Occupancy assumptions in the Home Energy Model: FHS assessment

A technical explanation of the assumptions.

March 2026

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Contents

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

To understand how these occupancy assumptions have been implemented in computer code, please see:

src/wrappers/future_homes_standard/future_homes_standard.py.

Overview

The Future Homes Standard (FHS) assessment wrapper specifies inputs and outputs for the Home Energy Model (HEM), for the use of the model in assessing whether a new home complies with the requirements of Part L of the Building Regulations 2025, i.e. the Future Homes Standard. Among the inputs are standardised assumptions relating to occupancy and energy demand.

This paper sets out the standardised associated occupancy assumption for the FHS assessment wrapper and explains how it has been derived.

The energy demanded for any activity by the occupants of a dwelling (e.g. hot water, lighting, cooking, electrical appliance use) depends on how many occupants are present and how this varies by time of day. Therefore, occupancy assumptions underlie the calculation of these energy uses, and of associated incidental losses to cold water and evaporation. This document also discusses the most direct dependence, the FHS assessment wrapper assumption of the heat energy the occupants provide to the building through their own metabolism (“metabolic gains”).

Other documents in this series describe the assumed hot water demand (HEMFHS-TP-03 FHS domestic hot water assumptions) and lighting, cooking, and electrical appliance use (HEMFHS-TP-04 FHS appliances assumptions) in the FHS assessment wrapper. The calculation of these demands take occupancy as an input in each case.

1. Standardised occupancy

The FHS regulates the energy use and associated carbon emissions of a dwelling under a standardised pattern of use. Foundational to this standardised use is the assumed number of occupants of the dwelling and how this varies over the day.

Occupancy analysis for the FHS is based on recent occupancy data from the English Housing Survey (EHS)[1] but the standard occupancy is deliberately set higher, for most dwellings, than a best fit to that data. Many homes in England are under-occupied and the FHS is intended to reflect the designed use of the dwelling. A higher standard occupancy leads to increased modelled hot water use but, because occupants’ activities provide heat gains into the space, to decreased space heating demand. For dwellings with heat pumps these effects tend to decrease the overall modelled coefficient of performance. In this sense it is a conservative adjustment.

Standardised occupancy is not expected to drive developers’ decisions about heating system sizing, although in the existing Approved Document L it affects permitted solar-thermal hot water installations, via the mandated volume of their dedicated storage vessel.

[1] Data from two EHS surveys (2017-18 and 2019-20) were combined to give a large data set (n=24,621).

The best-fit parameters to the EHS data are also reported in this document, as it is expected that these will be of use to researchers wishing to model typical occupancy in the English housing stock (this may also become available in the future through alternative wrappers for the Home Energy Model)[2].

1.1 Nature of the occupancy function: key assumptions

The standard occupancy assumed of the dwelling should be realistic: it should be recognisably appropriate to its designed use. To the extent possible, it should also reflect its expected use, where this differs from the designed use or capacity.

The expected, or predicted, average number of occupants is not necessarily a whole number and the standard, representing typical occupancy, need not be a whole number either. It will always be at least 1, as the standard models an occupied building.

Larger dwellings should not be modelled with fewer inhabitants than smaller ones.

In SAP occupancy was modelled as a continuous sigmoid (S-shaped) function of total floor area. In the FHS assessment wrapper we keep this functional form but add a dependency also on the number of bedrooms[3]. This reflects more realistically the way homes are occupied in England.

1.2 English Housing Survey evidence

In this analysis two full English Housing Survey (EHS)[4] surveys (2017-18 and 2019-20) were combined and their weights renormalised. To avoid spurious precision the size of a household (number of occupants) was capped by top-coding occupants at 6 and number of bedrooms at 5. (There are only 194 cases in the combined stock with more than 5 bedrooms, 0.8% of the sample).

[2] For a recent example see: Few et al. *The over-prediction of energy use by EPCs in Great Britain: A comparison of EPC-modelled and metered primary energy use intensity* (Energy & Buildings Volume 288, 1 June 2023) https://www.sciencedirect.com/science/article/pii/S0378778823002542

[3]The Approved Documents refer frequently to requirements for bedrooms but there is no statutory definition of what a bedroom is. In the English Housing Survey and official statistics, the number of bedrooms includes bed-sitting rooms, but not bedrooms converted to other uses unless they have been denoted as bedrooms by the household.

[4] https://www.gov.uk/government/collections/english-housing-survey

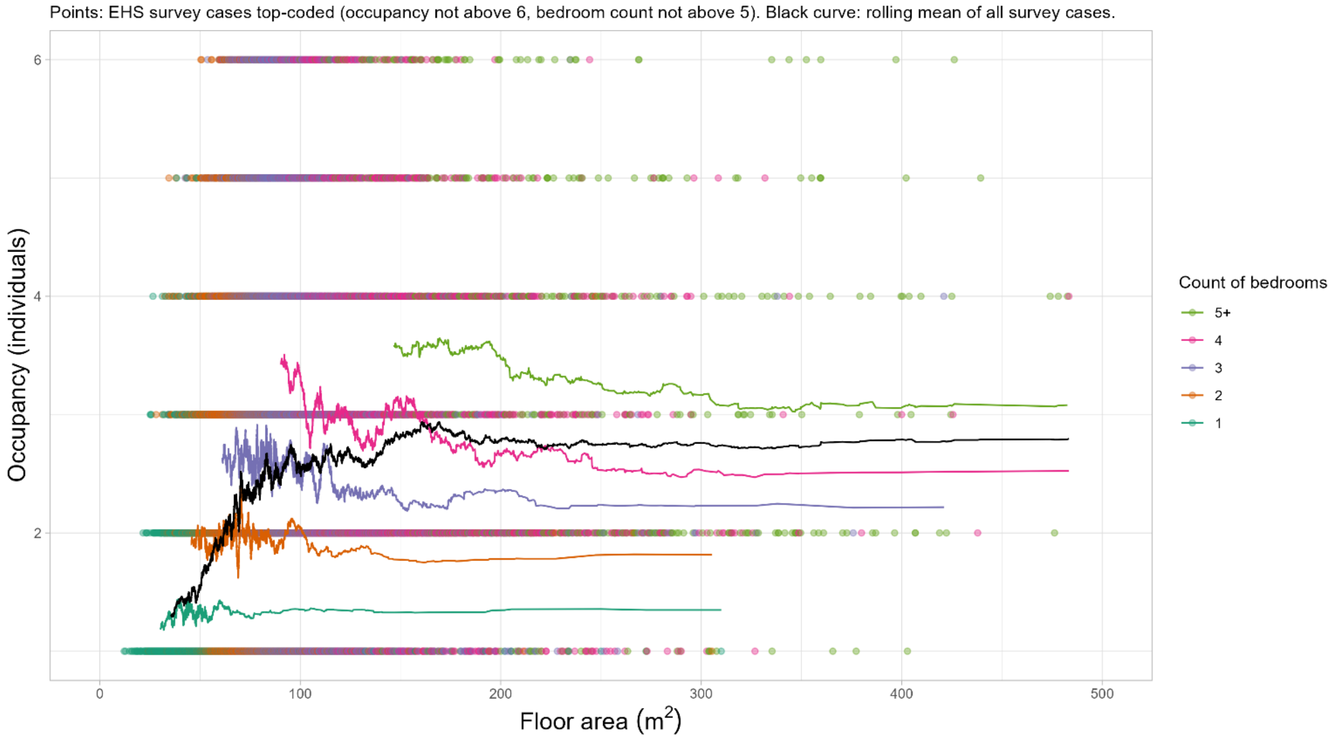

Figure 1 – Occupancy vs floor area, rolling means by bedroom count and overall.

Figure 1 plots the EHS survey cases by floor area, bedroom count and surveyed occupancy. Households of all sizes occupy homes of all sizes, except that there are few 1-bed dwellings with five or more residents. Note that the EHS household size is always a whole number.

In the data, bedroom count (R^2 = 19.2% for a simple linear fit) is a stronger determinant of occupancy than floor area (R^2 = 13.5% for a sigmoid function of area). On average, each additional bedroom is associated with about 0.5 of an additional occupant.

