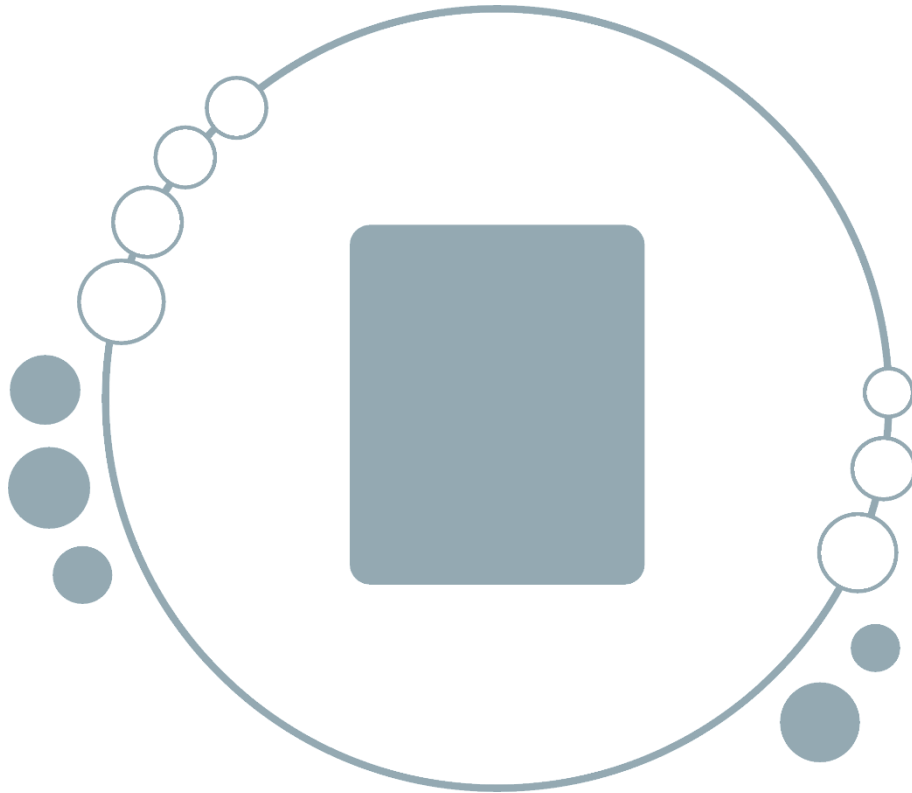




Lighting, cooking, electrical appliances, and incidental heat losses in the Home Energy Model: FHS assessment

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 [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 see how the energy uses described in this document are interpreted by the Home Energy Model core, please see:

HEM-TP-04 Space heating and cooling assumptions

HEM-TP-19 Appliances and cooking

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

src/future_homes_standard/future_homes_standard.py

src/future_homes_standard/FHS_appliance.py

Introduction

The Future Homes Standard Assessment wrapper specifies inputs and outputs for the Home Energy Model to assess whether a new home complies with the requirements of Part L of the Building Regulations. Among these specified inputs are standardised assumptions about demand for lighting, cooking, white goods, and other consumer electronics.

Cooking, lighting, and appliance use all have a significant effect on the energy balance of the dwelling but are only incidentally related to the building fabric or installed systems. Lighting is a regulated use of energy and contributes to the regulated energy efficiency and emissions measures for the dwelling output by the FHS Assessment wrapper. Energy demand for cooking and appliances is not regulated but results in thermal gains which affect the energy balance of the dwelling and therefore the demands made on the heating or cooling system. Lighting, cooking, and appliance demand can also be met by on-site generation (such as by photovoltaics) and will affect the proportion of electricity generation attributed to self-consumption.

This document explains the methodology and key assumptions that have been developed to provide the HEM core calculation with energy use and heat gains from cooking, lighting, and appliances. This approach equips the FHS wrapper with several functions:

1. Accept input information on the presence/absence of major appliances, cooking, and consumer electronics.
2. Provide a defined set of energy use figures for major appliances, cooking, and consumer electronics.
3. Provide a defined set of user behaviours for major appliances or end uses.
4. Create a more realistic profile of appliance energy use to improve HEM's calculation of peak demand, solar self-consumption, and usage of electric batteries.

1 Inputs

The HEM core calculation considers cooking, lighting, and appliances as sources of energy demand and heat gains. It requires detailed information, specifying the energy demand for each end use at every timestep of the calculation (refer to *HEM-TP-19 appliances and cooking*). The FHS wrapper creates this expanded input dataset based on appliances' presence and predefined assumptions.

1.1 Appliances and cooking

The user may specify which of the appliances listed below is either “Not Installed” or “Default.” Default appliance characteristics are listed in Section 2.9 and are based on EU Ecodesign regulations¹, as well as the 2012 Household Electricity Survey^{2,3} (more details in Appendix A).

- Fridge
- Freezer
- Fridge-Freezer
- Dishwasher
- Clothes Washing (Washing Machine)
- Clothes Drying (Tumble Dryer)
- Oven
- Hobs

1.2 Lighting

The user can specify the number, power rating, and efficacy of light bulbs. Daylight correction is used to adjust the required lighting output, and if this requirement is not met by the fixed lighting capacity, top-up lighting is added automatically (section 3.4).

¹ Ecodesign Directive 2009/125/EC

² R66141 Final Report Issue 4 Household Electricity Survey A study of domestic electrical product usage, Intertek 2014

³ Department of Energy and Climate Change, Intertek Testing and Certification Ltd. (2016). Household Electricity Survey, 2010-2011. [data collection]. UK Data Service. SN: 7874, <http://dx.doi.org/10.5255/UKDA-SN-7874-1>

2 Assumptions

The FHS wrapper makes assumptions about the usage and useful heat gains associated with each appliance. These are summarised in Table 1 below:

Appliance name	Usage Unit	Annual cycles per usage unit	Standby power (W)	Gains Fraction	Usage profile	Mean event duration (hours)	Event length deviation	Standard load size (kg)
Fridge	1	continuous	N/A	1	constant	N/A	N/A	N/A
Freezer	1	continuous	N/A	1	constant	N/A	N/A	N/A
Fridge-Freezer	1	continuous	N/A	1	constant	N/A	N/A	N/A
Other devices	1	continuous	N/A	1	**	N/A	N/A	N/A
Dishwasher	Number of occupants	132	0.75	0.3	**	1.5	0	N/A
Clothes Washing	Number of occupants	174	0.75	0.3	**	2.5	0	7
Clothes Drying	Number of occupants	145	0.5	0.7	**	0.75	0	7
Electric Oven	*	*	0.5	1	**	0.5	0.7	N/A
Gas Oven	*	*	0.5	1	**	0.5	0.7	N/A
Electric Hob	*	*	0.5	0.5	**	0.1	0.7	N/A
Gas Hob	*	*	0.5	0.5	**	0.1	0.7	N/A
Microwave	*	*	0.5	1	**	0.05	0.3	N/A
Kettle	*	*	0.5	1	**	0.05	0.3	N/A

*Usage of individual cooking appliances is determined from an overall cooking requirement, see Section 2.10.

**Time varying usage profiles - see Section 2.4.

Table 1 – Appliance usage statistics

The wrapper works out an additional demand due to miscellaneous consumer electronics (referred to as “Other devices” above), regardless of input. The total demand from these sources depends on the floor area and number of occupants in a manner determined by analysis of EFUS 2017 monitoring data⁴ (section 3.1).

Fridges and freezers are assumed to work constantly throughout the day, however the other listed appliances here work on the basis of discrete usage events. For these appliances, the units of energy consumption may be specified per cycle, per 100 cycles or per annum, reflecting variable units provided on energy labels (section 3.2).

For appliance use described by discrete usage events, the figure on the energy label may still be quoted as kWh per annum. There is an assumed number of uses of the appliance associated with this demand in the relevant EU standard.

- Dishwashers are assumed 280 standard uses per year⁵
- Clothes washing machines are assumed 220 standard uses per year⁶

⁴ Energy Follow Up Survey (EFUS) 2017 reports available at <https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2017-reports>

⁵ Commission Regulation (EU) 2019/2022

⁶ Commission Regulation (EU) 2019/2023

- Clothes dryers are assumed 160 standard uses per year⁷

To obtain the expected demand for a single usage of the appliance, the quoted kWh per annum figure is divided by this standard number of uses. These values may require updates in future as EU standards are updated.

2.1 Usage unit and annual cycles per usage unit

The FHS wrapper needs to work out an expected number of cycles of each appliance for one year, this is derived from the usage unit and annual cycles per usage unit listed in Table 1 above. Depending on the appliance, usage may depend on a variety of factors, hence the usage unit is flexible. For uses associated with cooking, a total cooking requirement is determined and assigned to whichever cooking appliances are available in the dwelling, see section 2.10 for more detail.

These parameters are used to determine the total demand for the appliance. The primary source for all appliances is the 2012 Household Electricity Survey; for more information refer to Appendix A.

2.2 Standby power

When an appliance is not in active use, it draws power equal to the standby value (see Table 1). Standby power is assumed to comply with by EU Ecodesign regulations⁸:

- from 2025, devices must not consume more than 0.5 W in standby or in off mode, or 0.8 W if they are on standby while displaying their status or information.
- from 2027, devices must not consume more than 0.5 W in standby, 0.3 W in off mode, or 0.8 W if they are on standby while displaying their status or information.
- from 2027, devices in networked standby must not consume more than 2 to 7 W depending on the product.

The 2025 limits form the basis for the FHS wrapper assumptions.

2.3 Gains fraction

This determines the recoverable proportion of demand from the appliance that is converted into internal heat gains. Values listed in Table 1 are approximate and based on those found in Passive House Planning Package (PHPP) 10⁹. Broadly, they are lower for appliances that heat up water which is then drained/ventilated away.

⁷ Commission Regulation (EU) 2023/2533

⁸ Ecodesign Directive 2009/125/EC

⁹ PHPP 10 Internal Heat Gain page

2.4 Usage profile

In addition to total annual demand, the FHS wrapper determines how the demand is distributed throughout the year for each appliance and cooking end-use, using time of day propensity profiles. For each end use, the profiles provide hourly values per day that are normalised per day and expanded to a full year. Depending on the end-use, the profile either represents continuous hourly demand or defines hourly probability of scheduling a usage event, for event-based appliances. Figure 1, below, specifies the likelihood of appliance operation for each hour of the day and supports scheduling of appliance and cooking activities. Appendix D describes how the profile was generated.

