three largest types of electricity use in survey homes are cooking, lighting and audio-visual equipment (see pie chart below). Taken together, these account for nearly 60% of the known evening peak. (A fifth of the peak load cannot be identified from data collected in the survey.) Unfortunately, all three of these present difficulties in changing the time of use. However, the lighting and refrigeration components could be reduced significantly if households used more efficient appliances.

In this survey, 140 households (56%) had an electric cooker, hob or oven. This is broadly consistent with data from the Market Transformation Programme[7] suggesting that in 2013 64% of households have electric ovens, and 44% have electric hobs.



Most of the known evening peak electricity demand (6-7pm) is used for cooking, lighting and audio-visual appliances

[6] See http://www.nationalgrid.com/uk/Electricity/Data/Demand+Data/

[7] DEFRA (unpublished) Market Transformation Programme: Energy using products evidence base models. London: DEFRA.

Cold appliances

After cooking, lighting and audio-visual, the next largest slice of known peak demand is for cold appliances, making up at least 10% of electricity demand from 6-7pm. It may be possible to shift at least part of the time of use of fridges and freezers, but probably not for the whole hour of peak demand. These appliances operate in cycles, activated by a thermostat. When the temperature is too warm a compressor cuts in and cools the appliance down to another set point. The compressor then shuts off until the unit has warmed up again. These cycles can vary in length depending on the insulation around the unit and the granularity set in the thermostat, as well as how often the door is opened. They can take more than an hour or just a few minutes. Energy use during the peak period could be suppressed in several ways:

- by adjusting the upper set temperature higher, so that the compressor Is activated later, or
- by pre-cooling the appliance to lower than the normal lower set temperature in advance of the peak period.

In both cases, freezers are likely to give more flexibility than fridges because they are typically opened less often at peak time and because their temperature is less critical: pre-cooling a fridge significantly could freeze some of the contents.

In addition, power use can only be delayed a short time. If a large number of appliances have their activity delayed there is a risk they will all come on together at the end of the period of suppression, causing a surge in demand.

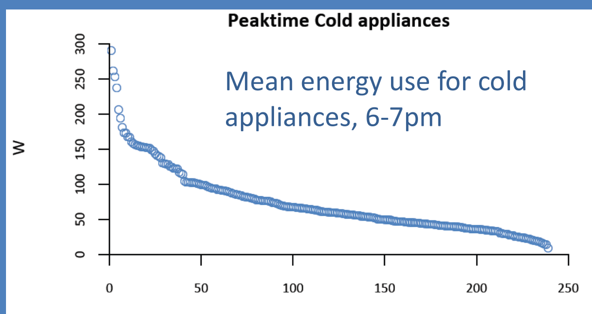
Modelling the savings which could be achieved is beyond the scope of this study. However, research for DEFRA[8] suggests that a 30-minute delay could be achieved, saving 28W in a 150W refrigerator without pre-cooling. With pre-cooling the delay could be increased. Other work suggests delaying the defrost cycle (which draws power to defrost and then more power to cool temperature to normal afterwards) until after the end of the peak period[9].

These savings would require 'smart' controls in the appliance, activated by frequency response or other signals from the grid, which means appliances (or their controls) would have to be upgraded. If the new units were also more energy efficient the savings would be even greater: upgrading from an A rated upright freezer to an A++ rating would save 40% by itself. A+++ appliances are now available with

Cold Appliances

We looked at cold appliances energy use in more detail. We found a wide range in energy use of cold appliances from 6-7pm – from 0 Wh to 291 Wh, see graph. Mean energy use for cold appliances in this period was 70 Wh, which factors up to around 26 kWh/year.

A very small number of homes had cold appliances using more than 200 Wh at this time of day, and it seems likely that most of these were in need of maintenance – either poor seals, wrongly set controls, or mechanical problems with the compressors.



This plot shows how few homes had very high energy use for cold appliances

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[8] EA Technology (2011) Delivering the benefits of smart appliances, London: DEFRA.
[9] See http://www.aham.org/ht/a/GetDocumentAction/i/51596

even greater savings.

In the best case scenario (and putting efficiency savings aside), if all power to cold appliances could be suspended, it would be possible to trim 10% from peak power demand for 30 minutes, or an average of 70 Wh for each household in our sample that replaces its cold appliances.

This is similar to DEFRA's estimate of a saving of 28W per refrigerator (given that most households have a freezer as well as a fridge, or a combined fridge-freezer). Based on current replacement cycles for white goods it would take at least 20 years to replace all cold appliances in UK homes, but DEFRA estimates that if 40 million appliances were replaced by units with smart controls, this could cut from 728 to 1174 MW from the country's peak load. This is a tiny saving compared to 50 GW or more total peak load on the grid in winter.

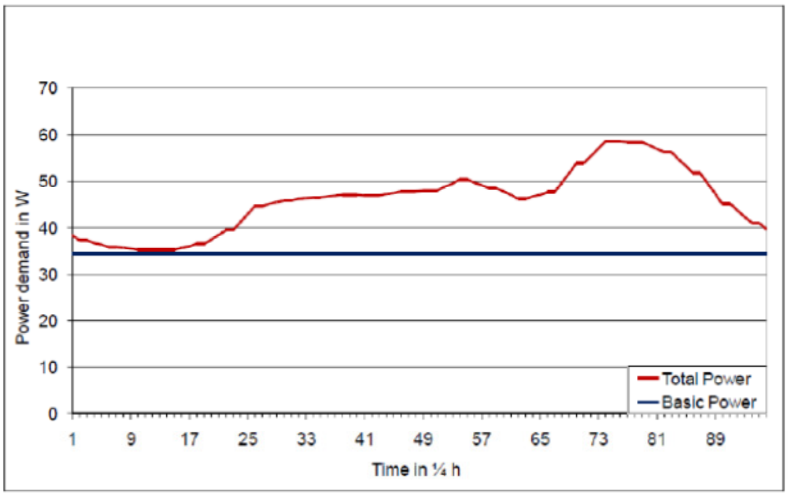
Other Evidence on Cold Appliances

The DEFRA/EA Technology report referred to above also included estimates of energy use over the year for four types of cold appliances – now, and in 2020. The table below shows their estimates of energy use for equipment with different energy labels, and the estimates are a little lower than the HES sample – possibly because they do not take account of deteriorating performance as cold appliances get older.

Table E.6 Energy Consumption (kWh/year) in 2010 and 2020 for cold appliances by energy label category

Energy Label	Chest Freezer		Fridge Freezer		Refrigerator		Upright Freezer	
	2010	2020	2010	2020	2010	2020	2010	2020
A+++	N/A	83	N/A	156	72	72	N/A	100
A++	123	104	195	195	91	90	140	125
A+	170	146	268	266	128	123	196	172
A	203	195	372	363	170	165	226	225
B	254	258	431	422	211	211	298	304
C	309	309	529	531	244	243	380	374
D	539	546	541	523	257	259	387	385
Fleet Average	323	183	446	286	200	124	316	189

The DEFRA/EA Technology report also cited work for the Smart-A project which assumed average energy use of 404 kWh/year per appliance, with average power demand of 138 W (assuming the appliances cycle on for a third of the time). This study included work by the University of Bonn which underlined that more energy is likely to be needed in peak periods, when appliance doors are more likely to be open. This assumes that 25% of cold appliance energy use is due to consumer behaviour, and the resulting use profile coincides with overall electricity demand quite closely, see graph.



Washing appliances

Washing machines, tumble driers and dishwashers make up the next biggest slice: at least 8% of the peak evening demand for the monitored households. This group of appliances is eminently switchable. On paper at least, householders could avoid using these appliances during the evening peak, even without any new controls.

The monitored homes used an average of 57 W (21 kWh/year) for washing appliances during the evening peak period from 6-7pm. Potentially, switching this load to periods of low electricity demand could bring small but worthwhile reductions in the peak load.

Persuading householders to use their washing appliances outside the peak load periods may require different electricity tariffs – so there is a financial incentive to run these appliances at different times – or other strategies geared towards changing behaviour. Again, this strays outside the scope of this study and we have insufficient evidence about how rigid householders' appliance-use habits might be.

Nevertheless, to give some idea of the savings that might be possible, if one million households did refrain from using their washing appliances during the evening peak, this would cut the country's peak load by up to 57 MW.

