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Energy Follow Up Survey: Household Energy Consumption & Affordability

Final report

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The EFUS 2017 has been undertaken by BRE on behalf of the Department for Business, Energy & Industrial Strategy (BEIS).

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Executive Summary

This report presents the results of the EFUS 2017 energy consumption and affordability analysis. The meter point data from 2017 was analysed alongside EFUS interview data, weighted to represent the English housing stock. Under-consuming households have been identified by comparison of metered consumption with BREDEM modelled energy consumption. Daily gas consumption profiles have been presented using detailed gas consumption data. The main findings are presented below:

Annual household energy consumption

The median gas consumption for all households has decreased since 2010, from 13,900 kWh/year to 12,300 kWh/year. The median electricity consumption has also decreased, from 3,600 kWh/year to 3,100 kWh/year. These figures were in line with the NEED 2017 consumption figures.

Based on linear regression analysis of gas consumption, for households with gas central heating, dwelling characteristics explained the most variability (48%) in gas consumption, and heating behaviours the least (21%). A final combined model explained 59% of the variability in gas consumption, and the most important factors which led to an increase in gas consumption were: increasing floor area, decreasing energy efficiency, increasing heating hours, increasing household size.

Based on linear regression analysis of electricity consumption, for households where electricity was not the main heating fuel, variables related to appliance ownership and use explained the most variability (50%) in electricity consumption, and dwelling characteristics the least (23%). A final combined model explained 58% of the variability in electricity consumption, and the most important factors which led to an increase in electricity consumption were: increasing number of wet and cold appliances and increasing household size. Other notable factors included: dwelling type, other appliance usage and ownership.

Detailed household gas consumption

Analysis was conducted using detailed gas consumption data from 143 households. Daily profiles of gas consumption during the EFUS heating season (October 2018 to April 2019) illustrated that households with larger floor areas; longer heating hours; more occupants; and low energy efficiency, had greater levels of gas consumption than the relative group.

During the coldest week of the year (28th January to 3rd February 2019) households increased gas consumption by, on average, 15% compared with the previous week, while 27% of households increased their gas consumption by 25% or more. Indicative findings suggested that household groups in the lowest incomes and households in fuel poverty, were less likely to increase their gas consumption by 5% or more in the coldest week. No differences were found for other household characteristics.

Household energy costs and affordability

Most households (57%) did not switch their energy supplier in the 2.5 years between the initial EHS and the EFUS survey, while 11% of households reported switching multiple times.

Households in fuel poverty were more likely to pay for their electricity by pre-payment, however, households on a pre-payment meter were not found to be on a more expensive tariff compared with other methods, illustrating the impact of the pre-payment tariff cap introduced in April 2017.

The median total household energy bill (gas, electricity and other fuels) was calculated to be £920 per year, using information on: gas and electricity consumption from meter point data; gas and electricity prices from tariff comparison rates (TCR); and reported other fuel costs for heating, hot water or cooking. The most frequently reported other fuel was wood (2.7 million households), with 44% of households not paying anything for this fuel. Costs for other fuels were greater for households with electricity as the main heating fuel (solid, oil, LPG: £200 per year), compared with gas (solid, oil, LPG: £50 per year).

In total, 19% of households reported struggling to keep up with their energy bills, a result mainly driven by household income. The following groups were more likely to struggle: lone parents with dependent children, renters, and larger households. Households in fuel poverty (40%) were more likely to struggle than non-fuel poor households (16%).

For households where keeping up with their energy bills was a constant struggle, or they had fallen behind: 94% changed the way they heated their home; 89% cut back on spending; and 56% borrowed money or missed rent/mortgage payments.

Modelled energy consumption

Based on a BREDEM calculation for an average dwelling archetype, gas consumption was modelled to decrease by 11.9% between 2010 and 2017 based on the following factors: fabric efficiency of the heated envelope; hot water cylinder insulation; heating system efficiency; and market share of the two main gas boiler types (standard and combi). This is comparable with the 11.7% decrease observed from the meter point data.

Comparison of BREDEM modelled energy consumption (gas and electricity only) with actual energy consumption showed that on average, households consumed 12% less energy than they theoretically required to meet the standard set in the fuel poverty methodology.

Households were defined as ‘under-consuming’ if relative to other households the percentage difference in modelled and actual energy consumption was in the lowest quintile, and households have been classified as ‘over-consuming’ if the percentage difference was in the highest quintile.

A key driver of under-consumption was income and affordability of energy bills, with the following households more likely to be under-consuming: fuel poor, private and housing association tenures, younger households, and lone parents with dependent children. High income households were more likely to be over-consuming, along with older households who tended to heat for longer and with warmer living room temperatures. Dwellings that were less energy efficient, or with non-central heating systems, were more likely to be under-consuming.

1. Introduction

There is an ongoing requirement to keep our knowledge and understanding of domestic energy use up to date. This is essential to ensure that policies, and policy interventions, are directed in the most efficient and effective manner; that legislation and standards are based on principles and assumptions that reflect how people are actually using energy in their homes; and that models and statistics which provide the underpinning evidence base in this area are as accurate as possible. Of particular relevance at the moment are policies relating to fuel poverty, decarbonisation of heat, smart metering and minimising household energy bills.

The data presented here is from the 2017 Energy Follow-Up Survey (EFUS). This was a follow-up survey of a sample of respondents from the English Housing Survey (2014-2017) and provided more detailed information on use of heating, hot water and appliances. Similar Energy Follow-Up Surveys were carried out in 1998 and 2011.

Today the Department of Business, Energy and Industrial Strategy (BEIS) has several overarching aims which need to be addressed by this new EFUS. These are:

1. To determine current domestic energy consumption and heating patterns in England and to investigate how they change over time through timeseries comparisons.

2. To understand how and why there are variations in energy consumption between similar dwellings, and similarities in energy consumption between different dwellings.

3. To understand how households in fuel poverty use energy and how their energy consumption patterns and behaviours compare with non-fuel poor households.

The questions addressed in this ‘Household Energy Consumption and Affordability’ report are:

- What is the total household energy consumption in 2017? What are the reasons for the change in gas consumption since 2010? How do gas consumption daily profiles differ by dwelling and household characteristics?
- How does energy consumption change when accounting for different dwelling and household characteristics, heating behaviours and appliance ownership and use? How does this compare between non-fuel poor and fuel poor households?
- How does metered energy consumption compare with modelled BREDEM energy consumption? Based on this difference, which households are more likely to be under-consuming (in the lowest quintile) or over-consuming (in the highest quintile)?
- How does the household pay for energy, who is the energy supplier, and do they have a smart meter? Has the household switched any of these recently?
- What is the total household fuel cost and how does this vary by fuel poverty status?
- Are there any trade-offs made by households? Are there differences between the fuel poor and non-fuel poor?

2. Methodology

Full details of the data collection and analysis methods used is set out in a separate methodology report, however, an outline is given below of the analysis, the interview surveys upon which this report is based, the meter point data, detailed gas consumption data and temperature data.

2.1 Surveys

The first of the householder surveys was undertaken in the autumn of 2017 and is referred to as Interview 1. A pilot survey of 94 households was carried out between May and June 2017, followed by the main survey of 1,867 households. This survey was conducted via a face-to-face interview conducted in the householders' home between August and October 2017. In order to boost the sample, an online version of the same survey was completed by a further 671 households between October and December, giving a total sample of 2,632.

The Interview 1 survey examined a number of areas including;

- Summer thermal comfort
- Cooling behaviours
- Hot water use
- Appliance use
- Lighting
- Energy tariffs and method of payment
- Dwelling improvements
- Changes to the household

The second of the householder surveys, a follow-up survey to Interview 1, was conducted between January and March 2018 and is referred to as Interview 2. To minimise disruption to the householders the survey was conducted via a telephone interview and 1,060 households completed the telephone survey. As with Interview 1, in order to boost the sample an online version of the Interview 2 survey was completed by a further 280 households, giving a total sample of 1,340. Therefore almost 51% of the Interview 1 households also completed the Interview 2 survey.

The Interview 2 survey examined;

- Use of main, alternative and supplementary heating systems
- Winter thermal comfort
- Winter ventilation behaviours
- Damp and mould

- Winter appliance and hot water use
- Lighting
- Trade-offs made by households unable to afford to heat their homes
- Occupancy patterns

The third of the householder surveys, another follow-up survey to Interview 1, was conducted between February and March 2019 and is referred to as Interview 3. The survey was conducted via a telephone interview and online survey; 447 households completed the telephone survey and a further 739 households responded online, giving a total sample of 1,186. Some 80% of the Interview 3 surveys had an Interview 1 and Interview 2 survey (944 households), while the remaining 242 households had an Interview 1 survey only. The interview 3 survey collected information on:

- Use of main heating systems including the heating season
- Proportion of the house heated
- Occupancy patterns
- Smart technologies
- Method of payment and tariffs
- Changes to property and household

The results presented in this report are based on the householder responses from all three interview surveys:

- Interview 1 and 3: household responses to energy suppliers, method of payment and switching, tariff rates and other fuels (Chapter 4)
- Interview 2: affordability of energy bills and cutbacks (Chapter 5)

Additionally, data from Interview 3 has been used in the analysis of detailed gas consumption data (Chapter 3), while Interview 1 and Interview 2 data was used in multi-variate analysis of gas and electricity consumption (Chapter 3), and comparison of modelled and metered energy consumption (Chapter 6)

2.2 Meter point data

Meter point data was provided by the BEIS National Energy Efficiency Data-Framework (NEED) team for 2,217 households, covering the period January 2017 through to January 2018 for electricity, and the period June 2017 to June 2018 for gas. After cleaning and validation, the resultant datasets contained information on 1,994 households with valid electricity data (93 households with solar PV were excluded), and 1,770 cases with gas data. Both the electricity data and gas data has been annualised, and the gas data has also been weather corrected. Further guidance on how this data was collected can be found here: https://www.gov.uk/government/publications/regional-energy-data-guidance-note.

The total gas and electricity consumption figures have been produced for 1,919 households with available gas and electricity data (or just electricity data where the household is not on the gas network).

2.3 Detailed gas consumption data

Detailed gas consumption data was collected from January 2018 to May 2019, with monitors installed in households between January 2018 and October 2018. The large time frame over which installations occurred means there are different amounts of consumption data recorded for each household. In order to minimise large variations in the amount of data being analysed for each household a detailed consumption monitoring period was defined, chosen to run from 1st May 2018 to 30th April 2019. This period maximises the data available for analysis over the EFUS heating season while also covering a full year of data for the 57% of households that had gas monitors installed before 1st May 2018.

Valid gas consumption data was collected in 143 households across the detailed consumption monitoring period, the amount of data available to analyse for each household ranges from 4 months' worth of data to a full year.

Gas consumption data was collected every 30 minutes for each monitored household and meter readings were summarised and averaged for analysis. Values calculated include:

- Daily averages for each household, calculated by summing the gas consumption each day to a daily total, then averaging these daily totals across a time period of interest and;
- Hourly averages for each hour in the day for each household, calculated by averaging the half hourly values into an hourly value, then averaging across all days in which data is recorded for that hour over a time period of interest.

Time periods of interest include the detailed consumption monitoring period, months of the year and the EFUS heating season.

2.4 Temperature data

Temperature loggers were installed in 750 households from August 2017 until October 2017 and internal temperatures were monitored up until April 2019. Temperatures were recorded in up to five rooms in any one household; the living room, hallway, main bedroom and second and third bedrooms (if present). Weather data was obtained from the Met Office (MIDAS dataset). The Met Office station closest to each household was identified, and the hourly external temperatures recorded by each station were time-matched to the temperature data recorded by the loggers.

Data was processed to calculate monthly and seasonal averages, including average temperatures during the coldest week of the year. Average internal temperatures were calculated for each room with data.

2.5 Weighting

The weighting factors for all three interview surveys were derived using a RIM weighting method and logistic regression, based on population targets so that each household in the EFUS dataset represent the number of households in England in 2017 (23.95 million) and 2018 (24.17 million). Additional weighting factors were derived for each subset of households with valid electricity data, gas data, and combined electricity and gas data. Further details are provided in the separate methodology report.

2.6 Analysis

Statistical analysis was used to measure the significance of the findings presented in this report. All statistical analysis was conducted on weighted data, and a design effect factor was used to account for the complex survey design. Further detail on the analysis is provided in the full methodology report.

The key dependent variables used in each chapter have been analysed by the defined set of EFUS social demographic and dwelling characteristic variables (listed below). As a rule, only statistically significant results at the 99% level (where $p < 0.01$) have been included in the text, although there are some instances when results that are significant at the 95% level ($p < 0.05$) are reported.

Household characteristics: tenure, household composition, household size, presence of pensioner, presence of child, age of the HRP (household reference person), employment status of household, household income, daytime occupancy, anyone in the household designated long-term sick or disabled, under-occupying status, fuel poverty status, and fuel poverty gap.

Dwelling characteristics: dwelling type, house or flat, dwelling age, floor area, region, rurality, presence of central heating, main fuel used, wall type, insulated walls, loft insulation thickness, double glazing extent, number of insulation measures, Energy Performance Certificate (EPC) rating band.

Further details on these characteristics are located in the Glossary. In addition to these dwelling and household characteristics, a suite of 'EFUS variables', derived from the EFUS 2017 interview and monitoring data, has been used in this analysis. This includes variables relating to heating patterns, household daytime occupancy, thermal comfort, lights and appliances ownership and use.

The following tests were used:

- The Chi-Squared (X2) test was used when comparing two categorical variables to determine if they are independent. Alongside this the Z-test for proportions was used to determine where the differences occur, with a Bonferroni correction. Cramer’s V test was used to analyse the effect size.

- Analysis of Variance (ANOVA) was used with continuous data to determine the impact of categorical variables, and the Tukey post-hoc test was used to determine where the differences occur. In addition, the effect size Eta-squared (η^2) has been calculated. Where assumptions for homogenous variances are violated, the result of the Welch test has been reported, and post-hoc testing has been conducted by independent t-tests.
- The Kruskal-Wallis test was used for non-parametric analysis of continuous or discrete data, to determine the impact of categorical variables. The Mann-Whitney U test was used to determine where differences occur, and the effect size was approximated based on the r statistic.
- Pearson correlations (R) have been reported for the correlation between two continuous variables.
- Paired T-tests were used when comparing two continuous variables, for a repeated measure. The Wilcoxon-signed rank test was used for non-parametric paired analysis.

All frequencies and percentages reported in the text have been rounded, with percentages rounded to the nearest percent. Annual consumption figures have been rounded to the nearest 100 kWh/year, and fuel costs rounded to the nearest £10. Measured temperatures have been rounded to the nearest tenth of a degree (°C).

In this report, where householders responded ‘don’t know’ to a question, and if the proportion of ‘don’t know’ responses was less than 5% of the unweighted sample then these were set to missing and excluded from the analysis.

2.6.1 Multi-variate analysis (MVA)

In addition to the bivariate analysis used throughout the report, linear regression models were used to determine the extent to which different groups of factors explain variation in annual gas consumption (section 3.2) and electricity consumption (section 3.3). Factors were grouped into dwelling characteristics, household characteristics, and EFUS (heating, occupancy and appliance related) variables. Factors included in each grouping were partly determined by the results of principal component analysis (PCA) and variance inflation factors (VIF). Any variables with a VIF of three or greater were excluded from the models and the VIF of variables included in the models indicated only negligible collinearity between them. Prior to running the regressions gas consumption was square root transformed and floor area was log transformed to normalise.

The linear regressions were run for each group of variables individually, and then combined, to test if additional groupings increased the explanatory power of the models. Stepwise selection using AIC (forwards and backwards) was used to determine which variables were left in the final models. Only variables selected by the individual models were included in the combined model.

The R^2 values have been reported for each model (how much of the variance each model explains), and an indication of the relative importance of each variable in the model has been calculated using the LMG[1] method. Finally, the estimated marginal means (coefficients) from the final model have been plotted against the results from the equivalent bivariate model.

[1] Grömping, Ulrike. (2006). Relative Importance for Linear Regression in R: The Package relaimpo. Journal of Statistical Software. 17. 1-27. 10.18637/jss.v017.i01.

3. Household energy consumption

This chapter provides the average household energy consumption figures, based on available meter point data for 2017. Discussion of the gas and electricity consumption figures, and how this has changed since 2010, will be included before moving onto multi-variate analysis to determine the main factors driving variability in gas and electricity consumption. Finally, results from detailed gas consumption data are presented, including daily profiles and analysis of the 2018/19 coldest week.

3.1 Energy consumption

The median annual energy consumption was calculated to be 14,100 kWh/year, based on English households with valid gas and electricity consumption data in 2017, with an indicated range of 9,000 kWh/year for the lower quartile, and 19,700 kWh/year for the upper quartile[2].

The median annual gas and electricity consumption for all households are shown in Table 3.1, alongside the lower and upper quartiles. Both the median gas and electricity consumption has decreased since 2010[3], where household gas consumption was 13,900 kWh/year, and electricity consumption was 3,600 kWh/year. The 2017 figures are in line with NEED[4] (which also uses meter point data) where in 2017 the median gas consumption was 12,300 kWh/year (LQ 8,300 kWh/year; UQ 17,100 kWh/year), and the median electricity consumption 3,100 kWh/year (LQ 2,000 kWh/year; UQ 4,700 kWh/year). In addition, the gas consumption figures are in line with the Ofgem typical domestic consumption values[5], which show low and high values for gas consumption of 8,000 kWh/year and 17,000 kWh/year respectively.

Table 3.1: Annual gas and electricity consumption in 2010 and 2017

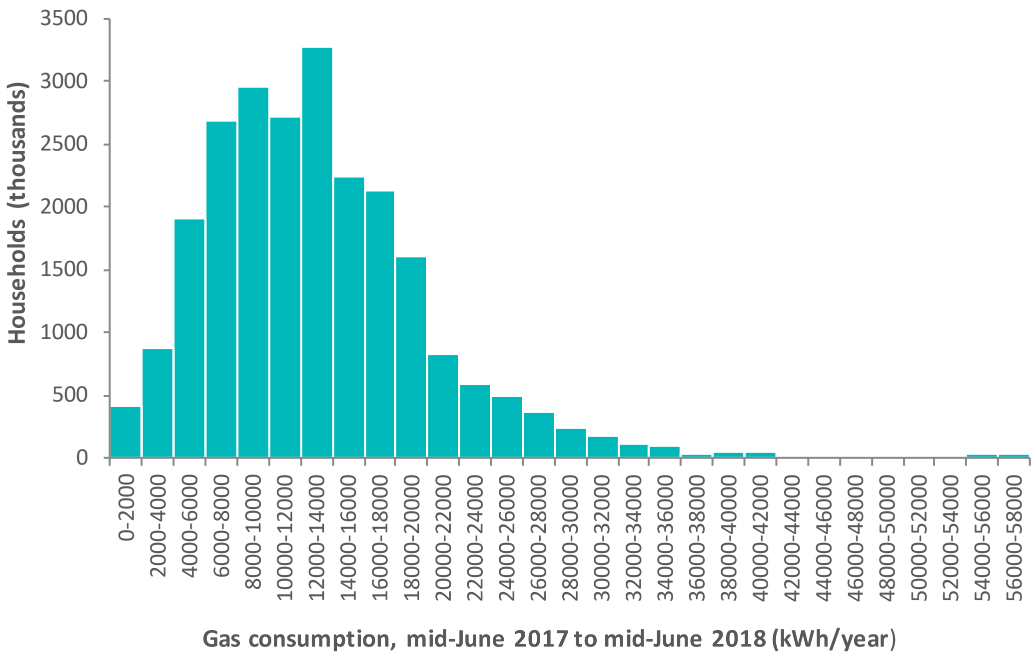
	Gas consumption (kWh/year)		Electricity consumption (kWh/year)	
	2010	**2017**	**2010**	**2017**
Percentile				
25%	9,900	8,000	2,300	2,100
50% (median)	13,900	12,300	3,600	3,100
75%	19,200	16,600	5,300	4,700

Base: all households with meter point data (n=1,326 for gas 1st October 2009 to 30th September 2010, n=1,528 for electricity 1st February 2010 to 31st January 2011), 2010; (n=1,770 for gas mid-June 2017 to mid-June 2018; n=1,994 for electricity 31st January 2017 to 30th January 2018), 2017.

2 Annex tables containing the underlying data for this section can be found in Tables_3.xls.
3 The 2010 meter point data was used for analysing change because of the availability to the project team, and to allow for a more accurate comparison with 2017 as both datasets were weather corrected.
4 https://www.gov.uk/government/statistics/national-energy-efficiency-data-framework-need-report-summary-of-analysis-2019
5 https://www.ofgem.gov.uk/gas/retail-market/monitoring-data-and-statistics/typical-domestic-consumption-values.

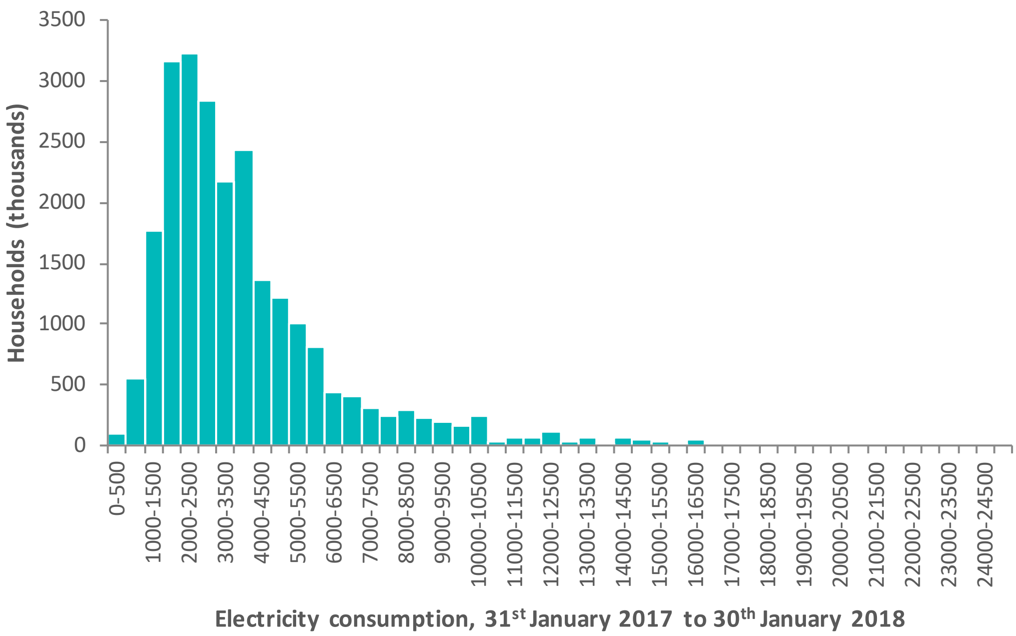
The distribution of the 2017 gas consumption for households can be seen in Figure 3.1, and for electricity consumption in Figure 3.2.

Figure 3.1: Distribution of annual gas consumption, mid-June 2017 to mid-June 2018



Base: all households with gas meter point data (n=1,770). (Annex Table)

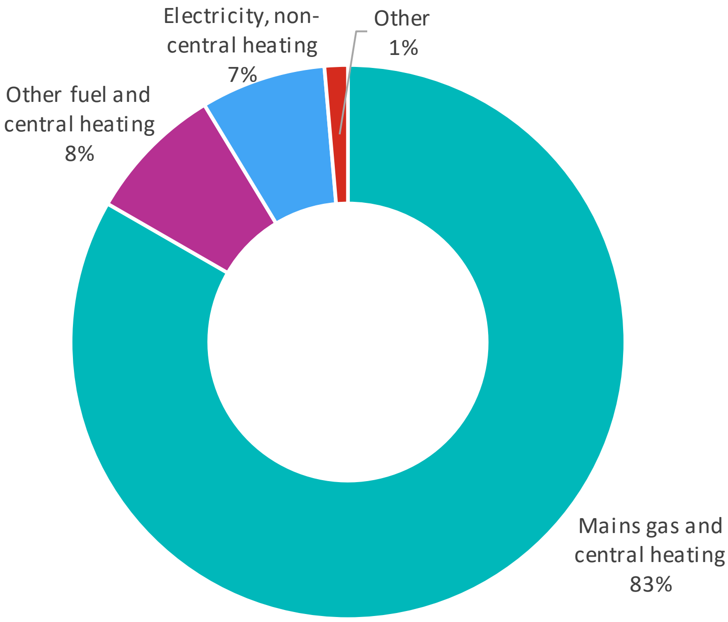
Figure 3.2: Distribution of annual electricity consumption, 31st January 2017 to 30th January 2018



Base: all households with electricity meter point data (n=1,994). (Annex Table)

Figure 3.3 shows the percentage of households split by fuel type and heating system at Interview 1. In total, 83% of households reported heating their homes using gas central heating, 8% used central heating with an 'other' fuel (such as oil, bottled gas or through communal heating), and 7% reported using electric storage heaters or room heaters.

Figure 3.3: Heating system and fuel type of households



Base: all households (n=2,632), Interview 1. (Annex Table)

Note: The percentages in the figure do not sum to 100% due to rounding

3.2 Gas consumption

Based on all households at Interview 1, 83% of households had mains gas central heating. Further analysis of gas consumption was conducted on this sub-group of 1,737 households. The median gas consumption for households with central heating was 12,400 kWh/year, the lower quartile was 8,100 kWh/year, and the upper quartile was 16,600 kWh/year.

3.2.1 Multi-variate analysis of gas consumption

Stepwise linear regression, was used to answer the following research questions[6], specifically for households with gas central heating:

[6] It was not possible to analyse changes in gas consumption in accordance with changes in external temperatures as the meter point gas consumption data was weather corrected. Furthermore, sample sizes were too small to explore changes in consumption when internal temperatures changed.

- To what extent do different groups of variables explain variations in annual gas consumption?
- Which dwelling, household and heating behavioural factors have the greatest impact on the variability of gas consumption?
- To what extent do different groups of variables explain variations in annual gas consumption, when comparing the fuel poverty status of households?

3.2.1.1 Overview

In total, five models were created based on regression analysis. The first three models were produced for dwelling, household, and EFUS heating behaviours individually; then two combined models were created based on the results of the individual models.

Table 3.2 indicates the variables considered for each model. Variables in bold indicate those that remained in the model after stepwise analysis; these were the most important of those considered at explaining variability in gas consumption. More details on the variables and the model outputs can be found in Appendix A.

Table 3.2: Derived variables used in the individual models of gas consumption

Model 1: Dwelling	Model 2: Household	Model 3: EFUS	Model 4: Dwelling and household	Model 5: Dwelling, households and EFUS
Dwelling type	**Tenure**	Heating season start	**Dwelling type**	Dwelling type
Floor area	**Household size**	**Central heating control**	**Floor area**	**Floor area**
Region	**Pensioner present**	**Thermostat temperature**	**Region**	**Region**
Boiler type	Child present	Vary thermostat	**Insulation measures**	Insulation measures
Wall type	**Income**	TRVs present	**SAP rating**	**SAP rating**
Insulation measures	Long-term sick or disabled	Non-regular heating	Tenure	Tenure
SAP rating	Employment status	**Daily heating hours**	**Household size**	**Household size**
		Unheated habitable rooms	**Pensioner present**	**Pensioner present**
		Gas secondary heating	**Income**	**Income**
		Non-gas secondary heating		**Central heating control**
		Thermal comfort		**Thermostat temperature**
		Weekday daytime occupancy		**Daily heating hours**
		Affordability of energy bills		Unheated habitable rooms
				Gas secondary heating
				Non-gas secondary heating

Base: all households with gas central heating and meter point data (n=385).

