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Smart Energy Research Lab: Energy use in GB domestic buildings 2021

Variation in annual, seasonal, and diurnal gas and electricity use with weather, building and occupant characteristics

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Report

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1 Executive summary

This report describes domestic gas and electricity energy use in Great Britain in 2021 based on data from the Smart Energy Research Lab (SERL) Observatory, which consists of smart meter and contextual data from approximately 13,000 homes that are broadly representative of the GB population in terms of region and Index of Multiple Deprivation[1] (IMD) quintile. The report shows how residential energy use in GB varies over time (monthly over the year and half-hourly over the course of the day), with occupant characteristics (number of occupants, tenure), property characteristics (age, size, form, and Energy Performance Certificate (EPC)), by type of heating system, presence of solar panels and of electric vehicles, and by weather, region and IMD quintile. Key findings include:

1. The SERL Observatory annual metered energy consumption is consistent with other national datasets such as NEED. This gives confidence that the SERL Observatory is representative of energy use in GB and thus fulfils its primary objective of providing an evidence base for a wide range of research investigating energy demand in domestic buildings.
2. Energy use reduces with improved EPC Energy Efficiency Rating. D-rated dwellings (the GB average) use 27% more gas and 18% more electricity than C-rated dwellings (the Government target for as many homes as possible by 2035).
3. There is a greater presence of rooftop photovoltaic arrays (PV) in A&B-rated dwellings. As a consequence, A&B-rated dwellings have a very different 24-hour electricity profile than C-rated ones. Peak demands for both gas and electricity are also significantly lower in homes with better ratings.
4. During the coldest periods, daily gas use peaks around 7:00am whereas electricity peaks at around 18:00, with the peak occurring later in the evening when the temperature is warmer.
5. Bigger homes use more gas and to a lesser extent more electricity. Floor area is closely correlated with occupancy and IMD quintile. In the case of electricity, large homes have an average daily base load higher than the peak loads in many smaller homes; similarly, throughout the daytime, even their average off-peak gas use exceeds the peak use of many smaller homes.
6. A detached house uses 48% more gas and 30% more electricity on average than a terraced house; this is likely to be related to the greater average floor area and occupancy in detached houses.
7. In general, older properties use more gas than modern ones, in part because they are bigger on average. Taking floor area into account, a modern home (2003 onwards) uses 26% less gas on average than a home built between 1930 and 1949; this is likely related to the introduction of building regulations and minimum standards of insulation. Electricity use shows little variation by building age.

[1] IMD, Index of Multiple Deprivation is an area-level score of deprivation. It is related to the average income and deprivation levels of households in the area, although there may be variation between individual households.

8. Homes with an electric vehicle (EV) have a median electricity use 2,000kWh per annum more than homes without. However, homes with EVs use 22% more gas as well as 70% more electricity, and within the SERL Observatory are larger and have more occupants, which will also contribute to their increased electricity use.
9. Homes with PV consume on average 62% less electricity (-1860 kWh per annum) from the grid than those without. This difference is significantly greater than the 14% reported NEED saving. However, note that NEED measures the change in *imported* electricity, whereas we report differences in *net* electricity demand (imports minus exports).

2 Introduction

We are delighted to release the first publicly available analysis of the 4th edition of the SERL Observatory data (Elam *et al.*, 2022), with data until the end of 2021. We would like to thank the 13,000+ homes, largely representative of the GB domestic population by region and IMD quintile, who have consented to the use of their data for scientific research.

This report is produced by the Smart Energy Research Lab (SERL), a UKRI/EPSRC-funded research project to provide access to gas and electricity smart meter data for the UK research community. More information about SERL, including how to apply to use the data, can be found on our website: www.serl.ac.uk.

This report is intended to be the first in a regular series of reports, analyses and aggregated statistics using SERL Observatory data, which we hope will be of interest to academics, government, NGOs and commercial organisations. This data is unique in terms of demonstrating the seasonal and diurnal (within-day) variation of gas and electricity use in British dwellings and how it varies with region, external temperature, occupancy, local deprivation (as measured by Index of Multiple Deprivation), building size, age, form, EPC, heating system, and presence of solar panels (PV) and electric vehicles (EV).

This report provides an overview of the data and high level descriptive and illustrative results for 2021. The aim is to summarise how energy use changes over months, days and half-hours in a format others may find useful and demonstrate the validity and value of the SERL Observatory data. We have tried to provide a range of useful graphical representations, and we welcome recommendations for revisions to the content for future SERL reports (contact info@serl.ac.uk). A description of the methods used to derive the data and results found in this report is included in the Appendix. Alongside this report we are also releasing a dataset of aggregated statistics (available via: https://serl.ac.uk/key-documents/reports/), a subset of which we have used to generate the results we present in this report.

We anticipate that the results reported here will raise far more questions than they answer and we encourage researchers to access both the aggregated statistical dataset and the high resolution controlled (secure access) dataset to undertake additional analysis utilising the full set of contextual variables available in the SERL Observatory dataset. The SERL Observatory data is described in detail by Webborn *et al.* (2021), full documentation is available via UKDS (SN 8666), and details of how to apply to use the data are available on the SERL website.

Only metered gas (i.e. mains gas) and electric energy is reported. Many of the homes monitored will use forms of un-metered energy, for example LPG, oil, coal, wood, etc. which are not currently included in the SERL data. In the case of homes with PV, the electricity use is net demand from the grid, i.e. the amount the household has imported minus the amount it has exported. Note that while SERL data measures imported and exported electricity in homes that have microgeneration it does not measure electricity *generated*. This means that we are unable to calculate the gross electricity demand for these households nor their self-consumption (how much of the electricity they generate is used within their home rather than exported to the grid).

We recommend care when interpreting the data presented in this report as it has not been weighted to account for sample design and non-response bias, nor normalised with respect to differences in weather, building size or other factors. As an example, occupancy may appear to have a very large impact on energy use, but this may be due to confounding factors such as the fact that the bigger homes tend to have more occupants. To fully account for how factors correlate requires more detailed multivariate analysis which is outside the scope of this report but which we have started to publish elsewhere (McKenna *et al.*, 2022).

Our analysis suggests that the results are consistent with other national data sources, such as NEED (BEIS, 2021c), which itself has been compared to ECUK and subnational data (BEIS, 2021a)) and EFUS (BEIS, 2021b). However, it should be noted that NEED corrects gas consumption for weather and does not take account of exported electricity. No directly comparable data was available for 2021 at the time of producing this report.

We are looking to continuously improve the quality of our outputs and we would welcome feedback on potential errors (contact info@serl.ac.uk). Any corrigenda will be published on our website.

2.1 SERL Observatory dataset and analysis for this report

The SERL Observatory contains smart meter data and linked contextual data for over 13,000 homes in GB. Full details of the Observatory data set are available in Webborn *et al.*, (2021) and full documentation is available via the UKDS (SN 8666). The SERL Observatory is made up of five core datasets:

- electricity and gas smart meter data
- weather data
- SERL survey data (collected when participants sign up)
- EPC data (for approximately half the sample)
- location data

Participants were recruited in three waves; Figure 1 shows the number of SERL participants over time. For information about the recruitment process see Webborn *et al.* (2021, 2022). Historic smart meter data for up to 12 months prior to recruitment was collected where possible, so the earliest smart meter data dates from August 2018.

The aim was to recruit households in proportions representative of the number of households in different regions of GB and within different Index of Multiple Deprivation (IMD) quintiles. Figure 2 shows that the 4th edition SERL sample is largely representative of GB regions within 1%, although Wales and Yorkshire are about 3% under- and over-represented respectively. Similarly, Figure 3 shows that the 4th edition SERL sample is representative of IMD quintile, with a maximum deviation of 1.7% over-representation for IMD quintile 2 (second least deprived quintile).

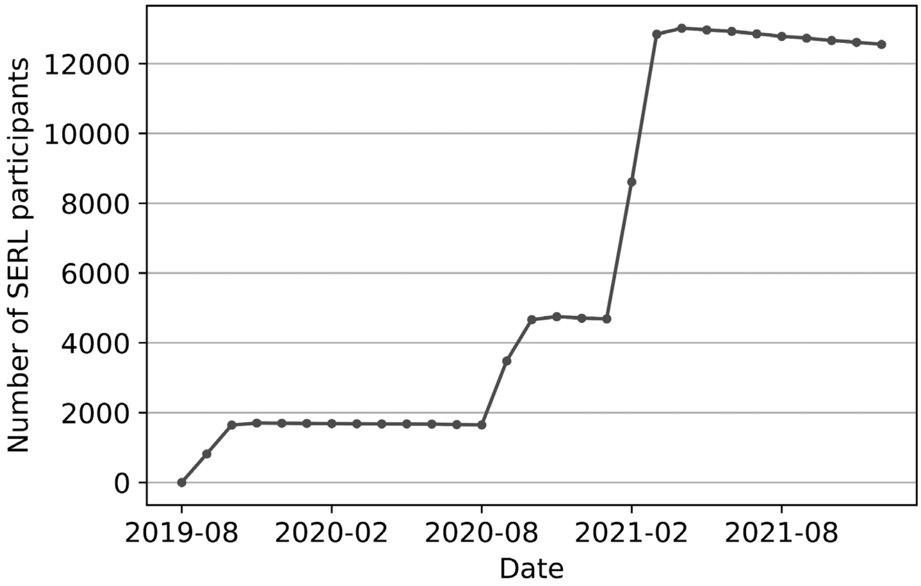

Figure 1. Number of SERL participants over time

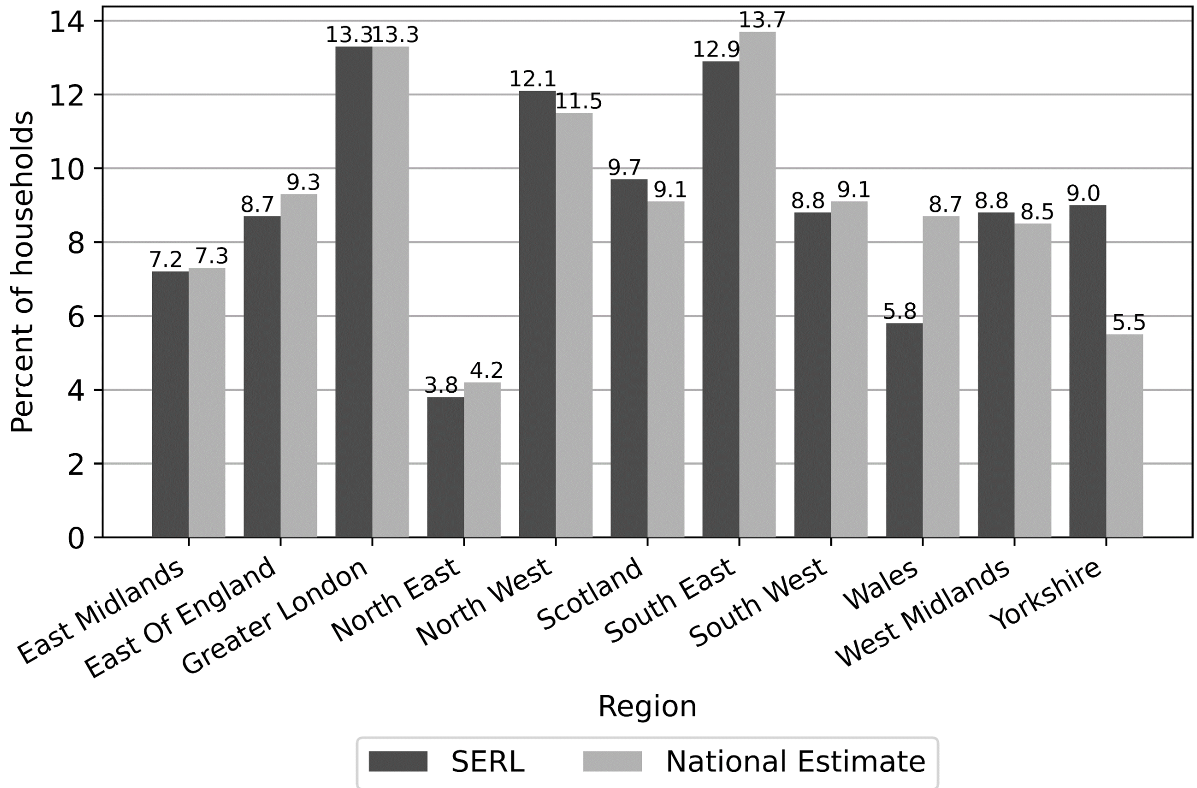

Figure 2 Percentage of SERL Observatory households in each region, compared with a national estimate from Address Base.

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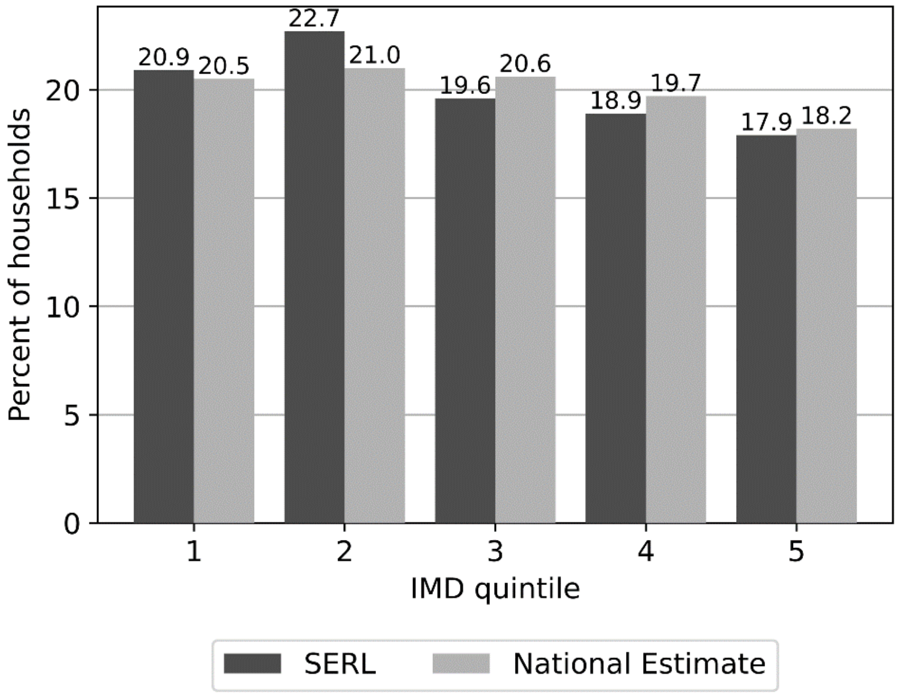

Figure 3 Percentage of SERL Observatory households in each IMD quintile compared with a national estimate from Address Base.

In this report we draw on each of the datasets within the SERL Observatory to provide an overview of energy use by SERL participants. The analysis for this report used the SERL Observatory 4th edition (Elam *et al.*, 2022). The majority of the report relates to 2021, although some data for 2020 is presented for comparison. We present the energy use for the whole SERL Observatory sample, as well as broken down by key contextual variables, including location-based variables (region and IMD quintile), ranges of mean external temperature, EPC variables (energy efficiency rating and floor area), survey variables (building type, building age, central heating system, number of occupants, EV ownership), and PV ownership (from EPC data and inferred from electricity exports).

Details of the data processing used to derive the results in this report are available in the Appendix and we will shortly make the code available via the SERL GitHub. However, a brief outline of the process is provided here to explain the statistics presented in this report. The following steps were taken to generate the energy use statistics presented in this report:

- Smart meter data underwent standard SERL data quality processing; see the SERL smart meter documentation at UKDS (SN 8666).
- Net electricity use (imports minus exports) was calculated for dwellings where microgeneration is present
- For each participating household:
    - The mean energy use per month for each fuel was calculated for total daily use as well as use in each half hour, if at least 50% of the data was available.
    - The mean energy use per day and for each half hour for each fuel was calculated for different mean external temperature ranges: 0ºC to 5ºC, 5ºC to 10ºC, 10ºC to 15ºC and 15ºC to 20ºC. Similarly to

above, the mean was calculated only if at least 50% of the data was available for the given temperature band.
  - For annual summaries, if the monthly energy use was available for all 12 months, then the mean of these (weighted by number of days in the month) was calculated and reported as the mean annual energy use. This ensures that any period of missing data should not unreasonably skew the annual result.
- This provides a distribution of mean energy use per participating household in the SERL Observatory over different time periods which may be further segmented by selected contextual variables; the statistics presented in this report are drawn from these distributions. For example, the mean annual consumption presented below is the mean of the mean energy consumption per participating household in the Observatory.
- Finally, to comply with Statistical Disclosure Control (SDC) requirements that all statistics are based on at least 10 observations, the percentile statistics presented are the mean of the 10 observations closest to the true percentile value. This affects median, upper, and lower quartile statistics in this report.

The smart meter data analysed as part of this report is originally net-metered energy (kWh) used or generated over a half-hour period. We have converted this to kWh/day and mean kWh/h (effectively the average power rating). The time stamps reported are local time and correspond to BST in the summer and GMT in the winter.

Alongside the energy use data, we also provide statistics related to the mean external temperature and heating degree days (HDD)[2] to a base temperature of 15.5 degrees Celsius, and an indication of the floor area, number of bedrooms and number of occupants related to each breakdown of the data. These are noted in the report below where they are of particular relevance and are provided within the statistical data release that accompanies this report. The temperature and HDD are calculated per participant using the same time periods as used to calculate the energy statistics. The floor area, number of bedrooms and number of occupants are calculated using data from all participants belonging to a specific category, not only those who had sufficient data to contribute to the energy statistics. For example, the mean floor area that accompanies the region = 'Scotland' statistic is the mean floor area of all Scottish participants with an EPC (as floor area is an EPC variable), while the mean number of occupants is calculated from all Scottish participants who answered the relevant question in the SERL survey. These building and occupant statistics are therefore only indicative, as they are based on all SERL Observatory participants in that particular category, not just those with sufficient energy data to contribute to the energy statistic that they accompany.

The aggregated statistics underlying this report are available here: https://serl.ac.uk/reports

[2] Heating degree days is a measure of the extent to which external temperature over a given period fell below a level below which central heating is assumed to be required (in the UK, commonly taken to be 15.5°C). The heating degree day values are calculated based on the hourly external temperature data.

The full SERL Observatory data can be accessed by UK researchers following an application process: more details can be found at https://serl.ac.uk/researchers/.

3 Annual energy use for 2021

3.1 Full sample

Table 1 summarises the key energy consumption statistics for participants in the SERL Observatory in 2021. Mean gas use for 2021 was 38.7 kWh/day. This is larger than the mean electricity use of 9.8 kWh/day, as most dwellings in the SERL Observatory use gas for space and water heating. Median gas and electricity use is lower than the mean and this reflects the typically skewed distribution of energy use per dwelling (see Figure 4 and Figure 5 below for examples). The sample size for electricity is larger than that for gas (10,764 versus 7,962). This is because not all dwellings are on the gas grid and therefore gas meters are not present in all the dwellings.

Table 1. Summary statistics of the distribution of mean energy consumption per day per participant in 2021.

	Mean	25th percentile	Median	75th percentile	Sample size	Mean external temperature	Mean heating degree days
Units	*kWh/day*				-	*(ºC)*	
Electricity	9.8	5.4	8.2	12.2	10,764	10.4	5.7
Gas	38.7	24.1	34.8	48.2	7,962	10.4	5.7

Table 2 compares the SERL 2021 energy consumption statistics (converted to annual totals) with the most recently published annualised meter data for 2019 (BEIS, 2021c). Overall, the two sets of values show very close agreement (less than 7% difference). The biggest difference is NEED 2019 shows 6.8% less gas use in the lower quartile than SERL 2021. However, 2021 was 0.1ºC colder than 2019 (gov.uk, 2022), NEED corrects gas consumption for weather, and SERL includes data from Scotland which generally experiences colder weather than England and Wales. We note that NEED data has been shown to be in good agreement with other data sources (BEIS, 2021a), suggesting that SERL would also show good agreement with these data sources. For comparison, in 2021 Ofgem used a medium Typical Domestic Consumption Value (TDCV) of 12,000 kWh for gas and 2,900 kWh for electricity profile class 1[3] (ofgem.gov.uk, 2022).

[3] Electricity profile class 1 is domestic unrestricted customers, not on Economy 7 meters.

Table 2 Summary statistics for SERL Observatory data in 2021 compared to NEED 2019 summary statistics.

	Data source	Mean	25th percentile	Median	75th percentile
Units	-	*kWh/year*			
Gas	SERL 2021	14,118	8,797	12,702	17,520
Gas	NEED 2019	13,300	8,200	12,100	17,000
Net Electricity	SERL 2021	3,588	1,975	2,982	4,453
Electricity	NEED 2019	3,600	1,900	2,900	4,400

3.2 Comparison of annual energy use between 2020 and 2021

While this report focusses primarily on 2021, here we present a comparison of the SERL Observatory energy use in 2020 and 2021. The following data is from subsets of SERL Observatory participants who have at least 50% data availability in all months from January 2020 to December 2021 (note that the final, third, wave of SERL recruitment was in early 2021, so these participants are only from the first two waves of recruitment).

Figure 4 and Figure 5 show histograms of the mean daily consumption for these groups of participants in 2020 and 2021, and Table 3 presents the corresponding summary statistics. For gas there was a right skew in 2021 compared to 2020, with the modal range shifting from 20-30 kWh/day in 2020 to 30-40 kWh/day in 2021, and the median value increasing from 33.2kWh/day in 2020 to 35.5 kWh/day in 2021. On average, 2021 was 0.5 ºC cooler than 2020, thus more space heating would have been required through the year. For net electricity consumption there was a greater right skew for 2020 than 2021 and the median decreased from 8.8 kWh/day to 8.4 kWh/day from 2020 to 2021. The increased consumption in 2020 may be associated with increased time spent at home for many households during Covid-19 lockdowns for a greater part of the year in 2020 than in 2021.

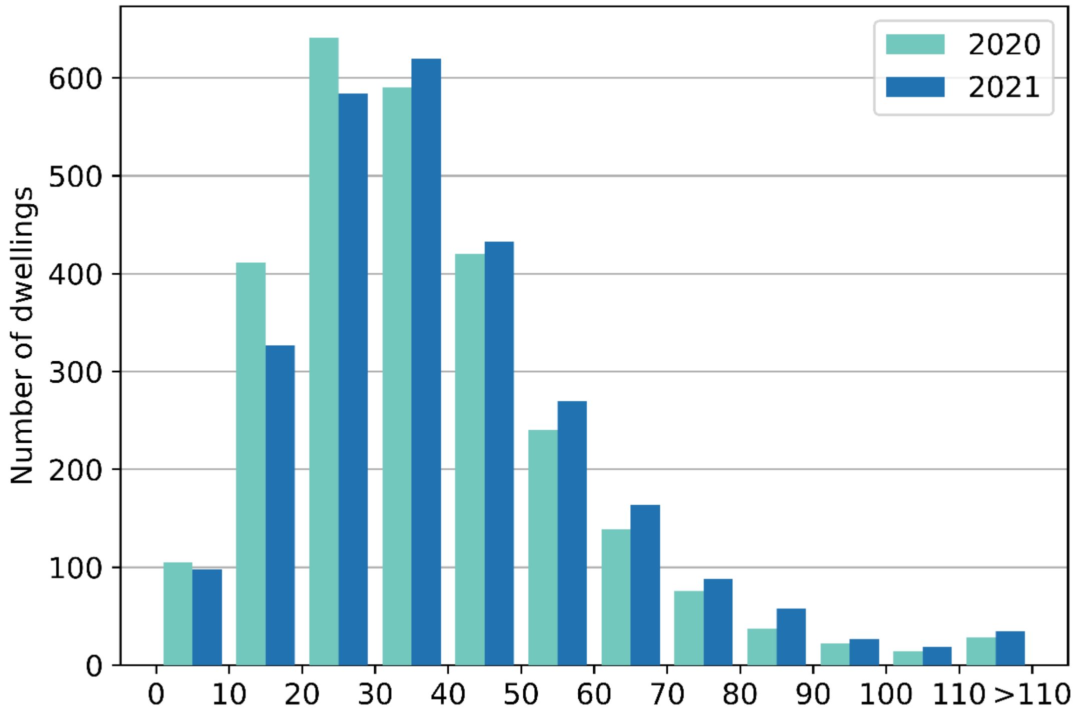

Figure 4. Gas consumption for the same 2723 participants in 2020 and 2021. Note that the final right-hand bin counts all participants with mean daily gas use over 110 kWh/day.

