Department for
Energy Security
& Net Zero

Domestic hot-water use

Observations on hot-water use from connected devices

March 2024

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Contents

Executive Summary

This project addresses a prior evidence gap around the detailed understanding of hot water use in a large sample of homes. It provides an updated evidence base around hot water use, the temporal variation of that use and typical demand ranges for domestic homes.

Introduction

The electrification of heat in domestic homes has been identified by the CCC as an important pathway to reducing the 16% of national carbon emissions that are directly attributed to homes. The most recent government estimate is that 18% of heat demand in homes is from hot water (UK Housing fact file, 2013).

The objectives of the research were:

- To understand changes in how much hot water is used in homes since the previous analysis (UK Housing fact file, 2013) and studies (Measurement of Domestic Hot Water Consumption in Dwellings, 2011);
- Understand how demand varies across different time periods and the factors that can affect energy demand such as temperature and duration of hot water demand events (e.g., showers, tappings);
- Provide the data needed to support half hourly modelling of energy in homes with sufficient confidence that the demand from those homes is representative of a wide range of UK typical households. Typical was defined as those households with a gas combination boiler, a system used in 62.6% (BSRIA, 2022) of UK homes.

The research provides a review and update of the evidence for the following significant variables on energy demand from hot water:

- Volume of water required – historically assumed to be linked to number and type of occupants or floor area (measured);
- Hot water supply temperature – user set point temperature for hot water (measured);
- Cold water inlet temperature – driven by external temperature subject to seasonal variation (from prior research).

The project explores the methodologies required to work with a novel source of data (connected devices) as a secondary objective. Data from connected devices (defined as those that transmit data to a central server) offer the potential of almost real time data collection in comparison to long lead times associated with traditionally procured research from commissioned surveys or field trials.

The project had access to 100 measured variables (such as: Heating mode, Heating Power level, Flow Temperature, Hot Water flow rate, Hot Water temperature, Pump status etc.) for 115,000 homes over the period May 2021 to May 2022 from which a final cohort of 45,000 homes were selected after data cleaning and validation. A smaller subset of 5,000 homes provided high frequency temporal data (~1 second sampling) for 24 million hot water events. This compares to the prior government commissioned research on hot water in 2007 which had a sample size of 112 homes with just monthly totals.

Evidence need

Historically energy demand from UK hot water has been estimated at ~18% of total domestic energy consumption (UK Housing energy fact file, 2013). The structure for this research has been designed to allow comparison with the last government commissioned research focussed only on hot water in 2008[1]. This is the evidence base for the current SAP (Standard Assessment Procedure) and BREDEM (Building Research Establishment Domestic Energy Model) models that produce EPC's (Energy Performance Certificates) which are used by the public and policy makers. EPC grades provided by those models form the basis for multiple policy objectives.

Gas combination boilers (providing heat for both space and hot water) are the dominant heating system in English homes. They are present in an estimated 63% of all domestic homes (English Housing Survey, 2021). Insights from combinations boilers are considered representative of the majority of homes, although checks on representativeness of the wider stock (in terms of energy demand) is necessary. The on-demand nature of hot water from combi boilers allows for an understanding of temporal variation in demand for hot water when not influenced by other system elements including hot-water tank size.

Prior evidence bases for hot water have been collected using observed field trials or unobserved imputed methods measured at the external water meter. This study uses a novel dataset of connected devices with measurements at the hot water supply outlet; the cohort is considered to be unobserved.

Key findings

What did the work reveal about hot water use?

- Absolute demand variation across homes is 19 – 222 litres of hot water a day (median of 90 litres)
- Typical hot water set point is 55°C
- Behavioural insights on hot water temperature set point variation shows that 71% homes do not adjust across the year

[1] https://www.gov.uk/government/publications/measurement-of-domestic-hot-water-consumption-in-dwellings

- Reduction in mean hot water demand to 90 litres per home per day from 104 litres according to prior study (2008, based on occupancy of 2.4 persons)
- Hot water as a share of overall demand for domestic heat (space heating and hot water) has not changed significantly: 19% compared to 18% (2013)

What did the analysis show about temporal demand variation of hot water?

- Seasonal hot water volume demand variation shows that daily usage varies over the year by +/- 5 litres per day
- Sub-daily hot water demand, i.e. what times of day have the highest hot water use, shows that peak use is 06:00-08:00 and 17:00-19:00
- Hot water ‘event’ (baths and showers) duration variation is: 4.7 – 7.5 mins (median 6.7 mins)
- Seasonal hot water energy demand varies between the seasons used in the energy models (+0.6 kWh/16% increase per day between September - May) from a median of 3.9 to 4.5 kWh per day and interquartile ranges of 1.9 - 6.6 and 2.1 - 8kWh per day.

What is the potential for flexibility from hot water thermal storage?

- Demand has daily (06:00-08:00 and 17:00 – 19:00), weekly (Sundays) and seasonal peaks
- Seasonal peaks coincide with major holidays (Dec. 24th is day of maximum observed demand across the year)
- Daily peaks are driven by larger events (showers / baths) in morning / evening
- Daily demand has the potential to be shifted out of peak times by means of hot water storage tanks/systems which would be necessary in an electrification scenario where the peak hot water demand coincides with peak electricity demand and price/carbon intensity.

Analysis method and data overview

All analysis was run on two data sets provided from a connected device manufacturer. The relationship between the data sets and the analysis run is given here:

- Sample population - ~115,000 domestic homes
- 'Daily' cohort - Subset of 45,000 homes from sample population with daily aggregate data (daily mean, minimum, maximum and totals for limited parameters)
- 'Time series' cohort (sub daily data) - Subset of 5,000 homes from sample population, same boilers as the daily cohort subset with sub minute time series data

The sample population is from internet connected devices/boilers enrolled on a service scheme and subscribed to an enhanced support offer via a monthly payment; how that relates to any bias in demand is explored later in this section and conclusions. The dataset had all personal identifiers removed including contextual metadata that would allow an understanding of the location, physical or occupant characteristics of the household.

The final sample cohort of 45,000 was drawn from a wider sample of 115,000 households. The range of boiler capacities are represented in Figure 1 below. The 25 kWp - 30 kWp capacity represent 59% of the market based on annual sales data (BSRIA 2020 UK Domestic Boiler Tables, Table 6). The analysis presented encompasses a full annual heating year, from May 2021 to May 2022. This is the first full year since the legally mandated Covid-19 lockdowns. This period is representative of the "new normal" working patterns, the report does not look to quantify or attribute demand change due to changing levels of household occupancy.

The final sample cohort was selected after review of the full cohort to ensure that all boilers covered the same date range and data fields of interest were valid and in the range of physical possibility (see appendix A). Normalization on occupancy was also applied to remove homes with 20 days or more of zero hot water demand in a 12 month period.

