Energy use and home temperatures in English housing: results from the energy follow-up survey

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Abstract

The Energy Follow-Up Survey (EFUS) is a large survey which was undertaken in England to collect new data on domestic energy use. The survey provided crucial new information which is being used to update the current assumptions about how energy is used in the home, and to inform energy efficiency policy.

The EFUS consisted of a follow-up interview survey of approximately 2,616 households first visited as part of the 2010/2011 English Housing Survey (EHS). Additionally, subsamples of these households were selected to have temperature loggers (823 households) and electricity consumption monitors (79 households) installed. Approximately 50 % of the EFUS sample allowed the compilation of gas and electricity consumption data from meter readings (1,345 households).

The survey provides valuable new quantitative data on heating patterns, hours of heating, secondary heating systems and other aspects of energy use in the home.

This paper outlines the main results from this survey, and summarises the implications for energy efficiency modelling and policy.

Introduction

This paper describes the key findings from a large survey of domestic energy use undertaken by BRE, on behalf of the UK Department of Energy and Climate (DECC). This survey was called the 2011 Energy Follow-Up Survey (EFUS) and was designed to collect new data on domestic energy use, in order to update the current modelling assumptions about how energy is used in the home, and to inform energy efficiency policy.

This paper summarises the results of this work, highlighting those of principal relevance, and discusses the implications of the findings. Full details of the survey, and further results can be found in the 11 reports (Hulme et al., 2013) found here http://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011. The survey had several components:

1. A follow-up interview survey of approximately 2,600 households first visited as part of the 2010/2011 English Housing Survey (EHS[1]) (see e.g. DCLG, 2011).
2. Sub-samples of these households were then selected for
   a. temperature monitoring
   b. whole-house electricity consumption
   c. compilation of gas and electricity consumption data from meter readings.

The principal objectives of the analysis to date are to inform energy efficiency policy, and provide data to update the assumptions in the key energy modelling methodologies in use in the UK: the BRE Domestic Energy Model (BREDEM) (Henderson, J & Hart, J 2015) and its derivative the UK Standard Assessment Procedure (SAP) (DCLG, 2013). BREDEM and SAP are widely used to predict the annual energy consumption in dwellings,

1. The English Housing survey is an annual survey undertaken by the UK Department of Communities and Local Government (DCLG). It collects information about people's housing circumstances and the condition and energy efficiency of housing in England. It has 2 component surveys: 1) a household interview and 2) a physical inspection of a sub sample of the properties.

and housing-related CO_2 emissions. The EFUS provides essential new data on the following aspects of energy use.

- How many hours are households heating their homes for on weekdays, and at weekends during the winter? How do these heating hours compare to those typically used as inputs into modelling?
- How many rooms are unheated in winter? What rooms are unheated?
- How are secondary heating systems being used?
- What average 24hr temperatures are found in homes? How do these compare to those typically calculated by the models?
- What temperatures are being achieved during periods of heating? How do these compare to those typically used as inputs into the models?
- How are conservatories being used? Are they being heated?
- How much lighting is found in homes, and how is it being used?
- What electrical appliances are found in homes, and how are they being used?

Background to the survey

The requirement for the 2011 EFUS was first highlighted by BRE in 2007 and 2008 as part of the ongoing development programme for the BREHOMES energy model (Shorrock, 1997), Energy Use In Homes analysis for Government (BRE, 2008) and Domestic Energy Factfile publications (Utley and Shorrock, 2008). At this point it was identified that a detailed survey was required to reflect changing patterns in home energy use and to update the evidence base underpinning modelling and policy. Developments in technology would also allow for the collection of detailed monitored data on home temperatures and electricity consumption for the first time.

A previous survey of this type was undertaken in 1998 (the 1998 EFUS) with results informing policies such as fuel poverty and SAP (see for example DTI/Defra 2001 and BRE, 2005) and it was considered that this evidence base needed to be updated. In particular, data on internal temperatures was particularly outdated with the most recent comprehensive survey over 30 years old (Hunt and Gidman, 1982).

The need for the EFUS was confirmed by a Public Accounts Committee report in 2009 (Public Accounts Committee, 2009) stating that UK Government departments were not gathering enough data from real homes to evaluate the impact of programmes on consumer behaviour and household energy efficiency. It recommended that the (newly formed) Department of Energy and Climate Change and the Department for Communities and Local Government should set out and implement strategies for evaluating and learning from the environmental and financial impact of their programmes, distinguishing the programme impacts from those of other factors, such as energy prices and household growth. The strategies should address how energy-use data will be obtained to:

- understand, monitor and respond to changing patterns of energy use in households, including appliance use and wastage;
- understand the impact in real homes of installing energy efficiency measures, and understand and improve the actual energy performance of new homes built to standards set out in the current and future Building Regulations.

Against this background, the EFUS was specified and developed.

The Energy Follow-Up Survey is so called because it revisits dwellings and households first visited as part of the 2010 English Housing Survey (EHS) (DCLG, 2011). By revisiting EHS properties, the data from the earlier survey (for example on the household type, or physical characteristics of the dwelling) can be combined with the data from the EFUS. This provides a much richer data source for analysis.

