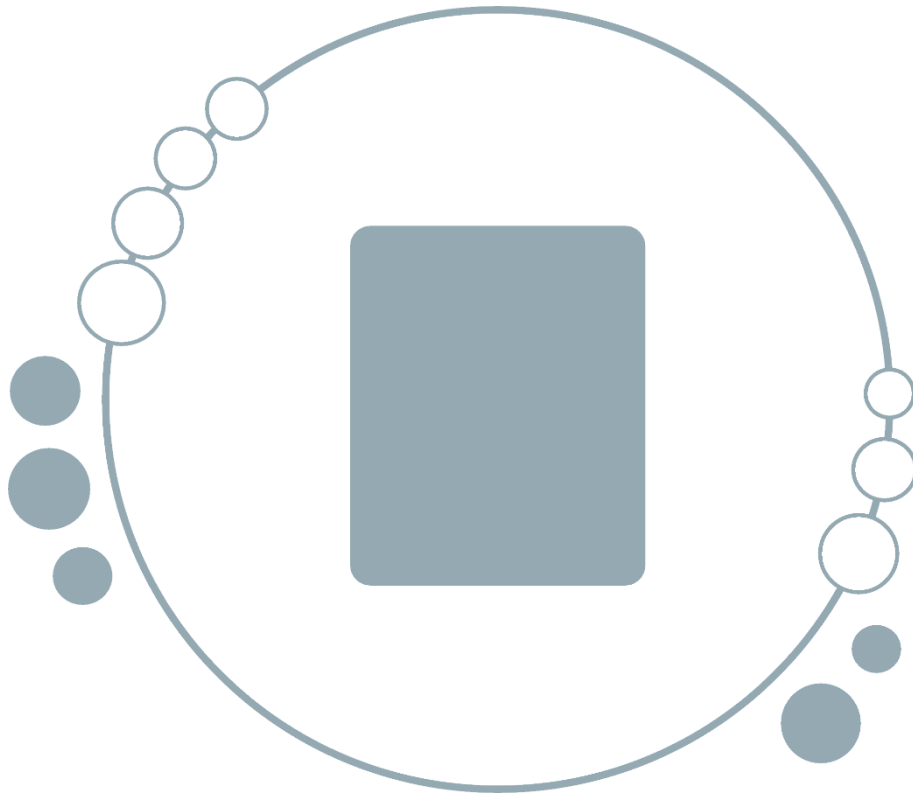




Hot water usage assumptions in the Home Energy Model: FHS assessment

A technical explanation of the methodology

Acknowledgements

This methodology has been developed for the Department for Energy Security & Net Zero by a number of organisations and individuals, including Sustenic, Qidos, Scene Connect, City Science, Hoare Lea, Oxford Brookes University, University of Bath, 10-x, Building Research Establishment (BRE), AECOM, Kiwa Ltd., Loughborough University Enterprises Limited, Chris Martin and John Tebbit.

Quality assurance has been undertaken by a consortium led by Etude, including Levitt Bernstein, People Powered Retrofit, University of Strathclyde's Energy Systems Research Unit, Julie Godefroy Sustainability, and UCL.

Document reference: HEMFHS-TP-04

Document version: v2.0

Issue date: March 2026

Home Energy Model: FHS assessment version: 1.0



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Background to the Home Energy Model: Future Homes Standard assessment

What is the Home Energy Model: Future Homes Standard assessment?

The [Home Energy Model: Future Homes Standard assessment](#) is a calculation methodology designed to assess compliance with the [Future Homes Standard \(FHS\)](#). It builds on the government's [Home Energy Model](#), which will replace the government's [Standard Assessment Procedure \(SAP\)](#).

Where can I find more information?

This document is part of a wider package of material relating to the Home Energy Model:

Home Energy Model: FHS assessment technical documentation (e.g. this document)

What: This document is one of a suite of [technical documents](#), which explain the approach to developing the standard assumptions and methodology used in the wrapper.

Audience: The technical documentation will be of interest to those who want to understand the justifications and evidence base behind the assumptions used in the model.

The Home Energy Model: Future Homes Standard assessment consultation and government response

What: The [Home Energy Model: Future Homes Standard \(FHS\) assessment consultation](#) sought views on the proposed methodology for demonstrating compliance with the FHS.

Audience: The consultation and response will be of interest to those who want to understand the proposed standardised assumptions around occupancy, energy demand etc. to be used when assessing compliance with the FHS, as well as the methodology for the calculation of the FHS compliance metrics.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model FHS wrapper has been published as a [Git repository](#). Note the reference code for the HEM core engine is published as a separate repository.

Audience: The reference code will be of interest to those who want to understand how the model has been implemented in code, and those wishing to fully clarify their understanding of the new methodology. It will also be of interest to any potential contributors to the Home Energy Model or those wishing to use it within their own projects.

Future Homes and Buildings Standards Government Response

What: The [FHS consultation and response](#) sets out the feedback received to the 2023 consultation on proposed Part L standards, and details the new regulations being introduced.

Audience: The consultation and response will be of interest to those wishing to understand the incoming standards for Building Regulations Part L.

Related Content

For information on how hot water events are simulated in the Home Energy Model core engine, please see technical paper *HEM-TP-09 Energy for domestic hot water*. The losses from hot water pipework after an event are described in paper *HEM-TP-10 Ductwork and pipework losses*.

To understand how this methodology has been implemented in computer code, please see:

`src/wrappers/future_homes_standard/future_homes_standard.py`

`src/wrappers/future_homes_standard/FHS_HW_events.py`

`src/wrappers/future_homes_standard/decile_banding.csv`

`src/wrappers/future_homes_standard/day_of_week_events_by_decile.csv`

`src/wrappers/future_homes_standard/day_of_week_events_by_decile_event_times.csv`

Overview

The Future Homes Standard (FHS) assessment wrapper specifies inputs and outputs for the Home Energy Model, enabling the model to be used in assessing whether a new home complies with the requirements of Part L of the Building Regulations. Among the inputs are standardised inputs relating to domestic hot water use.

This paper sets out the assumptions in the wrapper for estimating how much hot water a household will use, and the methodology for attributing that use to a schedule of baths, showers, and other uses. The annexes explain how these assumptions have been derived from survey data. In addition, this paper describes the methodology used to define the hot water distribution pipework based on building geometry and the number of wet rooms.

Methodology for hot water events

The assumed hot water use is dependent on the standardised occupancy of the dwelling, which is set out in paper *HEMFHS-TP-01 FHS occupancy assumptions*.

Domestic hot water consumption is represented in the Home Energy Model using a sequence of tapping events, divided between baths, showers and other events, as described in *HEM-TP-09 Energy for domestic hot water*.

In the FHS assessment wrapper, the events are generated as a pseudo-random sequence that is unique to a particular home, in order to capture the variation that can be expected from day to day, and in particular the possible peak loads on the storage capacity of the system from events clustering in time.

The schedule is derived in six stages:

1. The total daily demand for unmixed hot water is determined. This is a volume calculated as a function of the standardised occupancy of the dwelling. It is assumed in the wrapper that this volume of hot water is delivered to the tap at 52°C.
2. This demand volume places the dwelling in one of the deciles of hot water demand found in a large sample of UK homes. For this decile, a table (`day_of_week_events_by_decile.csv`) provides a frequency profile of the expected number of baths, showers, and other hot water use “events” on each day of the week, and their volumes. For baths and showers, the profile also varies by time of day.
3. The decile frequency for each type of tapping event is scaled so the total volume matches the original estimate from step 1.
4. For each day in a simulated year a schedule of tapping events is generated using a pseudo-random generator.

5. The volumes and durations of each event are calculated according to the showers and baths in the dwelling.
6. Further adjustments to the durations of the events are made to account for random variation introduced in step 4, compliance with part G regulations, and seasonal variation in the amount of hot water used over the course of the year.

This document presents the method outlined above in detail. Additional evidence and analysis supporting this method are reported in Annexes 1 and 2. The complete event tables used in the algorithm are published in the FHS wrapper code repository.

1. Total volume

For a household with N_{occ} occupants, the average daily demand volume of hot water in litres (at 52°C) excluding electric showers is calculated using Equation 1.

$$V_{HT} = 0.7 \times 60.3 N_{occ}^{0.71} \quad 1$$

Where V_{HT} is the demand volume at the tap for hot water, assumed to reach the tap at 52°C. It represents 70% of the typical daily volume V_B measured at the outlet of a combi boiler, as modelled from study data in Annex 1. It is worth noting here that the data source has some limitations, which are described in the appendix, so there is some remaining uncertainty in this area which could benefit from future research.

The factor of 70% represents the typical proportion of hot water drawn from the source that reaches the tap. The remaining 30% is assumed to be left in the pipework at the end of the event, attributed as described in Annex 1.

As explained in Annex 1, an uplift of 9.1% needs to be made to the required volume of hot water to account for electric shower events not being included in the data from which the total hot water demand was derived. Therefore, a correction factor of 1.091 is applied to the total hot water requirement (and all reference profiles against which it is later compared), as shown in Equation 2.

$$V_T = 1.091 V_{HT} \quad 2$$

The resulting total volume is initially calculated under the assumption that the shower flow rate in the dwelling is typical of the population. Dwellings with slower-flowing showers may meet their demand with a smaller volume of water: the Home Energy Model (HEM) handles this elsewhere¹. HEM also encodes thermostatic control of delivered water: if a storage cylinder holds water hotter than the delivery temperature of 52°C it will deliver a smaller volume, so that

¹ Once the number of shower events is calculated, the actual flow rate is applied to each event, such that the hot water requirement will be higher if high flow rate showers are used.

the mixed water drawn at the tap will be at the intended temperature (see HEM-TP-09 Energy for domestic hot water).