The curves show rolling mean occupancy as floor area increases, stratified by bedroom count and overall. Larger dwellings are likely to have more bedrooms and hence more occupants. However, for a fixed number of bedrooms, in 3-bed and larger properties, the bigger the dwelling floor area the smaller the average household size.

For dwellings above 90m^2, these two effects largely cancel out, and there is little change in occupancy with floor area (the black line, which reaches 2.4 occupants near 90m^2: there is another smaller increase around 130-160m^2, but it never strays far above or below its eventual value of 2.8).

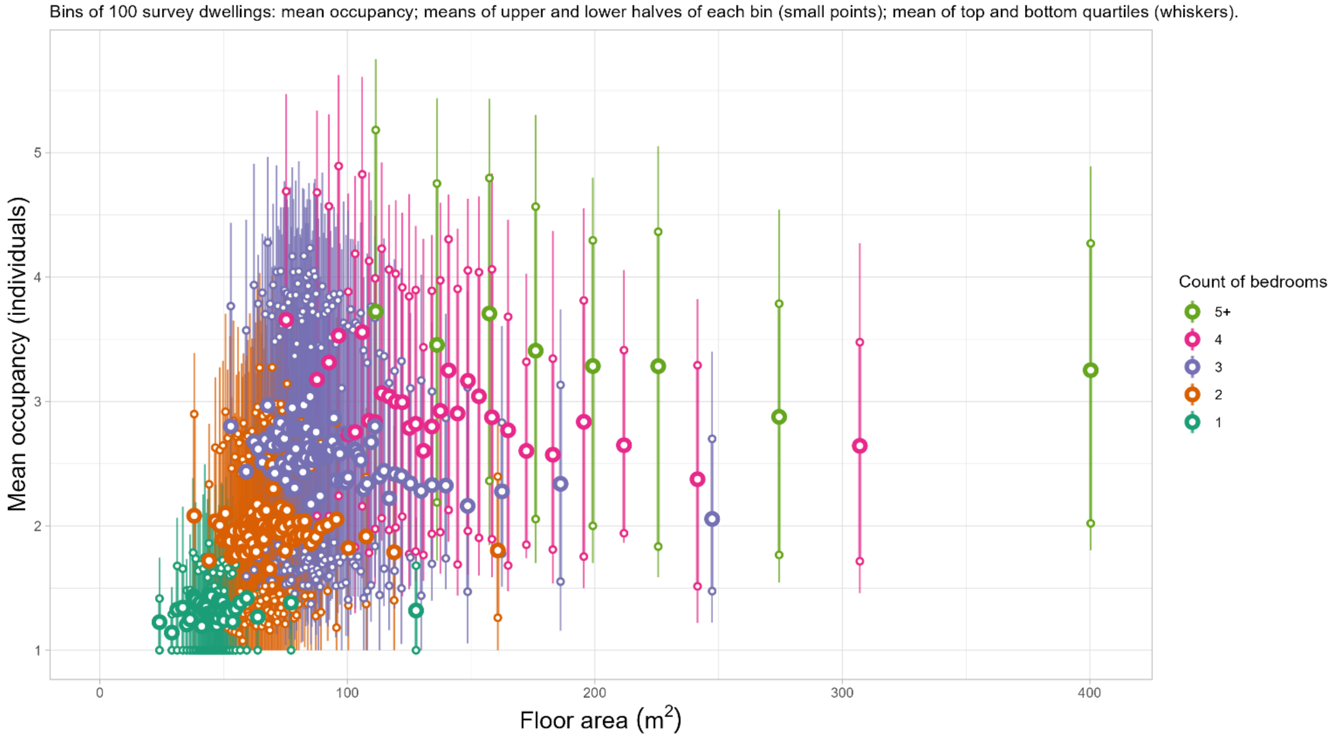

Figure 2 – Variation in occupancy.

Figure 2 shows the variation around the mean occupancy for dwellings of a given size. Here the EHS sample has been binned into groups of 100 survey cases by bedroom, in increasing order of area. The mean occupancy of the more- and less-densely occupied halves of each bin, respectively, and the range between the means of the top and of the bottom quartiles, are shown[5].

Even when looking only at the more densely occupied dwellings, the same pattern of larger 3+ bed homes having fewer occupants can be seen. One-bedroom homes, including studio flats, are again the only case where occupancy generally increases with area.

1.3 Occupancy curves

The standard occupancy function in SAP 10.2 is unchanged from SAP 2009[6]:

$$If\ Total\ Floor\ Area\ (TFA)\ \geq\ 13.9:$$

$$Occupancy\ =\ 1\ +\ 1.76\ (1\ -\ exp(-0.000349\ (TFA\ -\ 13.9)^2))\ +\ 0.0013\ (TFA\ -\ 13.9)$$

$$Else:$$

$$Occupancy\ =\ 1$$

This was fitted on English Housing Condition Survey data from 2002—2005.

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[5] The upper dot in each case is the mean of the filtered bin, as described in the following section, when the truncation parameter plotted in Figure 5 is 0.5. The top of the whisker is the mean of the filtered bin with truncation parameter 0.75.

[6] SAP technical paper STP09/NOFA01, April 2008, accessible at: https://www.bre.co.uk/filelibrary/SAP/2012/STP09-NOFA01_Occupancy_and_floor_area.pdf

Figure 3 makes the case for changing this for the FHS. The chart shows this function superimposed on the current EHS population (showing the mean occupancy for each bin as in Figure 2, and also the weight of each bin in the population). The SAP10.2 curve (hollow yellow line) remains a passable fit up to 100m^2 but overestimates typical occupancy above 100m^2 and fails to capture the clear clustering of homes by bedroom count. An updated sigmoid (using latest EHS survey data) fit to floor area (dashed line) resolves the first issue but not the second. A better solution is therefore a series of sigmoid floor area-dependent curves for each bedroom count (thin coloured lines).

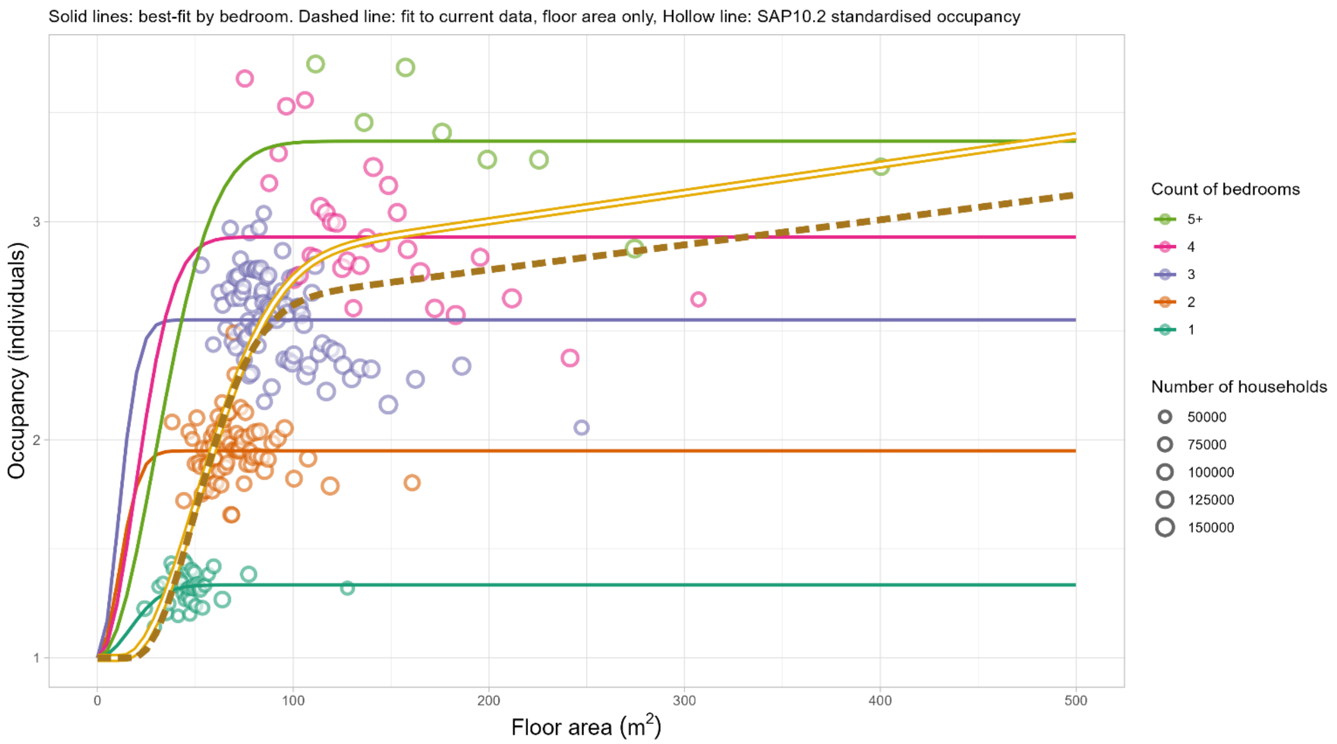

Figure 3 – Sigmoid fits to area by bedrooms and total floor area.