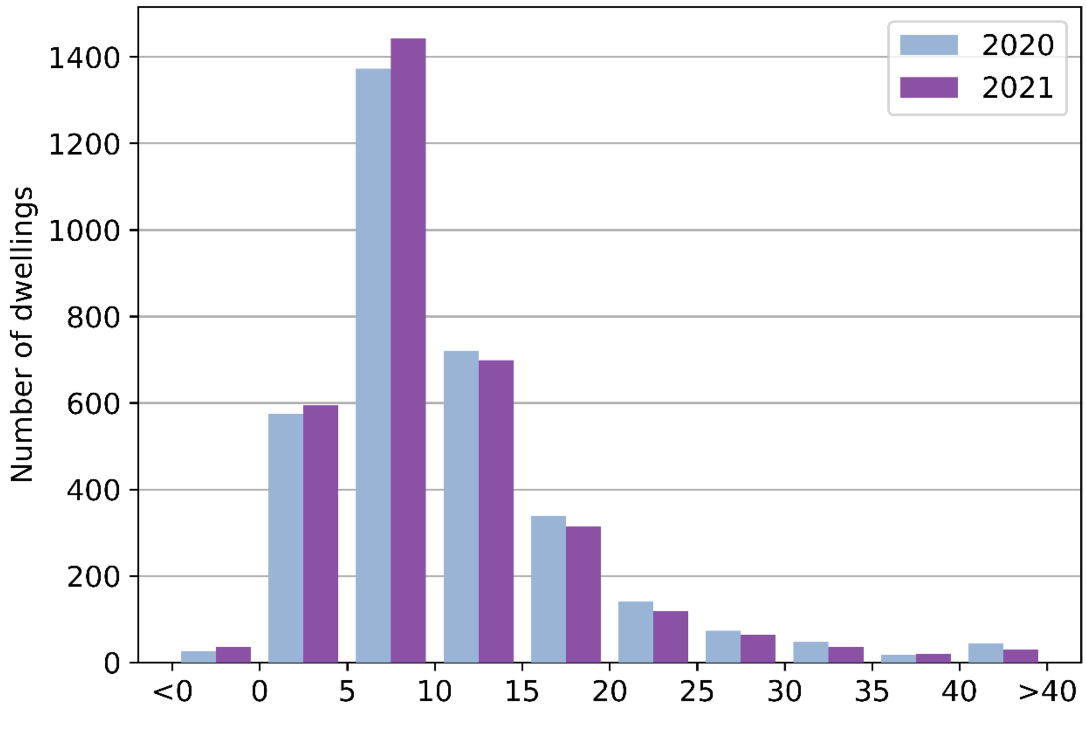

Figure 5. Electricity consumption for the same 3353 participants in 2020 and 2021. Note that the left- and right-edge bins count all participants with mean daily net electricity use less than 0 kWh/day and more than 40 kWh/day respectively.

Table 3. A comparison of energy use between 2020 and 2021 for subsets of participants with enough data in both 2020 and 2021.

	Year	Mean	Median	25th percentile	75th percentile	Sample size	Mean external temperature	Mean heating degree days
Units	-	*kWh/day*				-	*(°C)*	
Net Electricity	2020	10.9	8.8	5.9	13.4	3,353	11.0	5.1
Net Electricity	2021	10.3	8.4	5.7	12.7	3,353	10.5	5.6
Gas	2020	37.1	33.2	22.7	46.6	2,723	11.0	5.2
Gas	2021	39.5	35.5	24.6	49.3	2,723	10.5	5.6

3.3 Annual energy use within external temperature bands

Both gas and electricity consumption increased with decreasing external temperature (Figure 6). On days where the mean external temperature was between 15ºC and 20ºC, homes in the SERL Observatory had a similar median gas and net electricity consumption of around 7 kWh/day. However, on days with mean external temperature between 0ºC and 5ºC, the median electricity consumption increased by around 3 kWh/day to 9.8 kWh/day, whereas the gas consumption increased by more than 10 times to 71.1 kWh/day. The strong temperature dependence of gas use is largely due to the prevalence of gas boilers for space heating in the UK; gas use on warmer days is associated with cooking, hot water heating and some residual space heating. Net electricity consumption increases on colder days due to shorter daylight hours resulting in increased consumption associated with lighting in the winter, possibly due to increased time spent in the home, some electric space heating, and reduced electricity generation from photovoltaics.

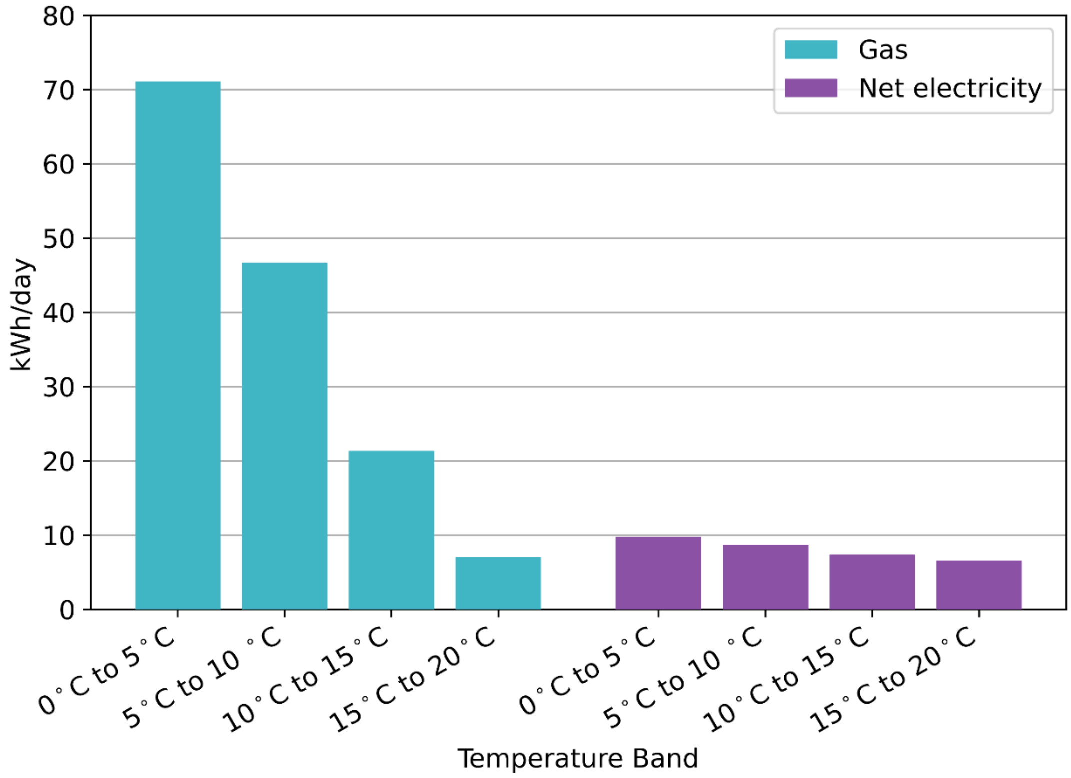

Figure 6 Median consumption of gas and net electricity on days falling within different ranges of mean external temperature.

3.4 Annual energy use by region

The relationship between net electricity and gas consumption with region is complicated (Figure 7). The South West has the highest mean external temperature and the lowest median gas consumption, however Scotland has the lowest mean external temperature but the third lowest median gas consumption. Similarly, there is no clear pattern for net electricity consumption in different regions. Differences between regions are likely to be a result of differences between building types, floor areas, affluence, weather and other factors.

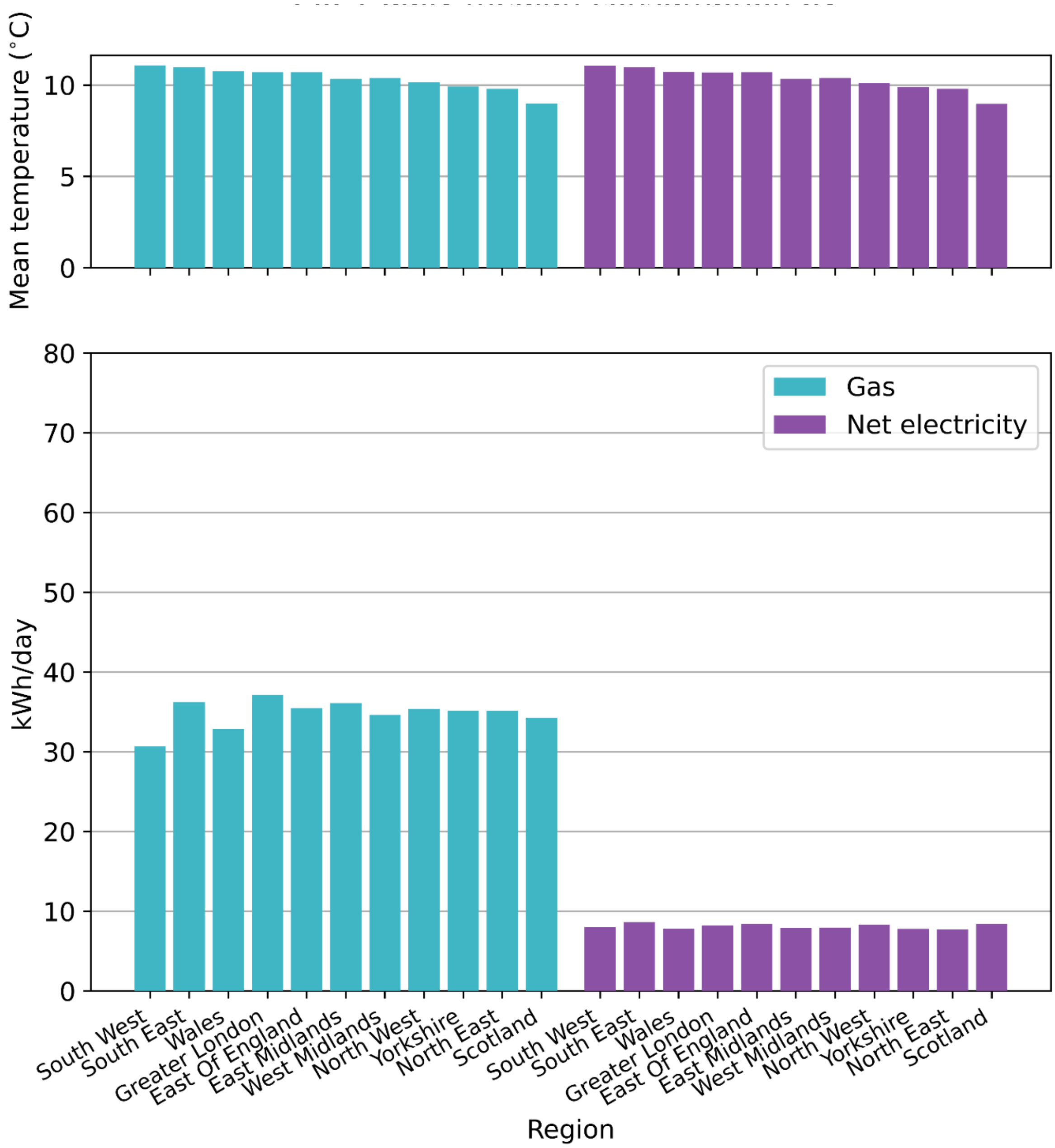

Figure 7 Median consumption of gas and net electricity for homes in the SERL Observatory within different regions of Great Britain. Bars are arranged from left to right from the highest to lowest mean external temperature in 2021.

3.5 Annual energy use by IMD (Index of Multiple Deprivation) quintile

Both electricity and gas consumption increase with higher IMD (i.e., lower deprivation) quintiles (Figure 8). Comparing IMD quintile 1 (greatest deprivation) with 5 (least deprivation), net electricity use increases by about 35% from 7.0 kWh/day to 9.4 kWh/day for electricity, while gas increases by about 56% from 28.4 kWh/day to 44.3 kWh/day. We note that, in the SERL Observatory sample, average floor area increases by 50% with IMD quintile, from a mean of 78 m^2 for IMD quintile 1 compared to 117 m^2 for IMD quintile 5. This increase in floor area is likely to contribute significantly to the apparent increase in energy use with IMD quintile.

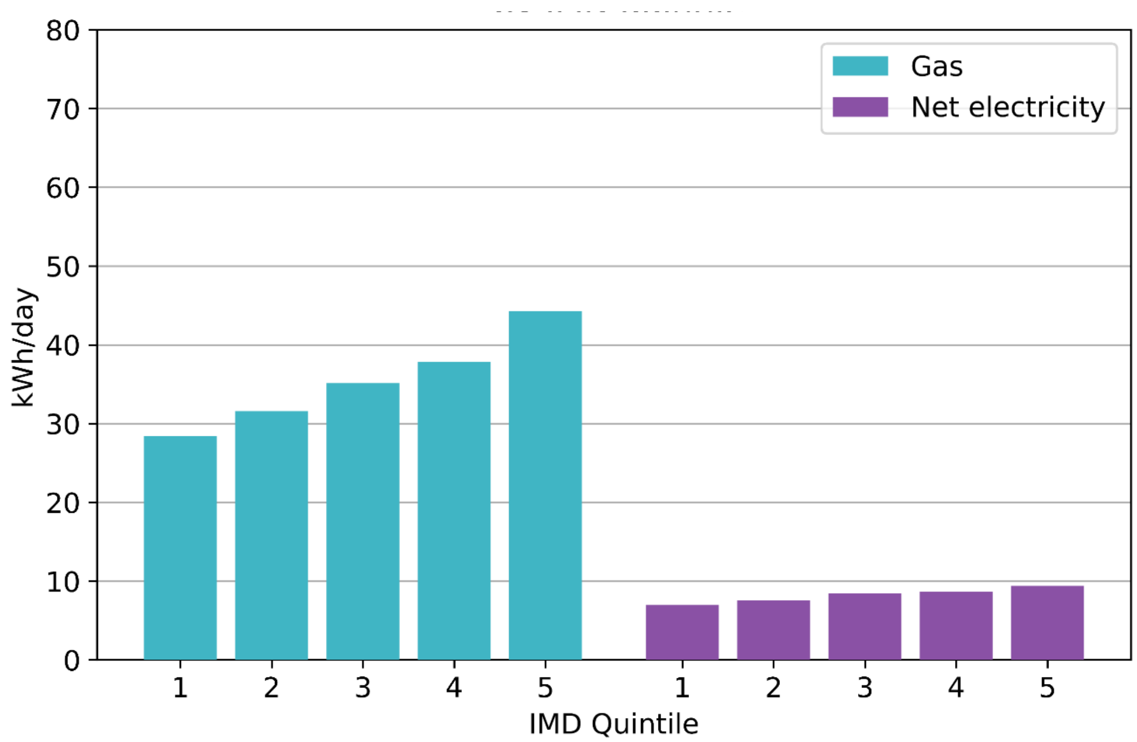

Figure 8 Median consumption of gas and net electricity for homes in the SERL Observatory by IMD quintile.

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3.6 Annual energy use by EPC energy efficiency rating

Approximately half of the SERL Observatory sample have an EPC and for these participants both electricity and gas use decrease with improving EPC energy efficiency rating (Figure 9). The average home in GB is D-rated (DHSG, 2020; ONS, 2021) while the government ambition is for as many homes as possible to reach a C-rating by 2035 (HMG, 2017). The median D-rated home in the SERL Observatory sample used 27% more gas and 18% more electricity than the median C-rated home. It should be noted that within the SERL Observatory, D-rated homes are on average 10 m^2 larger than C-rated homes.

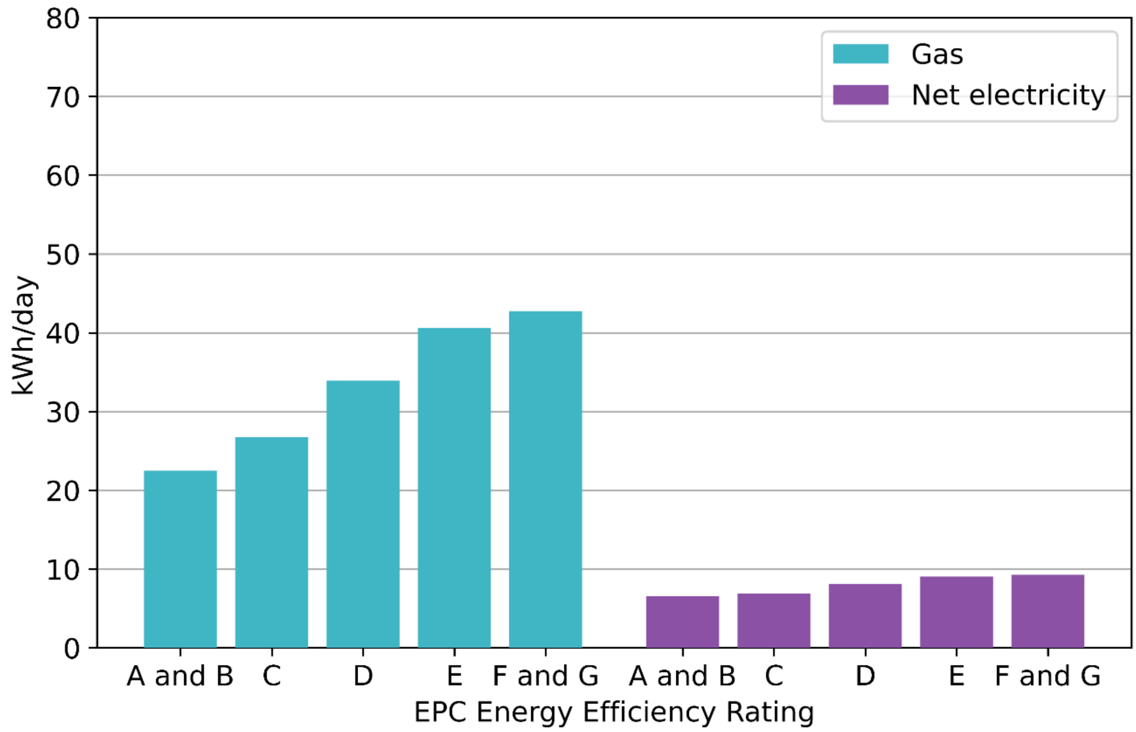

Figure 9 Median consumption of gas and net electricity for homes in the SERL Observatory by EPC energy efficiency rating

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3.7 Annual energy use by floor area

Both electricity and gas use increased significantly with floor area in our sample (Figure 10), noting that floor area is only available for homes with an EPC record (approximately half the sample). Electricity use more than trebled from 4.9 kWh/day for homes with less than 50 m^2 (42 m^2 mean floor area in the SERL Observatory) to 15.2 kWh/day for homes with over 200 m^2 (255 m^2 mean floor area in the SERL Observatory). Gas use more than quadrupled from 15.9 kWh/day to 76.0 kWh/day. Floor area is also closely correlated with number of occupants, IMD quintile and building type.

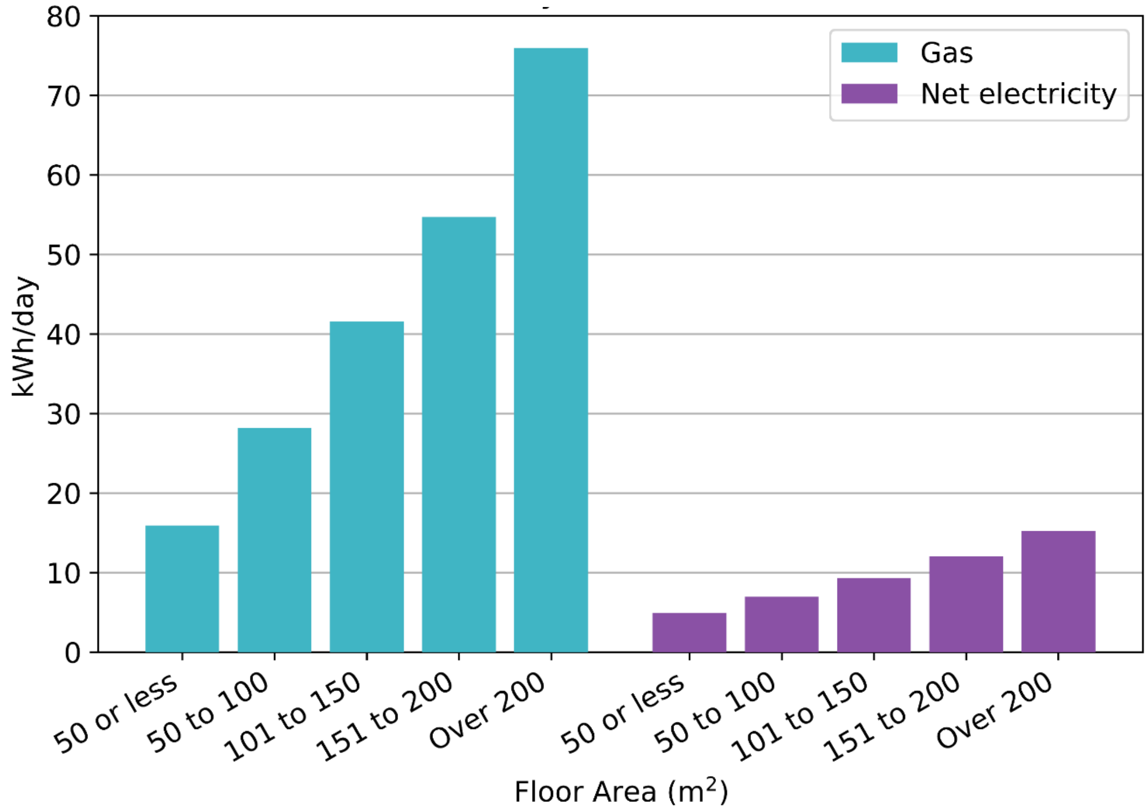

Figure 10 Median consumption of gas and net electricity for homes in the SERL by floor area

3.8 Annual energy use by building type

Both gas and net electricity use showed the same pattern with different building types (Figure 11). The changes in energy use for different building types correlate strongly with mean floor area and number of occupants. For example, the median gas use for a detached house is 48% more and electricity use is 30% more than for a terraced house, while the mean floor area for a detached house in the SERL Observatory is 50% greater and the mean number of bedrooms is 27% greater than for a terraced house.