3.2.1.2 Summary of models

The following individual models were created:

- Dwelling: The final dwelling model contained the explanatory variables dwelling type, floor area, region, insulation measures, and SAP rating; and explained 46%[7] of the variability in gas consumption
- Household: The final household model contained the explanatory variables tenure, household size, presence of a pensioner, and income; explaining 25% of the variability in gas consumption
- EFUS: The final EFUS heating model contained the explanatory variables central heating control, thermostat temperature, daily heating hours, unheated habitable rooms,

[7] Based on the adjusted R^2 value from the model

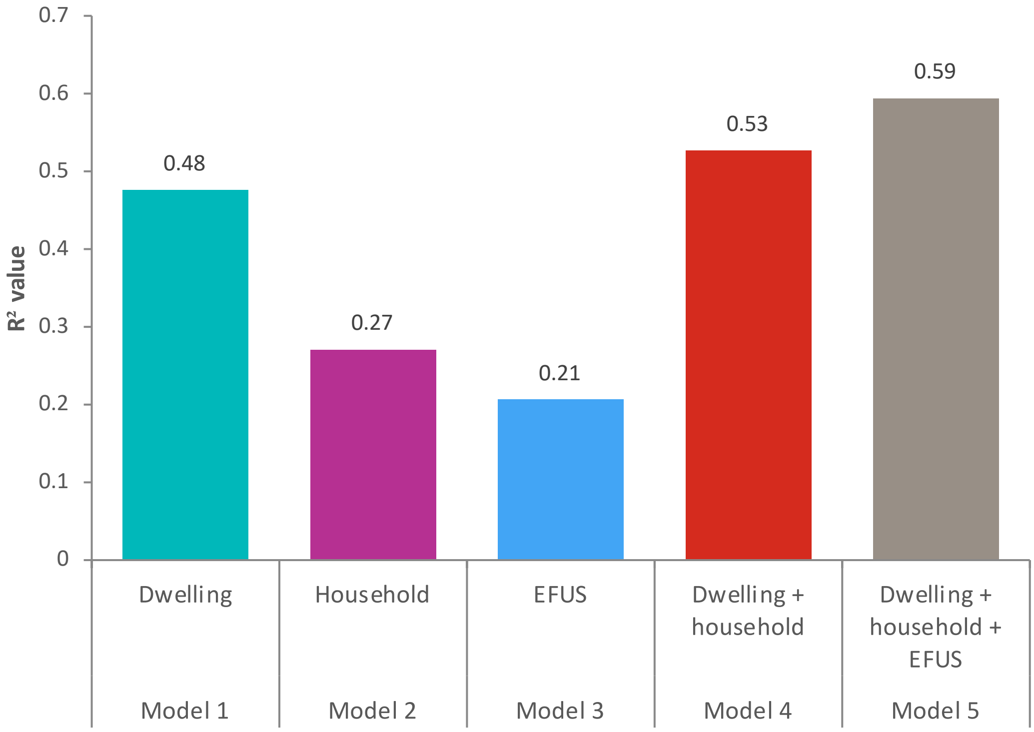
gas secondary heating and non-gas secondary heating; and explained 19% of the variability in gas consumption

The following combined models were created:

- Dwelling and household: The final model combining dwelling and household factors contained the explanatory variables dwelling type, floor area, region, insulation measures, SAP rating, household size, presence of a pensioner and income; and explained 50% of the variability in gas consumption
- Dwelling, household and EFUS: The final model combining all groups of variables contained the explanatory variables floor area, region, SAP rating, household size, presence of a pensioner, income, central heating control, thermostat temperature, daily heating hours, and gas secondary heating. The final model explained 58% of the variability in gas consumption

Figure 3.4 compares the multiple R2 values for each of the models. Of the individual models, dwelling characteristics explained the most variability (48%) in gas consumption, while EFUS heating variables explained the least (21%). Addition of household characteristics to the dwelling model did not add much to the explanation of the variability in gas consumption, however the addition of EFUS heating variables increased the explanatory power leading to a final model that explained around 59% of the variability in gas consumption.

Figure 3.4: R2 values for each of the gas models



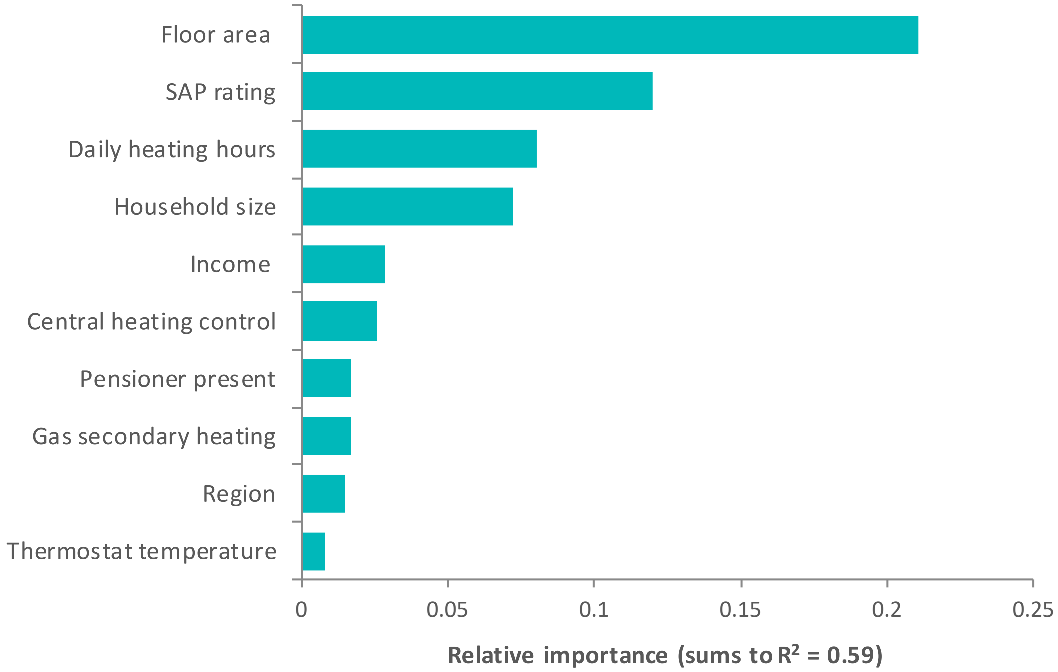
Base: all households with gas central heating and meter point data (n=385).

3.2.1.3 Final model

The output from the final model (considering dwelling, household and heating behaviours) along with a histogram showing fitted and metered gas consumption values are shown in Appendix A. The fitted values show that the model generally predicted gas consumption well but was poor at predicting very low or high gas consumption values. This is not unexpected as it is likely there are unpredictable behaviours that are difficult to capture in this analysis. Analysis of the types of household that were more likely to 'under-consume' or 'over-consume' in terms of energy use, is reported in Chapter 6.

An indication of the relative importance[8] of each variable in the final model is shown in Figure 3.5. It can be clearly seen that floor area was the most important variable in predicting gas consumption. Other notably important variables included the SAP rating, daily heating hours and the household size. All other factors included in the model alone explained little of the variability in gas consumption. These results are unsurprising; the floor area is a key driver of the space heating requirement in a household as it impacts on the fabric heat loss and ventilation heat loss calculations. The inclusion of household size within the final model as one of the more important factors, indicates that the number of people in the household was important in explaining part of the variability in gas consumption, in the context of the other variables in the model (e.g. the floor area).

Figure 3.5: Relative importance of each derived variable in the final gas model



Base: all households with gas central heating and meter point data (n=385).

[8] The sum of the relative importance of each variable equals the multiple R^2 value (0.59).

Accounting for the most important factors in the model, the impact on gas consumption[9] was as follows:

- Floor area: gas consumption (in kWh/year) increased as the usable floor area increased. Based on the bivariate analysis, dwellings with a floor area of 140 m² or over, used 3.3 times more gas than dwellings with a floor area of less than 50 m². Within the multi-variate model, the effect of floor area was much lower although still the main driver of gas consumption, after controlling for other variables in the model
- SAP rating: gas consumption increased as the energy efficiency of the dwelling decreased. In the bivariate analysis, for dwellings with an EPC band of E or lower, the gas consumption was 1.6 times greater than dwellings with an EPC band of C or higher. Within the model a similar effect was seen, indicating that the impact on the gas consumption from the energy efficiency rating was not well explained by the other variables in the model
- Daily heating hours: gas consumption increased as daily heating hours increased. In the bivariate analysis, for each extra hour the heating was on, gas consumption increased by 460 kWh/year. A similar trend was observed in the model, with a reduced effect
- Household size: gas consumption increased with increasing household size. In the bivariate analysis, households with 5 or more people used around 1.6 times more gas than households with one person. This effect was reduced in the model; however, the modelled gas consumption remained the greatest in households with 5 or more people, and lowest for one-person households

The remaining factors in the model were found to have the following impact on gas consumption:

- Increase in gas consumption: with increasing household income; with a pensioner in the household; where secondary gas heaters were used in the household; and with increasing thermostat temperature
- Decrease in gas consumption: for dwellings in the South, compared with the North; for households using a switch on their boiler[10], compared with a timer control

Differences between the final model coefficients, and the equivalent coefficients when running bivariate analysis is detailed in Appendix A.

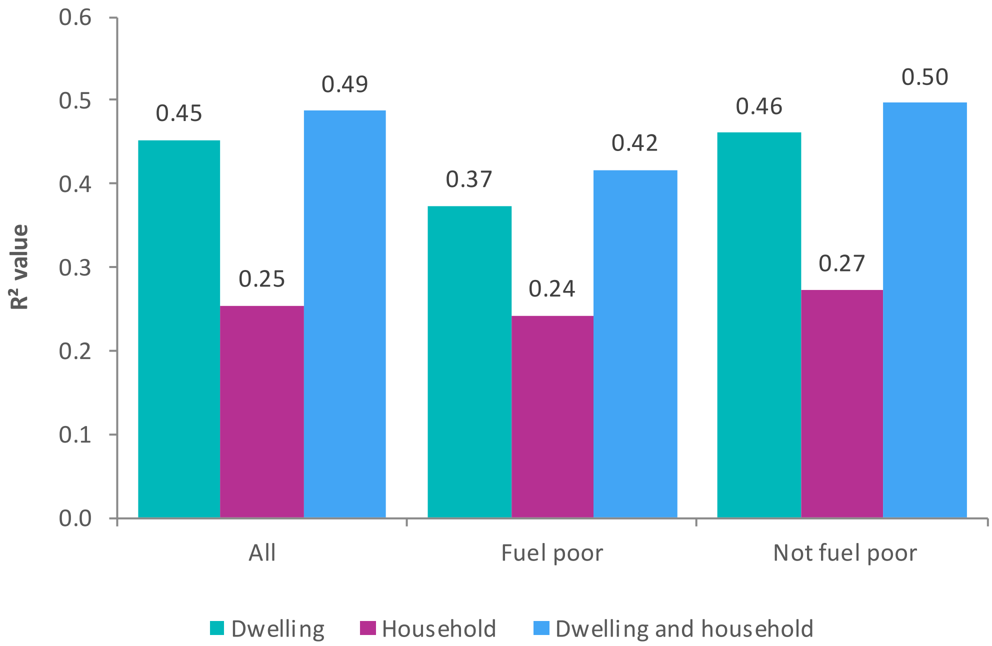
[9] Considering results from bivariate analysis on gas consumption (kWh/year), followed by a comparison of the coefficients. See Appendix A for more information on the coefficients from the multi-variate and bivariate models.
[10] Based on information collected on central heating control at Interview 2, where timer control includes households with smart heating or multiple controls due to small sample sizes.

3.2.1.4 Fuel poverty

Analysis of the impact of dwelling and household characteristics[11] on the variability in gas consumption was also run separately on 'fuel poor', 'non-fuel poor' and 'all household' datasets.

Overall, the same patterns were preserved across the three sub-sets, with dwelling characteristics explaining more of the variability in gas consumption, than household characteristics alone (Figure 3.6). However, while the household characterisics explained a similar amount of the variation in electricity consumption for both fuel poor and non-fuel poor households, the R2 value was lower for the fuel poor dwelling characteristics model. This indicates that for households in fuel poverty, dwelling characteristics were not as good at explaining the variability in gas consumption, as they were for households not in fuel poverty. Further information on these comparisons can be found in Appendix A, including analysis to account for different sample sizes, and a like-by-like comparison of R2 values from the full models. The characteristics of the fuel poor are discussed further in the EFUS 'Fuel Poverty' report.

Figure 3.6: R2 values for each of the models, by fuel poverty status



Base: all households with gas central heating and meter point data (n=1,735 for all households, n=430 for fuel poor, n=1,305 for non-fuel poor).

[11] Small samples prevented analysis of heating behaviours

3.3 Electricity consumption

Based on all households at Interview 1, it is estimated that 8% of households used electricity as their main fuel, in line with the percentage of households recorded in the EHS 2017[12]. For 2010 and 2017, Table 3.3 highlights the differences in the median electricity consumption, alongside the upper and lower quartiles, for: households where electricity was not the main heating fuel, and households where electricity was used as the main heating fuel. The electricity consumption of households where electricity was not the main heating fuel decreased between 2010 and 2017, whereas the electricity consumption of households who had electric main heating, stayed roughly the same.

At Interview 1, the following were more likely to use electricity as their main fuel: dwellings in rural locations (16%) compared with urban locations (7%); less energy efficient dwellings (EPC band E: 12%; F or G: 40%) compared with more energy efficient dwellings (EPC band A to C and D: both 5%); flats (22%) compared with houses (4%); and dwellings with smaller floor areas (<50 m2: 22%) compared with larger floor areas (2% to 11%). Further analysis in this section will focus on the electricity consumption of households where electricity was not used as the main fuel.

Table 3.3: Annual electricity consumption by main heating fuel type, 2010 and 2017

	Electricity consumption (kWh/year)			
	Gas/other		Electricity	
	2010	2017	2010	2017
Percentile				
25%	2,200	2,000	4,500	4,500
50% (median)	3,400	2,900	7,000	6,900
75%	4,900	4,200	10,100	10,200

Base: all households with meter point data (n=1,283 for gas/other 1st October 2009 to 30th September 2010, n=139 for electricity 1st February 2010 to 31st January 2011), 2010; (n=1,809 for gas/other mid-June 2017 to mid-June 2018; n=185 for electricity 31st January 2017 to 30th January 2018), 2017.

3.3.1 Multi-variate analysis of electricity consumption

In a similar way to the analysis of gas consumption, stepwise linear regression was used to answer the following research questions for households where electricity was not used as the main heating fuel:

- To what extent do different groups of variables explain variations in annual electricity consumption, and how does this differ to gas?
- Which factors related to appliance ownership and use, and dwelling and household characteristics, have the greatest impact on the variability of electricity consumption? Is fuel poverty status important?

[12] https://www.gov.uk/government/statistical-data-sets/energy-performance

3.3.1.1 Overview

In total, five models were created based on regression analysis. The first two models were produced individually for dwelling and household characteristics. The third individual model comprised other relevant variables: those related to appliance ownership and usage patterns, occupancy patterns and affordability of energy bills (termed EFUS appliance model). Finally, two combined models were created based on the results of the individual models.

Table 3.4 indicates the variables considered for each model. Variables in bold indicate those that remained in the model after stepwise analysis; these were most important in explaining variability in electricity consumption. More details on the variables and model outputs are in Appendix B.

Table 3.4: Derived variables used in the individual models of electricity consumption[13]

Model 1: Dwelling	Model 2: Household	Model 3: EFUS appliances	Model 4: Dwelling and household	Model 5: Dwelling, households and EFUS
Dwelling type	**Tenure**	**Cooling appliance use**	**Dwelling type**	**Dwelling type**
Floor area	**Household size**	**Electric water heating**	**Floor area**	**Floor area**
Region	Pensioner present	**Number of wet and cold appliances**	**Insulation measures**	**Insulation measures**
Wall type	**Child present**	**American fridge-freezer**	**Tenure**	Tenure
Insulation measures	**Income**	**Three or more TVs**	**Household size**	**Household size**
SAP rating	**Long-term sick or disabled**	**Electric cooking**	Income	Income
	Employment status	Microwave	**Long-term sick or disabled**	**Long-term sick or disabled**
	Fuel poverty	**Smart appliances**	Employment status	**Employment status**
		Energy intensive appliances	Fuel poverty	Fuel poverty
		Low energy light bulbs		**Cooling appliance use**
		Electric secondary heating hours		**Electric water heating**
		Weekly washing loads		**Number of wet and cold appliances**
		Weekly tumble dryer loads		**American fridge-freezer**
		Hours lights on in living room		**Three or more TVs**
		Weekday daytime occupancy		**Electric cooking**
		Affordability of energy bills		**Smart appliances**
				Energy intensive appliances
				Electric secondary heating hours
				Weekly washing loads
				Weekday daytime occupancy
				Affordability of energy bills

Base: all households with electricity meter point data, and gas/other main fuel (n=787).

3.3.1.2 Summary of models

The following individual models were created:

- Dwelling: The final dwelling model contained the explanatory variables dwelling type, floor area, and insulation measures; and explained 22%[14] of the variability in electricity consumption
- Household: The final household model contained the explanatory variables tenure, household size, child present, income, long-term sick or disabled, employment status and fuel poverty; explaining 35% of the variability in electricity consumption
- EFUS appliance model: The final EFUS model contained the explanatory variables cooling appliance use, electric water heating, number of wet and cold appliances, American fridge-freezer, three or more TVs, electric cooking, smart appliances, energy intensive electrical appliances[15], electric secondary heating hours, weekly washing

[13] Child present not included in the combined models (4 and 5) due to collinearity with household size
[14] Based on the adjusted R^2 value from the model
[15] Energy intensive electrical appliances are classified as those that use large amounts of energy e.g. saunas or workshop machinery. More information is included in the 'Lights, Appliances and Smart Technologies' report.

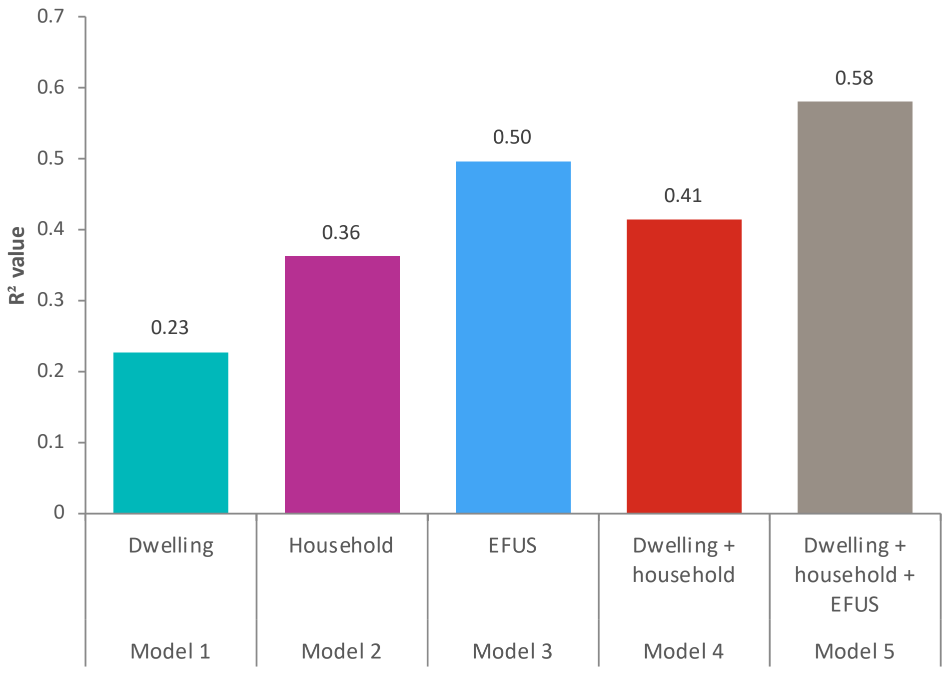
loads, weekday daytime occupancy and affordability of energy bills; and explained 49% of the variability in electricity consumption

The following combined models were created:

- Dwelling and household: The final model combining dwelling and household factors contained the explanatory variables dwelling type, floor area, insulation measures, tenure, household size, and long-term sick or disabled; and explained 40% of the variability in electricity consumption
- Dwelling, household and EFUS appliance model: The final model combining all groups of variables contained the explanatory variables dwelling type, floor area, insulation measures, household size, long-term sick or disabled, employment status, cooling appliance use, electric water heating, number of wet and cold appliances, American fridge-freezer, three or more TVs, electric cooking, smart appliances, energy intensive electrical appliances, electric secondary heating hours, weekly washing loads, weekday daytime occupancy, and affordability of energy bills. The final model explained 56% of the variability in electricity consumption

Figure 3.7 compares the multiple R2 values for each of the models. Of the individual models, EFUS appliance related variables explained the most variability (50%) in electricity consumption, while dwelling variables explained the least variability in electricity consumption (23%). These results contrast with gas (section 3.2.1.2) which showed the opposite effect. Appliance related variables explained more variability in the electricity consumption on their own (50%), than a combined model with dwelling and household characteristics (41%). With all models combined, the explanatory power was increased, with a final model that explained around 58% of the variability in electricity consumption.

Figure 3.7: The R2 values for each of the electricity models



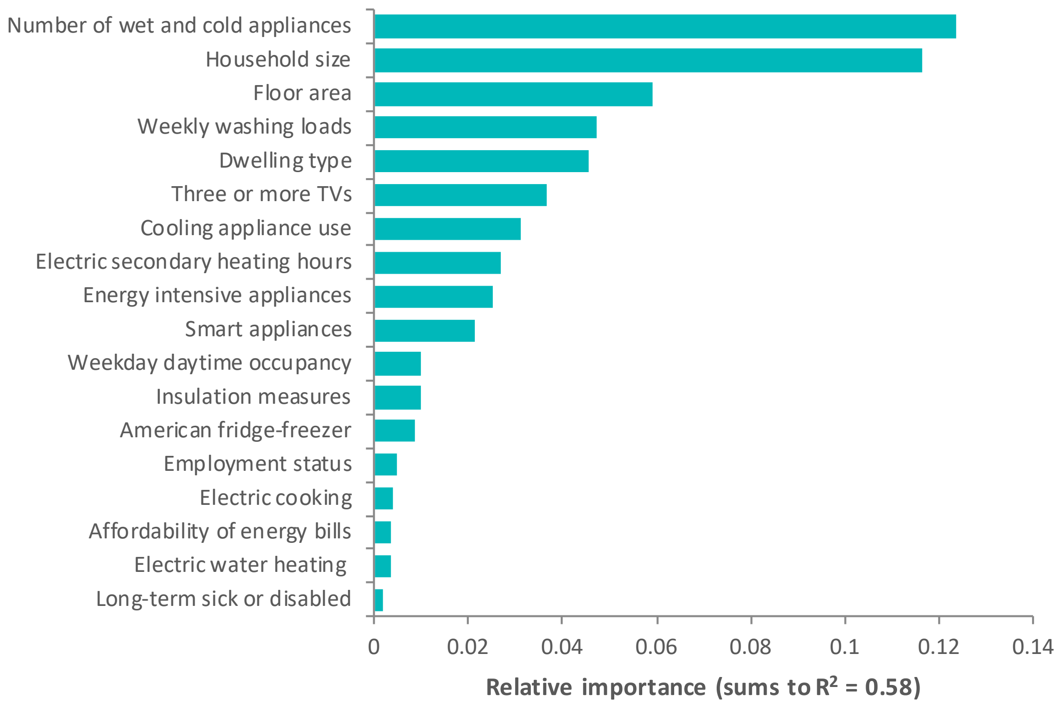
Base: all households with electricity meter point data, and gas/other main fuel (n=787).

3.3.1.3 Final model

The output from the final model (which combined all dwelling, household and appliance related variables) along with a histogram showing fitted and metered electricity consumption values are shown in Appendix B. The fitted values show that the model generally did a good job of predicting electricity consumption, however, was poor at predicting very low or high values, in a similar way to gas (section 3.2.1.3).

In total, there were 18 variables included in the final model for electricity consumption, where only a third of these variables were related to the dwelling or household characteristics. An indication of the relative importance of each of the variables is shown in Figure 3.8. The two most important variables in predicting electricity consumption were the number of wet and cold appliances and household size. Other variables also found to impact electricity consumption included dwelling predictors (e.g. floor area) and appliance ownership and use (e.g. number of washing loads).

Figure 3.8: Relative importance of each derived variable in the final electricity model



Base: all households with electricity meter point data, and gas/other main fuel (n=787).

The household size and number of appliances were most important in explaining the variability in electricity consumption, and the impact on modelled electricity consumption was as follows:

- Number of wet and cold appliances: the electricity consumption was found to increase by 13%, with each addition of a wet or cold appliance, while accounting for the household size
- Household size: the electricity consumption was greatest in households with 5 or more people where it was 48% higher than households with only one person, while accounting for the number of wet and cold appliances

Other groups of factors considered important in the model included:

- Floor area and dwelling type: Greater electricity consumption was observed with increasing floor area, and in detached dwellings compared with flats
- Number of washing loads, cooling appliance use, and hours of secondary electric heating: Greater reported appliance use led to an increase in the annual electricity consumption
- High number of TVs, energy intensive appliances and smart appliances: Electricity consumption increased with increased ownership of appliances

The remaining factors in the model had smaller relative importance values, and therefore the coefficients should be interpreted with more caution, they included: occupancy related variables (reported weekday occupancy, employment status, long-term sick or disabled) indicating an increase in electricity consumption when someone is in during the day; number of insulation measures; presence of an American fridge-freezer or electric cooking appliances; electric water heating; and affordability of energy bills.

The fuel poverty status of households was not found to be an important factor in explaining the variability in electricity consumption, when considering other variables within the final combined model. Based on bivariate analysis, fuel poor households were found to use around 10%[16] more electricity than households not in fuel poverty, however, it is likely that this is influenced by characteristics of the households who were more likely to be in fuel poverty (for example fuel poor households tend to be larger). In addition, households with electricity as the main heating fuel (excluded from the multi-variate analysis) were more likely to be in fuel poverty: at Interview 1, 20% of households with electricity as the main heating fuel were in fuel poverty, compared with 10% of households with mains gas.

Differences between the final model coefficients, and the equivalent coefficients when running bivariate analysis is detailed in Appendix B.