1.4 Disregarding under-occupied dwellings: adjustment of the EHS fit.

Many homes in England are under-occupied. Households' needs for space change over time, but they do not necessarily downsize. In England 36% of households have at least two bedrooms more than they need[7]; but this official measure does not capture the use of space for one- or two-bedroom homes. For the FHS assessment wrapper standardised occupancy, we take a data-led approach rather than seeking to define under-occupancy explicitly. The

[7] Couples are assumed to be able to share a room; children may do so depending on their ages and sexes. https://www.ethnicity-facts-figures.service.gov.uk/housing/housing-conditions/households-under-occupying-their-home/latest

intention is to reflect better the likely design capacity of dwellings by excluding some of the least-occupied homes from the data we fit to.

The rationale for setting the standardised occupancy higher than the best-fit values is as follows: matching the full EHS data is sensitive to the greater level of under-occupancy in large buildings noted above, but typical new build is smaller than the average of the existing stock. Lower occupancy implies a higher load on the heating system but a lower demand for hot water, so under-estimated occupancy may artificially influence the modelled performance of heating systems and drive out other technologies from FHS-compliant buildings.

FHS standardised occupancy has been derived by truncating the least-occupied 25% of dwellings from the EHS data set and fitting the sigmoid curves to the remaining data. The adjustment is distributed across the stock by truncating within the bins of 100 survey cases: that is, by filtering out some of the data behind each dot in Figure 3. In this truncation the weighting of EHS survey cases has been respected, so cases representing more real buildings also represent a higher proportion of their bin.

Figure 4 shows the difference this makes it gives an uplift of about 15% to the modelled occupancy for two or more bedrooms, and 8% for one-bedroom homes. Typical three-bedroom homes have standardised occupancy of just under 3, as opposed to just over 2.5 in the fit to the untruncated data.

For one-bedroom dwellings the sigmoid curve is significant, and standardised occupancy takes a value between 1.2 and 1.44. With more bedrooms the values are essentially constant over the stock, with the sigmoid confined to very small floor area ranges.

In Figure 4 the fitted curves cross each other, suggesting that more bedrooms in some cases means a lower occupancy. This occurs however only for smaller dwellings than can be built in practice. Among feasible buildings a larger home never has lower standardised occupancy than a smaller one. Further explanation is in

Annex A – mathematical details.

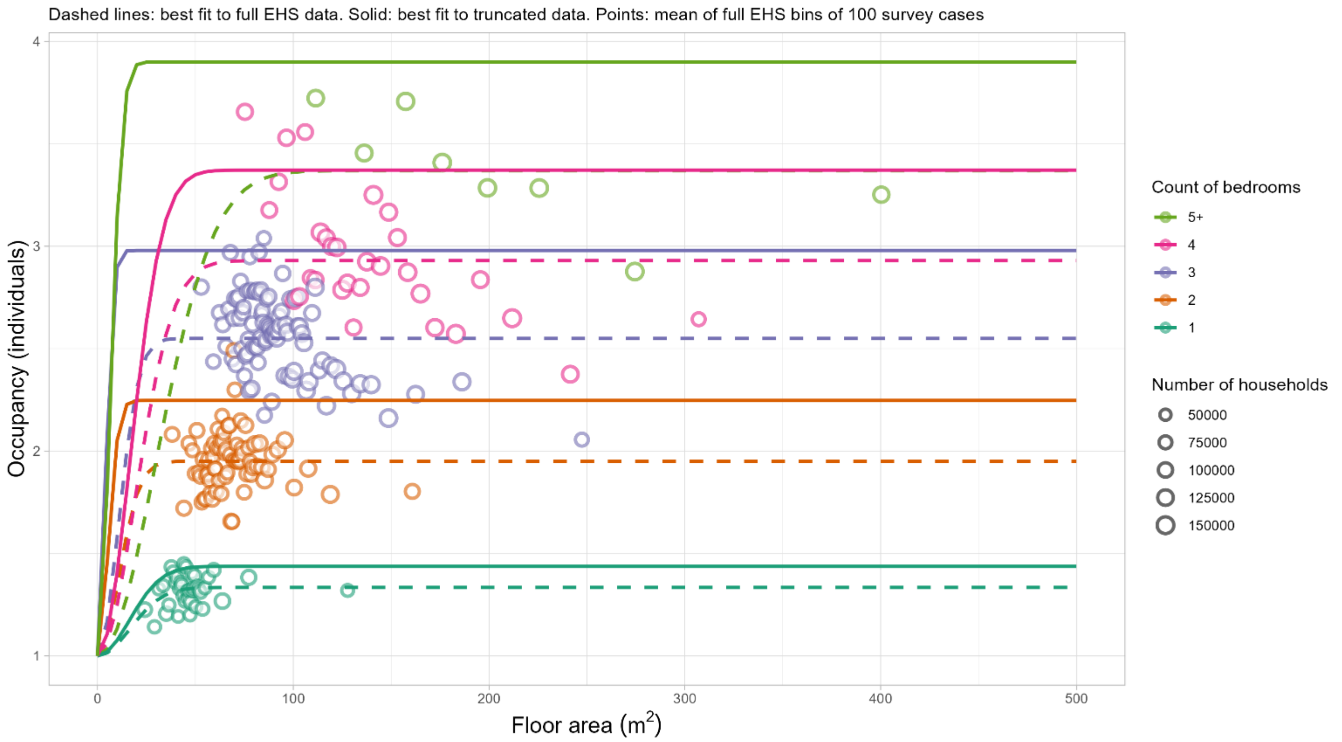

Figure 4 – Adjusted and best-fit sigmoid curves.

1.5 Specification of FHS assessment wrapper standardised occupancy

The fitted sigmoid curves found above are entirely flat (

Annex A – mathematical details), very close to their maximum, over the range of floor areas taken by existing homes with more than one bedroom. In the EHS data considered there are four survey cases for which the adjusted sigmoid is more than 0.01 (one hundredth of an individual) below the asymptotic value. These are all homes with floor areas below 55m^2 which are currently configured with 4 bedrooms. This compares with the National Space Standard minimum for a 4-bed home of 90m^2 (https://www.gov.uk/government/publications/technical-housing-standards-nationally-described-space-standard). These outliers are therefore not relevant to new-build dwellings outside very exceptional circumstances.

For the FHS assessment wrapper the standardised occupancy for dwellings with more than one bedroom can therefore be simplified without losing fidelity to the data. For these homes, the standardised occupancy depends only on the bedroom count, and not on area. The proposed specification is set out in Table 1 and illustrated in Figure 5.

	Bedrooms	Sigmoid function parameters		Constant value	Asymptotic occupancy for large dwellings
		j	k		
Home Energy Model: FHS assessment wrapper standardised occupancy	1+	0.4373	-0.001902		1.44
	2+			2.2472	2.25
	3+			2.9796	2.98
	4+			3.3715	3.37
	5+			3.8997	3.9

Table 1 - FHS assessment wrapper standardised occupancy.

where the sigmoid function for 1-bed homes is defined as

$$\text{Occupancy} = 1 + j\left(1 - e^{k\,A^2}\right)$$

Here A is total floor area.