To give an example of the application of the above, for a typically sized three-bedroom home where the FHS wrapper gives a standardised occupancy of 2.98, this results in an estimated volume at 52°C at the tap of 100 litres per day (including the electric shower correction).

2. Hot water use profile

The total volume V_T places the dwelling in one of the ten deciles of total consumption observed in the boiler study data described at Annex 2 below. The FHS assessment wrapper has a table with a weekly profile of water use for each decile. For each day of the week this gives the mean number of showers, baths and other events, and their volumes and duration, for that decile in the study sample. A part of the table is shown at Table 3 in Annex 2.

3. Calibration

The tabulated profile of events (`day_of_week_events_by_decile.csv`) is used to give an average of hot water use for real homes with a consumption close to the modelled daily demand V_T . To calibrate the profile and match V_T exactly, in expectation, the frequencies read from the table are adjusted by a ratio V_T/V_{ref} .

Here V_{ref} is the average total volume from 1000 randomly generated annual event schedules created (as in section 4 below) directly from the unadjusted table of events, `day_of_week_events_by_decile.csv`. (Note that the volume V_{ref} is for most deciles *more* than the daily consumption of any of the sample dwellings in the decile. In real homes there is a negative correlation between number and size of events: occupants taking more showers take shorter ones, for example. In the generated schedule all events of a particular type have the same volume, the mean for the decile).

4. Pseudorandom schedule

For each day of the week and each event type, the calibrated daily frequencies are distributed over 24 hours in the proportions found in the Connected Devices study², as illustrated in Table 4 in Annex 2. These hourly frequencies are interpreted as the expected number of events of that type in that hour.

² DESNZ Research Paper “*Domestic Hot Water Use: Observations on hot water use from connected devices.*” Published March 2024.
<https://assets.publishing.service.gov.uk/media/65f43b919d99de001d03df8a/domestic-hot-water-use-insights.pdf>

Now, for each hour of the year and each event type, a provisional schedule is created by sampling from a Poisson distribution with parameter λ equal to the hourly expected event count. Each event is allocated a random start time uniformly within its hour.

The generated schedule will be the same each time the wrapper is run, provided that the building occupancy is unchanged. The pseudorandom sampler produces an irregular pattern of events, statistically behaving like a randomly drawn Poisson sample. Since it is initiated with the same seed value each time it is called in the FHS assessment wrapper preprocessing function, the schedule will be replicated exactly if a dwelling with the same daily demand V_T is submitted.³ This ensures replicability of results and comparability of dwellings expecting the same standard occupancy.

5. Recalibration

The total volume V_Y of hot water consumed over the year in the resulting schedule of events is obtained by assuming the volume of hot water used in each event is exactly the mean value from the Connected Devices study (with pipework adjustment, as in Table 3 in Annex 2). The ratio between the expected annual hot water demand $365 \times V_T$ and this figure is calculated⁴ as shown in Equation 3.

$$FHW = \frac{365V_T}{V_Y} \quad 3$$

This figure quantifies the deviation from the mean that has occurred in the pseudorandom sampling process; multiplying the volumes of all the events in the generated profile by FHW would yield a profile whose total volume would exactly equal the expected value. This factor should be 1.0 ± 0.05 due to the profiles being composed of a large number of independent Poisson trials (8760, one for each hour of the year).

The durations of all hot water events as calculated in section 6 below are all multiplied by FHW in order to prevent pseudorandom variation from affecting the total annual hot water demand.

6. Hot water event assignment and sizing

Hot water demand events in the core HEM calculation are assigned to a specific end use and are given as a flowrate of mixed warm water at the tapping point and a duration of use. For baths they are given as a volume of warm water instead. In the FHS, these durations, flowrates and volumes depend on the features of the dwelling and vary from those found in the Connected Devices study in Annex 2.

³ Provided that the random number generator code itself does not change between runs, for example due to a different version of the NumPy library being used.

⁴ FHW is the variable name used in the Python code. It is short for 'Factor Hot Water'.

6.1 Small & long tap events

Generic tapping events (0_small_tap and 1_long_tap in Annex 2) are assumed to always last for the mean duration found in Annex 2 Table 3, multiplied by *FHW* as found in section 5, and a monthly behavioural factor as found in section 6.5 below. Finally, the durations are multiplied by 0.95 if the dwelling is stated to comply with Part G.

The flowrate of these events is always assumed to be 12.0L/min; the volume of 41°C mixed warm water demand in the core HEM calculation for each event is the duration multiplied by the flowrate.

6.2 Bath and shower assignment

The volume, duration and flowrate of bath and shower events depend on the showers and baths installed in the dwelling. Successive bath and shower events are allocated in rotation between the baths and shower outlets present in the dwelling to distribute these events evenly across them. If there are no baths present then bath events are reassigned to showers (but keeping their assigned duration; this is consistent with the interpretation of the survey data described in Annex 2, as shower events may be more than one person's shower, taken too close together in time for the monitoring sensor to distinguish them). If no showers are present in the dwelling, then showers are reassigned to baths with a standard bathtub size of 180L (the volume of the bath event is given in Table 1, below).

It is assumed that the water heating system cannot supply two showers or baths simultaneously⁵. If in the provisional schedule two such events overlap then the schedule is adjusted, moving one event by a random delay of up to half an hour. This adjustment is applied successively until no more overlaps occur. Instant electric showers are excluded from this adjustment: the cold water supply is assumed to be adequate to supply all appliances at once.

6.3 Shower event sizing

The duration of shower events is assumed to be the mean duration found in Annex 2 Table 3, multiplied by *FHW* as found in section 5, and a monthly behavioural factor as found in section 6.5 below.

The flowrate of a shower event depends on the flowrate of the shower outlet it is assigned to, and as in section 6.1 above, HEM uses this flowrate multiplied by the duration of the event to calculate a volume of mixed 41°C water demanded by the event.

6.4 Bath event sizing

The volume of mixed 41°C water used in bath events is assumed to depend on the volume of the bathtub and the displacement of the occupants bathing.

The displacement of the occupants is calculated to align with the surface area as predicted by the metabolic gains' calculation detailed in HEM-FHS-TP01. A rearrangement of the formulae obtained for bodily surface area (BSA) yields Equations 4 and 5.:

⁵ Arguably, if some systems can supply simultaneous showers while others can't, this should be reflected (e.g. by recording unmet demand) to recognise the benefit of those which can; so, this assumption may be revisited in future.

$$N_{adult} = \frac{1}{1.8881 - 1.0700} (2.0001N_{occ}^{0.8492} - 1.0700N_{occ}) \quad 4$$

$$N_{child} = N_{occ} - N_{adult} \quad 5$$

Where N_{occ} , N_{adult} and N_{child} are the number of occupants, adults, and children in the dwelling. From this the displacement of the average occupant, V_{occ} , can be calculated from the average weights of adults and children obtained in HEM-FHS-TP01, as shown in Equation 6.

$$V_{occ} = \rho \frac{m_{adult}N_{adult} + m_{child}N_{child}}{N_{occ}} \quad 6$$

Where the masses of adults and children are $m_{adult} = 78.6\text{kg}$, $m_{child} = 33.01\text{kg}$ and the density of the human body is assumed to be $\rho = 1.0\text{kg/m}^3$. The volume of water for a bath event is then calculated using Equation 7.

$$V_{event} = \frac{V_{bath}}{V_1} (V_{occ} + V_2) - V_{occ} \quad 7$$

Where V_{bath} is the volume of the bathtub, V_1 is a standard bathtub size of 180L, and V_2 is the size of a standard bathing event⁶, 73L. Finally, this event volume V_{event} is multiplied by FHW and the relevant monthly behavioural factor.

For cases where $V_{bath} = V_1$, as is assumed for dwellings with no shower fixtures, this formula recovers $V_{event} = V_2 = 73\text{L}$.

6.5 Monthly behavioural factors

A further adjustment to the duration of each event is made to account for behavioural differences over the course of the year⁷. These factors are adapted from SAP 10.2 specification Appendix J and are shown in Table 3, below.

An example monthly schedule of modelled hot water demand after application of this algorithm is shown in Figure 1.

⁶ This volume, 73L is the assumed volume of a bathing event in SAP10.2.

⁷ This is achieved using monthly adjustment figures, so does not include shorter term peaks, like Christmas celebrations. These could be significant in terms of a system's ability to meet peak consumption, so this might be something to refine in future.