Hot water

Water heating is rather different from other forms of power use during the peak period, because only a third of the households use any electricity at all for heating water at this time. (38 out of 250 for hot water, and another 54 for electric showers.) That is, two-thirds of these homes use no power at all for hot water or showers from 6-7pm. However, the 38 households that do use electrically-heated hot water use an average of 22 kWh/year for this – a little more than the average power use for washing, drying and dishwashers (taken together).

This suggests that it may be worth targeting households using peak electricity for water heating in order to reduce peak electricity use.

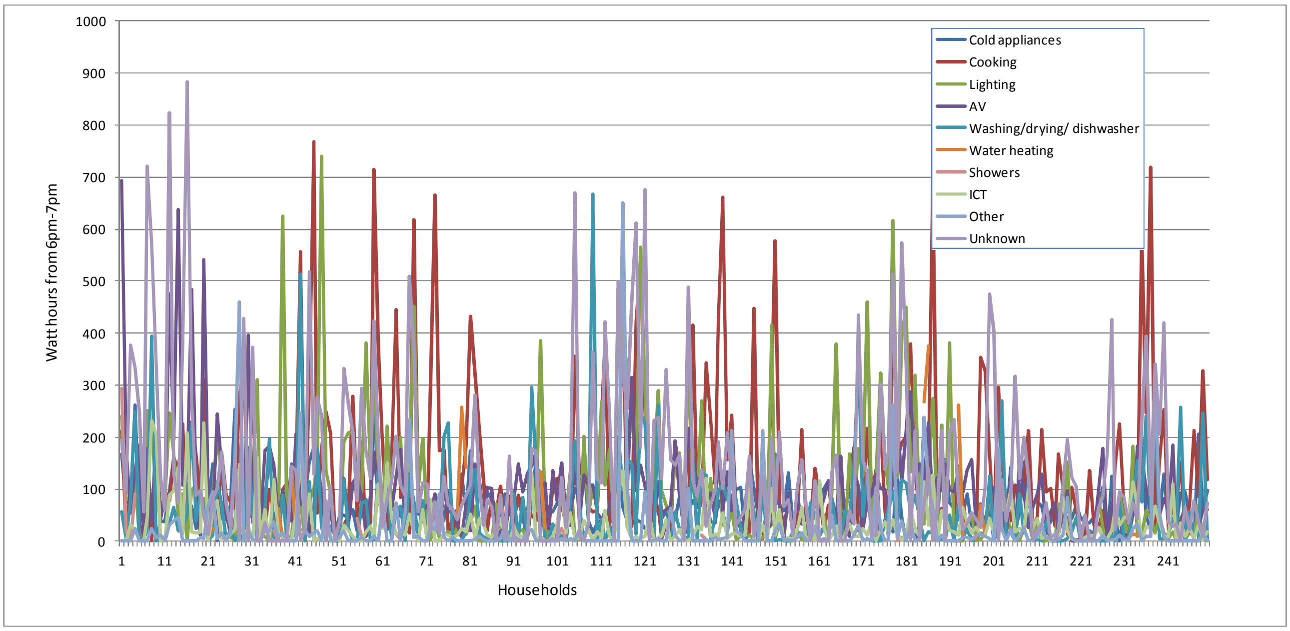
Showers

As for hot water, only a minority of homes have electric showers that they use in the peak period. For the 54 households in this category, the average power load from 6-7pm is 52 W per household – slightly less than the figure for electric water heating.

It may be more difficult to change a household's washing habits than how they control water heating. It probably makes sense to focus attention on electric water heating rather than electric showers, although there is undoubtedly a case for encouraging greater use of solar water heating, linked to showers, as a way to help reduce the peak electrical load.

Detailed analysis 6-7pm

There is a more detailed snapshot of energy use during the evening peak in the chart below. Again, these values are averaged across the monitoring period. Note that the ranking of electricity use differs considerably between households, and while some households have a red peak signifying that cooking energy is responsible for the largest share of their peak electricity use, other households have green (lighting), pale blue (washing appliances) or purple ones (audio-visual appliances). The largest contributor to the evening peak load is most often cooking energy, but lighting, washing appliances and audio-visual appliances are also quite often the single largest contributor to peak electricity demand.



Energy use during the evening peak is complex, and there is a wide variation in the pattern of use between households

This tells us that different strategies are needed for different households if we are to succeed in reducing peak load demand. In households where lighting is most significant there are almost certainly opportunities to install more efficient light fittings – either compact fluorescents or LEDs. In households where the peak is partly caused by electric water heating and/or space heating, there are probably also opportunities to change the time of use to reduce peak power demand.

Recommendations to encourage peak load shifting

■ Focus effort on improving energy efficiency on appliances used at peak times. For example, replacing inefficient efficient lights and cold appliances will cut peak electricity use without additional measures aimed specifically at load shifting.

■ Encourage time shifting for appliance types where the time of use is not important: washing and drying clothes, dishwashing and heating stored water.

■ Investigate opportunities for controlling cold appliances to avoid peak periods, and using price signals to discourage peak power use.

■ Investigate ways of identifying and fixing or replacing cold appliances that use more (peak load) electricity than they should. Some cold appliances, which may be faulty, use more than three times average electricity from 6-7pm.

Other Evidence on Peak Load Switching

PowerCentsDC[10] monitored 850 customers in Washington over 15 months. It found evidence that peak load pricing helped to reduce peak load demand between 4 and 34% in summer and 2-13% in winter.

Another US report[11] based on modelling suggested that smart appliances could reduce peak load demand from 3-6%. It predicted savings from dishwashers, cold appliances, washing appliances and tumble driers.

■ Recognise that different strategies suit different households, and the biggest opportunities for load shifting will come from households that currently use most electricity during the peak period.

[10] eMeter Strategic Consulting (2010) PowerCentsDC Program Final Report. Unknown location: eMeter Strategic Consulting.
[11] Sastry C, Pratt R, Srivastava V, Li S (2010) Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves. Washington: US Department of Energy/Pacific Northwest.

Understand what baseload demand consists of

Baseload is the minimum electricity consumption through the day – averaged over all houses this is the load between 3 and 4 am. The initial analysis of HES data[10] showed that overnight power use rarely drops below 150 W even in households with no electric heating, and some 20-30 W of this was not attributable to a specific appliance because the load was not recorded at the appliance level. The Department wishes to determine where this load comes from and whether the baseload can be reduced.

Approach

We extracted from the database of energy consumption electricity use during only the hour of least energy use for the 250 households monitored. In most cases this was overnight, but some households did use power at night time, and one appeared to have several people working night-shifts, so the record of 'baseload' power was occasionally taken during the daytime.

We anticipated significant differences between summer and winter baseload, so we analysed the data separately for summer (2nd April – 30th September) and winter (1st October – 1st April). In particular, we expected to see major differences in energy use for heating, cold appliances, and lights, which we know are all affected by temperature and daylight changes through the seasons.

The average (mean) summer baseload – again, defined here as the hour of the day when least power is used – across all homes was 112.1 W. The average winter baseload was quite similar: 108.0 W. Seemingly, the increase in average baseload heating during the winter is almost offset by the increased average use of fridges and freezers, see charts below.

Summer and winter baseload power use are remarkably similar, and cold appliances dominate both

In both summer and winter, cold appliances are responsible for by far the largest proportion of the known baseload: at least 36% in summer against at least 25% in winter. However, there are huge variations between households. Four households use less than 8 W for their cold appliances during the baseload period, whereas it is not unusual for a household to use 100 W for cold appliances, and one home uses 220 W for refrigeration (three fridge-freezers and one fridge).

Audio-visual appliances are the next highest energy-consuming appliance after cold appliances. In both summer and winter, they represent just over 12% of the known baseload electricity demand. Again, there is considerable variability. In 18 households, no power at all was used during the baseload period – suggesting that they are very careful to switch off their TV, audio equipment and other accessories.

Conversely, one household used more than 100 W on average during the base load period for a single hi-fi unit, and this item uses 60W even on standby.

Lights account for an average of at least 6.8% of baseload electricity use in summer, and 6.1% of known energy in winter. Higher summer use is largely due to lights being used more at night. The absolute averages are similar (7.7 W summer, 6.5 W winter). Two households have high electricity

[10] Zimmerman et al (2012) Household Electricity Survey: A study of domestic electrical product usage. Milton Keynes: Intertek/EST/DECC/DEFRA.