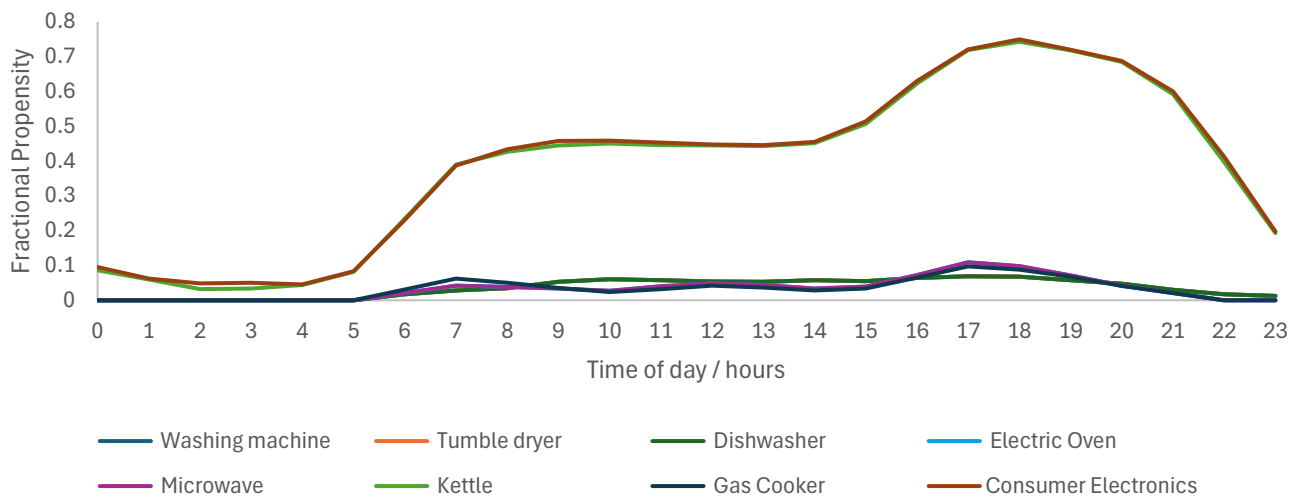


Figure 1 – Time of day appliance usage propensity (probability) profile

2.5 Mean event duration

The event duration determines how the demand per event is distributed. Many appliance usage events last longer than a single timestep, so this can affect the time alignment of energy demand/gains with heating and cooling schedules, flexible tariffs, availability of energy from on-site generation and batteries, or any other time dependent part of the model. This does not, however, have any effect on the total annual demand of the appliance itself. The total annual demand of a profile produced by the wrapper is completely independent of the event duration. Values for this parameter were obtained by analysis of the 2012 HES (Household Electricity Survey) monitoring data, see Appendix A.

2.6 Event duration deviation

This is the standard deviation of the event length. A deviation greater than 0 allows the duration of events to vary in length and magnitude from one event to another. This does not affect the total demand of the appliance. In the FHS wrapper, this variation is only applied to the durations of cooking events, while the durations of clothes washing, drying and dishwasher events are constant.

2.7 Standard load size

This statistic only concerns laundry appliances (see Table 1). It is assumed that each use of the washing machine or dryer in the source data (HES 2012 monitoring data, see Appendix A) is for 7kg of clothing, totalling 870kg of clothing per person, per year to be washed. It is also assumed that the washing machine in the HEM simulation is filled every time it is used, so for the default washing machine, with a drum capacity of 7kg, there is no adjustment to be made.

2.8 Residual moisture correction for clothes dryers

Clothes dryers are assumed to run their “eco programme” in accordance with EU commission regulation 2023/2533¹⁰, which dries clothes from 60% of their initial moisture content down to 0%. Since the FHS wrapper does not use spin-dry efficiency classes, it assumes a default residual moisture content of 60% for all loads, meaning no residual-moisture correction is applied.

2.9 Default appliances

Any appliance marked as “Not Installed” are excluded from the simulation; otherwise, the default information for each appliance is always used.

The energy supply for ovens and hobs is based on fuel available to the dwelling. If both mains gas and mains electricity are present, ovens use electricity and hobs use gas. If only one of the fuels is available, both appliances use that fuel. If neither is specified default to mains electricity for both appliances.

Category	Appliance	Demand unit	Demand value
White goods + household appliances	Fridge	kWh per annum	77
	Freezer	kWh per annum	128
	Fridge-Freezer	kWh per annum	137
	Other devices	kWh per annum	30 * (Number of occupants * floor area) ^{0.49}
	Clothes washing	kWh per 100 cycles	53
	Clothes drying	kWh per 100 cycles	98
	Dishwasher	kWh per 100 cycles	53
Cooking	Oven (electric)	kWh per cycle	0.59
	Oven (gas)	kWh per cycle	1.57
	Hobs	kWh per cycle	0.72
	Kettle	kWh per cycle	0.10
	Microwave	kWh per cycle	0.08

Table 2 – Default appliances

¹⁰ COMMISSION REGULATION (EU) 2023/2533 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for household tumble dryers

2.9.1 Default appliance demand

All demand values listed in Table 3 are based on the 25th percentile of a linear interpolation between the maximum possible energy use under current EU standards and the lowest energy use available on the market. The sources and results for this method are shown in Table 4 below.

To supply the HEM core with an approximate value for hob demand per cycle, it is assumed that the hobs present in the HES 2012 monitoring sample consist of hobs close to the least efficient permitted since 2019. Table A1 lists the estimated demand-per-cycle for hobs in the HES 2012 monitoring sample as 0.81kWh/cycle, scaling this by 176/195 – the ratio between the 25th percentile and the maximum permitted Wh/kg for Hobs shown in Table 4 below – yields 0.72kWh/cycle, the value used by the FHS wrapper, as stated in Table 2.

2.9.2 Other devices

“Other devices” is a miscellaneous category representing computing, TVs, and other consumer electronics. It cannot be further specified by the user and is always included regardless of user input – it cannot be specified as not present. The demand value listed in Table 3 above is a power law based on the number of occupants and total floor area measured in m². This reflects ~20% of the annual demand as calculated by a top-down analysis of the EFUS 2017 monitoring data - see Appendix B.

		Upper bound		Lower bound			HEM
Appliance	Demand unit	Model	Energy Use	Applicable EU standards	Date enforced	Energy Use under max permitted EEI	25th Percentile Energy Use
Dishwasher	kWh per 100 cycles	Miele G 15990-45 SCVI	47	EU 2019/2022 UK Ecodesign Regs 2021	01/03/2024	71	53
Clothes Washer	kWh per 100 cycles	BEKO WM520	44	EU 2019/2023 UK Ecodesign Regs 2021	01/03/2024	78	53
Clothes Dryer	kWh per 100 cycles	V-ZUG AdoraTrocknen V4000	86	EU 2023/2533	01/11/2015	133	98
Fridge	kWh per annum	Liebherr RBa 4250	61	EU 2019/2019 UK Ecodesign Regs 2021	01/03/2024	124.10	77
Freezer	kWh per annum	SEVERIN GS 8858	104	EU 2019/2019 UK Ecodesign Regs 2021	01/03/2024	200.75	128
Fridge-Freezer	kWh per annum	SIEMENS KI32LADD0	109	EU 2019/2019 UK Ecodesign Regs 2021	01/03/2024	222.65	137
Oven - Electric	kWh per cycle	Electrolux EB6PL40CN	0.52	EU 66/2014	03/02/2019	0.81	0.59
Oven - Gas	kWh per cycle	BEKO KDG653W	1.50	EU 66/2014	03/02/2019	1.79	1.57
Hobs - Electric	Wh/kg ¹¹	Bosch PIE645FB1E	170.0	EU 66/2014	03/02/2019	195	176

Table 3 – Sources for default appliance demand

¹¹ BS EN 60350-2:1999

2.10 Cooking

Usage of ovens, hobs, kettles, and microwaves is based on top-down assumptions about the household. A standardised total cooking demand $E_{year_{\mu}}$ is worked out according to the formula below and distributed between appliances. See Appendix C for the derivation of this formula.

$$E_{year_{\mu}} = 392.6 + 19.6 \times \text{Number of Occupants} \quad (1)$$

To work out the number of usage events n_c for each cooking appliance c present in the dwelling, their mean annual demands E_{year_c} from Table 4 below are summed and the proportion of the total made up by appliance c is multiplied by the standard total annual cooking demand $E_{year_{\mu}}$. This yields the annual demand for appliance c , to finally obtain n_c , this figure is then divided by the relevant mean demand per cycle E_{event_c} from Table 4.

$$n_c = \frac{E_{year_c} E_{year_{\mu}}}{E_{event_c} \sum_c E_{year_c}} \quad (2)$$

This means that the total cooking demand as calculated by HEM will deviate from formula (1) depending on how the stated demand per cycle of the appliance in question compares with the mean values in the HES – if an oven is expected to use more than 0.762kWh per use, the total demand will be greater than that predicted by formula (1).

Appliance c	Oven	Hobs	Microwave	Kettle
HES mean annual demand E_{year_c} /kWh	285.14	352.53	44.11	173.03
HES mean demand per cycle E_{event_c} /kWh	0.762	0.810	0.0772	0.0985

Table 4 – HES cooking statistics

2.11 Lighting

2.11.1 Lighting demand

Evidence for average lighting demand is taken from HES 2012, which reports detailed electricity consumption data for 250 households, however this survey predates the general transition away from incandescent bulbs. The corresponding average demand for a modern lighting mix is estimated from the EFUS 2017 monitoring data. By assuming that building-to-building behavioural variation in lighting demand in the EFUS 2017 sample is correlated with overall variation in electricity use, a curve characterising typical lighting requirement as a function of floor area and occupancy is fitted onto the EFUS 2017 data to obtain a formula for determining lighting requirement in HEM.

The detailed Household Electricity Survey report¹² shows (at Figure 452) the average number of bulbs of each type in a dwelling in the HES survey stock. The EFUS survey records the number of light bulbs of each type for most dwellings, of which 160 are in the filtered sample without electric space or water heating. The efficacy of LED lights has improved since the Household Electricity Survey. For analysis of the two data sets the respective efficacies shown in Table 5 are assumed (these assumptions are not used during the HEM calculations themselves, which rely on user-supplied efficacy values).

SAP 10.2 (for HES analysis)		EFUS analysis	
Lamp type	Efficacy (Lumens/Watt)	Lamp type	Efficacy (Lumens/Watt)
Linear fluorescent	80.5	Linear fluorescent	80.5
LEDs, CFLs	66.9	CFL	66.9
Halogen LV	26.1	Halogen	20
Halogen lamps	15.7	LED	100
Incandescent	11.2	Incandescent	11.2

Table 5 – Lamp efficacies

The HES summary report *Powering The Nation 2*¹³ states that lighting takes up 483kWh/yr, 11.8% of annual household electricity consumption on average.

Table 6 below shows the mean lighting energy demand, harmonic mean lighting efficacy, and mean lighting requirement in the HES sample. These were calculated using the efficacies assumed in SAP10.2¹⁴ (Table 5) and the lamp type occurrences from Figure 452¹⁵ in the detailed HES report.

	Average household
Lighting energy demand kWh/yr	483
Lighting efficacy lm/W	19.4
Lighting requirement klmh/yr	9341

Table 6 – Household Electricity Survey average lighting demand

¹² Zimmerman et al., Household Electricity Survey: A study of domestic electrical product usage, Intertek, May 2012. <https://www.gov.uk/government/publications/household-electricity-survey--2>

¹³ Powering the nation 2 report, 2014: [Powering the Nation 2 260614.pdf \(publishing.service.gov.uk\)](https://files.bregroup.com/SAP/SAP%2010.2%20-%2017-12-2021.pdf)

¹⁴ Table L1 of appendix L in SAP10.2 specification: <https://files.bregroup.com/SAP/SAP%2010.2%20-%2017-12-2021.pdf>

¹⁵ Zimmerman et al., as above, Figure 452

The lighting requirement is assumed to be the same for EFUS 2017 sample. Dividing this lighting requirement by the harmonic mean efficacy of lighting fixtures in the EFUS sample (42 lm/W) yields a mean annual lighting demand of 222kWh/yr. This is 9.5% of the mean annual electricity consumption across the filtered EFUS sample, which is 2835kWh/yr, and 8% of electricity consumption across the unfiltered sample, aside from electricity consumption for heating.