The time-series cohort was taken from the sample population in a representative manner based on total energy demand. The study period for this was across 12 months spanning July 2021 - July 2022, selected is a result of data availability; as sub-daily data is not retained by the provider for longer than the most recent 12 months, this study period was the most recent available data available at the time of commencing analysis.

Beyond the data cleaning, no further pre-processing of the raw data was applied. Data outliers were not removed. This decision was taken as hot water demand can be highly variable based on behaviour. The data should represent the full range of behaviours observed including the extremes. Given the size of the sample the median is used to provide a robust measure of typical behaviour.

The sample and cohort populations were not weighted as there was no metadata that would allow the sample to be compared to the known population. Analysis was run on total energy demand (for heat from gas) compared to the full population as given by ECUK for the nearest

reported year (2020) which had a mean figure of 12,000 kWh across homes of all sizes and levels of occupancy. The cohort mean figure is higher at 14,000 kWh, comparing this to a second data set from 2019 (NEED) for context, the figure is within the range of homes between 0 – 100 sq m.

This places the sample cohort toward the upper end of typical total energy demand (gas consumption by boiler for space and hot water heating) as recorded in ECUK 2020[2]. This is anticipated as the connected device is a premium offer to a paid service. This sample bias is useful for understanding the energy use in homes where demand is less constrained by economic factors. See Appendix B for further details.

Event identification

The device does not apply a classification by activity (shower, bath etc.) to the data. Hot-water event data were provided with the following key variables from sensors on the boiler hot water outlet which supplies the taps:

- Time of event start
- Duration outlet was running
- Flow rate of water, from which volume was derived
- Temperature across the event

To compare to other literature and prior evidence, events needed to be classified as an activity type i.e. the use of the hot water demand event such as hand washing or shower. Appendix C provides a review of prior event data classified by activity type. This evidence was combined with a simple robust approach to identifying natural clusters of events based on duration. This analysis was run in three steps.

- Initial clustering to identify short, medium and long events from a random sample of 500,000 events:
    - Showing that the majority (85%) of all events are short tapping's between 1 and 76 seconds.
- Secondary clustering on random sample of 900,000 events greater than 76 seconds using 4 clusters:
    - Identifying a natural and clear break in the duration of smaller events between 76 and 225 seconds to further separate clusters of events (66% of events over 76 seconds).
- Final clustering on random sample of 900,000 events over 225 seconds using 9 clusters

[2] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2020

The result of this clustering was a series of events and classification labels applied to the events by cross reference to prior research as below Table 1. Appendix C provides a more detailed summary on QA for the time series events against prior research.

Across the year the largest demand for household hot water use (litres) is from personal bathing (showers and baths) which consumes ~45% of all hot water, followed by small tappings (34%) (e.g. hand washing) and longer tappings (20%) (e.g. dish washing).

Table 1: Hot water tapping profiles

Event type (as % of all by count)	%	Duration Median (range) (seconds)	Temperature Median, 25-75th quartile (°C)	Volume Median (range) Litres (nearest) per event	Median (kWh) per event
All types of tapping	100%	21	40.9 - 52.4, 47.2	2	0.17
Small tapping	85.2 %	20	46.3, 39.9 - 51.9	2	0.14
Long tapping	9.8%	108	49.8, 46.1 - 53.2	11	0.8
Shower	3.7%	348	52.4, 49.7 - 55	37	2.58
Bath	0.8%	657	53.1, 50.1 - 55.5	69	4.72
Large event	0.4%	935	53.2, 50 - 55.6	97	6.79

Household demand variation (volume)

The data was reviewed for variation in demand using the following variables, all of which are behaviourally driven:

- Total volume of hot-water, driven by larger event length and number/frequency of those larger events. i.e. number of showers taken
- Demand variation by event type (as preceding section), i.e. shower length
- Hot water temperature set point: energy required to raise temperature of cold water (varies over year with cold water temperature

Annual demand variation

Annual demand is seen to vary by boiler capacity with larger capacity boilers showing higher median demand. NHBC standards provide hot-water flow rates; this was combined with research by the heating hub[3] for popular boiler models on the maximum flow rate per boiler capacity. As shown in Table 2, combining these data we assume that boiler capacity is a proxy for number of bathrooms which is strongly related to household floor area and occupancy, (further details in Appendix C).

Table 2: Bathroom and flow rate assumptions

Nominal power (kWp)	Assumed no. of bathrooms (NHBC)	Manufacturer max flow rate of boiler
25 (n=3.3k)	1 - Shower only	9 l/min
30 n=19.4k)	1 - Bath with shower	11 l/min
34 (n=1.8k)	2 - Baths with shower	12 l/min

Figure 1 shows that all boiler capacities had very high levels of demand for a small proportion of users.

[3] https://www.theheatinghub.co.uk/what-size-boiler-do-I-need

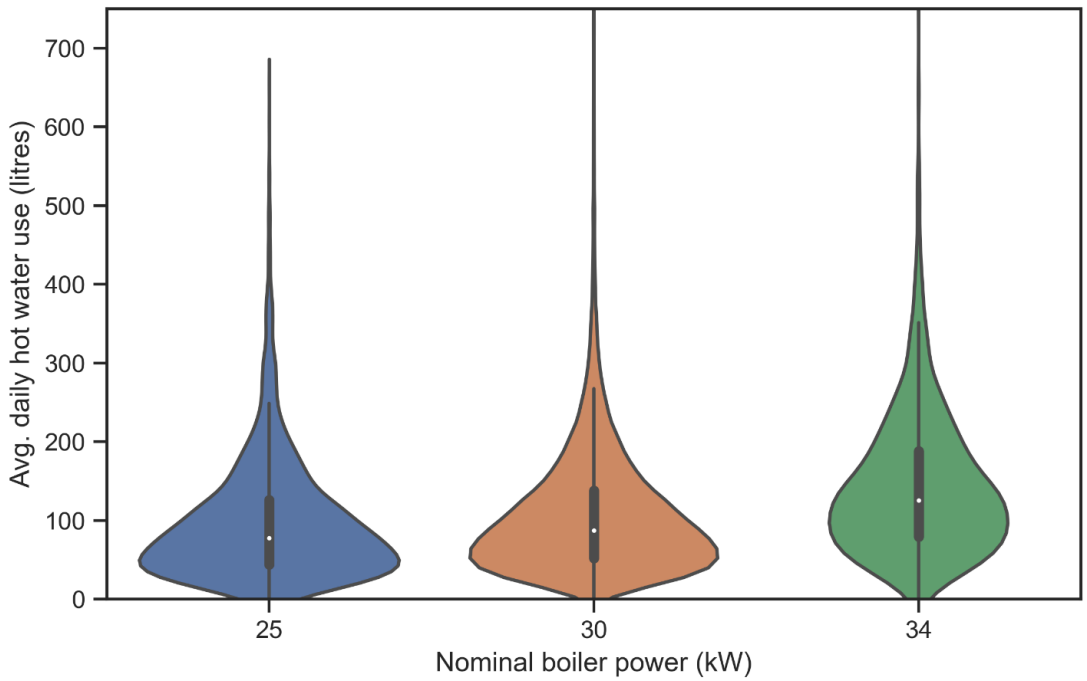

Figure 1: Annual average hot water use by homes, grouped by boiler power

Daily demand variation

The distribution of daily hot water demand for each of the boiler power group remains consistent across time periods and time scales, from annual to seasonal, to daily. Higher power boilers are associated with higher hot water demand from a daily to an annual scale, as shown in Figure 1 and Table 3.