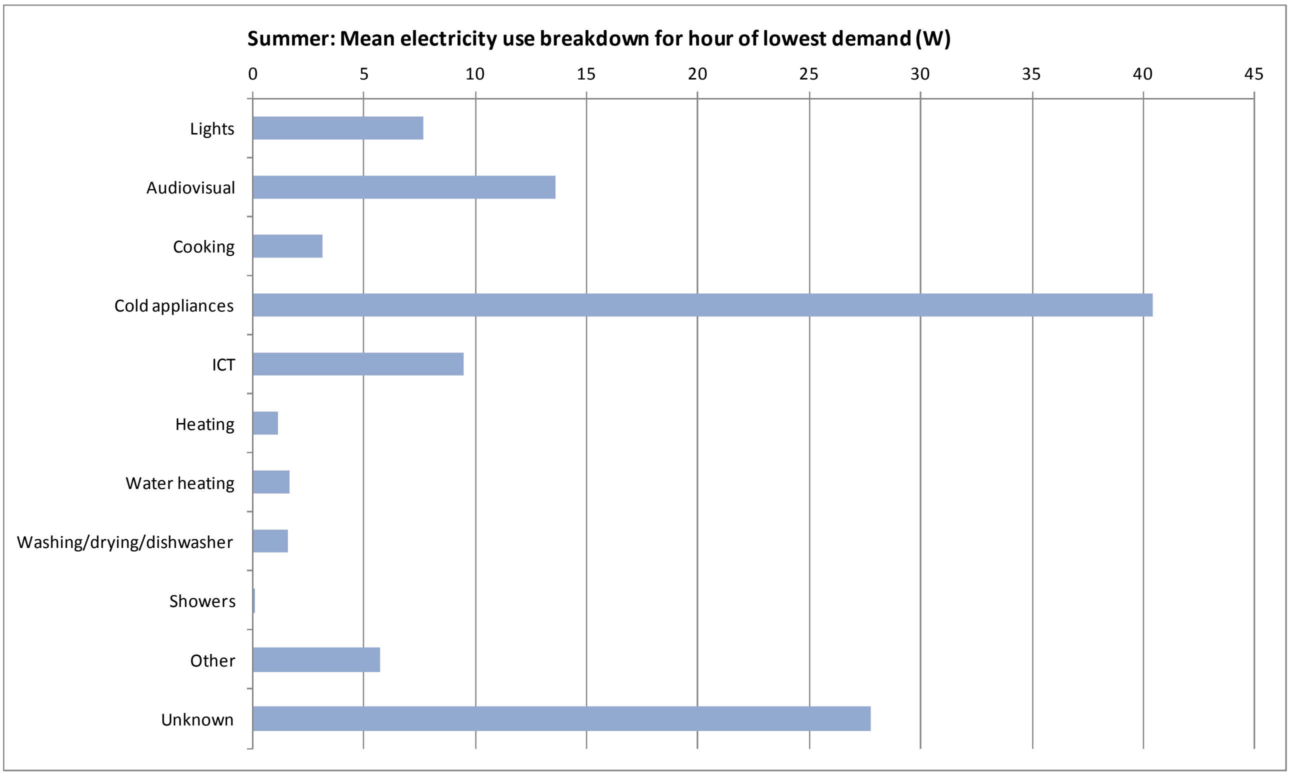
use for lights – from 80 to 110W during the hour of lowest demand in summer – whereas quite a few households use no power at all for lighting, and about half use less than 15 W during the baseload period.

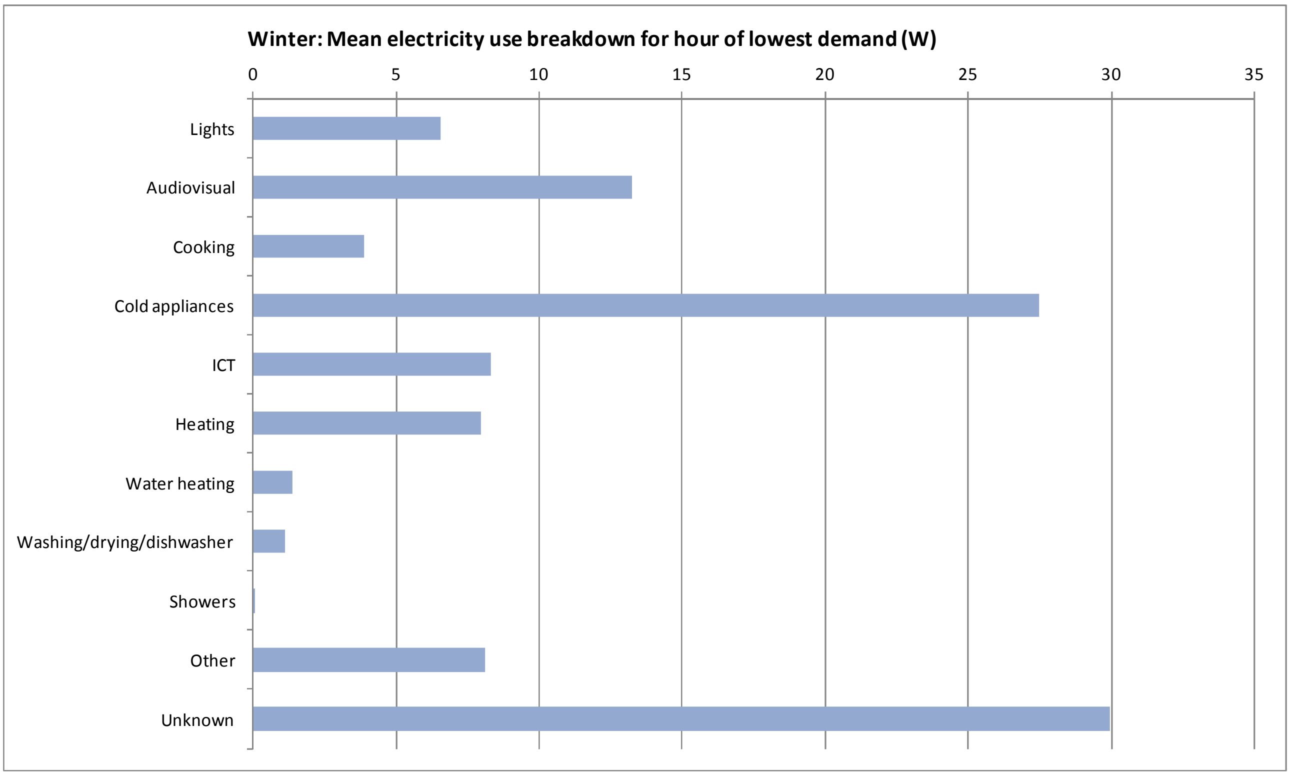
Information and communication technology is responsible for an average of at least 7.7% (winter) to 8.4% (summer) of known baseload electrical demand. Households were recorded with 65 PCs active during the baseload period: 47 desktops and 18 laptop computers. Even more homes had Internet routers active – 73 of them, and two of these homes had two routers running.

The high-consuming ICT appliances were more likely to be desktop PCs than other equipment, although there was also one fax/printer, and one modem, using more than 50 W during the hour of lowest demand. There were pronounced clusters of ICT equipment left running during the baseload period in particular homes. For example, a PC along with a monitor and a router or printer. There were also three households with fairly high-use appliances running together.

This is not hard to understand: households who make a habit of turning off one ICT appliance probably turn off other ICT appliances also – especially if they are located together on a single desk. There may also be some correlation between households owning an older computer (with higher electricity use) and other older accessories (with similarly high out-of-use power consumption).

Showers make up a tiny fraction of baseload power, see charts below, and only two households in the survey used any power at all for showers in the period of lowest demand. (In contrast to hot water, where 19 households used electricity during the baseload period.)