To obtain a formula for determining the lighting requirement of a dwelling being modelled by HEM-FHS, the lighting requirement for each dwelling in the filtered sample is estimated as 8% of the total annual electricity consumption in the dwelling, multiplied by the dwelling's mean lighting efficacy. This estimated lighting requirement is plotted against the product of total floor area and observed occupancy in Figure 2 below, and a power law is fitted onto the data.

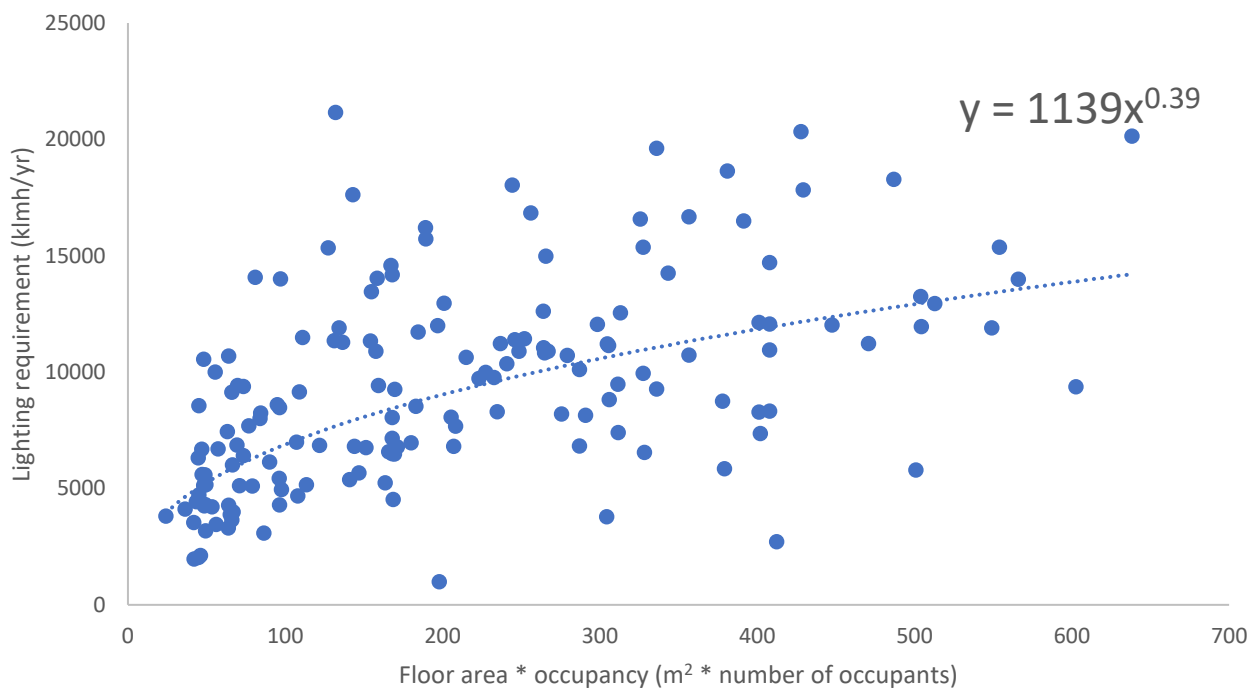


Figure 2 – Relationship between (floor area * occupants) and lighting requirement from the EFUS 2017 dataset. Subsample of households without electric heating and electric DHW, and with lighting efficacy data.

The resulting fitted curve from Figure 2 is adopted as the standardised lighting requirement in the FHS. Using the fitted curve, the estimate for the lighting requirement L_{req} measured in klm.h/yr follows as:

$$L_{req} = 1139(TFA \times O)^{0.39} \quad (3)$$

Where TFA is the total floor area of the dwelling in m² and O is the number of occupants in the dwelling as calculated by the methodology set out in *HEMFHS-TP-01 Occupancy assumptions*. E_L then follows as:

$$E_L = L_{req}/K \quad (4)$$

for a dwelling with average lighting efficacy K , with E_L and K measured in kWh/yr and lm/W, respectively.

2.11.2 Lighting gains fraction

The gains fraction is the proportion of the consumed energy which will result in thermal gains in the indoor space. For lighting, this excludes electricity for external lighting, which is assumed to account 15% of all lighting by energy consumed. Therefore, the factor for lighting is assumed as 0.85.

This figure is drawn from the SAP 2009 assumptions, where it is documented as derived from (unpublished) Lighting Association research data provided to BRE.

2.11.3 Lighting time-of-day profile

A lighting time-of-day profile is used to determine when demand and heat gains from lighting occur, much like the usage profiles in section 2.4. The evidence for the lighting time-of-day profile is derived ultimately from survey data gathered by the UK Domestic Lighting Project, 1996-7¹⁶. This is interpreted via an intermediate model by Stokes, M., Rylatt, M. & Lomas, K¹⁷. A different daily profile is supplied for each month of the year, and the total daily usage varies between months. As the overall demand for lighting E_L in the FHS is calculated separately via equations (3) and (4), proportional profiles were obtained by dividing the average energy consumption of Electricity Association homes at each half-hourly interval of the day by the annual average daily energy consumption. The lighting energy demand profile in an FHS calculation is then obtained by multiplying all values in the proportional profile by E_L .

The profiles are illustrated in the coloured Table 7 and Figure 3 below.

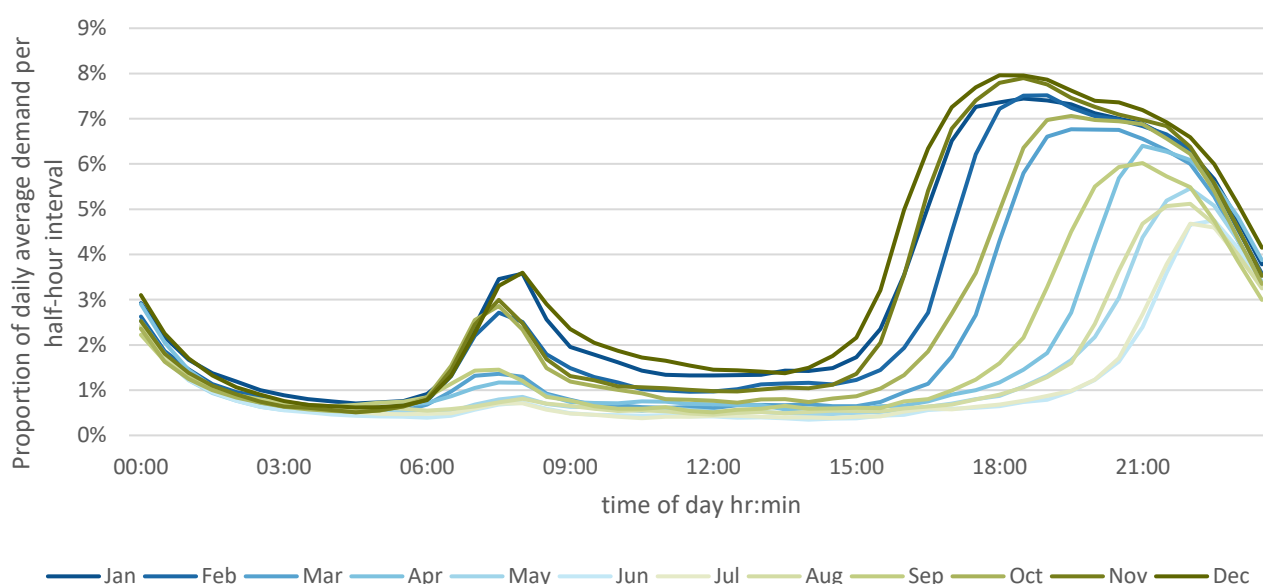


Figure 3 – Lighting profile factor by time of day and month

¹⁶ UK Domestic Lighting Project Preliminary Analysis. Load Research Group, Electricity Association, 1996. Not available online.

¹⁷ A simple model of domestic lighting demand, Stokes, M., Rylatt, M. & Lomas, K. (2004), available at https://www.academia.edu/15531665/A_simple_model_of_domestic_lighting_demand