[16] Note this is based on the sample used in the multi-variate analysis (n=787)

3.4 Detailed gas consumption

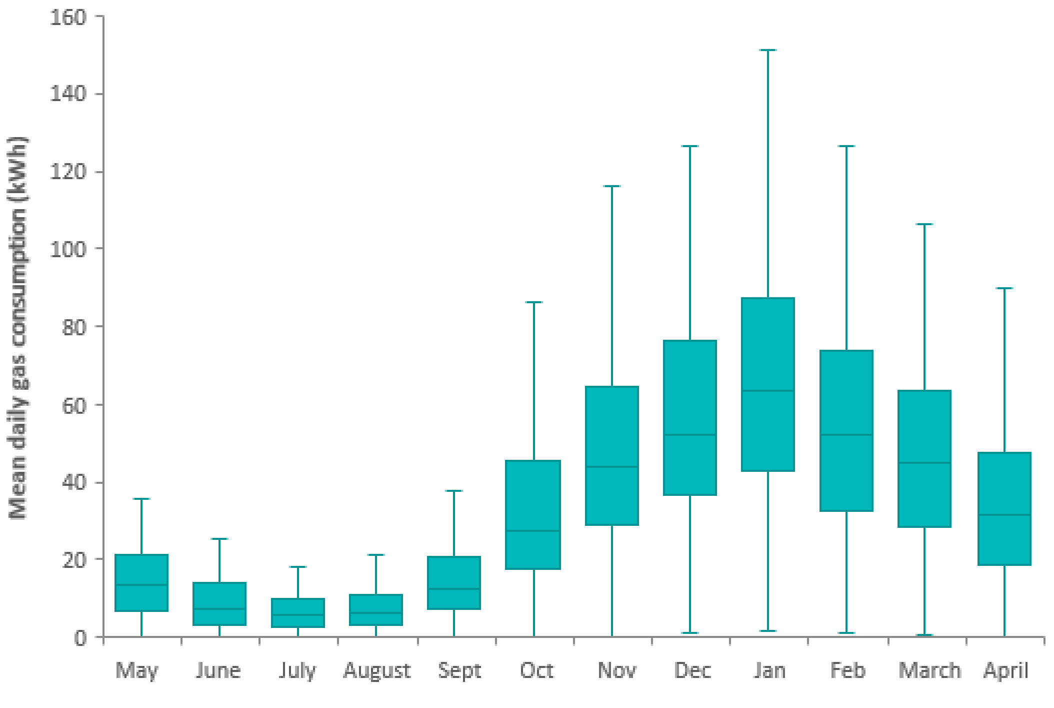
Detailed gas consumption was collected in a sub-set of 143 households, for the monitoring period May 2018 to April 2019[17]. Daily and hourly averages have been calculated, and used to:

- Assess how household gas consumption changes throughout the year
- Analyse variations in gas consumption throughout the day, during the heating season
- Investigate the impact of the coldest week of the year on gas consumption

3.4.1 Seasonal gas consumption

Figure 3.9 shows the spread of daily averages of gas consumption, for each month of the year.

Figure 3.9: Boxplot of mean daily gas consumption for each month from May 2018 to April 2019



Base: all households with gas detailed consumption data for each month (n=96–139).

During the summer months, gas consumption remained low for households, with the median daily gas consumption ranging between 6 and 7 kWh. There was a steady increase in the median daily gas consumption from September to January, and a decrease from January to May. These results are in line with the expected increase in gas consumption over the EFUS heating season, October to April, compared with the summer months. The coldest mean external temperatures observed in winter 2018/19 were in January (December 7.2°C; January

[17] Annex tables containing the underlying data for this section can be found in Tables_3_4.xls.

4.3°C; February 6.9°C)[18]. There was also a large range in daily gas consumption during the EFUS heating season (from 27 kWh/day in October to 64 kWh/day in January), reflecting the variety of gas use throughout the winter, dependent on dwelling and household characteristics. This variance is explored in the next section.

3.4.2 Daily profiles

For each hour in the day, the median gas consumption was calculated for different dwelling and household groups, and for different heating behaviours. These results have been plotted, to see how gas consumption varied throughout the day for the different groups. Key findings have been illustrated through Figures 3.10 to 3.17, focusing on the EFUS heating season and factors that were important in explaining the variability in gas consumption (section 3.2).

Due to small samples sizes when split by different groups, it is important that the results should be interpreted as indicative only. Notes have been included in the footnote of figures where individual group sample sizes drop below 30 cases.

3.4.2.1 Dwelling characteristics

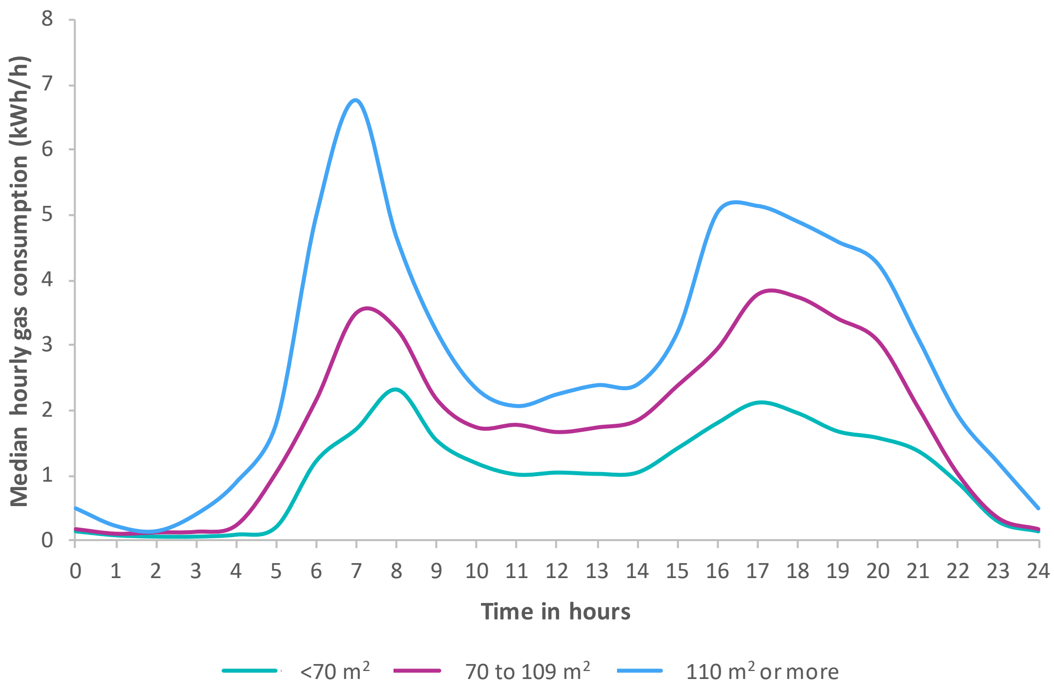
The floor area of the dwelling was found to be the most important factor in explaining variability in annual gas consumption. Figure 3.10 shows how gas consumption varied throughout the day depending on the floor area of the dwelling. We see a direct relationship between gas consumption and floor area in agreement with the multi-variate analysis; households in dwellings with the smallest floor area had the lowest gas consumption throughout the day while households in dwellings with the largest floor areas had the highest gas consumption.

Unsurprisingly the consumption pattern for detached dwellings was similar to that found for the largest dwellings, with a larger, sharper peak in the morning and a shallower but prolonged period of usage in the evening. Bungalows, terraces and semi-detached dwellings showed similar levels of consumption, particularly during the evening peak, with flats recording the lowest gas consumption across the whole day.

Figure 3.11 shows how gas consumption varied with the energy efficiency of the dwelling, grouped by EPC band, where households in the least efficient dwellings had the highest gas consumption throughout the day, whilst those in the most efficient dwellings had the lowest. This mirrors the findings from the multi-variate analysis which showed the energy efficiency rating to be important in explaining variability in gas consumption. Interestingly, for the least energy efficient dwellings (EPC band E to G), the evening peak consumption was higher than the morning peak, which was not observed for dwellings in other EPC bands.

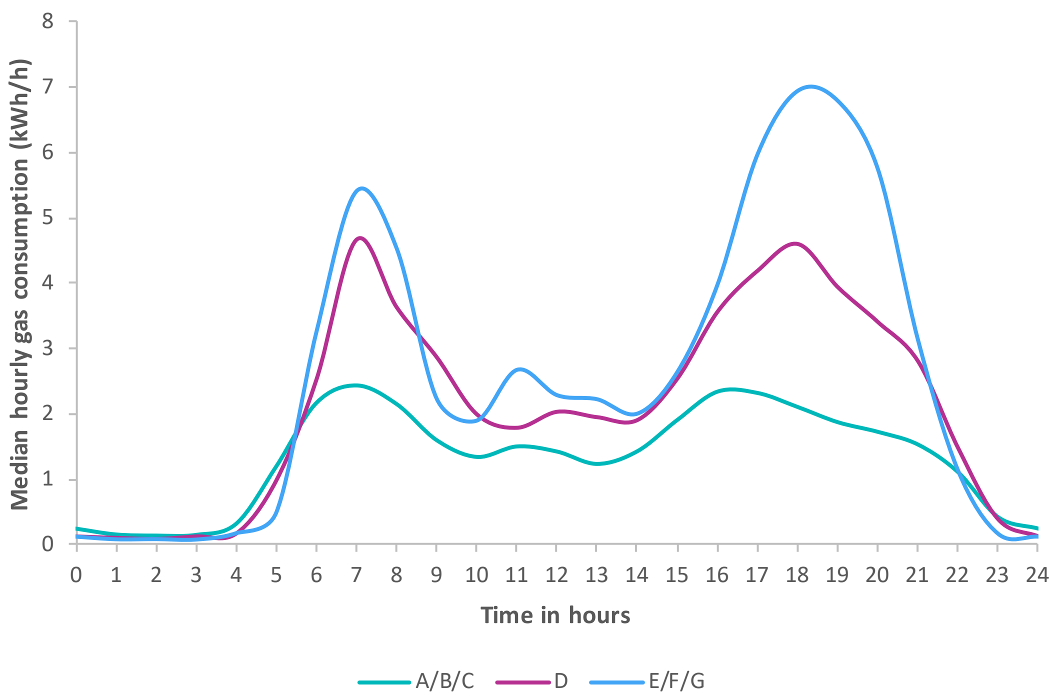
[18] The external monthly average temperatures are shown in Figure 3.1 of the ‘Thermal Comfort, Ventilation, Damp and Mould’ report.

Figure 3.10: Median profile of mean hourly gas consumption for the EFUS heating season, by floor area



Base: all households with detailed gas consumption data over the EFUS heating season (n=141).

Figure 3.11: Median profile of mean hourly gas consumption for the EFUS heating season, by EPC band



Base: all households with detailed gas consumption data over the EFUS heating season (n=107). Note: E-G profile based on a small sample size (n=10), indicative only.

3.4.2.2 Household characteristics

The household size was found to be the most important household characteristic in explaining variability in annual gas consumption and Figure 3.12 shows how gas consumption varied throughout the day by the number of occupants. The same general trend is seen for all households; two main peaks in consumption, one in the morning and one in the evening. For households with one person there were less defined peaks and lower levels of gas consumption in the morning and evening, compared with larger households. Differences between larger households were less clear.

Gas consumption was found to vary across households in different income quintiles, where households in the highest income quintile showed the highest level of gas consumption in the morning and evening periods, compared with households with lower incomes. In addition, households in the lowest income quintile had the lowest and latest morning peak compared with households with higher incomes.

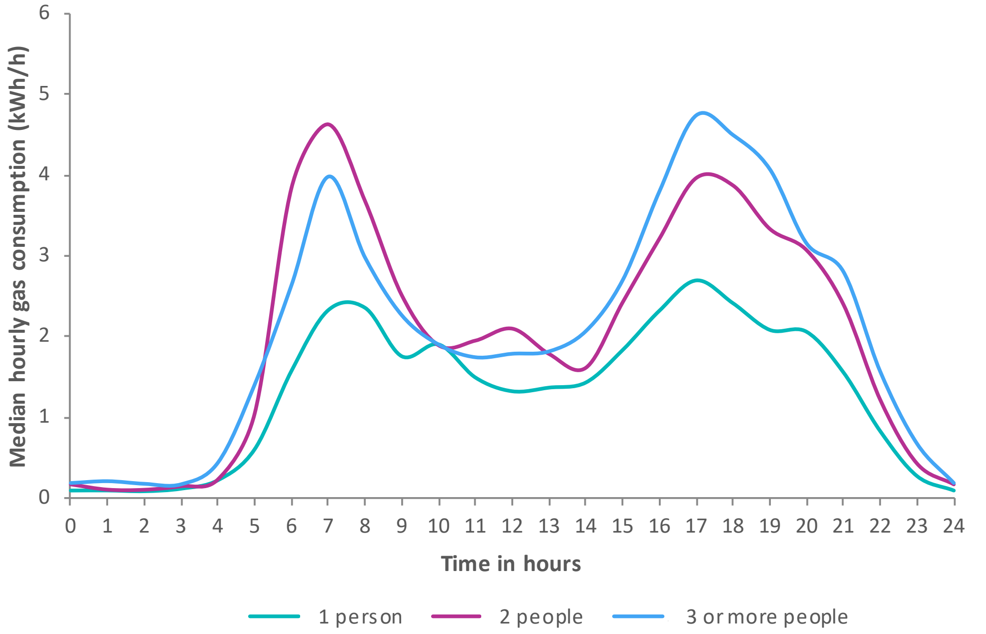
Households in higher income quintiles were less likely to be at home between 9am and 5pm than households in lower income quintiles. The influence of daytime occupancy on gas consumption can be observed in Figure 3.13. Although not found to be important in explaining variability in gas consumption[19], it can be seen that household occupancy influences when gas is used throughout the day, with clear differences between households who reported being at home between 9am and 5pm, compared with households where the occupancy pattern was either variable, or they were not in during these times.

3.4.2.3 Fuel poverty

For households in the detailed gas consumption subset, households in fuel poverty had greater levels of gas consumption in the morning and throughout the day, compared with households not in fuel poverty (Figure 3.14). This result is likely influenced by the types of household that make up the fuel poor group, as fuel poor households were larger and more likely to be in during the day. The nature of the LIHC definition also means that they were more likely to live in less efficient dwellings which, on average, result in higher energy costs.

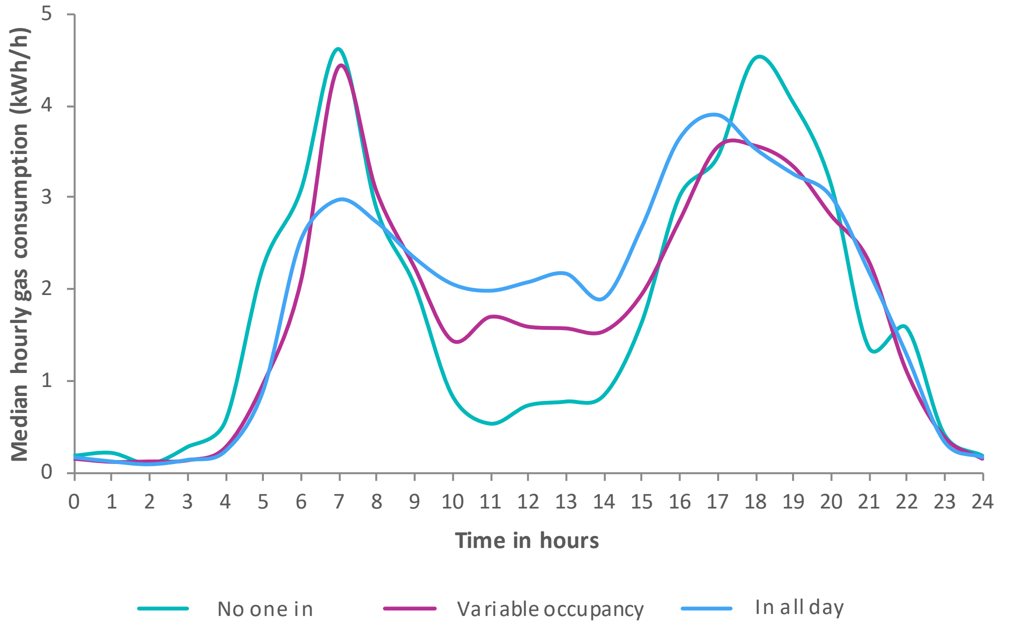
[19] Based on the occupancy provided at Interview 2

Figure 3.12: Median profile of mean hourly gas consumption for the EFUS heating season, by household size



Base: all households with detailed gas consumption data over the EFUS heating season (n=107).

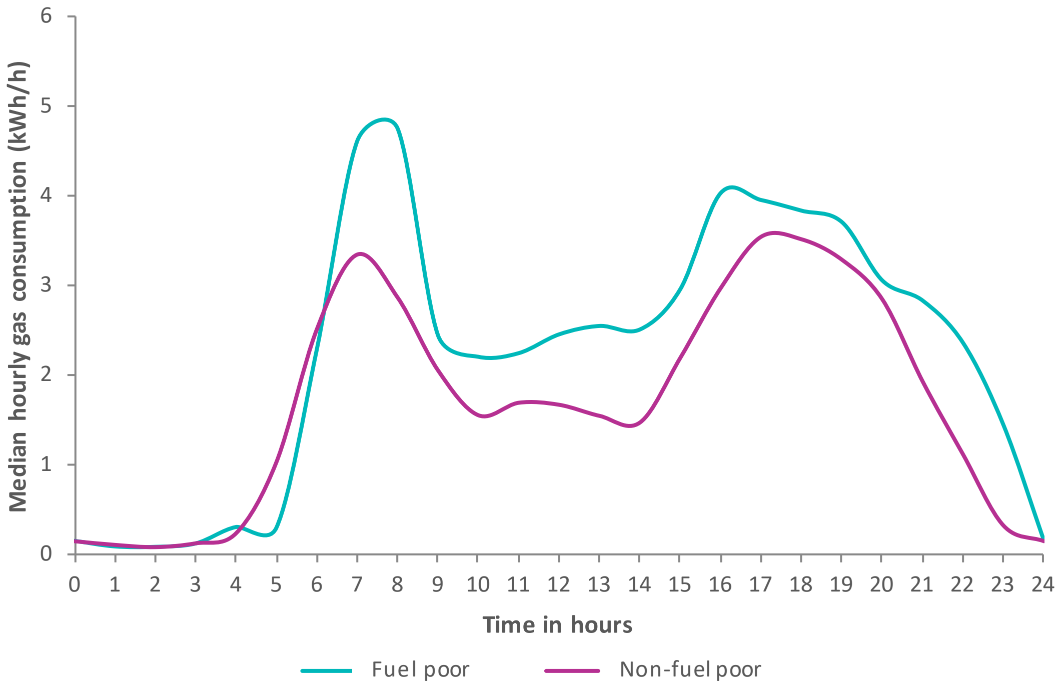
Figure 3.13: Median profile of mean hourly gas consumption for the EFUS heating season, by daytime occupancy during weekdays



Base: all households with detailed gas consumption data over the EFUS heating season (n=107).

Note: 'No one in' profile based on a small sample size (n=9), indicative only.

Figure 3.14: Median profile of mean hourly gas consumption for the EFUS heating season, by fuel poverty (LIHC) status



Base: all households with detailed gas consumption data over the EFUS heating season (n=107).

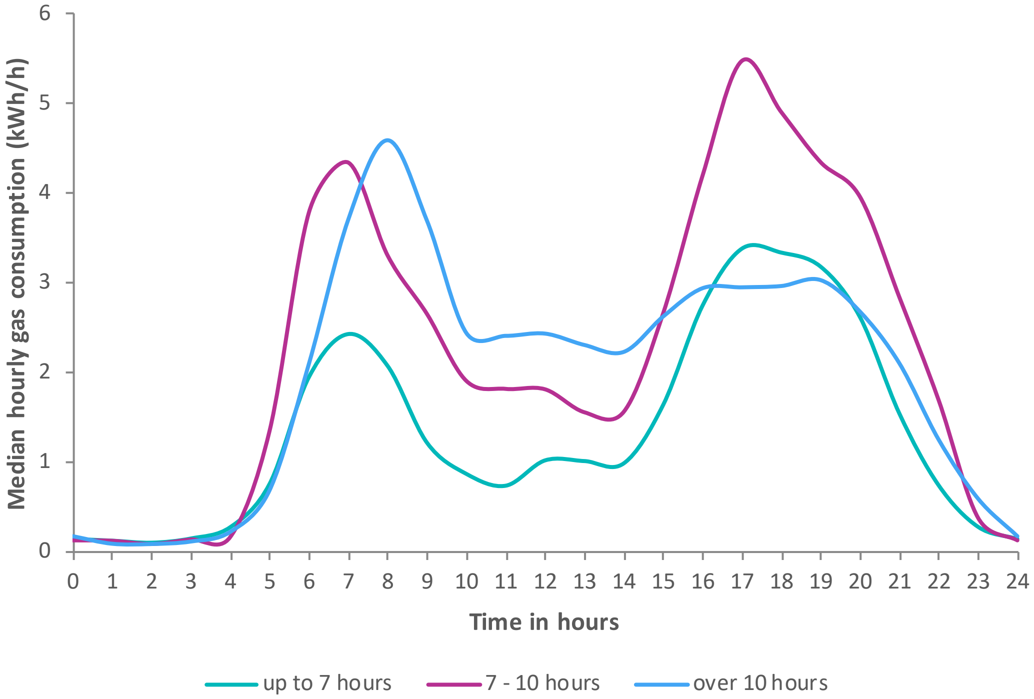
Note: 'Fuel poor' profile based on a small sample size (n=17), indicative only.

3.4.2.4 Heating behaviours

Figure 3.15 shows the variation in gas consumption over the day by number of daily heating hours, which the multi-variate analysis concluded to be one of the most important variables in explaining variability in annual gas consumption. As expected, households that heat their homes for up to 7 hours had the lowest consumption across the day, with higher consumption in the evening peak compared with the morning peak. Households that heated their homes for longer (7 to 10 hours) followed the same trend but with higher consumption in both the morning and evening peaks and throughout the day. However, for households that reported heating their home for over 10 hours, only one clear peak is observed in the morning, followed by a plateau in consumption across the rest of the day. It is likely that these households maintained a constant temperature throughout the day and into the evening instead of needing to reheat their home after it has cooled down throughout the late morning and afternoon.

The mean daily gas consumption was not significantly different between households heating for 7 to 10 hours and households heating their home for over 10 hours, which may be reflective of the types of dwelling that were represented in this unweighted exploratory analysis. In addition, there was no significant difference in mean daily gas consumption by the number of heating periods. The multi-variate analysis of annual gas consumption for households with gas central heating in 2017 (section 3.2) showed an increase in gas consumption with daily heating hours, and it is recommended that further work is conducted to compare daily and hourly gas consumption between different heating periods, for similar dwellings and households.

Figure 3.15: Median profile of mean hourly gas consumption for the EFUS heating season, by daily heating hours

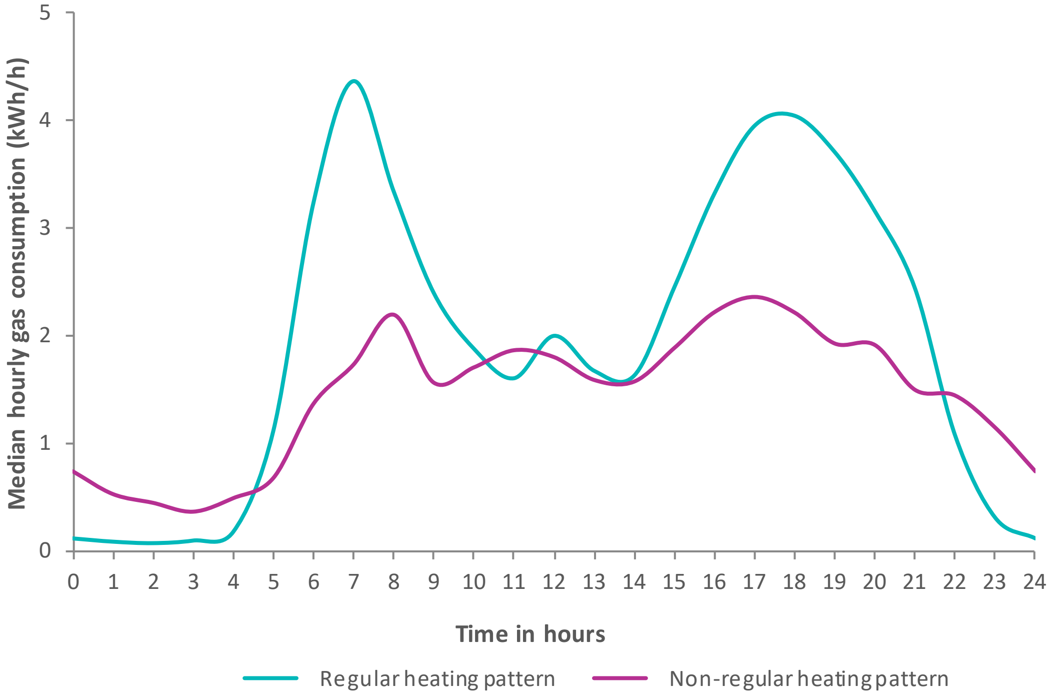


Base: all households with detailed gas consumption data over the EFUS heating season and reported heating hours over winter (n=99).

Figure 3.16 shows the variation in gas consumption throughout the day according to whether the household heated their home on a non-regular basis. The trend of two clear peaks in consumption, one in the morning and one in the evening, was observed in households that had a regular heating pattern. However, the profile for households with non-regular heating patterns[20] was much flatter; there was still evidence of a morning and an evening peak, although in both cases the peaks were shallower, and the period of peak consumption much shorter. The profile suggests that households that heated their home on a non-regular basis were more likely to use it at any time throughout the day rather than in defined periods. For households who reported regular heating patterns, the daily gas consumption was split by the reported heating periods and is shown in Figure 3.17. Here the differences can clearly be observed between households reporting using their heating once, twice, or three or more times throughout the day.

[20] Non-regular heaters at Interview 3 were those that responded ‘no’ to whether they had the main heating system on at regular times of the day, plus households with a timed main heating system who responded ‘no typical heating pattern’ to the number of heating periods.

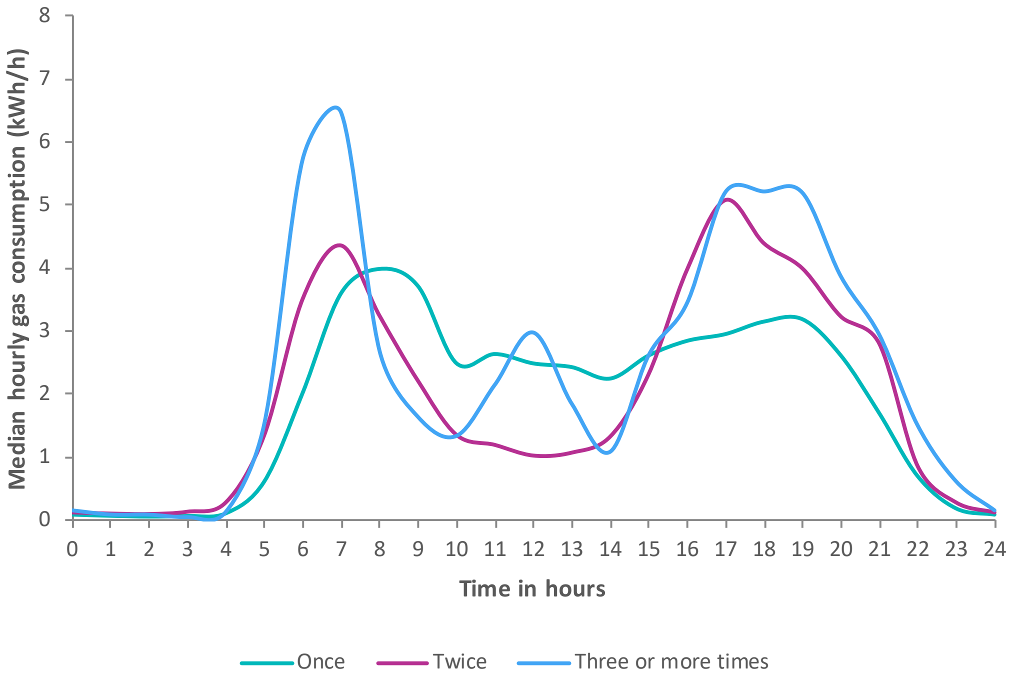
Figure 3.16: Median profile of mean hourly gas consumption for the EFUS heating season, by heating pattern



Base: all households with detailed gas consumption data over the EFUS heating season (n=107).