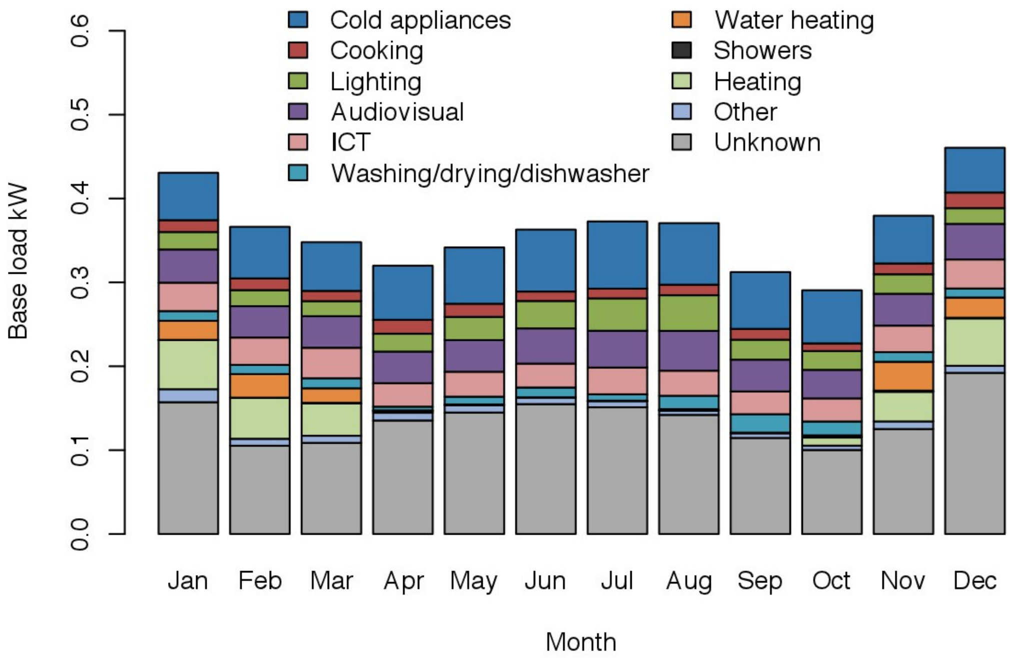
Detailed analysis: monthly baseloads

We also looked at the variation in baseload power use broken down month-by-month for the 26 homes monitored for a whole year. Water heating appears to be used only during the winter months. This is due to one household (101038) which uses a water heater overnight 3.30-4.30 am GMT (mentioned elsewhere). This overlaps with 3-4am in winter but not in summer.

Lighting's fraction of baseload power also appears to be quite strongly linked to the month of the year – although not in the expected way. The reduction from August to September is much sharper than seasonal changes we observed in daytime lighting. It is due to a step change in behaviour from just three households. Monitoring began in May or June and each of the three changed their behaviour abruptly, reducing their use of lighting overnight at some point in August or September. Since the households were only monitored for a year it is not possible to say whether the summer behaviour was repeated in subsequent years.

Nevertheless, there is some indication that patterns of baseload energy use for audio-visual appliances (purple) and ICT (pink) are less affected by the month of the year than lighting energy, cold appliances or electric cooking.

Note that 'unknown' electricity use accounts for a sizable fraction (30-40%) of baseload electricity use throughout the year. This shows that a significant proportion of the unmetered lights and appliances were used at night, and it is likely that at least part of this unknown use is for 24/7 appliances.



Baseload electricity use for space and water heating is closely related to the time of year in the 26 households monitored over the whole year.

Recommendations

■ Cold appliances are responsible for the lion's share of baseload power (at least 30%), and a third of these households use at least 40W for cold appliances during the baseload period in summer. This suggests initiatives aimed at reducing baseload demand should focus first on cold appliances.

■ Some households have many more cold appliances than average – one of these households has four. These households should be specially targetted in attempts to reduce baseload power use, perhaps encouraging them to rationalise food storage and/or ensure their appliances are energy efficient.

■ A small proportion of these households appear to leave audio-visual appliances on overnight, and one of them seems to leave a hi-fi on continuously. Perhaps better information on the energy used by the appliance, and how much it costs to run, would persuade householders to turn it off or replace with a lower power hi-fi.

■ Similarly, two households use more than 80 W for lights during the baseload period in summer. If they understood this, they might be willing to use compact fluorescents or LED lights in place of their existing (presumably incandescent) lights.

■ About 5% of computers are left on and use considerable electricity (at least 80W) in the hour of least power use. They do not appear to go to a low-power standby mode when not in use. Again, householders who override default low-power settings on their computers, and/or households owning older computer equipment, could be targetted to reduce baseload electrical demand.

■ Space and water heating are large contributors to baseload power use in winter – even though only a small proportion of the homes (7%) use electric space heating. If these households could be persuaded to use solar water heaters instead of immersion heaters, they could cut their baseload power use considerably in the summer.

Understanding more about standby energy use

Many appliances in the home are left on when they are not being used, at least some of the time. For items such as TVs there is a specific standby mode, which allows them to be re-activated quickly. In other cases, such as computers, they often have a sleep mode which they enter automatically after idling for a configurable period. EC Regulation 1275/2008 sets a limit of one watt for a range of appliances in standby mode. However, this only applies to items sold from 2010, whereas most of the appliances in this study are older than this. The EU Energy Labelling schemes for household appliances have been in force for much longer and include standby power in the calculations of energy ratings. Similarly, the US Energy Star certification scheme encourages energy saving in idle mode for computers, monitors, printers and other office equipment. However, Energy Star certification is less discriminating than the EU Energy Label because there is only one grade of pass.

The Departments wish to know which types of appliances consume most standby energy and whether existing policies are effective in reducing standby consumption for newer appliances.

Approach

The total amount of energy used by appliances in standby or idle mode is a product of how much power they use and the time spent in that mode. When householders switch them off, the standby power consumption is irrelevant. This survey revealed, for example, that TVs are turned off 70% of the time, but other appliances are often left on most if not all of the time.

The appliances of chief concern for standby power are audio-visual equipment and computer equipment, but kitchen appliances (such as cookers, microwave ovens, and washing machines) can also draw significant power. We investigated all three groups of appliances. We determined the standby power consumption of each relevant appliance (where possible) and the range between the worst 10% and the best 10% (the 10% to 90% range), as a measure of variability between appliances of the same type. We also compared the average over all with the average of newer appliances, bought in the past five years. (Age information was not always available, for example it was only known for 40% of TVs.)

The sample sizes for some appliance types was very low and these figures should be treated with caution. Appliances and age combinations with small samples are highlighted in red in the tables below.

Analysis

We developed an algorithm to determine standby power consumption by inspection of the profile of energy use, from the two-minute interval data (see Appendix). Overall we found that standby power accounts for an average for all 250 households of 23 W, continuously. This works out at a mean of 201 kWh/year, or 5.1% of total electricity.

Readers should note that the minimum reading from monitoring equipment is 0.01 Wh, so an appliance drawing 1W only gives a reading every six minutes. We configured the algorithm to register power as low as 0.025 W, which gives a reading only once in four hours. However, it is often impossible to distinguish a difference between off and very low standby power. This means we were unable to determine a reliable figure for many appliances – especially for TVs and some other AV equipment. The mean standby figures we report here could be biased, and higher than the real figures.

Audiovisual equipment

Appliance type	Mean standby power (W)	10%-90% range (W)	Mean for newer appliances (Sample Size) (W)	Pattern	Sample size (% standby identifiable)
Sky box	18.9	15.5 – 24.3	19.5 (22)	High+flat	25 (96%)
Set-top box	14.1	4.1 – 24.7	14.2 (132)	Variable	186 (84%)
Hi-Fi	6.8	0.5 – 14.3	8.4 (6)	Variable	23 (65%)
VCR	5.4	2.9 – 9.5	3.9 (9)	Reducing	33 (73%)
Home cinema sound	3.8	0.4 – 9.6	3.8 (5)	Variable	9 (56%)
Wii	3.3	0.9 – 10.2	3.0 (13)	Variable	46 (80%)
DVD	3.0	0.3 – 6.2	2.8 (57)	Variable	127 (70%)
PS3	2.5	0.3 – 4.3	3.1 (7)	Variable	18 (50%)
TV	1.4	0.0 – 5.0	1.0 (110)	Reducing	407 (42%)
CD player	0.9	0.1 – 1.9	0.3 (1)	Variable	4 (75%)
PS2	0.5	0.1 – 0.8	- (0)	-	9 (44%)

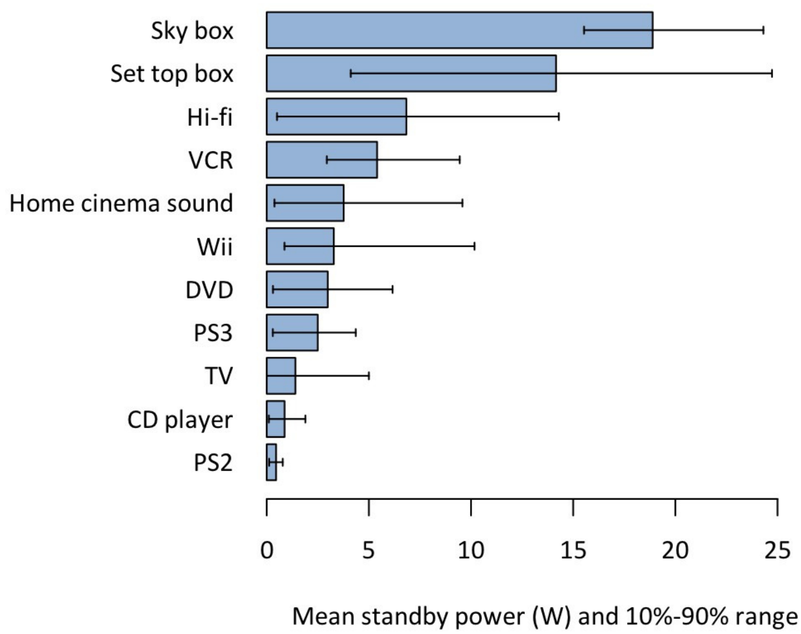
*Appliance and age combinations with small sample sizes are highlighted red. Readers should not put weight on findings from very small samples.