The EFUS consisted of an interview survey and several subsets

1. Interview Survey (2,616 homes): The EFUS 2011 interview survey was undertaken by interviewers from the market research organisation GfK NOP between December 2010 and April 2011. A total of 2,616 interviews were completed, drawn from a sample of addresses provided from the first three quarters of the 2010/11 English Housing Survey (EHS). These data were then weighted to account for survey non-response and to allow estimates at the national level to be produced.
2. Temperature monitoring survey (a sub-sample of 823 homes): During the interview survey, householders were invited to take part in a temperature monitoring study. This required the placement of up to three temperature monitors in three rooms of the home, which would record room temperatures every twenty minutes for around one year.
3. Meter readings (a sub-sample of 1,345 homes): To provide information on how much electricity and gas was actually being used, meter readings were also taken as part of the EFUS, and matched with original readings taken as part of the EHS. These readings provide data on annual gas and electricity consumption.
4. Electricity profiling (a sub-sample of 79 homes): Finally, a small number of properties had electricity profiling equipment installed to examine patterns of lighting, appliance and electrical cooking use. This equipment collected data at rapid intervals on how much electricity was being used in the home.

The EFUS data have been scaled up to represent the national population (and to correct for non-response) using weighting factors. The results presented in this report are therefore representative of the English housing stock, with a population of 21.9 million households.

Methodology

The EFUS interviews were carried out by GfK NOP between December 2010 and April 2011 with a total of 2,616 interviews being completed.

BRE supplied 3,288 addresses drawn from the first two quarters of the EHS (April to November 2010) to GfK. This represented all cases from these quarters where the respondent had previously agreed to a further interview (84 % of cases). The EHS 2010 is a simple random sample of addresses from across England, with each quarter being a random quarter of the full sample (i.e. there is no clustering by survey period). The quarters passed to the EFUS survey team were chosen as they were available in time to conduct the survey, and were as close as possible to the start of the EFUS interview to minimise the chance of changes to the dwelling or household.

When this sample was considered to be exhausted, BRE supplied an additional 400 cases from the third quarter of the EHS. As the number of interviews had been capped at approximately 2,600, this second sample was not fully utilised before fieldwork was complete. In all 135 interviewers were used on the project, and they were allocated cases based on proximity to where they lived. Interviewers were supplied with names, addresses and telephone numbers for the households in their assigned sample.

To enable the EFUS data to be scaled up to represent the national population and to correct for non-response, weighting factors have been calculated to align with national totals for tenure, Government Office Region and dwelling type.

During the survey, householders were invited to take part in a temperature monitoring study. The temperatures collected can be used to produce a temperature profile for the household and investigate overheating issues and provide accurate information for updating assumptions within SAP and BREDEM. This provides additional information in support of the reported data.

The temperature loggers used were modified TinyTag Transit 2 data loggers, produced by Gemini Data loggers. Each logger was marked for use in specific rooms. The loggers store temperature data internally, with a memory capacity of 32,000 readings, an accuracy of +/-0.2 °C and a resolution of 0.01 °C. The temperature range of the loggers is from -70 °C to + 40 °C. To maximise the number of readings possible in a period of a year, each logger was programmed to record data every 20 minutes until reaching capacity. All loggers were new and calibrated at manufacture, but BRE performed some additional tests on a sample of loggers before the survey began. This included testing of battery life, recording frequency and verification that the loggers had been set up with the correct starting dates and recording frequencies. All of the tested loggers operated as expected.

Of the 2,616 households interviewed, around 943 households received three temperature loggers to be placed in the living room, hallway and bedroom. A small number of households without all three rooms (e.g. bedsits) received only two loggers.

Interviewers were given instructions on proper placement of the loggers during the interview briefings, this was essentially emphasising the need for the loggers to be placed on an internal wall, away from heat sources and out of direct sunlight and at a height that could be reached by the occupant for removal of the logger (but out of the reach of small children). Because of practical issues placing loggers into the diverse circumstances found in homes, guidance on logger placement could not be overly prescriptive. Occasionally, the householder put the loggers up with instruction from the interviewer, for example in a private room like a bedroom which they were unwilling to allow access to.

A total of 118 sets of loggers failed to be returned by householders and two sets were returned with all three loggers faulty. Thus the total number of sets of loggers adequate for analysis is 823.

In a total of 79 homes, short time-step data on electricity consumption was obtained. This was collected using the Micro Amper digital voltage data logger. This is a stand-alone battery powered single channel data logger with a 0–1.5 V input signal range and a accuracy of 0.15 %. It was combined with a 0 to 50 Amp split-core current clamp (current transformer) to record whole house electricity consumption. The current clamp was placed around the red ‘live’ cable between the household electricity meter and the consumer unit and a thin data cable connected it to the monitor.

The current clamps used were ACT050-10-S (ACT 0 to 50 A). The clamp has an output signal 0 to 10 V AC, but the cabling was modified to include a resistor to ensure that the output of the current clamp did not overload the monitor. Configured and set-up with the 100 kΩ series resistor, the current measurement range is 0 to 82 Amps representing approximately 0 to 20 kW. Spot readings of consumption were recorded every 10 seconds with the data stored on a 2 GB Secure Digital Flash Memory Card. Each daily file comprises 8,640 data readings for each full day.

The final data collected related to actual consumption. During the EHS 2010/11 physical survey, EHS surveyors read the gas and electricity meters where possible. This reading forms the first (initial reading) of the EFUS meter reading dataset and were taken during the period April to September 2010.

To obtain the second (final) reading, a number of approaches were taken. At the end of the EFUS interview the householders were asked if they would consent to a further reading taken by a professional meter reader and around two thirds of the sample agreed to this. Follow up readings were attempted for all households by G4S, a meter reading company, in two batches: the first between February and March 2012 and the second in November 2012. A high number of readings were unobtainable in the first batch of data collection, necessitating a two stage process.