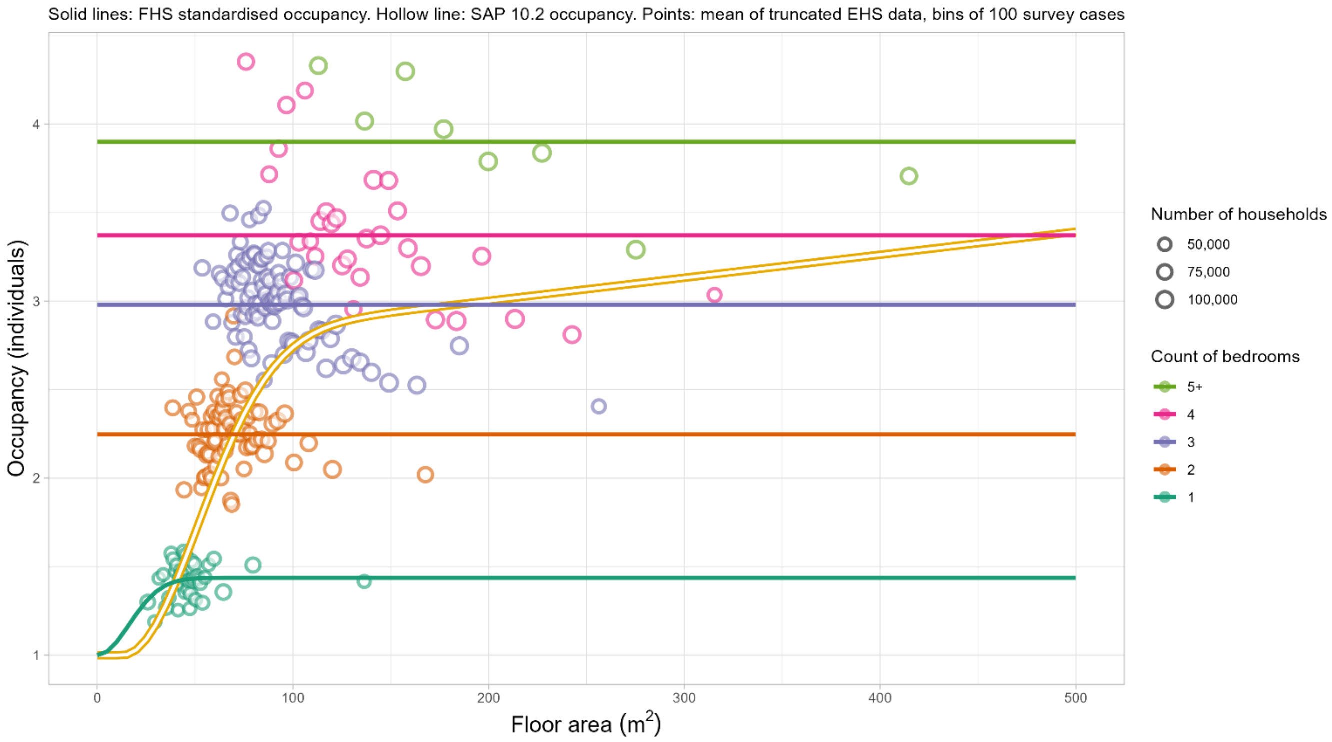

Figure 5 – FHS occupancy function.

1.6 Summary of method

Bringing together all of the above, the final approach used to determine the number of occupants in the FHS wrapper can be summarised in Table 2.

Number of bedrooms	Assumed occupancy
1	$1 + 0.4373\left(1 - e^{-0.001902\,A^2}\right)$
2	2.2472
3	2.9796
4	3.3715
5+	3.8997

Table 2 – Summary of method to determine the number of occupants in the FHS wrapper.

2. Metabolic gains

Metabolic gains are transfers of heat energy from the occupants' bodies into the space. They occur when the occupants are at home, and the rate depends on what they are doing. This energy entering the zone offsets the need for heat to be provided from the heating system.

2.1 Methodology

2.1.1 Metabolic heat output

The ASHRAE method[8] to calculate the heat output in W/m² from a human for a given metabolic rate was implemented in a spreadsheet. This was used to calculate the 6 specified elements of metabolic heat output (Table 3). The reason metabolic gains were split into latent and sensible proportions is so that gains associated with evaporation can be removed. This avoids adding them, only to remove them again via the evaporative losses dealt with elsewhere in HEM (see HEMFHS-TP-07).

[8] ASHRAE-55-2010, pages 23-24.

Type of heat	ASHRAE sub-category	Heat output (Watts)	Description
sensible	HL1	12.04631	Heat loss diff. through skin
latent	*HL2*	*19.5384*	*Heat loss by sweating*
latent	*HL3*	*8.56821*	*Latent respiration heat loss*
sensible	HL4	2.051532	Dry respiration heat loss
sensible	HL5	29.57186	Heat loss by radiation
sensible	HL6	17.43512	Heat loss by convection
mixed	HL(TOT)	89.21143	Total heat loss (sensible and latent)
latent	% latent	31.5%	% of total heat loss latent
sensible	HLdry	61.10482	Total sensible heat loss

Table 3 - Specified elements of metabolic heat output.

A subtotal of these was calculated summing only the non-latent elements, to give the dry heat (HLdry). The reason the dry heat only is required is to avoid adding gains associated with evaporation, only to remove them again via the evaporative losses (lost via ventilation).

Using this calculation, the dry metabolic output in W/m² was then calculated for the various metabolic rates (in MET units) listed for common activities, making assumptions about the level of clothing (in CLO units) for each - see Table 4.

ASHRAE activity categories	MET (3.5 mL O2/kg/min)	CLO (0.155 m² K / W)	dry heat (W/m²)
asleep	0.7	4	35.7209
reclining	0.8	2.25	40.62377
seated quietly	1	1.5	47.26661
standing relaxed	1.2	1.2	52.43967
light work (e.g. standing filing)	1.4	1.05	56.15869
lightish work	1.6	0.95	59.28941
cooking	1.8	0.9	61.10482
gently walking	2	0.85	63.13218
medium walking	2.5	0.75	67.97149
house cleaning	3	0.7	70.86884
brisk walking	3.5	0.65	74.19624
jogging	4	0.6	78.05166

Table 4 - Dry metabolic output in W/m².

It was assumed that these activities took place in the home (given the context of this being used for metabolic gains in a dwelling), assuming a fixed internal air temperature of 20°C and a radiant temperature of 18°C. The relative humidity was assumed to be 50%.

The following graph (Figure 6) compares the dry portion of the heat to the total (including latent heat).

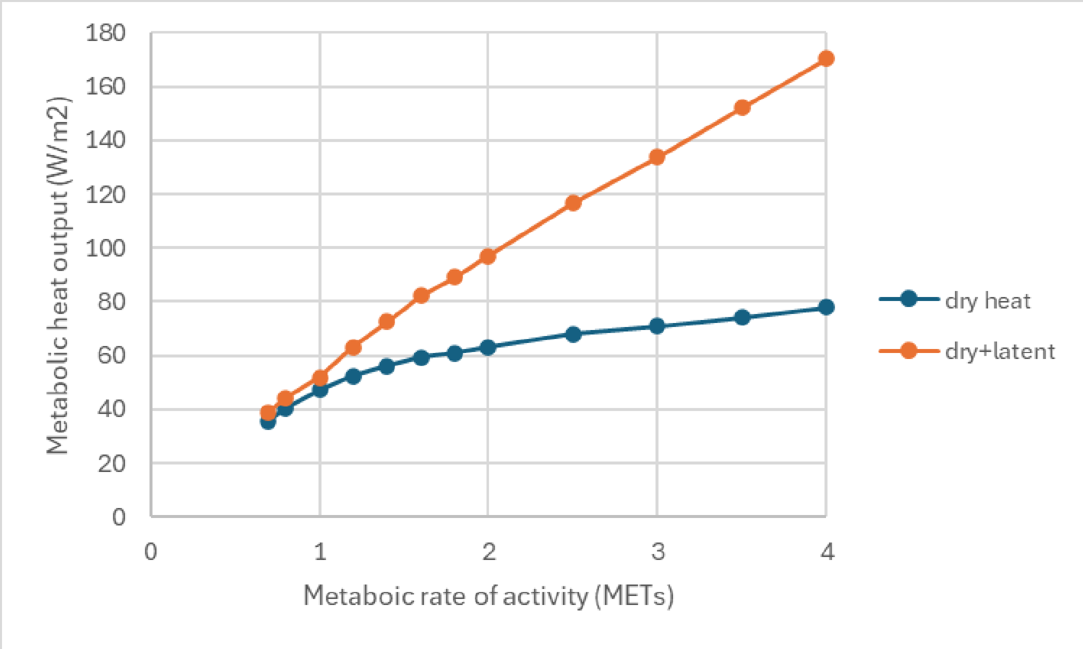

Figure 6 - Dry portion of the heat vs total.