Many TVs now have digital decoders built in and do not need a separate set top box. However, in this survey more than half the TVs also had set top boxes (232 set top boxes for 407 TVs), and another 25 had a Sky box.

Sky boxes and other set-top boxes (many types, including Virgin media) use significantly more 'standby' power than other audiovisual appliances. However, strictly speaking set top boxes and Sky boxes do not have a standby mode, because they are always active to some degree. We have included them in our analysis because they contribute in large part to the overall 'standby' of an audio visual site. Also some boxes consume a great deal less in idle mode than others, suggesting there is scope for improvement.

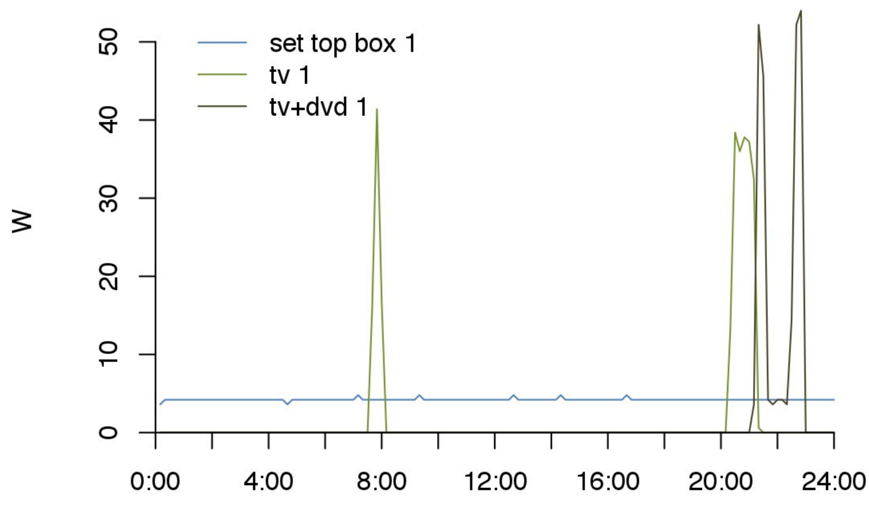
In March 2013 Sky announced a software update for some of their decoder products, introducing an option for a new eco-standby mode using only 0.5 W. This option is not on by default. In addition, the eco mode only activates overnight and if there are no recordings scheduled. (Wake up takes approximately 1 minute.) This is a positive move but the impact will be small unless householders are made aware of it and take the trouble to activate it.

TV standby power is generally lower than the set top boxes and shows some signs of falling over time, with newer devices using less power in standby mode on average.



TVs, DVDs, VCRs and other living room appliances are often plugged into the same socket, so there is little data for some types of individual appliances. It was also hard to interpret some of the games console data: some of the consoles in the survey seemed to have a standby mode but the numbers were not significant except for the Wii, and power use for this was variable.

The profile below shows AV appliances for one day in a household with a set top box and two TVs. It shows that although the TVs use considerably more power when they are on, in this household their total electricity consumption over the day is much less than the (always-on) set-top box, despite the set-top box drawing about a tenth of the power.



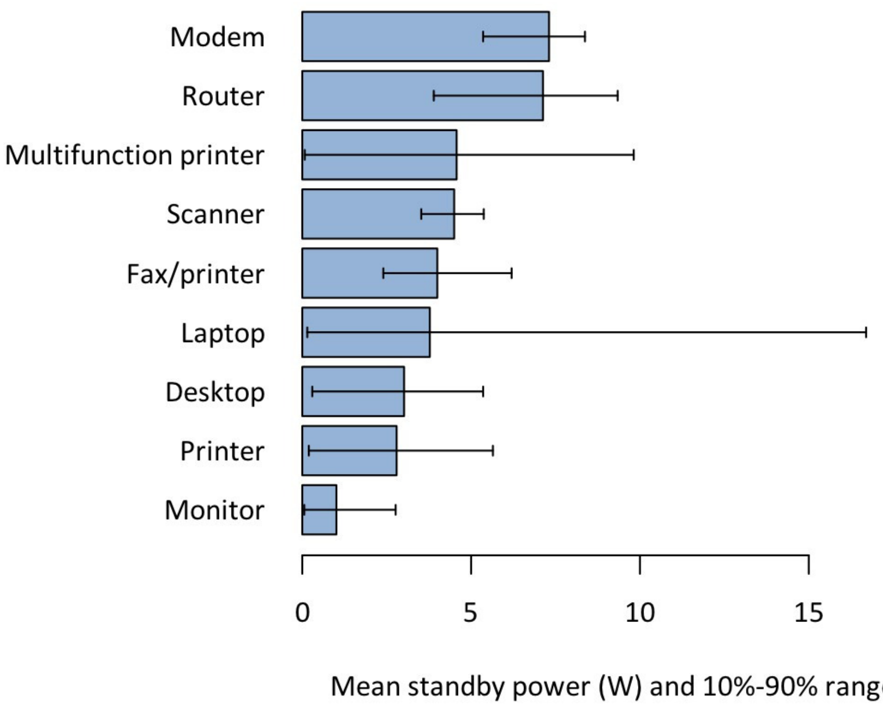
Although energy use of the set-top box in this household is far less than the TVs, its cumulative electricity use over the 24 hours is higher than both of the TVs put together – because it is always on.

ICT equipment

Modems and routers in the study use more energy than other pieces of information and communication technology equipment, see table and chart below. Monitors compare favourably to other ICT equipment, using much less power than other appliances in standby mode.

Appliance type	Mean standby power (W)	10%-90% range (W)	Mean for newer appliances (Sample Size) (W)	Trend	Sample size (% standby identifiable)
Modem	7.3	5.4 – 8.4	7.6 (10)	High	12 (100%)
Router	7.1	3.9 – 9.3	7.2 (118)	High	139 (98%)
Multifunction printer	4.6	0.1 – 9.8	2.4 (7)	Variable	14 (93%)
Scanner	4.5	3.4 – 5.4	4.7 (1)	High	3 (100%)
Fax/printer*	4.0	2.4– 6.2	5.0 (2)	High	5 (100%)
Laptop	3.8	0.2 – 16.7	3.9 (107)	Variable	174 (82%)
Desktop	3.1	0.3 – 5.4	2.7 (56)	Variable	104 (87%)
Printer	2.8	0.2 – 5.6	2.8 (65)	Variable	112 (84%)
Monitor	1.0	0.1 – 2.8	0.8 (52)	Low	103 (83%)

* Of the five fax/printers, two were inconsistent, and the worst apparently used over 70 W continuously for more than a week, which seems implausible for a printer.



Desktop computers often have a sleep mode, and they can be configured to switch to this state after being idle for an appropriate time. It is encouraging that sleep mode was detectable in 88% of desktop computers. However, some desktop computers use much less than others when 'sleeping'.