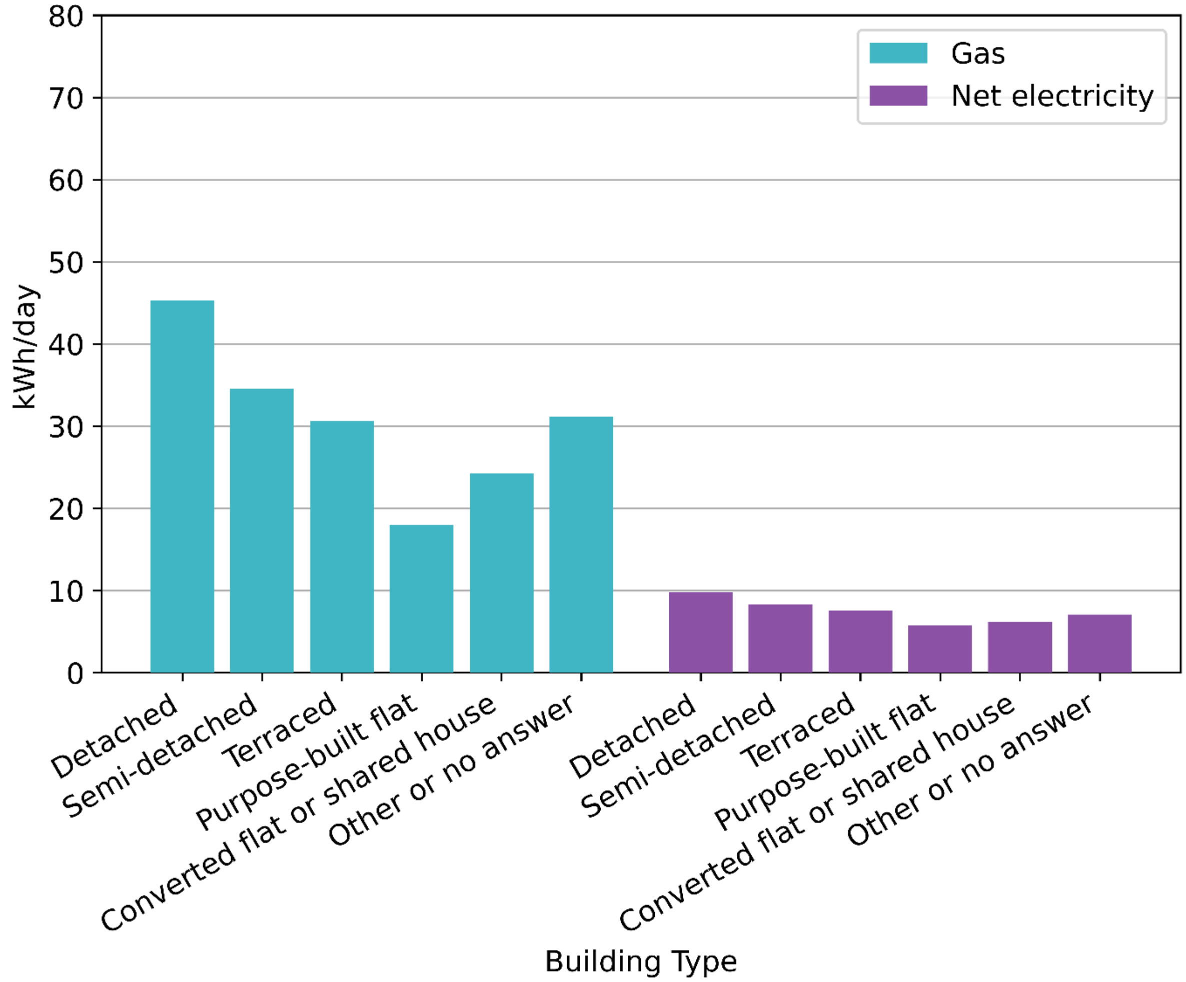

Figure 11 Median consumption of gas and net electricity for homes in the SERL Observatory by building type[4]

[4] Categories in this figure are based on participant responses to the following question: "B1. What type of accommodation do you live in? Tick one answer only". Some small categories have been merged for SDC reasons.

3.9 Annual net electricity use by central heating system

As expected, homes with electric central heating used more net electricity than homes without (Figure 12). However, there are significant differences in the floor area of homes with different central heating systems. The mean floor area is less than 65 m^2 for homes which are centrally heated by electric storage radiators, electric radiators, district or community heating. This is likely associated with their more frequent occurrence in flats. By contrast, the mean floor area was more than 100 m^2 for homes with a gas boiler and another type of central heating, oil, solid fuel or biomass, and other electric heating. Note that the gas boiler group is by far the largest with over 8,000 households contributing to the statistic (reflecting the prevalence of this type of heating), the rest are all less than 1,000 and other electric and district or community groups are less than 100.

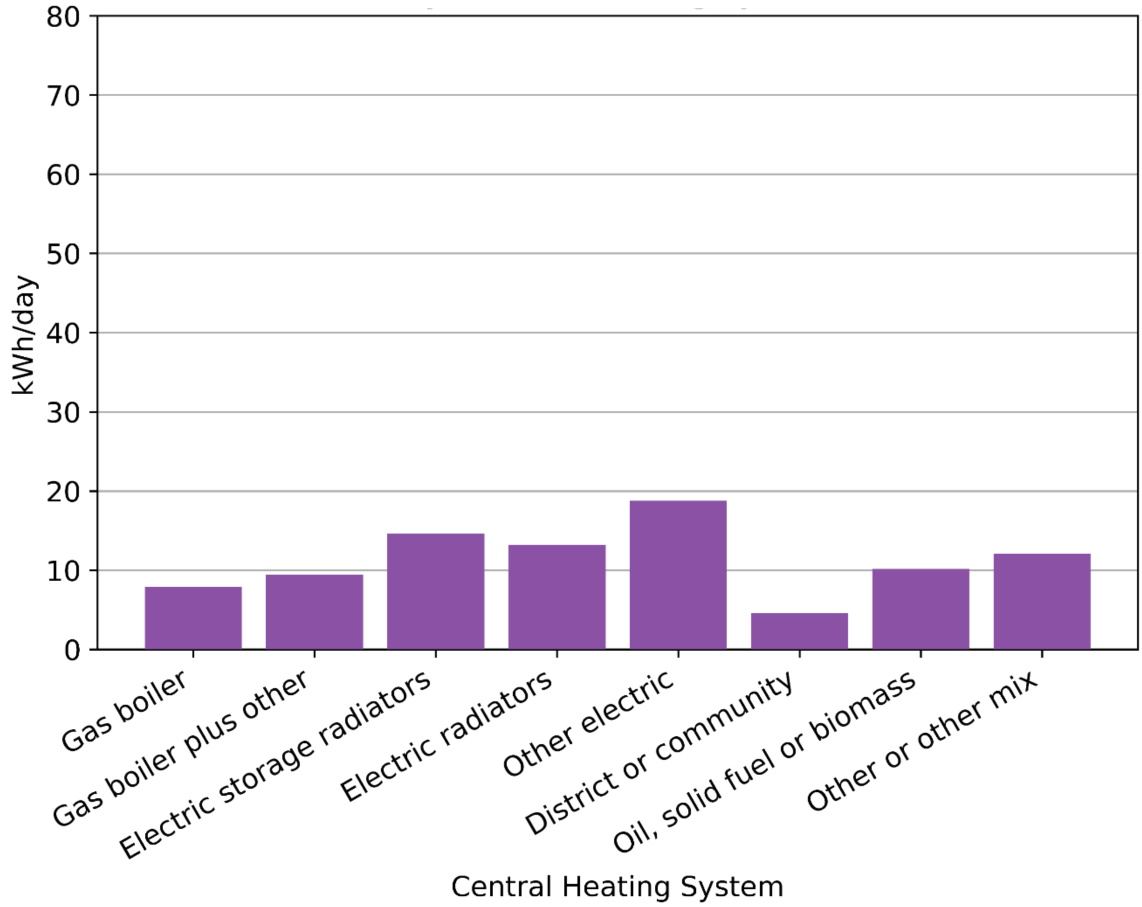

Figure 12 Median consumption of net electricity for homes in the SERL observatory by central heating system[5]

[5] Categories in this figure are based on participant responses to the following question: "A3. What type of central heating does your accommodation have? By central heating we mean a central system that generates heat for multiple rooms. Tick all that apply whether or not you use it'. Most participants chose only one type of heating, but those that chose multiple forms have been grouped in this figure either as 'gas boiler plus other' or 'other mix', some small categories have also been grouped for this figure.

3.10 Annual energy use by year of building construction

In general, older properties use more gas than modern ones (Figure 13). However, typical floor areas also vary with building age, for example pre-1900 homes have a mean floor area of 116 m^2 in the SERL Observatory, whereas post-2003 homes have a mean floor area of 97 m^2, which may partially explain the greater consumption in some older construction bands. Homes built between 1930-1949 have a mean floor area very similar to post-2003 homes; comparing these two bands, newer homes use 26% less gas than older homes. Electricity use shows relatively little variation with construction age band, with the greatest difference being less than 1 kWh/day between pre-1900 and 1976-1990 dwellings.

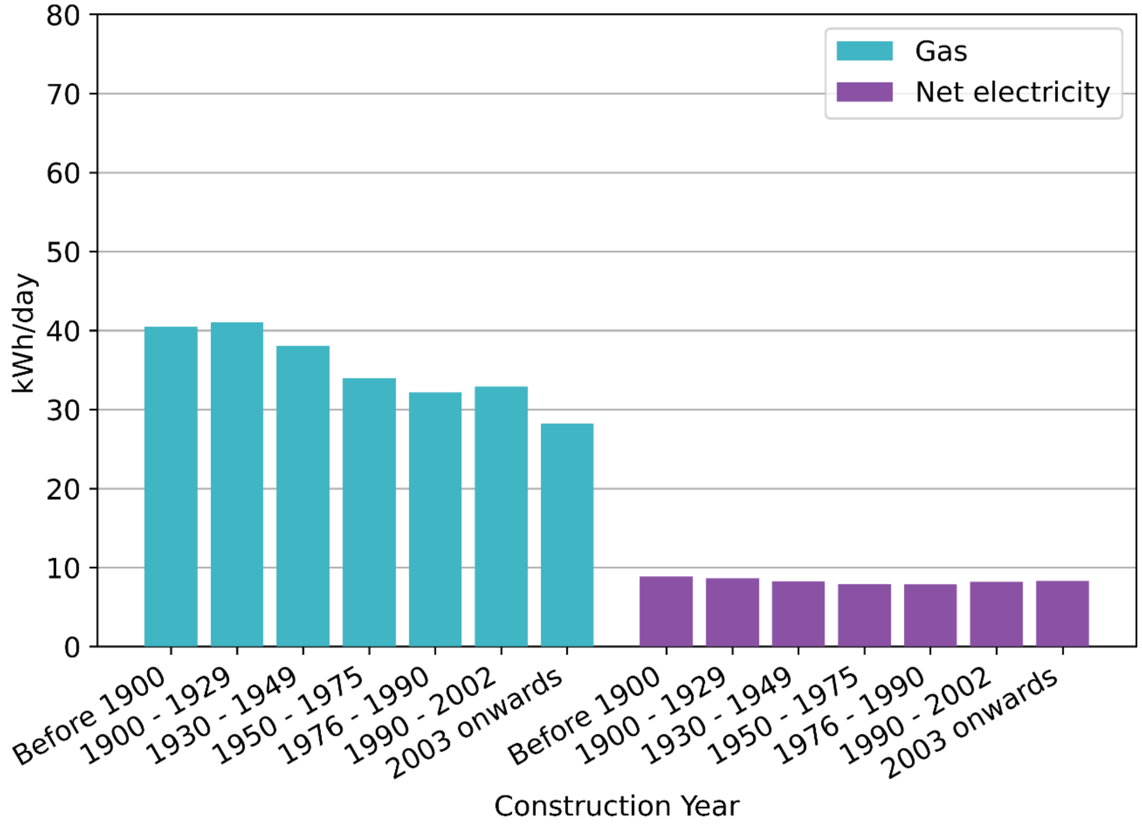

Figure 13 Median consumption of gas and net electricity for homes in the SERL observatory by construction year bands[6]

[6] Categories in this figure are based on participant responses to the following question: "B9. Approximately when do you think your accommodation was built? Tick one answer only."

3.11 Annual energy use by number of occupants

Both gas and electricity use increase with number of occupants (Figure 14). For both gas and electricity, an increase of 1 in the number of occupants shows the greatest increase in energy use when the number occupants increases from 1 to 2, with median gas use increasing by 10.0 kWh/day, and electricity use by 3.2 kWh/day. Floor area is also strongly correlated with number of occupants, increasing from a mean floor area of 73 m^2 for a single occupant, to 129 m^2 for 6 or more occupants.

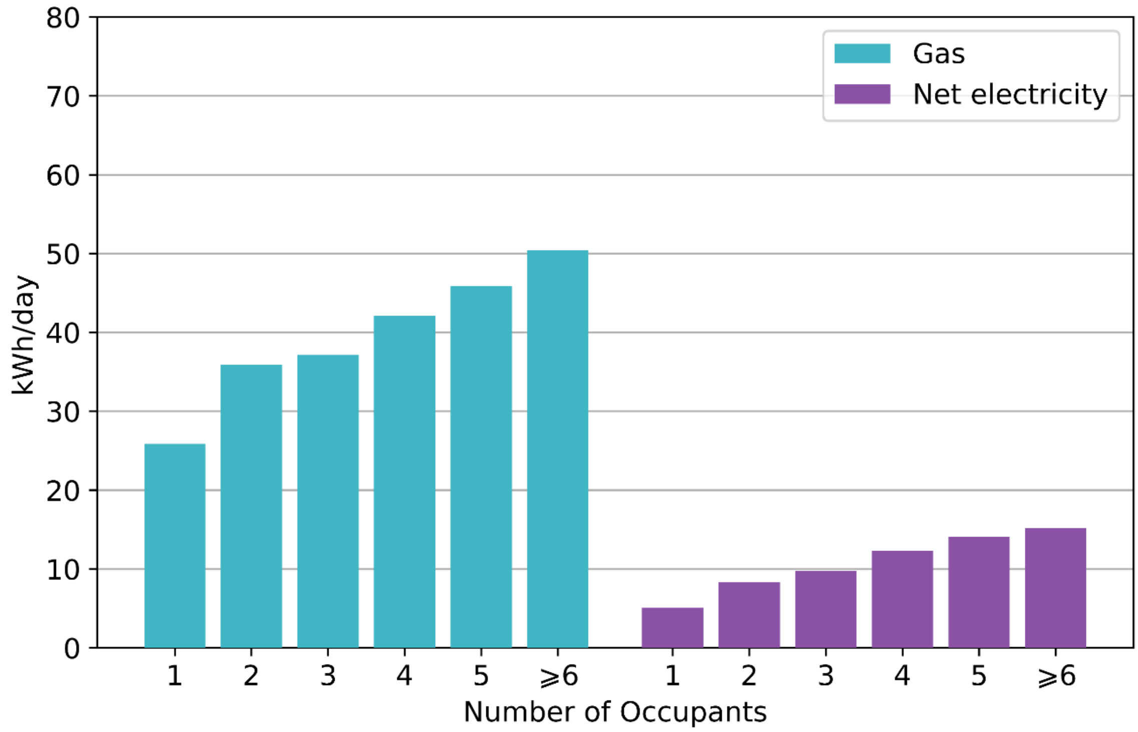

Figure 14 Median gas and net electricity use for homes in the SERL Observatory by number of occupants[7]

[7] Categories in this figure are based on participant responses to the following question: "C1. How many people currently live in your household, including you? Please include all those who are there regularly, even if not every day, including children who live away from home during term time." Large numbers have been grouped into one category for SDC reasons.

3.12 Annual energy use by tenure

Homes that are owned outright or with a mortgage and rent-free homes use the most gas and electricity (Figure 15). Both these groups also have a mean floor area of over 100 m^2, while social rent, private rent, and part-own part-rent all have floor areas less than 75 m^2. Tenure is also likely to be associated with affluence. Note that the rent-free and part-own part-rent groups are both small, with less than 100 participants in each category, and are therefore less likely to be reliable than the other categories.

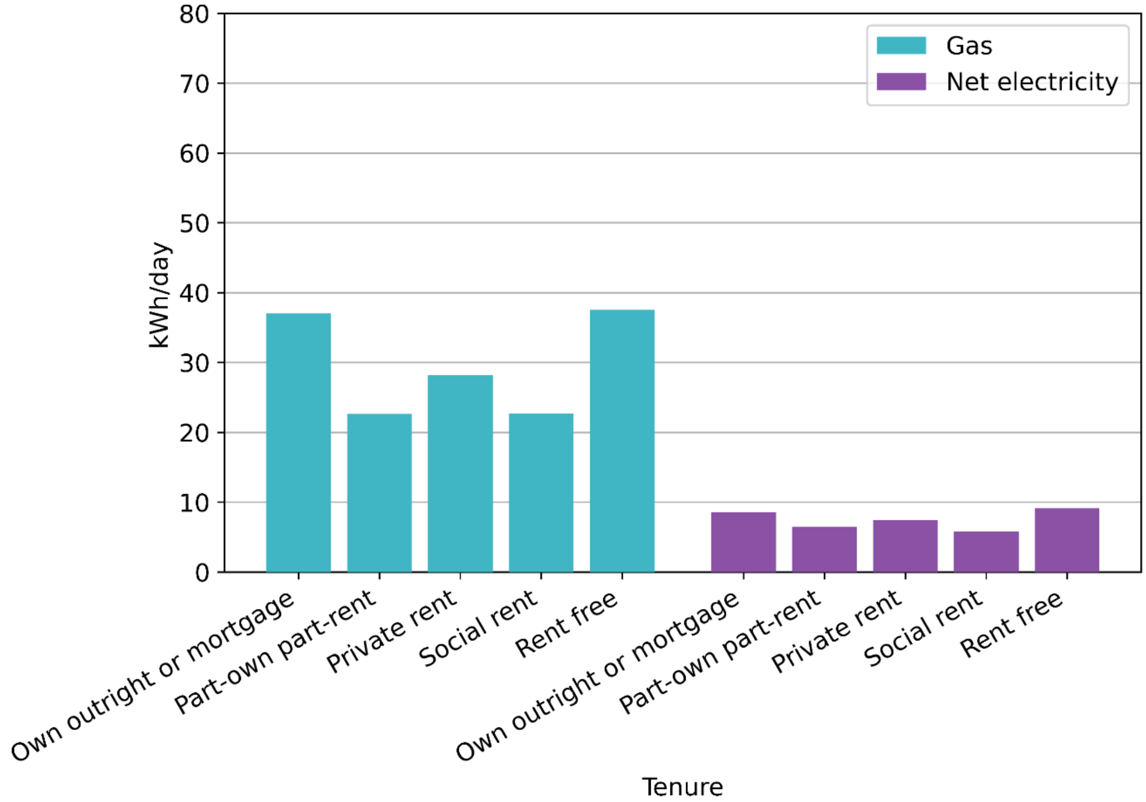

Figure 15 Median gas and net electricity use for homes in the SERL observatory by tenure[8]

[8] Categories in this figure are based on participant responses to the following question: "B4. Do you (or your household) own or rent this accommodation? Tick one answer only". Some small categories have been merged for SDC reasons.

3.13 Annual energy use by electric vehicle ownership

Homes with an EV use 70% more electricity and 22% more gas than homes without (Figure 16). However, within the whole SERL observatory homes with an EV have a larger floor area than homes without (132 m^2 compared to 95 m^2); this likely largely explains the increased gas use in homes with an EV. Homes with an EV also have a mean of 2.7 occupants compared to 2.3 occupants for homes without; this is also likely to contribute to the difference in electricity consumption.

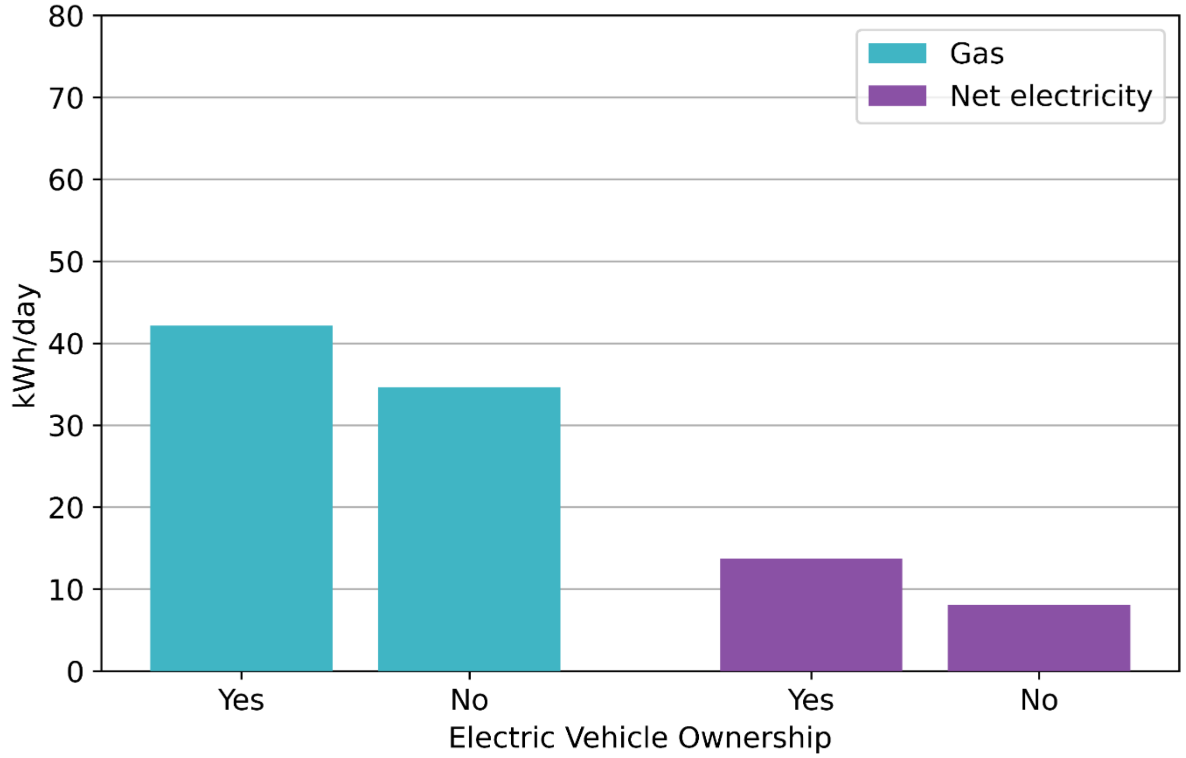

Figure 16 Median gas and net electricity use for homes in the SERL observatory by electric vehicle ownership[9].

[9] Categories in this figure are based on participant responses to the following question: "C5. Does your household have a plug-in electric vehicle? This does not include hybrid cars which are not plugged-in to charge. Tick one answer only".

