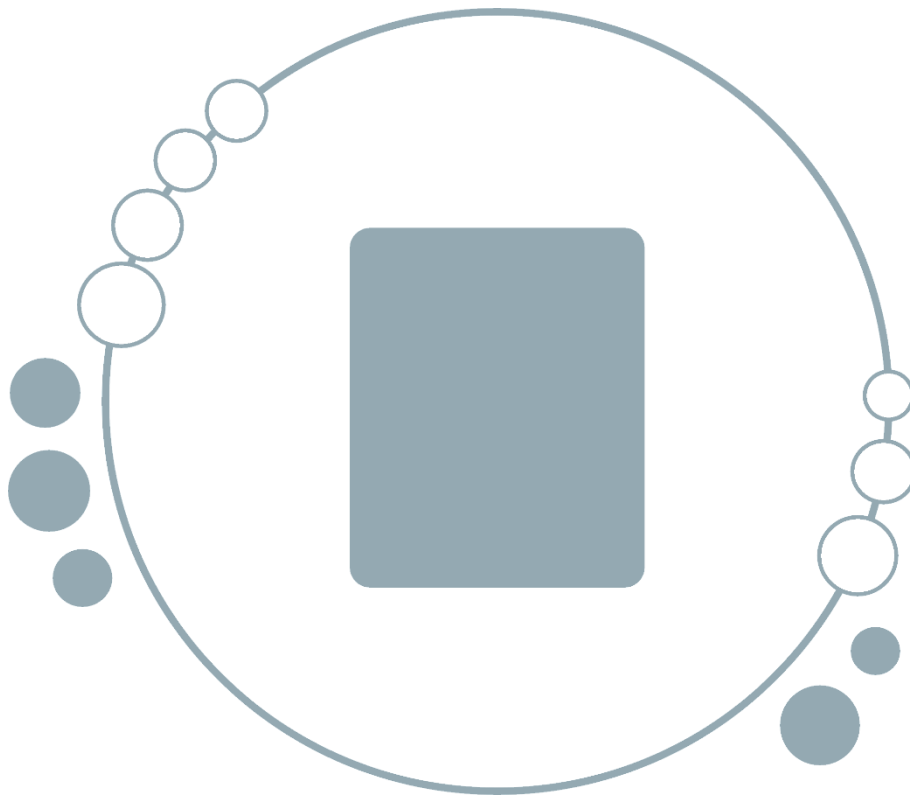




Calculating cold water and evaporative losses within the Home Energy Model: FHS assessment

A technical explanation of the methodology

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Background to the Home Energy Model

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

Some related content can be found in the paper on occupancy assumptions (HEMFHS-TP-02), as well as pipework losses for hot water (HEMFHS-TP-04).

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

future_homes_standard.py

cold_water_loss_profile.csv

evap_loss_profile.csv

Introduction

This paper reviews HEM's treatment of heat loss related to incoming cold water and evaporation, as well as the creation of heat loss factors for half hour time periods, for each day of the week.

Heat is lost to cold water entering the home, as the cold water warms towards the internal ambient temperature.

Heat is also lost through evaporation occurring within the home when the water vapour created leaves the dwelling via ventilation or infiltration, rather than condensing and re-releasing the energy of evaporation back into the space.

These losses need to be taken into account in HEM's core heat balance module when it calculates the heating requirement.

Examples of events which lead to cold water losses:

1. Toilet flushing – leading to cold water entering the cistern and feed pipework.
2. Cold water use (showers, baths, taps) – leading to cold water entering the feed pipework.
3. Hot water use – leading to cold water entering the feed pipework.

Regarding item 3, the calculation of the energy required for water heating already includes the energy required to heat incoming cold water from its cold temperature to the required hot water temperature, so the energy required to heat from cold temperature to room temperature is excluded to avoid double counting.

Examples of sources of evaporative loss:

1. Physical presence of humans (evaporation from skin and from breathing)
2. Drying clothes and towels indoors
3. Watering indoor plants
4. Cleaning activities
5. Spillages

This list is unlikely to be exhaustive.

Item 1 is not considered further here because this is dealt with elsewhere as part of the consideration of metabolic gains (see *HEMFHS-TP-02* for details).

