Occupancy assumptions in the Home Energy Model: FHS assessment wrapper

A technical explanation of the assumptions.

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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 2025 Future Homes Standard (FHS).It builds on the government's Home Energy Model, which will replace the government's Standard Assessment Procedure (SAP).

The Home Energy Model: FHS assessment is still under development and its first version will be implemented alongside the FHS in 2025. We are publishing information about the model while it is still at a formative stage to enable industry to participate in the ongoing development process.

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 go into further detail on the assumptions and the validation exercises that have been carried out. We intend to update and produce further technical documentation throughout the model development process.

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

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

Audience: The Home Energy Model: FHS assessment consultation 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 proposed FHS compliance metrics.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model and the Home Energy Model: FHS assessment has been published as a Git repository. This code is identical to that sitting behind the consultation tool. We are currently considering whether the open-source code could serve as the legal approved methodology for demonstrating whether new homes comply with energy performance standards in the Building Regulations.

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.

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 housing occupancy assumption for the Future Homes Standard 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 there are, so the occupancy assumption underlies the calculation of these energy uses, and of associated incidental losses to cold water and evaporation. This paper also contains 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 papers 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 Future Homes Standard 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.

Occupancy analysis for the Future Homes Standard is based on recent occupancy data from the English Housing Survey (EHS) 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 Future Homes Standard is intended to reflect the designed use of the dwelling. A higher standard occupancy leads to increase modelled hot water use but, because occupants’ activities provide heat gains into the space, to decrease 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.

The best-fit parameters to the EHS data are also reported in this paper, 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)[1].

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 Future Homes Standard assessment wrapper we keep this functional form but add a dependency also on the number of bedrooms[2]. 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)[3] 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).

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[1] 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

[2] 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.

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

Chart 1: Occupancy vs floor area, rolling means by bedroom count and overall

Points: EHS survey cases top-coded (occupancy not above 6, bedroom count not above 5). Black curve: rolling mean of all survey cases.