2.1.2 Applying metabolic output to activity profiles

ONS[9] activity data provide the average proportion of time UK occupants partake in various categories of activity, by hour of the day, separating weekdays from weekend days.

By mapping the ASHRAE activity categories to the ONS activities it was possible to assign a dry metabolic heat output level to each activity listed – see Table 5 (‘dry+lat’ is included only for comparison – not used).

Mapping ONS activities to ASHRAE categories			**W/m²**	
ONS category	**Nearest ASHRAE category**	**MET**	**dry heat**	**dry+lat**
Sleep and rest	asleep	0.7	35.721	39.053
Cleaning	house cleaning	3	70.869	133.968
Cooking	cooking	1.8	61.105	89.204
Other home activities	Average of ‘light work’ (1.4) and ‘cooking’ (1.8)	1.6	59.289	82.232
Outside of the home	out	0	0	0
Other / unknown	light work (e.g. standing filing)	1.4	56.159	72.592

Table 5 - Mapping ONS activities to ASHRAE categories.

It was then possible to calculate the weighted average heat output for each hour of the day, as illustrated in the following Table 6 (which represents weekdays).

[9] Time Use In The UK: March 2023, Office for National Statistics, https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/bulletins/timeuseintheuk/march2023

dry gain ▶	35.7209	70.8688	61.1048	59.2894	0.0000	56.1587		W/m^2
Hour	**Sleep and rest**	**Cleaning**	**Cooking**	**Other home activities**	**Outside of the home**	**Other / unknown**	**Check total**	*W. Ave*
0	89.63%	0.35%	0.00%	6.52%	1.90%	1.57%	99.97%	37.023
1	93.47%	0.03%	0.00%	3.48%	1.47%	1.50%	99.95%	36.333
2	95.28%	0.00%	0.00%	1.95%	1.17%	1.50%	99.90%	36.069
3	95.30%	0.12%	0.10%	1.77%	1.12%	1.52%	99.93%	36.116
4	96.87%	0.00%	0.07%	1.58%	0.92%	0.38%	99.82%	35.860
5	92.60%	0.07%	0.43%	3.90%	2.60%	0.37%	99.97%	35.921
6	74.72%	0.52%	1.87%	14.82%	7.73%	0.15%	99.81%	37.143
7	44.55%	1.57%	5.18%	29.65%	18.52%	0.23%	99.70%	38.014
8	21.20%	2.98%	4.15%	35.80%	35.38%	0.33%	99.84%	33.685
9	9.37%	7.23%	3.00%	36.05%	43.43%	0.63%	99.71%	32.125
10	5.18%	8.68%	2.40%	35.50%	47.40%	0.70%	99.86%	30.952
11	3.35%	8.30%	3.67%	32.78%	51.07%	0.65%	99.82%	29.174
12	1.98%	6.85%	5.77%	31.93%	52.75%	0.65%	99.93%	28.404
13	2.83%	7.27%	4.68%	33.82%	50.78%	0.57%	99.95%	29.409
14	2.83%	7.97%	2.65%	36.40%	49.62%	0.50%	99.97%	30.150
15	3.07%	6.32%	3.32%	39.98%	46.63%	0.62%	99.94%	31.675
16	3.05%	6.03%	6.88%	41.85%	41.33%	0.92%	100.06%	34.875
17	2.92%	5.68%	12.68%	43.87%	34.37%	0.60%	100.12%	39.117
18	2.22%	6.10%	11.38%	52.82%	26.95%	0.63%	100.10%	43.696
19	2.18%	5.25%	6.45%	62.45%	22.72%	0.85%	99.90%	45.990
20	3.77%	3.82%	2.67%	72.78%	15.63%	1.35%	100.02%	49.584
21	12.00%	1.93%	1.08%	72.90%	10.53%	1.62%	100.06%	50.416
22	39.27%	1.33%	0.40%	50.00%	6.92%	1.90%	99.82%	46.009
23	73.53%	0.60%	0.07%	20.57%	3.55%	1.62%	99.94%	39.863

Table 6 - Weighted average heat output for each hour of the day.

Note that due to rounding errors in the original data, the total proportions for each hour do not add to exactly 1, so a final correction is made for this by dividing by the sum of the individual proportions (denoted ‘check total’ in Table 6).

This was done for weekdays and weekends, giving the following profiles (Figure 7):

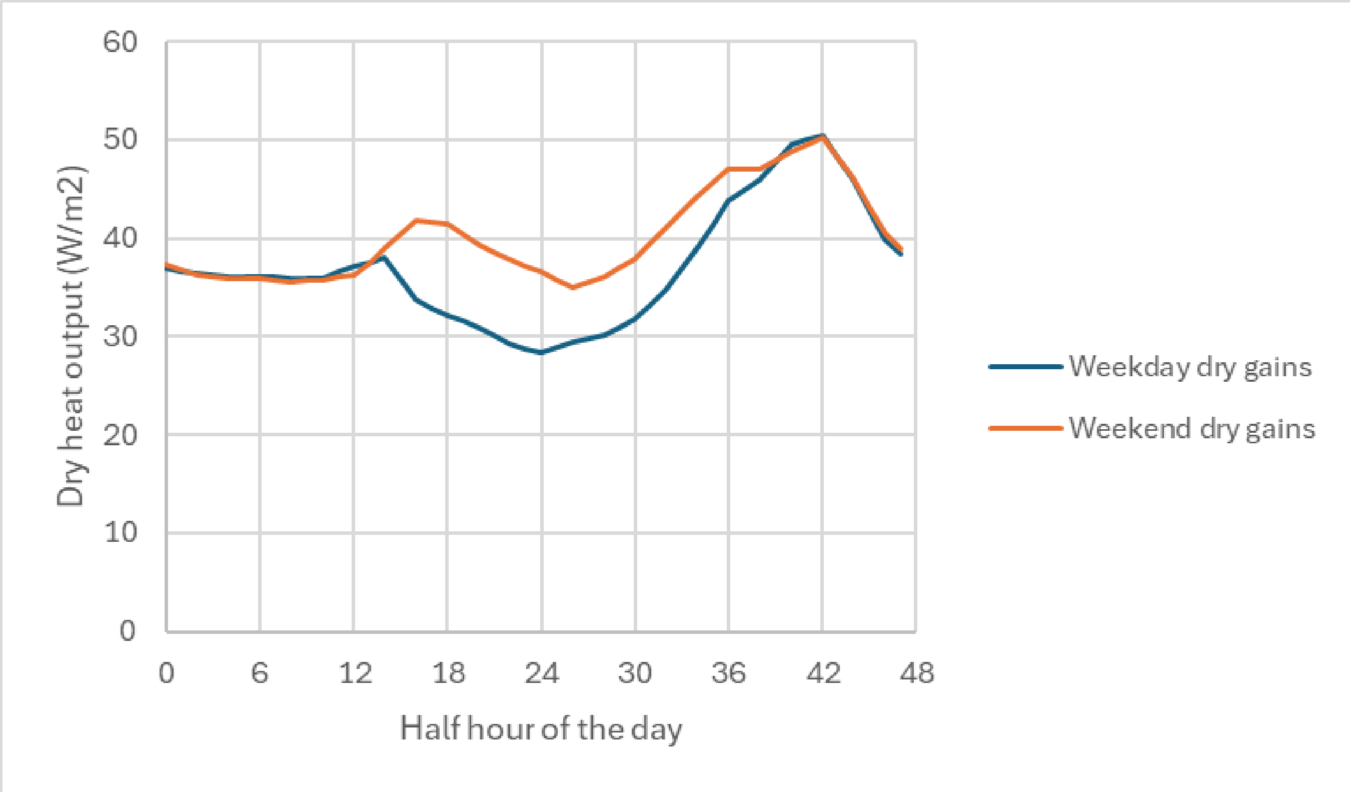

Figure 7 - Dry heat output for weekday and weekend dry gains.