Note: 'Non-regular heaters' profile based on a small sample size (n=24), indicative only.

Figure 3.17: Median profile of mean hourly gas consumption for the EFUS heating season,



by heating periods

Base: all households with detailed gas consumption data over the EFUS heating season and reported heating periods (n=83).

Note: 'Once' and 'Three or more times' profiles based on a small sample size (n=24, n= 13), indicative only.

3.4.3 Gas consumption in the coldest week

This section reports on the analysis of the daily average gas consumption recorded in the coldest week of the year (2018/19) and the weeks surrounding this. Due to small samples, the analysis presented here is unweighted and should be considered as exploratory analysis. Future work in this area is required to corroborate these findings. The following were examined:

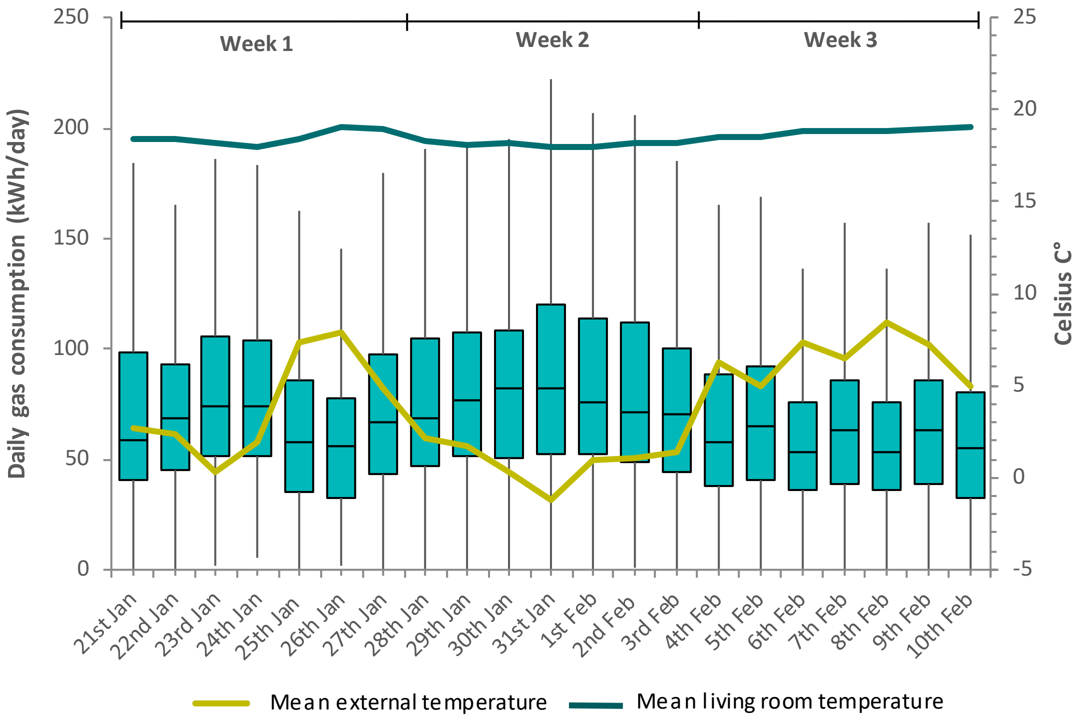
- The difference in gas consumption, external temperatures and internal temperatures between the coldest week, warmer weeks either side and the winter 2018/19 average
- The proportion of households with greater gas consumption in the coldest week
- The types of household less likely to increase their gas consumption in the coldest week

The coldest week, overlapping with the detailed gas consumption monitoring period, began on Monday 28th January 2019 and finished on Sunday 3rd February 2019. The average temperature for this period, for all households with temperature data, was 0.9°C. While this was the coldest spell in 2018/19, this was not as cold as the period in February 2018 (mean external temperature in England of -0.9°C) termed by the media as the 'Beast from the East'. The mean external temperatures were significantly colder in the coldest week, compared with the week prior to this (21st to 28th January 2019: 3.9°C) and the week after (4th to 10th February 2019: 6.5°C).

Mean 24-hour internal temperatures in the living room, and the main bedroom, were significantly colder in the coldest week (living room: 18.1°C; main bedroom: 17.8°C) compared with each week either side (living room: 18.5°C prior, 18.8°C after; main bedroom: 18.2°C prior, 18.5°C after), and it was also reported (see section 5.3 of the 'Thermal Comfort, Ventilation, Damp and Mould' report) that the mean internal temperatures in the coldest week were significantly colder compared with the winter 2018/19 average (0.8°C colder in the living room; 0.9°C colder in the main bedroom).

Exploratory analysis of the daily average gas consumption showed the median daily gas consumption in the coldest week (77 kWh/day) was significantly higher than the week prior to this (66 kWh/day) and the week after (59 kWh/day). Figure 3.18 illustrates the daily change in the gas consumption, corresponding with the changes in external temperatures over the three-week period, from 21st January 2018 to 10th February 2019.

Figure 3.18: Boxplot of mean daily gas consumption with mean external and living room temperatures, 21st January 2019 to 10th February 2019



Base: all households with detailed gas consumption data over the coldest week (n=136); all households with temperature monitoring sub-sample data (n=691, living room temperature) and all households with Met office data (n=746-750, external temperature).

To understand how households may change their heating behaviours from a warmer period, into a colder period, further analysis was focussed on the difference between week 1 and week 2, where for households with daily gas consumption data, the mean external temperature dropped by around 3°C and the mean 24-hour living room temperature dropped by around 0.2°C. On average, households increased gas consumption by 15% between week 1 and week 2, while over a quarter of the sample (27%) increased their gas consumption by 25% or more in the coldest week.

In total, 70% of households increased their gas consumption by at least 5%, between week 1 and week 2. This proportion was not significantly different by: tenure (private/social); household size; age (HRP less than 55/older households); whether a pensioner was present; whether a child was present; weekday occupancy; whether anyone was long-term sick or disabled; nor whether the household was under-occupying their home. This suggests that these households were responding to the cold weather in a similar way.

However, there were notable significant differences among two groups:

- Households in the lowest income quintile were less likely (41%) to increase their gas consumption by 5% or more in the coldest week, compared with 73% of households in higher income quintiles

- Households in fuel poverty (at the 95% level) were less likely (44%) to increase their gas consumption by 5% or more in the coldest week, compared with 70% of households not in fuel poverty

These differences may suggest that low income households were less likely to be able to change how they heat their home in particularly cold periods. Chapter 5 examines this issue further by investigating the types of household who were more likely to struggle to keep up with their energy bills, and the trade-offs made by these struggling households.

4. Household energy costs

Household energy costs have been calculated using information on: the gas and electricity consumption from meter point data; estimates of gas and electricity costs from the tariff comparison rates (TCR); and information on the annual cost of other fuels used by the household, such as oil and wood. This chapter presents the average annual energy costs and looks at household reported information on method of payment and energy suppliers.

4.1 Smart meters, energy suppliers, method of payment and switching

In the Interview 1 survey, households were asked questions on their energy supply, to obtain the following information:

- Whether the household has a smart meter
- The name of the gas and electricity supplier
- The method of payment for gas and electricity
- Whether the household has switched energy supplier or tariff type recently

In the Interview 3 survey the following year, a sub-set of the same households were asked follow-up questions on changes made since Interview 1[21].

4.1.1 Smart meters

At Interview 1, 27% of households reported having a smart gas or electricity meter, and at Interview 3 this proportion had increased to 36% of households[22]. At Interview 1, 21% of households had a smart meter along with an energy display that shows how much electricity/gas the household is using in real time. Since using this display, 69% of households reported using the same amount of energy, while 23% reported using less energy. No significant differences in energy consumption were observed between households who reported using less energy, and those who used the same amount or more.

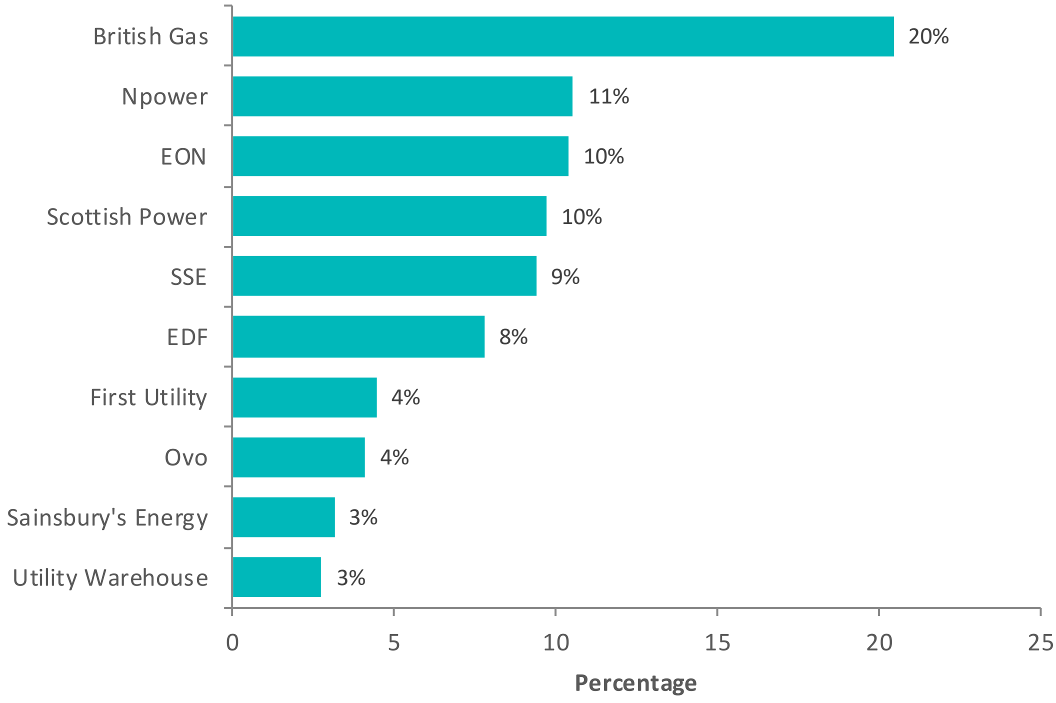
4.1.2 Energy suppliers

At Interview 1, the name of a valid electricity supplier was provided for 98% of households, and the name of a valid gas supplier was provided for 98% of households connected to the gas network. In total, 90% of households reported the same supplier for both gas and electricity,

[21] Annex tables containing the underlying data for this section can be found in Tables_4_1.xls.
[22] SmartEnergyGB reported that 29% of the population had a smart meter in their home (Smart Energy Outlook, March 2019 [https://www.smartenergygb.org/en/-/media/SmartEnergy/essential-documents/press-resources/Documents/Smart-energy-outlook-March-2019.ashx]. Official statistics [https://www.gov.uk/government/collections/smart-meters-statistics#2019] reported 38% of domestic meters operated by large operators were smart or smart-type meters (Q1 data:Figure2data)

and Figure 4.1 shows the top ten reported suppliers, for households with a dual fuel tariff[23]. The 'Big Six' suppliers still retained the largest proportion of households; more than two thirds (68%) of households reported their gas and electricity supplier as one of the 'Big Six' suppliers, and 20% of households reported their energy supplier to be British Gas (also the largest supplier in EFUS 2011 for 27% of households).

Figure 4.1: Top ten reported energy suppliers



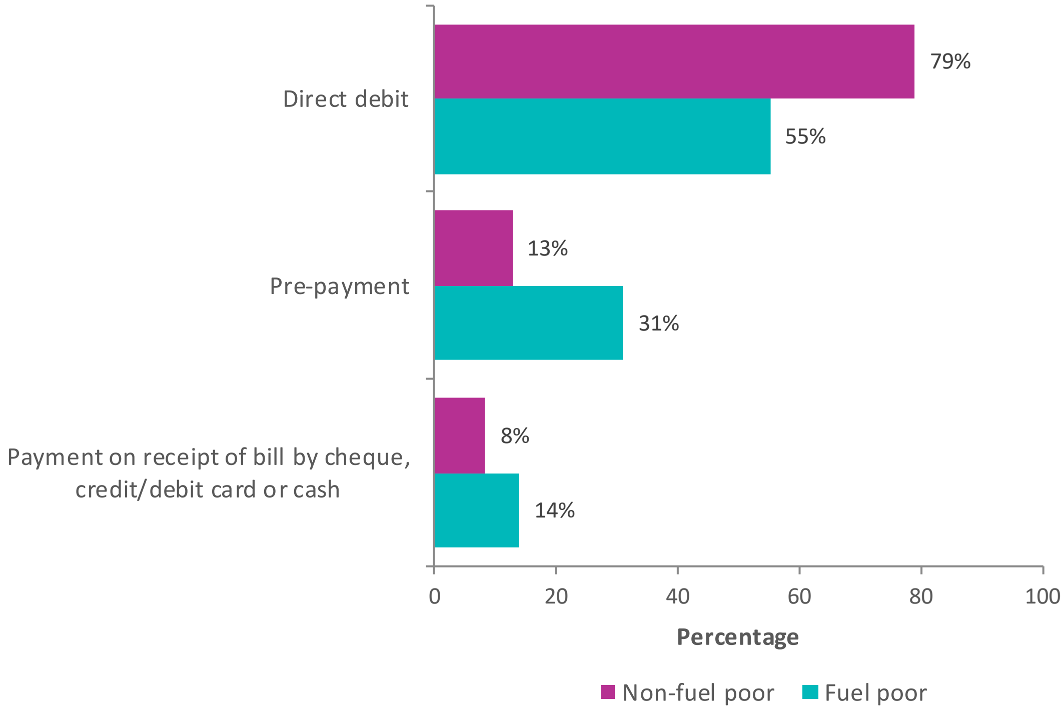
Base: all households with a dual fuel tariff and details of energy supplier (n=1,958), Interview 1. (Annex Table)

4.1.3 Method of payment

Where households knew the method of payment, 76% reported that they paid for their electricity by direct debit, 15% by pre-payment methods and 9% by standard credit. For gas, 77% paid by direct debit, 14% by pre-payment and 9% by standard credit. The electricity method of payment for households differed according to whether they were in fuel poverty. Almost a third (31%) of households in fuel poverty paid for their energy by pre-payment, compared with 13% of non-fuel poor households (Figure 4.2). However, households in fuel poverty with a 'high' fuel poverty gap[24], were more likely to pay by direct debit (68%) and less likely to pay by pre-payment (20%) compared with households with a low to medium fuel poverty gap (direct debit: 51%, 46%; pre-payment: 37%, 36%). This indicates the importance of other factors such as tenure, where housing association and local authority tenures were more likely to pay by pre-payment (50%, 53%) compared with private renters (22%), and again for private renters compared with owner occupiers (3%).

[23] It is assumed that households were on a 'dual fuel' tariff when the supplier was the same for gas and electricity
[24] Based on a banded fuel poverty gap with three weighted categories: 'low' 'medium' and 'high' costs.

Figure 4.2: Electricity method of payment, by fuel poverty



Base: all households (n=2,604), Interview 1. (Annex Table)

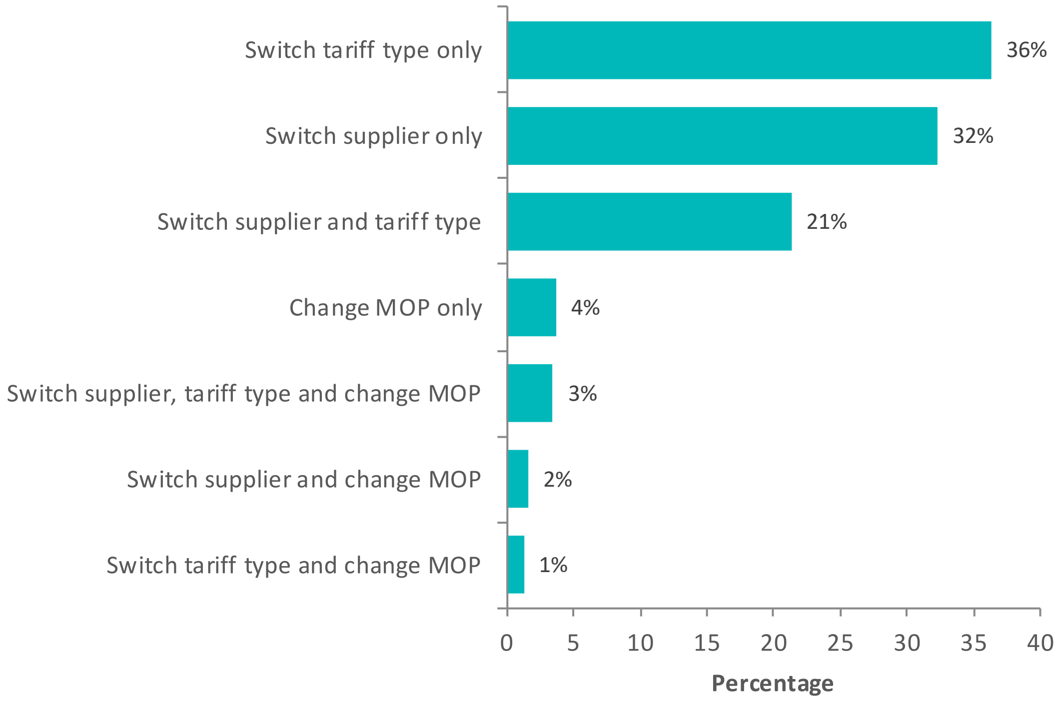
4.1.4 Switching

At Interview 1, households reported on the following types of energy switch in the past 12 months: switching of gas/electricity supplier; switching tariff type; and changing the method of payment. Some 21% of households reported switching their gas or electricity supplier. This is slightly higher than the 18% derived from the Quarterly Energy Prices switching statistics[25], however while EFUS looked at gas and/or electricity switching for households in England, the domestic energy switching statistics reported separate gas and electricity switches for households in Great Britain. Some 23% of households reported switching their tariff type in the past 12 months, yet only 4% of households at Interview 1 reported a change in the way they pay for their energy, and it was found that within this group, a greater proportion of households where the HRP was aged 16-44 changed the way they paid (6%), compared with 2% of households where the HRP was aged 45 or older.

[25] https://www.gov.uk/government/statistical-data-sets/quarterly-domestic-energy-switching-statistics. Table 2.7.1 used to derive switching rate of 18.2% for gas and 18.3% for electricity customers.

When considering all positive responses to switching, 36% reported switching the tariff type alone, 32% reported switching just the gas/electricity supplier, and 21% reported switching both the supplier and tariff type (Figure 4.3).

Figure 4.3: Combinations of energy switching



Base: all households reporting some form of energy switch (n=883), Interview 1. (Annex Table)

To investigate how many households were either actively changing their energy supplier, or changing their tariff type while staying with their current energy supplier, Interview 3 questions were changed slightly to improve how this information was gathered. The following questions were asked[26]:

- 'Have you switched either your gas or electricity supplier since the <last> EFUS interview?'
- If answered no above: 'Have you changed your type of energy tariff for your electricity (or gas) since the previous EFUS interview?' Households could then answer 'Yes – actively switched energy tariff', 'Yes – reverted to the standard tariff' or 'No – tariff type is the same'

In total, the percentage of households reporting switching their energy supplier increased from 23% at Interview 1 (reported switch in the past 12 months) to 31% at Interview 3 (reported switch since Interview 1) which could be explained partly by the longer timeframe between Interview 1 and Interview 3 (between 12 and 18 months). At Interview 3, 11% of households reported switching their energy supplier at least twice in the past two and a half years, 32% at

[26] Please see the interview questionnaire for the exact wording of the questions

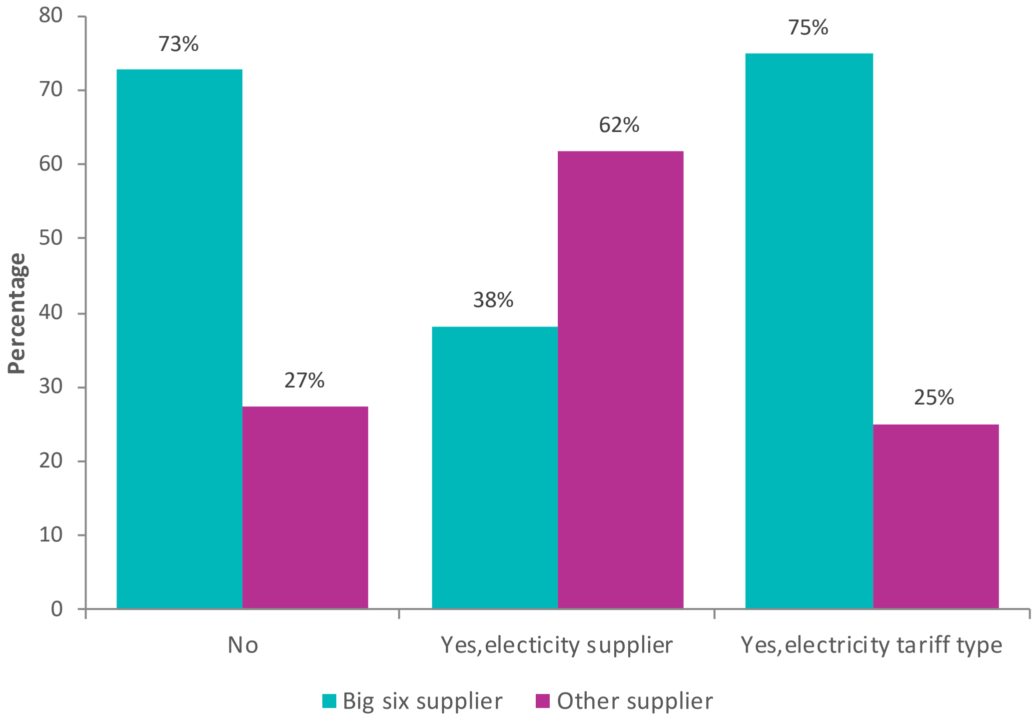
least once (reported switch at either Interview 1 or Interview 3), while the majority (57%) did not report switching their energy supplier at either survey.

At Interview 3, 22% of households reported some form of switch to their tariff type. Of those households who answered 'no' to switching their electricity supplier, 27% reported having actively switched their electricity energy tariff; 6% reported reverting to the standard tariff; while the majority (68%) reported their tariff type was unchanged. In total 50% of all households at Interview 3 had 'actively' switched their energy supplier or tariff type since Interview 1.

Among households who actively switched their electricity supplier or tariff type in the period between Interview 1 and Interview 3 (Figure 4.4), significant differences in the electricity supplier were observed:

- Households who had not switched their electricity supplier, but who had actively changed the type of tariff, were more likely to be with one of the 'Big Six' suppliers (75%). This was similar to households who had not actively switched their supplier or tariff type (73%)
- Households who had switched their electricity supplier were less likely to be with one of the 'Big Six' suppliers (38%)

Figure 4.4: Actively switched electricity supplier or tariff type since Interview 1



Base: all households (n=1,105), Interview 3. (Annex Table)

Results at Interview 3 also indicated that households who were switching their energy supplier multiple times (from 12 months prior to Interview 1 up until Interview 3), were more likely to be with an electricity supplier that is not one of the 'Big Six' (73%), than households who only switched once during this period (57%), and of households who have not switched (19%) in this period.

4.2 Total gas and electricity costs

In the Interview 1 survey, if households had their electricity or gas bills to hand, then they were asked to provide the tariff comparison rate (TCR) for each fuel (where applicable). The metered energy consumption has been combined with the TCR costs to calculate an estimate of total gas and electricity costs for each household. The average TCR values have been presented, and then any significant differences in energy cost based on energy supply information, dwelling and household characteristics, and fuel poverty status have been reported[27].

4.2.1 Tariff comparison rate

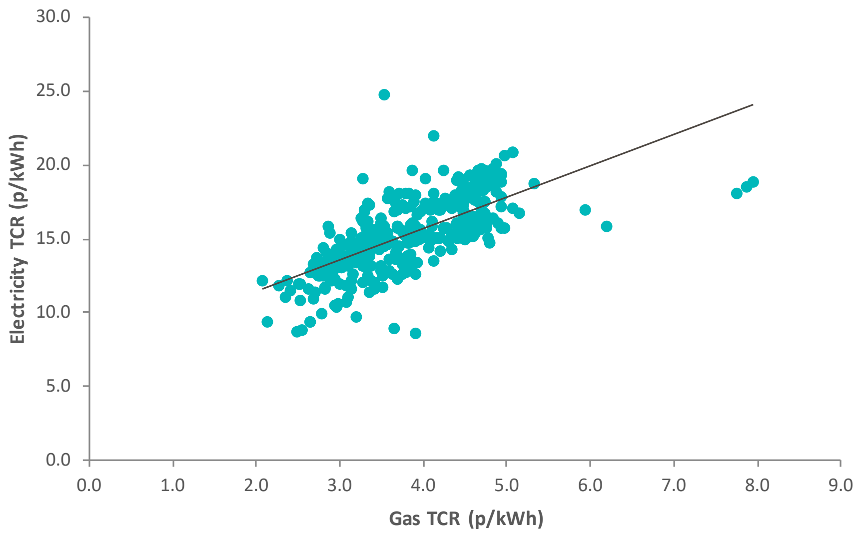
The tariff comparison rate (TCR) was used between 2014 and 2017 as a way of helping consumers compare the cost of energy tariffs. It is the average cost of each unit of energy, based on a typical user and includes the unit rate, standing charge and any discounts. At Interview 1, householders were able to report the TCR from their energy bill.

The median TCR was 15.44 p/kWh for electricity, and 4.01 p/kWh for gas. Half of all households with a valid TCR value, had an electricity TCR within 13.90 to 17.44 p/kWh, and a gas TCR within 3.33 to 4.52 p/kWh. Differences within the TCR values can have a large effect on the cost of gas and electricity to a household, where based on these TCR ranges an average household could spend between £410 and £560 on their annual gas bill[28], and £400 and £510 on their electricity bill[29].

For households with a dual fuel tariff, the median electricity and gas TCR values were 15.31 p/kWh and 3.89 p/kWh, respectively. There was a strong positive correlation between the electricity and gas TCR values (R = 0.715), indicating that higher electricity TCR values were observed with higher gas TCR values (Figure 4.5).