Lighting demand by time of day and month, proportion of daily average demand per half-hour interval (%).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	2.92	2.63	2.54	2.90	2.38	2.40	2.44	2.39	2.22	2.36	2.53	3.10
00:30	2.17	1.86	1.82	2.06	1.69	1.69	1.80	1.69	1.64	1.63	1.81	2.25
01:00	1.67	1.46	1.28	1.44	1.22	1.23	1.34	1.29	1.27	1.24	1.38	1.70
01:30	1.37	1.13	0.96	1.08	0.93	0.95	1.05	1.02	1.06	1.00	1.10	1.33
02:00	1.19	0.96	0.79	0.86	0.77	0.77	0.86	0.88	0.89	0.84	0.91	1.07
02:30	1.00	0.86	0.68	0.73	0.63	0.63	0.75	0.77	0.79	0.72	0.74	0.90
03:00	0.88	0.74	0.61	0.68	0.56	0.56	0.66	0.66	0.71	0.63	0.64	0.76
03:30	0.80	0.67	0.55	0.64	0.57	0.51	0.62	0.60	0.68	0.57	0.61	0.67
04:00	0.75	0.61	0.51	0.60	0.55	0.46	0.57	0.60	0.65	0.54	0.56	0.65
04:30	0.71	0.58	0.49	0.57	0.52	0.44	0.51	0.59	0.68	0.52	0.51	0.62
05:00	0.73	0.58	0.48	0.58	0.51	0.42	0.47	0.62	0.72	0.54	0.56	0.62
05:30	0.76	0.64	0.54	0.67	0.54	0.41	0.47	0.59	0.75	0.65	0.64	0.66
06:00	0.92	0.77	0.68	0.72	0.50	0.39	0.48	0.54	0.85	0.84	0.79	0.78
06:30	1.36	1.31	0.97	0.86	0.52	0.43	0.49	0.58	1.14	1.53	1.44	1.31
07:00	2.42	2.20	1.31	1.05	0.68	0.57	0.60	0.64	1.43	2.55	2.45	2.26
07:30	3.45	2.71	1.36	1.17	0.79	0.68	0.70	0.73	1.45	2.86	2.99	3.31
08:00	3.58	2.51	1.29	1.16	0.85	0.73	0.71	0.81	1.20	2.34	2.48	3.60
08:30	2.56	1.79	0.92	0.89	0.70	0.59	0.57	0.70	0.85	1.49	1.69	2.90
09:00	1.95	1.49	0.79	0.73	0.63	0.49	0.48	0.65	0.78	1.19	1.31	2.35
09:30	1.79	1.29	0.67	0.72	0.62	0.45	0.45	0.59	0.64	1.09	1.22	2.05
10:00	1.61	1.17	0.67	0.71	0.58	0.45	0.41	0.54	0.59	1.01	1.09	1.87
10:30	1.43	1.02	0.62	0.75	0.54	0.43	0.38	0.55	0.59	0.93	1.06	1.72
11:00	1.34	0.99	0.61	0.74	0.60	0.45	0.41	0.53	0.62	0.80	1.04	1.65
11:30	1.32	0.97	0.63	0.69	0.56	0.42	0.41	0.48	0.54	0.79	1.01	1.54
12:00	1.33	0.97	0.60	0.69	0.52	0.42	0.44	0.46	0.51	0.77	0.98	1.46
12:30	1.33	1.02	0.67	0.67	0.52	0.39	0.43	0.50	0.57	0.72	0.97	1.43
13:00	1.34	1.13	0.67	0.67	0.52	0.40	0.41	0.52	0.59	0.80	1.01	1.41
13:30	1.43	1.15	0.67	0.57	0.49	0.38	0.40	0.49	0.65	0.80	1.05	1.37
14:00	1.43	1.16	0.69	0.59	0.48	0.35	0.40	0.52	0.59	0.74	1.04	1.49
14:30	1.49	1.13	0.64	0.53	0.47	0.37	0.38	0.54	0.60	0.81	1.12	1.75
15:00	1.73	1.22	0.64	0.57	0.50	0.38	0.41	0.54	0.61	0.86	1.36	2.16
15:30	2.35	1.44	0.74	0.65	0.52	0.44	0.42	0.53	0.60	1.04	2.05	3.21
16:00	3.55	1.93	0.95	0.66	0.57	0.46	0.53	0.60	0.75	1.33	3.53	4.99
16:30	5.06	2.71	1.14	0.75	0.63	0.56	0.60	0.64	0.80	1.85	5.41	6.35
17:00	6.51	4.50	1.74	0.90	0.70	0.59	0.58	0.68	0.99	2.69	6.78	7.26
17:30	7.26	6.21	2.66	1.00	0.80	0.61	0.63	0.79	1.23	3.59	7.40	7.69
18:00	7.36	7.22	4.30	1.17	0.87	0.64	0.68	0.90	1.59	4.97	7.79	7.96
18:30	7.45	7.51	5.80	1.45	1.07	0.74	0.76	1.06	2.16	6.36	7.90	7.95
19:00	7.40	7.52	6.61	1.82	1.32	0.79	0.87	1.29	3.28	6.97	7.75	7.87
19:30	7.32	7.24	6.77	2.71	1.66	0.97	0.99	1.60	4.50	7.06	7.46	7.62
20:00	7.12	7.06	6.76	4.22	2.17	1.22	1.23	2.46	5.50	6.97	7.26	7.39
20:30	7.00	6.98	6.75	5.69	3.04	1.63	1.71	3.64	5.93	6.94	7.09	7.36
21:00	6.89	6.84	6.55	6.40	4.37	2.39	2.68	4.68	6.02	6.88	6.97	7.19
21:30	6.61	6.66	6.30	6.27	5.19	3.59	3.78	5.07	5.73	6.56	6.84	6.92
22:00	6.27	6.32	6.00	6.09	5.46	4.66	4.68	5.12	5.49	6.22	6.38	6.59
22:30	5.66	5.56	5.28	5.58	5.07	4.75	4.59	4.67	4.74	5.40	5.57	6.00
23:00	4.75	4.55	4.31	4.83	4.31	4.14	3.95	4.00	3.85	4.35	4.59	5.11
23:30	3.78	3.57	3.37	3.87	3.39	3.32	3.31	3.25	2.99	3.35	3.52	4.15

Table 7 – Proportional consumption of lighting by time of day and month

3 Methodology

This section of the document is concerned with the process by which the wrapper turns the inputs and assumptions about appliances into detailed inputs for the core HEM calculation.

3.1 Continuous appliance usage

For appliances in continuous use, the Consumer Electronics profile in Figure 1 is scaled to produce a year long time series that sums up to the annual demand supplied in the inputs. This profile is used directly by the HEM calculation as a representation of the demand due to the appliance, and the gains from the appliance are obtained by multiplying the demand at any given time by the gains fraction.

3.2 Event based appliance usage

For event-based appliances, the following process creates a list of usage events that can be accepted by the core engine (see *HEM-TP-19 Appliances and cooking*).

- The normalised hourly propensity profile (see section 2.4) represents the relative likelihood of appliance use at different times of the day. This daily profile is repeated to cover all timesteps in the simulation.
- These weights are then converted into actual events. First the expected annual number of uses is calculated from annual demand assumptions. Then a Poisson sampling process converts these likelihoods into the actual event counts for each timestep.
- For each timestep with events, the exact start time is chosen randomly within the timestep. A uniform random offset is added to the timestep ensuring the events do not begin at the timestep boundaries. A fixed pseudorandom seed means that the same series of events will always be generated for a particular set of dwelling inputs.
- Event durations incorporate random variation. An event cannot have a negative duration, so in the case where the random sample gives a value less than or equal to -1 times the mean event duration, another sample is taken.
- When multiple events occur within the same timestep, they are placed sequentially to avoid overlap.
- This generates a year-long list of start times and durations for the HEM core engine.

3.3 Appliance demand time series examples

Figure and Figure below illustrate appliance demand as calculated by the HEM core engine from a test file, demonstrating the pseudorandom distribution of events, which may last longer than one timestep. The demand for electricity is highly intermittent – a property which aggregate load curves fail to adequately capture.

It is noticeable that clothes washing and drying events frequently occur during the night - propensities calculated from the ONS for these appliances are at most 3 times higher during the day than they are at night (Figure), so approximately one quarter of these events happen overnight.

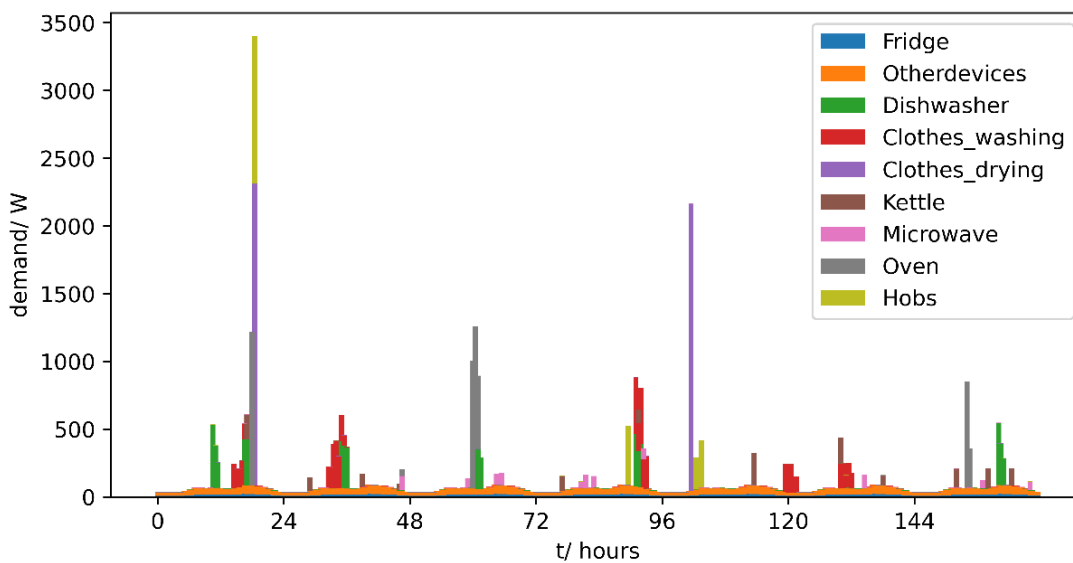


Figure 4 – Example week-long electricity demand profile from appliances using current FHS wrapper assumptions.

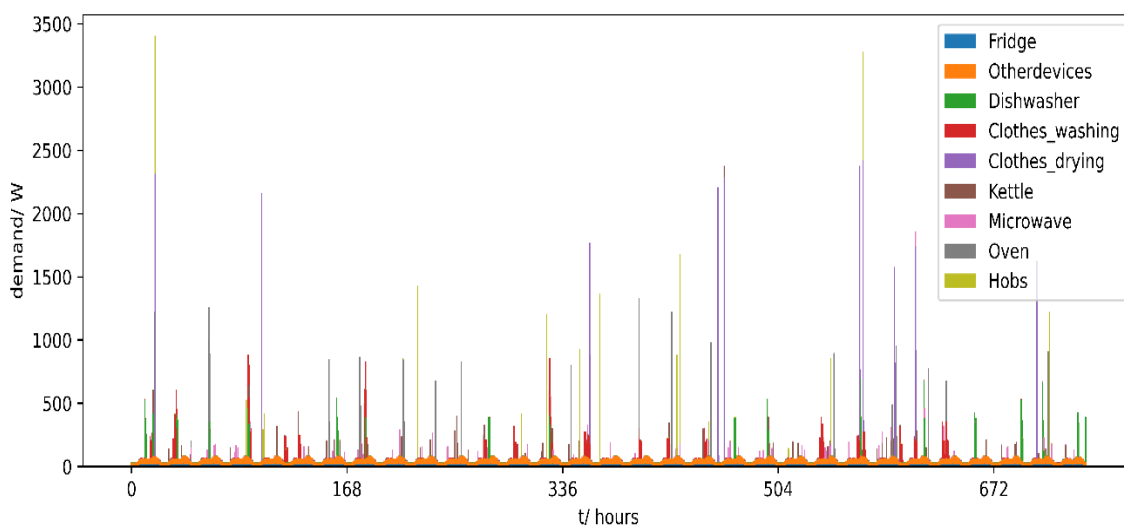


Figure 5 – Example month-long electricity demand profile from appliances using current FHS wrapper assumptions.

3.4 Lighting

3.4.1 Daylight correction factor for lighting

The daylight correction factor $C_{daylight}$ accounts for the incidence of daylight through windows which provide a source of natural lighting. It is assumed that the amount of daylighting is dependent on the area A_w , frame factor F , and transmittance factor g of windows, as well as a shading reduction factor Z_L and a , the total floor area of the dwelling. The daylight correction factor, $C_{daylight}$ is then calculated at follows:

$$C_{daylight} = \begin{cases} 52.2G_L^2 - 9.94G_L + 1.433, & G_L \leq 0.095 \\ 0.96, & G_L > 0.095 \end{cases} \quad (5)$$

Where:

$$G_L = \frac{1}{a} \sum_w 0.9FgZ_L A_w \quad (6)$$

These formulae for $C_{daylight}$ are adapted from the SAP10.2 methodology for daylighting¹⁸. Shading reduction factor Z_L is calculated for each half hourly timestep in the simulation, depending on weather and shading by external objects, using methods set out in *HEM-TP-08 Solar gains and shading*. The resulting $C_{daylight}$ is then applied to the lighting time-of-day profile (see section 2.11.3) at each half-hourly timestep.