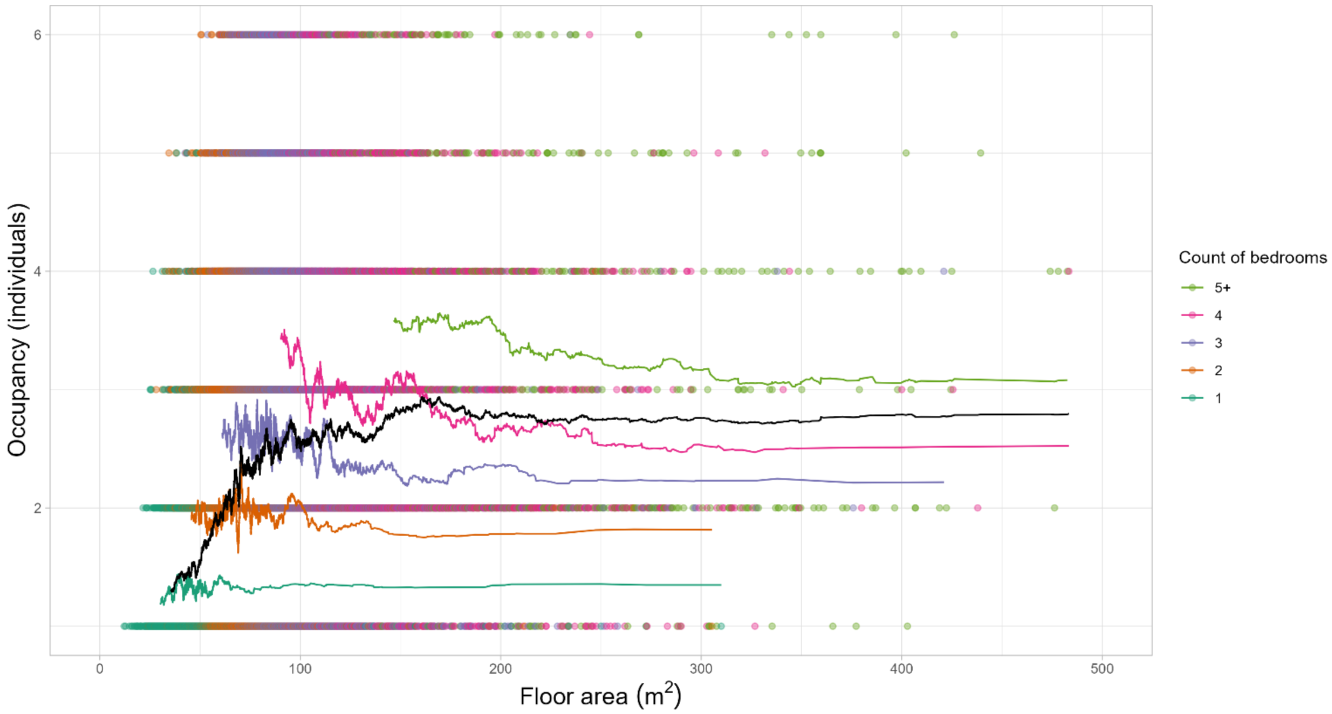


Chart 1 plots the EHS survey cases by floor area, bedroom count and surveyed occupancy. Households of all sizes occupy homes of all sizes, except that there are few 1-bed dwellings with five or more residents. Note that the EHS household size is always a whole number.

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 90m2, 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 90m2: there is another smaller increase around 130-160m2 but it never strays far above or below its eventual value of 2.8).

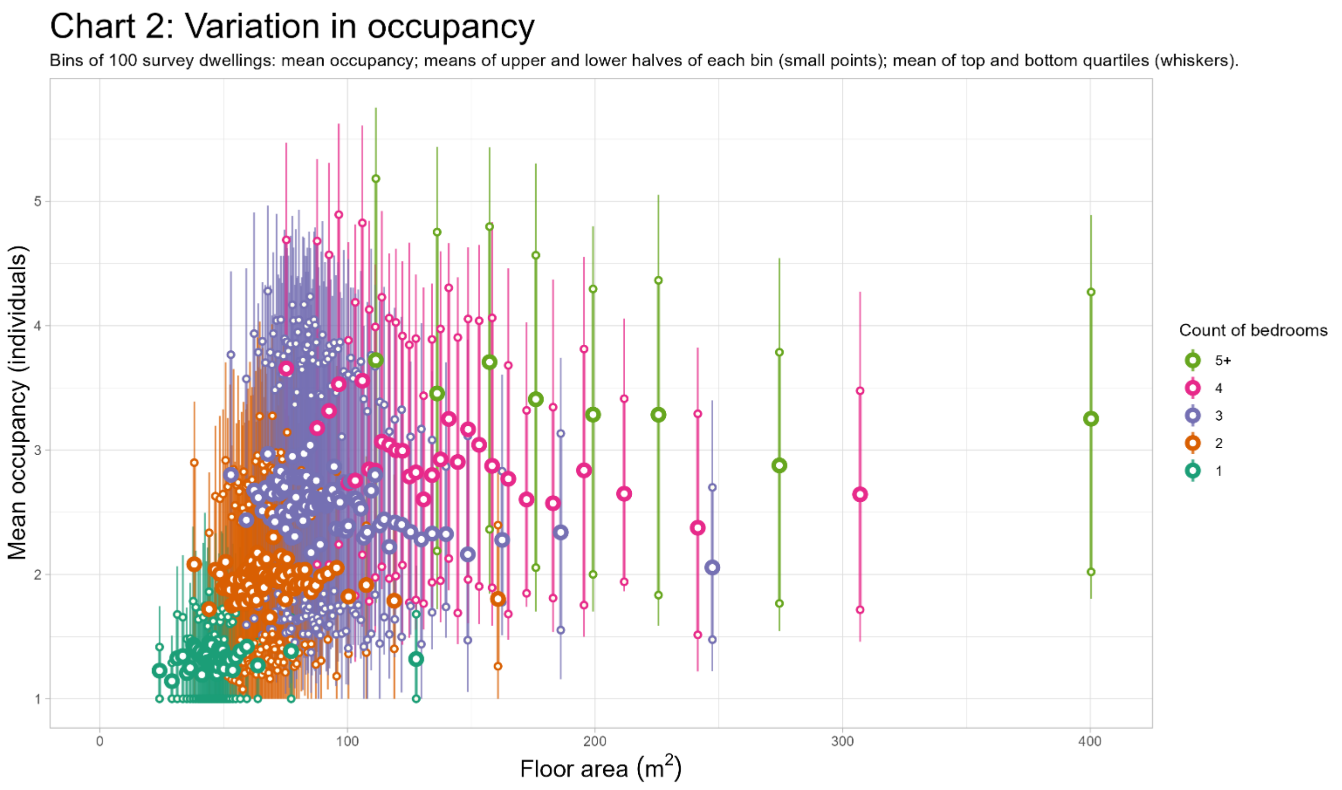


Chart 2 shows the variation around the mean occupancy for dwellings of a given size. Here the EHS sample has been binned into groups of 100 survey cases by bedroom, in increasing order of area. The mean occupancy of the more- and less-densely occupied halves of each bin, respectively, and the range between the means of the top and of the bottom quartiles, are shown[4].