[27] Annex tables containing the underlying data for this section can be found in Tables_4_2.xls.
[28] Based on 2017 EFUS median gas consumption of 12,300 kWh/year (Table 3.1)
[29] Based on 2017 EFUS median electricity consumption (not main heating fuel) of 2,900 kWh/year (Table 3.3)

Figure 4.5: Correlation of electricity TCR with gas TCR



Base: households with a dual fuel tariff and electricity and gas TCR value (n=453), Interview 1. (Annex Table)

4.2.2 Switching, energy supplier and method of payment

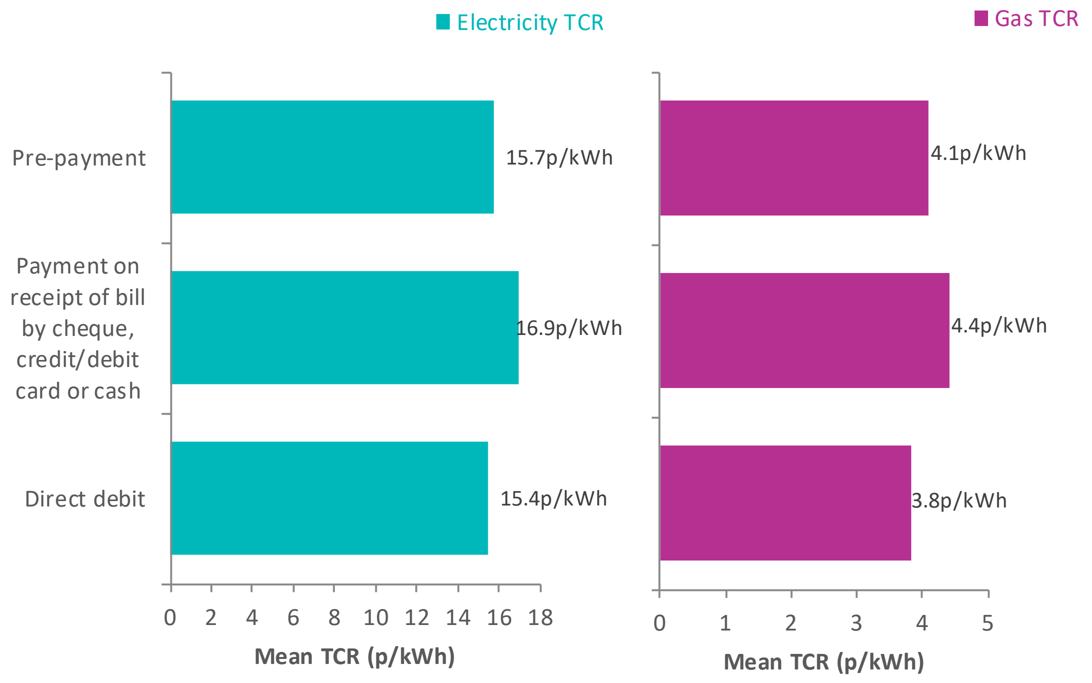
The mean TCR value (for both electricity and gas) was found to vary according to whether the household reported to be with one of the 'Big Six' suppliers, and whether or not they had switched supplier or tariff type in the past 12 months:

- For electricity: households who had switched supplier or tariff type in the past 12 months had significantly lower tariff costs than households who had not, regardless of the supplier
- For gas: households who had switched supplier or tariff type in the past 12 months had significantly lower tariff costs than households who had not. Additionally, households with one of the 'Big Six' suppliers who had not switched supplier or tariff type in the past 12 months had significantly higher tariff costs than all other households

The electricity and gas TCR values were found to significantly differ when comparing different payment methods. For both gas and electricity tariff costs, households who paid by standard credit were paying more for their energy than households who paid by direct debit (Figure 4.6). However, the electricity and gas tariff costs for households with pre-payment meters, were not significantly different to households who pay by direct debit, likely illustrating the effect of the pre-payment cap that came into place in April 2017; prior to this date tariff prices had been the highest for households who used a pre-payment meter to pay for their energy[30]. There were no differences observed in the mean TCR value (for both electricity and gas) when comparing the fuel poverty status of households.

[30] https://www.ofgem.gov.uk/data-portal/retail-market-indicators#thumbchart-c7770745751913637-n95439

Figure 4.6: Mean electricity and gas TCR, by method of payment



Base: all households with TCR value (n=626 electricity; n=551 gas), Interview 1. (Annex Table)

4.2.3 Gas and electricity costs

Total household gas costs, and total household electricity costs have been calculated using the following information: valid electricity and gas meter point data for all households (energy consumption in kWh/year); and reported electricity and gas TCR values (gas and electricity tariff costs in p/kWh). Data was then used to calculate an estimate for a combined gas and electricity annual bill[31]. Due to smaller sample sizes, non-parametric analysis was used to analyse any differences in gas and electricity costs, when split by dwelling and household characteristics and other key variables.

The median total 2017 gas costs, for households with gas as their main heating fuel, was calculated to be £450 per year; and the median total 2017 electricity costs, for households with electricity as their main heating fuel, was calculated to be £830 per year[32]. Where electricity was not the main heating fuel, the total 2017 electricity costs were calculated to be £410 per year. The total combined gas and electricity costs, for households where the main fuel was either gas or electricity, was calculated to be £880 per year (Table 4.1).

[31] If households did not have a gas supply, then only the electricity data was used in the calculation.
[32] Note: only 8% of households used electricity as their main heating fuel, therefore the number of households in this sub-set is low (34 cases) and the calculated fuel costs for electricity should be interpreted with caution.

Table 4.1: Annual gas and electricity costs, 2017

	2017 gas & electricity cost (£/year)
Percentile	
25%	630
50% (median)	880
75%	1,250

Base: all households with cost data, and gas or electricity as main fuel (n=428). (Annex Table)

Analysis of the total estimated annual gas and electricity costs, for households with gas or electricity as the main heating fuel, showed consistent findings with energy consumption where gas and electricity costs increased with increasing floor area and increasing household size. Higher costs were also evident for: houses compared with flats; for owner occupiers compared with renters; households with children present; and for dwellings with no insulation measures compared with insulated dwellings. In addition, median gas and electricity costs for households in fuel poverty (£1,080) were higher than households not in fuel poverty (£860).

4.3 Total household energy costs

Total household energy costs were calculated as above (section 4.2.2) using information on: the estimated gas and electricity costs, and household reported information at Interview 1 on the annual cost of other fuels used for heating, hot water and cooking[33].

4.3.1 Other fuels

At Interview 1, 16% of households reported using other fuels in the household for heating, hot water or cooking. Of these households, 36% reported using more than one type of fuel. The largest proportion of households using other fuels (71%; 2.7 million households) reported using wood; 28% (1.1 million households) reported the use of heating oil; and 17% (0.7 million households) reported using house coal. In total, 91% of households using heating oil were spending at least £100 per year, whereas for other solid fuels fewer than a third of households (wood 31%; coal 33%) were spending at least £100 per year on these fuels. In addition, 44% of households using wood reporting not paying anything for this fuel.

Combining similar fuels[34], the median reported cost of oil was £800 per year; for LPG £400 per year; and for solid fuels £50 per year. When looking at rurality and heating related variables, it was found that the cost of other fuels was significantly greater where households were in a rural location or not on the gas network. As expected, other fuel costs were greater when other fuels were used with the main heating system (£800 per year), however other fuel costs were also higher where the main heating fuel was electricity (solid, oil, LPG: £200 per year)

[33] Annex tables containing the underlying data for this section can be found in Tables_4_3.xls.
[34] Solid = house coal, anthracite, smokeless fuel, wood; oil = heating oil, kerosene; gas = bulk or bottled LPG

compared with gas (solid, oil, LPG: £50 per year). No differences in other fuel costs were observed for fuel poor households.

4.3.2 Household energy costs

The median total household energy costs, when combining other fuels with gas and electricity costs[35], was calculated to be around £920 per year. Analysis of the total household energy costs, by dwelling and household characteristics, showed the following significant differences between groups:

- **Floor area** Total household energy costs increased with floor area, where households living in the smallest dwellings (<50 m2) had the lowest median total energy costs (£590), and households in the largest dwellings (>140 m2) had the highest costs (£2,070)
- **Household size** Total household energy costs also increased with household size. One person households had the lowest median total energy costs (£700) and larger households (5 or more people) had the highest costs (£1,330)
- **Dwelling type** Households living in detached dwellings had the highest median total energy costs (£1,310) while flats had the lowest median total energy costs (£670)
- **Household composition** One person households under 60 had the lowest median total energy costs (£610). Couples with dependent children (£1,210) and couples aged 60 or over (£1,160) had higher median total energy costs than other single person households
- **Tenure** Owner occupiers had higher median total energy costs (£1,010) compared with rented tenures (£630 to £770)
- **EPC band** Households in dwellings with an EPC band of A to C had lower median total energy costs (£790) than households with an EPC band of D to G (£940 to £1,210)
- **Fuel type** Households that used other fuels such as bottled/bulk gas, solid fuel, or oil had higher median total energy costs (£1,550) compared with households using mains gas (£910)
- **Rurality** Households living in urban areas had lower median total energy costs (£880) compared with households living in rural areas (£1,390)
- **Children present** Households with children present had higher median total energy costs (£1,210) compared with households without children (£870)
- **Fuel poverty** Households in fuel poverty had higher median total energy costs (£1,190) compared with households not in fuel poverty (£910)

[35] Excluding households with communal/district heating systems, or households who have not reported their other fuel costs.

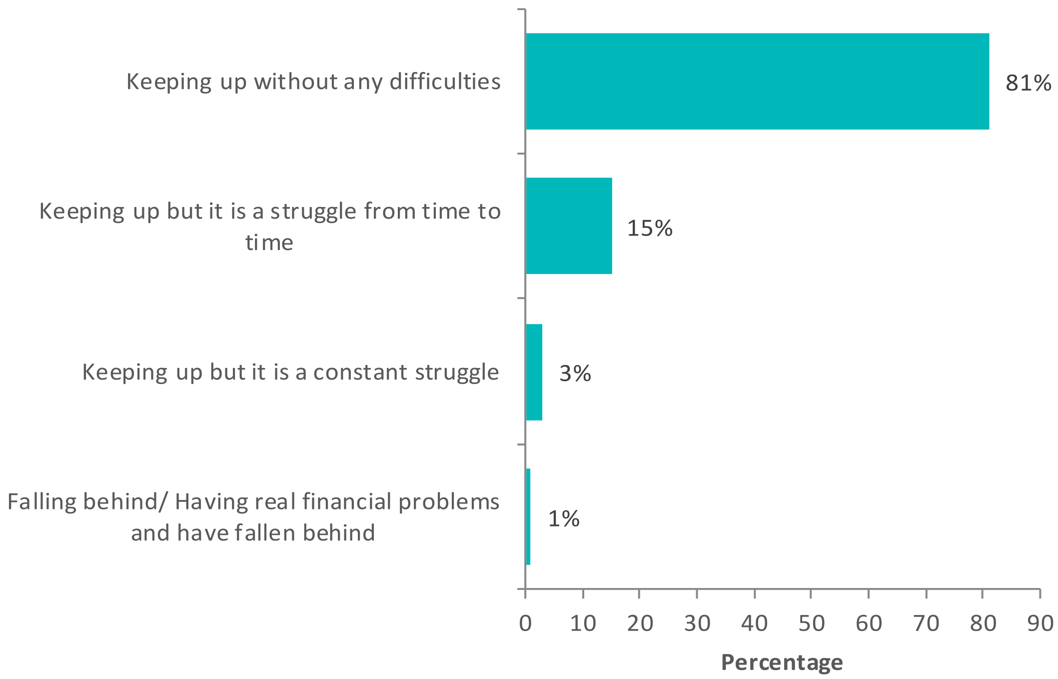
5. Affordability

The Interview 2 survey included a set of questions to determine the trade-offs that households make to be able to afford to pay their energy bills. Firstly, the interviewed households were asked about how they are keeping up with their energy bills. Secondly, for households struggling to keep up with their energy bills, questions were asked on the changes to heating and spending habits of these households[36].

5.1 Keeping up with energy bills

At Interview 2, the majority of households (81%)[37], reported keeping up with their energy bills with no difficulties (Figure 5.1). A further 15% reported keeping up but struggling from time to time, and the remaining households reported that it was a constant struggle, or they were falling behind.

Figure 5.1: Affordability of energy bills



Base: all households (n=1,312), Interview 2. (Annex Table)

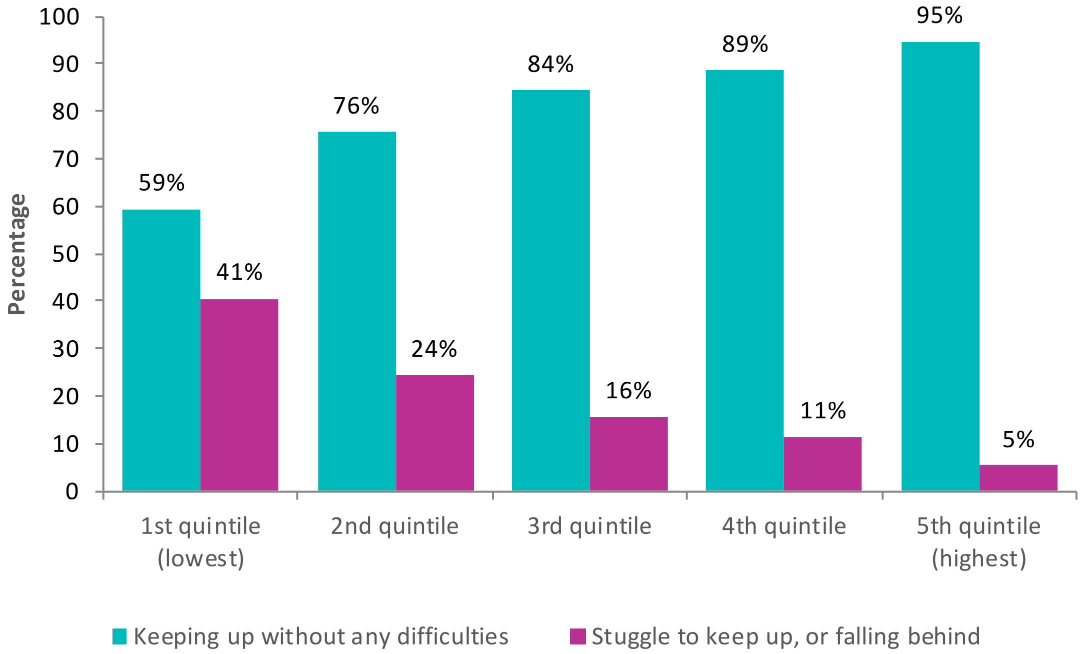
5.1.2 Households struggling to keep up with their energy bills

In total, 19% of households reported struggling to keep up with their energy bills at Interview 2. Households in fuel poverty were more likely to report struggling to keep up with their energy bills (40%) compared with 16% of non-fuel poor households. Income was the major driver for whether a

[36] Annex tables containing the underlying data for this section can be found in Tables_5.xls.
[37] Households were excluded from analysis if they answered 'don't have any energy bills'.

household reported being able to keep up with their energy bills as shown in Figure 5.2. Among households who reported a constant struggle to keep up with payments, or they were falling behind with their energy bills, 66% were in the lowest income quintile, compared with 33% of households who reported struggling from time to time and 14% who were keeping up without difficulties.

Figure 5.2: Affordability of energy bills, by income quintile



Base: all households (n=1,312), Interview 2. (Annex Table)

The influence of income was the key factor impacting on whether the household was struggling to pay their energy bills, and this was reflected in the following household groups that were found to be more likely to be struggling with such payments[38]:

Tenure Households in the private rented (32%) and social sector (38% to 39%) were more likely to report struggling to keep up with their energy bills, compared with owner occupiers (10%). The differences observed between the private rented and social housing tenures were not statistically significant.

- Household composition Lone parents with dependent children (51%) were more likely to report struggling to keep up with their energy bills, compared with 6% of couples aged 60 or over
- Age of HRP Households where the HRP is younger than 55 (23% to 29%) were more likely to report struggling to keep up with their energy bills compared with households where the HRP is 75 or older (5%)

[38] Results are presented from Interview 2 to allow for comparison with energy consumption.

- Under-occupancy Households not under-occupying their homes (24%) were more likely to report struggling to keep up with their energy bills compared with under-occupiers (7%)
- Pensioners present Household with no pensioners present (24%) were more likely to report struggling to keep up with their bills compared with households with a pensioner present (8%)
- Children present Households with children present (31%) were more likely to report struggling to keep up with their energy bills, compared with households without children (15%)
- Household size Larger households with five or more occupants (41%) were more likely to report struggling to keep up with their energy bills compared with smaller households with two people (16%) or one person (13%)

In addition, households with someone who is long-term sick or disabled (24%) were more likely to report struggling to keep up with their energy bills compared with other households (16%), however the employment status of households and the reported weekday occupancy pattern were not found to have a significant effect on the ability to pay energy bills.

The energy efficiency rating of the dwelling did not have a significant effect on the ability of a household to pay their energy bills, supporting the results above where income appears to be the major driver. In addition, whether a household had low or high costs based on the fuel poverty definition, did not cause a significant decrease in the ability to afford energy bills; and nor did the depth of the fuel poverty gap[39].

Households who reported feeling uncomfortably cold in the living room in winter were more likely to struggle to keep up with their energy bills (42%), compared with households reporting feeling uncomfortably cold never, rarely or sometimes (16%). As found in the ‘Thermal Comfort, Ventilation, Damp and Mould’ report, income was seen to be a main driver of reported discomfort in the living room, indicating a link between affordability of energy bills and feeling uncomfortably cold.

Samples were too small to be able to comprehensibly compare the differences in energy costs between households who reported difficulties in keeping up with their energy bills, with households who reported no difficulties. However, analysis of the difference between modelled and metered energy consumption, for households using only gas and/or electricity as heating fuels, indicated (at the 95% level) a lower level of actual consumption compared with modelled for households struggling to keep up with their energy bills, and additional work is recommended in this area to quantify the level of the difference.

[39] Based on a banded fuel poverty gap with three weighted categories: ‘low’ ‘medium’ and ‘high’ costs.

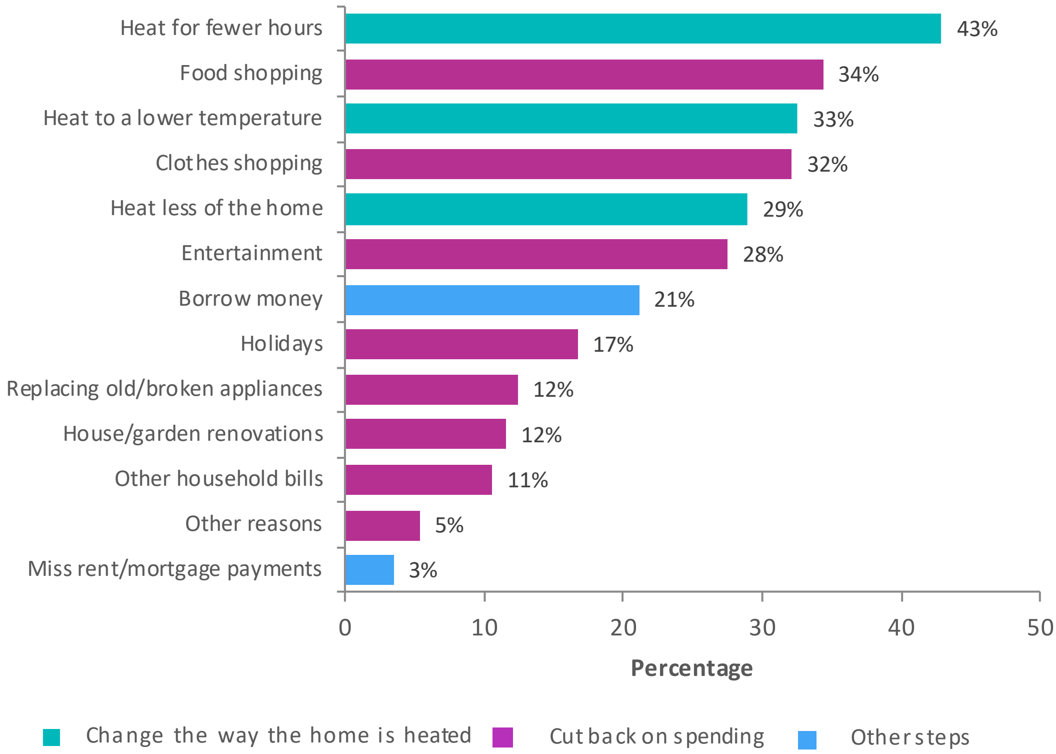
5.2 Cutbacks for households who had difficulties paying energy bills

Three questions were asked for all households who reported struggling to keep up with their energy bills in some way, with a focus on affordability during the winter months:

- ‘This winter, have you had to change the way you heat your home in any of these ways to try and afford your energy bills?’ The following options were provided: ‘heat for fewer hours than you would like to’; ‘heat to a lower temperature than you would like to’; ‘heat less of your home than you would like to’
- ‘This winter, have you had to cut back your spending on anything else in order to try and afford to pay your energy bills?’ The following options were provided: ‘food shopping’; ‘clothes shopping’; ‘other household bills (e.g. insurance, phone bills)’; ‘replacing old or broken household appliances’; ‘house or garden decoration/renovation’; ‘entertainment (days out/nights out)’; ‘holidays’; ‘other’
- ‘This winter, have you had to do any of these in order to try and pay your energy bills?’ The following options were provided: ‘borrow money’; ‘miss rent/mortgage payments’

The most frequently reported change to a household’s heating or spending habits at Interview 2, was to heat for fewer hours (43%), and this was followed by cut backs in spending on food shopping (34%), heating the home to a lower temperature (33%) and cut backs in spending on clothes (32%). It should also be noted that around a fifth of households (21%) reported that they borrow money to be able to keep up with their energy bills. The different responses are shown in Figure 5.3.

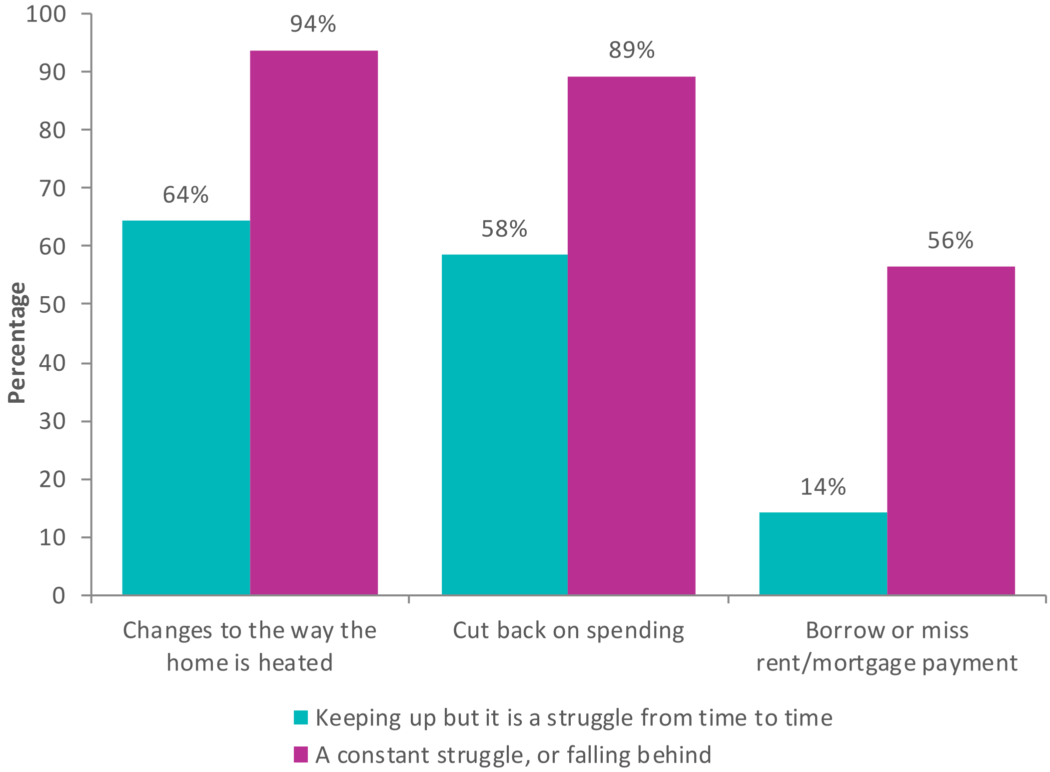
Figure 5.3: Changes to heating or spending habits



Base: all households struggling to keep up with their energy bills (n=279, change heating; n=281, cutback on spending; n=282, other steps), Interview 2. (Annex Table)

Households in fuel poverty were more likely (at the 95% level) to cut back on spending, borrow money or miss a rent/mortgage payment than households who were not in fuel poverty. Where households reported that keeping up with their energy bills was a constant struggle or they had fallen behind, they were more likely to make changes compared with households that reported struggling from time to time: 94% of households who reported that keeping up was a constant struggle or they had fallen behind changed the way they heat their home; 89% cut back on spending in some way; and 56% borrowed money or reported missing rent payments (Figure 5.4).

Figure 5.4: Changes to heating or spending habits, by the extent of difficulty in keeping up with energy bills



Base: all households struggling to keep up with energy bills (n=279, change heating; n=281, cutback on spending; n=282, other steps), Interview 2. (Annex Table)

6. Modelled energy consumption

This chapter uses the BREDEM calculation[40] to, firstly, explore the reasons for the observed decrease in gas consumption since 2010. Secondly, the EFUS 2017 modelled energy consumption has been compared against the actual metered energy consumption and households have been defined as under-consuming and over-consuming based on the difference in energy consumption. The reasons for under-consumption and over-consumption have been explored, linking to results reported within this report, the 'Heating Patterns and Occupancy' report, and the 'Thermal Comfort, Ventilation, Damp and Mould' report.

The BREDEM modelled energy use is the theoretical consumption required to provide an adequate level of warmth, hot water, lights, appliance and cooking use; in its application to fuel poverty modelling, BREDEM is provided with a range of dwelling and household characteristics as set out in the definition of fuel poverty[41].

6.1 Gas consumption changes since 2010

The meter point data indicated that among households receiving gas through the mains gas supply network, consumption dropped by around 12% between 2010[42] and 2017. There are several potential contributing factors to this drop in consumption and the EFUS and accompanying EHS data has been used to investigate some of the likely main drivers of the observed change.

6.1.1 Approach

A BREDEM calculation has been used to construct a model of a house that is broadly representative of the English housing stock. A three-bed semi-detached house has been used because this is the most common dwelling type in the English housing stock - comprising around a quarter of all dwellings - and has what might be considered average characteristics for many of the key metrics (for example floor area). The house has been created within the BREDEM model using average values obtained from EHS data in each of the two years in question to create the model inputs. The average dwelling has been modelled in four different configurations:

- 2010 average performance figures with a standard boiler with hot water provided via a cylinder
- 2010 average performance figures with a combination boiler providing both heat and instantaneous hot water

[40] https://www.bre.co.uk/filelibrary/bredem/BREDEM-2012-specification.pdf
[41] Fuel Poverty Methodology Handbook, 2020. Section 5.6.
[42] The 2010 meter point data was used for analysing change because of the availability to the project team, and to allow for a more accurate comparison with 2017 as both datasets were weather corrected. The previous EFUS was conducted in 2011 and therefore has been used to assess changes in occupant behaviour over the period.

- 2017 average performance figures with a standard boiler with hot water provided via a cylinder
- 2017 average performance figures with a combination boiler providing both heat and instantaneous hot water

The BREDEM methodology provides the flexibility to vary inputs as observed in the EFUS, allowing for more accurate predictions to be made.