3.4.2 Top-up lighting

Top up lighting is assumed to be in use where the fixed lighting capacity of lighting is below what is required to provide a sufficient level of artificial lighting. This methodology is an adaption of the SAP10.2 assumptions¹⁹ for top up lighting and compares the lighting capacity with a reference capacity to determine the need for top up lighting. If the fixed capacity is below the minimum requirement determined by the reference, the shortfall is assumed to be topped up by poor efficacy lighting. The assumptions for the reference capacity, minimum requirement and efficacy of top-up lighting are all as specified in SAP10.2.

The fixed lighting capacity C_{fixed} is defined as the sum of the power P_b (in Watts) multiplied by lighting efficacy K_b (lm/W) for all fixed light outlets b in the dwelling:

$$C_{fixed} = \sum_b P_b K_b \quad (7)$$

The reference capacity C_{ref} is also defined as a function of the total floor area of the dwelling:

$$C_{ref} = 330TFA \quad (8)$$

¹⁸ Appendix L, SAP10.2 Specification: <https://files.bregroup.com/SAP/SAP%2010.2%20-%202017-12-2021.pdf>

¹⁹ As above

The lighting provision L_{prov} is defined as L_{req} (from Equation (3)) adjusted by the ratio between C_{fixed} and C_{ref} .

$$L_{prov} = \frac{C_{fixed}}{C_{ref}} L_{req} \quad (9)$$

Finally, top-up lighting requirement L_{topup} covers the shortfall if the lighting provision falls below the reference range:

$$L_{topup} = \begin{cases} \frac{L_{req}}{3} - L_{prov}, & L_{prov} < \frac{L_{req}}{3} \\ 0, & L_{prov} \geq \frac{L_{req}}{3} \end{cases} \quad (10)$$

This top-up lighting requirement is assumed to be provided by lighting of poor efficacy (21.3lm/W).

3.4.3 Average lighting efficacy

The assumptions set out in section 0 enable the FHS to obtain a lighting demand profile given dwelling floor area, occupancy and average lighting efficacy (equations (3) and (4)). Occupancy is obtained via methods set out in *HEMFHS-TP-01* and floor area is the sum of the area of all zones in the dwelling. Average lighting efficacy K is calculated by the FHS from user input details about each bulb b in each zone z as follows:

$$K_z = \frac{\sum_{b \in B_z} P_b K_b}{\sum_{b \in B_z} K_b} \quad (11)$$

Where P_b and K_b are the power in W and efficacy in lm/W of a bulb b in B_z , the set of bulbs in zone z . The average lighting efficacy K is then obtained from the zone lighting efficacies K_z as:

$$K = \frac{1}{a} \sum_z K_z a_z \quad (12)$$

Where a_z is the floor area of zone z and a is the total floor area $\sum_z a_z$. That the efficacy is weighted by floor area reflects the assumption that internal heat gains are proportionally distributed by zone floor area in the HEM core calculation, see HEM-TP-19.

4 Further development

Improvements listed below refer to potential improvements that could be made to the quality of data and validity of assumptions made in modelling appliances in the FHS wrapper, as well as potential for improving the flexibility and detail of the modelling methodology.

4.1 Dishwasher place settings

Similar assumptions to washing machine loading could be made about dishwasher sizing via place settings to account for varying sizes of dishwashers.

4.2 Refrigerator cycling

A more realistic model of refrigerator energy demand could be based on cycling events (derived from HES monitoring data for example).

4.3 Appliance use correlation

The methods set out in section 3.2 and Appendix A consider the usage of each appliance independently, where in fact it would be expected that use would be correlated – for example clothes drying is presumably more likely to occur immediately after clothes washing than at any other time.

4.4 Hob demand in Wh/kg

Efficiencies for hobs as determined by BS EN 60350-2:1999 are measured in Wh/kg, not kWh per cycle; to utilise commonly available test data for hobs, a reliable methodology should be developed to convert reported figures in Wh/kg into useful assumptions about cooking demand per occupant throughout the year. The derivation for the demand for default hobs shown in section 2.9.1 may serve as a basis for this.

4.5 Consumer electronics demand

Demand for consumer electronics as obtained in Appendix B is based on an assumed constant proportion of total appliance demand. While it is inherently difficult to obtain a robust estimate of demand from miscellaneous unregulated uses, a more robust analysis could consider ownership and usage of consumer electronic devices over a range of household sizes.

4.6 Lighting

The assumption that lighting demand in the EFUS 2017 sample is a constant proportion of all electricity consumption (other than that used for space and water heating), as floor area and occupancy vary, needs justification. The efficacies in Table 5 which were used to obtain this estimate of lighting demand are based on conservative assumptions. If typical bulb efficacy has improved over time (e.g., due to widespread adoption of LED bulbs), a smaller estimated demand from lighting would result. Direct survey evidence of lighting demand in modern households (since the widespread adoption of LED lighting) should be sought.

EN15193-1 outlines a bottom-up methodology for the calculation of domestic lighting, accounting for daylighting, illuminance, occupancy, and controls. A detailed, event-based method for domestic lighting could be explored in future analysis to consider if such an approach is preferable.

More recent evidence for the proportion of lighting used outdoors should be sought.

4.7 Time of day profile

A new propensity profile (see Figure 1 above and Appendix D below) can be generated when new EFUS and ONS data is released in the future. If a 30-minute time step were available in the EFUS data, the profiles could be rebuilt in 30-minute time steps to synchronise with the rest of the FHS HEM wrapper.

If a large-scale event is observed that has the likelihood to change the way people use their homes (for example: Covid lockdowns) it may be that a new profile is warranted, using the most up to date ONS data release.

The consumer electronics profile currently includes all electronics used within a dwelling except for fridges, fridge-freezers, freezers, and those listed in Table D2. This could be further disaggregated if additional data on occupants' use of individual devices becomes available.

Currently the ONS data from weekdays and weekends is combined to provide a single daily propensity profile. While these profiles differed only slightly, a future update could seek to produce separate profiles for weekdays and weekends. Profiles for different appliances are currently the same due to the limitations of the data. A future update could look to use additional data about specific appliance use (for example from the Powering the Nation Household Electricity Survey²⁰) to refine the profiles for individual appliances.

The profiles produced from the data does not vary seasonally, instead having the same single average days' worth of propensities repeated 365 times. The data could be used to introduce seasonal variation in the profiles, or demand could be made to respond to external conditions such as weather, where applicable.

²⁰ Powering the Nation Household Electricity Survey, [Department of Energy & Climate Change](https://www.gov.uk/government/publications/household-electricity-survey--2), <https://www.gov.uk/government/publications/household-electricity-survey--2>

Appendix A – HES 2012 analysis

The Household Electricity Survey monitored a total of 250 owner-occupier households across England from 2010 to 2011. Twenty-six of these households were monitored for a full year. The remaining 224 were monitored for one month, on a rolling basis throughout the trial.

Participants also kept detailed diaries of how they used certain appliances, which can be matched against actual energy use monitoring for their homes. They had between 13 and 85 appliances in their homes, with about a third of households owning between 30 and 40 appliances.

A1 Diary data and table 22

The headline figures for annual usage cycles per occupant in HES 2012 are based on the diary data. Similar diary data also exists for ovens and cookers. The available data on HES does not include the exact length of the diary period for each household, only the indication that it was approximately 2 weeks, and there is no indication of what data cleaning or weighting was done. To attempt a recreation of this analysis, diaries with only one entry or only one day of entries were abandoned and for the remaining cases the monitoring period was assumed to be the time between the first and last entry. Table A1 shows both the reported figures and those obtained from this recreated analysis, as well as figures obtained by the method outlined in

Appliance	Uses annual (HES 2012 table 22)	Uses annual per occupant (HES 2012 table 22)	Uses annual (diary data)	Uses annual per occupant (diary data)	Uses annual (monitoring data)	Uses annual per occupant (monitoring data)
Washing Machine	284	174	208	92	358	166
Tumble Dryer	260	145	281	112	438	195
Dishwasher	254	132	301	133	442	197
Oven	-	-	217	111	**	178
Cooker	-	-	425	234	**	235
Kettle	-	-	-	-	1783	921
Microwave	-	-	-	-	710	315

Table A1 – HES 2012 appliance usage stats, bold figures in green are those selected for use in the wrapper.

A2 Monitoring data

To distinguish usage events from the HES 2-minute and 10-minute timeseries monitoring data, a script was developed that reads each time series, and upon encountering a reading that exceeds the 95th percentile of all readings for that appliance, marks the beginning of a usage event. The next reading that drops below the 95th percentile is then considered the end of the

event. It is then trivial to obtain the total demand, duration, and power for the event by summing up the demand and duration for the relevant timesteps.

To avoid mistaking different parts of the same usage event as separate, events occurring within 15 minutes of the previous one are considered part of the same usage event. 15 minutes was chosen due to the timeseries' maximum timestep of 10 minutes. This is particularly important for ovens and dishwashers, which appear to have multiple prominent peaks in demand per usage cycle. Finally, time series for ovens and cookers where the mean event power was below 500W or there were over 1000 events per occupant were abandoned. That this can occur seems to be a limitation of using percentiles to distinguish usage events – if the appliance is in use for less than 5% of the day on average, the standby power may exceed the threshold 95th percentile and erroneously suggest thousands of tiny usage events.

The resulting annual usage statistics are shown in Table A2. Note that there are households in the monitoring data that are not present in the diary data.

Appliance	Mean annual events	Mean event demand/ kWh	Mean event power/W	Mean event length/minutes	std dev event length/ minutes
cooker 1	235.45	0.81	1166.68	47.50	44.29
kettle 1	921.41	0.10	779.69	9.36	6.46
microwave 1	315.05	0.08	375.14	14.06	16.01
oven 1	177.71	0.76	958.31	52.81	40.75
dishwasher 1	196.92	0.97	728.30	93.05	57.56
tumble dryer 1	195.26	1.42	1174.77	70.41	41.77
washing/drying machine 1	190.59	0.65	590.94	84.13	64.58
washing machine 1	166.06	0.53	404.34	87.51	54.21

Table A2- Event statistics from HES monitoring data

Some households in the HES data contain multiple ovens, cookers and combined oven and cooker units, these were ignored for the purposes of this analysis. “Cookers” were renamed as “Hobs” within HEM to avoid confusion with combined units with both hobs and ovens.

Appendix B - Energy demand from consumer electronics

Demand for consumer electronics (other devices in Table 2) is determined by a power law relation based on floor area and occupancy. This was obtained by top-down analysis of total energy demand from appliances in the EFUS 2017 monitoring sample. Demand from consumer electronics was assumed to form a constant fraction of this total.

B1 Total appliance demand in EFUS 2017

Detailed electricity consumption was collected for 436 dwellings as part of the EFUS 2017. The monitoring period for data collection was 1st May 2018 to 30th April 2019.

The monitoring period for electricity consumption varied from dwelling to dwelling (between 3 months and 1 year). Annualised consumption was determined by calculating the average electricity consumption in a half hourly period across the monitoring period for the individual building and scaling up (without seasonal adjustment) to an annual value.

For this analysis, dwellings with electric heating (primary or secondary) and electric domestic hot water (electric showers and immersion heaters) were filtered out of the sample, along with some outliers with unusual, recorded consumption. In the remaining 171 dwellings, metered electricity consumption of the dwellings is then assumed to be divided between lighting, cooking, electricity used by boilers and fans, and appliances.