Table 3: Daily, annual and seasonal demand observed.

Period	Nominal power (kWp)	Volume median (litres)	Volume range (10th & 90th percentile)
Annual	25 (n=3.3k) 30 (n=19.4k) 34 (n=1.8k)	39,415 44,925 65,065	10,845-106,615 16,750-137,290 13,775-114,850
Daily	25 30 34	79.8 90.6 130	18.9 - 222 21 – 241 38 - 302
Daily seasonal (Summer May - Sep)	25 30 34	68 78 115	15.7 - 192.5 18.7 - 206.5 31.4 - 277.7
Daily seasonal (Winter)	25 30 34	73 83 120	15.9 - 212.1 18.8 - 226.2 31.4 - 293.3

Figure 2 looks at demand (volume in litres) by day across a full year. As illustrated by the charts the data reveals a consistent pattern across weeks of a Sunday peak for weekly demand. Across the year demand can be seen to vary, with the annual peak occurring on the 51st week of the year (Christmas eve). Lower peaks are observed around remaining bank holidays. This would support prior studies and assumptions linking hot-water to occupancy. The lowest demand coincides with the school summer holiday period. Within the largest samples (25 and 30 kWp capacity boilers) the overall variability in demand between households has limited variation (indicated as the lighter tone around the main plotted values), i.e. most households are using similar volumes of water for a given time of the day/year when they have the same boiler size.

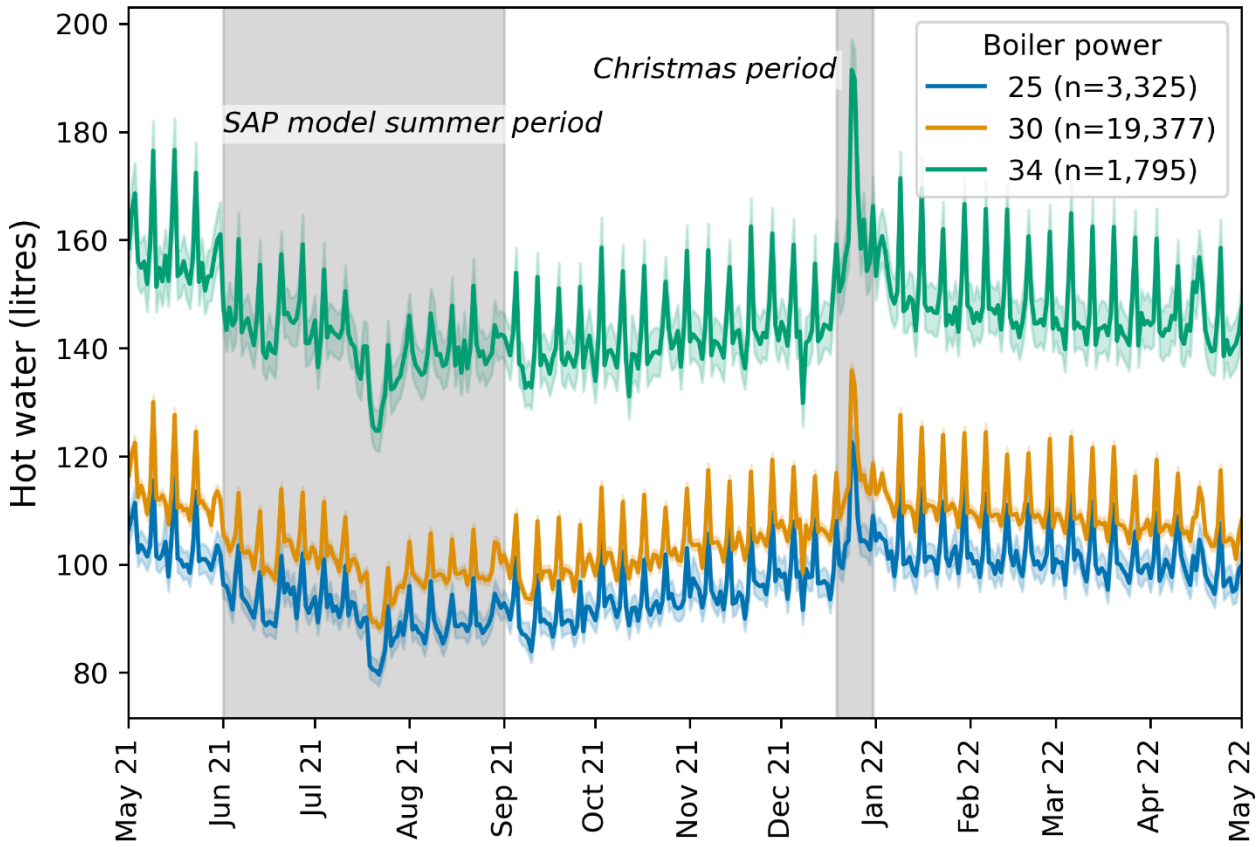

Figure 2: Variation in hot water demand (litres per home) by boiler capacity (variability shown in lighter tones around central plots for the 3 boiler sizes)

Hot water set-point

In modern homes, with mixer tap systems, reducing hot water temperature set point is a low regrets opportunity to reduce energy demand. A lower temperature set point would result in less cold water mixing at the tap but would not affect the temperature experienced by the individual. Lower temperatures enable boilers to operate at their maximum efficiencies.

As shown in Figure 3 shows, across the cohort there was limited variation in the number of hot water set point adjustments for individual boilers. The hot water setpoint is the temperature for hot water coming out of the boiler to supply the taps. 71% of boilers had a single setpoint for hot water for the entire year, 27% of households had multiple set points all of which used a 0°C temperature during some days of the year.