3.14 Annual energy use by PV ownership

The median daily net electricity consumption from the grid for homes with PV is 3.2 kWh/day, whereas for homes without PV is 8.3 kWh/day (Figure 17). This suggests a saving of 1,860 kWh/year, or 62% lower net electricity imported from the grid by homes which have PV. This difference is significantly greater than the 14% reported NEED saving (BEIS, 2021c). However, note that NEED measures the change in *imported* electricity, whereas we report differences in *net* electricity demand (imports minus exports).

Within the SERL Observatory, homes with PV have a higher mean floor area (115 m^2 compared to 94 m^2) and a higher mean number of occupants (3.3 compared to 2.9) than homes without PV. Homes with PV in the SERL Observatory would therefore be expected to use more electricity in total than those without, suggesting that the reduction in net electricity consumption may be even greater than suggested above. There is no significant difference in median gas consumption between the groups, despite the difference in mean floor area and number of occupants. This suggests that homes with PV are also likely to be more thermally efficient than homes without.

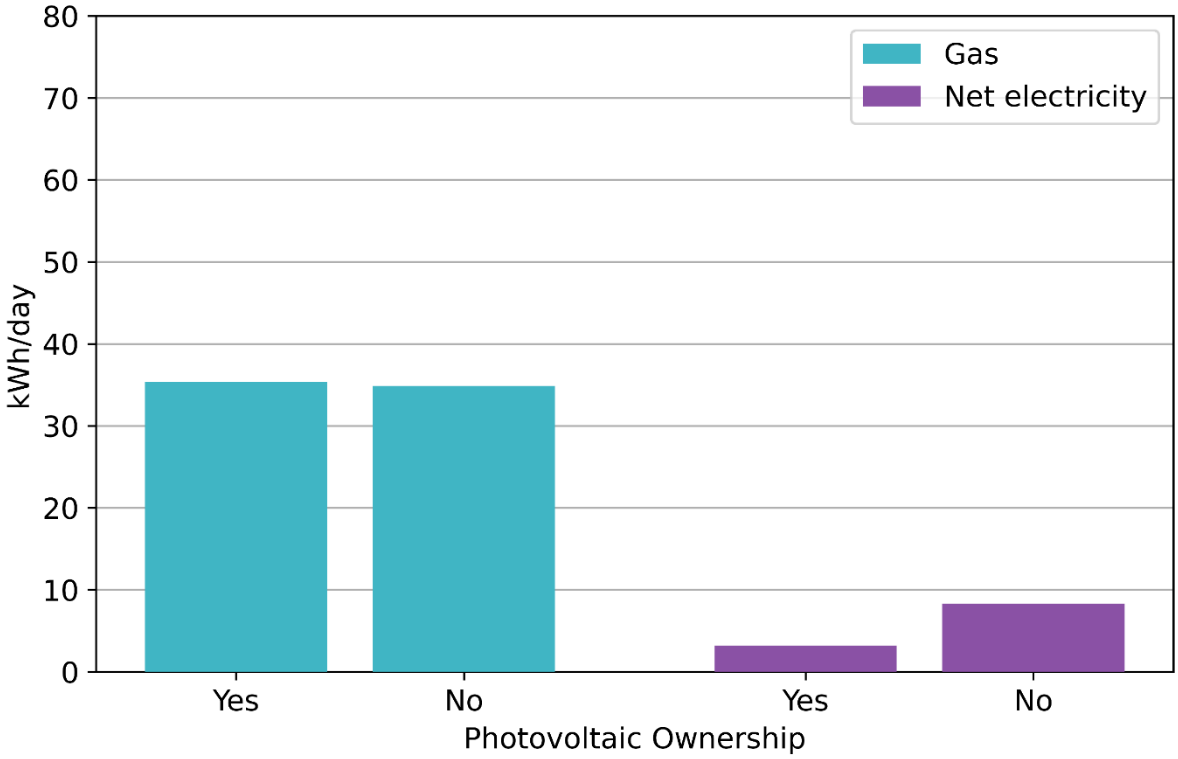

Figure 17 Median gas and net electricity use for homes in the SERL observatory by PV ownership[10]

[10] Categories in this figure are based on the presence of electricity export data from the smart meter, and the photoSupply variable in EPC data which indicates the percentage of the roof area that is taken up by photovoltaics.

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4 Monthly energy use for 2021

4.1 Comparison of monthly energy use between 2020 and 2021

Figure 18 shows the median of the mean daily energy use per participant per month in 2020 and 2021 using data from all available participants. Average gas consumption varied substantially over 2020 and 2021 between a high median value across the sample of 74.3 kWh per day in January 2021 and a low median value of 6.1 kWh per day in July 2021. Space heating is the main driver of gas consumption in homes with gas central heating, which comprise 87% of homes in the SERL Observatory sample. Gas consumption can be seen to vary closely with the mean external temperature. Other factors also influenced gas consumption, for example April 2021 was particularly sunny despite being colder than March 2021 (Met Office, 2021). High solar gains in April 2021 likely contributed to reduced gas use compared to March 2021. The low gas use observed in summer months can be attributed to residual levels of space heating as well as hot water and cooking.

Electricity demand also varied month by month across 2020 and 2021, although substantially less so than the variation in gas consumption. About 7% of homes in the SERL Observatory sample have some form of electric central heating, which contributes to the observed variation. Other seasonally varying electricity uses may contribute to the observed variation too, such as use of lighting and indoor leisure activities, and increased generation from about 6% of homes in the sample with solar PV.

Figure 19 to Figure 22 below break the monthly data down further to show how gas and electricity demand relate to a home's EPC rating and floor area for 2021 only.

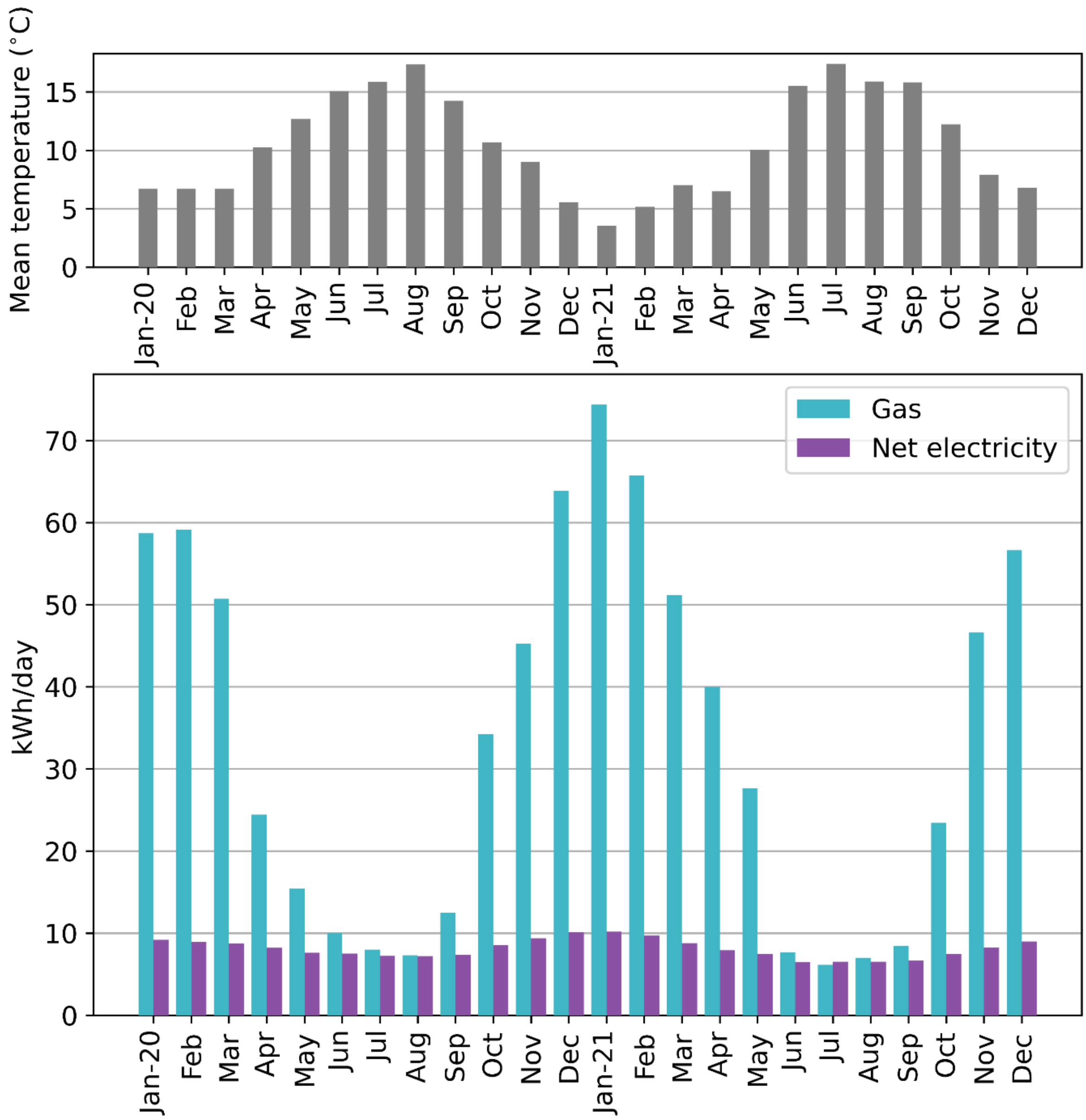

Figure 18. Median daily energy consumption by month from January 2020 to December 2021[11]

[11] The final wave of SERL recruitment occurred in early 2021 and historic data was collected for up to one year prior to recruitment. As a result, participant numbers contributing to each month varies from 3300 for gas and 4000 for electricity in January 2020 to 8700 for gas and 11700 for electricity in December 2021.

4.2 Monthly energy use by EPC energy efficiency rating

Gas consumption by month also varied by EPC energy efficiency rating (Figure 19). January 2021 was the coldest month of the year (averaging 3.7 ºC), and median gas consumption in F&G-rated homes was almost twice that of A&B-rated homes (97.0 kWh/day compared to 47.1 kWh/day). F&G-rated homes are less thermally efficient, but it is also important to note that in the SERL Observatory sample homes with rating A&B have a mean floor area of 93 m^2, whereas F&G homes have a mean floor area of 119 m^2. The difference in median gas consumption between EPC ratings reduces considerably over the summer months when average temperatures are above 15 ºC, although the bottom four bands continue to use more gas than the top 3 bands, possibly because of lower boiler efficiency for hot water.

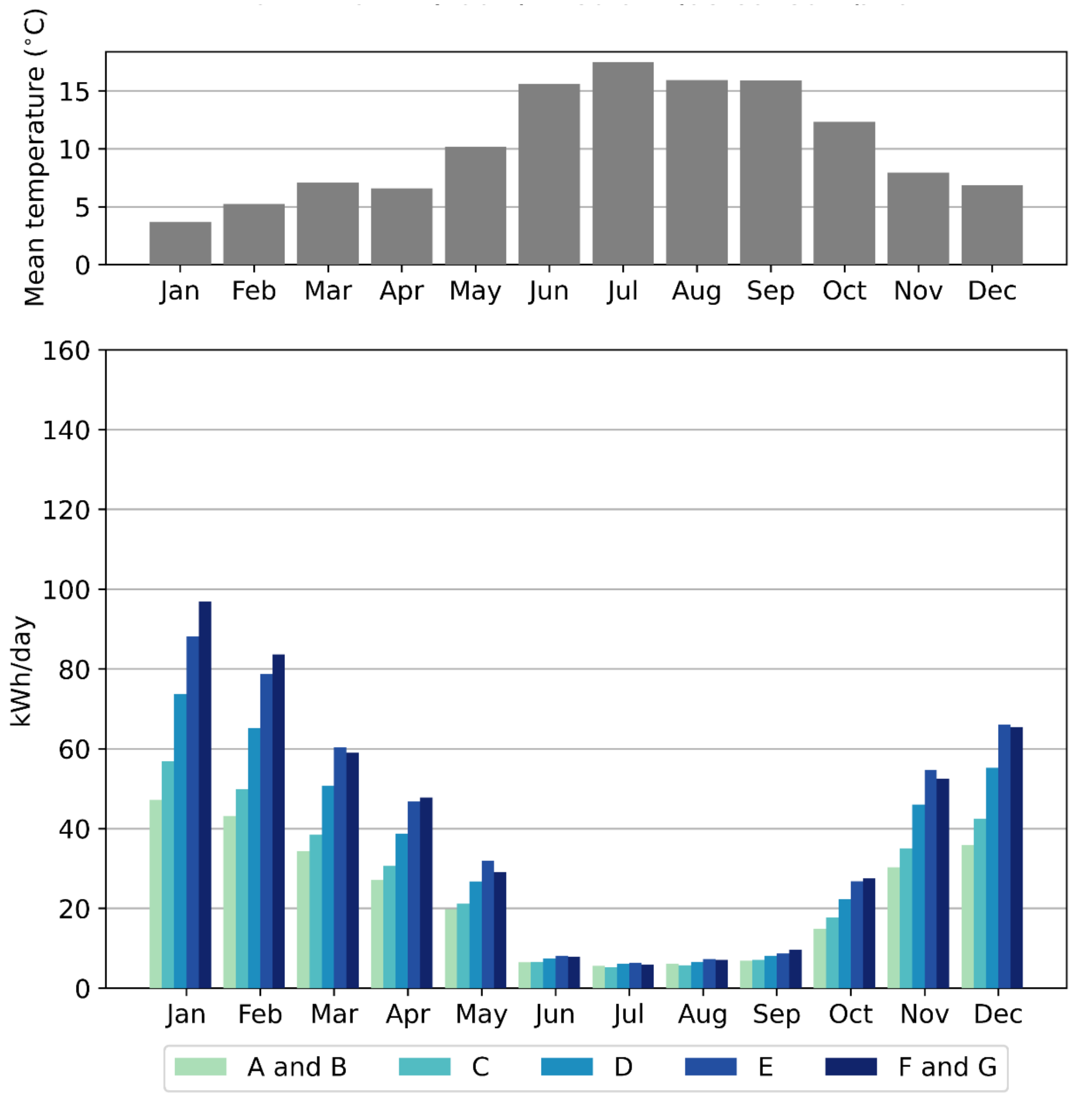

Figure 19 Median gas consumption per day for homes in the SERL Observatory sample by month and EPC energy efficiency rating in 2021.

Net electricity demand also varied by month and EPC rating (Figure 20), although by less than the variation in gas consumption, with lower-rated homes consuming more electricity. The difference in net electricity consumption between A&B-rated homes and C-rated homes was greater in spring and summer than in winter; this is likely because A&B-rated homes are much more likely to have photovoltaic electricity generation and thus offset more of their electricity consumption over the summer.

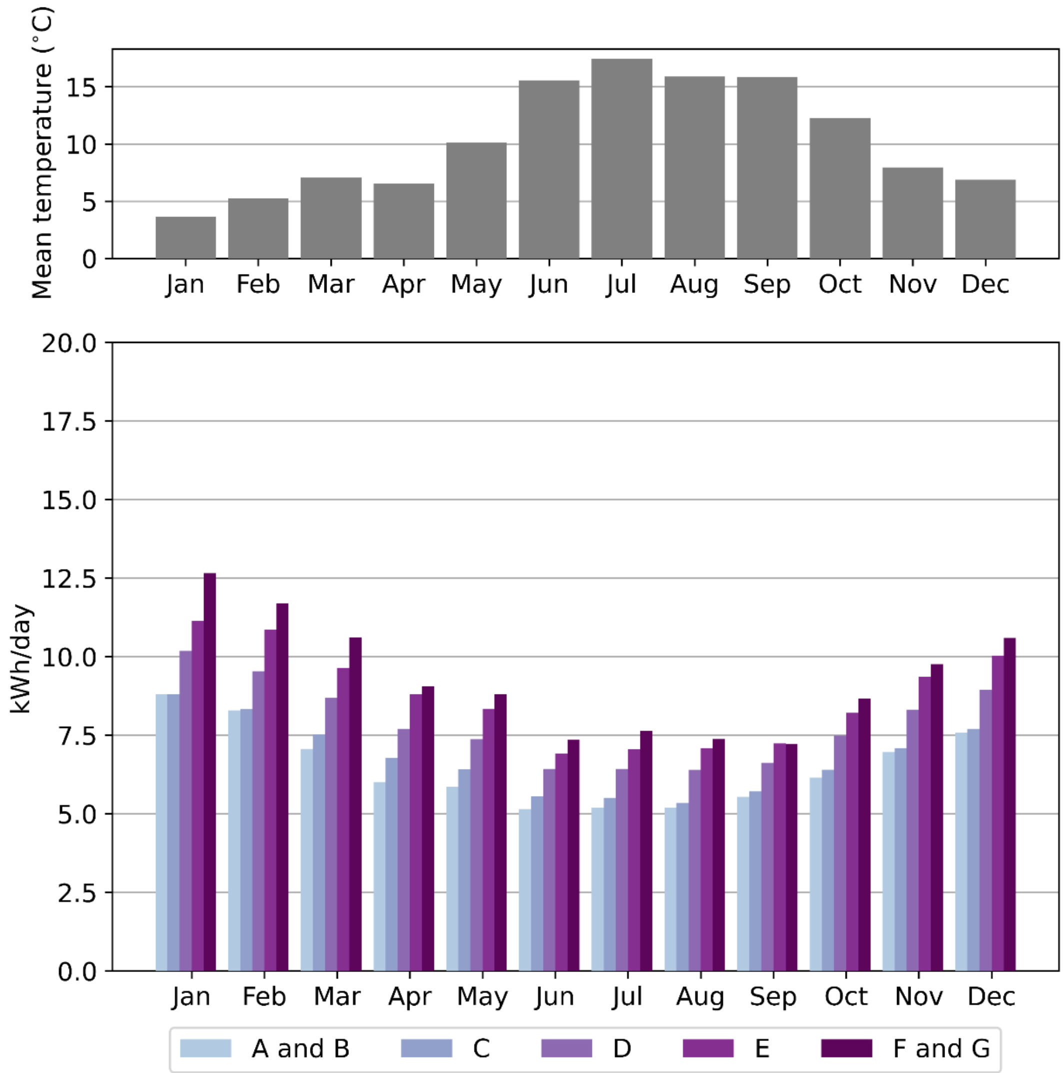

Figure 20 Median net electricity consumption per day for homes in the SERL Observatory sample by month and EPC energy efficiency rating in 2021.

4.3 Monthly energy use by floor area

Gas consumption by month also varied by floor area (Figure 21). January 2021 was the coldest month of the year (3.7 ^{o}C), and median gas consumption in homes over 200 m^2 was just over four times larger than in homes of 50 m^2 or less (38.8 kWh/day compared to 157.6 kWh/day). Smaller homes continue to use less gas over the summer months, and in the warmest month of the year (July, 17.5 ^{o}C), the smallest homes again use four times less gas than the largest (3.2 kWh/day compared to 12.6 kWh/day). Across the whole SERL Observatory, homes of 50 m^2 or less have a mean of 1.5 occupants whereas homes of 200 m^2 or more have a mean of 3.1 occupants, so it is likely that larger homes have greater hot water demand during the summer than smaller homes.

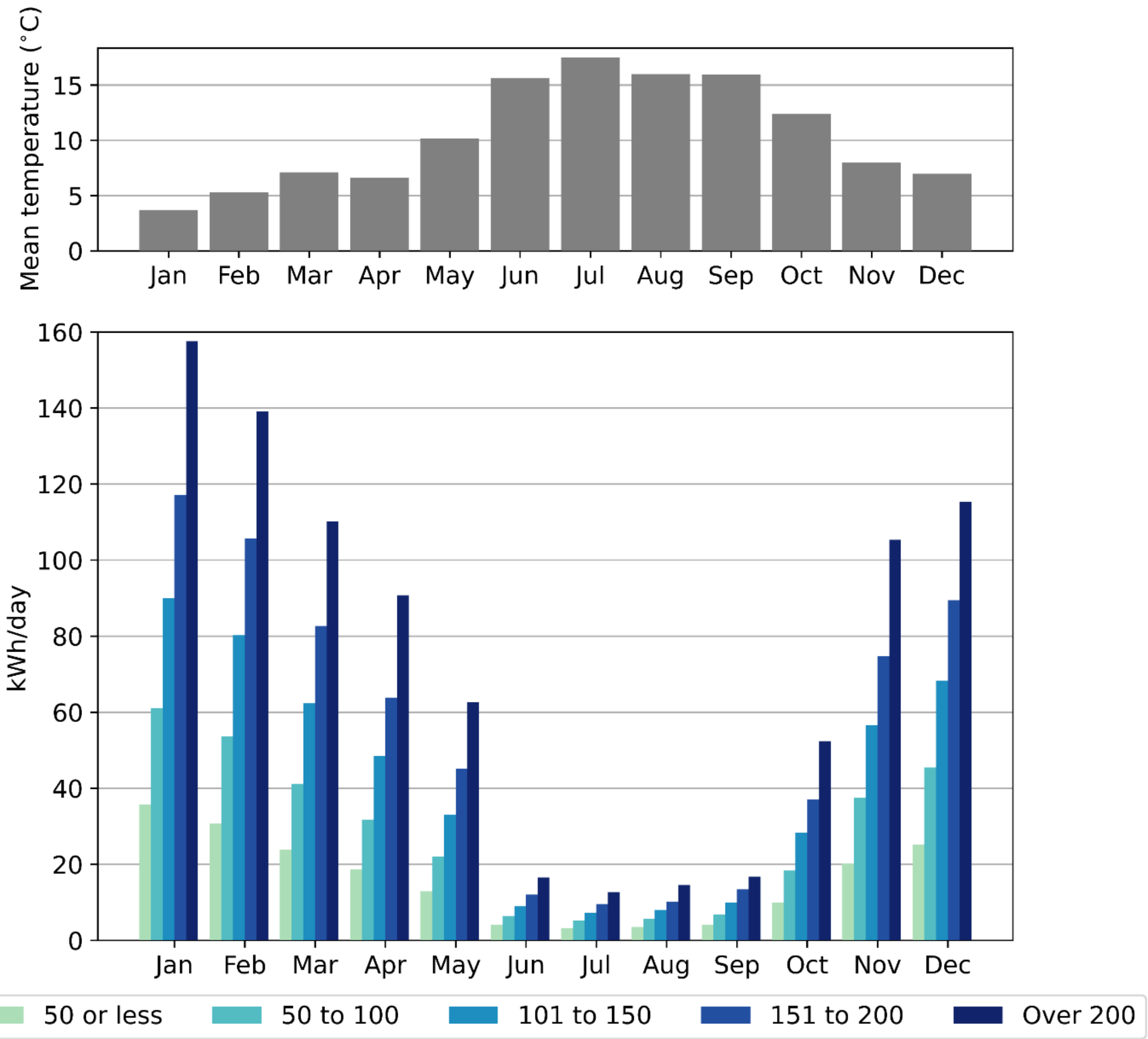

Figure 21 Median gas consumption per day for homes in the SERL Observatory sample by month and floor area in 2021.

Net electricity demand also varied by month and floor area (Figure 22), although by less than the variation in gas consumption, with smaller homes consuming less electricity. Homes smaller than 50 m^2 had a median consumption of 5.9 kWh/day in January; less than a third of the median consumption of homes larger than 200 m^2, which used 19.6 kWh/day in the same month. This was similar in the warmest month, where the smallest homes had a median consumption of 4.1 kWh/day and the median consumption for the largest homes was almost three times higher (11.9 kWh/day).