Total appliance demand was modelled as the residual of EFUS electricity consumption in buildings without electric space or hot water heating, after subtracting.

- the modelled typical consumption for lighting (9.5%),
- the modelled typical consumption for cooking (10.8% for electric cooking, 5.4% for mixed fuels),
- 250kWh, to account for auxiliary electricity used by heating system fans, pumps, and control systems.

The value of 250kWh for auxiliary consumption is approximately the median figure for condensing boilers found in an in-situ Energy Saving Trust study.²¹

The sample of residual electricity use is skewed by some dwellings with a very high consumption. These outliers are assumed to represent homes with atypical appliances which are not present in the standardised household and are excised from the sample. Removing 9

²¹ In situ monitoring of efficiencies of condensing boilers and use of secondary heating, Energy Saving Trust 2009 (page 43)

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/180950/In-situ_monitoring_of_condensing_boilers_final_report.pdf

of cases from the sample (of 190, initially) aligns the mean and median residual consumption of the remaining sample at 2020kWh/yr.

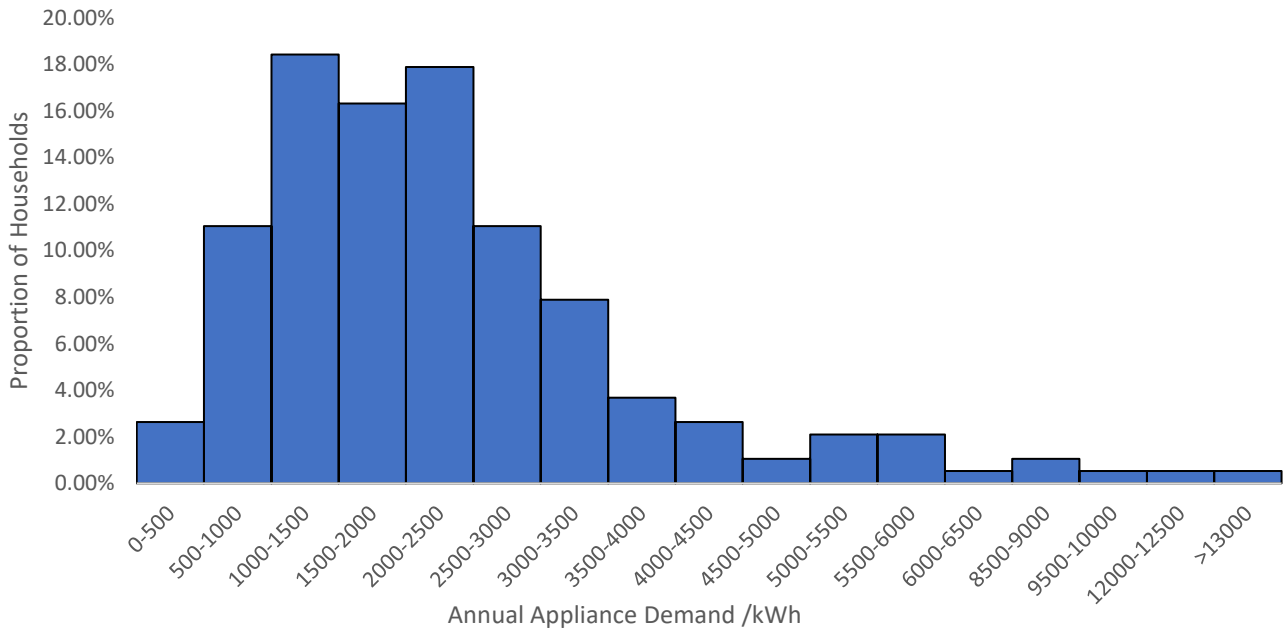


Figure B1 - EFUS 2017 Residual electric consumption distribution, households with no electric space or water heating

B2 Power law fit for total appliance demand

Both the size of the household and of the home itself affect the residual electricity consumption. Fitting a power-law relationship on the product of occupancy and floor area captures more of the variance in the sample than fitting to occupancy or floor area alone - the non-linear fit to the product yields $R^2=0.36$, compared with $R^2=0.26$ for fitting on occupancy alone, and $R^2=0.25$ for floor area. Appliance demand was not fitted as a function of occupancy and floor area as independent variables to avoid over-fitting. The resulting fit is shown in Figure B2 below.

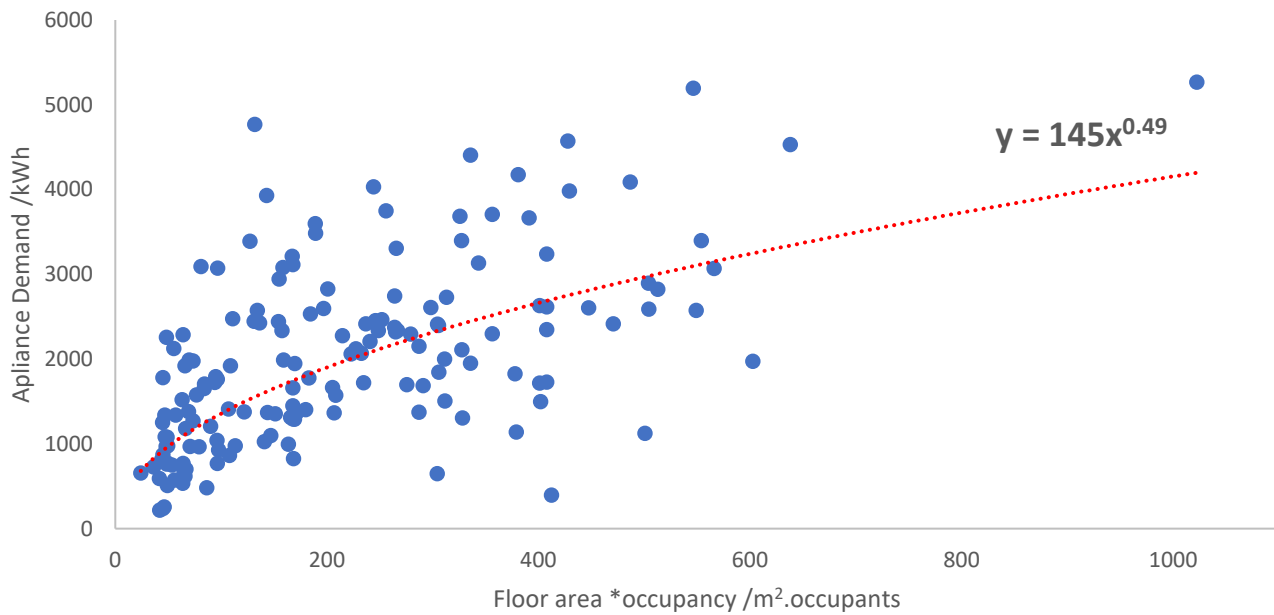


Figure B2 – Residual electricity consumption vs floor area * occupancy, from the EFUS 2017 monitoring dataset. Households with no electric space or water heating, outliers trimmed.

B3 Demand from consumer electronics as a constant proportion of total appliance demand

The HES 2012 summary report *Powering the Nation 2* identifies demand from audiovisual equipment and “other” electronics as making up 19% of typical peak load. The estimated demand from consumer electronics in HEM was obtained by assuming that this is also the typical proportion of annual demand (rounded to 1 s.f.), and that this proportion remains constant with varying annual demand.

$$Demand_{Other\ devices} = 30 * (Occupants \times Floor\ area)^{0.49}$$

Where floor area is measured in m².

This formula determines the demand attributed to other devices in Table 2.

Appendix C – Cooking behaviour

This appendix serves as a derivation for Formula (1) in section 2.10. The formula is a weighted average between a linear fit on EFUS 2017 electricity demand data and a constant value from the HES 2012 headline report. The weighting was obtained through demographic data from the English Housing Survey (EHS).

C1 EFUS 2017

The EFUS 2017 survey records the presence of ovens and hobs and the types of fuel they use. Figure 4.11 of the Lights & Appliances report²² plots the median excess electricity consumption over a typical day for a household with any electric cooking appliance over those without. Electric cooking is associated with higher consumption at all hours of the day, even outside cooking hours. The difference is approximately 566kWh/year, of which 175kWh/year can be attributed to a baseline (extrapolating from 1am-5am consumption) and 391kWh/year of cooking demand.

For the present analysis, a filtered subsample of those (gas-heated) homes with both electric oven and hob is compared to those with both a gas oven and hob, as in Table C1.

	Mean total consumption, kWh/yr	Difference attributed to cooking, kWh/yr	Proportion of total consumption, %
Electric cooking	3360	430	12.8%
Gas cooking	2930	-	-

Mean across 47 electric- and 29 gas-cooking homes.

Table C1 – EFUS 2017 electricity consumption for cooking (subsample excluding dwellings with electric heating)

The typical difference attributed to cooking of 430kWh/yr and 12.8% of total consumption compares well with the 391kWh/yr from the EFUS published analysis and with the corresponding 10.9% and 448kWh reported in *Powering the Nation 2*.

Due to small sample sizes it was not possible to work out this difference as it varies with number of occupants, so to account for behavioural variation it was instead assumed that cooking typically accounts for 12.8% of household electricity consumption and so a linear fit was applied to 12.8% of the total demand for each household against the number of occupants, this is shown in Figure C1 below. The resulting formula is:

$$EFUS\ 2017\ Electric\ Cooking\ demand = 171 + 98 \times Occ$$

²² *Lights, appliances and smart technologies Final report*, BEIS 2021.

<https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2017-reports>

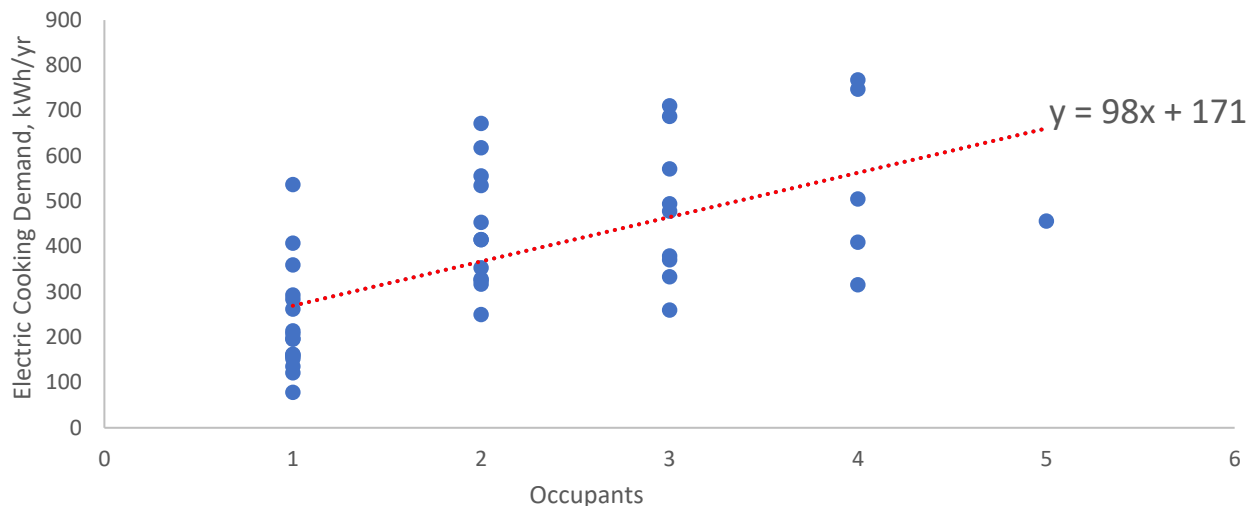


Figure C1 – Electricity consumption attributed to cooking vs occupancy in EFUS 2017 monitoring sample with linear fit.