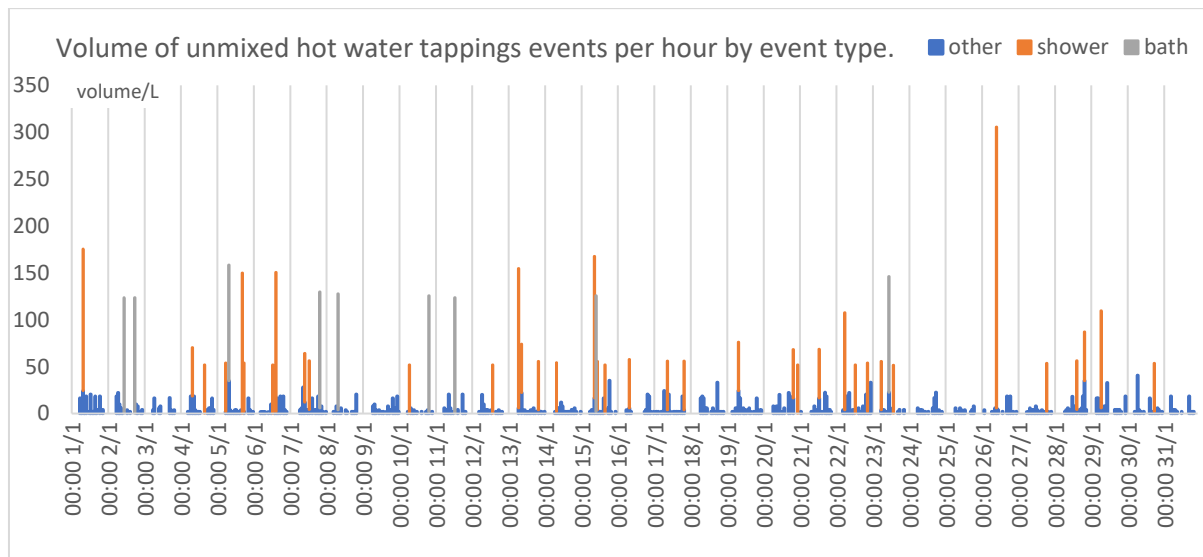


Figure 1: Example generated profile for 3.9 occupants, showing total volume of HW tapping events per hour for each event type for the first month of the year (744 hours), stacked.

Temperatures, heating times, and other default values

Table 1 gives the assumed values of other variables used in calculating the energy used for domestic hot water and fixed by the FHS assessment wrapper.

Table 1: Standard temperatures and volumes.

Variable	Value	Interpretation
Hot water delivery temperature	52.0	The temperature of unmixed hot water at the tap in °C. Assumed to be equal and constant for all events.
Hot water storage temperature	60.0	The temperature set point for any hot water storage cylinder in °C. When the cylinder draw-off temperature falls below the hot water delivery temperature (52.0°C) water heating starts, until the temperature reaches 60.0°C.
Mixed temperature for showers	41.0	Temperature in °C of mixed hot/cold water run in showers
Mixed temperature for baths	41.0	Temperature in °C of mixed hot/cold water run in baths

Mixed temperature for other hot water uses	41.0	Temperature in °C of mixed hot/cold water used in other hot water tapping events
Cold water feed temperatures		Seasonal value as shown in Table 2 in °C.
Water heating times		For standard cylinder, heat to the hot water storage temperature (see above) and maintain this from 00:00 to 02:00. For the rest of the day, switch on when the temperature falls below the hot water delivery temperature (see above) and switch off when the temperature rises to the hot water storage temperature. For smart hot water tank, schedule is based on state of charge: 100% between 00:00 and 02:00; recharge to 60% if below 10% between 02:00 and 03:00; recharge to 50% between 03:00 and 07:00; and recharge to 60% if state of charge falls to 10% between 07:00 and 00:00. For instantaneous systems (e.g. combi boiler), always available.
Default bath-sized event – volume	73	Volume in litres (of mixed water) of an event of type “bath” ⁸ when there is neither a bath nor a shower in the dwelling, subject to calibration factor and monthly behavioural factors.
Default flow rate	12.0	Flow rate in litres/second for baths and hot water tapping events not associated with a shower – this is measured at the tap, as a volume of mixed 41°C.

The assumed hot water delivery temperature of 52.0°C is unchanged from the assumption previously used in SAP 10.2. It is derived from an Energy Saving Trust (EST) study⁹, which found that average delivery temperatures were consistent across the year, although they were lower for combi boilers (50.0°C) than regular boilers with a hot water cylinder (52.9°C). The 2022 DESNZ Connected Devices study, analysed along with the EST study in Annex 1 below, provided new evidence which is broadly consistent with this assumption (see Annex 2).

⁸ Since there is no bath in this case, this model’s the use of an equivalent amount of hot water use to a bath, although it is unclear what would actually happen in such an unlikely case.

⁹ https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

The assumed hot water storage temperature of 60.0°C, and the requirement to maintain this for two hours each night, is set in line with Health and Safety Executive (HSE) recommendations for legionella control¹⁰.

The temperature assumed for mixed water showers and baths are unchanged from those in SAP, on evidence outlined in SAP 2016 consultation paper CONSP:08¹¹. No new evidence has been identified regarding this assumption.

The temperature of the cold-water feed to the hot water system depends on the time of year, and on whether water is drawn directly from the mains or from a header tank. The average monthly temperatures are averages across the UK of the measurements found in the Energy Saving Trust 2008 study referred to above. No regional variation is assumed.

Table 2: Monthly assumed cold feed temperatures.

Cold water temp. /°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
From header tank	11.1	11.3	12.3	14.5	16.2	18.8	21.3	19.3	18.7	16.2	13.2	11.2
From mains	8.0	8.2	9.3	12.7	14.6	16.7	18.4	17.6	16.6	14.3	11.1	8.5

Table 3 reports the monthly behavioural factors applied at stage 6 in the schedule algorithm. These factors replicate those in tables J5 and J2 of SAP 10.2, as derived from tables 8 and 9 in paper CONSP:08 and based on the EST study. This accounts for the small seasonal variation in hot water use that was observed.

Table 3: Monthly behavioural usage factors applied to hot water event frequency.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baths and showers	1.035	1.021	1.007	0.993	0.979	0.965	0.965	0.979	0.993	1.007	1.021	1.035
Other events	1.100	1.060	1.020	0.980	0.940	0.900	0.900	0.940	0.980	1.020	1.060	1.100

¹⁰ <https://www.hse.gov.uk/healthservices/legionella.htm>

¹¹ "Consultation Paper: CONSP:08 Amendments to SAP's hot water methodology", <https://bregroup.com/sap/standard-assessment-procedure-sap-2016/sap-2016-technical-papers/>

Hot water pipework

The FHS wrapper distinguishes between total pipework length and cumulative pipework length. The total pipework length is the physical length of pipework, which is calculated based on building geometry, according to BS EN 15316-3:2017¹². The cumulative length is required by the HEM Core to calculate pipework losses, and it is calculated in the FHS wrapper based on the total length and the number of wet rooms.

Total pipework length

To calculate the total pipework length, the DHW pipework is organised into three sections, as described in Table 4. These sections use pipes with external diameter of either 22mm or 15mm (according to type) and their lengths are calculated using Equations 8–10, where the equation inputs are defined in Table 5.

Table 4: DHW pipework section descriptions.

Pipework section	External diameter (mm)	Length (m)
1. Base distributor/collector – primary distribution pipes running horizontally and supplying DHW circuits from the boiler or hot water tank.	22	L_V
1. Vertical shafts – vertical pipes within shafts connecting mains to individual levels.	15	L_S
2. Connection of outlets to vertical shafts – short horizontal branches from vertical shafts to DHW tapping points.	15	L_A

$$L_V = L_L + 0.0625 \times L_L \times L_W \quad 8$$

$$L_S = 0.038 \times L_L \times L_W \times H_B \quad 9$$

$$L_A = 0.0625 \times L_L \times L_W \times N_{lev} \quad 10$$

¹² BS EN 15316-3:2017 Energy performance of buildings. Method for calculation of system energy requirements and system efficiencies. Part 3: Space distribution systems (DHW, heating and cooling), Modules M3-6, M4-6, M8-6.

Table 5: Inputs for DHW pipework length calculations.

Input	Definition	Units
L_L	Building length	m
L_W	Building width	m
H_B	Building height (internal)	m
N_{lev}	Number of floors (levels)	-
N_{WR}	Number of wet rooms (rooms with hot water tapping points)	-

Cumulative pipework length

The cumulative length is the sum of each length of pipework from the source to individual tapping points, where shared sections of pipework are counted for each tapping point. The cumulative length of 22 mm pipework is calculated using Equation 11 and for 15 mm pipework using Equation 12. The base distributor pipework, L_V , and the vertical shafts, L_S , are assumed to be used by each tapping point except the kitchen, and so the length is multiplied by the number of wet rooms minus 1.

$$L_{22mm} = \frac{L_V(N_{WR} - 1)}{2} \quad 11$$

$$L_{15mm} = \frac{L_A + L_S(N_{WR} - 1)}{2} \quad 12$$

Future development

The assumption that the observed pattern of events for a combi boiler is representative of any household's true demands (see Annex 1) may be revisited in future, subject to suitable evidence being available. As it stands, the generated schedules may include large events which could not be met in practice by an ordinary size of storage cylinder.

The assumed water heating hours do not align with observed household water heating patterns when using gas boilers with storage cylinders. This assumption may be revised in future, either to match typical use patterns, or to differentiate between system types (e.g. heat pumps vs boilers). In the EST study the most typical space heating pattern used was to heat during the hours 08:00 to 10:00 and 18:00 to 23:00 daily, but most households heated water only as and when it was required, and for a much shorter time than this: the mean water heating duration was 2.6 hours/day. No more recent study was available (the Connected Devices study being of combi boilers only).