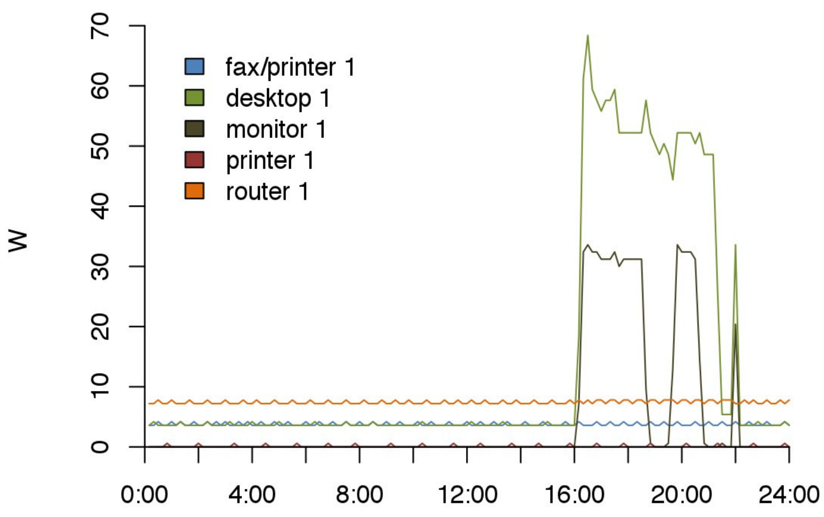
Laptops generally consume less energy than desktops, but they sometimes show higher idle power. This is because when they are plugged in they are often charging their battery, so this is not strictly speaking a 'standby' mode. Also, they have different power management functions from desktops and it is not always easy to identify a clearly defined standby mode mode. Most laptops consumed less than 3 W for significant periods, but 10% never consumed less than 16 W (probably because, since they were plugged in for less time, they were always charging batteries).

Nearly half of all monitors were left on for more than 20 hours a day, but standby mode was detected for 83% of monitors, and this typically uses little power. Some monitors never show a standby mode, presumably because they are not configured to activate it.

Printers were also often left on: nearly half were on for more than 20 hours a day. However, printers use more power than monitors when in standby mode, as much as a desktop, and multi-function printers use even more. Scanners also take significant power, however they are less common.

Routers and modems are run for long periods – often even when the desktop computer is switched off. For example, they may serve a Wi-Fi network. In this study the routers were on for an average of 21 hours/day. As with set top boxes, strictly speaking this is not a standby mode, but they are included in the analysis because they form a significant part of an idle computer site. They are not covered by the US Energy Star certification.

The chart below shows profiles for ICT appliances in one household for one day. All the equipment is on all day, and although it consumes much less power than the desktop computer when the computer is being used, the router (orange) is the largest component of the standby power consumption: a continuous 8 Watts.



The desktop computer (green) and monitor (dark grey) run simultaneously. Note, though, that the monitor switches to standby mode for half-an-hour after about three hours, while the computer continues using virtually the same amount of power. If the computer also switched to standby mode, there would be an electricity saving.

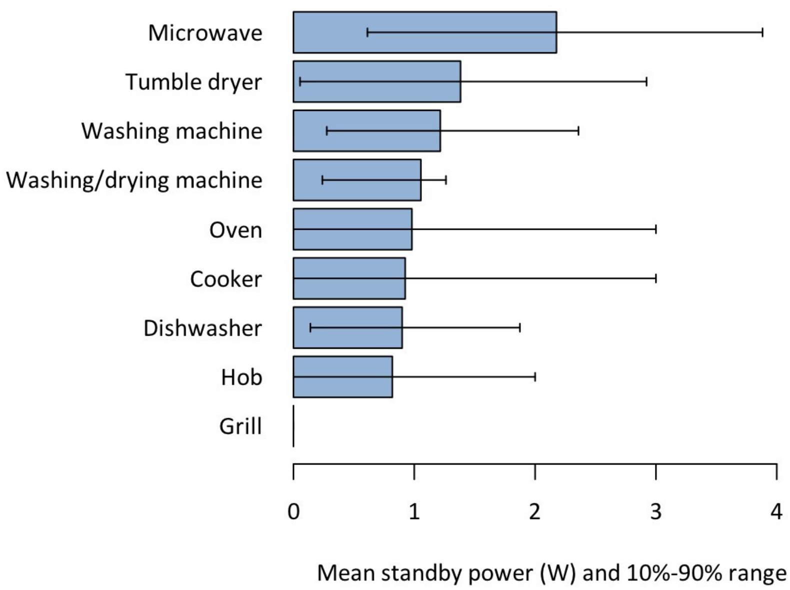
Kitchen equipment

Data from this study suggests that cookers, ovens and hobs are usually on all the time, so standby power is particularly important for them: it is good to see that it is only discernible in a quarter of cookers and a third of ovens. The maximum standby power seen for a cooker was 11W, but for new cookers standby electricity use was not detectable (see table below).

Wet appliances such as washing machines are often left on standby for long periods after a cycle has finished. In this survey the standby consumption was higher than expected from new appliances sold since EC Regulation 1275/2008 came into force, see table.

Appliance type	Mean standby power (W)	10%-90% range (W)	Mean for newer appliances (W), sample size in brackets	Pattern	Sample size (% standby identifiable)
Microwave	2.2	0.6 – 3.9	1.9 (74)	Variable	218 (66%)
Tumble dryer	1.4	0.0 – 2.9	1.2 (24)	-	112 (32%)
Washing machine	1.2	0.3 – 2.4	1.2 (64)	No change	206 (52%)
Washing/drying machine	1.0	0.2 – 1.3	0.6 (7)	Reducing	23 (65%)
Oven	1.0	0.0 – 3.0	0.2 (5)	Reducing	51 (100%)
Cooker	0.9	0.0 – 3.0	0.0 (8)	Reducing	135 (99%)
Dishwasher	0.9	0.1 – 1.9	0.9 (50)	Low	112 (81%)
Hob	0.8	0.0– 2.0	- (0)	-	11 (100%)
Grill	0.0	0.0 – 0.0	0.0 (2)	Low	5 (100%)

Although the sample sizes for new appliances are very small in all three cases, there is some evidence of falling standby power for washing-drying machines, ovens and cookers. Appliances in these three groups have lower mean power use in standby periods than older equivalents.



Standby power use in microwaves is remarkably high – perhaps because manufacturers have not focused on low power standby modes. There is no obvious reason why microwaves have mean standby power more than double the average for cookers, and the low-point in the range of power consumption shows that it is possible to reduce standby power in microwaves.

Recommendations

■ The standby power for high consuming appliances such as printers, scanners and computers is very variable. Householders might benefit from more information about their energy use, perhaps by adding them into the EU Energy labelling scheme which grades appliances from A+++ to G. At the moment they are covered by the Energy Star certification scheme but this only discriminates between pass/fail.

■ Routers and set-top boxes consume significant 'idle' power and are on for long periods, often all day, but they are not covered by any energy rating scheme. Adding them into a scheme would give householders more information about their energy use.

■ Householders could be given more information about options for reducing energy use from appliances in standby mode, such as timer switches or master/slave power strips which cut power to the 'slave' devices when they detect the 'master' (such as a computer or TV) is turned off.

■ Manufacturers could be encouraged to install timers on routers and set-top boxes so they draw no power, or very low power, in periods households define (e.g. at night or when householders are routinely out).

Compare 24/7 appliances against manufacturers' figures

There are a number of appliances which take power 24 hours a day, seven days a week, regardless of the behaviour of the household. These include door bells, smoke alarms and burglar alarms. The question is whether the power consumed by these appliances matches the manufacturers' figures and whether the appliance efficiencies can be improved.

Approach

Daily energy consumption was calculated for each appliance during the monitoring period, and this figure was used to estimate annual energy consumption. We assumed there was no seasonal variation in energy consumption of these appliances. Although there are 23 records in the appliances database about door bells and alarms, only 12 of these had electricity use data, and analysis of the electricity data from one appliance suggested that it was not an alarm so it was discarded from further analysis.

No model numbers or energy ratings were recorded during the initial survey so we could not compare directly with manufacturers' specifications. Instead we found manufacturers' energy consumption figures for similar products in each appliance group and compared them to the estimated annual energy use calculated from the measured data.

Analysis: Comparing manufacturers' energy use and actual energy use

We obtained manufacturers' figures for the energy use of smoke detectors and doorbells, but we were unable to find manufacturers' figures house alarms.

Doorbells

Average annual energy consumption for the two doorbells monitored in the study was 52 kWh (1.4% of annual electricity use in the monitored households). The two appliances varied by a factor of three in their energy use, but this may be related to differences in product functions or energy efficiency.

Summary statistics for doorbells

Appliance number	Number of days monitored	Average power (W)	Energy consumption (kWh)			
			Daily			Annual
			Mean	Min	Max	
1	36	9.0	0.22	0.22	0.22	78.9
2	28	3.0	0.07	0.07	0.07	26.2
Average	**32**	**6.0**	**0.14**	**0.14**	**0.14**	**52.5**

Just two mains-powered doorbells is too small a sample to draw anything more than indicative findings. However, this does show that energy use by doorbells can vary by at least a factor of three – from 26 to 79 kWh/year.