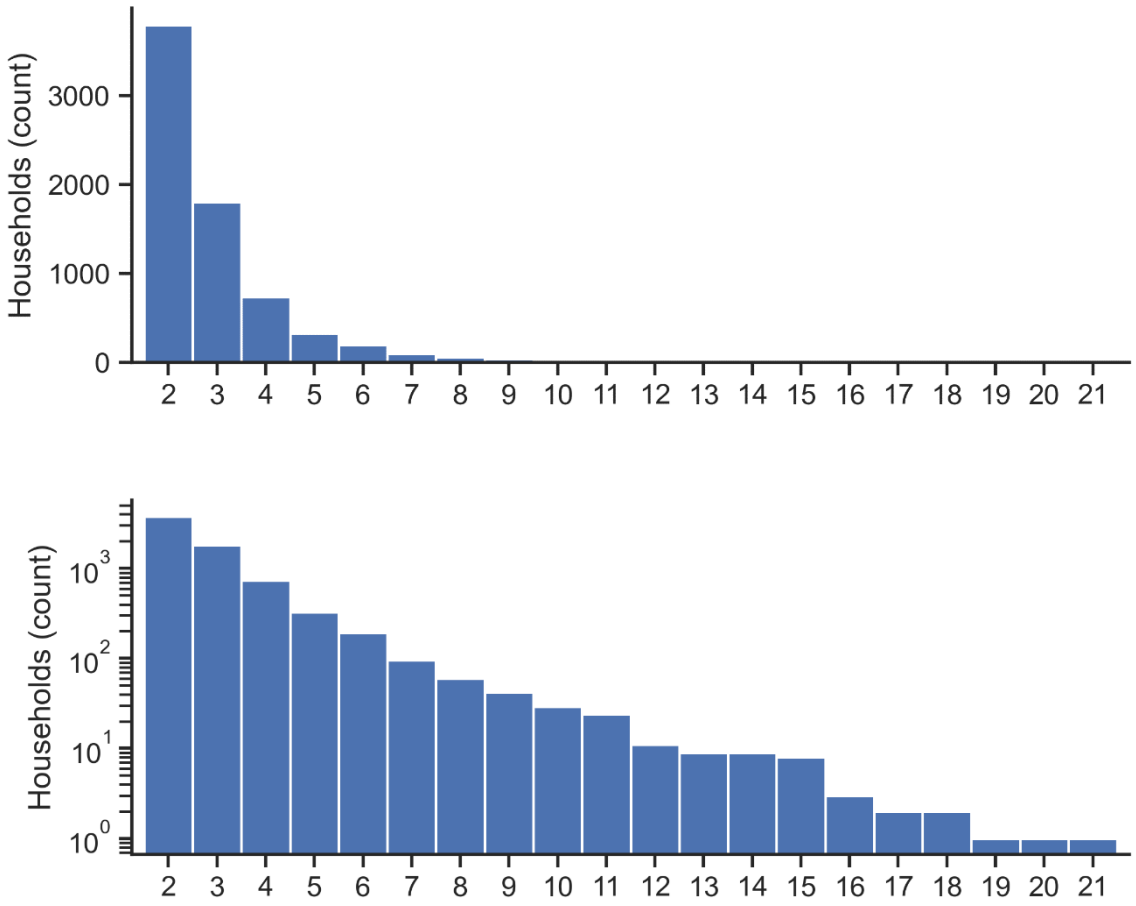

Figure 3: Number of distinct hot water set points recorded for homes with multiple set points recorded.

As shown in Figure 4, below, a narrow range of set points is observed with the majority between 54 – 57 °C with a median value in that range of 55 °C. NHBC guidelines require a boiler to be able to deliver a temperature at an outlet of 50°C within 1 minute of operation.

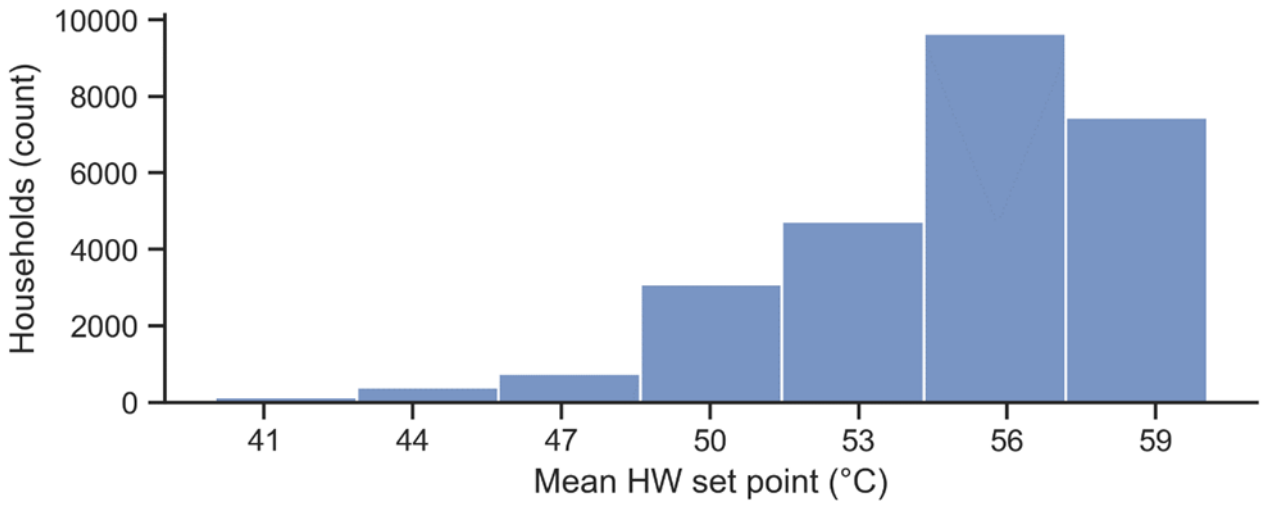

Figure 4: Average hot water set point (all in cohort)

Hot water delivery temperatures

The maximum set point temperature will normally be reached at a hot water outlet when the boiler is in full flow and existing water in the distribution network has left the tap. For short tapping's (washing of hands) the boiler may not achieve set point. This is illustrated by Figure 5.