Alongside this second reading attempt by G4S, a number of further approaches were made to households to increase the size of this dataset:

1. Self-read cards were sent to remaining households.
2. During the EFUS interview, households were asked if they would consent to DECC obtaining information of electricity and gas consumption directly from their energy supplier, with over 60 % of all EFUS cases agreeing. Two major energy suppliers supplied initial and final meter reading data. Other suppliers were unable to assist with this task.
3. A small number of meters were read by BRE staff (with the householder’s permission) while installing and removing other monitoring equipment

In order to obtain a final set of cases for reporting, a validation process was applied to the meter readings from all sources. This process was assisted by comparison with the Meter Point data (a national data set of consumption) provided to the survey team by DECC for comparison purposes. Cases with a missing first or second reading were removed and the remaining data were inspected to decide on the validity of their consumption data, including day and night rates of electricity where applicable. Cases were dropped where the consumption was implausibly high or produced a negative figure, although in a number of cases the data could be consolidated and retained where there was clear evidence for the source of the discrepancy, e.g. a negative value resulting from a meter passing through 9,999 during the consumption period. Implausibly high consumptions were identified by examination of the data close to and above 70,000 kWh for gas and 30,000 kWh for total electricity (by inspecting plots of the data, these extreme values became apparent above these points). Values at the top end of this range were then checked, looking for possible errors in the actual meter readings along with comparisons against the meter point estimates and dwelling and household size. Similar checks were done for apparently valid consumptions close to 0. These checks lead to around 40 cases (approx. 3 %) being dropped. Following this validation process a complete set of initial and final electricity meter readings was obtained for 1,345 cases (51 % of total EFUS sample). Of these, 1,197 cases had a mains gas supply and produced valid gas consumption values (89 % of the meter reading sample, and 45 % of the total EFUS sample).

Summary of key survey findings

The EFUS has provided a wealth of new information about how energy is being used in English homes. Presented below are summaries of the key findings for modelling and policy in a number of key areas.

MEAN HOUSEHOLD TEMPERATURES

Average internal temperatures (i.e. the average temperatures in a dwelling over a 24 hr period) are of importance when quantifying energy consumption within dwellings. Average internal temperatures are key quantities in calculations of the energy requirement of homes, and it is valuable to compare the averages calculated by the models in use in the UK to the average temperatures observed by the EFUS.

Mean household temperatures have been produced from the EFUS using data collected during February 2011 to January 2012 inclusive. These give a dataset of monthly mean temperatures in the three rooms monitored (living room, main bedroom and hallway). Data from individual rooms have also been combined to produce proxies for the BREDEM (Henderson, J & Hart, J 2015) zone 1 and zone 2 (BREDEM zone 1, the living room, is generally considered to be heated to a higher temperature than BREDEM zone 2 which is the rest of the heated space) and the whole dwelling.

The mean monthly room temperatures recorded are shown in Figure 1. During the heating season (October to April) these are 19.3 °C for the living room, 18.8 °C for the hallway and 18.9 °C for the bedroom, from which heating season mean temperatures of 18.8 °C for zone 2 and 19.0 °C for the dwelling have been derived. These temperatures are significantly higher than those recorded in a previous national survey of home temperatures from 1978 (Hunt & Gidman, 1982).

The differences between the zone 1 (living room) and zone 2 temperatures are less than those typically calculated through SAP (the UK's energy rating system). The EFUS suggests differences of approximately 0.6 °C, whereas the difference calculated for a typical semi-detached house in SAP is approximately 1.3 °C in the heating season. This provides some evidence that the SAP model in use in the UK may need to be recalibrated, if it is to match actual temperature differences between different zones in the home.

There are no statistically significant differences seen between weekday and weekend monthly mean temperatures in the living room, bedroom, zone 2 or the dwelling as a whole. The difference between weekday/weekend mean temperatures currently calculated in SAP is not observed in the monitored data. This supports the results of analysis of main heating patterns (see section below) in which householders reported no change in the number of hours that their heating was on between weekdays and weekends.

The variation in average heating season temperatures for different dwelling and household characteristics has also been investigated. Dwellings that are fully double glazed, those with someone in during the day during a weekday, and those in which the occupants are not under-occupying show both living room and zone 2 mean heating season temperatures that are significantly *higher* than their alternative category.

Some groups of dwellings have significant differences in the mean heating season temperatures in one or other of the zones but not both. For example, flats are seen to have *higher* living room mean heating season temperatures than detached or semi-detached dwellings but no difference is seen between dwelling types for zone 2 mean heating season temperatures.

METERED ENERGY CONSUMPTION

Annual consumptions have been produced using gas and electricity meter readings collected as part of the EHS and EFUS.

The median annual mains gas consumption determined using the EFUS meter reading data is around 14,000 kWh, with a median value of around 3,700 kWh for electricity[2].

Significant differences are found in the median consumption levels for different categories of dwelling and household types. Gas use appears closely associated with dwelling floor area and type as well as household size, with detached houses having a median gas consumption more than twice that found in flats. Electricity use appears to be more strongly affected by the number of people in the household, with the data showing a median consumption of around 2,400 kWh for single people, compared with a figure of around 6,000 kWh where there are at least 5 people in the household.

Households living in dwellings built between 1919 and 1944 show a significantly higher median gas consumption than those from other periods with a median of 17,100 kWh per year. These households also have a higher median electricity consumption than households living in dwellings built between 1965 and 1980.