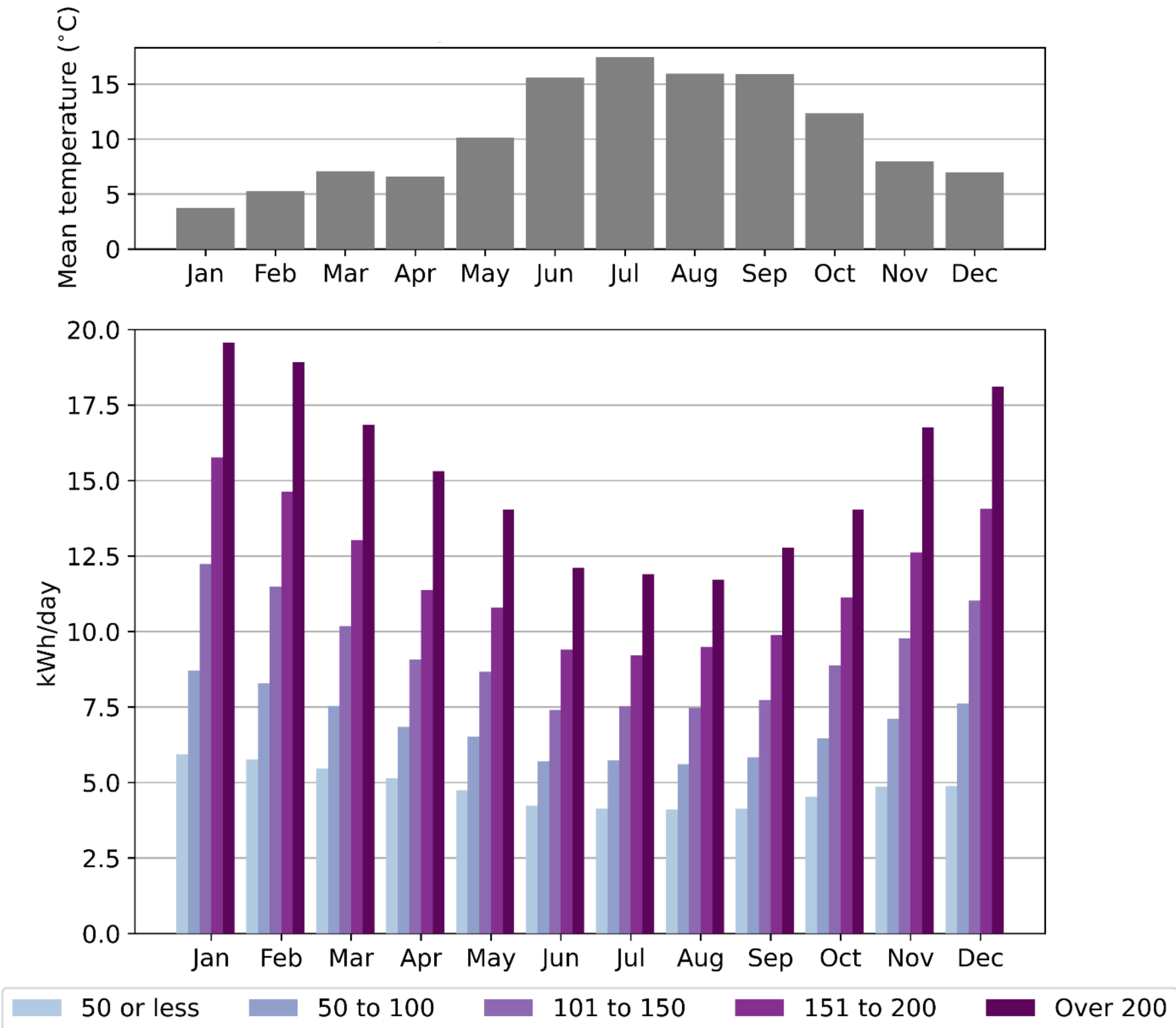

Figure 22 Median net electricity consumption per day for homes in the SERL Observatory sample by month and floor area in 2021.

5 Diurnal energy use for 2021

5.1 Full sample

Gas consumption over the course of the day (Figure 23) shows two main peaks, in the morning and evening, with little overnight consumption and moderate levels during the day between the peaks. The median and quartiles presented here are drawn from the distribution of the mean energy use per participant in each half hour independently. For statistical disclosure control, the median and quartile values shown are the mean of the 10 values closest to the median or quartile, although note that each half hour is not necessarily comprised of the same 10 dwellings. The median morning peak occurs at 08:00 whilst the afternoon peak occurs at 18:30; both are almost the same, 2.44kWh/h and 2.45kWh/h respectively. Daytime usage falls to a little over half of this, at 0.25kWh/h; a very slight peak centred on 12:30 can be observed. Overnight usage falls close to zero (below 0.1kWh/h from 01:00 to 04:00).

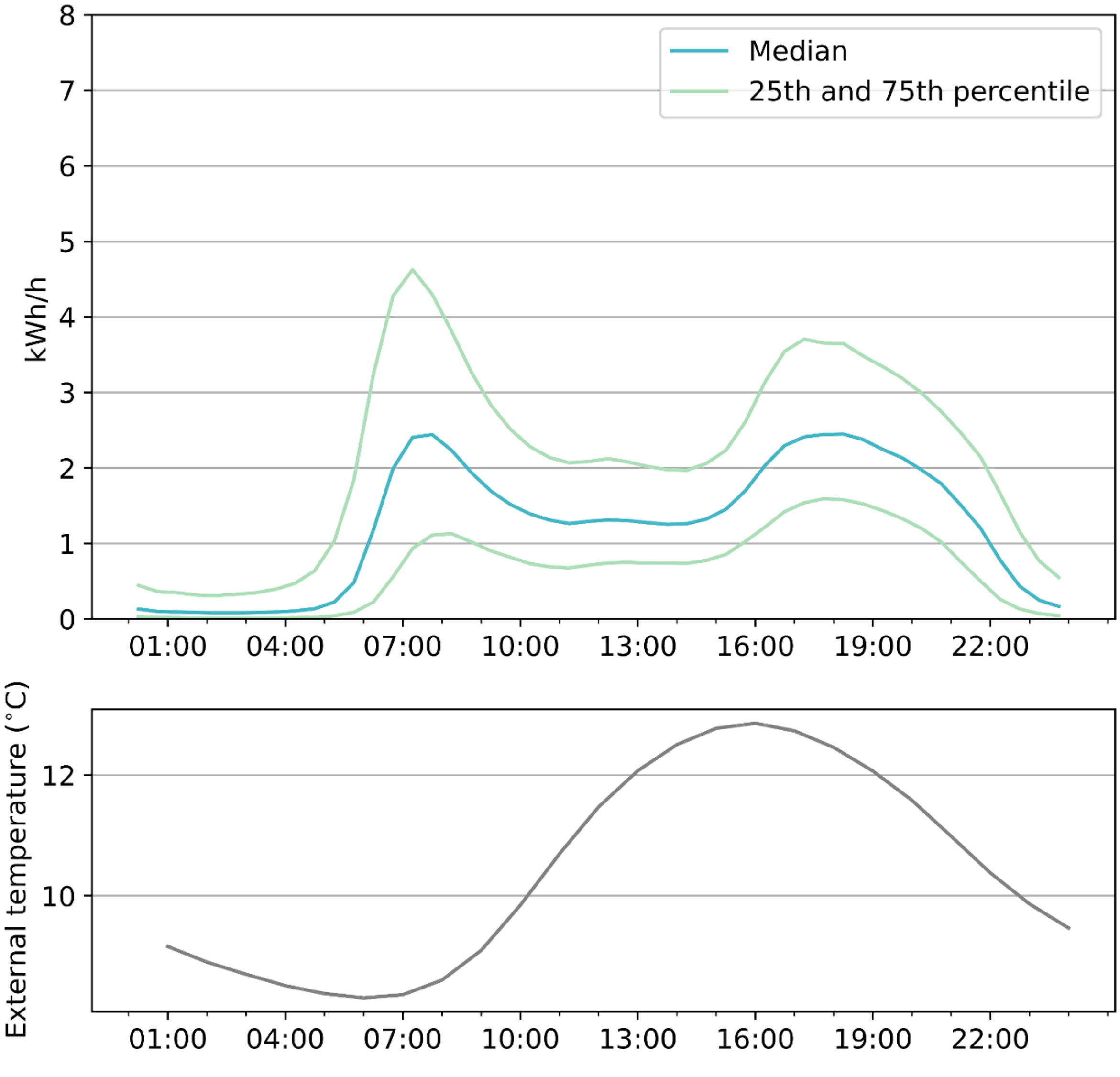

Figure 23 Quartiles of gas consumption for SERL Observatory participants in 2021

For the 25th percentile, the morning peak occurs slightly later, at 8:30, and is only around half the size of the median peak (1.13kWh/h). The afternoon peak is larger than the morning's, reaching 1.59kWh/h at 18:00. The 75th percentile meanwhile shows a larger morning rather than evening peak (4.63kWh/h at 7:30 vs. 3.70kWh/h at 17:30). Overnight usage is also low, although three times that of the median, at a minimum 0.31kWh/h.

Net electricity use across the day shows a different profile to gas (Figure 24), generally flatter, with a rise in the morning from the overnight lows then a levelling off until an evening peak, then gradually declining into the early hours of the next day. A slight peak near the middle of the day, around 13:00, can again be discerned.

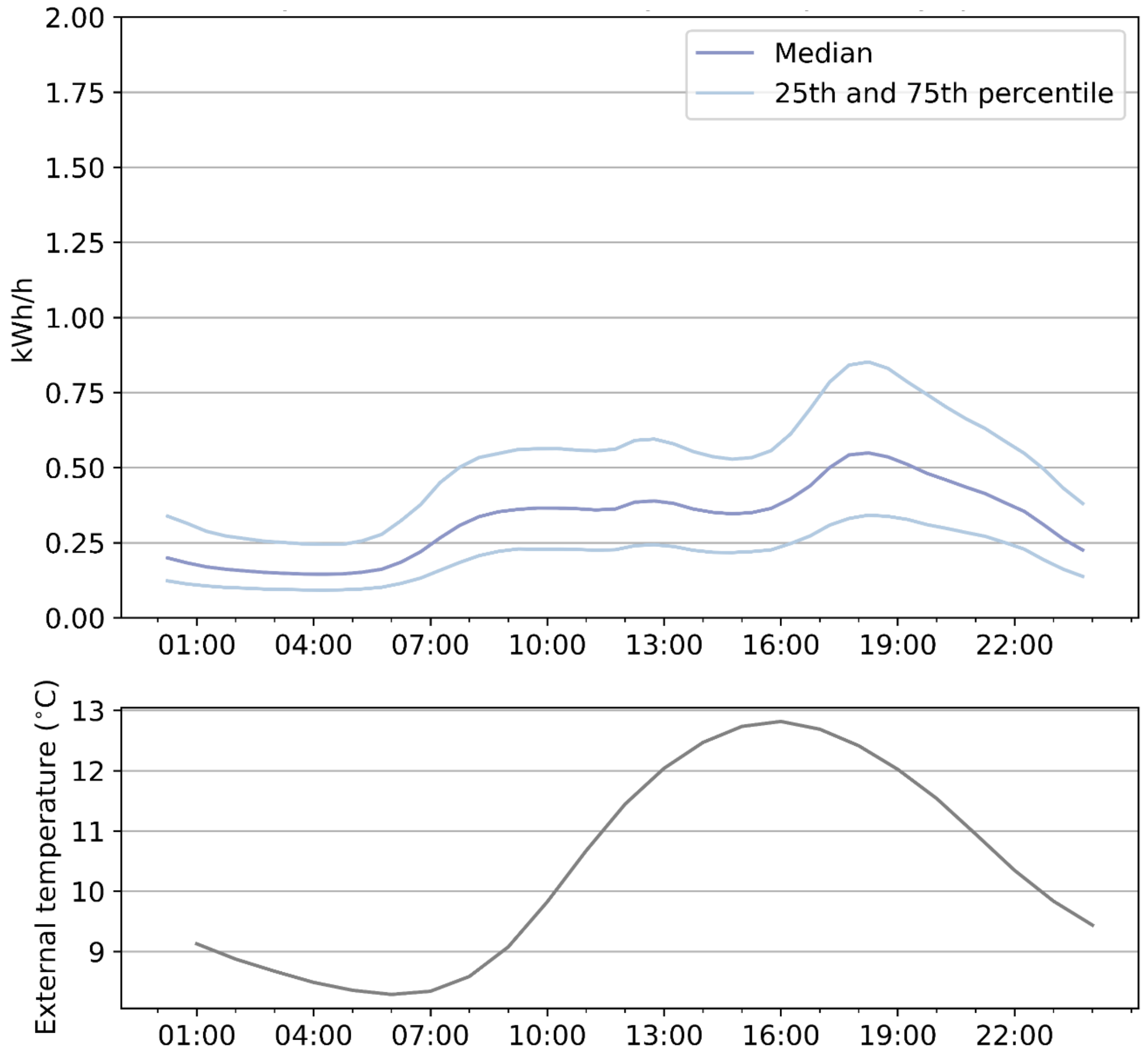

Figure 24 Quartiles of net electricity consumption for SERL Observatory participants in 2021

The median profile reaches a morning plateau of 0.37kWh/h by 10:00, staying at approximately this level until 16:00, aside from a rise to 0.39 kWh/h by 13:00. From 16:00 net usage begins to rise to the evening peak of 0.54kWh/h by 19:00, then declines slowly to an overnight low of 0.15kWh/h by 03:00.

The 25th and 75th percentiles show very similar profiles, simply scaled lower or higher. The 25th percentile morning high is 0.23kWh/h, reached by 09:30, while the evening peak is 0.34kWh/h, at 18:30, just over 62% of the respective median figures. The overnight low is 0.09kWh/h, reached at 04:00. For the 75th percentile, the morning high is 0.56kWh/h at 10:30, while the evening peak is 0.85kWh/h at 18:30, some 57% higher than the median. The overnight low is 0.24 kWh/h, reached at 04:30.

5.2 Diurnal energy use within temperature bands

Plotting half-hourly gas consumption by external temperature band (Figure 25) provides more detail on the strong relationship between external temperature and gas use reported earlier. Morning and evening peaks are evident across all the temperature bands, even the 15 to 20 °C band mostly associated with the summer period, with gas use between the two peaks lower, but falling to a smaller proportion of peak usage at lower temperatures. A smaller spike in use is also evident around midday.

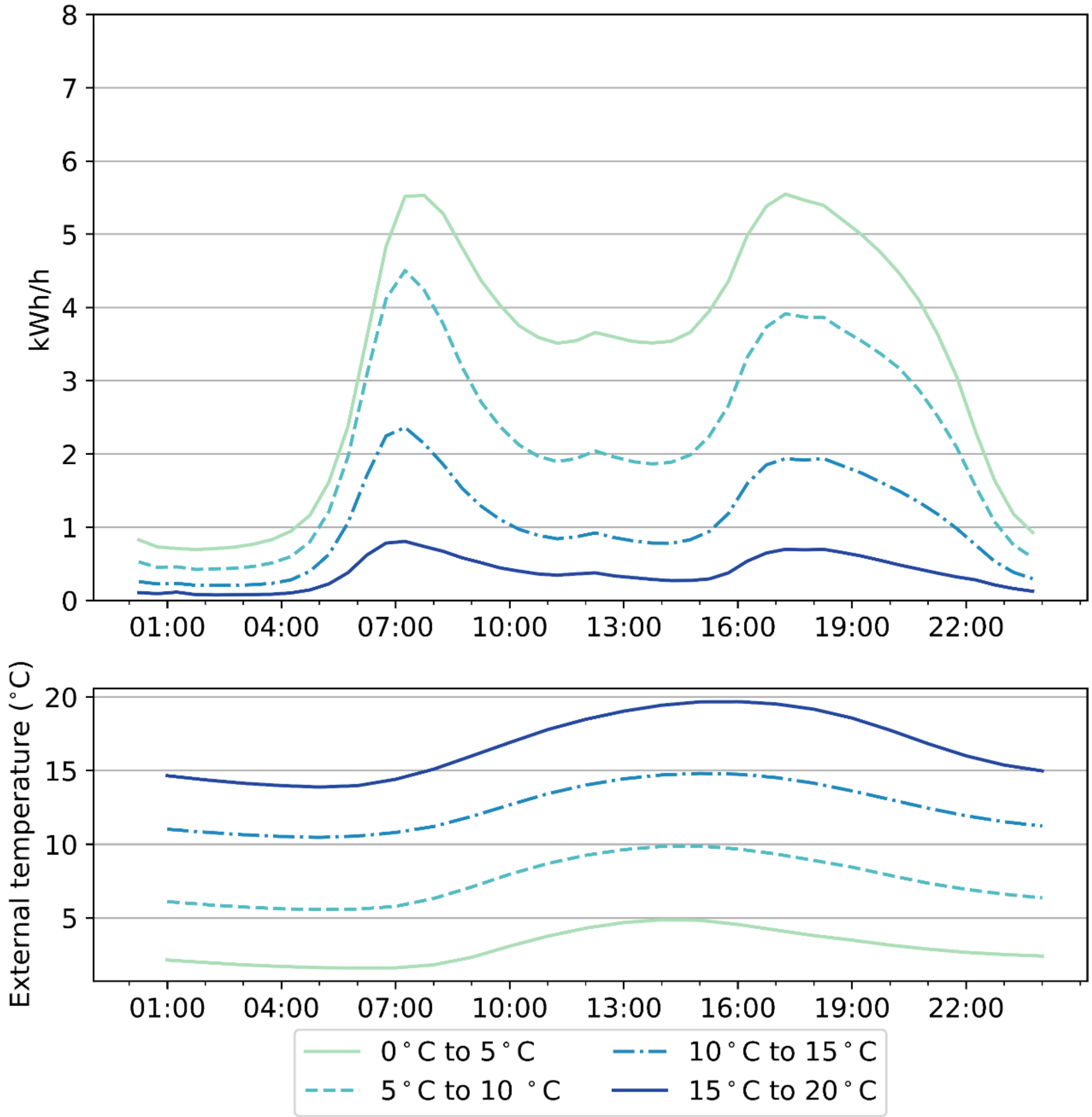

Figure 25 Mean gas consumption by temperature band in 2021

In the coldest temperature band shown, 0-5 °C, the morning peak usage is almost seven times that of the warmest band, 15-20 °C, reaching 5.53kWh/h (occurring at 08:00) compared to 0.81kWh/h (at 07:30). The evening peak of that coldest temperature range is similarly high, 5.55kWh/h, at 17:30, nearly eight times that of the peak during the warmest days shown, which is 0.70 kWh/h (at 17:30 and 18:30). For the coldest days plotted, the midday peak (at 12:30) is around two thirds of the morning and evening one, at 3.66kWh/h. In the warmest band, the midday peak (also at 12:30) is only 47% of the morning peak.

Night-time use is relatively low at all temperatures, although the lowest mean usage in the 0-5 ^{0}C temperature plot (0.69kWh/h, at 02:00) is almost the same as the peak mean usage in the 15-20 ^{0}C plots.

Overall, the figures reflect the predominance of gas central heating in the sample, perhaps with cooking accounting for the midday spikes, as well as contributing to the morning and evening peaks. The lower evening peaks in the middle temperature ranges could be due to the increase in external temperature by the afternoon and the fact many homes had already been warmed by that time; on the coldest days the much smaller relative drop in daytime usage after the morning peak perhaps reflects more homes needing to have the heating on more intensively to maintain a desired internal temperature throughout the day, or perhaps higher occupancy during the day when it is colder outside.

The net electricity profile (Figure 26) for the warmest days shows a morning peak, a gradual and slight decline through to the afternoon before a rise to the evening peak of 0.48kWh/h at 18:30. The profile for the coldest days shows a similar morning rise but then an overall levelling off until the increase in the afternoon, up to an evening peak of 0.88kWh/h at 18:00. Across all bands, a slight rise in usage in the early afternoon is observed, perhaps due to cooking for lunch.

The variation that is observed between temperature bands likely reflects a range of factors, such as: a small proportion of homes utilising electric heating as their main or supplementary heating; solar PV reducing net demand during the daytime more in the summer months (warmer) than winter (colder); increased use of lighting and indoor activities in colder, winter months.

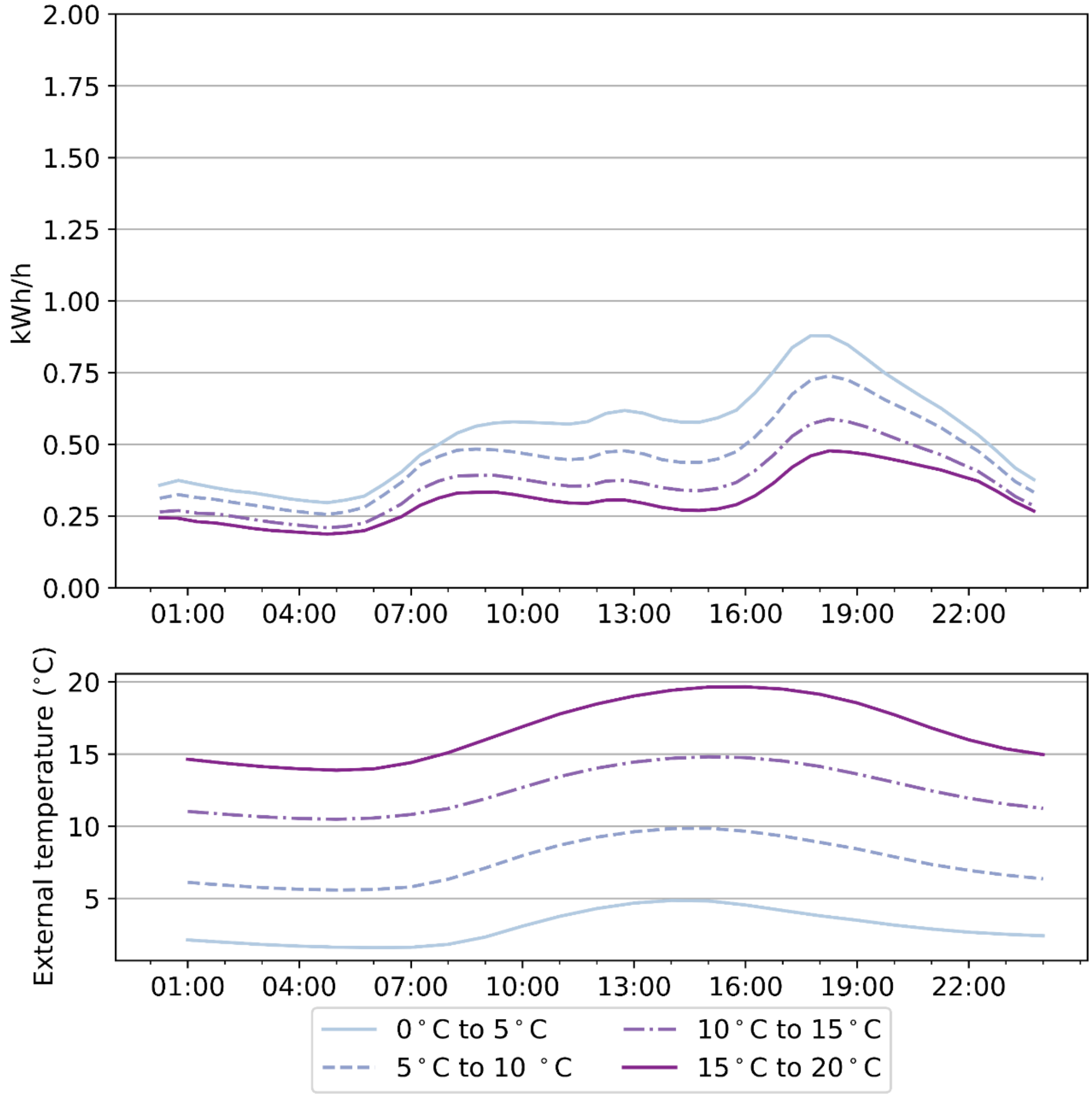

Figure 26 Mean net electricity consumption by temperature band in 2021.