More generally, as described in Annex 1, there are important limitations with the data that underpins the hot water assumptions in HEM which could benefit from future research.

The use of the pseudorandom schedule described in section 4 could be improved by allowing for variation in the sizes of events of each of the five types, rather than assuming all events use the mean amount every time. Correlations in event timing could also be investigated. This would potentially impact the peak load of the dwelling.

Presently the inclusion of a dishwasher in an FHS assessment does not affect the prediction of total annual HW demand; work should be undertaken to ascertain how much hot water is saved by the reduction in hand washed dishes, as well as to account for other potential dependencies in hot water demand.

The methodology for calculating the cumulative length of the hot water distribution pipework was developed based on a limited dataset, which included only 20 flats. The method could be improved via validation and refinement against a larger and more varied sample of dwellings.

Annex 1: Estimating the relationship between hot water consumption and occupancy

This analysis is informed by two datasets:

- “EST,” Energy Saving Trust data from 2008¹³: mean daily consumption for 112 households, of which 39 have combi boilers. This dataset includes household occupancy, for which the sample is biased: it has a mean occupancy of 3.04, against a population mean of 2.37 (per the EHS 2018¹⁴).
- “Connected Devices” (“CD”)¹⁵ – high-frequency metered data for 45,000 contemporary combi boilers gathered between May 2021 and May 2022, of which 26,246 were available at the time this analysis was undertaken; this dataset is also the source of the event schedule described in Annex 2. The CD sample is large and current but is not matched to household type or occupancy and may not be wholly representative of the underlying stock¹⁶ (no statistical sampling has been used to compensate for any biases).

In both cases the data has considerable limitations in the sample size and representativeness. However, there is no ideal data set to rigorously underpin the FHS hot water assumptions instead the approach taken has been to maximise the usefulness of these two data sets to provide the best available evidence and highlight where the greatest limitations may occur.

In both cases the data relates to volume of water in litres drawn from the boiler, V_B . A separate deduction is made to estimate the volume of hot water in litres reaching the outlets, V_{HT} : see sections 5 and 6 of this Annex.

In the broadest terms, the approach taken here to correct for differences between the 2008 and 2022 dataset is to impute the contemporary distribution of hot water consumption onto the 2008 112-home sample. In doing so it is assumed that although the distribution of demand has changed, the households’ relative position within the distribution has not, so that a home with median (or 25th centile) consumption in 2008 would have median (or 25th centile) consumption in 2022. The best fit dependency between imputed distribution of hot water consumption and dwelling occupancy can thereby be derived.

¹³ Measurement of Domestic Hot Water Consumption in Dwellings, EST 2008.

<https://www.gov.uk/government/publications/measurement-of-domestic-hot-water-consumption-in-dwellings>

¹⁴ [English Housing Survey 2018 to 2019: headline report - GOV.UK](#)

¹⁵ [Domestic hot-water use: observations on hot-water use from connected devices.](#)

¹⁶ The report on the data reflects on this as follows: ‘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 20202. This is anticipated as the connected device is a premium offer to a paid service.’

The picture is complicated by the differences in the EST sample between consumption by combi and by conventional boilers, and the EST sample being biased towards larger households. The methodology described below takes these aspects of the data into account.

The Connected Devices sample, despite being much larger, is not representative of all households: the devices studied are all newer boilers with data connections, so some tenures and income deciles are unlikely to be captured, and this may also distort the distribution of occupancies in the sample. There has been no attempt to compensate for biases in the CD sample.

Table 1 – Summary characteristics of survey samples, including average delivery temperatures for each sample

Data	Sample size	Mean litres/day (std dev)	Median litres/day
CD, Boiler data, combi (46.3 – 53.2°C) ¹⁷	26246	109.4 (82.5)	89.5
EST, combi (50.0°C)	39	141.8 (90.0)	115.7
EST, conventional (52.9°C)	73	110.8 (99.1)	76.6
EST, all (52.0°C)	112	121.6 (96.8)	87.5

These data show that consumption by combi boilers is significantly lower in the more recent CD data; conventional boilers in the 2008 study consumed much less than combi boilers; and the data in both samples is significantly skewed.

Although there is a strong dependency of consumption on boiler type, for the FHS assessment wrapper an estimate is required of the consumption independent of the technology delivering it. As combi boilers deliver hot water on demand, unconstrained by cylinder capacity, the consumption by households fitted with them is taken as the true demand. Accordingly, boiler type is not used in fitting the transformed data back onto the EST dataset, nor in the final dependency.

Both EST and Connected Devices studies reported temperature data as well as volumes but not in a way to let us improve this analysis by looking at the delivered energy of an event. Accordingly, variation in temperature of the water is not considered when estimating the distribution of the volumes demanded.

It is conjectured that the difference between combi and conventional boilers is explained partly by shower and tap flow rates, as combi boilers deliver water at higher pressure than conventional boilers with vented cylinders, which may be represented in the dataset. The EST

¹⁷ See 'Temperatures of events' in Annex 2

study report also suggests that at the kitchen tap (but not elsewhere) consumers may run off more water from combi boilers as they take longer to heat to the demand temperature.

Method

The approach taken to correct for differences between the 2008 and 2022 datasets is as follows.

Identifying the median dwelling in a small sample of highly non-normal data is contentious. The middle three points in the ranked EST combi boiler data have consumptions 102, 116, 119 litres/day; the midmost point could have been chosen anywhere in a range of 17l/d. The scale of the possible sample error here is as large as the secular change in median consumption being modelled. Therefore, instead of looking at the sample median the whole distributions are looked at using the following steps:

1. To compensate for the bias in the EST data, it is treated as a stratified sample by occupancy and weighting each stratum to match the proportion of dwellings of that size found in the English Housing Survey 2017-2020 (consistent with the analysis for the FHS assessment wrapper standardised occupancy).
2. The distribution of daily consumption across the CD population is identified. Assuming that the distribution of demand has remained constant over time although the level has changed, distributions of the same family were fitted to the weighted EST data.
3. A linear transformation was found which, applied to the EST sample, matches the median of the fitted distribution to the CD median.
4. This transformation was applied to the EST data and possible regression relations tested for the final dependency.

Two supplementary steps were then taken to make corrections to the hot water requirement:

5. An adjustment to the total hot water volume was applied to account for pipework losses.
6. An adjustment to the total hot water volume was applied to account for the use of electric showers not being included in the data.

The sections below give more details for each of these steps.

1. Weighting the EST data.

We trim outliers from the EST data, discarding one dwelling recording hot water use above 500 litres/day.

We group the largest English Housing Survey dwellings together. The EST sample is biased towards households with four or more people. The derived weights are applied in both the subsequent steps of analysis: transforming the EST data to match a modern consumption pattern, and in fitting the best-fit consumption estimate as a function of occupancy.

Table 2 – EST survey sample and English Housing Survey total weights, by household size

Occupancy	1	2	3	4	5	6	7+
EST count	11	38	18	29	13	2	1
EHS count	6,721,432	8,533,532	3,623,831	3,215,192	1,088,983	300,972	177,809
Weight	611,039	230,636	201,324	110,869	83,768	150,486	177,809

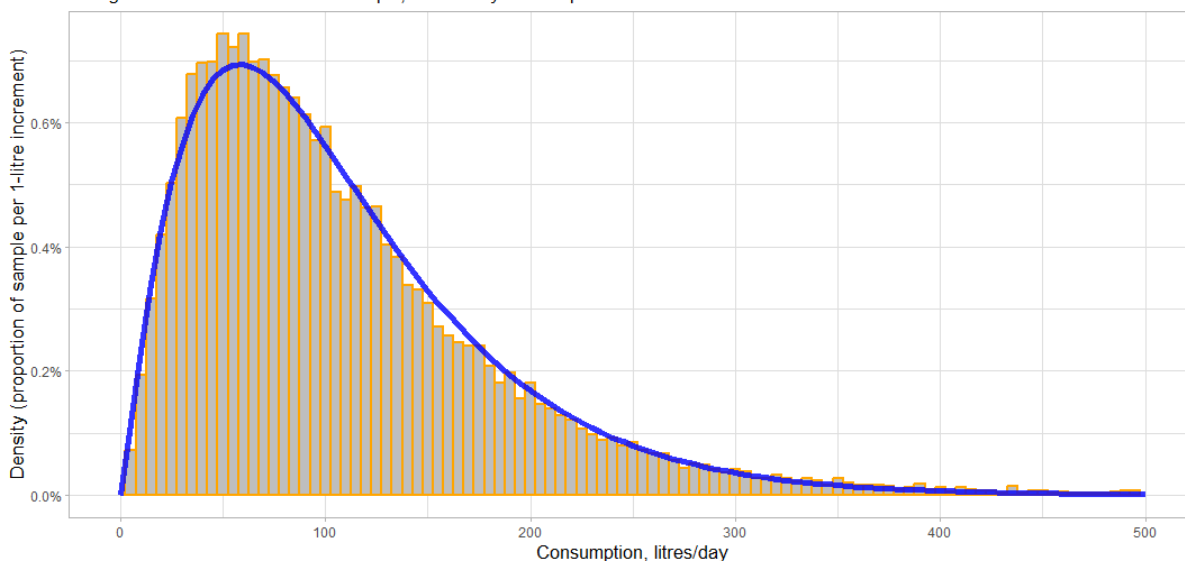
2. Distribution of consumption in the two samples.