A doorbell manufacturer estimated energy use of just 8.8 kWh per year[11], which suggests that either the doorbells monitored have very high energy use, or that the manufacturer has a very conservative estimate of actual energy use. However, this may be due differences in the functions and specification of the products.

Traditionally, doorbells are not mains powered, but a number of mains-powered doorbells are now on the market. It is possible that more mains powered doorbells could increase energy use if more dwellings start to use mains powered devices.

Burglar or fire alarms

Average annual energy consumption for the nine monitored alarms was 72 kWh – approximately 2% of annual electricity use in the sample households. (We cannot be certain whether they are burglar or fire alarms, and there are probably some of each.) There is a wide range in annual energy use for alarms, from 0.8 kWh to 169 kWh. This shows that some house alarms account for up to 5% of typical household electricity consumption – much more than expected. The alarms with high energy use may have extra functions (e.g. many motion detectors and other sensors), however, as the functions of appliances were not captured in the initial survey, we cannot assess their impact on energy use.

The range in energy use calculated for the house alarms, coupled with the difficulty in sourcing annual energy use data from manufacturers, suggests that better information for consumers would be beneficial. If house alarms have similar functions but differ considerably in their energy use, energy labels could encourage consumers to buy more efficient models.

Summary statistics for alarms

Appliance number	Number of days monitored	Average power (W)	Energy consumption (kWh)			
			Daily			Annual
			Mean	Min	Max	
1	27	19.3	0.46	0.45	0.47	168.7
2	38	18.0	0.43	0.43	0.44	157.8
3	28	9.6	0.23	0.22	0.24	84.2
4	27	8.9	0.21	0.21	0.22	78.3
5	27	6.0	0.14	0.14	0.14	52.6
6	26	6.0	0.14	0.14	0.14	52.6
7	25	4.8	0.11	0.11	0.12	41.9
8	28	1.4	0.03	0.02	0.04	11.9
9	28	0.1	0.00	0.00	0.01	0.8
Average	**28.2**	**8.2**	**0.19**	**0.19**	**0.20**	**72.1**[12]

[11] Personal communication from http://www.lloytronuk.co.uk/llyzc/index.php?main_page=product_info&cPath=26_57&products_id=4957&zenid=nfnrisju5d0ltskncgp3b6n8m3

[12] The initial analysis of the Electricity Survey reported a lower value because one of the appliances was wrongly identified as an alarm.

Two of the households have alarms with dramatically higher energy use than the others – more than double the mean (72 kWh/year). Conversely, two households have exceptionally low energy use, and one uses hardly any power for the alarm (just 0.8 kWh/year – possibly because it is switched off most of the time).

All nine households have very similar minimum and maximum daily energy use. This shows that house alarms tend to draw a consistent current and how they are used (i.e. how often they are set) does not impact significantly on energy use.

Smoke detectors

Only one smoke detector was monitored so the figures reported should be treated with caution. Energy use for this product is extremely low and based on this case, increased uptake of mains powered smoke detectors may not have a significant impact on energy use.

Annual energy use figures from the manufacturers of three smoke detectors ranged between 7 kWh, 7 kWh and 96 kWh[13]. These figures are significantly higher than the smoke detector studied here (ten to 140 times more). As only one smoke detector was monitored, further study of mains powered smoke detectors is required to compare actual and specified energy use.

Summary statistics for smoke detectors

Appliance number	Number of days monitored	Average power (W)	Energy consumption (kWh)			
			Daily			Annual
			Mean	Min	Max	
1	26	0.08	0.002	0.000	0.004	0.68

Overall, based on these small samples, it appears that these 24/7 appliances consume only a very small proportion of household electricity use. In total, they account for an average of less than 4% of annual electricity even among the small proportion of homes with burglar alarms. However, there are some burglar alarms that use considerably more power than others, and it would be worthwhile exploring why, and how common these high-power alarms are.

Recommendations

- Consider introducing energy labels for house alarms to encourage more efficient alarms.
- Investigate why some mains burglar alarms use so much more electricity than others.
- Explore why some mains powered doorbells use so much more electricity than others.
- Collect more data on smoke detectors to compare actual and specified energy use.
- Future appliance studies should collect data on appliance functions as well as energy use.

[13] Personal communication from http://www.safelincs.co.uk/kidde-firex-mains-powered-alarms-with-alkaline-battery-backup/

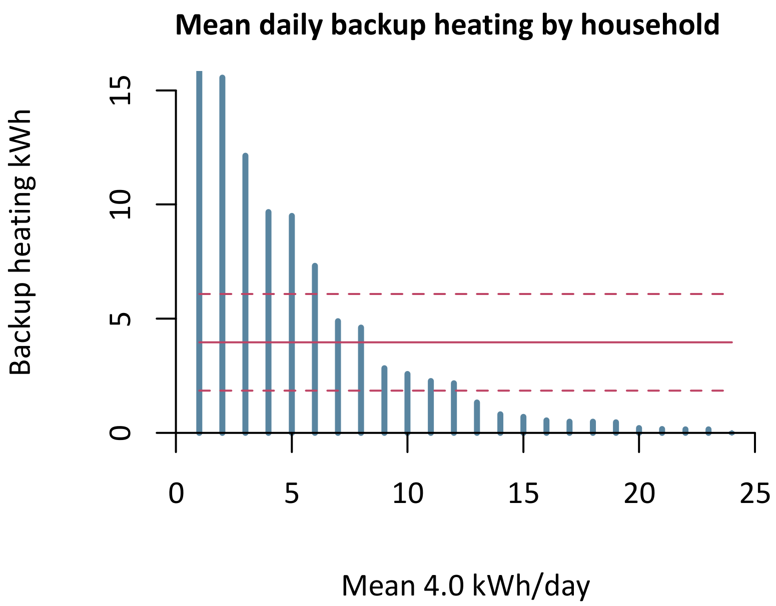
Savings from avoiding back-up electric heating

Space heating accounts for a significant proportion of electricity use even when this is a backup to the main system. In this survey, households using electricity in addition to a gas or oil main heating system used an average of 590 kWh/year for this. (For comparison, households using electricity for their primary heating used 4,860 kWh/year on average.) Households using electric heating as a backup to their main heating system may be able to use their main heating instead, or to shift this demand away from peak periods by heating their home at other times. The Departments wish to determine how much electricity use could be saved in this way.

Approach

We selected the households in the dataset that used electricity for backup heating and were monitored during the period from the 1st November to March 31st – the core heating period. There were only 24 such homes (only five monitored for the whole period) and they varied greatly in heating use. We explored this variation using graphs of the daily electric heating profile and the average daily heating total for each house.

There is a wide variation in energy use for heating for the 24 homes with backup (secondary) heating.



Of the 24 households using back-up electric heating, seven account for more than three quarters of electricity use for heating. The mean is 4.0 kWh/day. The 95% confidence interval (between the dashed lines) is 1.8 to 6.1 kWh/day.

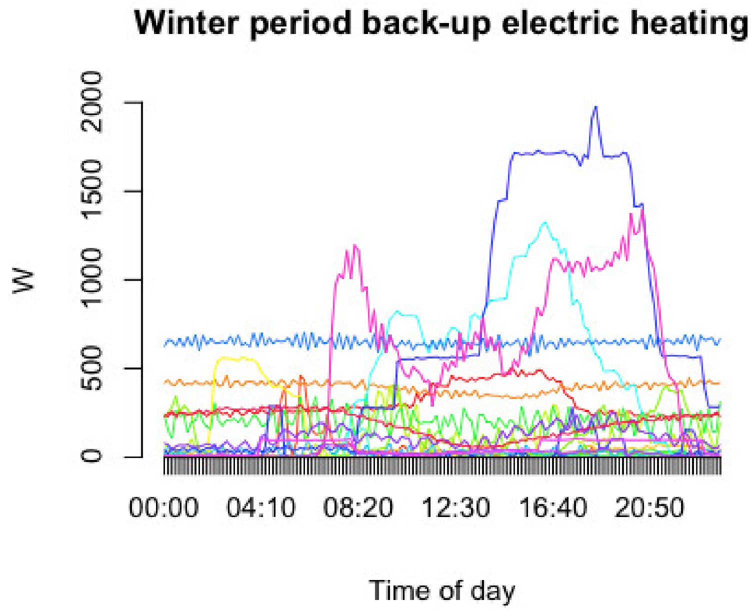
Eleven of the households used less than 1 kWh/day for backup heating, but six households used more than 5 kWh/day. Considering the thirteen using more than 1 kWh/day, we found they were less likely to live in a flat or a terraced house. Also they were smaller in terms of numbers of occupants and less likely to have children. This is a small sample, and should be treated with caution, but the details are shown in the table below.