Note that the hourly periods have been converted to half-hour periods by interpolation in the above graph (Figure 7), since this is the format most directly consumable in the FHS wrapper.

2.1.3 Converting from W/m^2 to W

The metabolic heat gain in W/m^2 needs to be converted to W by multiplying by the total body surface area of the occupants. It was previously assumed that the surface area of each occupant was 1.8m^2 (a typical figure for an adult). However, some occupants will be children, so this was an overestimation.

To improve this aspect of the calculation, NHS data[10] on weights and heights was analysed. The 2019 data set[11] was used since this was the most recent to contain data for children.

It was then possible to use the 'Du Bois' formula[12] for estimating body surface area from weight and height:

$$BSA = 0.007184 \times weight^{0.425} \times height^{0.725}$$

[10] Health Survey for England, 2021: Data tables - NHS England Digital
[11] HSE19-Overweight-obesity-tab.xlsx (live.com) – see tables 1, 2, 14 and 15.
[12] DuBois D, Dubois EF. A formula to estimate the approximate surface area if weight and height be known. Arch Intern Med 1916;17:863-871

This yielded the following average body surface areas[13] (Table 7):

	Height (cm)	Weight (kg)	Surface area (m²)
Adult	168.40	78.60	1.8881
Child	128.69	33.01	1.0700

Table 7 - average body surface areas.

EHS data for the number of adults and children in a household was then used to derive a formula to estimate the total body surface area of occupants as a function of the total number of occupants, taking account of the proportion of adults and children. This was achieved by analysing data from two full EHS surveys (2017-2018 and 2019-2020) combined and with their weights renormalised (using the same data as for the original occupancy calculations). The number of occupants was then capped by removing entries with more than 10 occupants (there are only 3 cases with more than 10 occupants representing just 0.0125% of the combined stock) to avoid spurious fits resulting from low number statistics at the high occupancy end.

For each dwelling in the stock the actual number of adult and child occupants were extracted from the combined EHS data and converted into a total Body Surface Area (BSA) by multiplying the number of adults and children by the respective average surface area for each derived above such that

$$BSA = (Number\ of\ adults \times 1.8881) + (Number\ of\ Children \times 1.0700)$$

The relationship between BSA and the actual occupancy of the dwellings was assumed to follow a power law which was fit using a least squares minimisation technique taking account of the weights assigned to each household in the EHS to ensure that the sample accurately represents the population of households in England.

Figure 8 below shows the mean total Body Surface Area for each total occupancy with the vertical bars showing the standard deviation about this mean to indicate the spread of the data. The green line represents the line of best fit to the full data sample.

[13] The BSA for children is a weighted average of the BSAs calculated using the weights/heights for each age groups in the NHS data, which gives a slightly different answer to calculating it from the already averaged weights and heights shown in the table.

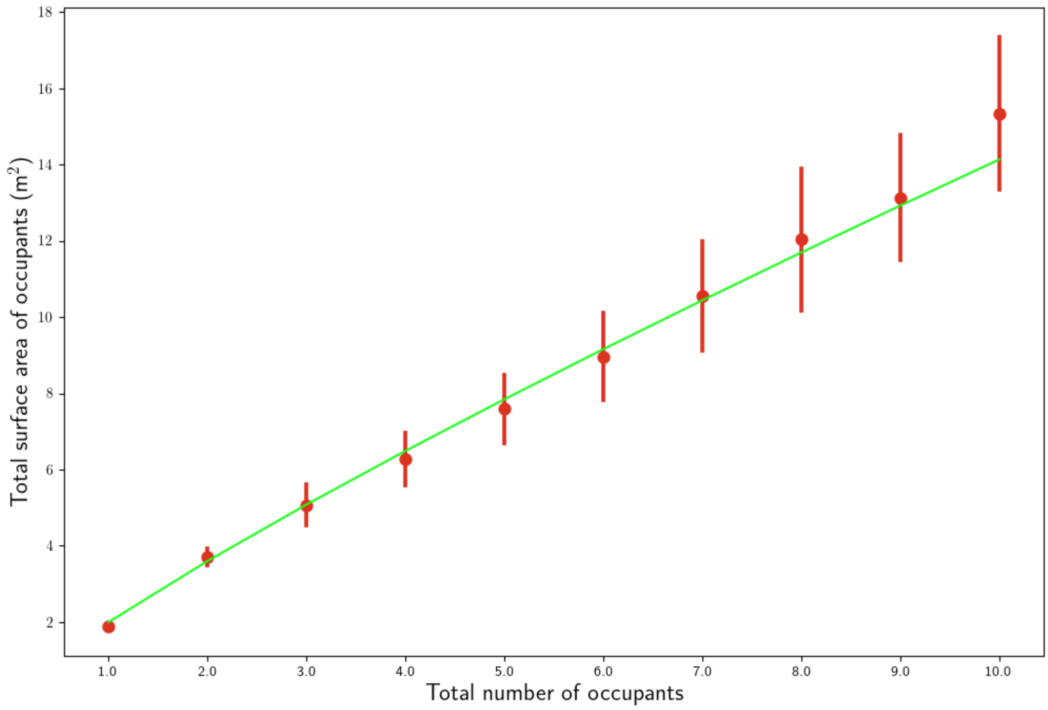

Figure 8 - Plot showing the relationship between Total Body Surface area and the number of occupants in a dwelling. The red points show the weighted mean total body surface area at each occupancy value with the red vertical bars showing one standard deviation about that mean to indicate the spread of the data at that occupancy value. The green solid line shows the line of best fit to the full weighted sample representing the entire population of households in England.

The equation giving this best fit through the data can then be applied to calculate total body surface area for any number of occupants (including non-integers):

$$BSA = 2.0001 \times Occupancy^{0.8492}$$

The resulting total Body Surface Area can then be multiplied by the dry metabolic rate for each half-hour of the day to give the dry metabolic gains in W, for inclusion in the data sent to HEM's core calculation engine.

2.2 Impact

Comparing the metabolic gain level from the new method to the previous method (in place in the time of the FHS consultation in December 2023) for an example case with 2.62 occupants shows that the profile of metabolic gains is now quite different from before (Figure 9):