We trim outliers from the CD data to discard dwellings recording a median daily consumption of zero (which were unoccupied for most of the sample dates) or above 500 litres/day (which are likely to be non-domestic premises).

The remaining sample of 26,139 dwellings has a mean consumption following a Gamma distribution, with parameters: alpha (shape) = 2.17, beta (rate) = 0.0202. This can be written as $\Gamma(\alpha = 2.17, \beta = 0.0202)$. See the histogram in Figure 2, below.

Figure 2: CD data - distribution of daily hot water demand

Histogram of Connected Devices sample, mean daily consumption. Blue: fitted Gamma distribution



This shows an excellent fit, and it suggests that an explanatory model is possible. Gamma distributions arise as the waiting time for multiple arrivals in a Poisson process, which has at least some relation to meeting an expected demand.¹⁸

Table 3, and figures 3 and 4, shows parameters and plots for gamma distributions fitted to CD and EST datasets.

¹⁸ If a steady stream of water is diverted into a new bucket at random but on average every 50 litres, then the observed distribution would occur if each household was allocated a consumption of 2.17 buckets (in an appropriate sense). More realistically, households have a number of activities needing unequal amounts of water but differ in how much they consume for each use. This dataset gives support to a conjecture that their preferred depth of a bath or duration of a shower follows more a Poisson than a normal distribution.

Table 3 – Gamma distributions fitted to each dataset

Data	Fitted distribution	Median of distribution (litres/day)
CD, combi	$\Gamma(\alpha = 2.17, \beta = 0.0202)$	91.5
EST, all	$\Gamma(\alpha = 1.77, \beta = 0.0191)$	76.4
<i>EST, combi</i>	$\Gamma(\alpha = 2.51, \beta = 0.0215)$	101.5
<i>EST, conventional</i>	$\Gamma(\alpha = 1.41, \beta = 0.0149)$	73.2

Note that as expected the medians of the distributions differ markedly from the EST sample medians.

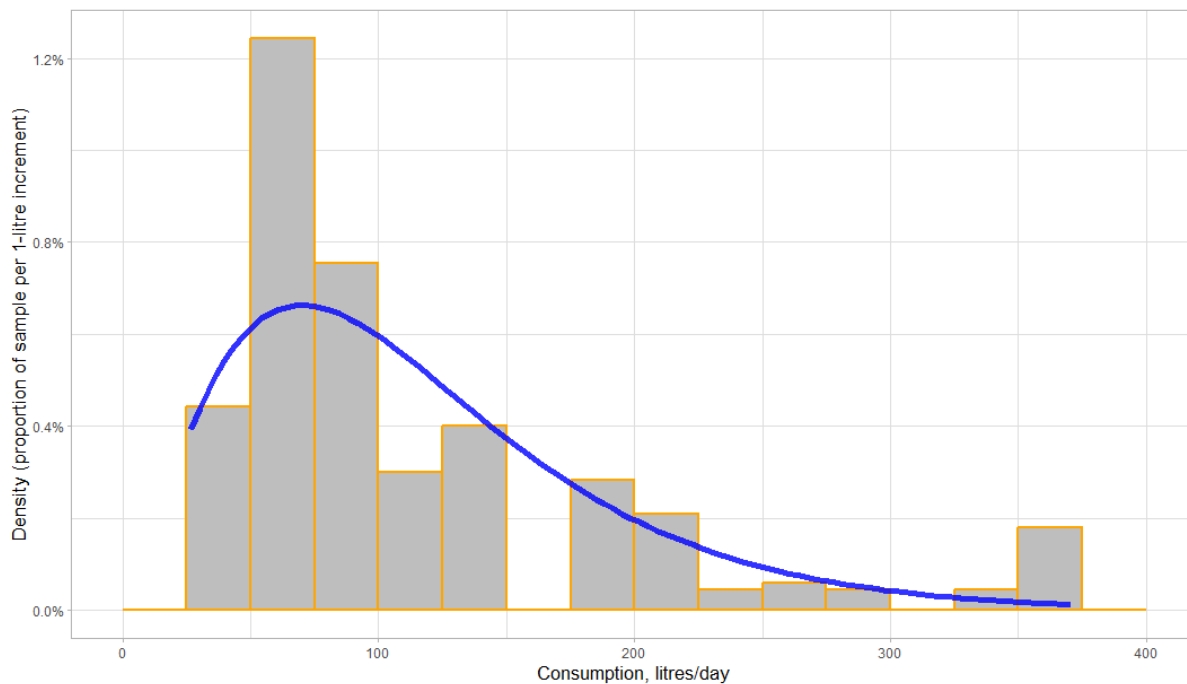


Figure 3: EST combi boilers – distribution of daily hot water demand. Histogram of combi boiler sample in weighted EST data. Blue line is fitted Gamma distribution.

Looking only at the EST combi boilers, a reduction factor can now be calculated,

$$R = \frac{\text{median(CD combi distribution)}}{\text{median(EST combi distribution)}} = \frac{91.5}{101.5} = 0.902.$$

The value of 0.902 represents a reduction of nearly 10% in the typical hot water draw from a combi boiler since 2008. This is a smaller reduction than comparing sample mean or median values would have implied.

It is not possible to calculate a similar figure for conventional boilers, because the CD data set only contains combi boilers, so the equivalent graph shown in Figure 4 is only of passing interest.

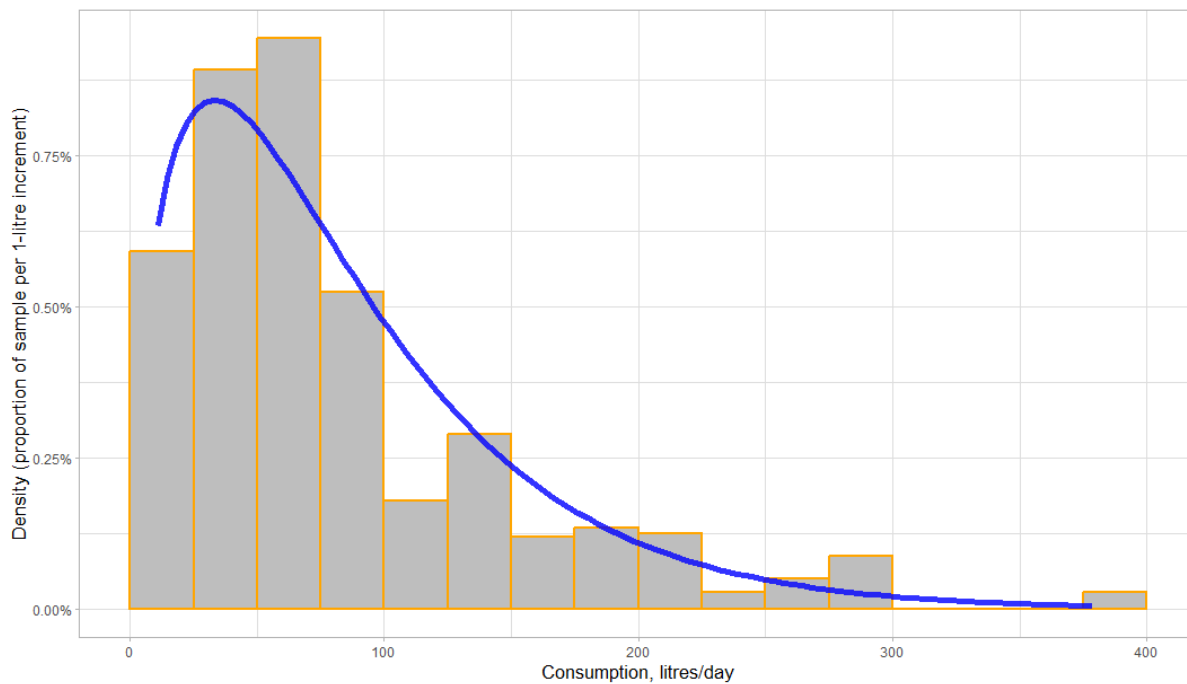


Figure 4: EST conventional boilers – distribution of daily hot water demand. Histogram of conventional boiler sample weighted EST data. The blue line is the fitted Gamma distribution.

3. Transformation of EST consumption to simulate Connected Devices distribution

The linear transformation applied to the EST data is, where $V_{observed}$ is the measured daily consumption of a home in the sample:

$$V_{adjusted} = 1.01 V_{observed} + 11.68.$$

where $V_{adjusted}$ is the corrected figure.

The decline in typical consumption over time, from 2008 to 2021, is more than matched, across the whole sample, by typical consumption from combi boiler systems being greater than from conventional boilers. The combined effect is best captured by a nearly constant increase in consumption across all dwellings. This subsection explains how the above transformation is derived.

The Gamma distribution of the combi-only subsample has a similar shape parameter, α , to that of the CD sample, and a simple scaling by $R = 0.902$ would be a satisfactory update. However, for the full sample including conventional boilers a shape transformation is needed.

We apply this in three stages:

- 3.1. construct the exact, non-linear transformation between the EST and BD distributions.
- 3.2. approximate the exact transformation with a linear map, for transparency.
- 3.3. apply a further reduction factor to match the median of the resulting distribution (in order to compensate for the loss of fidelity with the linear map).