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[5]:

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

[4] 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 chart 5 is 0.5. The top of the whisker is the mean of the filtered bin with truncation parameter 0.75.
[5] SAP technical paper STP09/NOFA01, April 2008, accessible at: https://www.bre.co.uk/filelibrary/SAP/2012/STP09-NOFA01_Occupancy_and_floor_area.pdf

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

$Else:$

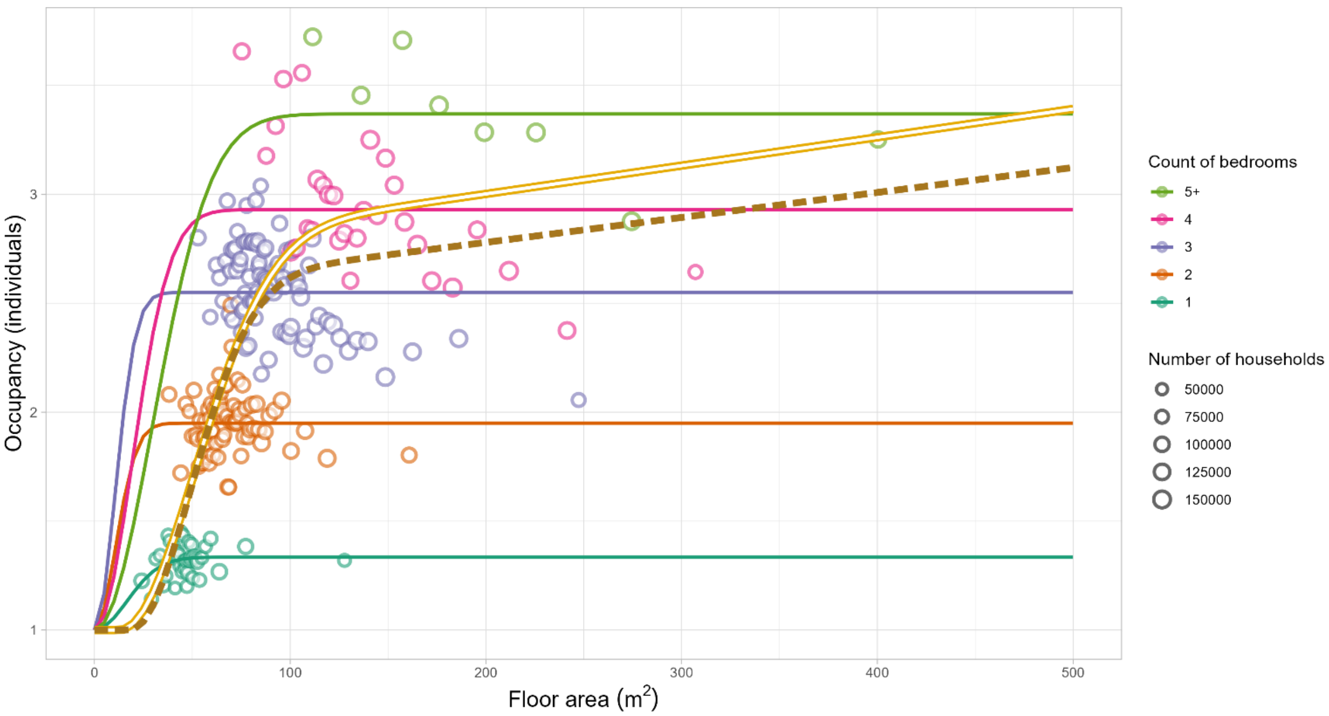
$$Occupancy\ =\ 1$$

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

Chart 3 makes the case for changing this for the Future Homes Standard. The chart shows this function superimposed on the current EHS population (showing the mean occupancy for each bin as in Chart 2, and also the weight of each bin in the population). The SAP10.2 curve (hollow yellow line) remains a passable fit up to 100m2 but overestimates typical occupancy above 100m2 and fails to capture the clear clustering of homes by bedroom count. An updated sigmoid 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).

Chart 3: Sigmoid fits to area by bedrooms and floor area

Solid lines: best-fit by bedroom. Dashed line: fit to current data, floor area only, Hollow line: SAP10.2 standardised occupancy



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[6]; but this official measure does not capture the use of space for one- or two-bedroom homes. For the Future Homes Standard assessment wrapper standardised occupancy we take a data-led approach rather than seeking to define under-occupancy explicitly. The 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. And 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 Future Homes Standard-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 chart 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.