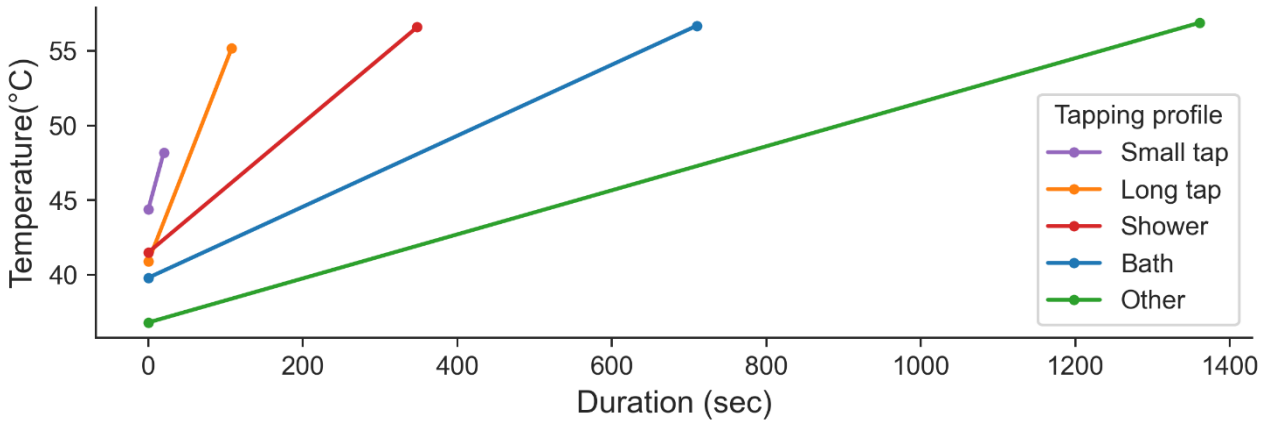

Figure 5: Sub daily median temperature rise and duration by event type

The connected device records the average temperature measured across all tapping's during a day. This average temperature returned represents a combination of event type and feed temperature. For example, changes in the inlet temperature will result in higher median temperatures as the majority of events are short duration making the daily average sensitive to inlet temperature. The average temperature is additionally sensitive to longer events (which reach the maximum temperature), this is shown during winter months.

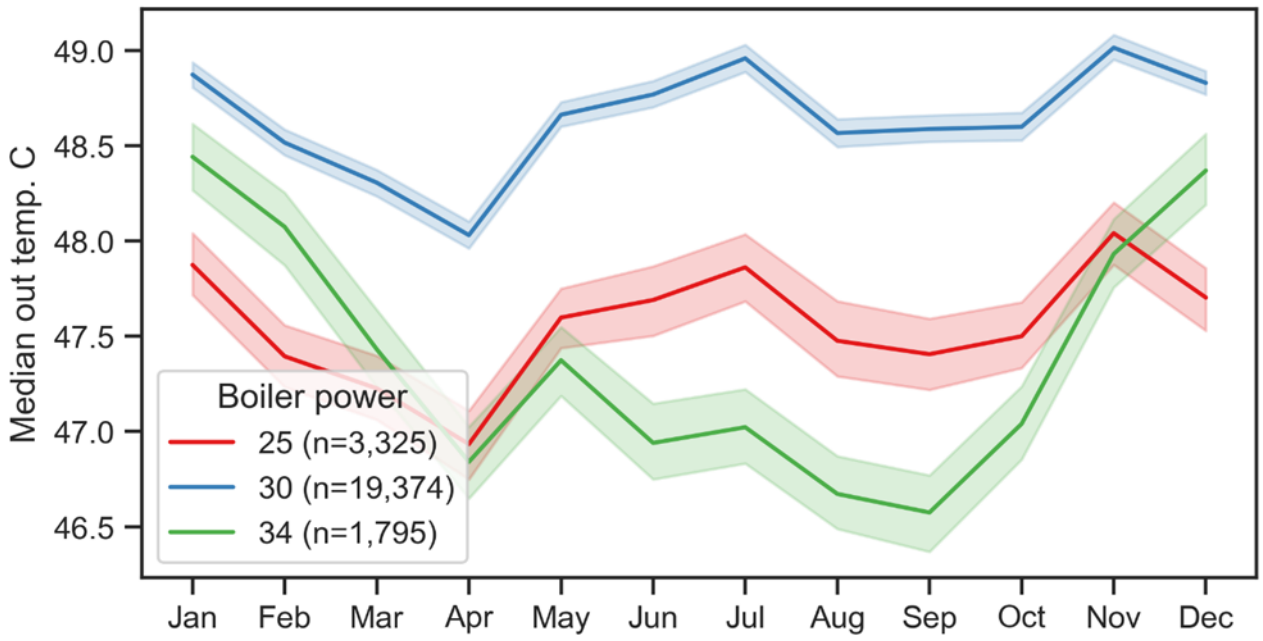

Figure 6: Median daily delivered hot water temperature

As shown in Figure 6, above, actual delivery temperature can be described using a single average (see Table 4); the preceding section of this report looks at variations in delivery temperature by hot water event type. There are limited (± 1°C) changes in delivery temperature (for all event types) across the year as shown in Figure 6 and Table 4.

Table 4: Hot water delivery temperature (°C) statistics (from daily aggregate)

Period	Median	Mean	Min - Max (of dwelling means)	Temperature range (10th & 90th percentile)
Annual	48.7	48.4	22.3 - 59.9	42.6, 53.7
Seasonal SAP summer (5 months)	48.8	48.3	18.7 - 59.3	42, 54.2
Seasonal SAP winter	48.7	48.3	11.2 - 60.1	42.7, 53.7

Temporal demand variation

Preceding sections provided observations on variation in demand (volume of hot water). This final section focussed on the temporal variation in absolute energy demand (kWh) which is driven by the seasonal variation in demand (volume) and the energy required to heat each unit of water (driven by the unmeasured cold water inlet temperature)

Demand variation (kWh)

Looking at variation of total energy demand in absolute terms without normalisation for changing delivery temperature or volume we observe the following distribution by nominal boiler capacity.