The exact transformation takes the form, for x the daily consumption of a dwelling in the EST sample:

$$T_0(x) = q_{\Gamma(2.17, 0.0202)} \left(p_{\Gamma(1.17, 0.0191)}(x) \right).$$

Here p_{Γ} is the cumulative distribution function, and q_{Γ} is its inverse, the quantile function. The composition map is very close to linear, as shown in Figure 5:

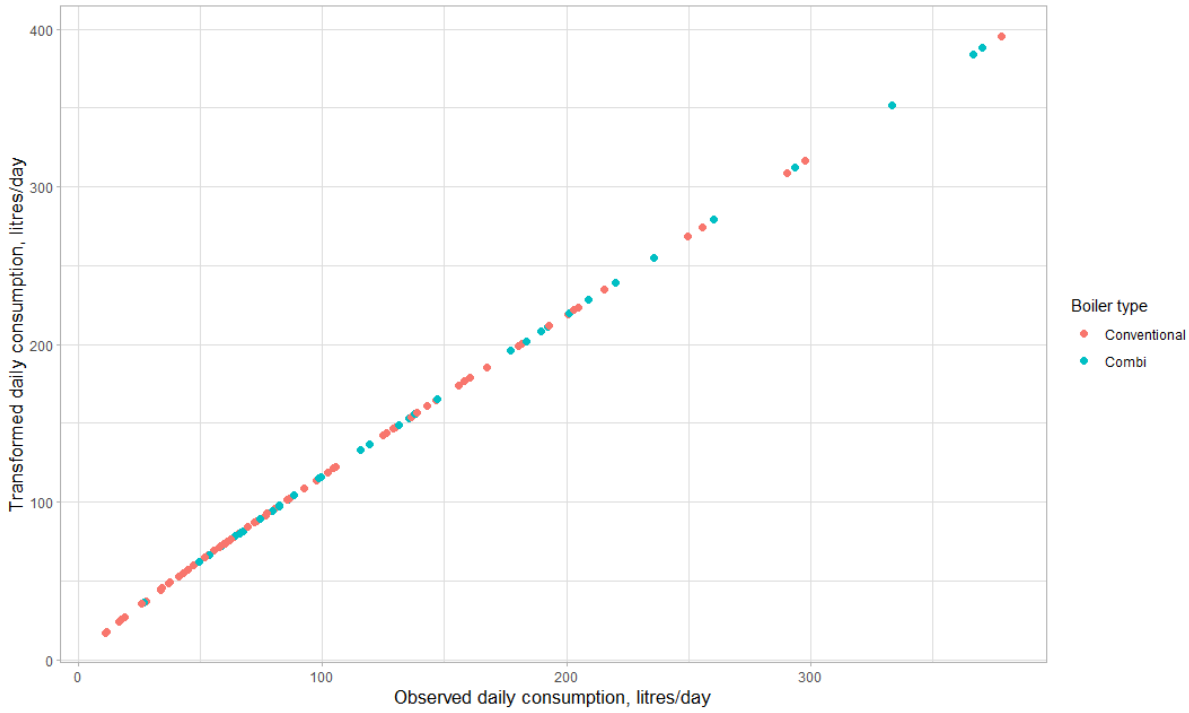


Figure 5: Quantile transformation from EST distribution to simulate CD data.

The linear approximation to this curve is $T_1(x) = 1.03x + 11.89$. After transformation with T_1 the sample has the fitted distribution $\Gamma(\alpha = 2.38, \beta = 0.0220)$. This value of α is acceptable, but to match the median of the desired CD distribution a further scaling factor is needed,

$$T_2 = \frac{\text{median}(\text{CD combi distribution})}{\text{median}(t_0(\text{EST}) \text{ distribution})} = \frac{91.5}{93.1} = 0.983.$$

The final transformation is then $T(x) = T_2 T_1(x) = 1.01x + 11.68$.

The EST data is adjusted, both for combi and conventional boilers, by applying this linear transformation to give a modelled daily consumption from the same sample if measured today, with combi boilers installed.

As a check of the method a Gamma distribution is fitted to the transformed data. The fitted parameters are $\Gamma(\alpha = 2.38, \beta = 0.0224)$ and this has the desired distribution median of 91.5.

4. Dependency of modelled consumption on household size and boiler type.

The sampled relationship between adjusted consumption and occupancy is shown in the jittered¹⁹ scatter plot at Figure 6. (Recall that although boiler type for the dwelling is shown, the transformed consumption is modelling an all-combi-boiler stock.) There is a visible upward trend in consumption with occupancy, but a wide variance about the trend.

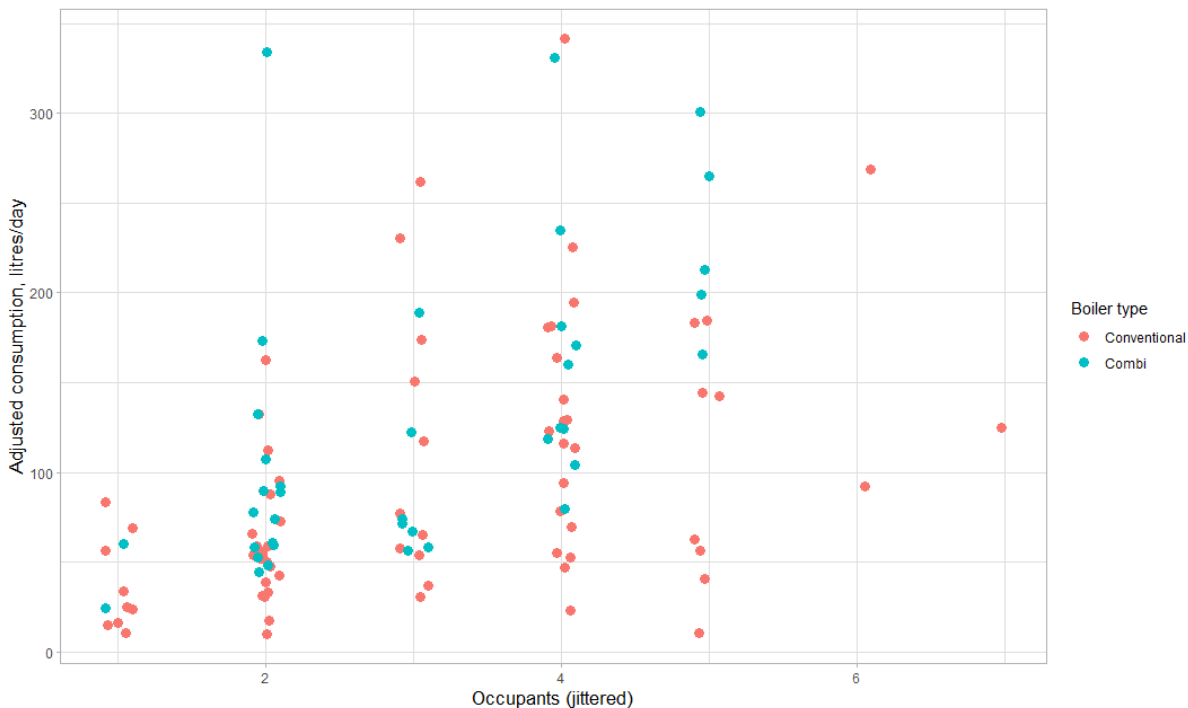


Figure 6: Adjusted daily consumption by occupancy and boiler type.

To select a model, linear, log-linear, and power-law relationships were considered, fitting to the weighted sample data. A power law was also tried, using linear regression after a log-log transformation, for reasons discussed below.

¹⁹ Jittering separates points that would otherwise overlap by plotting them to left or right of their true position, which in this chart is always a whole number of occupants.

Table 4 – Alternative models fitted to the data in Figure 6

Model	Formula	Adjusted R ²
Linear, occupancy	$V \sim 32.89 \text{ occ} + 29.96$	28.96%
Log-linear, occupancy	$V \sim 79.52 \log(\text{occ}) + 50.71$	29.97%
Power law, occupancy	$V \sim 60.32 \text{ occ}^{0.7119}$	29.79%
Log-log, occupancy	$V \sim 49.80 \text{ occ}^{0.7629}$	37.32%* (26.10%)

Here V denotes consumption in litres/day; occ = dwelling occupancy.

R^2 for the log-log models is calculated with respect to residuals in the log-transformed variables. The value in brackets is the R^2 with respect to residuals in the untransformed variables.

Figure 7 plots the models under consideration. Note that the log-log fit lies below the other lines, which are otherwise very close for dwellings with two to four occupants. Under the log transformation, the regression minimises the total *proportional* error, and this weights points below the regression line more, those above the line less.