5.3 Diurnal energy use within deprivation quintiles

In Figure 27, mean gas consumption for different levels of deprivation are presented. The figure shows that over the whole day mean gas consumption increases with Index of Multiple Deprivation (IMD) quintile (i.e. with reducing deprivation). Peak usage, particularly in the morning, varies most, whilst usage during the daytime varies less; overnight usage varies little with IMD. In IMD quintile 1, the evening peak tends to be higher; by IMD quintile 2, morning and evening mean peaks are almost identical; for quintile 3 and above the morning peak becomes the largest peak.

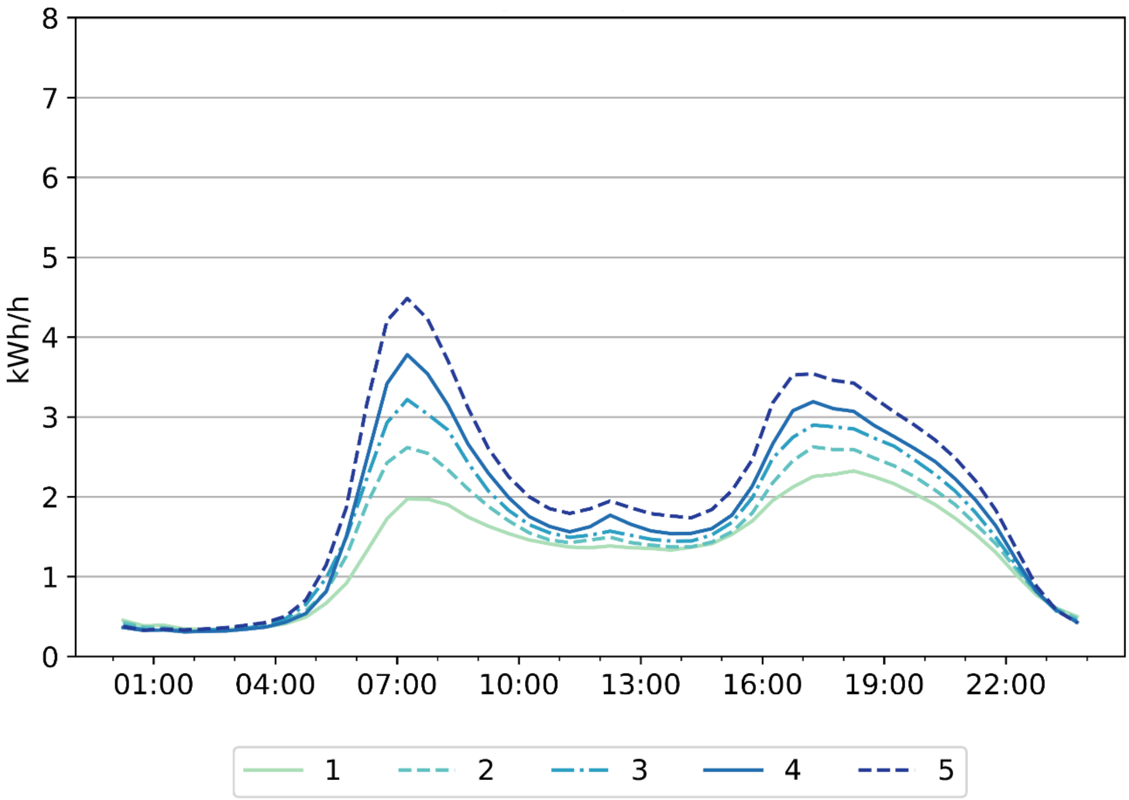

Figure 27 Mean gas consumption by IMD quintile in 2021

Morning peaks vary by 2.3 times between the highest and lowest IMD values, reaching 1.97kWh/h in the lowest IMD quintile and 4.48kWh/h in the highest, both at 07:30. Evening peaks vary by just 1.5 times, reaching 2.32kWh/h in IMD quintile 1 and 3.54kWh/h in IMD quintile 5. A smaller midday spike becomes more prominent as IMD increases, being barely present in IMD quintile 1.

Figure 28 shows net electricity consumption by IMD quintile. The typical electricity profile for the full sample is broadly present across all IMD bands, with the morning peak being relatively small, of a similar order to the daytime usage up until the late afternoon, when it begins to rise to an evening peak. Across the day, mean electricity usage is generally but not always higher as IMD score increases. A slight morning peak is visible in IMD quintiles 3-5 that is absent in quintiles 1 and 2.

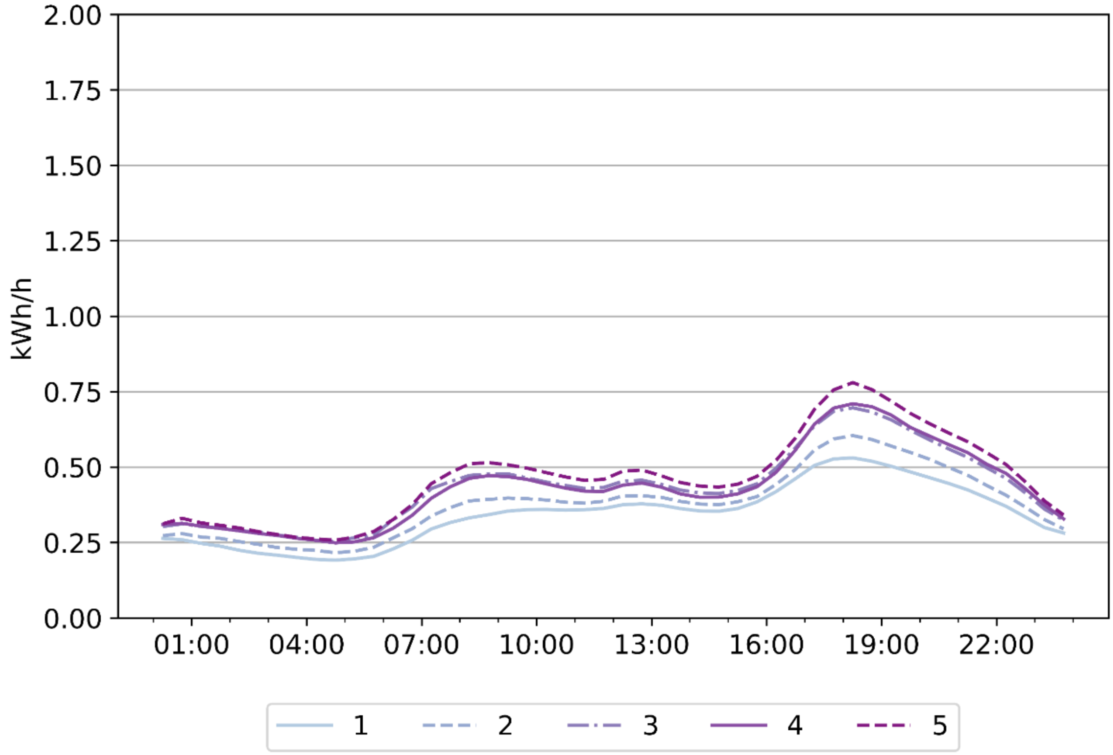

Figure 28 Mean net electricity consumption by IMD quintile in 2021

5.4 Diurnal energy use within EPC bands

Figure 29 presents mean gas usage by EPC energy efficiency rating. The general picture is of gas usage being lower across the day for homes with higher EPC ratings, however there are interesting nuances. Among the most energy efficient homes (bands A, B and C) there is relatively little difference until around midday, when usage becomes generally slightly lower in bands A&B compared to C. The difference between bands C and D is more substantial, and present throughout most of the day. Bands E to G have substantially more gas use than D, but again are similar to each other overall; the main difference being bands F&G having slightly higher usage after the morning peak until the evening peak, and again after it, compared to band E. As noted previously, care should be taken in interpreting these differences as the average floor areas in the homes in the SERL sample varies with EPC rating, with A&B rated homes having a mean area of 93 m^2, C 87 m^2, D 97 m^2, E 107 m^2 and F&G rated homes having a mean area of 119 m^2.

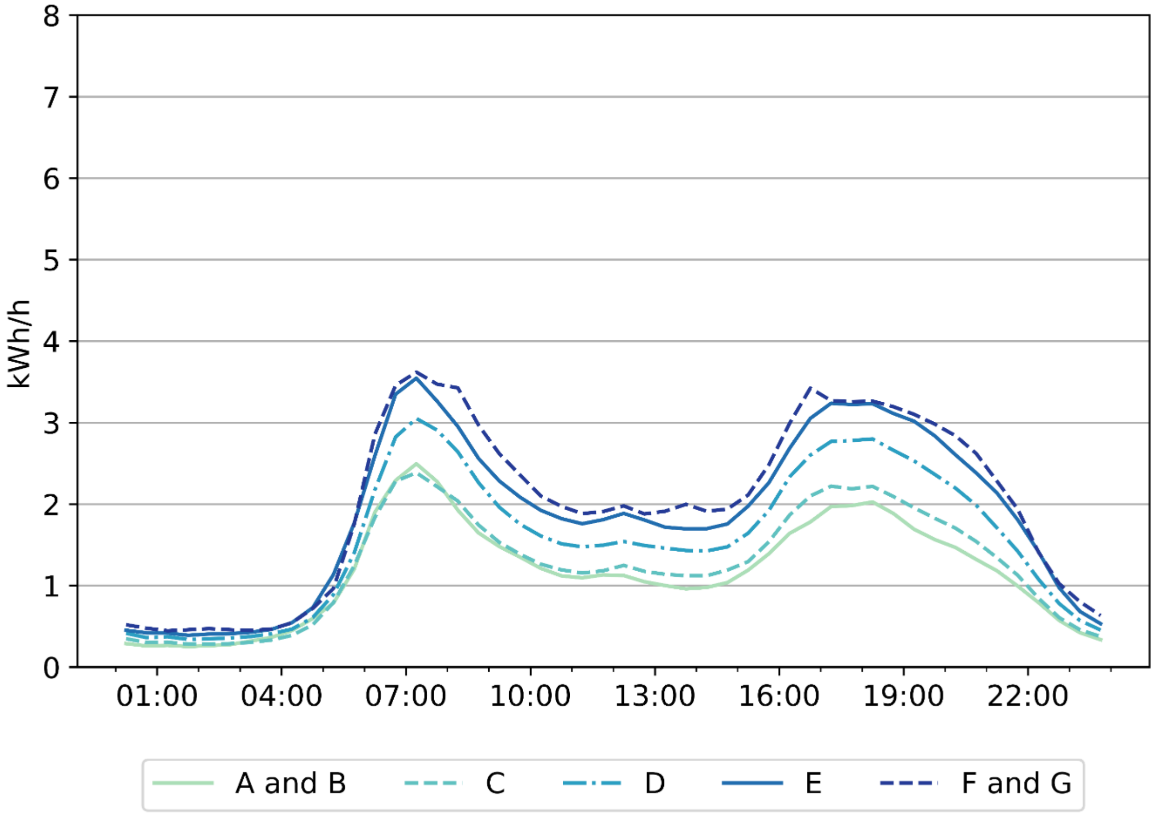

Figure 29 Mean gas consumption by EPC energy efficiency rating in 2021

Figure 30 presents net electricity use by EPC rating. Net electricity use consistently correlates with EPC across the day between bands F&G to C, falling as the energy efficiency rating increases. The A&B-rated properties have a somewhat different 24-hour electricity profile to C-rated homes; after reaching a similar morning high in usage, demand levels off in band C, whilst it falls substantially through the morning in bands A&B. The difference remains until usage rises to an evening peak, and usage peaks and remains slightly higher in the most efficient bands than in band C, remaining higher throughout the night. The lower daytime usage is likely a reflection that A&B-rated homes are more likely to have rooftop solar PV, and these figures represent net demand from the grid, i.e. household consumption minus generation. The higher usage at other times may be due to differences in property type between bands A&B and C, average floor areas, affluence and appliance usage.

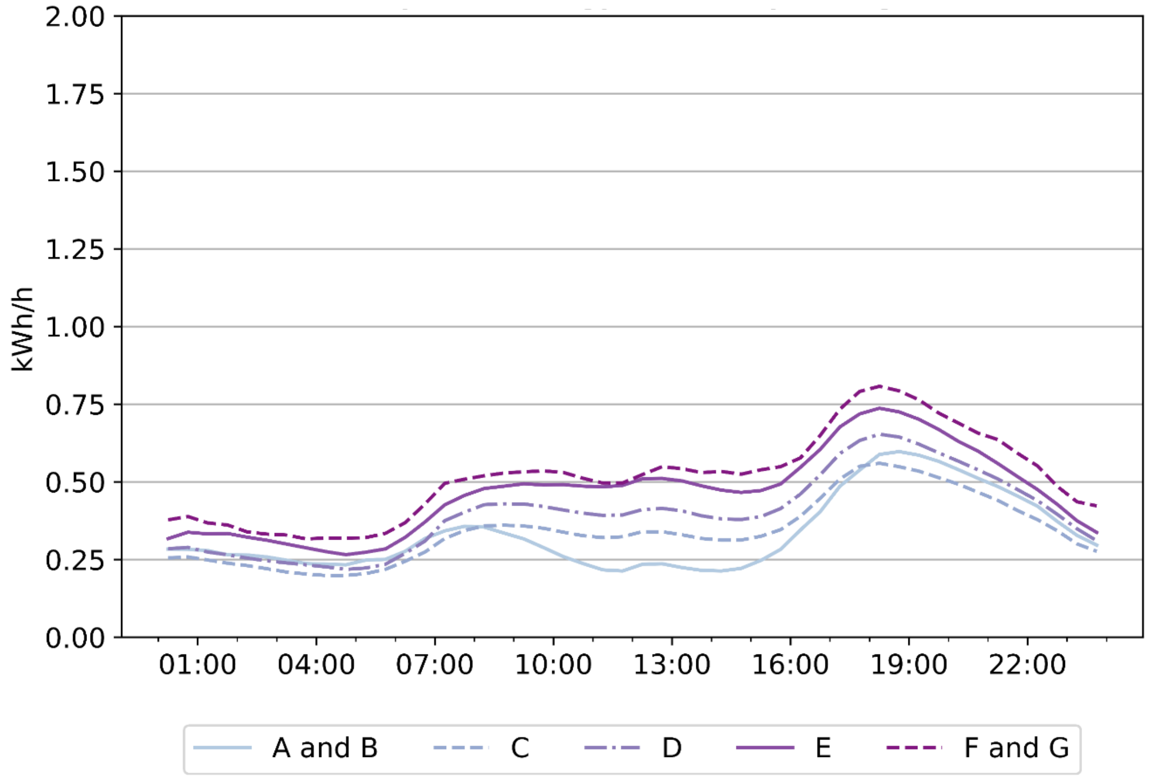

Figure 30 Mean net electricity consumption by EPC energy efficiency rating in 2021

5.5 Diurnal energy use within floor area bands

Gas consumption throughout the course of the average day varies substantially by floor area (Figure 31), with the greatest variation occurring during the peak periods. The morning peak is 3.3 times higher in homes over 200 m^2 than in homes of 50 m^2 or less (2.20kWh/h compared to 7.23 kWh/h); the evening peak 2.9 times higher (6.41kWh/h compared to 2.20kWh/h). The morning peak time is at 07:30 in both cases; in the evening, it occurs an hour earlier in the larger homes (17:30 vs 18:30). During the day, the mean gas use of larger homes is higher than the mean peak use of the smaller homes.

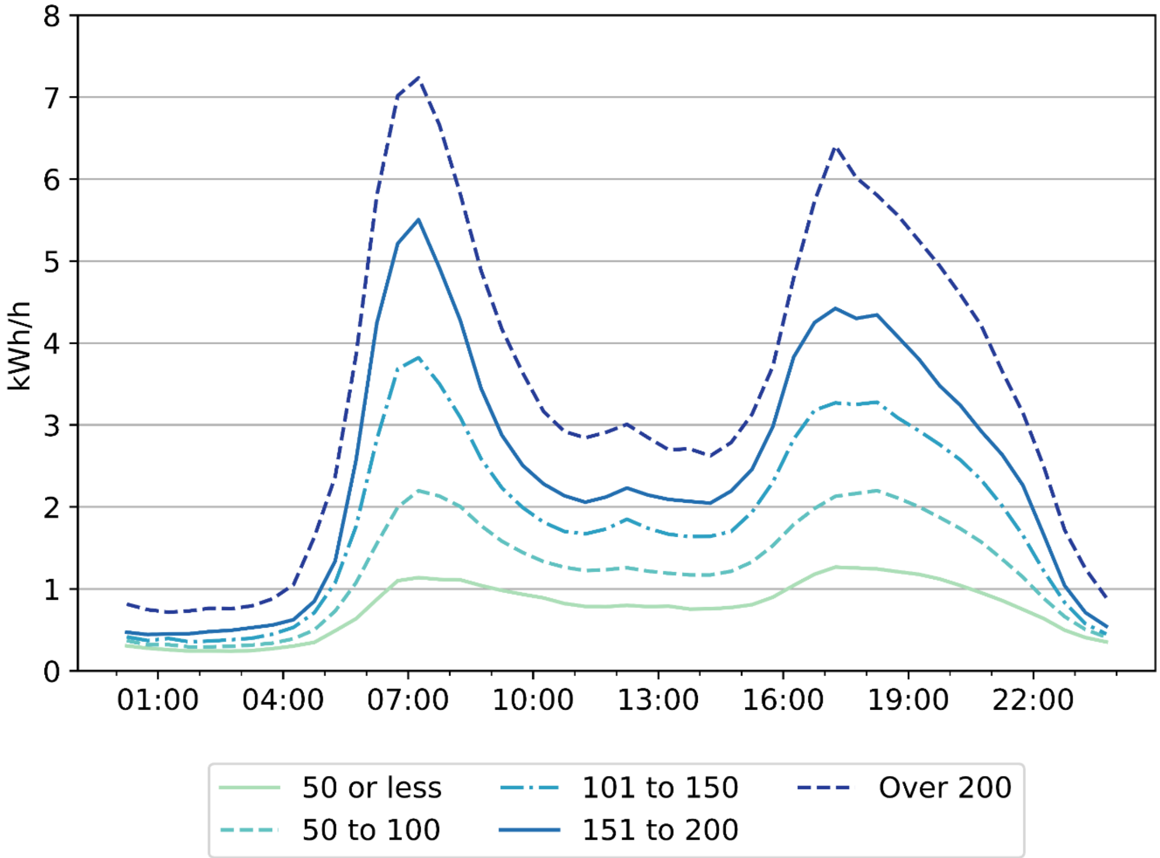

Figure 31 Mean gas consumption by floor area in 2021

Electricity use also varies substantially by floor area (Figure 32), and the profile varies in shape to an extent, with a morning peak only apparent in the largest three size bands presented. Energy use differs between homes proportionally more during peak times, with a maximum difference of a factor of 3.7 between the largest and smallest bands during the morning peak, and a minimum difference of 2.7 in the early afternoon and early hours of the night.

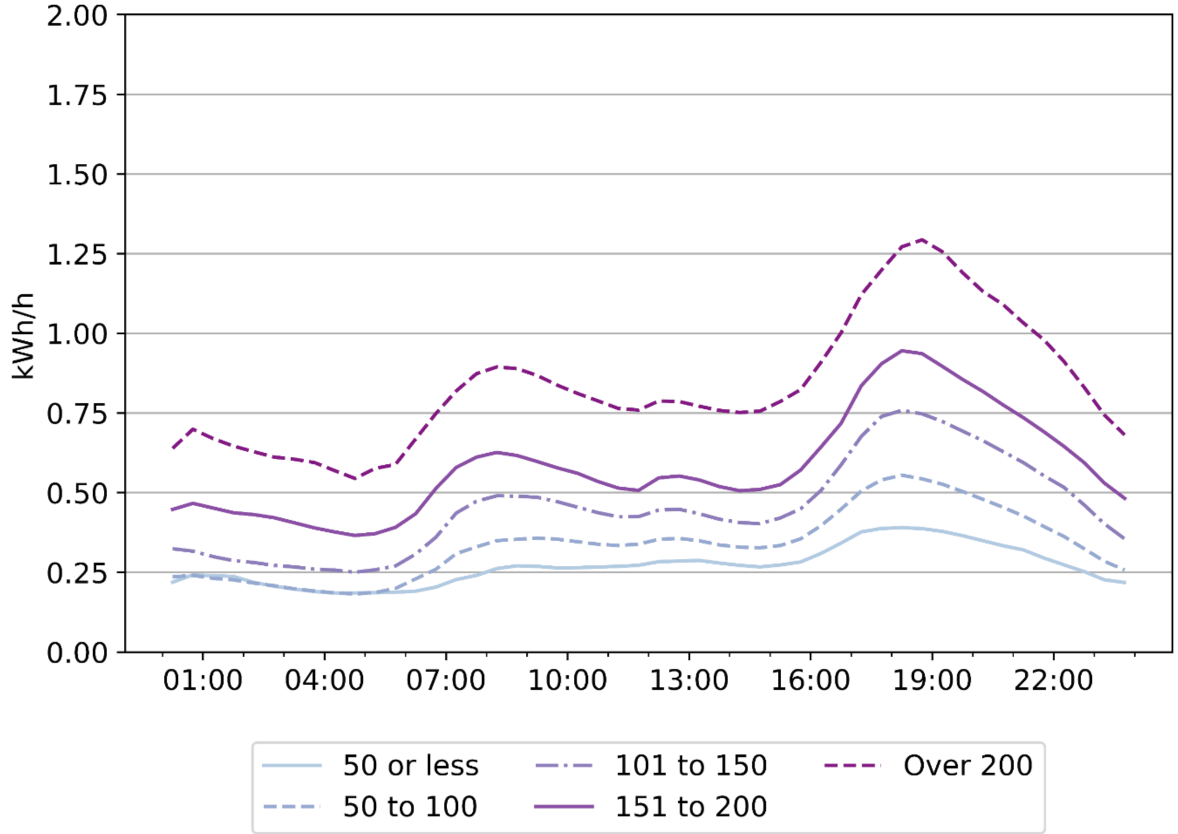

Figure 32 Mean net electricity consumption by floor area in 2021

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5.6 Diurnal energy use within dwelling type

Comparing building types (Figure 33), mean gas usage in terraced flats, semi-detached houses and other (or unknown) is similar across the day. Converted flats and shared houses on average have slightly lower usage during the daytime; purpose-built flats have substantially lower usage; and detached homes by far the highest usage, especially during the morning peak. There are likely to be substantial interactions between building type, floor area, occupancy levels, energy efficiency and other factors underlying these overall patterns.