There is no statistically significant difference in the median gas consumption of households living in rural or urban areas. However, median electricity consumption is significantly higher in households in rural areas compared to urban areas, related to the large number of dwellings without a gas supply in these areas.

There is some evidence of lower median gas consumption with increasing levels of different insulation measures, although

2. The data used to produce these estimates have been adjusted using degree days to represent the core period of meter reading data collection (the period November 2010 to November 2011). They have not, however, been weather corrected to a standardised temperature profile. It should be noted that the core period includes the very cold period in December 2010, which acts to raise consumption of the EFUS data when compared to other estimates, such as Energy Consumption in the UK (DECC, 2014a) which do not include this month.

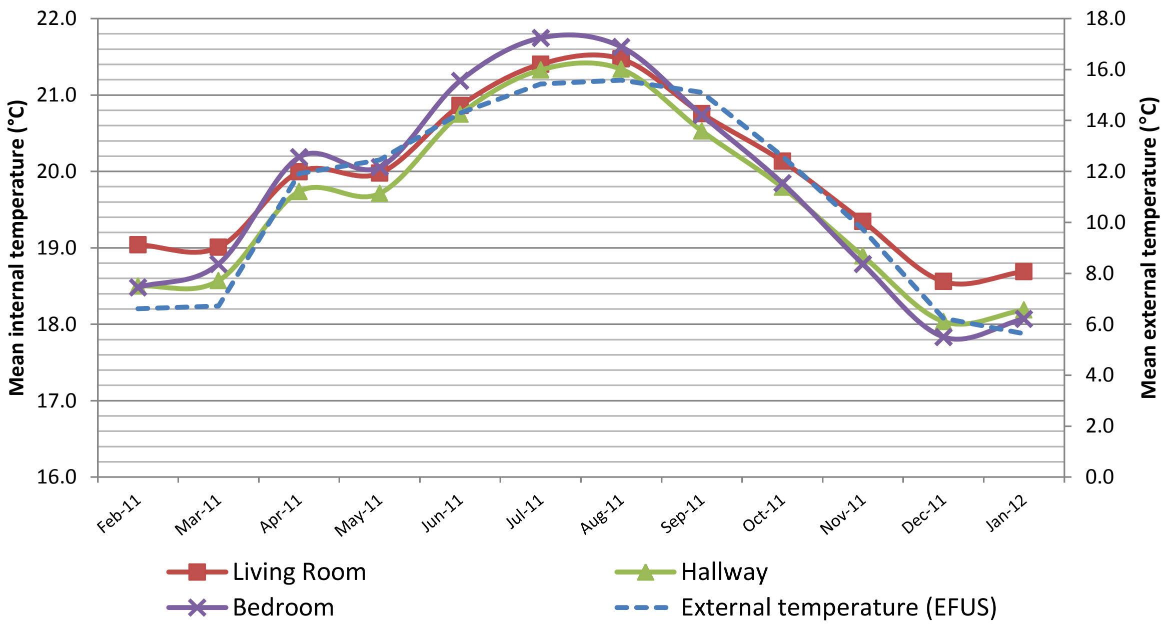

Figure 1. Monthly mean room temperatures (left y-axis) and external temperature (right y-axis) recorded during EFUS 2011. Base: All households in EFUS 2011 temperature sub-sample (n=823).

the only statistically significant difference can be seen between those households living in 'well insulated' dwellings who have both lower gas and electricity consumption than households living in 'poorly insulated' dwellings. Owner occupiers tend to consume more gas than households in all other tenures and more electricity than households in the private rented or local authority tenures. For both fuels, households in the private rented, local authority and Registered Social Landlord (Housing Association) tenures show no significant differences in their median annual consumption rates.

MAIN HEATING SYSTEMS

Domestic energy use is dominated by energy used by the main heating systems in homes. (Shorrock & Utley, 2009). Understanding how these systems are used is of great importance to energy efficiency policy and modelling. The analysis of these data examines the heating patterns of households, and the temperatures achieved when the main heating system is on (as opposed to the 24 hr average temperatures described under the mean household temperatures section above), providing new data in this area.

The EFUS collected detailed information on the type and use of main heating systems. Data were obtained on the months that heating took place, and the times that heating was used on different days of the week. Table 1 provides a summary of the use patterns of the main heating system reported by households.

Households that are in during the day on weekdays report heating their homes for a longer period of time (median 9.4 hours per day) than households that are not in during the day on weekdays (median 8 hours per day). This difference is lower than the typically assumed standards in many energy modelling applications which attempt to account for household occupancy**.**

Households report that they heat their homes regularly for a period of 6 to 7 months (the EFUS temperature data suggests a similar length). This is 1–2 months shorter than currently assumed in SAP (DCLG, 2013).

Mean achieved temperatures (i.e. those temperatures achieved at the end of the longest period of heating within the dwelling) in the living room (zone 1) fall within the range of 19.7–20.4, with the mean being 20.2 °C, and the mean temperature achieved for the (hallway and bedroom) zone 2 within the range of 18.7–19.4, with the mean being 19.1 °C. The zone 1 temperature used in SAP is approximately 0.8 °C higher than the mean living room achieved temperature derived from the EFUS temperature data. Higher achieved temperatures are observed in the living room in the homes of older households (approximately 22 °C in those households with a Household Reference Person aged over 75, compared to 20–21 °C for those younger than 75) and in dwellings with insulation present (20–21 °C for those with at least one insulation measure, compared to 19 °C for those with none).