	Households using backup heating	All households in the survey
Average number of occupants	1.8	2.4
Proportion with children	8% (1 of 13)	31%
Proportion in flat or mid-terrace	8% (1 of 13)	24%

Perhaps this is because smaller households are less likely to need to heat the whole dwelling even when they are at home. Electric heating is easier to target in particular areas than central heating.

There was also a small difference in house size (those using backup heating were larger) and in terms of SAP rating (those using backup heating had a worse rating). However these differences were not statistically significant.

The daily use profiles show that many households use their backup heating continuously through the day and night. However, there were a few that had fluctuating energy use for backup heating, which consumed more than 1kW during the peak period from 6-7pm.



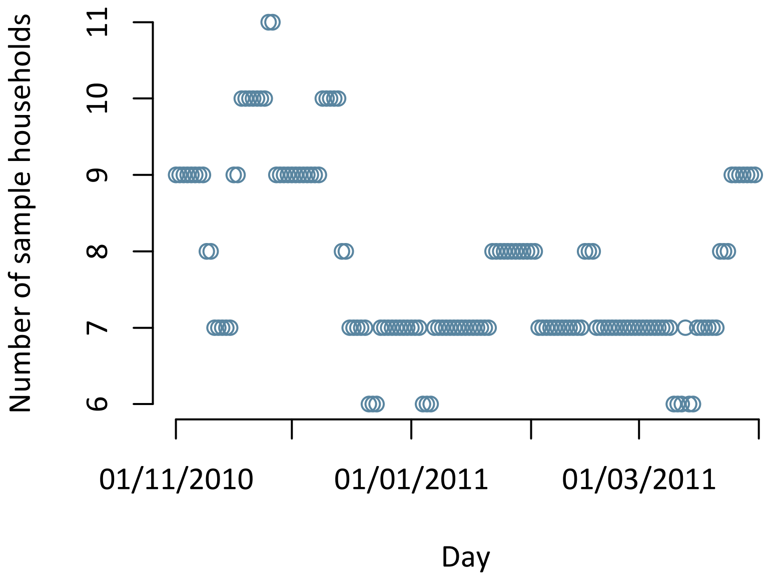
The average daily demand profiles for backup heating in all 24 homes show that there are many different patterns of energy use for secondary heating.

Considering only heating electricity in the peak period, just five of the 24 households were responsible for three quarters of the electricity use. (Just 4% of the total number of households monitored during that period.)

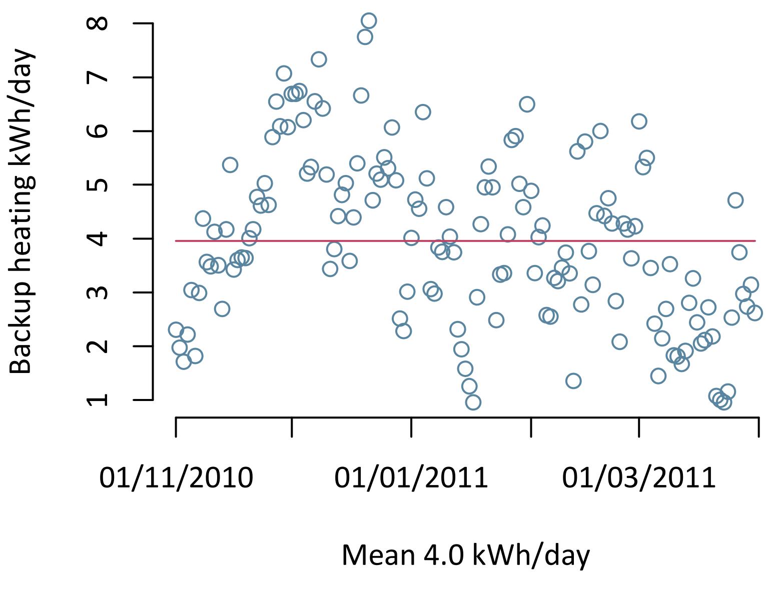
Analysis: average by day

Of the 24 households, five were monitored all year and the rest for only one month. The actual number of households monitored on each day varied between six and 11, see plot below. Averaging for each day shows a significant variation even from one day to the next.

Number of households monitored each day during the winter period



Mean backup heating by day



Heating use was greatest in December, which was the coldest month that winter.

Analysis: averaging over all monitored households

We compared the electricity used for backup heating with total electricity use during the November – March period, as shown in the table below. This shows consumption averaged over the 24 households with additional backup heating. (Defined here as electric heating when the main heating fuel is gas or oil.) Backup heating accounted for 20% of electricity consumption for these homes during the period.

Electricity for backup heating	Daily heating consumption (kWh)	Percentage of total daily electricity	Average heating power 6-7pm (W)	Average maximum power 6-7pm (W)
All days	4.0	20%	180	610
Work days	4.0	22%	180	570
Holidays	3.9	19%	180	610
Coldest day	7.8	27%	480	570

For the peak period, we investigated the average power demand per household and also the per-household maximum required during the peak time. We calculated the average heating demand across *all* the households in 10 minute intervals, and determined the maximum.

The table suggests that total electricity use for backup heating differed little between work days and holidays, though we know that there are considerable differences for other aspects of electricity use. Nearly twice as much heating was used on the coldest day as on an average day.

There is considerable uncertainty in these figures, from a number of sources:

- The number of households in the sample is small and there is a great deal of variation between them: the 95% confidence interval is approximately +/- 50% of the mean.
- There is variation from day to day. However, because there are far more sample points for days than for households the uncertainty in the mean from this source is small.
- There were also households in the survey who apparently had heaters that were not monitored. This could be because they rarely used them, but it is possible that some households used backup heating without it being monitored, so the electricity use for backup heating could be higher than the estimates given here.

Ignoring the last point, but taking into account the variation between households, the daily backup heating consumption through the winter for these households was between 3.7 and 4.2 kWh/day. (This is the 95% confidence interval for the mean of 4.0 kWh/day given in the table above.) During the peak hour was 160 to 200 W (the equivalent 95% confidence interval for average peak heating of 180 W in the table).

There are approximately 4.2 million homes using electric backup heating in England (19%, based on CAR's analysis of the English Housing Survey 2010[14]). If our survey is representative then, by

[14] Department of Communities and Local Government (2013) *English Housing Survey* Available at: https://www.gov.uk/government/organisations/department-for-communities-and-local-government/series/english-housing-survey

avoiding secondary heating in peak periods, they could save between 680 MW and 820 MW during the peak hour 6-7pm on average, and up to 2.0 GW in cold periods.

Recommendations

■ Persuading the 4.2 million English households with secondary electric heating to use another form of heating, or abstain from heating, from 6-7pm could save 680-820 MW during the peak period. In very cold periods the saving could rise to 2 GW.

■ Most households with backup electric heating use it continuously day and night. These households could be encouraged to invest in storage heaters to shift their use outside the peak period.

■ A few households use significant peak time heating. It may be possible to identify these by their electricity use pattern and target them specifically.

■ Backup heating seems to be used by small households to avoid heating the whole house unnecessarily. Better central heating controls, including room thermostats and thermostatic radiator valves, could potentially reduce this.

Appendix – Standby consumption algorithm

The algorithm we used for determining the standby power from an appliance profile is as follows. It uses a number of parameters with values tuned for different types of appliance.

- Identify stretches of energy use at a consistent power level (+/- 20% or *N* units whichever is greater, where *N* varies depending on the appliance). Stretches of single readings at intervals of up to 4 hours are allowed, in order to detect power draw down to 0.025W.
- Record the maximum power seen, and the total time the appliance is on (power draw greater than zero).
- Discard stretches shorter than *MIN* minutes, 20 to 120 minutes depending on the appliance.
- Sort the remainder by mean power and search for a sequence of stretches of similar power which corresponds to *MINPERCENT* of the on time, 15-50% depending on the type of appliance (because devices which are likely to be switched off will display standby mode for less time).
- Discard unreasonably high standby more than *MAXSTANDBY* or *MAXFRACTION* of the maximum power seen, unless the standby power draw corresponds to more than two thirds of the total monitoring period for the appliance.

This chart shows power use profile for a TV for one day. During the standby period, there is approximately one reading per hour. The average power use for standby in this case is 0.1W.