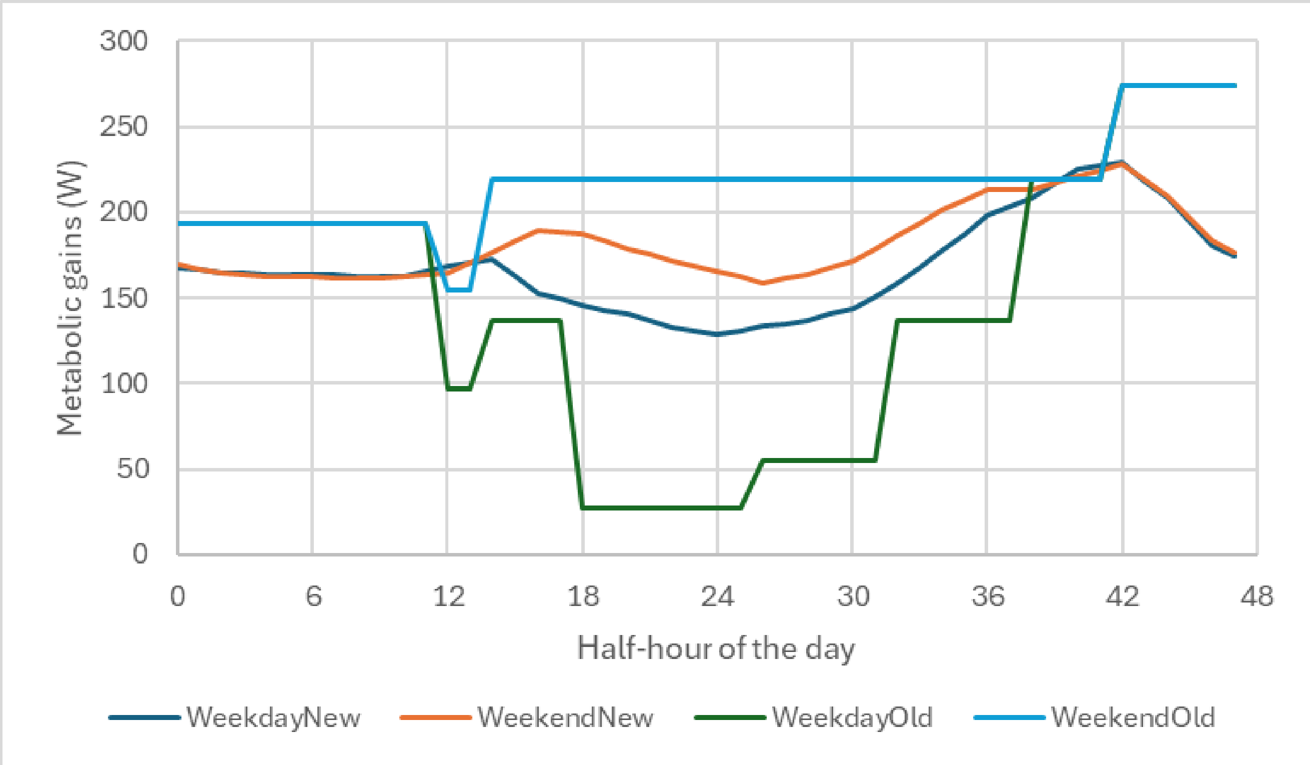

Figure 9 – Methods comparison metabolic gain level.

The average level of gains over 24 hours is higher in this example by an average of 16% on weekdays and lower by 16% on weekend days. As there are more weekdays, overall, this would tend to increase the metabolic gains over the course of a week by around 7%. Note that this would vary depending on the number of occupants, with larger increases for homes with fewer occupants and smaller increases, or in some cases decreases, for homes with more occupants.

The main reasons explaining the changes are as follows:

- The previous method did not have latent heat removed (nor was this energy subsequently removed via evaporative losses, so this was incorrect). Removing this accounts for a reduction of around 25% in the level of metabolic gains.
- All occupants were assumed to have an area of 1.8m² previously. Now adults are assumed to have an area of 1.89m² and children 1.07m². In this example this reduces total body surface area by 4%[14].

[14] This may seem a minor change, but a home with 2.62 occupants, on average, consists mostly of adults, where the body area assumed has *increased*, nearly offsetting the inclusion of the smaller body area for children. In a home with more occupants, a higher proportion of children would be assumed, and a greater reduction would be seen.

- There are substantial changes in the assumed time/amount people are present in the home, based on the more accurate ONS activity data. A *higher* proportion of people are now assumed to be out during the day at the weekend and a *lower* proportion out during the day on weekdays. This accounts for the increase in weekday gains and the decrease in weekend gains seen in this example.
- We have moved away from the previous assumption that the daytime activity level was constantly equivalent to 'quiet seated.' This had been a deliberately conservative assumption made in light of the fact other simplifications were known to increase metabolic gains (e.g. adult body area being used for all occupants). In the new method, a more realistic mix of activities is assumed based on ONS data. This change leads to an increase in metabolic gains, counteracting the decreases due to the removal of latent heat and the reduction in body surface area.

Annex A – mathematical details for occupancy derivation.

This Annex explains some choices made in the methodology for this determining standardised occupancy the type of curves considered, and the value of the truncation parameter excluding the least-occupied homes.

Number of coefficients.

The functional form of the occupancy functions presented in this analysis inherit from the sigmoid curves fitted for SAP2012 – SAP10.2. Other forms were analysed but did not offer any improvement to the fit. Sigmoid curves have the desirable properties of smooth transitions between low and high values and either a finite maximum value or finite asymptotic growth. Curve fitting was performed in R version 4.2.2, using the function nls.lm from the minpack package version 1.2-3 implementing non-linear least squares optimisation.

The previous SAP10.2 occupancy curve was specified with four coefficients as:

$$\text{Occ}_{10.2} = 1 + j\left(1 - e^{k(A-x_0)^2}\right) + m(A - x_0)$$

with fitted values as in Table A1. Here m is a linear term permitting occupancy to grow without limit as floor area increases, A is the Total Floor Area, and x_0 is an offset to the position of the sigmoid.

For the data stratified by bedroom count the simpler functional form

$$\text{Occ} = 1 + j\left(1 - e^{k\,A^2}\right)$$

was used. The linear term m is constrained to be non-negative (or larger buildings would have smaller occupancy) but in the data average occupancy is ultimately decreasing (as explained above) and the optimal solutions have $m = 0$, on the boundary of the permissible set. As the optimal solution was certain to lie on this boundary, the linear term with its parameter m were excluded. The offset parameter x_0 was also removed as the non-linear optimiser did not converge when it was included. The reason for this is explained below.

Of the remaining two parameters, j is the asymptotic value: large buildings will have occupancy close to $1 + j$. The value of k sets the width of the sigmoid, which takes its midpoint value $1 + j/2$ at $A = \sqrt{\ln 2}/\sqrt{-k}$.

Under-determination of sigmoids

With the exception of 1-bedroom dwellings the fitted curves reach their maximum level to the left of the data: even the smallest homes in the stock have the same occupancy as all the others. The parameter k, determining the width of the sigmoid, is thus under-determined: for any sufficiently large negative k (that is, any sufficiently narrow sigmoid) the fitted occupancy function will take essentially the same value for all the dwellings in the data, and the non-linear optimiser is fitting to a very small signal in the observed sample. As the truncation parameter varies, indeed, the fitted value of k remains constant for beds = 1, but takes apparently random values for beds = 2 or more. Describing these curves with both k and the offset parameter x_0 is even less well-determined and with x_0 retained as a free variable the nonlinear optimiser did not converge.

In general, as the number of bedrooms increases so does the floor area of the smallest possible home, so the curve for 5-bed dwellings is free to reach its maximum at a larger area without it affecting the fitted value for any dwelling in the data. So, if the underdetermined parameter is chosen at random by the nonlinear solver, we expect the fitted sigmoids to cross.

Sensitivity to the truncation parameter

Figure A1 plots the sensitivity of standardised occupancy, derived by this method, to the truncation parameter. It shows what the standardised occupancy for typical-to-large buildings would be, depending on the degree of truncation chosen, (i.e., it plots the asymptotic value for large floor areas of the fitted occupancy function as the truncation parameter varies). For the FHS the truncation is at 0.25 on the x-axis, where the y values of the five bedroom curves align with the levels achieved in Figure 4.

Not shown is the shape parameter determining at what floor area the sigmoid approaches its asymptote. Note that the overall best-fit curves have their asymptotic values represented at the far left of the chart (truncated proportion = 0).