Around 65 % of households (14.3 million households) have one or more rooms that are not heated by the main heating system. Conservatories, separate WCs, bedrooms, hallways and kitchens are more likely not to be heated by the main heating system than living rooms, dining rooms, studies and bathrooms. The only significant difference in the likelihood of a certain household characteristic group having one or more rooms not heated by the main heating system is seen for fuel poverty status; households that are calculated to be fuel poor are more likely to have one or more rooms not heated by the main heating system than those households that are not fuel poor.

The 9 hours of heating on weekdays, currently used in SAP, is supported by the analysis of the both the EFUS interview and temperature data for centrally heated dwellings. Non-centrally heated households, however, may be heating for significantly longer than this (10 to 15 hours). The EFUS interview and tem-

Table 1. Summary of the key findings reported by households with respect to the heating patterns used.

<table>
<tr><th>Type of main heating system</th><th>Regularity of heating</th><th colspan="2">Number of heating periods</th><th colspan="3">Boost heating (asked of households with CH controlled by timer to give regular heating) (12.2 m households; n=1,399)</th><th>Daily heating hours (including source of data)</th></tr>
<tr><td rowspan="6">Centrally Heated

19.7 m households (90 %)

(n=2,356)</td><td rowspan="4">Regular heating
14.7 m households (75 %)

(n=1,715)</td><td>0 heating periods</td><td>*1 %
(n=20)</td><td rowspan="4">Use boost heating at least once per week?</td><td rowspan="2">Yes</td><td rowspan="2">7.5 m households (61 %)
n=850)</td><td rowspan="4">95 % C.I. of median daily heating hours

8.4–8.8
(Householder responses)

8.8–9.5

(Temperature data derived)</td></tr>
<tr><td>1 heating periods</td><td>21 %
(n=395)</td></tr>
<tr><td>2 heating periods</td><td>69 %
(n=1,158)</td><td rowspan="2">No</td><td rowspan="2">3.2 m households (26 %)
n=378)</td></tr>
<tr><td>3+ heating periods</td><td>8 %
(n=142)</td></tr>
<tr><td rowspan="2">Non-regular heating
5 m households (25 %)

(n=641)</td><td rowspan="2">Heating periods N/A</td><td rowspan="2">N/A</td><td rowspan="2">Use boost heating?</td><td>N/A</td><td>N/A</td><td rowspan="2">95 % C.I. of median daily heating hours

4.0–5.1
(Householder responses)

9.8–11.3
(Temperature data derived)</td></tr>
<tr><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="6">Non-Centrally heated

2.2 m households (10 %)

(n=260)</td><td rowspan="4">Regular heating
1.3 m households (60 %)

(n=158)</td><td>0 heating periods</td><td>*8 %
(n=15)</td><td rowspan="4">Use boost heating?</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="4">95 % C.I. of median daily heating hours

10.7–15.3
(Householder responses)

9.1–16.5
(Temperature data derived)</td></tr>
<tr><td>1 heating periods</td><td>81 %
(n=128)</td></tr>
<tr><td>2 heating periods</td><td>*9 %
(n=14)</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td></tr>
<tr><td>3+ heating periods</td><td>*1 %
(n=1)</td></tr>
<tr><td rowspan="2">Non-regular heating
0.9 m households (40 %)

(n=102)</td><td rowspan="2">Heating periods N/A</td><td rowspan="2">N/A</td><td rowspan="2">Use boost heating?</td><td>N/A</td><td>N/A</td><td rowspan="2">95 % C.I. of median daily heating hours

2.3–4.6
(Householder responses)

15.6–23.4
(Temperature data derived)</td></tr>
<tr><td>N/A</td><td>N/A</td></tr>
</table>

Base: All dwellings in EFUS 2011 Interview Survey representing 21.9 million households in England (n=2,616).

perature data suggest that the total number of hours heating are approximately the same on weekends as they are on weekdays.

Currently, SAP implements a heating pattern of 9 hours for weekdays and 16 hours for weekends in the living room for all heating system types. These assumptions may need to be reviewed in light of these results.

Currently, SAP implements a demand temperature of 21 °C in zone 1 and 18–21 °C in zone 2. The results from the EFUS suggest mean achieved temperatures of 20.2 °C in zone 1 (living room) and 19.1 °C in the zone 2 proxy (mean of hallway and bedroom) – i.e. the zone 1 temperature in SAP is 0.8 °C higher than the average living room achieved temperature from the EFUS temperature data. The zone 2 temperatures are within the expected range.

Interesting patterns are seen in the temperatures achieved by different types of households. There is a clear pattern of higher achieved temperatures in older households (approximately 22 °C for those aged over 75). Similarly, higher achieved temperatures are seen in dwellings with insulation present (20–21 °C) than in those with no insulation (19 °C).

The temperature data show that for those households heating twice a day, the first period of heating is typically for a short interval, and the time that the heating is on for in many households may not be sufficient to bring the room temperatures to the thermostat set-point temperature. In general, most models (including SAP and BREDEM) assume that temperatures demanded by households are reached in all periods of heating. The fact that many households are not achieving these temperatures may be resulting in an overestimate of energy consumption by these models.

SECONDARY HEATING SYSTEMS

Secondary heating systems are those that provide space heating which is in addition to that provided by the main heating. This can be as heating in rooms where the main heating is not present or not used (referred to in this analysis as alternative heating); or as 'top-up' heating in rooms where the main heating is used (referred to in this analysis as supplementary heating). Prior to the EFUS, little was known about the use of these systems. Currently SAP and BREDEM modelling simply assigns a proportion of total energy use to secondary heating systems. New SAP and BREDEM algorithms could potentially be developed using these data, to more appropriately model the use of different types of heating systems. This analysis examines how these systems are used in homes, providing valuable new data in these areas.