C2 HES 2012

By contrast, Figure 419 in the HES final report (reproduced in Figure C2 below) suggests that the average annual cooking energy consumption does not increase as a linear function with number of occupants and instead tends to remain at a relatively consistent 448kWh. This is most likely due to the demographics of the participants in that survey - the sample for the HES was not intended to be representative of the population in England as a whole, but was recruited to be as representative as possible of the owner-occupier population in England, meaning that the trend in Figure 419 is representative of family groups who cook together, as opposed to HMO style occupancy where this behaviour would not be expected. Indeed, section 11.3 of the HES final report states:

“Figure 419 shows the annual consumption per person as a function of the number of people in the household. The values per person should be treated with some care because the family structure has to be taken into account as well. The annual consumption decreases from 460 kWh/person for single-person households, to 230 kWh/person for 2 people and to 150 kWh/person for 3 people. It is then stable around this value for 4, 5 or 6 people at 100 kWh/person. Cooking is most efficient in terms of electricity consumption if done for more than 2 people.”

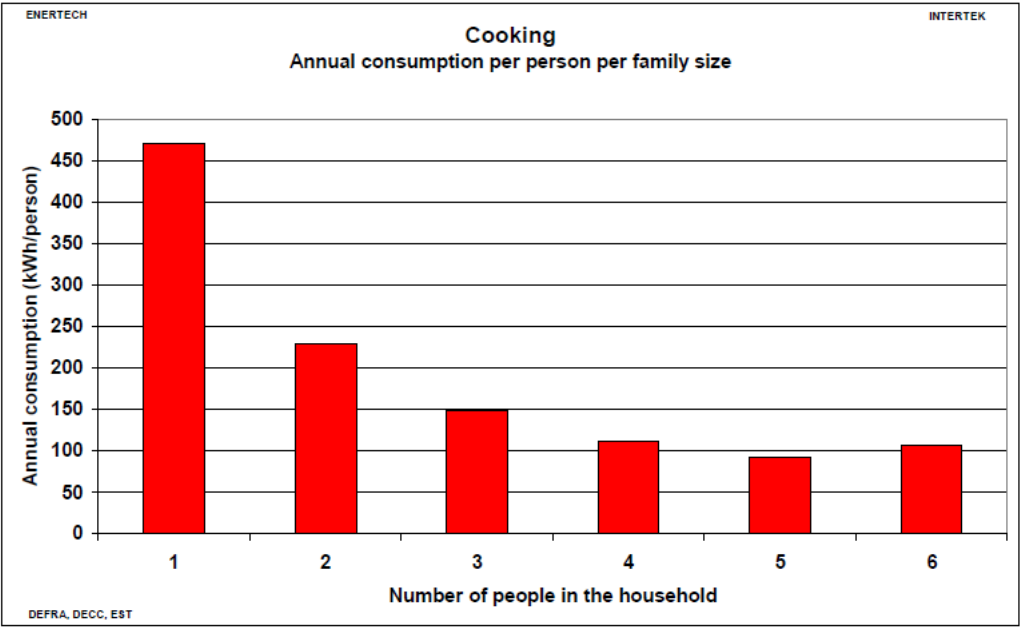


Figure 419 Cooking – Annual consumption per person per family size

Figure C2 – Figure 419 in the HES final report

C3 Assumed demographic correlation of group and individual cooking

Reproduced below (Table C2) is Annex Table 1.9 from the EHS 2022-2023 rented sectors report²³, with household types who might be expected to cook individually highlighted in blue. While the percentages of owner occupiers and of all households match reasonably well, the expected behaviours of those groups highlighted are not seen in the figure above.

²³ English Housing Survey 2022 to 2023: rented sectors, MHCLG 2024

Annex Table 1.9: Household type by tenure, 2022-23

all households								
household type	owner occupiers			private renters	social renters			all households
	own outright	buying with mortgage ¹	all owner occupiers		local authority	housing association	all social renters	
	percentages							
one person	40.6	19.5	31	33	44.6	45.6	45.2	33.7
couple, no children	41.6	26	34.5	21.5	9.8	11.8	11.1	28.2
couple, non-dep children only	5.8	6.9	6.3	2.1	2.9	3.5	3.3	5
couple, dependent children	5	38.3	20.1	18.4	15.4	13.3	14.1	18.8
lone parent, non-dependent children or	3.8	2	3	2.5	6.9	6.1	6.4	3.4
lone parent, dependent children	0.7	4.7	2.5	10.8	14.3	16	15.4	6.2
two or more families	1.1	1.5	1.3	1.8	3.4	1.3	2.1	1.5
lone person sharing with other lone pei	1.5	1.2	1.4	9.9	2.7	2.2	2.4	3.1
total	100	100	100	100	100	100	100	100
sample size	2,798	2,168	4,966	2,573	1,416	2,250	3,666	11,205

¹Includes shared ownership

Source: English Housing Survey, full household sample

Table C2– Annex Table 1.9 from the EHS 2022-2023 rented sectors report

Excluding the “one person” category, 80.4% of all (multiple occupant) households are expected to cook as a group, while 19.6% would cook individually.

To reconcile the HES report and formula (2), cooking appliance usage in HEM is calculated as a weighted average of these two behaviours, 80/20 in favour of a constant 448kWh vs the EFUS 2017 derived formulae. As this total demand is compared with mean figures from the HES monitoring data (see Table 5) to obtain a number of usage events per cooking appliance, only the formula for electric cooking was used – the HES sample does not account for gas cooking, any increased demand due to the relative inefficiency of gas cooking appliances will be accounted for in the stated demand per cycle. This leaves us with:

$$\text{Standard Annual Cooking kWh} = 0.8 * 448 + 0.2 * (171 + 98 * \text{Number of Occupants})$$

which reduces to Formula (1).

Appendix D – Time of day profile

This section introduces the methodology and assumptions behind the creation of the Time-Of-Day profiles, which are used to schedule events for appliance and cooking use. The profiles are shown in Figure 1 of the main text.

Two data sources have been used for the creation of these profiles, Time in Use data from the Office for National Statistics (ONS)²⁴ and energy use data from the Energy Follow Up Survey (EFUS)²⁵.

The ONS time in use data from March 2023 is a study of 5,600 adults and their daily activities. Each participant kept a diary of the different categorised activities throughout each day for the duration of the study. The OTUS weighting process takes account of non-response and individual diaries are calibrated with calibration controls applied for age and sex groups, geographical regions, ethnicity, and employment. Diaries are split into two subsets for weekdays and weekends, which are each calibrated separately. They are then recombined and rescaled using a ratio of 5:2 (weekdays: weekends). In this way, the diary data are made representative of how the UK adult population spends time over the course of a week. The activities contained within this data are categorised into one of six broad categories: Sleep and rest; Cleaning; Cooking; Other home activities; Outside of the home; and Other/unknown. This data is used to indicate when occupants are likely to be conducting activities which make use of appliances relating to that activity within a dwelling. Whilst no information is available about the ratio of respondents residing in new versus existing homes, it is assumed that this survey is biased towards existing homes due to the prominence of these within the UK housing stock. However, at the time of writing there are no available studies of this type on only new homes.

The Energy Follow Up Survey (EFUS) is a large interview and measurement survey of household occupancy and heating patterns, thermal comfort, and energy consumption over 2017 to 2019. It is a detailed follow-up to the annual English Housing Survey. It includes interviews with around 2,500 households and half-hourly temperature measurements from around 750 homes between autumn 2017 and spring 2019. It also contains daily profiles of gas and electricity consumption from 150 and 450 households respectively, taken over the 2018 to 2019 heating season. This data is used to indicate when energy is being consumed within a dwelling which could be the result of appliance use. However, care must be taken when using these profiles as they represent the total energy consumed by the household, which will include the energy required to heat the dwelling (as the data was taken during the heating season). Again, this study did not specifically target new homes and is thus assumed to be biased towards existing dwellings but no alternative studies of this nature targeting new homes exists at the time of writing.

The ONS data for time use in the UK was cleaned to remove any non-numerical entries or missing values. The ONS data has a native sampling of 10-minutes, while the EFUS data

²⁴ Office for National Statistics (ONS), released 04 July 2023, ONS website, statistical bulletin, [Time Use in the UK: March 2023](#)

²⁵ EFUS 2019 [Energy Follow Up Survey \(EFUS\) 2017 reports - GOV.UK \(www.gov.uk\)](#)

reports at 1-hour intervals. As the EFUS data's sampling most closely matches the time steps used in HEM:FHS it was decided to re-bin the ONS data to match EFUS so that they could be combined. The alternative approach of resampling the EFUS data to a 10-minute time step would have required interpolation between the existing data points (introducing uncertainties) and would have resulted in profiles which were oversampled compared to those needed by HEM:FHS. The ONS data was thus re-binned from 10-minute intervals into 1-hour time steps to match the EFUS average Gas and Electricity consumption datasets.

In addition to the six categories contained within the ONS data, three new, compound categories were created for this analysis. These are:

1. Occupied – Produced by taking 100% and subtracting the propensity for occupants being outside of the home. This profile is not used in the creation of the appliances and cooking events schedules but is used elsewhere within HEM:FHS for calculating metabolic gains from occupants.
2. Occupied and active – Produced by taking the occupied propensity and subtracting the propensity for occupants to be sleeping or resting. This profile represents the overall likelihood that occupants are within the dwelling and able to make use of appliances.
3. Home activities – Produced by summing the Cooking, Cleaning, and Other Home Activities propensities. This profile represents the likelihood that occupants are conducting activities within the home which might make use of appliances.

D1 Assigning appliances to categories

The HEM FHS wrapper produces appliance use event profiles for eight different classes of home appliances: Washing machines; Tumble dryers; Dish washers; Electric ovens; Microwaves; Kettles; Gas cookers; and consumer electronics. Consumer electronics is very broad class containing all other devices which do not fit into one of the other seven appliance classes. Each class of appliance is assigned to one of the ONS categories (including the new categories listed above) which most appropriately matches the activities during which the appliance would be used.

Cooking: Electric ovens, Microwaves, and Gas cookers are typically only used when an occupant is cooking and are thus assigned to the Cooking category.

Cleaning: Washing machines, Tumble Dryers, and Dishwashers are all cleaning appliances so are assigned to the Cleaning category.

Home activities: Kettles will potentially see use during both cooking and cleaning activities; but also, more widely (e.g. for making hot drinks) whenever an occupant is conducting activities within the home. As such Kettles are assigned to the compound category, Home activities.