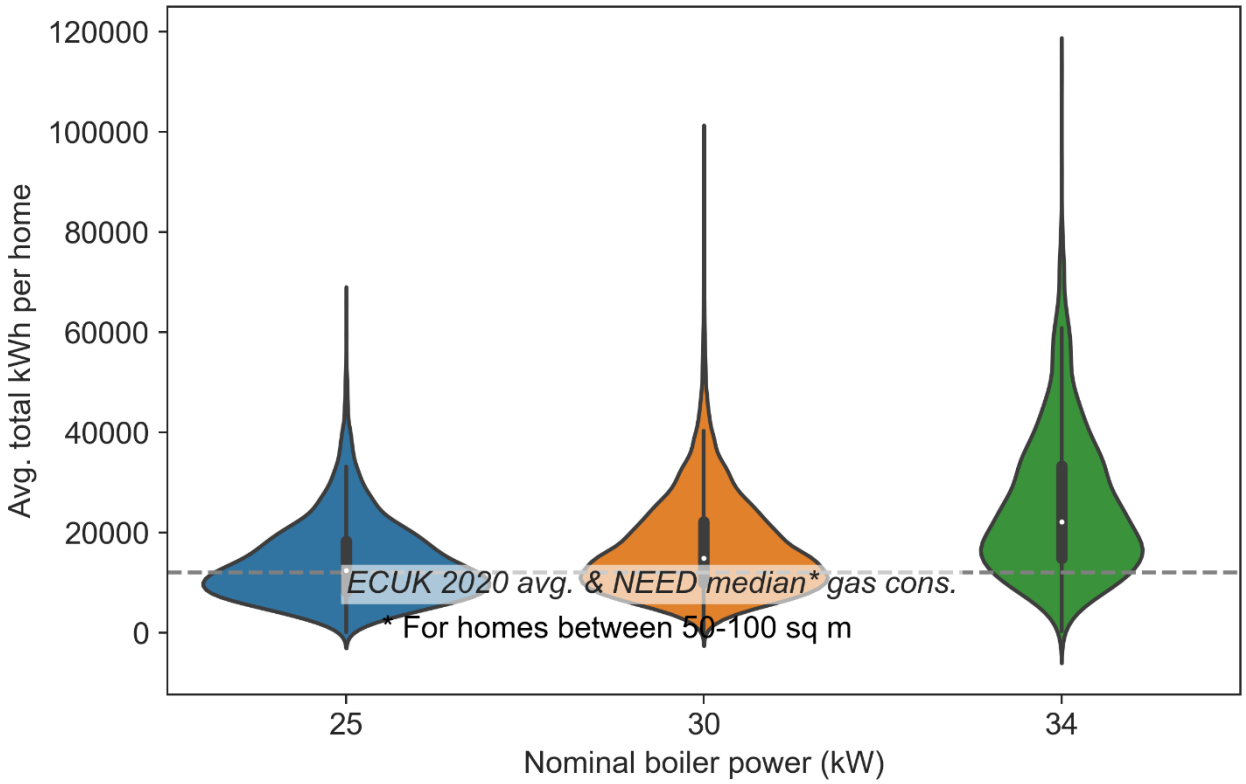

Figure 7: Variation in total energy demand (annual kWh) by boiler capacity

Table 5: Daily, annual and seasonal (summer June - August) energy demand (hot water) observed

Period	Nominal power(kWp)	Energy median (kWh) hot water	Energy range (kWh) 25th & 75th percentiles
Annual	25 (n=3.3k) 30 (n=19.4k) 34 (n=1.8k)	1,906 2,281 3,460	528 – 5,090 696 – 6,700 1,267 – 8,006
Seasonal SAP summer	25 30 34	432 516 793	239 – 737 295 – 860 482 - 1253
Seasonal SAP winter	25 30 34	1464 1761 2663	774 – 2557 968 – 3018 1615 - 4288
Daily annual	25 30 34	3.3 4 6	0.75 - 10 0.89 - 12.2 2 – 15.3
Daily SAP summer	25 30 34	3 3.6 5.4	1.5 – 5.4 1.8 – 6.2 3.1 – 8.6
Daily SAP winter	25 30 34	3.5 4.1 6.3	1.6 – 6.5 1.9 – 7.5 3.5 – 10.2

Figure 8 looks at average daily hot water energy demand across the year; the distribution is similar to that of total volume of hot water. There are consistent weekend peaks along with a seasonal change, with an average 0.6 kWh per day additional energy used by the median home and specific highs that coincidence with notable holidays.

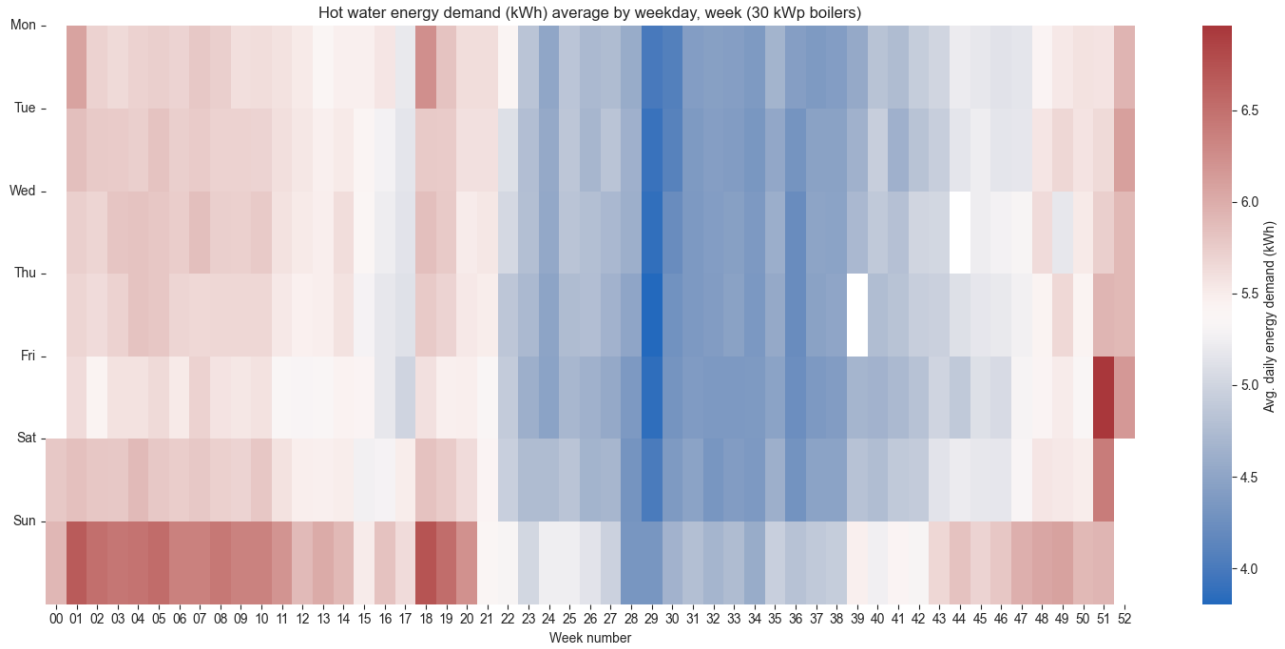

Figure 8: Daily average hot water energy use by week and day of year (30 kWp)

The data set contains observations on energy demand by source (hot water or space heating). Figure 9 shows hot water as a percentage of household heating demand. An assumption in current energy models (SAP/BREDEM) is that households don't use space heating in the summer season (June - August); however the observed data shows that across all homes a median of 16% of heat demand (kWh) is used for space heating in summer. Based on the observations from this study, further research is required into this assumption.