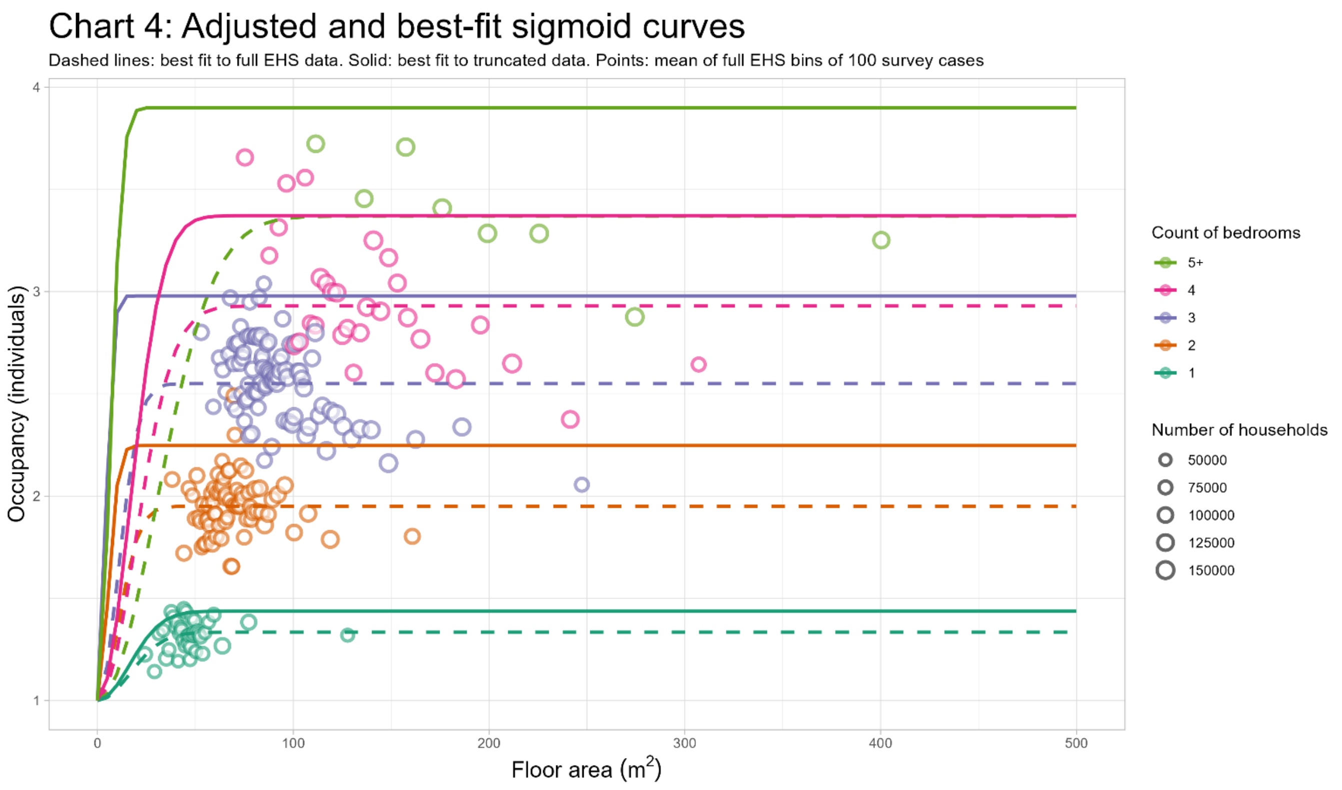
Chart 4 shows the difference this makes: it gives an uplift of about 15% to the modelled occupancy for two or more bedrooms, or 8% for one-bedroom homes. Typical three-bedroom homes have standardised occupancy of just under 3, as opposed to just over 2.5 in the fit to the untruncated data.

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 the technical annex, below.

As noted in HEM-VAL-01 Intermodel validation, the impact of FHS assessment wrapper assumptions, including occupancy, on modelled energy use will continue to be tested as part of the on-going validation process of HEM and HEM-FHS.

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



1.5 Specification of FHS assessment wrapper standardised occupancy

The fitted sigmoid curves found above are entirely flat, 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 55m2 which are currently configured with 4 bedrooms. This compares with the National Space Standard minimum for a 4-bed home of 90m2 (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 chart 5.