Occupied and active: Consumer electronics, being such a broad class, can potentially see use whenever a dwelling is occupied. However, the vast majority (excluding continuously running appliances such as fridge freezers which are treated separately) will only see use while occupants are awake, so these are assigned to the Occupied and active category.

While the profiles for each of these ONS categories gives an indication of when occupants are performing these activities it is important to consider that this does not strictly represent when the appliances related to these activities will be used. Most of these activities can be conducted without using appliances or do not strictly need to use appliances for the full duration that occupants are conducting them. For example, cooking can include chopping and other food preparation while cleaning can include tidying or sweeping, none of which make use of any appliances. Similarly, many of the appliance classes considered can be started relatively quickly and then run for a long duration (e.g. Washing machines, Dishwashers, Ovens etc.).

To account for this, we must also consider when energy is being used within dwellings for these activities. To do so the ONS profiles must be combined with the EFUS Average Gas and Electricity use profiles appropriate to the appliance in question.

D2 Combining datasets

Before combining the two datasets a correlation analysis was run to ensure that the correlation between the EFUS data and the ONS data was sufficient to extract reasonable propensity profiles from the EFUS data. For this purpose, we consider the four ONS categories assigned in the previous section and calculate the Pearson correlation coefficient and Spearman's rank correlation coefficient against the relevant energy type for each set. Across all proposed combinations both statistics have values in the range of 0.7 to 0.9 indicating a strong correlation between the data sets. This analysis finds that the likelihood that the two data sets are unrelated is extremely low, less than 1 in 10,000 for all combinations. This level of correlation seen between all relevant profiles was deemed sufficient to include the EFUS data in the production of the final appliance propensity profiles. An example of this strong correlation between the ONS and EFUS profiles is illustrated in Figure D2.1.

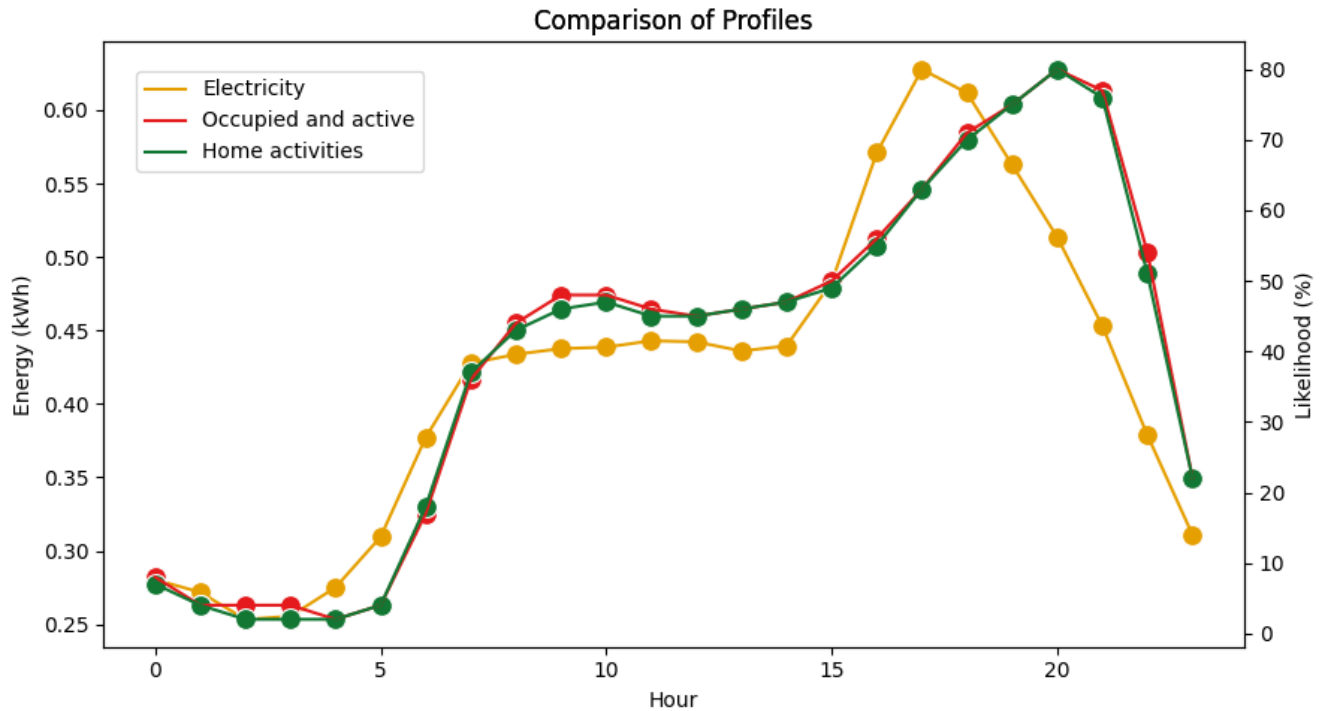


Figure D2.1: Comparison between the Electricity consumption and the two ONS profiles for occupied and active and Home Activities showing the strong correlation between the two data sets.

A regression analysis was then run to provide the best fitting relationship between the ONS propensity profiles and the relevant EFUS energy consumption. Given the high values for the Pearson's correlation coefficient, it was decided that a linear relationship was most appropriate for this comparison. These relationships were used to produce a propensity for each appliance by taking the average energy (Electricity or Gas) consumption within each timestep and using it to estimate the propensity for appliance use within that time step. These new propensity profiles gave a separate estimate of when energy was being used for each appliance class.

To combine these profiles with the ONS profiles of when occupants were conducting activities likely to use appliances the mean of the ONS propensity profiles and EFUS propensity profiles was taken. For this purpose, the geometric mean ($\bar{x}_{geo} = \sqrt[n]{x_1 \times x_2 \times \dots \times x_n}$) was used, where $\bar{x}_{geo}$ is the geometric mean, n is the number of samples, and x_n are the individual samples.

The geometric mean was selected as it is the most appropriate method to use when calculating the mean of probabilities, which can potentially span several orders of magnitude. An example of how this final propensity model compares to the ONS propensity and the EFUS consumption modelled propensity can be seen in Figure D2.1. The combined overall propensity at each time step t is then given by

$$Propensity_t = \sqrt[2]{ONS\ Propensity_t \times EFUS\ Propensity_t}$$

Prior to combining the two profiles in this way, a floor was implemented in both the ONS and EFUS profiles to ensure that no appliance ever had a negative propensity to be used in either profile. This ensured that the propensity profiles represented physically meaningful likelihoods that an appliance was used in a particular time step. The final resulting appliance propensity

profiles are shown in Table D2. These are then used to help set the appliance event/use profiles as detailed in HEM FHS-TP-04.

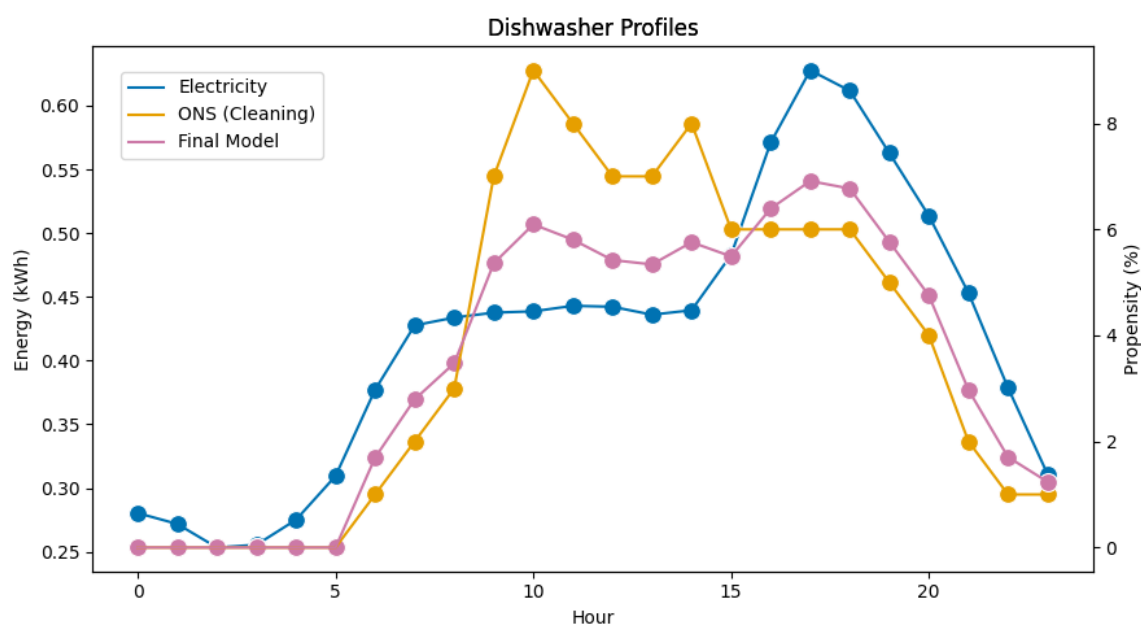


Figure D2: A comparison of the appliance use propensity predictions for dishwashers showing the ONS cleaning propensity, the cleaning propensity modelled on the EFUS electricity consumption, and the final propensity model (the geometric mean of the two).

Hour	Occupied	Washing machine	Tumble dryer	Dishwasher	Electric Oven	Microwave	Kettle	Gas Cooker	Consumer Electronics
0	0.98	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.10
1	0.98	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06
2	0.99	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.05
3	0.99	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.05
4	0.99	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.05
5	0.97	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.08
6	0.92	0.02	0.02	0.02	0.02	0.02	0.23	0.03	0.23
7	0.81	0.03	0.03	0.03	0.04	0.04	0.39	0.06	0.39
8	0.65	0.03	0.03	0.03	0.04	0.04	0.43	0.05	0.43
9	0.57	0.05	0.05	0.05	0.03	0.03	0.44	0.04	0.46
10	0.53	0.06	0.06	0.06	0.03	0.03	0.45	0.02	0.46
11	0.49	0.06	0.06	0.06	0.04	0.04	0.45	0.03	0.45
12	0.47	0.05	0.05	0.05	0.05	0.05	0.44	0.04	0.45
13	0.49	0.05	0.05	0.05	0.04	0.04	0.44	0.04	0.45
14	0.50	0.06	0.06	0.06	0.03	0.03	0.45	0.03	0.45
15	0.53	0.05	0.05	0.05	0.04	0.04	0.51	0.03	0.51
16	0.59	0.06	0.06	0.06	0.07	0.07	0.62	0.07	0.63
17	0.66	0.07	0.07	0.07	0.11	0.11	0.72	0.10	0.72
18	0.73	0.07	0.07	0.07	0.10	0.10	0.74	0.09	0.75
19	0.77	0.06	0.06	0.06	0.07	0.07	0.72	0.07	0.72
20	0.84	0.05	0.05	0.05	0.04	0.04	0.68	0.04	0.69
21	0.89	0.03	0.03	0.03	0.02	0.02	0.59	0.02	0.60
22	0.93	0.02	0.02	0.02	0.00	0.00	0.40	0.00	0.41
23	0.96	0.01	0.01	0.01	0.00	0.00	0.19	0.00	0.20

Table D2: Final appliance propensities, rounded to two decimal places, consistent with the profile presented in Figure 1.