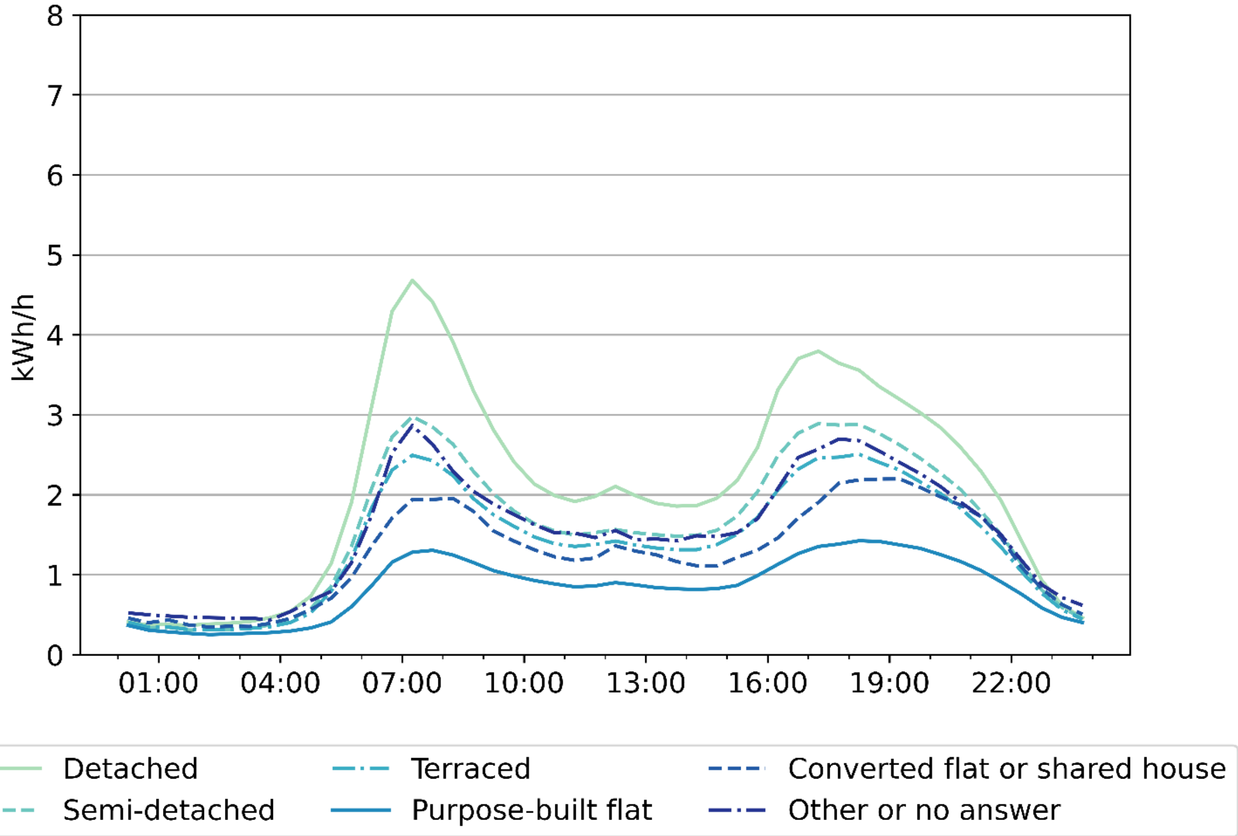

Figure 33 Mean gas consumption by building type in 2021

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The mean daily profiles by building type for net electricity use (Figure 34) are similar to those for gas, although with smaller differences between the building types. However unlike with gas use for which purpose-built flats have the lowest night-time usage, converted flats and shared homes have the lowest night-time net electricity usage.

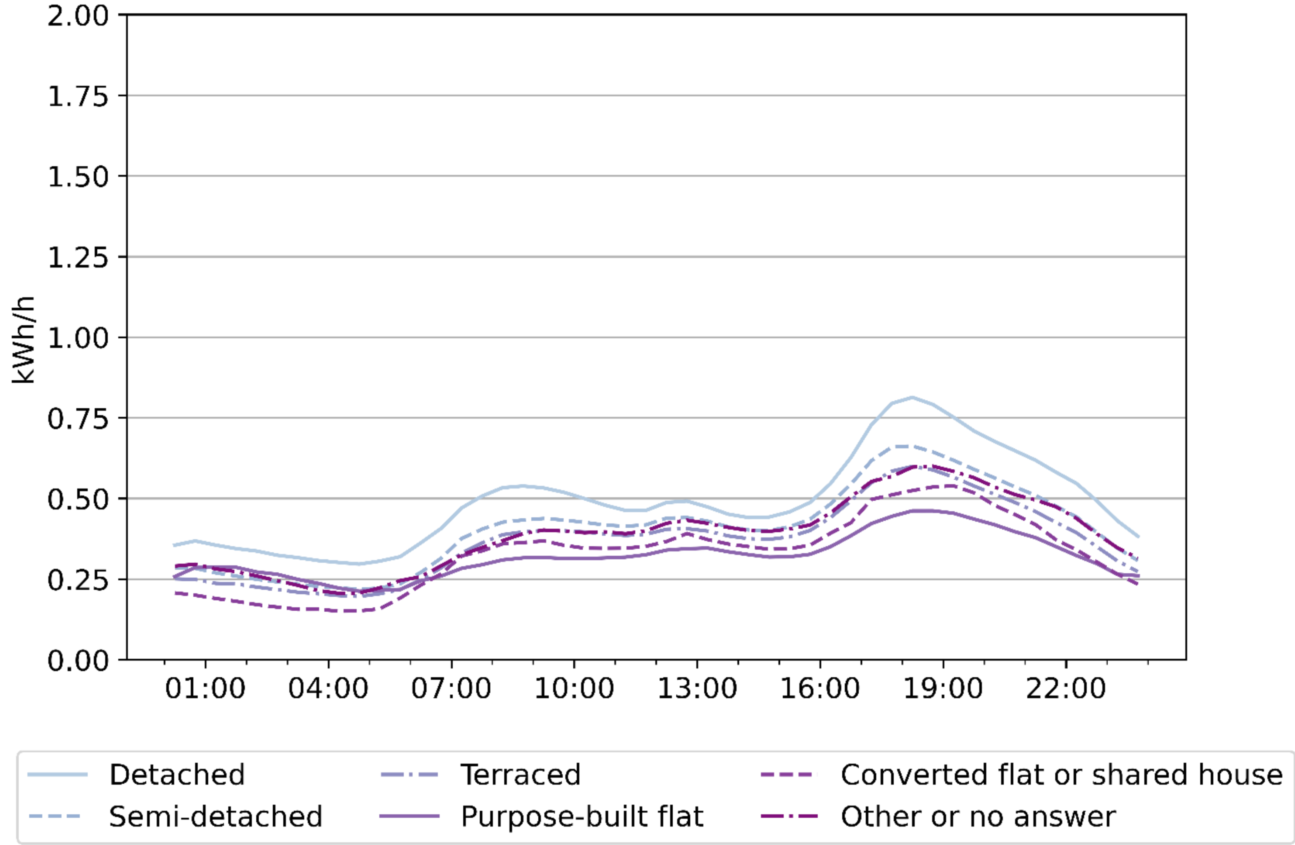

Figure 34 Mean net electricity consumption by building type in 2021.

5.7 Diurnal energy use by heating system

Figure 35 presents an initially complex picture of the relationship between heating system and net electricity use over the day. The text below deals first with homes with electric heating, and then with other non-electric forms of heating.

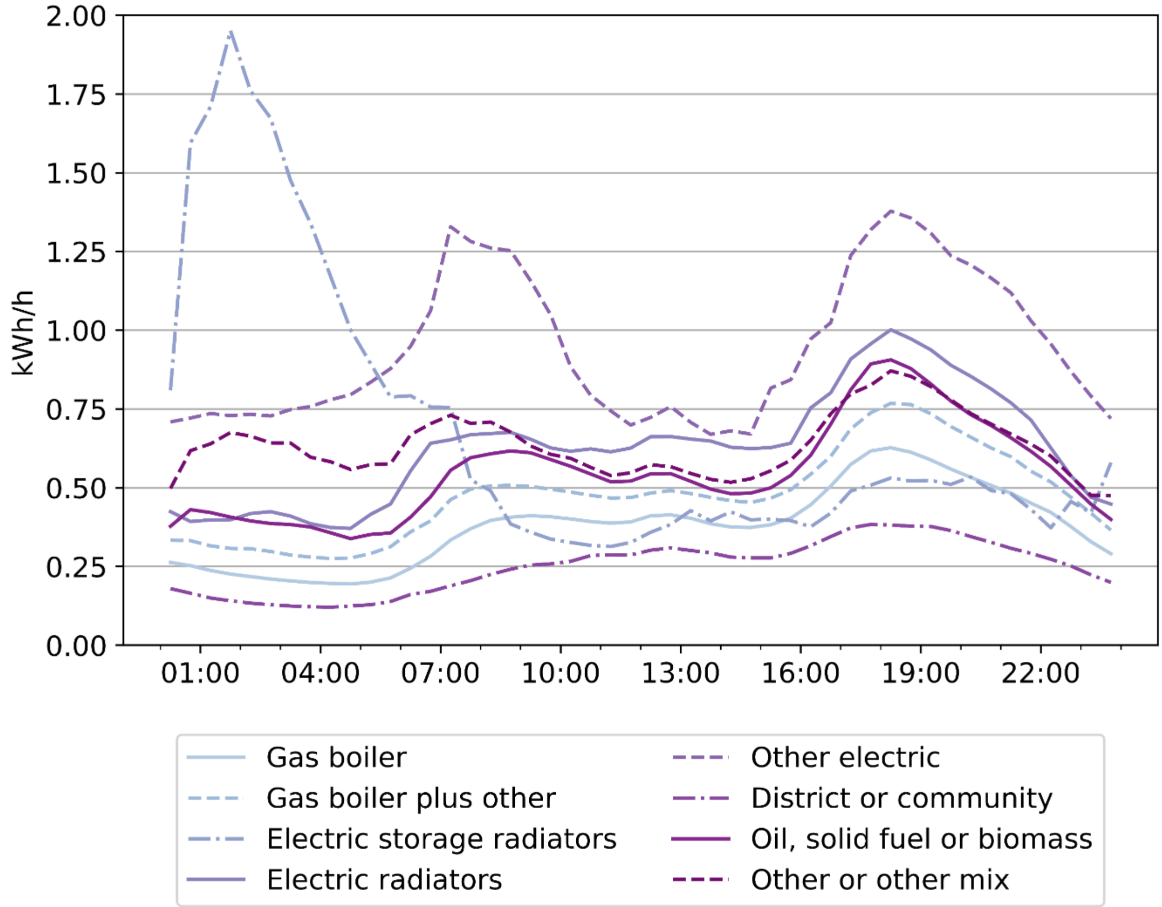

Figure 35 Mean net electricity consumption by central heating system in 2021

Electric storage radiators are the only type of central heating with a large overnight peak; when the radiators use electricity to build up their heat store for use during the day. Homes with electric radiators appear to use them more during the day than at night; the profile is only slightly higher than that of gas boiler-heated homes, however this is most likely because they have on average a 32% smaller floor area and 21% fewer occupants. Homes with 'other' electric heating have by far the highest average energy use across the day, in particular having a high morning and evening peak and more overnight use. The overnight use is consistent with homes that have heat pumps; the daytime peaks are more likely to be primarily due to homes with more conventional forms of electric heater. Due to the range of electric heating options available in the survey, it is possible that response errors may also account for some of the differences between groups observed.

Homes with a gas boiler or district or community heating, which therefore do not rely on electric heating, have the lowest overall electricity usage profile. The differences between the gas boiler and the district/community heating groups are likely down to differences in average floor areas (homes with gas boilers are on average 69% larger than those with district or community heating in the SERL Observatory) and household size (30% more occupants in the gas boiler group). Homes with oil, solid fuel or biomass heating also do not use electric heating; their substantially higher electricity profile throughout the day compared to gas boiler-heated homes is likely down to their also being on average 50% larger than homes with gas boilers.

Homes with 'other' heating in addition to gas boilers have slightly higher usage across the day than those with just gas boilers, likely in part explained by being slightly larger homes on average and with slightly more occupants, as well as being down to having supplementary electric heaters.

5.8 Diurnal energy use by number of occupants

Broadly, gas consumption across the day correlates with number of occupants (Figure 36). The difference in peaks is greatest between 1 and 2 occupants, and less so after that. The differences are not consistent with different numbers of occupants – homes with 2 and 3 occupants have very similar profiles throughout most of the day, while homes with 4 and more occupants have similar profiles over the morning peak, but correlate with occupant numbers outside that. The increase with occupant numbers in daytime and night-time usage outside peak periods is more uniform than it is during peak periods. For six or more people, peak usage is 73-75% higher than for homes with one occupant (3.85kWh/h compared to 2.23kWh/h for the morning peak, and 3.79 kWh/h compared to 2.17 kWh/h for the evening peak). The small lunchtime peak is 115% higher meanwhile.

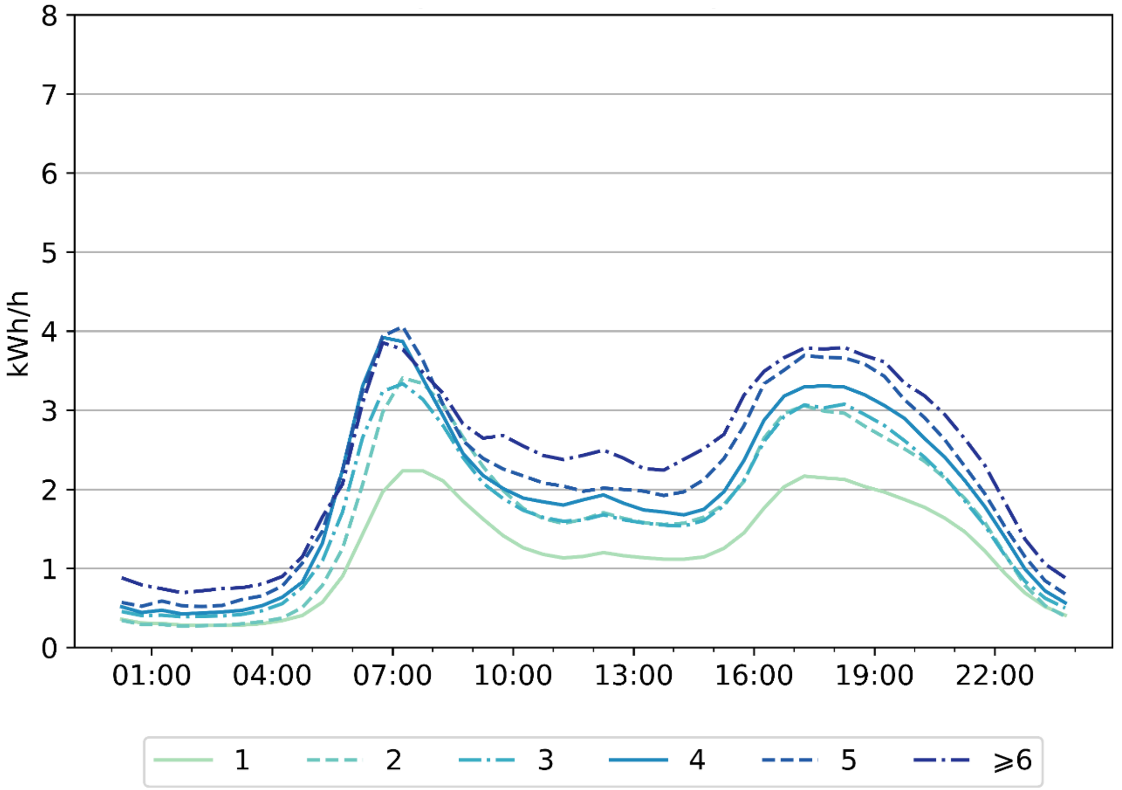

Figure 36 Mean gas consumption by number of occupants in 2021

The observed patterns are likely due to a range of interacting factors, including: larger households tend to live in larger homes that require more space heating to reach a given indoor temperature (mean floor area in the 6+ group with data was 129 m^2, for single occupants it was 73 m^2); many households will likely heat all or most of their home when it is occupied, so increasing the number of occupants has little effect on heat energy demand; conversely, as the number of occupants increase, there is more likelihood of the home being occupied during the daytime, hence there is more likely to be daytime space heating, hot water usage and cooking (hence daytime usage grows proportionally faster with occupant numbers than does peak usage).

Differently to gas usage, electricity usage across the day differs more substantially with the number of occupants (Figure 37), with usage in homes with six or more occupants varying between 2.3 and 3.3 times that of homes with one occupant. The variation is lowest around 06:00-07:00 and highest in the afternoon. The increase with number of occupants is generally more linear than it is for gas too, although homes with five occupants and with 6 or more have very similar profiles.

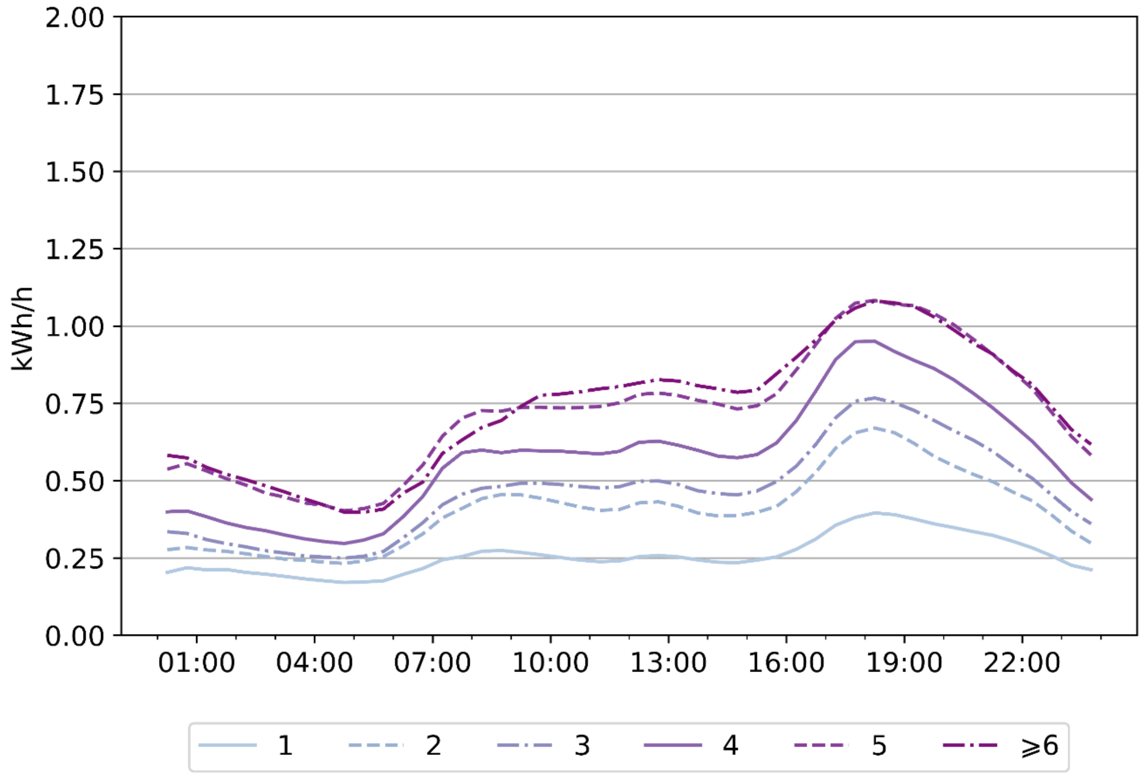

Figure 37 Mean net electricity consumption by number of occupants in 2021

This pattern could be accounted for by the types of activities which use electricity. Unlike gas usage, where space heating is largely shared by the occupants, more electricity-using activities are per-person, e.g. heating water for washing, laundry, hot drinks; personal electronic devices; lighting of more rooms; etc.

5.9 Diurnal energy use by day of the week

Both electricity and gas usage show a small amount of variation between weekdays and weekends, with similar differences for both fuel types (Figure 38 and Figure 39). Compared to weekdays, weekend morning peaks in usage occur slightly later and progress into slightly higher daytime usage, before converging to very similar evening peaks and overnight usage patterns. This is likely an effect of typical Monday to Friday working patterns, with more households getting up later and staying home during the day at weekends; hence using more energy.

The average temperature profile over the day is presented for weekdays and weekends to highlight that in 2021 these, unusually, differed by about 0.4ºC.