Table 1 – FHS assessment wrapper standardised occupancy

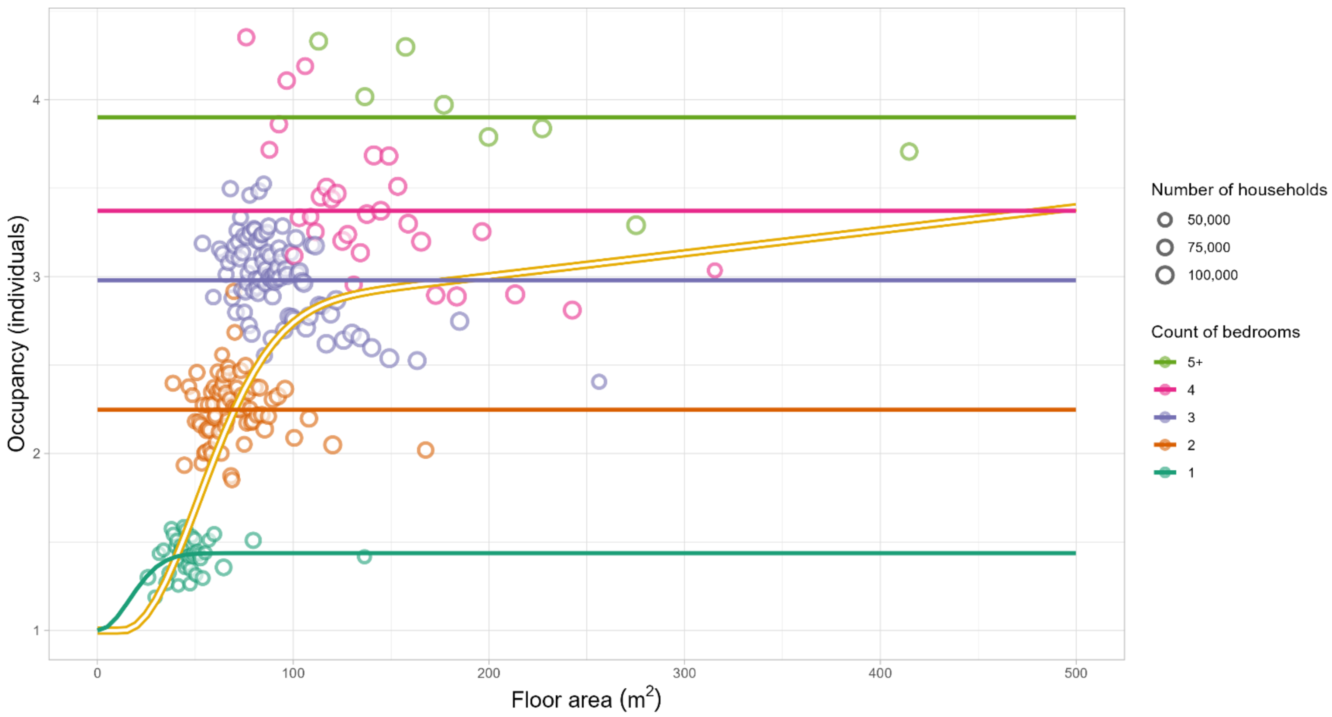
		Sigmoid function parameters		Constant value	Asymptotic occupancy for large dwellings
	Bedrooms	**j**	**k**		
Home Energy Model: FHS assessment wrapper standardised occupancy	1+	0.4373	-0.0019		1.44
	2+			2.2472	2.25
	3+			2.9796	2.98
	4+			3.3715	3.37
	5+			3.8997	3.9

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

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

Chart 5: Future Homes Standard occupancy function

Solid lines: FHS standardised occupancy. Hollow line: SAP 10.2 occupancy. Points: mean of truncated EHS data, bins of 100 survey cases



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.

2.1 Occupancy factor

This is the proportion of the household assumed to be at home at any time. Separate profiles are assumed for weekdays and weekends. The values are drawn from Annex C of BS EN 16798-1:2019, as illustrated in chart 8. Over the course of a week residents are out of the home 22% of the time, and the weighted occupancy factor is 0.78. The same profile is applied for every week of the year, with no allowance for seasonal variation or holidays.