Two types of secondary heating are considered by the analysis:

1. Alternative heating – defined as heating that is used *instead* of the main heating in a room. This could either be where the main heating is turned off or does not extend into this room.
2. Supplementary heating – defined as heating that is used in *conjunction* with the main heating in a room.

Approximately 65 % of all households have one or more rooms not heated by the main heating system. Of these, 26 % (17 % of all households) use alternative heating to heat these rooms. Alternative heating is typically used in one room per household, and the predominant type of alternative heater used is electric (74 % of households with alternative heating). Households using storage radiators as their main heating are most likely to use an alternative heater.

Close to half of all households (48 %) indicate that they have supplementary heating in one or more rooms. Approximately 79 % of households using supplementary heating use it in only one room per dwelling, with a further 17 % using it in two rooms per dwelling. Of households with supplementary heating, 83 % use it in living rooms and 12 % in bedrooms. Supplementary heating is rarely used in other room types. Typically supplementary heaters are either electric (46 %) or mains gas (41 %).

On average, households use alternative heating for 17.5 hours per week (median) during their heating season. Supplementary heating is typically used for a shorter period of 8 hours per week (median).

Almost half (47 %) of all households using supplementary heating indicate that they use their heaters 'to provide extra heat when the heating system is on', about a quarter (26 %) state that it is used 'to provide heat when the heating system is not on', 18 % say that it is used for both these reasons.

No heating is provided from the main or alternative heating system (including main heating turned off) in one or more rooms in 48 % of all households. The majority of these households (60 %) report less than a fifth of all rooms in the dwelling are unheated. Typically, circulation spaces, WCs and 'other' rooms (which include rooms such as utilities etc.) are much more likely to be unheated than other types of rooms. Approximately 23 % of households with at least one bedroom have one or more bedrooms that are not heated by the main or alternative heating system. The most common responses from households to the question of why they do not heat specific rooms were that the room is warm enough already (41 % of households), the room does not have a heater (36 % of households) or that the room does not need a heater as the room is not used (33 % of households). Only 5.2 % of households reported that they do not heat a room due to expense.

CONSERVATORIES

Conservatories are increasingly common additions to homes in England. In general, however, no additional energy losses are assigned to homes with conservatories under standard energy modelling assumptions (as it is presumed that they are thermally separated from the dwelling, and unheated). The EFUS collected data on thermal separation (the presence and use of a door) and heating in conservatories.

Conservatories are found in approximately 18 % of households in England. Most conservatories (95 %) open on to the living room, kitchen or dining room.

Around 77 % of conservatories have heating. Just over half of those with heating (55 %) are connected to the central heating system, and 42 % have storage or direct acting electric heaters. In winter, 56 % of conservatories with heating are heated every day. Most occupants report that they heat the conservatory to the same (45 %), or a lower (39 %) temperature than the house.

In approximately 91 % of dwellings with conservatories there is a separating door. Most households with a conservatory with a separating door (83 %) keep it shut in winter. This is mainly to keep heat in the room, and also for security. Of the small proportion (17 %) of households who report the door is kept open, it is reported to be mainly for convenience.

In summer 81 % of households report that they keep the door to the conservatory open for a period of time. This is reported to be mainly for convenience and to let heat into the adjoining room, and also to make the room feel more spacious.

These results demonstrate that a significant proportion of conservatories are heated, with potentially important implications for domestic energy modelling methodologies. Under the SAP methodology, a conservatory is currently ignored (i.e. no energy use is assigned) if it is 'thermally separated'. While 91 % of conservatories studied by the EFUS have a separating door (and it is likely that most of these may be included in the definition of 'thermally separated'), the EFUS results indicate that the majority of these conservatories will actually be heated. The thermal separation may, therefore, be irrelevant in many cases. In light of these results consideration should be given to amending SAP to assign energy usage to conservatories whether or not thermal separation exists. Any changes to SAP should also note that most households report heating the conservatory to the same or a lower temperature than the rest of the dwelling.

There are further potential implications for Building Regulations. Under current Building Regulations guidance, conservatories are exempt from energy efficiency requirements given certain conditions, one being that the heating system is not extended into the conservatory. This does not cover the case of conservatories in which portable heaters are used, which this report indicates is about half of heated conservatories. Consideration should therefore be given to including conservatories under Building Regulations under other circumstances, perhaps where there are gas or electric points that portable heating may be connected to.

LIGHTING

Information was collected in the EFUS 2011 Interview Survey about the number of sets of lights, the number of bulbs per set, the types of bulbs in each set and the length of time each set is used, in three of the main rooms of the house (living room, main bedroom and kitchen), as well as lights left on overnight and outside lights powered from the household electricity supply.

In the living room and main bedroom approximately 40 % of light bulbs are tungsten (traditional light bulbs – not of a low-energy type), and 30 % low energy compact fluorescents (CFLs). In the kitchen however, halogen bulbs (50 %) and fluorescent strip lighting (15 %) are the dominant type of lighting. Lighting is reported to be used for about 2 to 3 times as long in winter as summer (5–8 hours per day in the winter compared to 2–3 hours per day in the summer).

Lights are reported to be left on in one or more rooms overnight by 17 % of households. Of these households, 92 % leave a light on in just one room and a further 7 % in two rooms. These rooms are typically the hallway/landing, bathroom with a WC or the second bedroom. For the households that leave lights on in either of the hall/landings overnight, just under 60 % of them use low energy CFLs. This may reflect the fact that households value the energy savings these bulbs provide for this type of usage. However, just over 20 % of households leaving lights on in hallways overnight use tungsten bulbs.