This analysis is not intended to be comprehensive; there are several aspects that are too impractical to investigate. Rather it is intended to identify what are likely to be the main drivers and to indicate how much they are likely to be contributing to the observed change. Factors that are likely to influence gas consumption are presented below along with a brief discussion of each. These are informed to some extent by previous findings from the BEIS Solid Wall Insulation research programme[43] which identified the most influential inputs when using a BREDEM calculation to predict consumption:

- There are several variables that might be collectively referred to as "occupant behaviour" that were found to have a large influence on the accuracy of the BREDEM model prediction in the SWI project. The first of these is heating hours. The analysis in the EFUS 2017 'Heating Patterns and Occupancy' report indicated that heating hours have not changed significantly since EFUS 2011 and so this has been excluded as a factor.
- Similarly, the thermostat set-point temperature was found to be important in the accurate prediction of consumption. As with heating hours this too was found not to have changed significantly since 2011.
- The other commonly referred to occupant behaviour factor is heating extent. This is the proportion of the home that is heated. Again, there were no significant changes in EFUS reported heating extent between 2011 and 2017 and therefore for this and the other occupant behaviour variables above it was assumed that there was no change on average between 2010 and 2017.
- The other main variable related to occupants is the number of occupants per household. The average household size in the English stock has declined gradually over time, however the reduction in average household size in mains gas consuming households is small enough (2.5 to 2.45 persons) that it is not realistic to include in modelling of this nature. Therefore, the household size has been kept constant.
- Another of the most influential variables is external temperature. As the climate has tended to get warmer over the period it is reasonable to associate this with a drop in consumption, however this has been excluded from our analysis because the meter point consumption data was weather corrected in both years' datasets. Therefore, changing external temperatures should be accounted for. It is possible that there are additional positive feedback affects associated with warmer external temperatures that

[43] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/787459/Closing-the-gap_Pre-post-insulation-field-trial.pdf

may mean that the relationship between external temperature and consumption is more complex; however it is not possible to explore this here.

- In terms of dwelling characteristics, gas consumption is positively correlated with floor area so falling consumption could be partly explained by the average size of homes decreasing (for example, because more flats are being built). This is not suggested by EHS data trends over time and therefore this has been excluded as a factor.
- The fabric of the dwelling and any applied insulation are important determinants of heat losses which strongly influence energy consumption for heating. The fabric efficiency of all elements of the heated envelope have increased steadily over time. This can be applied in the BREDEM model by using average U-values for each of the main elements in 2010 and 2017. RdSAP assumptions, based on the age of elements, have been used in order to assign each element a U-value for each dwelling heated by mains gas. Improvements in average U-values were over 10% for each of the main elements (walls, roof, windows) with the exception of floors where the improvement was more like 4%.
- Often associated with fabric improvements is an increase in airtightness. Less leaky dwellings will require less heating and consume less gas. It is difficult to apply sensible assumptions to the fabric ventilation parameters beyond the basic assumptions in RdSAP and therefore we have assumed that there has been no change in this metric. In reality it is likely that across the stock, airtightness would have improved slightly so this may lead to an underestimate of the overall contribution to the reduction.
- The other main insulation measure we considered was hot water cylinder insulation. This only applies to dwellings with a standard boiler as combi boilers do not typically have a storage cylinder.
- There has been a steady increase in the market share of combi boilers as they have become more popular than standard boilers. The modelling indicates that; due to a reduction in storage and transmission losses, an identical home heated with a combi boiler will consume less gas over a year. EHS data showed that the market share of combi boilers (in homes with mains gas central heating) has increased from around 53% in 2010 to around 64% in 2017.
- The final area we investigated for this analysis was the efficiency of the heating appliance. We have restricted our analysis to mains gas boilers as this represents the vast majority of homes using mains gas for heating. As boilers are replaced; particularly older boilers, they tend to be replaced by more efficient condensing appliances. Therefore we would expect to see a gradual improvement to the average efficiency of the boilers in use in the housing stock and this was indeed the case. Between 2010 and 2017 the average boiler efficiency of boilers in the EHS matched with the PCDB has risen by between 2% and 5%. This will clearly lead to a reduction in consumption. It should be noted that this is the rated seasonal efficiency according to SEDBUK. It is not possible here to reflect actual performance efficiencies.
- There are likely to be several other variables that will have an impact on consumption that we have been unable to account for, however we expect their impact to be small

compared with those identified. For example we have not looked at the change in patterns of cooking fuel use. Similarly, we have not explored changing water use behaviours in terms of shower use. In line with standard assumptions in this kind of modelling, in the absence of any data, we have assumed that showers are heated electrically by an electric shower unit. If there has been a switch over time to lower cost shower types, using water heated by the mains gas heating system, then this will have led to a reduction in cost for the occupants however it will have led to an increase in gas use for that purpose. Conversely, an increase in electric shower usage will have led to a decrease in gas used for water heating.

6.1.2 Results

When all of the factors described above are accounted for in a BREDEM calculation, we see a reduction in gas consumption for the average dwelling archetype (Table 6.1). The details of this can be seen in the table below which gives separate results for standard and combi boiler driven systems[44].

Table 6.1: Reduction in gas consumption for the average dwelling archetype

	2010	2017	
	Gas consumption (kWh/year)	Gas consumption (kWh/year)	Percentage reduction (%)
Boiler type			
Standard	19,000	16,400	13.3
Combi	17,400	15,700	9.8

Base: all English Housing Survey (EHS) households, combined years 2009+2010 and 2016+2017

We can see that dwellings with standard boiler systems have seen a greater improvement over the period than those with combi boiler driven systems. The data showed that the combi boilers in 2010 had a better starting efficiency than standard boilers. This is likely related to the fact that combi boilers will be on average younger than standard boilers (owing to their more recent increase in popularity). We can account for the changing boiler mix in the housing stock by weighting the average consumption in both years according to the mix of the two main boiler types. The EHS shows that the split between standard and combi boilers in mains gas heated households went from 47% standard and 53% combi in 2010, to 36% standard and 64% combi in 2017. Applying these ratios as weights to the average consumption values gives a weighted average mains gas consumption in 2010 of 18,200 kWh and in 2017 of 16,000 kWh; a reduction of 11.9%.

It can therefore be stated that the factors investigated here can explain almost all of the reduction in mains supplied gas over the period 2010 to 2017. To summarise, the factors investigated were;

44 Annex tables containing the underlying data for this section can be found in Tables_6_1.xls.

- Fabric efficiency of the heated envelope
- Hot water cylinder insulation
- Heating system efficiency
- Market share of the two main gas boiler types (standard and combi)

The BREDEM modelling we have conducted indicates an 11.9% reduction compared to meter-point data indicating a reduction of around 11.7%. Therefore the factors considered appear to explain virtually all of the observed reduction. As stated, the modelling has not considered all factors and is limited to using a single average archetype to represent the whole English housing stock. There are likely to be more complex interactions and feedback loops that could lead to a bigger or smaller overall effect however this can be seen as a useful first approximation to the contribution of the main factors.

6.2 Comparison of metered energy with modelled energy use

This section examines the difference between the actual metered energy use (gas and electricity)[45] and the modelled energy use, as calculated for the fuel poverty statistics using the BREDEM energy model. It is commonly acknowledged that the theoretical consumption is more likely to overestimate, rather than underestimate, actual energy consumption; the EFUS 2011 Underspend report and the Energy Trends special feature report[46] that compared NEED data with fuel poverty modelled fuel costs reported a similarly high proportion of households with modelled fuel costs higher than their actual fuel costs (67% and 69% of households respectively)[47].

The following analysis was undertaken on a sub-sample of households for which no dwelling alterations, nor changes to the household occupants, had occurred since the EHS survey to allow for a more accurate comparison of energy consumption. Dwellings using any fuel other than mains gas or electricity, for space or water heating, were also excluded from the analysis[48]. The percentage difference between actual and modelled energy consumption is reported, where a negative percentage indicates some level of under-consumption (actual consumption less than modelled), and a positive percentage indicates some level of over-consumption compared with the modelled assumptions. Households have been classified as under-consumers if relative to other households the percentage difference was in the lowest quintile, and as over-consumers if the percentage difference was in the highest quintile.

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[45]The 2017 gas meter point data has been weather corrected

[46] Energy Trends: March 2019, special feature article – Comparison of theoretical energy consumption with actual usage.

[47] Annex tables containing the underlying data for this section can be found in Tables_6_2.xls.

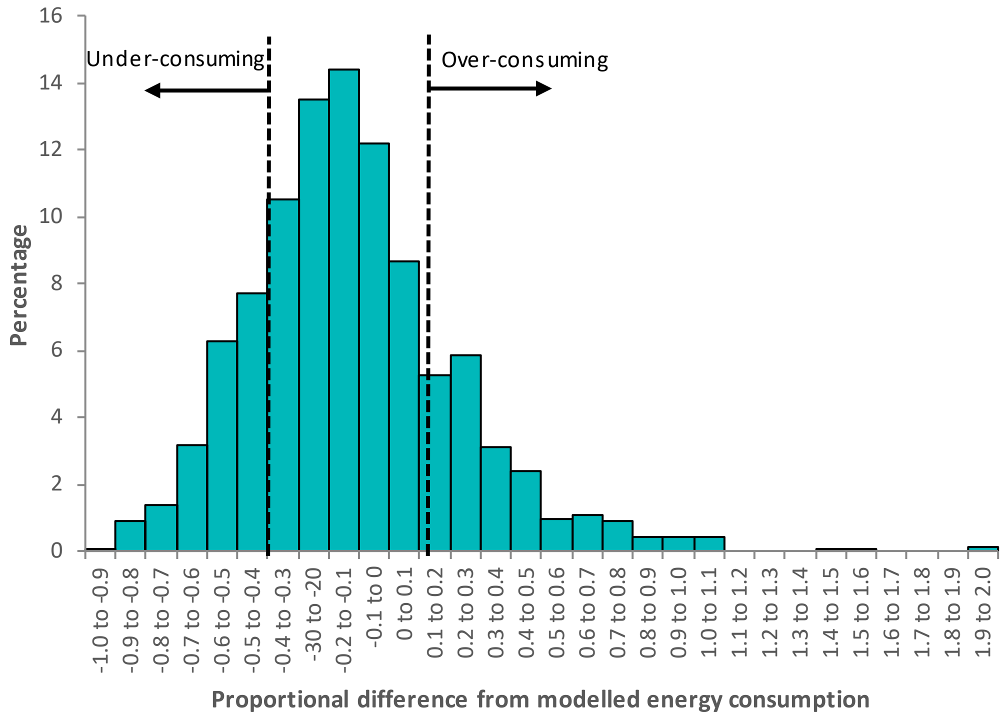
[48] The analysis presented was for this sample weighted to population totals using the meter point data weighting factor. It is recognised that some bias was introduced by excluding these cases, however comparisons of key dwelling and household splits show negligible differences for household characteristics, with a slight bias to fewer pre-1919 dwellings, fewer rural dwellings and more EPC rating A to C dwellings.

The divergence from modelled energy consumption across the standard set of dwelling and household groups, as well as the householder reported heating pattern information, measured mean internal temperatures and other energy related variables has been explored.

6.2.1 General findings

The distribution of the proportional difference of the actual energy consumption from modelled consumption is shown in Figure 6.1. Some 70% of households used less energy than modelled; the remaining 30% used more energy than modelled. Actual energy consumption was on average 12% lower than modelled energy consumption. For households in the highest quintile (classified as over-consuming), they consumed at least 12.5% more energy than the modelled consumption, however, for households in the lowest quintile (classified as under-consuming), they consumed at least 40% less energy than the modelled consumption.

Figure 6.1: Histogram of the proportional difference between actual and modelled energy consumption, June 2017 to June 2018



Base: all households in the meter point data sub-sample, eligible for comparison with BREDEM modelled consumption (n=1,181). (Annex Table)

6.2.2 Heating behaviours

As noted earlier in section 6.1, the BREDEM methodology uses a set of assumptions in the calculation of the energy consumption. In particular there are three behavioural based assumptions, which have a large impact on the calculated energy consumption: heating hours, demand temperature, and heating extent (proportion of the home that is heated). These are discussed further below.

Heating hours

Households that used their main heating for more than 10 hours a day were more likely to be over-consuming (47%) compared with households that heated for anything less (10% to 23%), and similarly households heating for fewer than 4 hours a day were more likely to be under-consuming (40%) compared with households heating for 7 hours or more (2% to 14%). In terms of averages, the median weekday heating hours for over-consumers (10hrs:00mins) were double the weekday heating hours for under-consumers (5hrs:00mins).

The BREDEM calculation assumes that, for weekdays, heating hours are 16 hours for someone in during the day, and 9 hours (split into two heating periods) for remaining households, so behaviours that deviate from this lead to higher or lower levels of consumption compared with the model. Levels of under- or over-consumption were not found to differ by daytime occupancy, while the 'Heating Patterns and Occupancy' report showed that at Interview 3 the median weekday heating hours were greater for households that were in all day (8hrs:30mins), compared with households with variable occupancy (7hrs:00mins), or who were out all day (6hrs:00mins).

Related heating behaviours include the following: households with non-regular heating patterns (34%), and households not heating their home daily during the winter (52%), were more likely to be under-consuming than regular heaters (17% and 19%, respectively); while households using secondary gas heating were more likely to be over-consuming (41%) than households without or not using gas secondary heaters (18%). Results from the multi-variate analysis (section 3.2) indicated that centrally-heated households with a switch on the boiler used less gas than households using a timer, and these households were also more likely to be under-consuming (32%) than households using a timer (13%); and less likely to be over-consuming (7%) than households using a timer (27%) or controlling the heating using a thermostat (20%).

Thermostat set-point temperature

Within BREDEM, demand temperatures of 21°C in the living room, and 18°C in the rest of the house are assumed. There was some indication from the multi-variate analysis in Chapter 3 that higher demand temperatures led to an increase in gas consumption, however differences were only significant at the 95% level for thermostat temperature differences between average consumers and over-consumers. It is likely that the interactions of the heating system control, the thermostat set-point and the actual achieved temperatures are complex. In the 'Heating Patterns and Occupancy' report it was found that 39% of households with a thermostat vary the temperature throughout the day (section 3.2.3), while in total 34% of households controlled their central heating manually using a thermostat (section 3.2.1).

In order to work around this variability when relating consumption to set point temperatures, internal 24-hour mean temperatures and thermal comfort levels have been reported on throughout the discussion in section 6.2.3, as households reporting thermal discomfort were more likely to be under-consuming; households reporting feeling uncomfortably cold in the living room or main bedroom were more likely to be under-consuming (38%) than households not reporting this (18%); while households with 3 or more rooms that were uncomfortably cold were more likely to be under-consuming (51%) compared with households with none (21%). Also, under-consuming households had colder mean living room temperatures (under-consuming 17.0°C; over-consuming 19.9°C) and main bedroom temperatures (under-consuming 16.6°C; over-consuming 19.3°C).

Heating extent

The proportion of house heated (heating extent) is modelled according to under-occupancy in BREDEM (whereby if a household is under-occupying their home, they are assumed to heat only a portion of the zone 2 area[49]). The number of unheated rooms was not determined in EFUS 2017, however in the 'Heating Patterns and Occupancy' report (section 3.5.2) it was reported that 24% of households have at least one unheated habitable room, and this was more likely to be the case for under-occupying households. It was found that under-occupying households were more likely to over-consume (34%) compared with households not under-occupying (15%), indicating an over-estimation of the number of unheated rooms by BREDEM. The effect of under-occupancy on consumption is discussed further in section 6.2.3.

6.2.3 Dwelling and household characteristics

There were many significant differences seen across the various dwelling and household characteristics in terms of the proportion of households considered to be under-consuming (lowest quintile: actual consumption at least 40% lower than modelled energy consumption) and over-consuming (highest quintile: actual consumption at least 12.5% higher than the modelled energy consumption).

All the dwelling characteristics except region, rurality and wall type had some significant differences at the 95% level between categories, as did all the household characteristics except whether someone in the household was long-term sick or disabled. The key observations are shown in Table 6.2 which highlights the groups that were more likely to be under- or over-consuming. In addition, results for heating hours, internal temperatures and thermal comfort have been included.

[49] The BREDEM calculation assumes two zones: a living area (zone 1) and a non-living area (zone 2).

Table 6.2 Households most likely to be under-consuming or over-consuming

	More likely to be under-consuming	More likely to be over-consuming
Heating Behaviours		
Weekday median heating hours	Fewer hours (5hrs:00mins)	Longer hours (10hrs:00mins)
24-hour mean internal temperatures	Colder (living room: 17.0°C; main bedroom: 16.6°C)	Warmer (living room: 19.9°C; main bedroom: 19.3°C)
Thermal comfort	Living room or bedroom is uncomfortably cold (38%), 2 rooms cold (38%), 3+ rooms cold (51%)	Living room or bedroom is not uncomfortably cold (24%)
Dwelling characteristics		
Dwelling type	Flats (36%)	Detached (35%), bungalows (29%)
Floor area	Smaller (<50m^2: 39%)	Larger (110 to 140m^2: 34%)
Energy efficiency	Non-insulated walls (26%) and less energy efficient (EPC band E: 32%, F or G: 49%)	Insulated walls (23%) and more energy efficient (EPC band A to C: 27%; D: 19%)
Heating system	Electric main fuel (40%), non-central heating (39%)	*Not applicable*
Household characteristics		
Under-occupancy	Not under-occupiers (23%)	Under-occupiers (34%)
Age & household composition	Younger (no pensioner: 23%; one person under 60: 37%)	Older (pensioner: 28%; couple aged 60 or over: 31%; HRP aged 75 or more: 32%)
Income & fuel poverty	Lower income (1st quintile: 29%), fuel poor (31%)	Higher income (5th quintile 35%), not fuel poor (21%)
Tenure	Housing association (32%) and private rented tenures (29%)	Owner occupiers (25%)
Household size & children	Smaller 1-person households (30%)	Households with no children (23%)

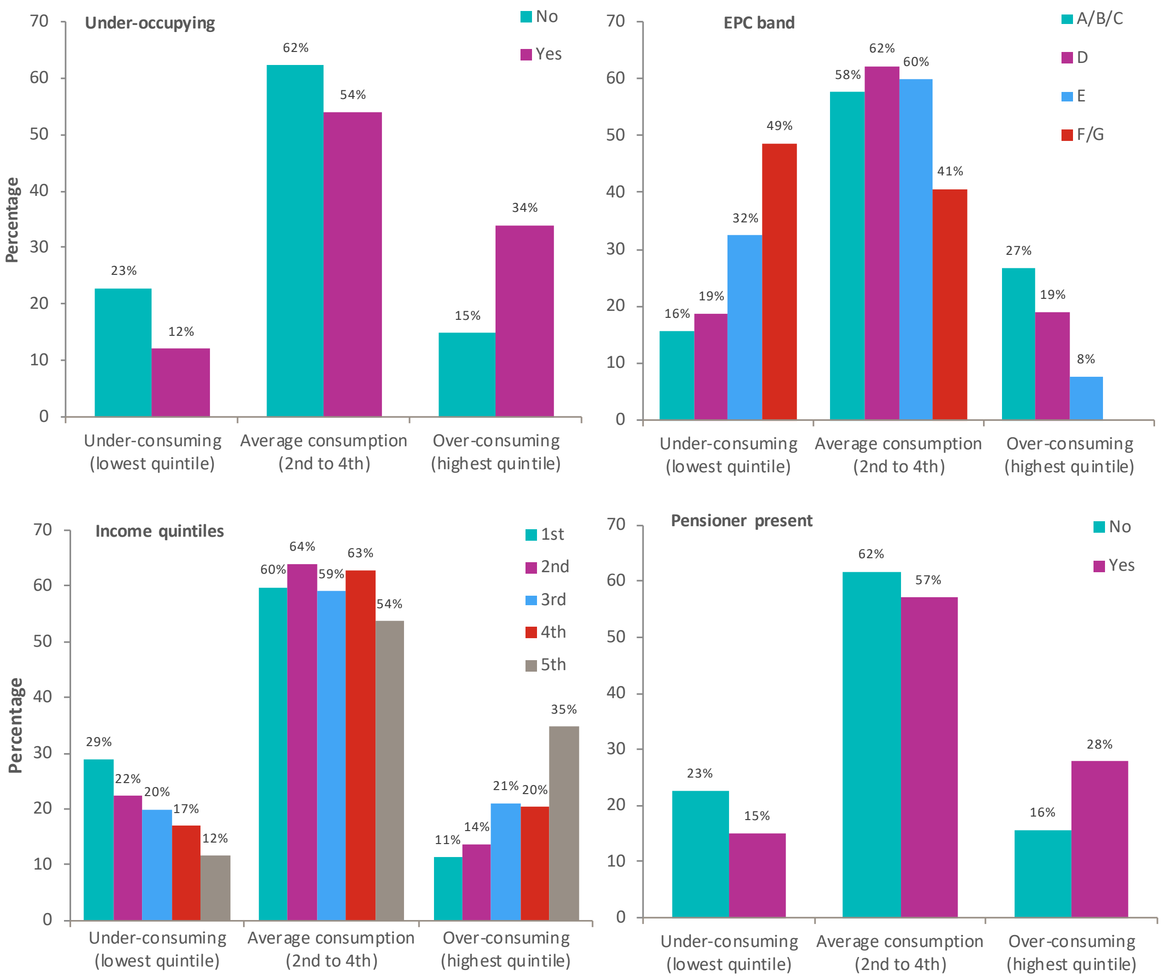
Base: all households in the meter point data sub-sample, eligible for comparison with BREDEM modelled consumption (n=1,181, dwelling and household characteristics; n=357, weekday heating hours; n=356, living room temperature; n=343, bedroom temperature, n=620, thermal comfort). (Annex Table)

Throughout the following discussion, behaviours relating to heating hours, 24-hour mean internal temperatures, occupancy patterns and reported thermal comfort and affordability of energy bills have been used to help provide possible explanations for the divergence of key dwelling types and household groups away from modelled energy consumption. Due to the overlapping nature of the results, the discussion has been structured to guide through possible reasons for differing levels of consumption, and as such does not exclusively cover all reasons for under- and over-consumption for each factor.

Under-occupancy

While it was not possible to analyse the level of under- or over-consumption by the number of unheated habitable rooms, households considered to be under-occupying their homes were more likely to be over-consuming (34%) than households not under-occupying (15%) (Figure 6.2). This indicates that the proportion of unheated rooms in the house may be over-estimated within the BREDEM model. As reported in the 'Heating Patterns and Occupancy' report (section 3.5.2), results showed that non-centrally heated dwellings were more likely (44%) to have unheated habitable rooms compared with centrally heated dwellings (23%), and this result was found to have a larger impact than under-occupancy. Therefore, a better approximation of unheated rooms may be based on the heating system used, however the fuel poverty methodology assumes that the heating regime is met regardless of heating system, as this is deemed to be necessary to maintain an adequate level of warmth.

Figure 6.2: Proportion of households under- and over-consuming by: under-occupancy, EPC band, income quintiles and pensioner present



Base: all households in the meter point data sub-sample, eligible for comparison with BREDEM modelled consumption (n=1,181). (Annex Table)

Dwelling characteristics

Households with electricity as their main fuel (40%), or non-central heating systems (39%), were more likely to be under-consuming than households using gas, or with central heating systems (18% for both). The prevalence of non-regular heating was higher for households with non-central heating systems[50] (non-central heating: 40%; central heating: 27%) which is likely to contribute to the higher level of under-consumption. However it is unlikely to be driven by heating hours for regular heaters, as at Interview 3 median weekday heating hours for households reporting regular heating were similar (7hrs:00mins) for households with and without central heating. It may, therefore, also be that the number of heated rooms, as required to calculate the heating extent, is fewer for households with non-central heating, but further work would be required to confirm this.

Households living in less energy efficient dwellings were more likely to be under-consuming (EPC band F or G: 49%; E: 32%) compared with more energy efficient dwellings (EPC band A to C: 16%; D: 19%), where non-centrally heated systems were more prevalent in F or G rated dwellings (18%) compared with centrally heated systems (1%). As reported in the 'Thermal Comfort, Ventilation, Damp and Mould' report (section 5.1), households with lower energy efficiency ratings measured colder 24-hour internal temperatures in both the living room (EPC band F or G: 17.2°C; A to C: 18.6°C) and main bedroom (F or G: 15.7°C; A to C: 17.8°C), while they were also more likely to use supplementary heating[51] (F or G: 52%; A to C: 19%). Alongside this, high levels of bedroom thermal discomfort[52] (31% of dwellings with an EPC band of F or G were uncomfortably cold in the bedroom, compared with 8% of dwellings with and EPC band of A to C) suggests that these households were not heating to the BREDEM requirements and were unable to achieve adequate levels of comfort in the home.

Households living in flats were more likely to be under-consuming (36%) compared with houses (16%), and detached dwellings were least likely to be under-consuming (6%) and more likely to be over-consuming (35%). Similarly to less energy efficient dwellings, households living in flats were more likely to report feeling uncomfortably cold in the bedroom (17%) compared with households living in detached dwellings (3%). In contrast however, flats were heated for fewer hours (on average 2 hours fewer than detached houses[53]) and had warmer 24-hour living room temperatures (on average 1.0°C warmer than houses). It is likely that the combination of factors such as energy efficiency, the heating system and household characteristics caused higher levels of under-consumption within flats; flats were more likely to be occupied by other household groups with a propensity to be under-consuming: private and housing association tenures; younger and smaller households; and households with lower incomes.

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[50] 'Heating Patterns and Occupancy' report, section 3.4.3
[51] 'Heating Patterns and Occupancy' report, section 3.6
[52] 'Thermal Comfort, Ventilation, Damp and Mould' report, section 5.2.2
[53] 'Heating Patterns and Occupancy' report, section 3.4.4

Household characteristics

Households in fuel poverty and in the lowest income quintile were more likely to be under-consuming (31% and 29%, respectively) than households not in fuel poverty or in the highest income quintile (19% and 12%, respectively). As discussed in section 5.1, income was strongly related to the ability to keep up with energy bills, with 41% of households in the lowest income quintile struggling to pay energy bills, compared with just 5% of households in the highest income quintile. For struggling households, answers to questions on whether households change their heating hours (43%); their thermostat temperature (33%); or the number of rooms they heat (29%), suggested that 26% of struggling households made more than one heating behaviour change. Heating behaviour changes would contribute to lower levels of consumption compared with BREDEM and would explain why low income and fuel poor households were more likely to report feeling uncomfortably cold[54] in the living room (low income 21%; fuel poor 23%) and bedroom (low income 14%; fuel poor 16%), compared with high income and non-fuel poor households in the living room (high income 6%; not fuel poor 11%) and bedroom (high income: 6%; not fuel poor: 9%).

The following groups were more likely to be under-consuming: private renters (29%) and housing association tenures (32%) compared with owner occupiers (15%); lone parents with dependent children (29%) compared with couples aged 60 or over (12%); and non-pensioner households (23%) compared with pensioner households (15%). All these under-consuming household groups were more likely to report feeling uncomfortably cold in the living room and main bedroom, and were more likely to report struggling to keep up with their energy bills. For lone parents in particular, 51% reported struggling to keep up with their energy bills and 28% reported feeling uncomfortably cold in the living room. These results indicate a link between thermal comfort, income and affordability, however results for household size and children present were less clear, as both larger households and households with children were more likely to struggle with energy bills but were not found to be more likely to be under-consuming.