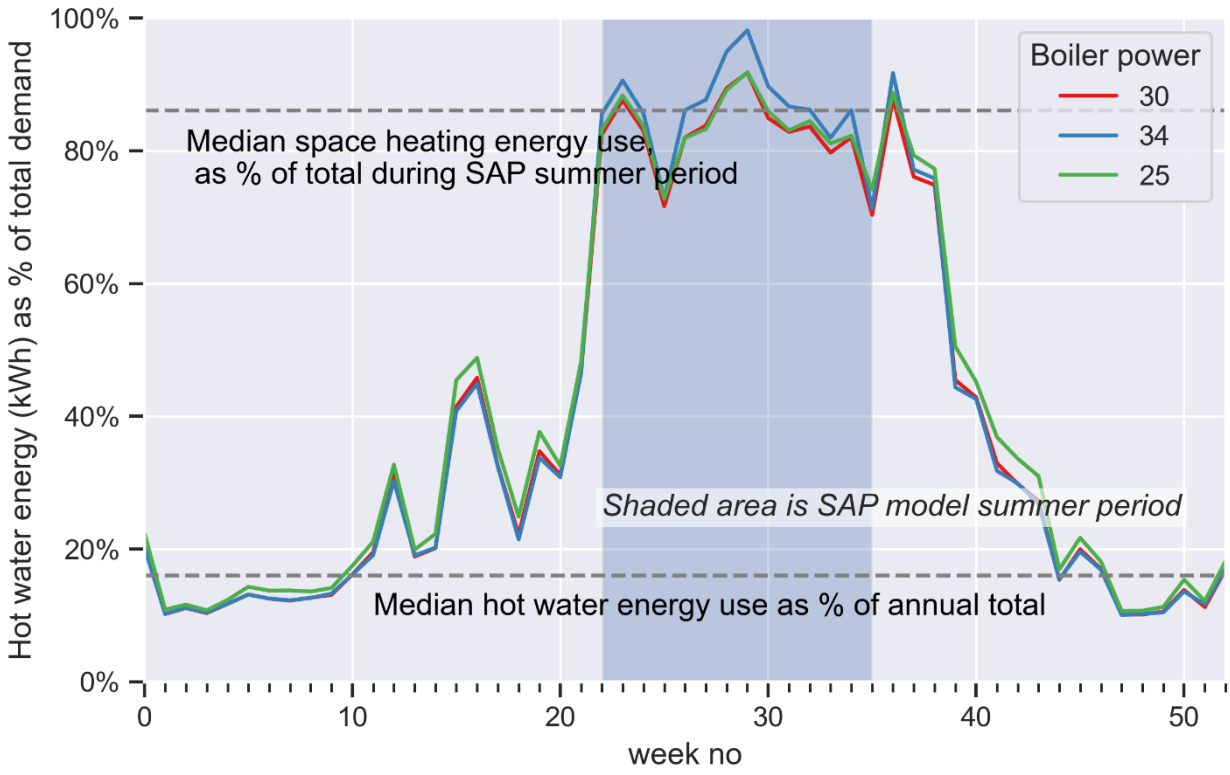

Figure 9: Hot water as a percentage of total energy (kWh) by week

Conclusion

Since the previously commissioned research into domestic hot water usage in UK homes (Measurement of Domestic Hot Water Consumption in Dwellings, EST, 2007) there has been a reduction in average hot-water demand (from 104 to 90 litres per day median). The data set offers the widest sample yet of below the meter monitoring of gas end use in UK domestic homes. Whilst the sample cannot be said to be completely representative of the whole stock, it is shown to be sufficiently representative of higher demand households to be a valuable insight into energy use for hot water. The data shows that energy demand is primarily driven by volume heated. Table 7 shows the decile bandings for median daily hot-water use. Further modelling would be required to confirm the relationship between hot-water and other characteristics such as occupants and floor area. In an electrification of heat scenario there seems to be potential for load shifting of peak hot water demand (on-demand/storage free of combi boilers only in the analysis) which currently coincides with peak electricity demand/cost periods (figure 2 and supplementary document “Hot water event distribution 2022”); further modelling would be needed to determine the impact and potential benefit.

The large sample size for sub-daily hot water events has enabled the publishing of a probability of event by time of day and day of week per event type. This schedule is published as a separate document titled “Hot water event distribution 2022” published alongside this report.

Table 6: Daily demand (volume) by decile

Decile	Lower bound / L	Median daily hot water demand at the tap / L	Upper bound / L
1	19.7	37.9	47.9
2	47.9	56.0	63.2
3	63.2	69.8	76.8
4	76.8	82.8	90.0
5	90.0	96.1	101.8
6	101.8	109.8	116.0
7	116.0	123.3	131.4
8	131.4	141.1	152.3
9	152.3	162.9	179.6
10	179.6	197.8	220.7

Appendix A

Data cleaning and normalisation

Data cleaning

The supplied data went through an ETL (extract transform load) procedure which included data cleaning. Data cleaning was limited to removing observations through two criteria (physically improbably values and data quality) as listed in the below Table 7

Table 7: Criteria used to clean and filter data

Physically improbable	Data quality
Max power (space heat kWh) should not exceed stated boiler power x 24 hour	Sample period provided by logger above 98.9% of day
Hot water runtime should not exceed 12 hours	Only analyse boilers that are free from null values in the study period for the variables of interest
Mean hot water flow should be between 0 - 75oC	
Max power (hot water kW should not exceed stated boiler power x 24 hour	
Event data filtered to events with a flow rate of >= 2 litres per second	

Normalisation for occupancy

Hot water demand is known to be occupancy driven, normalisation was applied to the data on occupancy. A maximum number of days un-occupied was set as 20. This is to ensure a consistent comparison across the homes only.

Appendix B

Review of sample to full population

Analysis was undertaken to compare the sample cohort to wider population statistics as in Figure 1 and Table 1. This places the sample cohort toward the upper end of typical demand for total energy demand (gas consumption by boiler for space and hot water heating) as recorded in ECUK 2020. This is anticipated given the nature of the connected device is a premium offer to a paid service. This sample bias is useful for understanding the energy use in homes where demand is less constrained by economic factors.