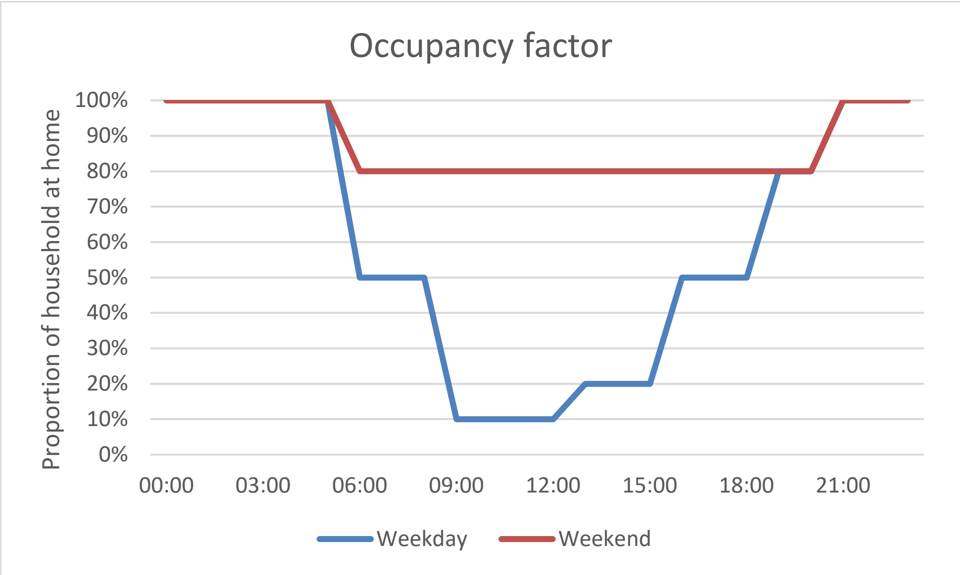


Chart 6 – BS EN 16798-1:2019 occupancy factors

2.2 Metabolic rates

Metabolic gains in buildings are covered in CIBSE Guide A, Environmental Design[7] which incorporates methodology from BS EN ISO 7730:2005. The method assesses thermal comfort for building occupants by looking at the heat balance between them and their environment. Accordingly metabolic rate is expressed in units of watts per m2 of body area. The reference activity level, 1 "met" = 58.15 W/m2; sleep is 0.7 mets; most sedentary activity is 1.1 mets and other domestic activities might be up to 1.7 mets.

[7] Guide A Environmental design (2015, updated 2021), Chartered Institute of Building Services Engineers, https://www.cibse.org/knowledge-research/knowledge-portal/guide-a-environmental-design-2015

We assume a low activity level in the occupants when at home, as shown in table 2. This is not entirely realistic as a freestanding assumption. However the standard references the average body area of an adult, 1.8m2, which is likely to be higher than the true population average (since children and the elderly would typically have smaller body areas). Additionally some proportion of the metabolic output is released as latent heat of water vapour in the breath or sweating (ranging from 8% at rest to 42% in extreme exertion, if calculated by the methodology of the standard referred to above). Exactly capturing this requires better understanding of true activities in the home. The low assumed activity level is intended to compensate for these biases pending further study (see Future development section).

Table 2 – Assumed metabolic gains

Activity	Metabolic rate (mets)	Metabolic output (W/m2)	Metabolic gains per occupant (W)	Time
Sleeping	0.7	41	73.8	00:01 – 07:00
Seated quiet	1.0	58	104.4	07:00 – 23:59

The resulting metabolic gains assumed in the dwelling are shown in chart 7.