One person households under 60 were more likely to be under-consuming (37%) than couples aged 60 or over (12%), and along with private renters and non-pensioner households, were more likely to have no-one in during the daytime[55]; with 34% of one person households under 60 reported to have no-one in during the day compared with couples aged 60 or over (n<5). This corresponds with lower heating hours, for example one person households under 60 had fewer median heating hours (5hrs:30mins) than couples aged 60 or over (9hrs:00mins). In addition, there was an indication of differences in 24-hour living room temperatures for these groups[56].

The following households with older occupants were more likely to be over-consuming: households where the HRP is 75 or older (32%) compared with households where the HRP is between 16-34 (9%); households with a pensioner present (28%) compared with non-pensioner households (16%) and couples with no dependent children aged 60 or over (31%). Households with older occupants were more likely to be in during the day (pensioner present

[54] ‘Thermal Comfort, Ventilation, Damp and Mould’ report, section 5.2.2
[55] ‘Heating Patterns and Occupancy’ report, section 4.2
[56] ‘Thermal Comfort, Ventilation, Damp and Mould’ report, section 5.1

63%; no pensioner present 34%), and were found to typically heat for longer and to higher average temperatures in the living room; households aged 75 or over heated on average for 4 hours longer than households in the youngest age group (16-34), and had living rooms that were on average 1.4°C warmer.

Households in the highest income quintile (35%) were also more likely to be over-consuming compared with households in the lowest quintile (11%). However in contrast to the results seen for older occupants, the patterns for living room temperatures and heating hours were less clear, with no apparent relationship between increasing income and heating hours or increasing income and living room internal temperatures. Nonetheless, households in the highest income quintile were less likely to report feeling uncomfortably cold in the living room (6%) and bedroom (6%) compared with households in the lowest income quintile (21% and 14%, respectively), indicating that this may be linked to under-occupancy and daytime occupancy patterns (see section 3.4.2.2 for an average daily profile for gas consumption by daytime occupancy).

To summarise, many of the same groups of households who were struggling to keep up with their energy bills were also reporting feeling uncomfortably cold in the living room or main bedroom, and the lack of income also appeared to be a key driver of under-consumption in EFUS households. Alongside this, households with low energy efficiency ratings and non-central heating systems were more likely to deviate away from BREDEM assumptions with lower levels of consumption in comparison. Older households who heated for longer, and with warmer living room temperatures were over-consuming, while households with high incomes were over-consuming alongside under-occupiers.

While it is acknowledged that BREDEM is used to calculate the energy required for an adequate level of comfort for fuel poverty calculations there may be areas where assumptions can be improved upon, for example, in the case of under-occupancy. Future work is therefore recommended in this area to determine whether the gap between modelled and actual consumption can be reduced, and to better establish the reasons for deviations between modelled and measured consumption.

7. Conclusions

The ‘Household energy consumption and affordability’ report is part of a series of reports that present the findings from the EFUS 2017. The meter point data for 2017, detailed gas consumption data, and findings from the three interview surveys have been used to present results including: the average annual household energy consumption and analysis of key drivers of energy consumption; daily gas consumption profiles; information on energy switching and affordability of energy bills; exploration of the reasons for a reduction in gas consumption since 2010; and analysis of under-consuming and over-consuming households.

7.1 Annual household energy consumption

The meter point data for 2017 has been used to calculate the average annual gas consumption for 1,770 households (covering the period June 2017 to June 2018) and the average annual electricity consumption for 1,994 households (January 2017 to January 2018). Stepwise linear regression models were used to determine to what extent different groups of factors explain variation in annual gas consumption (for 385 households with gas central heating), and annual electricity consumption (for 787 households where electricity was not the main heating fuel). The key drivers of variability in gas and electricity consumption have been identified in each of the models.

The median gas consumption, for all households, was calculated to be 12,300 kWh/year, a decrease of 12% since 2010 where the median gas consumption was 13,900 kWh/year. The median electricity consumption, for all households, was 3,100 kWh/year, a fall since 2010 of 13%. The 2017 figures were in line with external data sources (e.g. NEED).

For households where electricity was not the main heating fuel, the electricity consumption decreased from 3,400 kWh/year in 2010 to 2,900 kWh/year in 2017. There was, however, no significant fall in consumption for households using electricity as their main heating fuel; the electricity consumption was 7,000 kWh/year in 2010 compared to 6,900 kWh/year in 2017. Flats and dwellings with smaller floor areas (<50 m2) were more likely to use electricity as their main heating fuel (22% for both), compared with houses (4%) and larger dwellings (2% to 11%); while flats also had warmer 24-hour living room temperatures than houses, by on average 1°C (section 5.1 of ‘Thermal Comfort, Ventilation, Damp and Mould’ report).

Based on linear regression analysis of gas consumption, dwelling characteristics were found to explain the most variability (48%) in gas consumption from the individual models, followed by household characteristics (27%) and heating behaviours (21%). Combining dwelling and household models (53%) only added a small amount to the explanatory power of the model, indicating that dwelling characteristics were predominantly controlling the level of household gas consumption.

A final combined model of dwelling and household characteristics and EFUS reported heating behaviours, was found to explain 59% of the variability in gas consumption, based on the following explanatory variables: floor area, SAP rating, daily heating hours, household size, income, central heating control, presence of a pensioner, gas secondary heating, region, and thermostat temperature. In total, 41% of the variability in gas consumption was not accounted for which could be due to reasons including: survey data quality, model assumptions, and other explanatory variables that were not used in the models.

The most important drivers of the variability in gas consumption were found to be the following:

- Floor area: gas consumption increased as the usable floor area increased;
- Energy efficiency: gas consumption increased as the energy efficiency decreased;
- Daily heating hours: gas consumption increased as daily heating hours increased;
- Household size: gas consumption increased with increasing household size.

Results indicate that dwelling characteristics were not able to explain the same level of variability in gas consumption for households in fuel poverty, as for non-fuel poor households. Further work is recommended to understand the reasons for this; however, it may be that this is driven by the type of households within the fuel poor group, or by behavioural characteristics of these households.

Based on linear regression analysis of electricity consumption, variables related to appliance ownership and usage were found to explain the most variability (50%) in electricity consumption from the individual models, followed by household characteristics (36%) and dwelling characteristics (23%). Combination of dwelling and household characteristics (41%) explained less variability than EFUS variables, indicating that it is information about the appliances used in the household that can better determine how much electricity is used by the household.

A final combined model of dwelling and household characteristics and appliance related variables, was found to explain 58% of the variability in electricity consumption. The model included the following variables: number of wet and cold appliances, household size, floor area, weekly washing loads, dwelling type, three or more TVs, cooling appliance use, electric secondary heating hours, energy intensive electrical appliances, smart appliances, weekday daytime occupancy, number of insulation measures, American fridge-freezer, electric cooking, affordability of energy bills, electric water heating, and long-term sick or disabled. Similarly to gas, a large amount of the variability in electricity consumption (42%) could not be accounted through the modelling.

The most important drivers of the variability in electricity consumption were found to be the following:

- Number of wet and cold appliances: electricity consumption increased with an increasing number of appliances, while accounting for household size;
- Household size: electricity consumption increased with an increasing household size, while accounting for the number of wet and cold appliances.

- Other notable factors included: the floor area and dwelling type; the usage of washing machines, cooling appliances, and secondary heaters; and ownership of three or more TVs, energy intensive electrical appliances, and smart appliances.

When accounting for other factors in the model, fuel poverty was not found to be important in explaining the variability in electricity consumption.

7.2 Detailed household gas consumption

Exploratory analysis of detailed gas consumption data for 143 households investigated how gas consumption varied across the year, and during very cold periods. In addition, daily profiles have been used to study how gas consumption varies across the day during the EFUS heating season (October 2018 to April 2019), for different groups of households.

Based on daily averages of gas consumption for each month, the median consumption ranged from 6 kWh/day in July and August to 64 kWh/day in January. There was a larger range in gas consumption over the EFUS heating season, reflecting the impact of space heating requirements, for different dwelling and household types.

Daily gas consumption profiles have been presented in the report for key variables representing dwelling and household characteristics and heating behaviours. The floor area, household size, daily heating hours and EPC band of the dwelling (all important in explaining variability in gas consumption) were included. Indicative analysis showed greater levels of gas consumption throughout the day for households in dwellings with larger floor areas, and with longer heating durations. For households with three or more occupants, or households with an EPC band of E or lower, the gas consumption was notably greater in the evening period.

Other interesting daily profiles include reported weekday occupancy; households reported to be out during the day showed more distinct morning and evening peaks in gas consumption, compared with households who were in during the day. For households reporting non-regular heating patterns, the gas consumption profile was lower and the peaks less distinct, compared with households reporting regular heating patterns. Finally, the daily gas consumption profiles clearly showed the differences throughout the day for households who reported heating their home for one, two, or three or more periods.

The average temperature and daily gas consumption for the coldest week in winter 2018/19 (28th January to the 3rd February 2019), was compared with the average temperature and consumption in the week prior to this (21st January to 27th January 2019). The mean external temperature decreased from 3.9°C in week 1 to 0.9°C in week 2 and on average, the household gas consumption increased by 15% over the same period. In total, over a quarter of the sample increased their gas consumption by 25% or more in the coldest week. Indicative findings suggest that households in the lowest income quintile (41%) and households in fuel poverty (44%) were less likely to increase their gas consumption by 5% or more in between the two weeks, indicating that low income households were less able to change the extent to which they are able to heat their homes in particularly cold periods, compared with households with higher disposable incomes.

7.3 Household energy costs and affordability

Findings from the EFUS interview surveys (Interview 1 in autumn 2017/18 of 2,632 households, Interview 2 in winter 2017/18 of 1,340 households, and Interview 3 in winter 2018/19 of 1,186 households) have been presented here, related to topics on energy suppliers, energy switching and affordability of energy bills. The average tariff comparison rates (TCR) have been included, where the TCR is the average cost of each unit of energy and was provided on energy bills between 2014 and 2017 to help consumers compare the cost of energy tariffs. Total household energy costs have been calculated, using information on: gas and electricity consumption from meter point data; estimates of gas and electricity costs from TCR values; and reported costs of other fuels used by the household for heating, hot water and cooking.

In total, 27% of households reported having a smart gas or electricity meter at Interview 1 (autumn 2017/18) and 36% of households at Interview 3 (winter 2018/19). At Interview 3, 50% of households had reported either switching their energy supplier or actively changing their tariff type, since Interview 1.

More than two thirds of households with a dual fuel tariff reported to be with one of the 'Big Six' suppliers at Interview 1 (British gas, Npower, EON, Scottish power, SSE and EDF). For households who reported actively switching their electricity supplier between Interview 1 and Interview 3, they were more likely to switch to a challenger supplier (62%) compared with households who had not switched (73%). This was more pronounced when analysing the total number of switches (from 12 months prior to Interview 1 through to Interview 3), where households who had switched multiple times were more likely to be with a challenger supplier (73%) than households who had switched once during this period (57%) or not at all (19%). However, most households (57%) reported no switch to their energy supplier at Interview 1 or Interview 3, with just 11% of households switching at least twice in the two and a half year period.

Most households reported paying for their electricity bills by direct debit (76%) compared with pre-payment methods (15%) and standard credit (9%). Households in fuel poverty were found to be more likely to pay for their electricity by pre-payment (31%) than households not in fuel poverty, however, tariff costs (based on reported TCR) were not found to significantly differ between households paying by pre-payment and direct debit, likely illustrating the effect of the pre-payment cap that was introduced in April 2017.

The median TCR values were 15.44 p/kWh for electricity, and 4.01 p/kWh for gas. Based on average consumption figures for gas and electricity, and the TCR inter-quartile range, annual fuel bills could range between £410 to £560 for gas, and £400 to £510 for electricity (where electricity was not the main heating fuel). The lowest tariff costs were reported for households who had switched supplier or tariff type in the past 12 months. There were no significant differences in tariff costs when comparing by the fuel poverty status of households.

In total, 16% of households at Interview 1 reported using other fuels for heating the home, hot water or cooking. The most popular of these was wood (2.7 million households), with 44% of households using wood not paying anything for this fuel. This contrasts with heating oil (0.7 million households) where the median reported cost of oil was £800 per year. The median fuel costs for LPG were £400 per year, and for solid fuels £50 per year. Costs for other fuels were greater for households with electricity as the main heating fuel (solid, oil, LPG: £200 per year) compared with gas (solid, oil, LPG: £50 per year).

The median annual 2017 gas cost, for households with gas as their main heating fuel was £450 per year, and the median annual 2017 electricity cost, for households where electricity was not the main heating fuel, was £410 per year. Median total energy costs (combining gas, electricity and other fuels) were calculated to be around £920 per year.

Total household energy costs were found to be highest for the following groups: larger dwellings compared with smaller dwellings; larger household sizes; owner occupiers; dwellings with an EPC rating of D or lower; households living in rural areas; and households in fuel poverty.

In total, 19% of households reported struggling to keep up with their energy bills at Interview 2. Households in fuel poverty were more likely to report struggling to keep up with their energy bills (40%) compared with 16% of non-fuel poor households. In addition, 66% of households who reported that it was either a constant struggle, or they were falling behind with their energy bills, were in the lowest income quintile, compared with 33% of households who reported struggling from time to time, and 14% who were keeping up without difficulties.

Household income was the key factor in determining whether a household was struggling to pay their energy bills, and this was reflected in the following groups that were more likely to struggle: households in the private rented sector (32%) or social sector (38 to 39%); lone parents with dependent children (51%); households where the HRP is younger than 55 (24%) or no pensioners are present (24%); households with children present (31%); and larger households with five or more occupants (41%).

For households who reported struggling to keep up with their energy bills in some way, 43% of households said they heated for fewer hours, 34% cut back on spending on their food shopping, and 33% reported heating to a lower temperature. In total, 21% of households reported that they needed to borrow money to be able to keep up with their energy bills. In addition, households who reported feeling uncomfortably cold in the living room in winter were more likely to struggle to keep up with their energy bills (42%) compared with households reporting feeling uncomfortably cold never, rarely or sometimes (16%).

Where households reported that keeping up with their energy bills was a constant struggle, or they had fallen behind: 94% changed the way they heat their home; 89% cut back on spending in some way; and 56% borrowed money or reported missing rent payments, indicating that large changes to behaviour (both in terms of heating and spending) were necessary for households who cannot afford to keep up with their energy bills.

7.4 Modelled energy consumption

The BREDEM modelled energy consumption is the theoretical consumption required to provide an adequate level of warmth, hot water, lights, appliance and cooking use; and is used in the modelling of fuel poverty. Firstly, the BREDEM calculation has been used to explore the reasons for the 12% decrease in gas consumption between 2010 and 2017, by comparing the assumptions used in the model with outputs from the EFUS and accompanying EHS data. Secondly, the difference between household metered energy consumption and their BREDEM modelled energy consumption was calculated for households using only mains gas or electricity for space or water heating (1,181 households). The types of dwellings and households who were more likely to be under-consuming, or over-consuming, in relation to the BREDEM modelled consumption have been explored.

A BREDEM calculation was used to construct a model of a house that is broadly representative of the English housing stock. The following factors that are likely to influence gas consumption were considered: heating hours, thermostat set-point temperature, heating extent, number of occupants, external temperature, floor area, dwelling fabric, airtightness, hot water cylinder insulation, boiler type, and efficiency of the heating appliance. Based on the EFUS and EHS data, changes to the BREDEM model have been applied to account for improvements between 2010 and 2017 for the: fabric efficiency, the hot water cylinder insulation for standard boilers, and the efficiency of gas boilers.

When factors were accounted for within the BREDEM calculation for the average dwelling archetype, gas consumption was modelled to decrease by 13% for standard boilers, and 10% for combi-boilers. Considering the change in the market share of standard and combi boilers, from 47% standard and 53% combi in 2010 to 36% standard and 64% combi in 2017; the weighted gas consumption was found to decrease by 11.9%. The factors considered appear to explain the observed reduction in the meter point data gas consumption, which had decreased by 11.7% between 2010 and 2017. There are likely to be more complex interactions and feedback loops that require further investigation; however, these results provide a useful first approximation of the reasons for the reduction in gas consumption since the EFUS 2011 survey.

Comparison of BREDEM modelled energy consumption (gas and electricity only) with actual energy consumption derived from meter point data showed that on average, households consumed 12% less energy than theoretically required by the fuel poverty methodology standard.

Households have been classified as under-consumers if relative to other households the percentage difference in modelled and actual energy consumption was in the lowest quintile (using less energy than modelled), and households have been classified as over-consumers if the percentage difference was in the highest quintile (using more energy than modelled). Under-consumers were found to consume at least 40% less energy than modelled, while over-consumers were found to consume at least 12.5% more energy than the modelled consumption.

Analysis of the likelihood of certain groups under- or over-consuming, across a suite of dwelling and household types has shown differences exist. This indicates that certain households are choosing, or are necessitated, to use less (or more) energy than standards dictate. Results from the 'Heating Patterns and Occupancy' and 'Thermal Comfort, Ventilation, Damp and Mould' reports have been used to provide possible reasons for the differing levels of consumption in relation to heating hours, mean internal temperatures, thermal comfort, and occupancy patterns; along with reported affordability of energy bills from this report.

Households in fuel poverty and in the lowest income quintile were more likely to be under-consuming (31% and 29%, respectively) than households not in fuel poverty or in the highest income quintile (19% and 12%, respectively). As well as being a key driver for the affordability of energy bills, low incomes likely influenced the households found to be more likely to be under-consuming, including: private renters and housing association tenures; lone parents with dependent children; and non-pensioner households. These groups were all more likely to struggle to keep up with their energy bills and to have reported feeling uncomfortably cold in the living room and main bedroom.

Households in less energy efficient dwellings were more likely to be under-consuming (EPC band F or G: 49%; E 32%) compared with more energy efficient dwellings (EPC band A to C: 16%; D: 19%), which was also linked with higher levels of thermal discomfort and lower internal temperatures in these less efficient dwellings. Non-centrally heated dwellings were more likely to be under-consuming (39%) than households with central heating (18%), which may be related to the proportion of rooms heated in these dwellings and the greater prevalence of non-regular heating.

Households with older occupants were more likely to be over-consuming; where 32% of households where the HRP was 75 or older were over-consuming, compared with 9% of households in the youngest age group (16-34 years). Households aged 75 or over had warmer living rooms (on average 1.4°C warmer) and heated on average for 4 hours longer, compared with households aged 16-34, indicating the influence of occupancy patterns and required thermal comfort for older occupants.

Finally, households in the highest income quintile were also more likely to be over-consuming (35%) compared with households in the lowest income quintile (11%), and households considered to be under-occupying their homes were also more likely to be over-consuming (34%) than households not under-occupying (15%). The latter result indicates that the proportion of unheated rooms in the house may be over-estimated within the BREDEM model, and further work is recommended in this area to better establish reasons for the deviation between modelled and measured consumption as a result of under-occupancy, and for other assumptions used within BREDEM.

Glossary

Term	Description
Age of dwelling:	This is the date of construction of the oldest part of the dwelling. Recorded by surveyors in the EHS physical survey.
Age of HRP:	The Household Reference Person (HRP) is the person in whose name the dwelling is owned or rented or who is otherwise responsible for the accommodation. In the case of joint owners and tenants, the person with the highest income is taken as the HRP. Where incomes are equal, the older is taken as the HRP. This procedure increases the likelihood that the HRP better characterises the household's social and economic position. The age of the HRP is derived from: variables obtained from the EHS Interview survey for households that had not changed since the earlier EHS interview. householder responses to questions 45-50 in EFUS Interview 1 and questions 41-45 in EFUS Interview 3 for new households.
Alternative heating:	Heating system present in a room (or rooms) used as an alternative to the main heating system.
After housing costs equivalised income – weighted quintiles:	This is calculated based on the fuel poverty income (from 2015 & 2016 fuel poverty datasets) and updated to account for any changes to income at Interview 1 and Interview 3 EFUS questionnaires. Validation of income based on reasons why household income had changed for the Interview 3 questionnaire provided increased confidence and reliability of the income.
Boiler type:	Derived from the EHS data.
Children Present:	Anyone in the household who is 16 years old or younger at the time of the EFUS interview. This is derived from; variables obtained from the EHS Interview survey for households that had not changed since the earlier EHS interview. householder responses to questions 45-50 in Interview 1 and questions 41-45 in Interview 3 in the EFUS questionnaires for new households
Daytime Occupancy	Derived from the EFUS survey. A household has been classified as being 'in during a weekday' if they indicated being generally in the house on weekdays during the winter, for both the morning and afternoon periods. A household is classified as 'not in during the day' if they responded as not being in for both the

Term	Description
	morning and the afternoon periods. Households who were in for either the morning or afternoon period were coded as 'Variable' occupancy.
Dwelling insulation:	The number of insulation measures (0 to 3) where positive responses for 'fully double glazed', 'insulated walls' and having loft insulation greater than 200mm count as insulation measures. EFUS Interview 1 and interview 3 questionnaires asked respondents about new insulation measures installed since the EHS survey. New windows installed since the EHS survey are excluded from the analysis as it cannot be assumed that this resulted in the dwelling being fully double glazed.
Dwelling type:	Classification of dwelling on the basis of the surveyors' inspections during the EHS physical survey.
Employment status of the household:	Derived from W1_q56 of EFUS Interview 1, and the modelling assumes responses are for all adults in the household (HRP, partner and any other additional adults in employment). 'Don't know' responses were coded as having no employment. Households either have at least one person employed, or all adults are unemployed.
Energy Performance Certificate (EPC) band:	Energy Performance Certificate band, also sometimes known as the Energy efficiency rating (EER) band (SAP 2012) of the dwelling. Bands from A to G that are used in the Energy Performance Certificate. 'A' is the most efficient and 'G' is the least efficient. Derived from the SAP 2012 methodology used for the 2016 EHS. SAP2012 was re-modelled for dwellings which have had improvements between the EHS and EFUS Interviews 1 and 3.
Fuel poverty (LIHC) status:	Based on the 'Low Income High Cost' (LIHC) definition, a household is considered to be fuel poor if: they have required fuel costs that are above average (the national median level); were they to spend that amount, they would be left with a residual income below the official poverty line. Each household's fuel poverty status has been updated using EFUS data on household changes, incomes and modelled fuel costs due to dwelling improvements.
Fuel poverty gap:	The difference in pounds between the required energy costs for each fuel poor household and the nearest fuel poverty threshold.
Fuel type of main heating system:	As recorded by surveyors in the EHS physical survey. Grouped into 'mains gas', 'electricity' and 'other', which includes bottled gas, bulk gas, solid fuels, oil and community schemes. The data

Term	Description
	was updated at Interview 2 and Interview 3 if a household reported using a different main heating system. Assumptions for households reporting having central heating but did not answer about fuel type: - Set to mains gas if a mains gas connection was recorded in the EHS - If not on mains gas set to EHS recorded main fuel - If reported not on gas in EFUS Interview 1, then categorised as 'other' gas (e.g. bottled).
Fully double glazed:	Derived from the 'dblglaz4' EHS variable as recorded by surveyors in the physical survey. Fully double glazed is defined as 'entire house double glazed'. Not fully double glazed is anything less than fully double glazed. New windows installed since the EHS survey were excluded from the analysis as it could not be assumed that this resulted in the dwelling being fully doubled glazed.
Heating season:	The months when there is a requirement for the main heating system to provide heat. For the EFUS 2017 survey this is calculated based on householder responses to a question in Interview 2 (what month heating began every day) and a question in Interview 3 (what month heating stopped every day), both asked in relation to Winter 2017/18.
Household size:	Number of persons in the household, banded into 5 groups, derived from the 'hhsizex' variable from the EHS Interview survey. The data was updated following any changes to household composition recorded in EFUS Interview 1 and Interview 3 questionnaires.
Insulated walls:	Derived from the 'wallinsx' variable as measured by surveyors in the EHS physical survey and refers to any insulation for the predominant wall type. The 'solid uninsulated' category includes non-cavity other wall types such as timber, steel or concrete framed. EFUS Interview 1 and Interview 3 questionnaires asked the household about the installation of wall insulation since the EHS survey and the 'wallinsx' variable was updated.
Loft insulation:	Banded variable of 'loftinsx', the level of loft insulation recorded by surveyors in the EHS physical survey. EFUS Interview 1 and Interview 3 questionnaires asked the household about the installation of loft insulation since the EHS survey and the 'loftinsx' variable was updated.
Long-term sickness or disability:	Whether anyone in household has long-term illness or disability that limits their activities. And/or whether anyone in the

Term	Description
	household is registered disabled. This is self-reported by EHS interview respondents.
Pensioner Present:	Anyone in the household who of state pension using data from the EHS Interview survey. Updates using responses to questions 45-50 in Interview 1 and questions 41-47 of Interview 3 EFUS questionnaires.
Region:	Government Office Region that the dwelling is located in. Obtained from the EHS.
Rurality:	Is the dwelling in a rural (village or isolated hamlet) or urban (urban or town or fringe) location. Derived from the 'rumorph' variable in the EHS.
SAP rating:	The energy cost rating as determined by Government's Standard Assessment Procedure (SAP) and is used to monitor the energy efficiency of dwellings. It is an index based on calculated annual space and water heating costs for a standard heating regime and is expressed on a scale of 1 (highly inefficient) to 100 (highly efficient with 100 representing zero energy cost). An updated SAP rating was modelled for dwellings which had improvements between EHS and EFUS Interviews 1 and 3.
Supplementary heating:	Heating systems used in addition to the main heating system to boost internal temperatures.
Tenure:	Derived from the EHS but updated from householder responses in EFUS to q52 in Interview 1 and Q51 of the Interview 3. Cases responding 'don't know' left as the original EHS category. The modelling assumes a response of 'renting' to be a household living in the private rented sector.
Type of (main) heating system:	Derived from the EHS but adjusted for EFUS Interview 2 and Interview 3 responses (question 02). Grouped into central heating or non-central heating categories. Non-central heating includes storage radiators, gas fires, electric heaters, coal/wood/ smokeless fuel fires or stoves and other less common systems.
Under-occupying:	A household is considered to be under-occupying if the dwelling is more than large enough for the number (and type) of occupants living there. For the full definition of under occupancy, see the fuel poverty methodology handbook, which is available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829010/Fuel_Poverty_Methodology_Handbook_2019.pdf

Term	Description
	Derived from EHS data and updated based on age and household changes at EFUS Interview 1 and 3.
Useable floor area:	The total usable internal floor area of the dwelling as modelled for the EHS 'floorx', rounded to the nearest square metre. It excludes integral garages, balconies, stores accessed from the outside only and the area under partition walls. Grouped into 6 categories.
Water heating system	Derived from EHS data. Categories are: 'with central heating', 'dedicated boiler', 'electric immersion heater', 'instantaneous', 'other'.