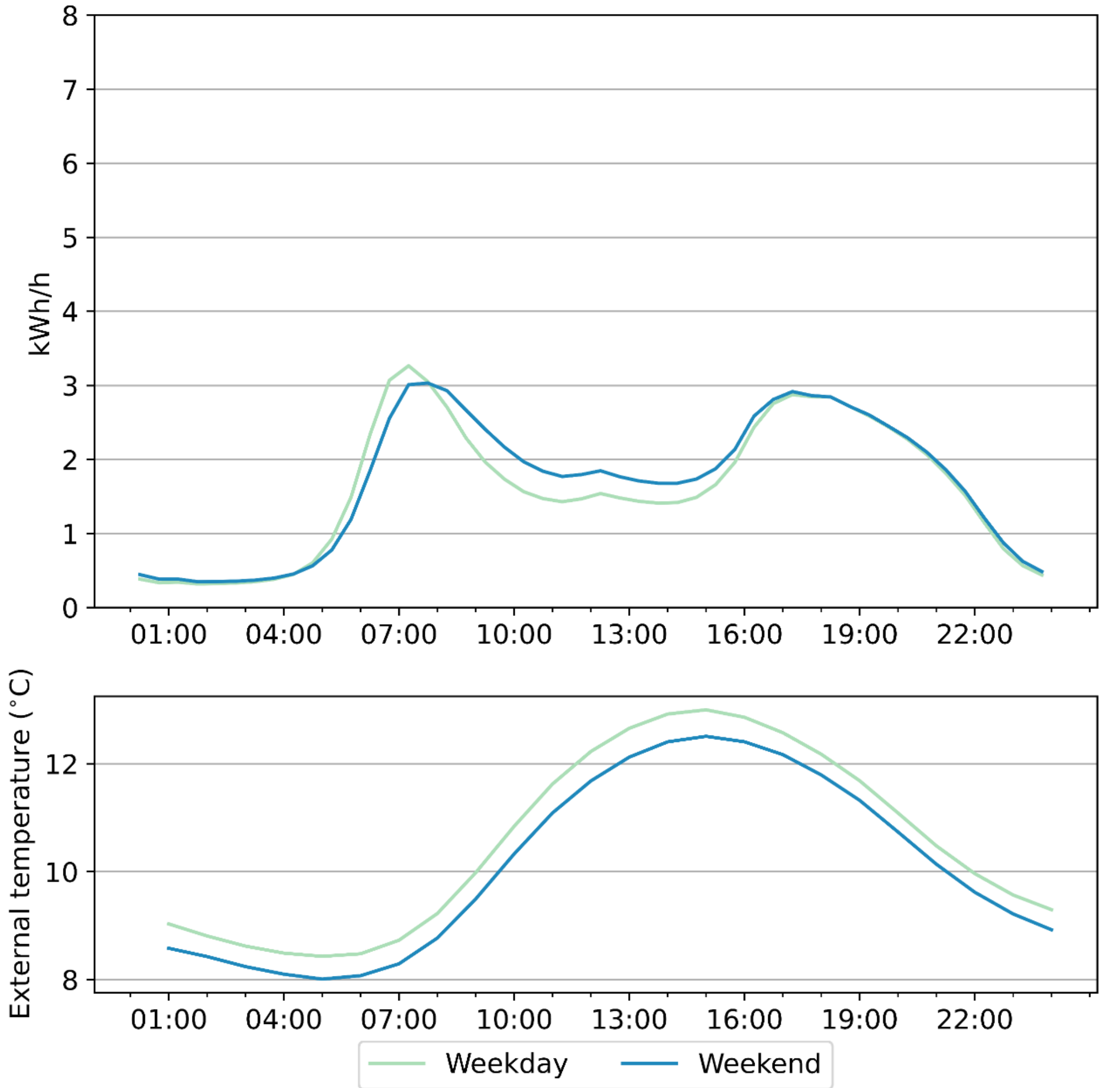

Figure 38 Mean gas consumption by weekend and weekday in 2021

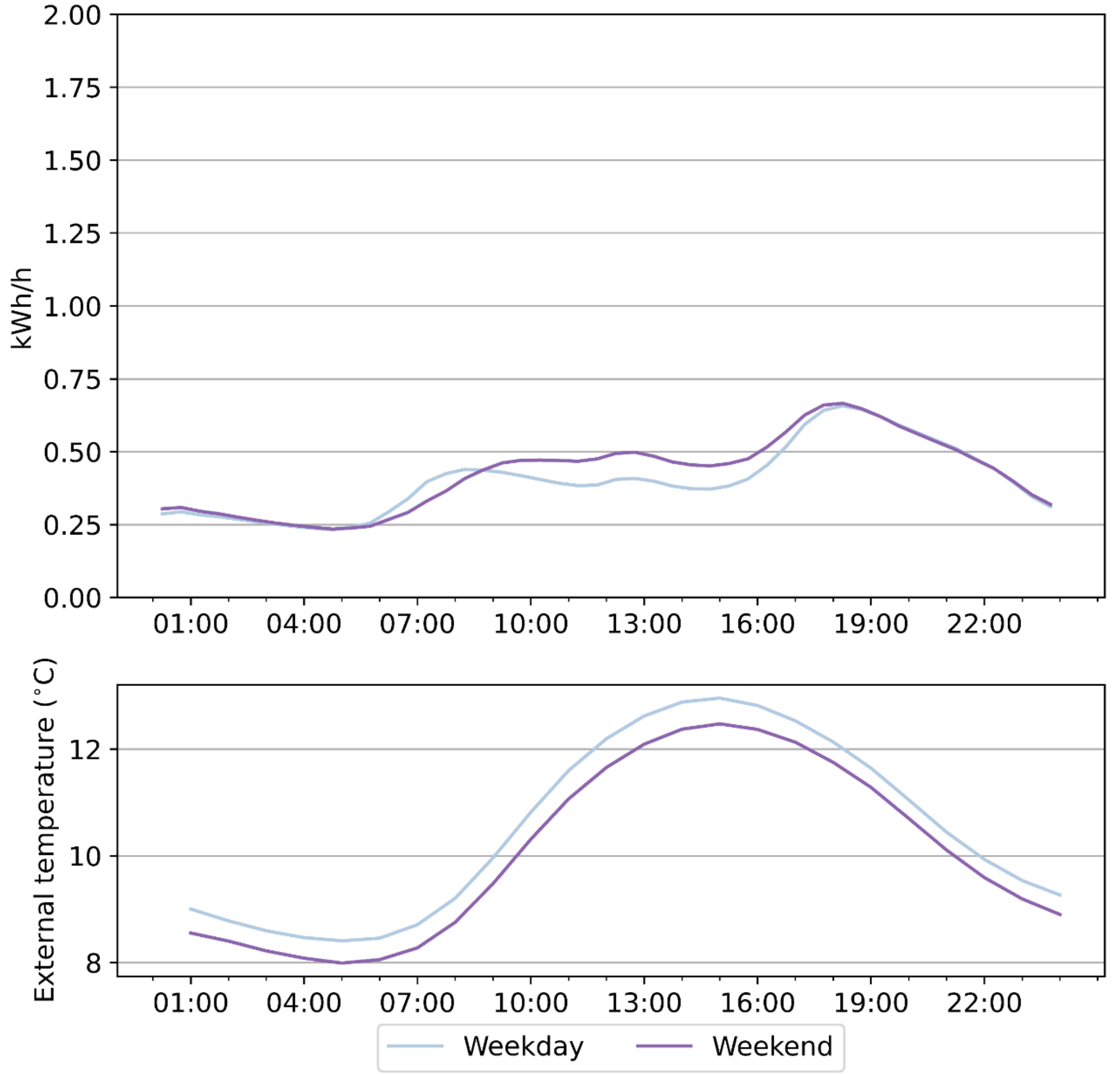

Figure 39 Mean net electricity consumption by weekend and weekday in 2021

5.10 Diurnal energy use by EV ownership

Throughout the day, households with electric vehicles have a higher mean net electricity use than those without (Figure 40). Here, households who own EVs are identified based on their responses to the SERL participant survey. For most of the day the mean profile is similar in shape. The exception is overnight from approximately midnight until around 05:00, when the EV group shows a peak in usage that reaches levels similar to its evening peak, which is most likely due to the automated charging period for the electric vehicles. In addition to EV charging during the day, the higher electricity usage among the EV group at other times of the day could be more down to differences in other characteristics between the two groups: notably, the households with electric vehicles on average have 40% larger dwelling floor area (mean of 132 m^2 compared to 95 m^2) and have more occupants (mean of 2.7 compared to 2.3).

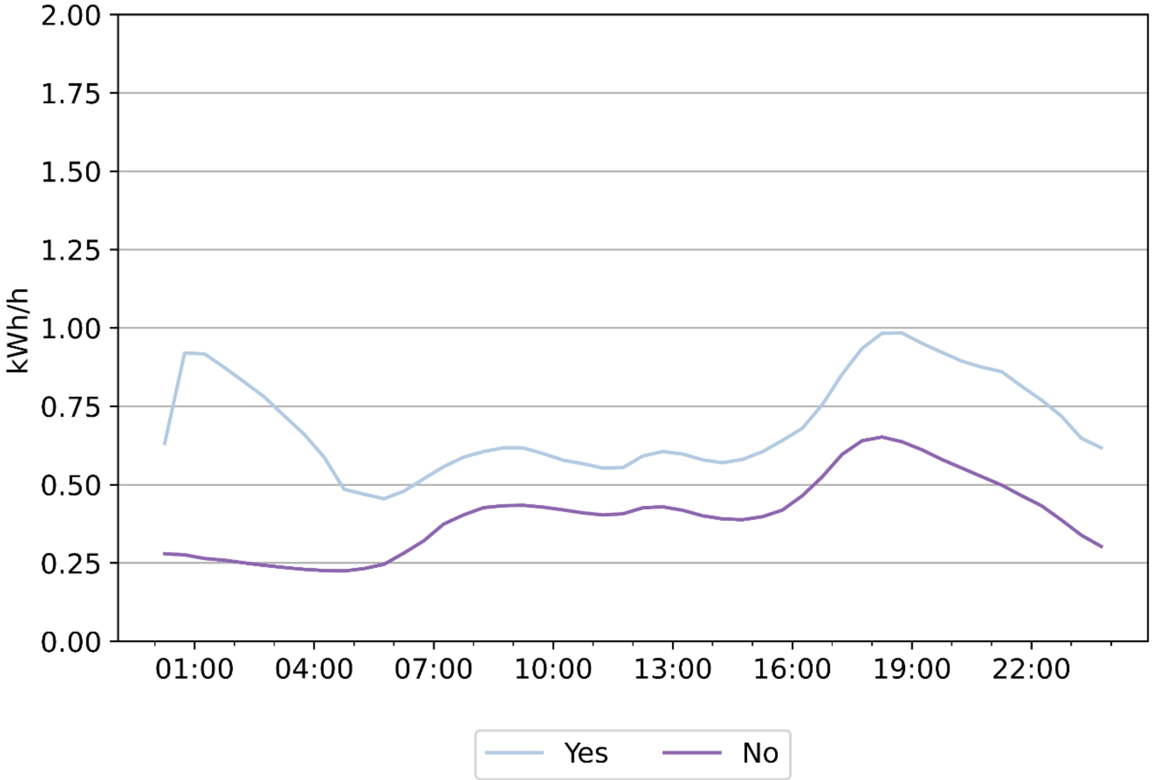

Figure 40 Mean net electricity consumption by electric vehicle ownership in 2021

5.11 Diurnal net electricity use by PV ownership

Finally, we present the mean household net electricity demand for homes with and without solar photovoltaic rooftop panels (Figure 41). Recall that the figures presented are *net* demand, that is, the household's consumption minus its generation, including periods when it may be exporting to the grid and hence have net negative demand. Households with PV are identified from their EPC where available or from having a positive half-hourly export read in their smart meter data (indicating export to the grid).

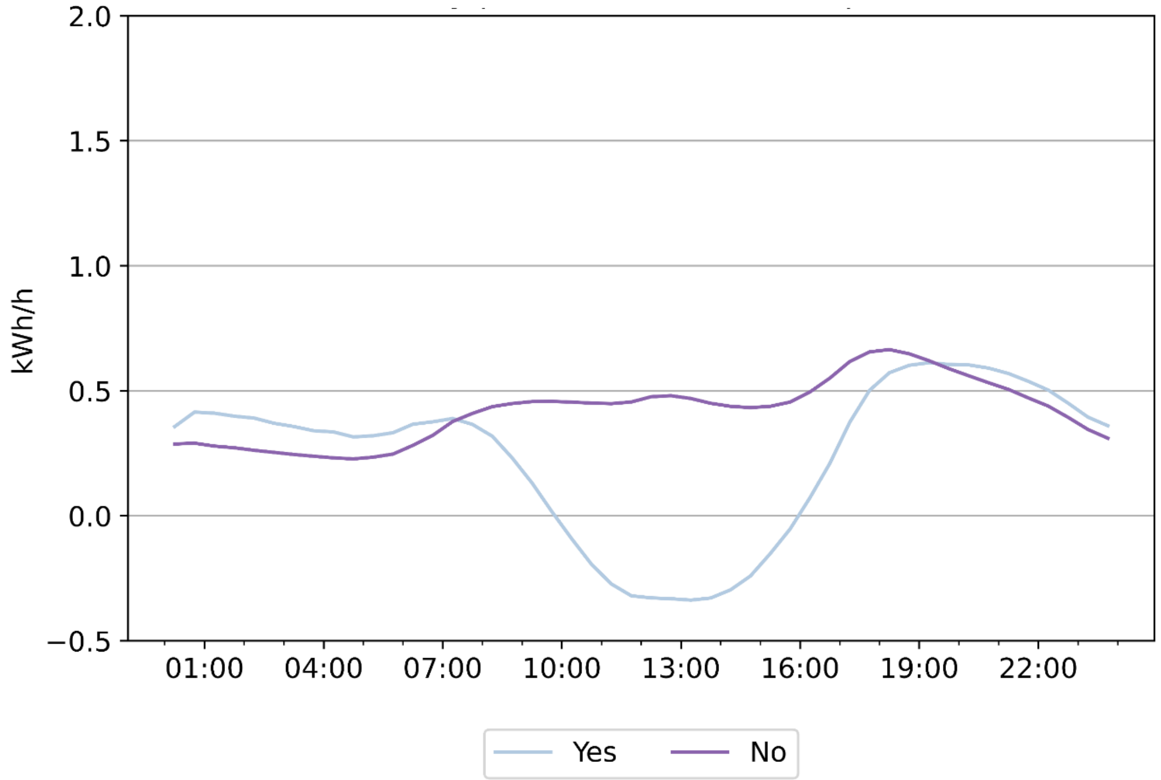

Figure 41 Mean net electricity consumption by photovoltaic ownership in 2021

The effect of the PV is clearly visible in the large difference in net demand during the day; indeed, mean net demand from the PV group is negative between 10:30 and 16:00, falling as low as -0.34 kWh/h.

Profiles overnight between the two groups are similar, with the higher consumption by the PV households likely accounted for by the fact that homes in that group are 22% larger on average by floor area than homes in the non-PV group (115 m^2 compared to 94 m^2); mean occupant numbers are 2.3 in both groups.

6 Future work

The need for research related to domestic energy use has never been greater as we undergo a net zero and energy security transition and enter a period of rapidly rising energy and living costs. The SERL Observatory will help to track how this transition is occurring over time, providing data complementary to other national data sources such as NEED and EFUS. The main advantages of SERL are its relatively quick data provisioning (quarterly rather than more than 12 months in arrears), wide range of relevant contextual variables, and high resolution (half-hourly) for both gas and electricity. This enables the diurnal energy profile (comprising 48 half-hourly readings) to be compared between homes with EVs, PVs, different heating systems and EPC ratings, which are all areas of significant research and policy focus, as well as comparisons between many other factors.

SERL data collection is ongoing and we will provide an update to the analyses presented here at regular intervals. Subsequent SERL statistical reports will provide a deep insight into how the energy transition is progressing and track changes in domestic demand due to energy price rises, post-pandemic behaviours and other factors. Future reports are likely to include more breakdowns by season and weather conditions to give more information regarding the variation in energy use through the year, and also include statistics normalised by floor area where possible, as this is known to be a significant factor related to domestic energy use.

This report has demonstrated that many factors are correlated with domestic energy use but does not attempt to understand how these interact with each other. We have begun to undertake analyses of such interactions in McKenna *et al.* (2022), and future work will continue to explore this.

The coronavirus pandemic dramatically affected peoples' lives from 2020 onwards and it is likely that resulting behaviour changes and the transition to a 'new normal' in terms of domestic energy consumption will continue for several years to come. SERL was collecting data prior to the onset of the pandemic, and thus we are in a particularly strong position to understand how domestic energy use has changed and will continue to evolve. Analysis of a questionnaire delivered to SERL Observatory participants in the early stages of the pandemic has been published (Huebner *et al.*, 2021), and the survey data is available as part of the 4th edition of the SERL data. This will be complemented by ongoing research to understand how energy use has changed overall, as well as how diurnal profiles of energy use varied over the course of the pandemic and beyond.

More recently, unprecedented increases in the consumer price cap in April 2022 and the war in Ukraine are likely to significantly affect the way people use energy in their homes. We will be investigating this using the data currently available as part of the SERL Observatory dataset and, for the first time, using tariff data which is also collected from the smart meters. We will be using this to assess the impact of the price rise on different types of households (for example, those that are likely to be in fuel poverty).

Government policies aim to increase the EPC ratings of dwellings and increase the uptake of heat pumps, solar panels (PVs) and electric vehicles (EVs). SERL data provides an insight into the actual impact these changes are having on energy use in the home, and we plan to undertake more detailed analysis in these specific areas.

Alongside these priority areas of research, we will also be further developing a backbone of analysis techniques to understand the underlying patterns of domestic energy use in GB. This will be via a range of approaches including developing models for understanding and analysing different aspects of the data e.g., statistical models for explaining and predicting variation in energy use over different time periods, cluster analysis for understanding profiles of consumption and specific models to assess the thermal performance of dwellings.

This and future similar reports will summarise high-level aggregated statistics for the SERL Observatory. However much of the value and benefit of SERL will be derived from the many individual research projects undertaken by the wider research community. These projects utilise the full longitudinal, high-resolution, controlled SERL Observatory dataset.

Applications for further research projects wishing to utilise SERL data are strongly encouraged from across the research community. The SERL Observatory dataset is available to accredited researchers via a secure lab environment. See below for information on accessing the full SERL Observatory dataset.

7 Further information

The SERL Observatory data is available to UK accredited researchers via the UK Data Service. See the SERL website for instructions on how to apply for access to use SERL data for your research. The SERL Observatory Fourth Edition of data was made available in April 2022 and provides data from August 2018 until the end of 2021. We aim to release new editions with updated data every three to six months.

The aggregated statistics underlying this report can be found at: https://serl.ac.uk/key-documents/reports/.

We have endeavoured to ensure that the information presented here is as free from errors as possible, however any corrections will be published here.

We welcome feedback and comments, both about this report and about the Observatory data; please contact info@serl.ac.uk.

The SERL Observatory includes European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 data. Neither the European Commission nor the European Centre for Medium-Range Weather Forecasts is responsible for any use that may be made of the Copernicus information or data it contains.

8 Acknowledgements

We would like to thank:

- The 13,000+ SERL Observatory participants for giving permission for the use of their data for scientific research.
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- Ben Anderson for feedback on an early draft of this report.
- The SERL Independent Advisory Board, SERL Research Programme Board, and SERL Data Governance Board, who have guided the development of SERL and our research.
- The BEIS Smart Meter Implementation Programme team, whose hard work on the smart meter roll-out has enabled this type of research and who have provided continued support in helping us to maximise the research value from smart meter data.

However, we take sole responsibility for the accuracy of the reported data and its accompanying narrative.

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Appendix: Methods

All the outputs in this report are based on statistical analysis of the SERL Observatory dataset SN 8666:

Elam, S., Webborn, E., McKenna, E., Oreszczyn, T., Anderson, B., Few, J., Pullinger, M., European Centre for Medium-Range Weather Forecasts, Ministry of Housing, Communities and Local Government, Royal Mail Group Limited, 2022, *Smart Energy Research Lab Observatory Data, 2019-2021: Secure Access*, [data collection], UK Data Service, 5th Edition. SN: 8666, DOI: 10.5255/UKDA-SN-8666-5

The statistical release that accompanies this report consists of aggregated summaries of the electricity and gas consumption data with aggregated linked contextual data, optionally grouped by one of the categorical variables (e.g. region, EPC rating) or banded continuous variables (e.g. temperature band) available in the contextual data.

The summaries are provided at the following levels of aggregation:

1. Annual – annual averages of daily electricity or gas consumption, external temperature, and heating degree days
2. Monthly – monthly averages of daily electricity or gas consumption, external temperature, and heating degree days
3. Diurnal – annual averages of half-hourly electricity or gas consumption, and hourly external temperature

The categorical variables which are used for grouping are:

- Temperature – data is grouped by mean external temperature bands: 0 to 5 °C, 5 to 10 °C, 10 to 15 °C, 15 to 20 °C
- Region
- Index of Multiple Deprivation (IMD) quintile – 1 to 5
- Energy Performance Certificate rating – from A to G
- Floor area of building (in bands)
- Heating system e.g. gas boiler, electric radiators, etc.
- Year of construction of building (in bands)
- Building type
- Number of occupants
- Tenure
- Electric vehicle ownership
- Photovoltaic ownership

Two sets of households are used in these summaries:

1. All households with sufficient data to estimate an annual average for the year 2021
2. All households with sufficient data to estimate annual averages for both the year 2020 and 2021

As recruitment of participants to the SERL project occurred in waves, the first set has more households and includes the households that are in the second set. As it is larger, we use the first set for all outputs relating to 2021. However, a small number of outputs use the second, smaller set to provide information about how energy consumption changed from 2020 to 2021 *for the same group of households*. Indicative sizes of the two sets: first set has >10k households for electricity and ~8k for gas, while the second set has ~3k for electricity and for gas. Note that the actual N for each statistic may be substantially lower than this due to contextual variable segmentation and missing data.

The process for producing these is as follows.

1. Household-level aggregation

For each household, half-hourly and daily electricity and gas consumption, and hourly external temperature data is aggregated for each month to produce:

- average (mean) and percentiles of half-hourly consumption and mean external temperature for each month and
- average (mean) and percentiles of daily consumption and mean daily external temperature, and mean heating degree days for each month.

For each household, these monthly aggregations are then aggregated over the whole year to produce an average half-hourly profile (mean for each half-hour over all months) for each year and to produce average daily values (mean daily consumption, mean temperature and mean heating degree days over all months) for each year.

Note on missing data: we use a missing data threshold of 50% for the monthly aggregations i.e. at least 50% valid half-hourly reads are required to estimate the average for any given month. And we require all monthly aggregations to produce the annual aggregations (i.e. 0% missing data threshold). This ensures that if data is missing in any particular season then the annual result will not be skewed as a result.

This results in

- **household-level annual summaries of daily averages**
- **household-level monthly summaries of daily averages**
- **household-level annual summaries of half-hourly averages**

This step is repeated with household-level data filtered by temperature band (e.g. household-level averages of daily consumption on days with mean temperature between 0-5ºC) and for weekdays vs weekends. This results in a further set of household-level summaries *for each temperature band and for weekends/weekdays*.

Note the household-level annual summaries are **not** included in the statistical dataset released to the public as part of the SERL Annual Report but are used to create the outputs included in this report, in particular the histograms, and the 'grouping-level aggregated outputs' described below.

Note on histograms: the count of observations in each bin is checked to ensure >10. Final categories are aggregated to reduce small tail issues.

2. Grouping-level aggregation

Groupings of households into the categories listed above are used for specific outputs. This could be 'all households' or could be determined by a categorical variable segmentation such as 'all households in Region equals Scotland'.

For each grouping, the relevant household-level summaries are calculated for the households corresponding to that grouping. The following aggregations are calculated:

- Mean of the following
  - Electricity and gas consumption
  - External temperature
  - Heating degree days (for daily summaries only)
- Standard deviation of the following
  - Electricity and gas consumption
- Percentiles (25^{th}, 50^{th}, 75^{th}) of the following
  - Electricity and gas consumption
- N – the number of household-level summaries used to compute the statistic

Note on percentiles: the N referenced for each percentile calculated refers to the number of observations relating to the underlying percentile value. We ensure percentiles refer to at least 10 observations by reporting the mean of the ten closest observations to the percentile.

This results in

- **Grouping-level annual summaries of daily averages**
- **Grouping-level monthly summaries of daily averages**
- **Grouping-level annual summaries of half-hourly averages**

Note on groupings: the number of observations in each grouping is manually checked and where less than 10 the group is merged with another group. Also note that the groups contain different participants for electricity and gas statistics.

These grouping level summaries are then used to create the following output types:

- Descriptive statistics – presenting mean, median or percentiles (25^{th}, median, 75^{th})

For each grouping some key summary statistics are calculated using the SERL Observatory as a whole. These are:

- Mean floor area (only available for homes with an EPC – about half of the sample)
- Mean number of occupants
- Mean number of bedrooms

For example, we calculate these means for households with region equals Scotland, and all other groupings. Alongside this we report the number of cases used to calculate these means.

Note on figures: where statistics are broken down by contextual variables based on the SERL survey we have not presented data for the participants who did not answer the question or who answered, 'don't know'. This data is available in the statistical release that accompanies this document.

For half hourly smart meter data, the energy use associated with the data at timestamp 11:00 occurred between 10:30 and 11:00. For this reason, in the figures of diurnal profiles, we have plotted the data in the middle of the half hour slot over which the energy use occurs (i.e. at 10:45 in the above example).

Finally, for all figures of the same type, we have used the same y-axis limits to aid comparisons between figures. The exception is the diurnal profile of net electricity use by PV ownership where the y-axis drops below zero.

We will make the code used to produce the statistical dataset and outputs available on the SERL GitHub.