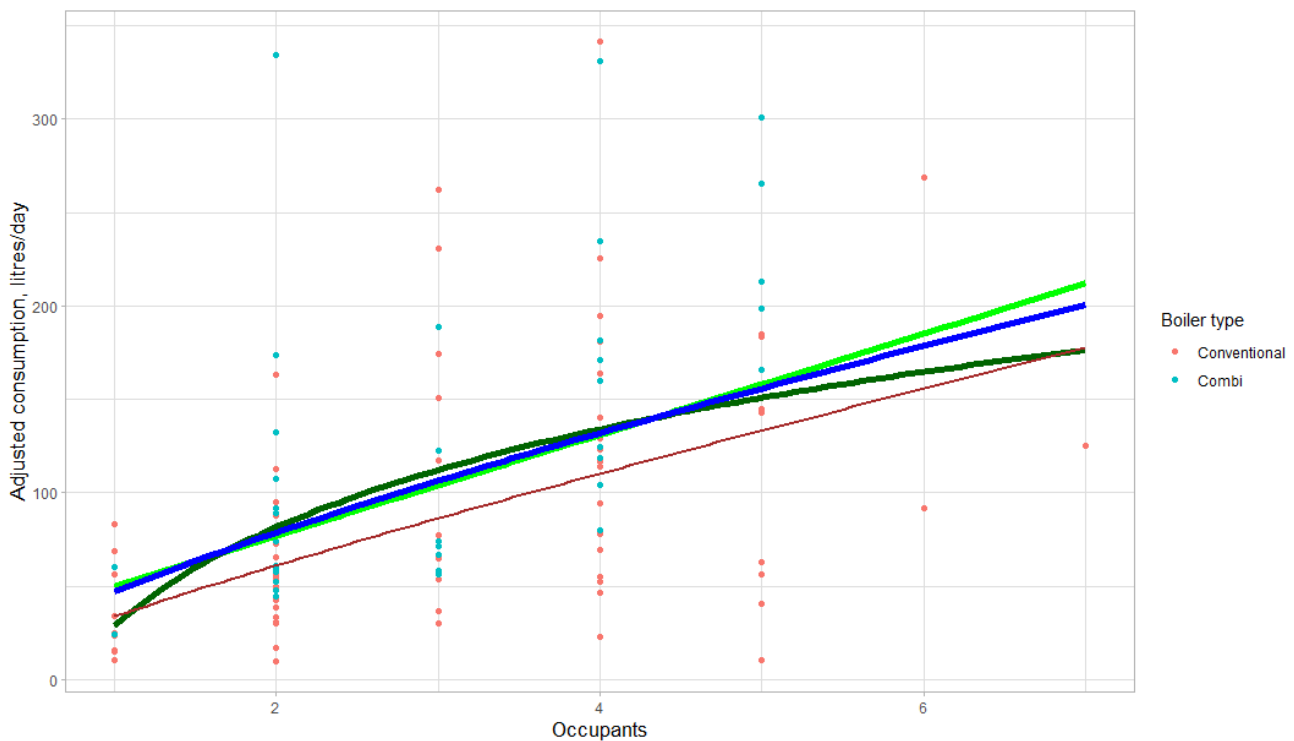


Figure 7: Comparison of fitted models: green=linear, dark green=log-linear, blue=power law, brown=log-log.

Examining further diagnostic plots (residuals vs fitted, residual scale/location, not shown in this report) shows that the untransformed data does not have uniform variance of residuals as occupancy varies (i.e. it is not homoscedastic). Larger households have, unsurprisingly, a wider variance in their consumption; while unusual usage patterns can include very large daily volumes on one hand but cannot become negative on the other. The log-log-transformation brings the data more closely in line with the assumptions for a linear regression and this is reflected in the much higher R^2 achieved. This relationship could appropriately be used to represent the typical hot water use of a household with no unusual demands.

The remaining three models are close together, especially among 2 - 4 person households in their predicted values, and very close in the R^2 measure of their predictive success. The highest R^2 is achieved by the log-linear model but this implies unrealistically low consumption for one-person households: 50.7 L/day, against 105.8L/day for a two-person household. The second person in the home is unlikely to consume more hot water than the first, and this rules the log-linear model out of contention. The power-law model is accordingly preferred.

The R^2 values are sensitive to outliers and excluding the single dwelling with improbably high consumption from the EST sample roughly doubles R^2 for all models.

Conclusions and selected model

Previous analysis of the EST data, both in the original report and in technical papers for SAP²⁰, has grappled with the difference between conventional and combi boiler consumption volumes, which is noticeable but not statistically significant.

The stock of boilers has changed since 2008, and it is not reasonable to make implicit use of the ratio of combi and conventional boilers in the EST sample to predict consumption for a generic contemporary building. In this analysis the consumption of *all* buildings was modelled as if they had combi boilers, as in the Connected Devices stock, while preserving the scatter of households of different sizes across the quantiles of the consumption distribution.

Rejecting the log-linear model for its unrealistic predictions for small households, the best fitting of the models considered is the power law:

$$V_B \sim 60.32occ^{0.7119}$$

where consumption is proportionate to the 0.7119 power of the number of residents. As the exponent is <1, additional household members contribute less to the total than the initial ones, as expected.

Parsimonious rounding reduces the model used for the FHS assessment wrapper to

$$V_B \sim 60.3occ^{0.71}$$

For a home with the average 2.37 residents this predicts consumption of 112L/day at 52°C.

²⁰ STP 11/B09 Changes to the treatment of heating and hot water systems with boilers in SAP 2012, https://www.bre.co.uk/filelibrary/SAP/2012/STP11-B09_BoilerChanges.pdf

Table 5 – values of V_B at different occupancy levels

Household size	1	2	2.37	3	4	5	6
Consumption at the boiler, litres/day of unmixed hot water	60.3	99.3	112.2	133.0	163.6	192.1	219.1

For households with two or more occupants the predicted consumption (at the hot tap) is within 3 litres/day of the SAP 2012 assumption, which was based on the EST data alone. For 1-member households it is 16% lower. The similar outturn is arrived at by a different route, as the SAP assumption takes the best linear fit from EST data (trimmed more robustly than here) and makes an adjustment to account for systematic errors in the logging data.

5. Adjustment of total hot water volume to account for pipework losses

The Home Energy Model defines a tapping event as the period for which hot water is flowing at the tap or shower head. Before this can begin the existing ambient-temperature water in the pipe must be drained and replaced with water from the hot supply; an equivalent volume of hot water remains in the pipe after the event.

The total volume of hot water that remains in pipes was estimated by modelling a home with the average 2.37 occupants. The daily number of showers, baths and other tapping events were taken from the medium load profile provided in BS EN 13203-2:2018. The shower head flow rate was assumed to be the same value used in the standard, 6 litres/minute. Pipe runs to each tapping point were assumed to be 10m in length with 20.4mm inner pipe diameter for showers and 13.4mm inner pipe diameter for taps and cleaning. The volume of water remaining in the pipe after each tapping event was calculated and found to be 47% of the total drawn from the taps. Equivalently, this is 32% of the water drawn from the boiler or cylinder. Given the use of a number of uncertain assumptions, this is rounded to 30% to avoid implying undue precision. With V_B the volume of water drawn from the boiler or cylinder, and V_{HT} the water reaching the hot tap or other final outlet, this gives:

$$V_{HT} = 0.7 V_B$$

Distributing a 30% reduction over all events in the sample implies 15 – 23 seconds of flow to charge the pipe (varying slightly by decile, as flow rates vary between them) and the duration and volume of each event has been reduced by this amount in the tables in Annex 2²¹.

To reiterate, the assumed 30% volume remaining in the pipe has been used to derive the standard estimate for demand at the tap V_{HT} from the sample data which measured draw-off at the boiler V_B . When the Home Energy Model calculates the energy used for hot water in a given dwelling (and the associated space heat gains due to pipework losses), this assumption is not used, and the specifics of that dwelling are taken into account.

²¹ Some larger events recorded in the sample may represent adjacent or overlapping uses of water in the monitored home, for example, successive showers. There is no time between these events for the (shared length of) pipework to revert to ambient temperature, so no extra allowance is needed here.

6. Adjustment of total hot water volume to account for electric shower use

The CD sample naturally only included hot water events supplied by the combi boiler. It is assumed that there were no other central water heating systems present in each dwelling. However, it is likely some homes in the study also had instantaneous electric showers. Their use would not have been captured as hot water events in the CD data.

While there is no data on how many of the homes in the sample had electric showers, it is known that electric showers are far from rare in the UK, with a range of estimates from 26% to 46%²². With some uncertainty, it is therefore assumed here that 30%²³ of the homes in the sample also had an electric shower, meaning that a significant number of showers may have been missed out and now need to be accounted for.

To convert this to an additional number of shower events an assumption must be made about how often electric showers were taken relative to showers provided by the combi boiler. In the absence of any data on this, an expert group decided it was reasonable to assume electric shower would be used about half as often as showers provided by the combi boiler (on the basis that the combi would give a preferable flow rate²⁴).

Therefore, the required uplift to the number of shower events that should be included is $50\% * 30\% = 15\%$. This can be applied directly to equations and tables where shower frequency is stated directly, but it is also necessary to multiply by the fraction of hot water used for showers before applying to the total hot water use. In the CD sample, 60.685% of all hot water used was for events classified as showers. Therefore, the uplift to apply to the total hot water requirement is $15\% * 60.685\% = 9.10\%$. So, the correction factor applied is **1.091**.

This is applied to the overall hot water demand calculation, and also to the event count figures in hot water deciles/events tables, to retain consistency.

²² Patterns Of Hot Water Use, University of Manchester, March 2013, suggest 26%; 'At Home With Water 1', EST, 2013 (data collected 2010) suggests 35%; Water and Energy Efficient Showers: Project Report, Liverpool John Moores University on behalf of United Utilities, 2007 suggests 46%.