Appendix A: Gas multi-variate analysis

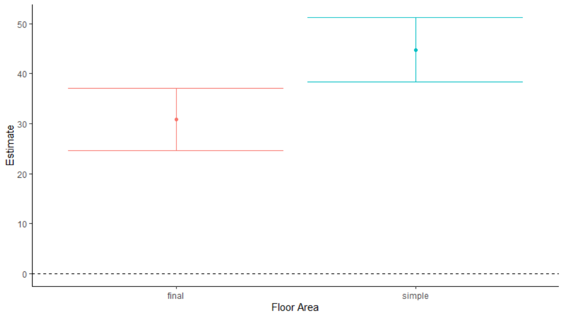
Tables of variables included in models

Variable name	Categories (sample size)
Dwelling Characteristics	
Dwelling type	Flat (Intercept, 33), End terrace (38), Mid terrace (53), Semi detached (134), Detached (103), Bungalow (24)
Floor area (logged)	n/a
Region	North (Intercept, 118), Midlands (116), South (151)
Boiler type	Standard boiler (floor or wall) (Intercept, 65), Back boiler (to fire or stove) (11), Combination boiler (26), Condensing boiler (106), Condensing-combination boiler (177)
Wall type	Cavity (Intercept, 278), Solid (including other) (107)
Insulation measures	No insulation measures (Intercept, 33), All 3 insulation measures (107), 2 insulation measures (149), 1 insulation measure (96)
SAP rating	n/a
Household Characteristics	
Tenure	Owner occupied (Intercept, 264), Private rented (42), Local authority (33), RSL (46)
Household size	1 (Intercept, 78), 2 (158), 3 (59), 4 (66), 5 or more (24)
Pensioner present	No (Intercept, 246), Yes (139)
Child present	No children (Intercept, 277), At least one child (108)
Income	1st quintile (lowest) (Intercept, 77), 2nd quintile (74), 3rd quintile (54), 4th quintile (82), 5th quintile (highest) (98)
Long-term sick or disabled	No (Intercept, 245), Yes (140)
Employment status	No (Intercept, 144), Yes (241)
EFUS	
Heating season start	Other (Ja/F/Mar/Ap/May/Aug) (Intercept, 11), September (43), October (180), November (98), December (25), Heating used all year round (17), Haven't heated my home everyday this Winter (11)
Central heating control	Timer controls system (Intercept, 324), Switch on boiler/control panel (61)
Thermostat temperature	n/a
Vary thermostat	Generally leave it at one temperature (Intercept, 266), Vary the temperature setting (119)
TRVs present	All or all but one (Intercept, 231), Most (74), Some (36), None (44)
Non-regular heating	No (Intercept, 338), Yes (47)
Daily heating hours	n/a
Unheated habitable rooms	No, all habitable rooms with main heating present are heated by that system (Intercept, 285), At least 1 habitable room with main heating present but not heated by it (100)
Gas secondary heating	No (Intercept, 320), Yes (65)
Non-gas secondary heating	No (Intercept, 265), Yes (120)
Thermal comfort	No (Intercept, 332), Yes (53)
Weekday daytime occupancy	No (Intercept, 54), Variable (117), Yes all day (214)
Affordability of energy bills	Keeping up without any difficulties (Intercept, 317), Struggle to keep up, or falling behind (68)

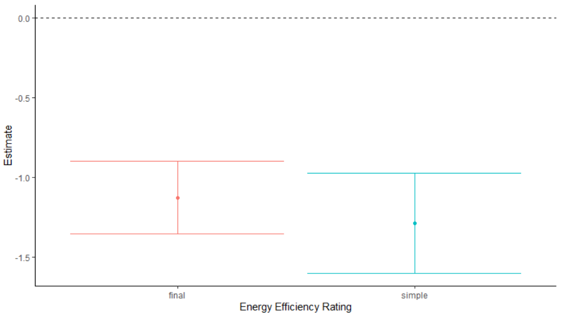
Some categories are n/a because these variables are not categorical

Final model output and coefficient graphs

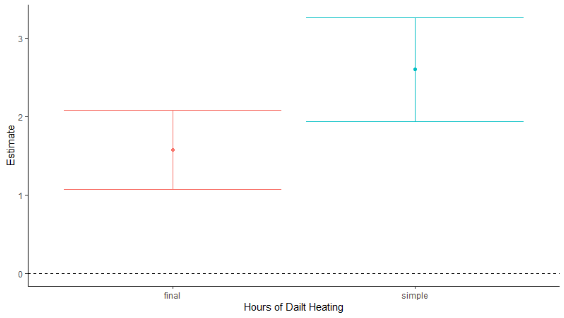
Variable (category)	Estimate	Std. Error	p-value
Intercept	-3.79	19.06	0.842
Floor area (logged)	30.83	3.20	0.000
Region (Midlands)	-3.93	2.85	0.169
Region (South)	-9.78	2.65	0.000
SAP rating	-1.13	0.12	0.000
Household Size (2)	4.43	2.71	0.104
Household Size (3)	19.55	4.02	0.000
Household Size (4)	13.10	4.04	0.001
Household Size (5 or more)	22.65	6.02	0.000
Pensioner present (Yes)	4.86	2.53	0.055
Income (2nd quintile)	6.98	3.92	0.076
Income (3rd quintile)	3.12	4.02	0.438
Income (4th quintile)	12.28	3.74	0.001
Income (5th quintile (highest))	9.56	3.76	0.011
Central heating control (Switch on boiler/control panel)	-15.47	3.30	0.000
Thermostat temperature	1.40	0.41	0.001
Daily heating hours	1.57	0.26	0.000
Gas secondary heating (Yes)	8.33	2.78	0.003



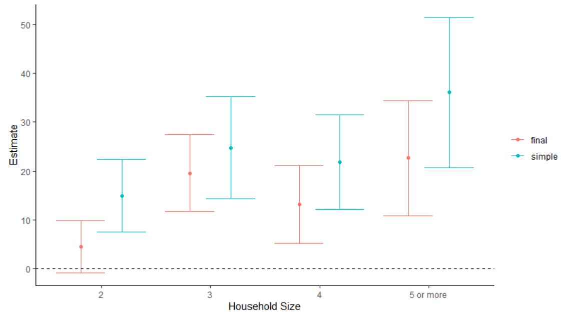
Estimate
0
10
20
30
40
50
final
simple
Floor Area



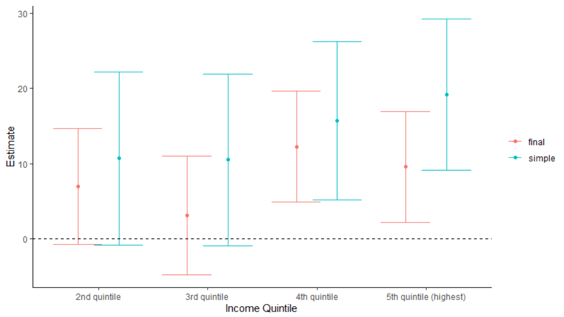
Estimate
0.0
-0.5
-1.0
-1.5
final
simple
Energy Efficiency Rating



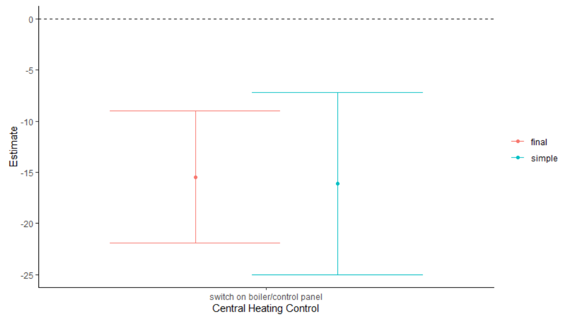
Estimate
0
1
2
3
final
simple
Hours of Dailt Heating



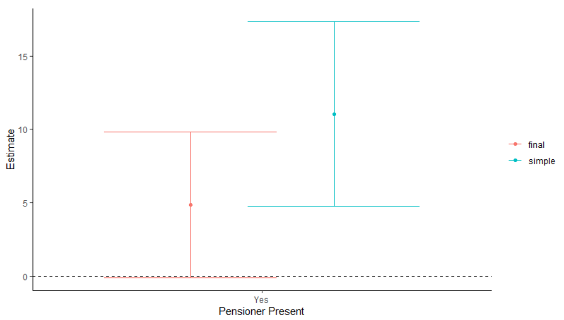
Estimate
0
10
20
30
40
50
2
3
4
5 or more
Household Size
final
simple



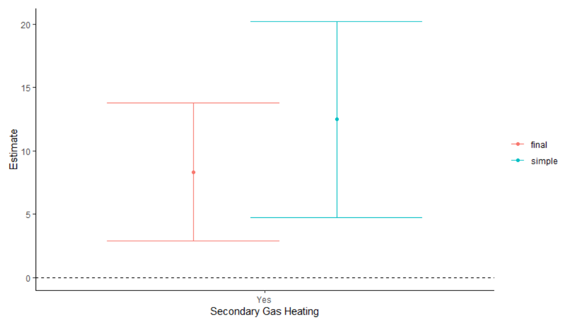
Estimate
0
10
20
30
2nd quintile
3rd quintile
4th quintile
5th quintile (highest)
Income Quintile
final
simple



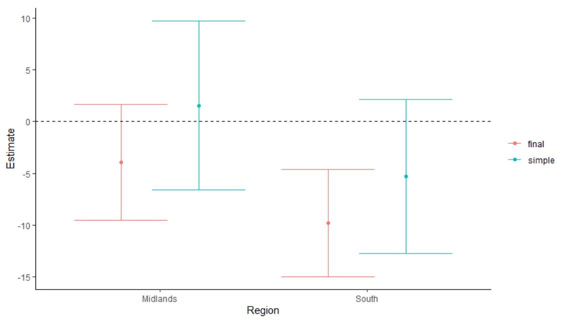
Estimate
0
-5
-10
-15
-20
-25
switch on boiler/control panel
Central Heating Control
final
simple



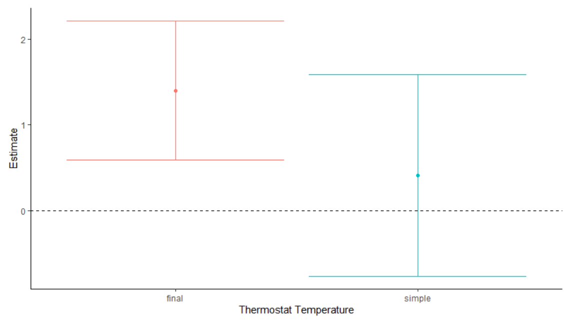
Estimate
0
5
10
15
Yes
Pensioner Present
final
simple



Estimate
0
5
10
15
20
Yes
Secondary Gas Heating
final
simple

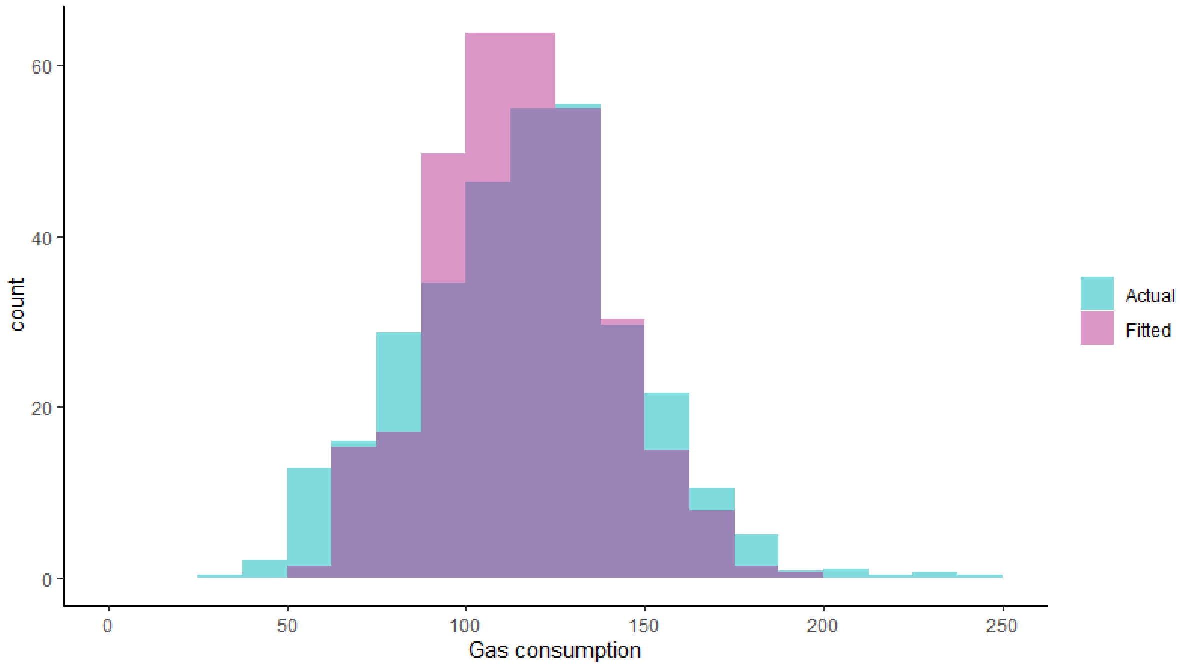


Estimate
10
5
0
-5
-10
-15
Midlands
South
Region
final
simple



Estimate
0
1
2
final
simple
Thermostat Temperature

Gas sconsumption fitted values histogram

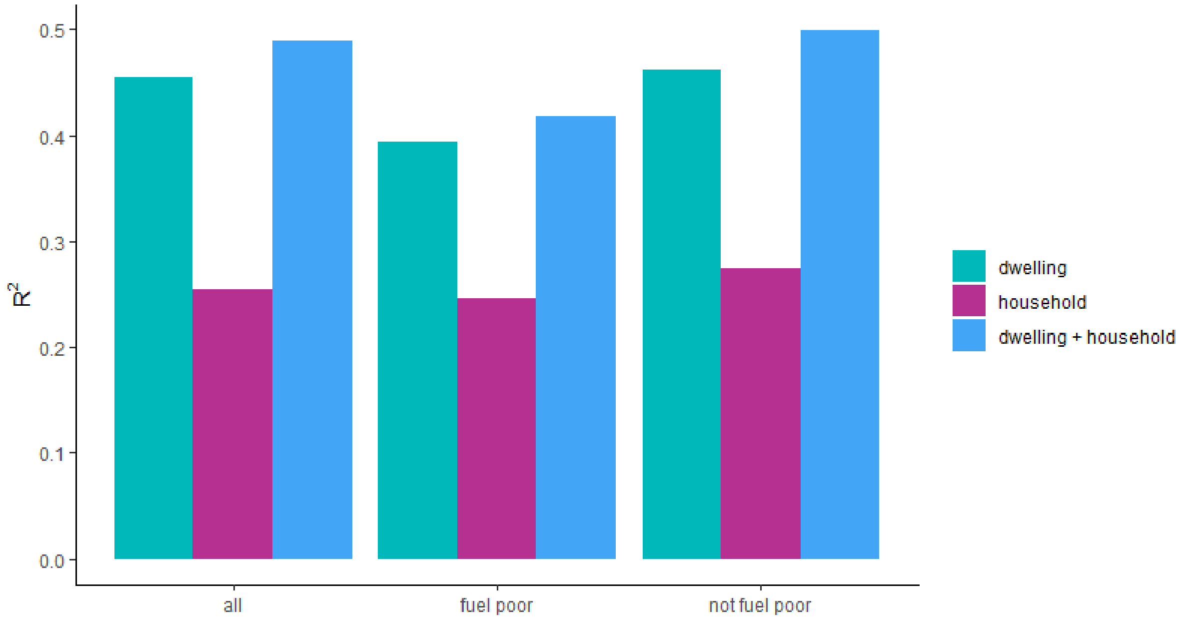


Variance inflation factors

Variable	VIF
Floor area (logged)	1.51
Region	1.18
SAP rating	1.08
Household size	1.91
Pensioner present	1.42
Income	1.58
Central heating control	1.20
Thermostat temperature	1.13
Daily heating hours	1.19
Gas secondary heating	1.15

Comparison of fuel poor with non-fuel poor households

Due to differences in sample size, models were re-run 1,000 times for the non-fuel poor on a reduced dataset, and the differences in R2 values for the dwelling model, between fuel-poor and non-fuel poor, were preserved. The figure below shows the R2 values from the full linear regression models, to provide a like-by-like comparison of the fuel poor and non-fuel poor models.


0.5
0.4
0.3
0.2
0.1
0.0
R2
all
fuel poor
not fuel poor
dwelling
household
dwelling + household

Appendix B: Electricity multi-variate analysis

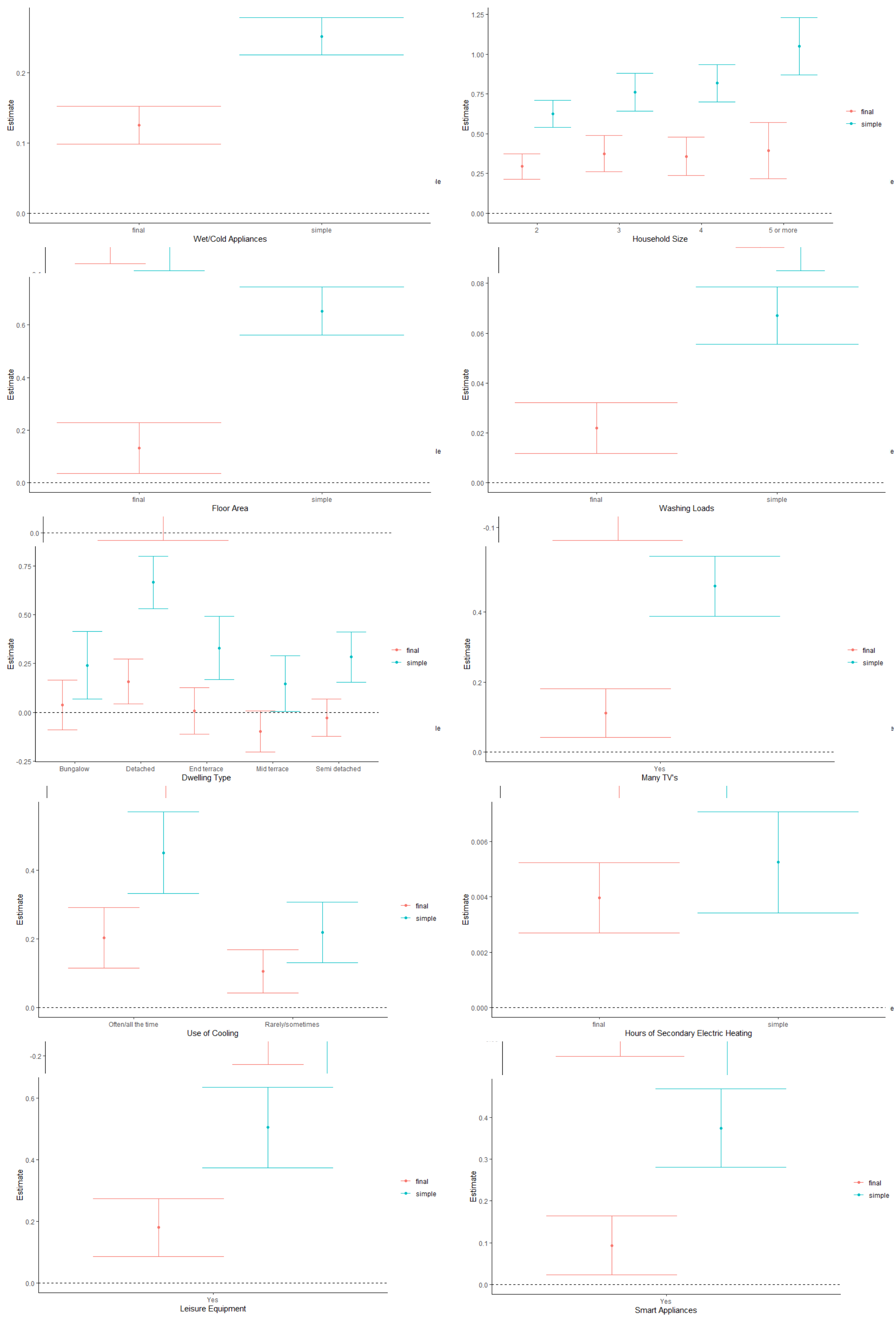
Tables of variables included in models

Variable name	Categories (sample size)
Dwelling Characteristics	
Dwelling type	Flat (Intercept, 111), End terrace (78), Mid terrace (135), Semi detached (245), Detached (148), Bungalow (70)
Floor area (logged)	n/a
Region	North (Intercept, 256), Midlands (265), South (266)
Wall type	Cavity (Intercept, 560), Solid (including other) (227)
Insulation measures	No insulation measures (Intercept, 52), All 3 insulation measures (235), 2 insulation measures (303), 1 insulation measure (197)
SAP rating	n/a
Household Characteristics	
Tenure	Owner occupied (Intercept, 455), Private rented (104), Local authority (99), RSL (129)
Household size	1 (Intercept, 219), 2 (294), 3 (115), 4 (111), 5 or more (48)
Pensioner present	No (Intercept, 490), Yes (297)
Child present	No children (Intercept, 580), At least one child (207)
Income	1st quintile (lowest) (Intercept, 197), 2nd quintile (165), 3rd quintile (127), 4th quintile (149), 5th quintile (highest) (149)
Long-term sick or disabled	No (Intercept, 473), Yes (314)
Employment status	No (Intercept, 144), Yes (241)
Fuel poverty	No (Intercept, 632), Yes (155)
EFUS	
Cooling appliance use	No appliance/never (357), Rarely/sometimes (287), Often/all the time (143)
Electric water heating	None (487), Less than daily (69), Daily (231)
Number of wet and cold appliances	n/a
American fridge-freezer	No (722), Yes (65)
Three or more TVs	No (532), Yes (255)
Electric cooking	No (215), Yes (572)
Microwave	No (76), Yes (711)
Smart appliances	No (197), Yes (590)
Energy intensive appliances	No (697), Yes (90)
Low energy light bulbs	No (669), Yes (118)
Electric secondary heating hours	n/a
Weekly washing loads	n/a
Weekly tumble dryer loads	n/a
Hours lights on in living room	n/a
Weekday daytime occupancy	No (Intercept, 92), Variable (241), Yes all day (454)
Affordability of energy bills	Keeping up without any difficulties (Intercept, 620), Struggle to keep up, or falling behind (167)

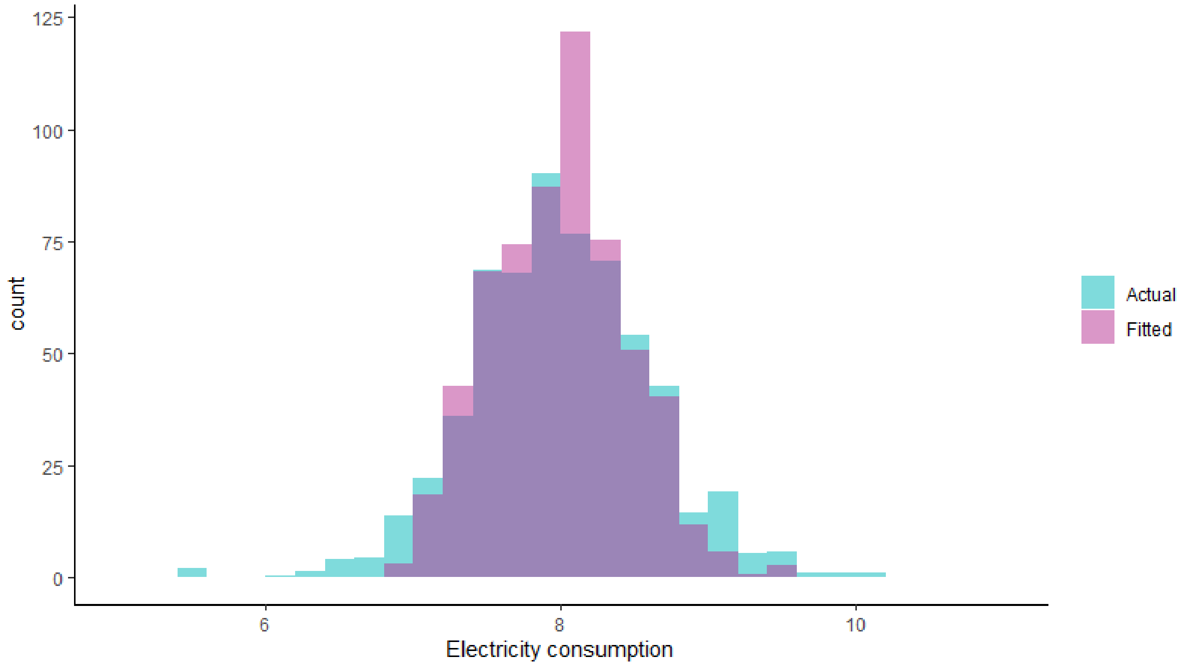
Some categories are n/a because these variables are not categorical

Final model output and coefficient graphs

Variable (category)	Estimate	Std. Error	p-value
Intercept	6.425	0.219	0.000
Dwelling type (End terrace)	0.007	0.061	0.905
Dwelling type (Mid terrace)	-0.097	0.053	0.070
Dwelling type (Semi detached)	-0.027	0.049	0.579
Dwelling type (Detached)	0.158	0.058	0.007
Dwelling type (Bungalow)	0.039	0.065	0.544
Floor area (logged)	0.131	0.049	0.008
Insulation measures (All 3 Insulation measures)	-0.202	0.058	0.001
Insulation measures (2 insulation measures)	-0.135	0.056	0.015
Insulation measures (1 insulation measure)	-0.085	0.057	0.136
Household size (2)	0.295	0.041	0.000
Household size (3)	0.375	0.059	0.000
Household size (4)	0.357	0.062	0.000
Household size (5 or more)	0.393	0.090	0.000
Long-term sick or disabled (Yes)	0.047	0.032	0.147
Employment status (Yes)	-0.056	0.035	0.108
Cooling appliance use (Rarely/sometimes)	0.106	0.032	0.001
Cooling appliance use (Often/all the time)	0.203	0.045	0.000
Electric water heating (Less than daily)	-0.114	0.053	0.031
Electric water heating (Daily)	0.038	0.034	0.261
Number of wet and cold appliances	0.125	0.014	0.000
American fridge-freezer (Yes)	0.086	0.055	0.117
Three or more TVs (Yes)	0.111	0.036	0.002
Electric cooking (Yes)	0.062	0.034	0.073
Smart appliances (Yes)	0.093	0.036	0.010
Energy intensive appliances (Yes)	0.180	0.048	0.000
Electric secondary heating hours	0.004	0.001	0.000
Weekly washing loads	0.022	0.005	0.000
Weekday daytime occupancy (Variable)	0.013	0.047	0.782
Weekday daytime occupancy (Yes all day)	0.077	0.047	0.098
Affordability of energy bills (Struggle to keep up, or falling behind)	0.074	0.042	0.078



Electricity consumption fitted values histogram



Variance inflation factors

Variable	VIF
Dwelling type	2.16
Floor area (logged)	2.02
Insulation measures	1.23
Household size	2.51
Long-term sick or disabled	1.15
Employment status	1.43
Cooling appliance use	1.25
Electric water heating	1.12
Number of wet and cold appliances	1.60
American fridge-freezer	1.14
Three or more TVs	1.34
Electric cooking	1.07
Smart appliances	1.20
Energy intensive appliances	1.11
Electric secondary heating hours	1.07
Weekly washing loads	1.55
Weekday daytime occupancy	1.32
Affordability of energy bills	1.15

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