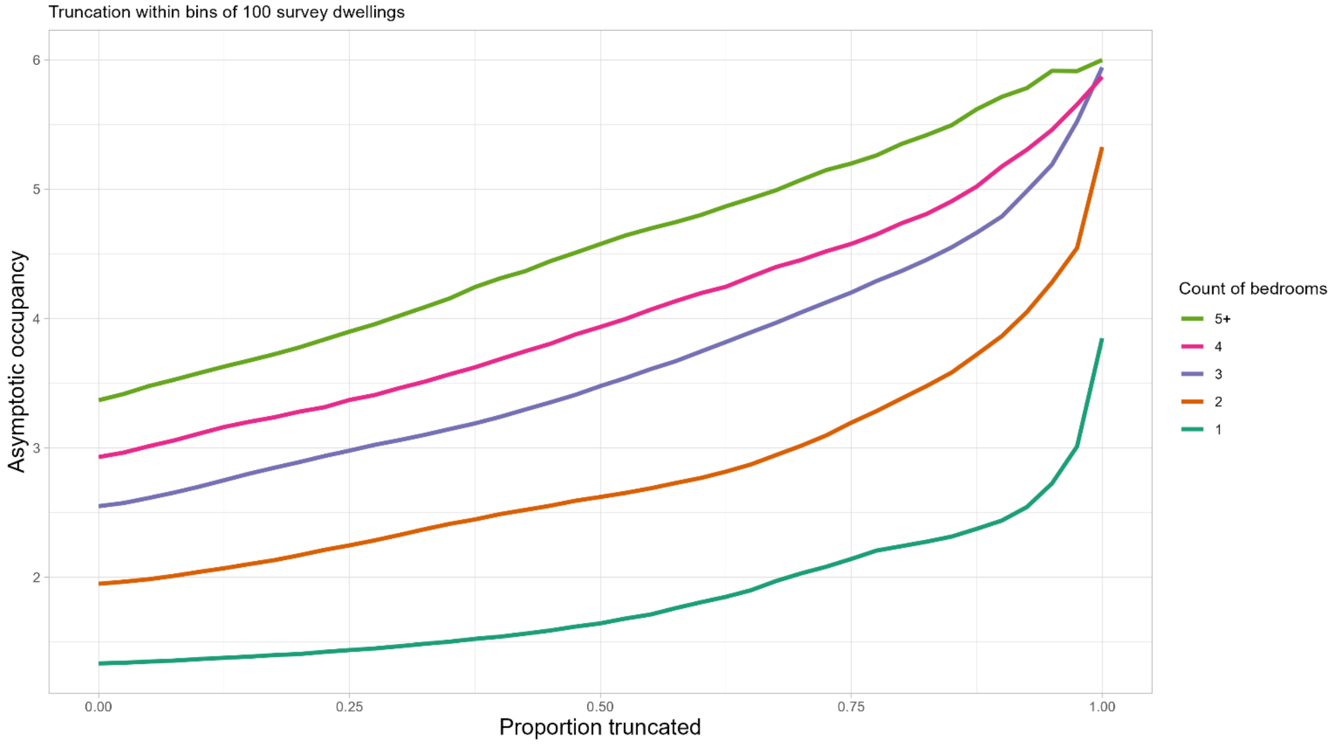

Figure A1 – Asymptotic occupancy by proportion of low-occupancy homes filtered out.

Figure A2 shows the SAP 10.2 occupancy function alongside the adjusted sigmoid curves, at the selected 25% truncation. At this truncation, the SAP 10.2 curve is very close to the adjusted curves for the most typical 1- and 2-bedroom dwellings, passing centrally through the clouds of points representing the midpoints of the truncated bins. The SAP 10.2 curve departs from the truncated data points for homes with three or more bedrooms, and for unusually large or small dwellings for their bedroom count the adjusted curves are visibly closer to the data.

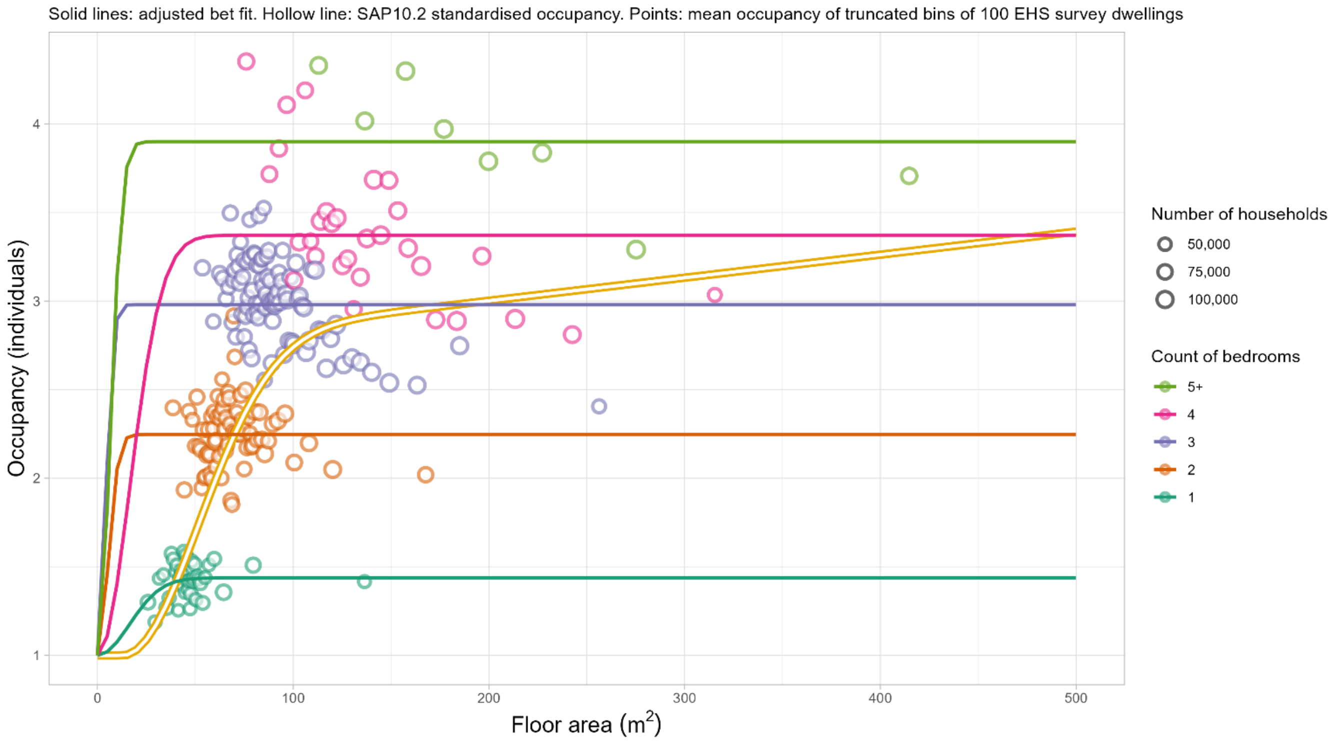

Figure A2 – SAP10.2 occupancy against the adjusted best-fit sigmoids.

Parameters for the sigmoid occupancy curves

Table A1 contains parameters for the various functions fitted during this analysis, for reference. Other occupancy functions may be useful for users of the Home Energy Model beyond assessing compliance with the FHS.

Where occupancy is a function of the number of bedrooms, the sigmoid curves are specified using the functional form

$$\text{Occupancy } = 1 + j\left(1 - e^{k\,A^2}\right)$$

where A is the total floor area of the dwelling[15] and j and k are coefficients read from the row of Table 1 for the number of bedrooms in the dwelling.

Coefficients for the EHS overall best fit by bedrooms, the SAP10.2 occupancy function, and the result of fitting a single sigmoid to all dwellings regardless of bedroom count, are included for reference. For the SAP 10.2 and best-fit single curves the functional form is

$$\text{Occupancy } = 1 + j\left(1 - e^{k\,(A-x_0)^2}\right) + m(A - x_0).$$

The floor area at which the sigmoid reaches half of its final value is reported, to describe the width of the curved part of the functions: it is notable that these would all be extremely small dwellings.

[15] As defined in the Building Regulations. For the analysis in this note this was proxied with the EHS derived variable *floory*, adjusted to include unheated conservatories in the gross internal area.

	Bedrooms	Asymptote of sigmoid j	Width of sigmoid k	linear component m	offset x0	Asymptotic occupancy for large dwellings	Midpoint of sigmoid / m²
Adjusted sigmoid occupancy	1	0.4373	-0.001902			1.44	19.09
	2	1.2472	-0.018511			2.25	6.12
	3	1.9796	-0.031784			2.98	4.67
	4	2.3715	-0.001866			3.37	19.27
	5+	2.8997	-0.013386			3.90	7.20
Best fit sigmoid occupancy	1	0.3342	-0.001824			1.33	19.49
	2	0.9498	-0.004389			1.95	12.57
	3	1.5498	-0.004645			2.55	12.22
	4	1.9300	-0.001368			2.93	22.51
	5+	2.3692	-0.000573			3.37	34.77
SAP 10.2		1.76	-0.000349	0.0013	13.9	-	44.57
Best fit single curve		1.752	-0.000807	0.000077	26.32	2.75	29.30

Table A1 - coefficients of sigmoid occupancy functions.

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