Approximately 62 % of households have outside lights powered by their mains electricity supply. Of these, almost half (47 %) have one bulb and a further 37 % have two or three bulbs. The most commonly-used type of bulb in outside lights was described as tungsten. This may indicate a preference for instant, brighter light for this purpose. Manual switching is the most usual form of control with more than 60 % of lights being switched manually.

DOMESTIC APPLIANCES, COOKING AND COOLING EQUIPMENT

The EFUS 2011 has revealed detailed information on patterns of ownership and use of key domestic appliances, including cooking and cooling equipment, which is of use for the development of energy efficiency policy and refinement of energy modelling methodologies such as SAP and BREDEM.

Almost all households own a washing machine (97 %), a fridge (99 %), a freezer (93 %), a television (98 %), an oven (95 %) and a hob (93 %). Other appliances are less universally owned. Almost 80 % of households own a grill, 80 % a microwave, 62 % a tumble dryer, and 41 % a dishwasher. The EFUS has identified differences in patterns of ownership and use among different household groups. Owner occupiers are more likely to own washing machines and tumble dryers compared to the other tenures. Single person households, households without any children, households in which the HRP (Household Reference Person) is 75 years old or more, households in which none of the occupants is working, households with incomes in the lowest income quintile and households that are not under-occupying are all *less likely* than their counterpart groups to own a washing machine or tumble dryer. There are no apparent differences in fridge ownership across the different household groups suggesting that this appliance is considered a necessity. Freezer ownership and dishwasher ownership across the different household groups is more variable with similar differences in the patterns of ownership as those seen for the laundry appliances. There is a particularly strong relationship between dishwasher ownership and income.

The median number of washing loads per week is 4 and the median number of drying loads per week is 3 in the winter. Approximately 59 % of households report typically running their washing machine at 40 °C; 27 % report typically washing at 30 °C, and 8 % report typically using temperatures hotter than 40 °C. As to be expected, there is a pattern of more frequent washing machine use among large households, particularly those with children. The median number of loads per week also increases as household income increases. However, households with at least one pensioner present, and households that are considered to be under-occupying, use their washing machines less than their counterpart groups.

Electricity is the dominant fuel used in ovens (almost 70 % of households with ovens have electric ovens and just under 30 % have gas ovens). For hobs, the prevalence of fuels is reversed with gas being the dominant fuel (38 % of households have electric hobs, whereas 61 % have gas hobs). Households use their hobs and microwaves more frequently than their ovens or grills.

The number of televisions in homes ranged from 0 to 9, with a mean number of 2.3 televisions per household. Owner occupiers typically have more televisions than any of the other tenures. Additionally, the mean number of televisions in a household increases as household size increases. Households in the lowest income quintiles have fewer televisions on average than households in any of the four high income quintiles.

Households with children present, and households where no pensioners are present, also report owning more televisions compared to their counterpart groups.

The main (most used) television in the home is likely to be a flat screen type. Owner occupied households are *more likely* to have a flat screen television than a standard cathode-ray tube (CRT) type as the most used television compared to households in the social rented sector, whereas households in the lowest income quintile are *less likely* to have a flat screen model as the television used the most compared to households with higher incomes. Additionally, single person households are *also less likely* to have a flat screen television as the most used television compared to larger households.

The television used most often in the house is reported to be used for approximately 5 to 6 hours per day. The average number of hours is greater for households that are in the social rented sector compared to owner occupiers or private renters, and higher for households with children, containing someone of pensionable age, where someone is in during the day and households that are not under-occupying.

43 % of all households report using portable fans. Other fixed fans are reported to be in use by around 9 % of households. Air conditioning use is very rare with less than 3 % of households using fixed or portable air conditioning units during the summer months. Around 17 % of households use portable fans on a daily basis during the summer months. Just under 40 % of households with portable fans use them more than once per week but not every day, and a further 39 % of households use them less than once a week.

Considerable scope has been identified for the replacement of older appliances in the stock which may represent a significant potential for energy saving. The survey suggests that over 2.1 million washing machines, and 2.6 million tumble dryers, are more than 10 years old. A large number of refrigeration appliances are more than 10 years old, including around 24 % of standalone fridges and 24 % of standalone freezers (equivalent to around 2.5 million of each of these types of appliance). Approximately 22 % of ovens are over 10 years old (equivalent to around 4.5 million ovens).

HOUSEHOLD UNDERSPEND

The methodology used to produce estimates of fuel poverty in England defines a regime which is considered sufficient to provide adequate energy for heating and other uses in the home. This includes energy for heating, lighting, appliance use and cooking. A household is said to be "underspending" when its actual fuel expenditure is below that predicted by this theoretical regime.

Approximately 67 % of all households are underspending to some degree. Around 35 % of all households are underspending by more than 25 % of the required fuel bill, and approximately 8 % of all households are underspending by more than 50 % of the required fuel bill.

Households that are underspending have lower mean internal temperatures, and lower achieved temperatures, than those that are not. Households exhibiting the highest levels of underspend also report heating for fewer hours per day than households that are not underspending.

Fuel poor households (using the Low Income High Costs definition – see DECC, 2014b) are more likely to be underspending than non-fuel poor households. Around 80 % of those in fuel poverty are underspending, compared to 65 % of households not in fuel poverty underspending.