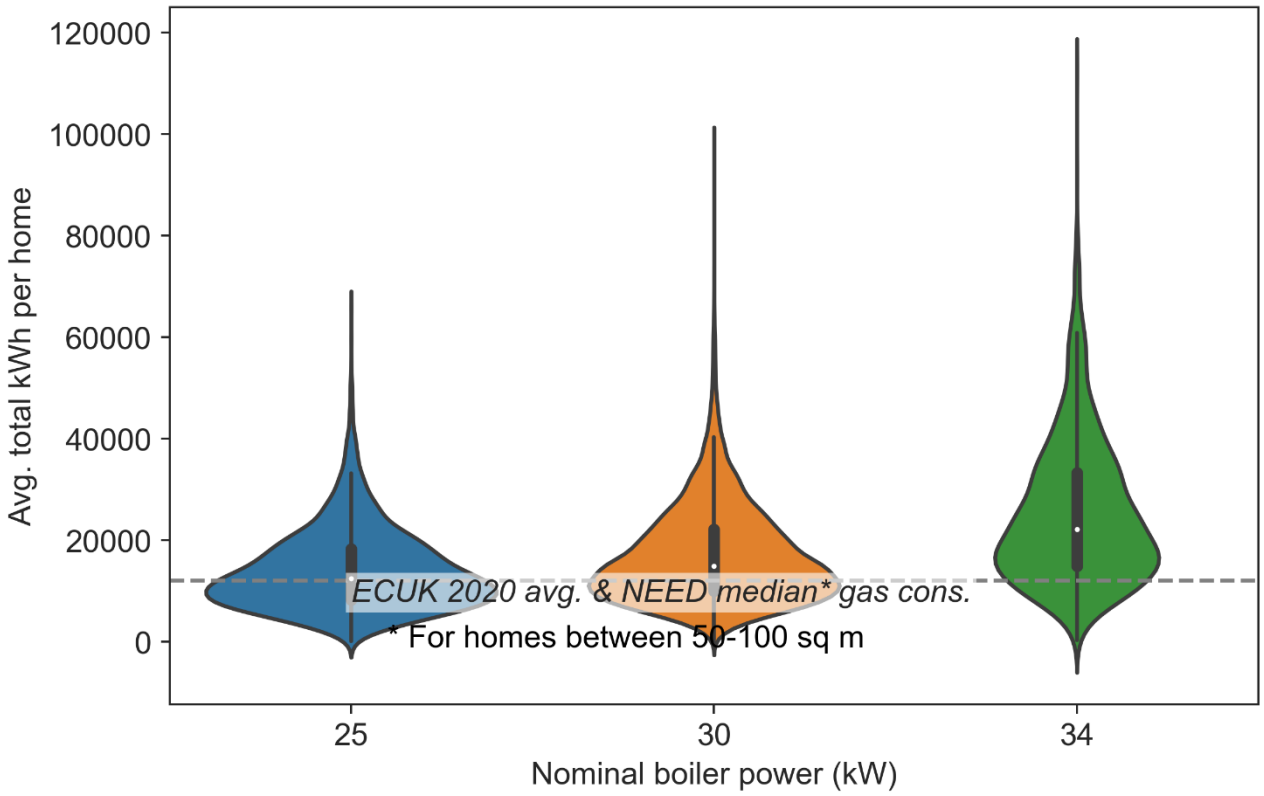

Figure 10: Total annual energy use (gas) by homes in cohort

Table 8: Comparison of average annual gas demand by source

Source	Mean average (kWh) rounded to '000
Connected devices cohort 25 kWp (n=3,325) Capax. for 3 bed	14,000
Connected devices cohort 30 kWp (n=19,377) Capax. for 5 bed semi-det	17,000
ECUK 2020 figure	12,000
NEED 2019 floor area band 2 (< 50 sq.m)	12,000
NEED 2019 floor area band 3 (51-100 sq.m)	15,800

Appendix C

Literature review

Trends in hot water demand

The adoption of BREAM and similar energy efficiency frameworks as part of planning conditions has reduced hot water demand (volume) through mandated use of aerated taps and showers. Part G[4] of the English building regulations established maximum volumes of water use for newly formed dwellings of 125 or 110 litres per person per day, the same regulations established a maximum delivery temperature for bathwater. In combination with this the 1999 water supply regulations introduced limitations on the maximum number of litres of water that maybe used by white good appliances. The market for white goods has moved from hot and cold fill to cold fill appliances further reducing demand for hot water from a heating appliance. As shown in Figure. 11, energy used for hot water as a share of total household consumption has declined over time.

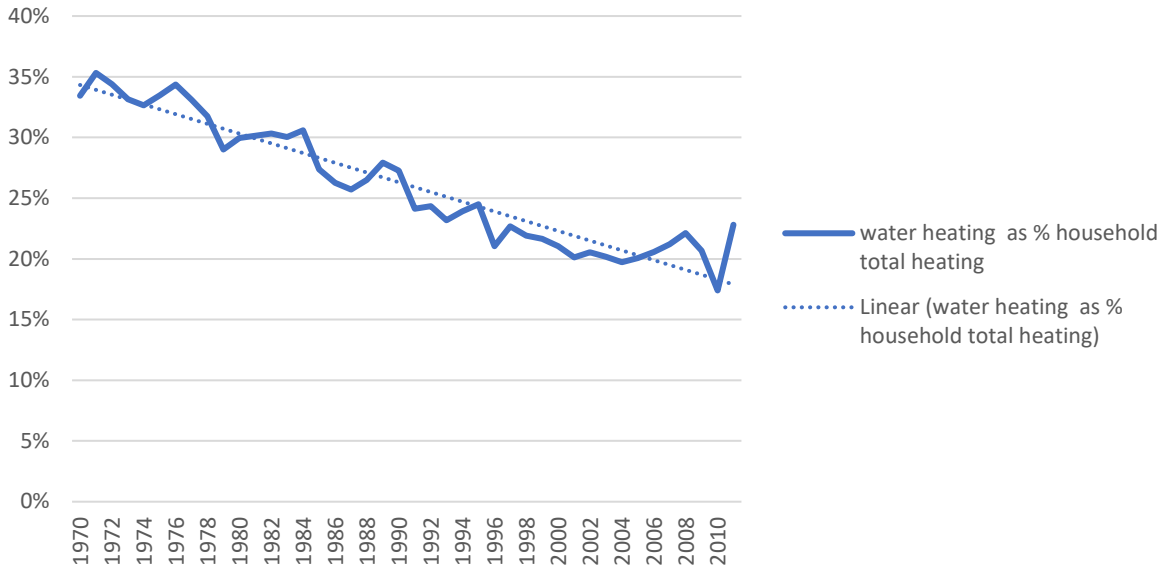

Figure 11: Energy demand from hot water as component of total household energy

[4] Approved document Part G (2010)

Hot water events – comparison to prior studies

The data set offers the largest observation of measured hot water use that has been published. The data is unique in measuring only hot water at the boiler outlet tap, historical studies have measured from the water meter (all water into a property) or at the tap (often post mixing with cold water). The observations are recorded from 2,700 homes across approximately 24 million individual events.

Table 9: Summary of existing literature on hot water events

Reference	Method	Date	Sample size	Event lengths (mins)
EST (Energy Savings Trust) (link)	Measurement at outlets	2006 - 2007	112 (39 combi)	Not given
EST – At Home with water (link)	Self-reported using online questionnaire	2013	86,000	Shower 7.30 mins
EST – At home with water 2 (link)	Inferred from water meter	Oct 2013 – Jan 2014	58	Shower 7.48 mins
ATKINS for SES Water (Link)	Modelled in part from EST data	2022	200	Shower 7.9 mins

Boiler capacity and recommended type/number of bathroom fittings served

NHBC Household type[5]	NHBC flow rate req. (L/min)[6]	Heating hub Boiler capax. Supporting flow rate
Shower only	9	18 kW +
Bath only	12	18 kW +
Bath and shower	15	Typically 25 kW +
Bath and two showers (using showers in preference to baths)	18	Requires hot-water tank
Bath with two showers	21	Requires hot-water tank

Where shower is combined with additional demands min. design flow rate on shower is lowered to 6

[5] Table 4, '8.1.5 Hot water service' (no date) *NHBC Standards 2023*. Available at: https://nhbc-standards.co.uk/8-services/8-1-internal-services/8-1-5-hot-water-service/

[6] Table 3 Ibid.

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