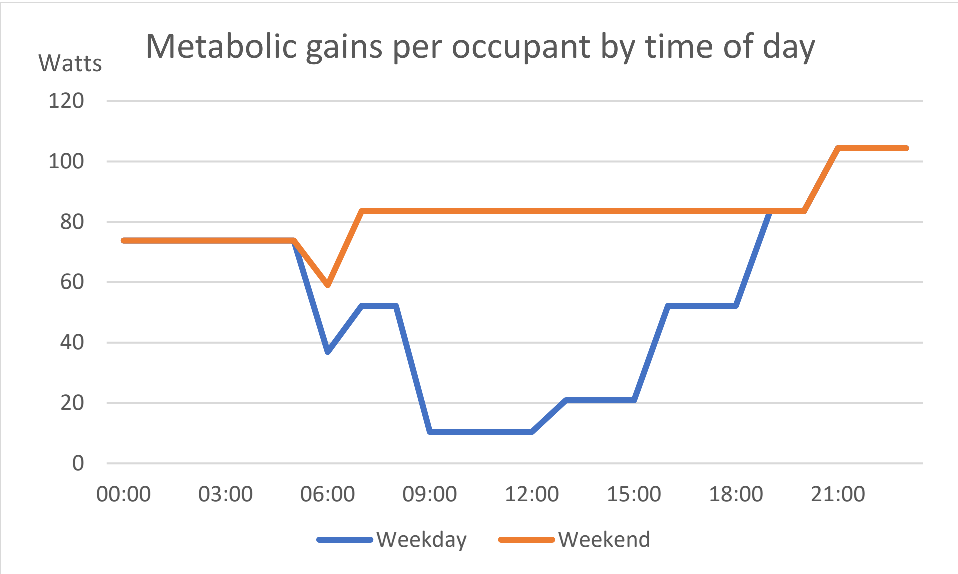


Chart 7 – FHS assessment wrapper profile of metabolic gains per person taking into account activity levels and occupancy factor.

Future development

Ongoing validation exercises for the Home Energy Model and FHS assessment wrapper will examine the effect of varying occupancy in the model. A response to these exercises might be to change the truncation parameter used to set standardised occupancy.

Further study is proposed to refine the metabolic gains assumptions, making use of data from the ONS study Time Use in the UK[8] to identify activity levels and time spent at home, and from EHS demographic data to account for typical proportions of adults and children in the household. The refined assumption would further distinguish thermal and latent gains into the space, as the Home Energy Model methodology does not include levels of humidity in the home and latent gains should not be included in the gains submitted from the wrapper to the core engine.

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

Annex A – mathematical details

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 1. Here m is a linear term permitting occupancy to grow without limit as floor area increases, 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 illustrated 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

Chart 8 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 chart 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).