There is no clear relationship between underspending and income. High income households are as likely to be underspending as low income households. Similarly, the likelihood of underspend is not directly influenced by other household factors including household type, age of household or employment status. However, a clear relationship exists with the energy efficiency of the property as defined by the SAP rating. Those households living in higher energy efficiency properties are less likely to be underspending than those in lower energy efficiency properties. Approximately 90 % of those living in the least energy efficient properties (below a SAP rating of 30) are underspending (relative to the modelled requirement for those dwellings), compared to 47 % underspending in the most energy efficient properties (SAP >70). This is shown in Figure 2.

This relationship with energy efficiency is reflected in the fact that households in older properties are more likely to underspend, as are those without gas central heating systems, and in poorly insulated properties. The may have significant policy implications as improvements made to poorly performing properties may simply reduce the level of underspend, rather than deliver reductions in consumption.

Conclusions and discussion

The EFUS has provided a wealth of new data on energy use in English households. The results summarised above from the survey provide essential new information to assist in the development of energy efficiency policies, and to enhance the energy models which underpin them.

The purpose of the EFUS was to challenge existing ideas and concepts, many of which have been established for several years (indeed, in many cases decades) and to provide new data to develop enhanced methods.

The data supports many of the conventional heating assumptions in key areas such as the number of hours that heating is on weekdays. In other areas, if provides evidence to vary from the existing assumptions. In particular, differences have been identified in the hours heated at the weekend (fewer than generally assumed), internal temperatures (slightly lower in the living room, but higher in the other areas than generally assumed), and the widespread heating of conservatories (generally these are assumed unheated). These are important inputs into our calculations and models. Heating is the largest end use of energy in the home (DECC, 2014a) and any variance in the hours or temperature of heating can significantly affect the final energy consumed by a household. Similarly, a heated conservatory may be a significant source of additional heat losses. We are now able to take these data into our models and calculations as both direct inputs, or quantities to control and calibrate our outputs against, and have some increased confidence that they and their results represent reality.

Novel data have also been collected that may allow the construction of completely new algorithms and methods for modelling appliance use, and secondary heating use. This work has not yet begun, but the EFUS data allows this to proceed.

One of the principal aims of producing this paper for the ECEEE is to highlight to international colleagues that primary

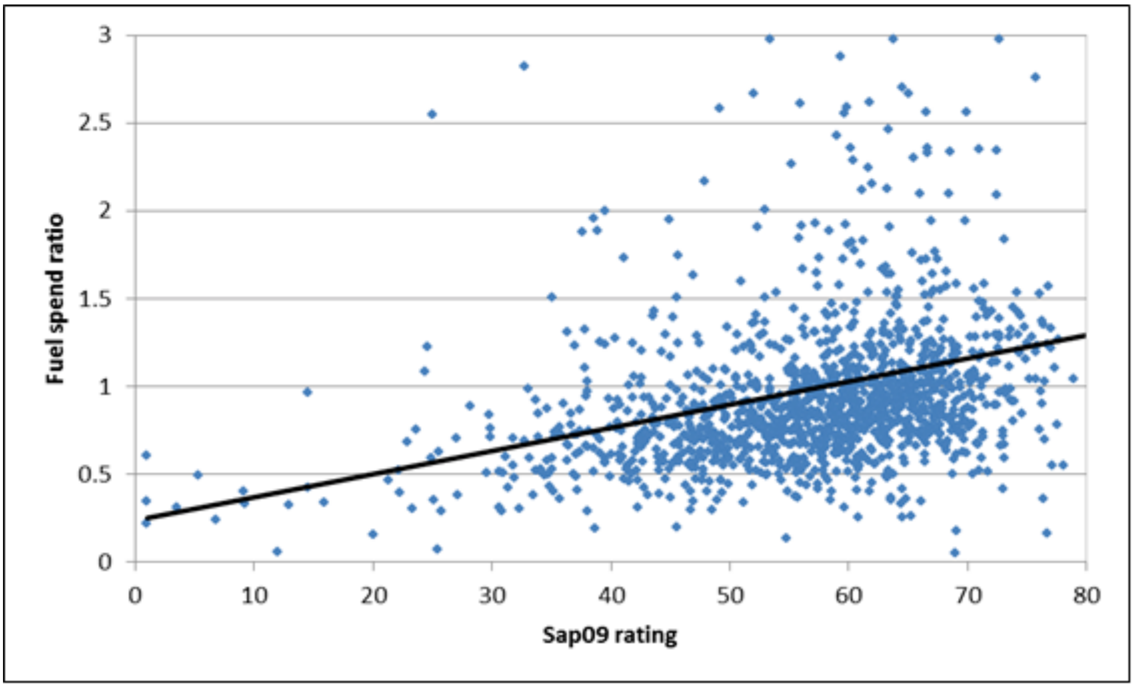

Figure 2. Relationship between SAP rating and fuel spend ratio. SAP ratings run from 1 (lowest energy efficiency) to >100 (highest energy efficiency). A fuel spend ratio of >1 represents an actual spend above the requirement, a ratio <1 represents and actual spend below the requirement.

data collection is essential if we are to understand how energy is being used in the domestic sector, and provide an example of how this has been done in the UK. These types of data both challenge and support the conventional assumptions used and allow us to check that our models are adequately representing reality. The English statistician George Box stated that "essentially, all models are wrong, but some are useful" (Box & Draper, 1987). While more data is always required, and all models will only ever be able to simulate the real world imperfectly, primary data such as from the EFUS help to ensure they are as least wrong but remain as useful to us as possible.

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