²³ This is weighted towards the two lower sources on the basis that they are more recent.

²⁴ Due to the power limitations for an electric shower (~11kW) a flow of around 6l/min is about the most that can be achieved. With a combi boiler, flow rates of >10l/min are usually possible.

Annex 2: Schedule of events

The Home Energy Model distinguishes three use cases for hot water: baths, showers, and other tap draws (which include handwashing and washing up, for example). These differ in their treatment of thermal gains (to the space or to waste-water heat recovery) and in the building parameters that affect them (bath volume and shower flow rate). The model simulation therefore requires a schedule of events of each type. Monitoring data of the water drawn from the boiler in a sample of UK homes was used and event types imputed onto these draws-offs. From this, tables could be constructed of how frequently, and when, events of each type occur. This Annex describes how this was done.

The Connected Devices study²⁵ analysed a cohort of 45,000²⁶ internet-connected boilers monitored during a full heating year, from May 2021 to May 2022. This was the first full year since the legally mandated Covid-19 lockdowns. Within this cohort a sub-sample of 2,700 homes had been analysed as part of the original work to provide measured observations of hot water drawn from the boiler output tap: these consisted of about 24,000,000 events (i.e. continuous periods of flow through the output).

The sample of homes is ordered into deciles by total consumption, as in Table 1.

Table1 – Hot water demand deciles²⁷

Decile	Lower bound / L	Median daily hot water demand at the tap / L	Upper bound / L	Calibration volume / L ¹	Dwellings in decile under FHS assumptions ²
1	16.2	31.2	39.5	3.7	1-bed
2	39.5	46.1	52.1	5.7	
3	52.1	57.4	63.3	7.2	
4	63.3	68.2	74.1	8.6	
5	74.1	79.1	83.8	11.1	2-bed
6	83.8	90.4	95.6	11.4	3-bed
7	95.6	101.6	108.2	13.3	4-bed
8	108.2	116.2	125.4	16.2	5-bed
9	125.4	134.2	147.9	17.2	
10	147.9	162.9	181.7	27.2	

1. This is the average daily draw from a pseudorandom schedule generated from the events in this band, used to calibrate the schedules generated for dwellings in the FHS assessment wrapper (as in the main section of this document).

2. Variation of the floor area of a dwelling does not affect FHS standardised occupancy enough to change its band.

Allocation of events to use types

Data in the Connected Devices study classified all water-drawing events into five types²⁸ by duration. There is no comparable study of domestic hot water use able to provide a fine-

²⁵ [Domestic hot-water use: observations on hot-water use from connected devices](#)

²⁶ As this part of the analysis was done later than the work described in Annex 1, the full data set was available.

²⁷ Taken from Table 6 of [Domestic hot-water use: observations on hot-water use from connected devices](#)

²⁸ Small_tap, long_tap, shower, shower_big and bath.

grained allocation of events to different uses. For this analysis, all events from a band were therefore attributed to the same use.

There has been a change in personal bathing habits since 2002 with showers increasingly supplanting baths, but there is little recent systematic data. In the At Home With Water study, conducted in 2012, the average volumes reported imply a typical use of 264 litres/week of mixed water in showers and 104 litres in baths: that is, about 28% of bathing water was taken in baths. There was wide distribution in shower lengths: a mean shower was 7.5 minutes with a range of 0 to 30+ minutes²⁹.

In the tables that form part of the FHS wrapper code³⁰, the two smallest event types are allocated to 'other.' Baths make up the fourth type, which are events with an average volume of 69 litres. Events in the third and fifth types are allocated to showers (standard size and 'big' showers, respectively). Under these assumptions baths make up 29% of bathing water use, reproducing the 2012 sample proportion within each individual dwelling.

Table 2: Mean volumes and durations of events, across all deciles		
Event type	Mean volume / L	Mean duration / s
0_small_tap	0.5	5.9
1_long_tap	9.6	99.9
2_shower	35.5	340.8
3_bath	67.6	640.4
2b_shower_big	102.4	1034.9

It is acknowledged that bath and shower volumes may in practice overlap and there is no way to disentangle them using this data. However, using the categories in this way gives us a use pattern that is consistent with the available data both in the pattern of draw-offs (determining the demands on the hot water supply) and the overall proportion of water uses (determining the attributable heat gains).

Temperatures of events

Boilers in the CD study had a wide range of set points, with a median of 55°C. For events interpreted as showers and baths in Table 2, the median hot water temperature was between 52.4 and 53.2°C. The median temperatures for the shorter 'tap' events were 46.3 and 49.8°C. The evidence did not therefore provide a clear reason to vary the assumed delivery temperature of water from 52°C. A future extension of this work might consider short events in more detail.

Hot water draw-off events are categorised into five event types, by duration of the event, as described above. For each decile, and each day of the week, the mean daily frequency of

²⁹ i.e. the largest category was for 30 minutes *or more*.

³⁰ src/wrappers/future_homes_standard/decile_banding.csv,
src/wrappers/future_homes_standard/day_of_week_events_by_decile.csv, and
src/wrappers/future_homes_standard/day_of_week_events_by_decile_event_times.csv

events in each band is reported: this includes the mean volumes and durations within the band. An excerpt for decile 1 is shown here as Table 3.

The Future Homes Standard assessment wrapper interprets the average daily event count found in this dataset as the *expected* number of such events for a building in its standardised use, given the decile into which its standardised total consumption of hot water falls.

Table 3: Events by decile and day

Decile	Day	Event band	Mean events per day	mean event volume / L	mean event duration / s
1	Monday	0_small_tap	10.792	0.9	10.2
1	Monday	1_long_tap	1.295	9.0	97.1
1	Monday	2_shower	0.283	31.0	323.8
1	Monday	3_bath	0.092	58.9	639.5
1	Monday	2b_shower_big	0.056	89.0	1072.0
1	Tuesday	0_small_tap	10.513	1.0	10.2
1	Tuesday	1_long_tap	1.236	9.0	96.8
1	Tuesday	2_shower	0.279	29.8	317.7
1	Tuesday	3_bath	0.09	60.5	644.1
1	Tuesday	2b_shower_big	0.063	91.3	1078.7
1	Wednesday	0_small_tap	10.086	0.9	10.2
1	Wednesday	1_long_tap	1.192	9.0	97.2
1	Wednesday	2_shower	0.28	29.3	316.8
1	Wednesday	3_bath	0.078	59.0	637.0
1	Wednesday	2b_shower_big	0.06	92.3	1078.1
1	Thursday	0_small_tap	10.143	0.9	10.3
1	Thursday	1_long_tap	1.192	9.1	97.1
1	Thursday	2_shower	0.273	30.0	320.2
1	Thursday	3_bath	0.083	57.7	636.8
1	Thursday	2b_shower_big	0.063	91.5	1056.1

Table 4 reports the overall frequency of events of each event type for each hour in the week. This dataset is only available for events interpreted as baths and showers. A sum of the number of events of all types is imputed to the two smaller categories, as illustrated in Table 4 with solid grey bars. The FHS assessment wrapper assigns the probability of hot water events to times within a day in proportion to this observed hourly data.

Table 4: events by hour

Count of events		Event type				
day	hour	0_small_tap	1_long_tap	2_shower	2b_shower_big	3_bath
Monday	0	563	563	407	62	70
Monday	1	354	354	274	22	50
Monday	2	330	330	262	18	45
Monday	3	823	823	681	36	107
Monday	4	2953	2953	2285	187	453
Monday	5	9574	9574	7357	612	1558
Monday	6	17267	17267	13349	1069	2851
Monday	7	18265	18265	14491	1042	2708
Monday	8	14761	14761	11712	810	2224
Monday	9	11391	11391	8801	744	1843
Monday	10	8509	8509	6332	572	1439
Monday	11	6005	6005	4322	541	1094
Monday	12	4576	4576	3281	430	815
Monday	13	4059	4059	2954	385	658
Monday	14	4244	4244	3138	355	722
Monday	15	5953	5953	4386	537	1019
Monday	16	8884	8884	6436	864	1591
Monday	17	12299	12299	8978	1235	2194
Monday	18	13259	13259	9662	1322	2328
Monday	19	11235	11235	8060	1168	2065
Monday	20	8321	8321	6015	930	1402
Monday	21	5297	5297	3916	549	873
Monday	22	2736	2736	2017	275	462
Monday	23	1195	1195	868	142	178

Illustrating this using a worked example

A dwelling in decile 1 (i.e. has hot water use falling in the lowest decile) has a 28%³¹ likelihood of a shower event on a Monday (Table 3).

For showers, 7% occur in the hour 8am – 9am (Table 4).

Hence each Monday the pseudorandom schedule assigns a 1.98% probability to a shower taking place in this hour.

The use of a Poisson sampler³² allows for the possibility that two showers might take place (albeit with likelihood less than 1 in 2500) in that hour. If a shower does occur it is equally likely to start at any minute between 08:00 and 08:59; if two showers occur in that hour, their start times are randomly adjusted so that they do not overlap.

³¹ Since, in the CD dataset, there was a median of 0.283 showers taken per Monday for homes falling in that decile – according to the third data row of the Table 3.

³² Giving a normal distribution of probability around a mean.