Chart 8: Asymptotic occupancy by proportion of low-occupancy homes filtered out

Truncation within bins of 100 survey dwellings

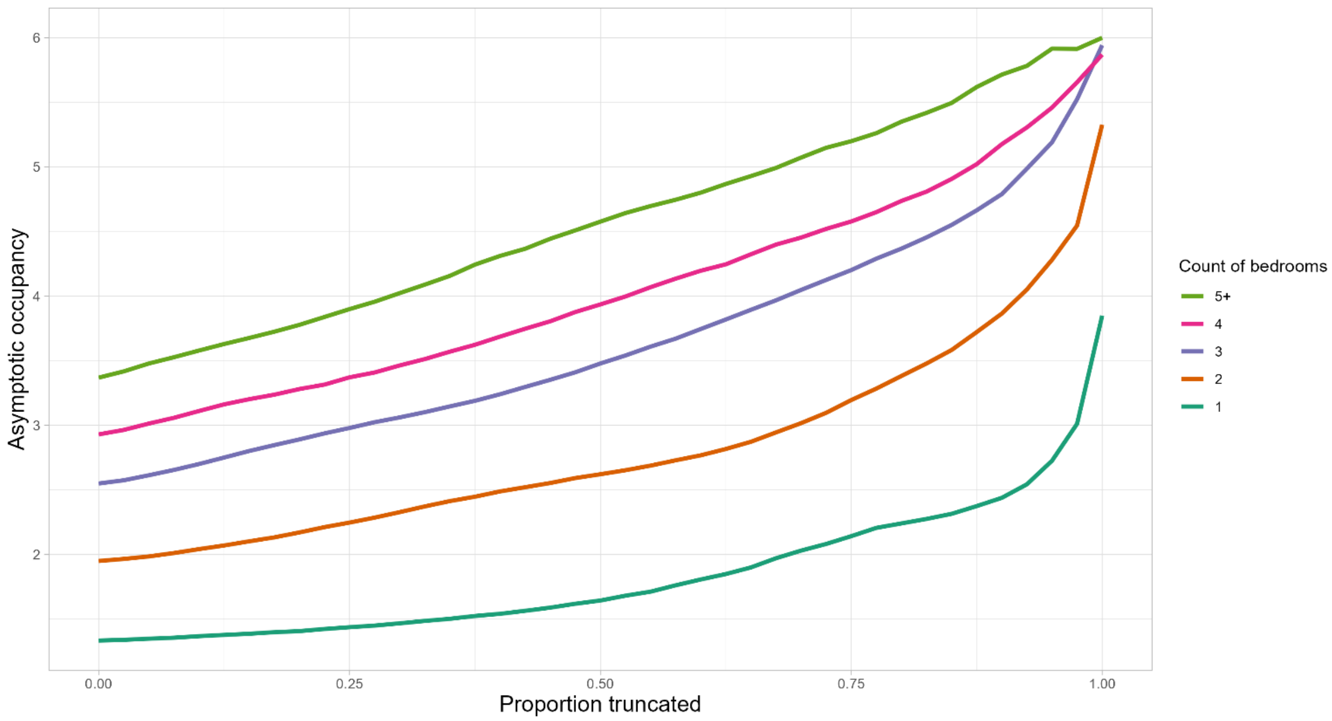
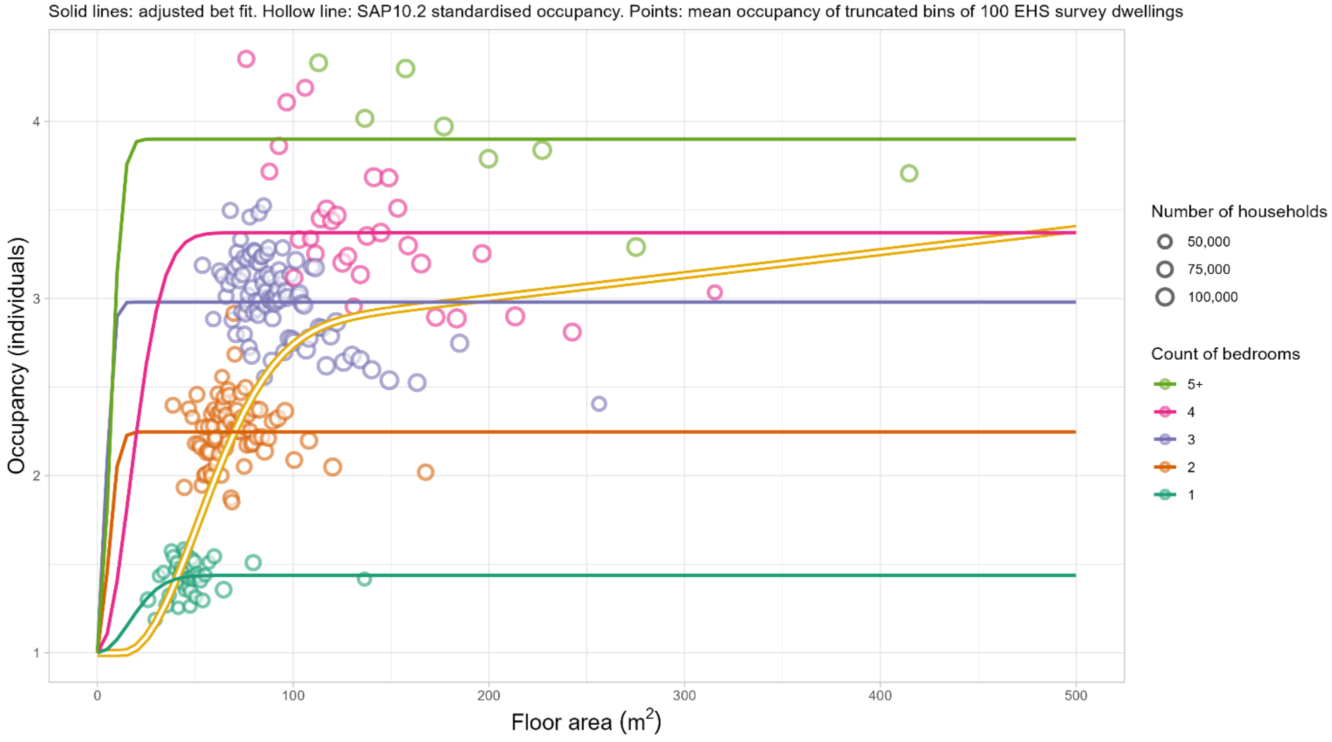


Chart 6 shows the SAP 10.2 occupancy function alongside the adjusted sigmoid curves, at the selected 25% truncation. At this truncation the SAP 10.2 curve is very close to the adjusted curves for the most typical 1- and 2-bedroom dwellings, passing centrally through the clouds of points representing the midpoints of the truncated bins. The SAP 10.2 curve departs from the truncated data points for 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.

Chart 6: SAP10.2 occupancy against the adjusted best-fit sigmoids

Solid lines: adjusted bet fit. Hollow line: SAP10.2 standardised occupancy. Points: mean occupancy of truncated bins of 100 EHS survey dwellings



Parameters for the sigmoid occupancy curves

Table 3 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 Future Homes Standard.

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[9] 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.

Table 3 – coefficients of sigmoid occupancy functions

	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

[9] 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.

This publication is available from: https://www.gov.uk/government/publications/home-energy-model-future-homes-standard-assessment-technical-documentation