Cooking also results in evaporative losses, but this is factored in the cooking energy consumption/gains calculation, so is also not treated here.

Level of losses

No existing methodology or standard was identified which provides an approach suited to HEM for establishing losses to cold water or via evaporation.

Similarly, no new dataset stating or implying the level of losses from these sources was found. The only reference values identified were from Passive House Planning Package (PHPP) documentation¹.

The physics of determining the magnitude of losses of these types are straightforward – heat transfer from/to pipes as a function of pipe/air temperature is implemented elsewhere in HEM and evaporative losses are easily calculated from the volume of water evaporated. But to calculate these losses directly in HEM would require a lot of detail about the system and how it is used. For example, to work out cold water losses the layout of the pipework to all outlets would need to be known, as would a schedule of individual outlet use (for which we have no data – unlike for hot water use). Direct modelling of this within HEM was therefore deemed impractical in terms of the data available and the input data requirements that would be required for HEM.

There are standards describing how to calculate heat loss from pipework, such as the method used elsewhere in HEM taken from 2021 ASHRAE Handbook², Section 4.4.2. There are also system design guidance standards (e.g. CIBSE Guide B) which are relevant for estimating pipework lengths and diameters. However, as noted above, this is only useful if a realistic temperature profile can be applied to that pipework, on which there is no data, and which would not be practical to use in HEM.

This leaves the PHPP basis as the only usable source for the level of these losses. PHPP assumes a fixed 25 W/person for evaporative losses (from non-metabolic sources) and a value of around 20 W/person for cold water losses from this equation³⁴⁵⁶.

$$\text{Losses to incoming cold water (W/person)} = 70 \times 1.16 \times 0.5 \times (T_{\text{int}} - T_{\text{ground}}) / 24$$

Where:

T_{int} is the internal air temperature °C – assumed to be 22 degrees.

T_{ground} is the incoming cold water temperature in °C - assumed to be 10 degrees⁷

The FHS wrapper has adopted these figures as the average level of losses.

¹ SAP applies value of 40 W/person, but this is in turn based on PHPP.

² <https://www.ashrae.org/technical-resources/ashrae-handbook/ashrae-handbook-online>

³ [Internal heat gains in relation to living area \[Passipedia EN\]](#) (sections 7 and 9)

⁴ 70 Litres per day PHPP assumption on per person hot water consumption

⁵ 1.16 Wh per litre per Kelvin = 4.186 kJ/kg·K (the specific heat capacity of water)

⁶ PHPP assumes the cold water will only heat to 50% of the internal temperature before new cold water is added.

⁷ PHPP assumes cold water comes in at the ground temperature (hence the variable name), but HEM receives cold water temperatures from the input file, so this does not have to be the ground temperature.

Time-of-day profiles

No specific data relating to the timing variation of evaporative and cold-water losses was found (it is not needed for PHPP/SAP), but some insight can be gained from considering occupancy and occupant activity data⁸ held by the Office for National Statistics (ONS).

Evaporative losses

Evaporative losses due to household activities (drying, cleaning, plant watering, etc.) are predominantly related to active occupancy – such that new sources of moisture will largely cease to be created when occupants are asleep or away from home.

ONS data on householder activities tells us both the level of occupancy by time of day and the types of activity being undertaken.

The profile shown in Figure 1, when occupants are both in and not asleep (labelled 'in-and-awake'), is used as the basis for a time-of-day profile for evaporative losses. Note that only the weekday profile is shown here – there is a different profile for the weekend.

Most sources of moisture generation will have considerable 'tails' on them. While these may be *initiated* by events that take place at times of active occupancy, evaporation will not suddenly cease when occupants are out or asleep, meaning a direct link with the in-and-active occupancy profile above would underestimate evaporative losses at other times.

Therefore, a decay-style smoothing is applied so that evaporation is assumed to continue after the causal event. For example, it is assumed that drying evaporation falls exponentially, such that this can be characterised by a halving time. To apply this smoothing, a set of 24 factors⁹ was generated which halve in a defined time and sum to a total of 1, as shown in Figure 2.

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

⁹ Since the ONS activity data has one value per hour.

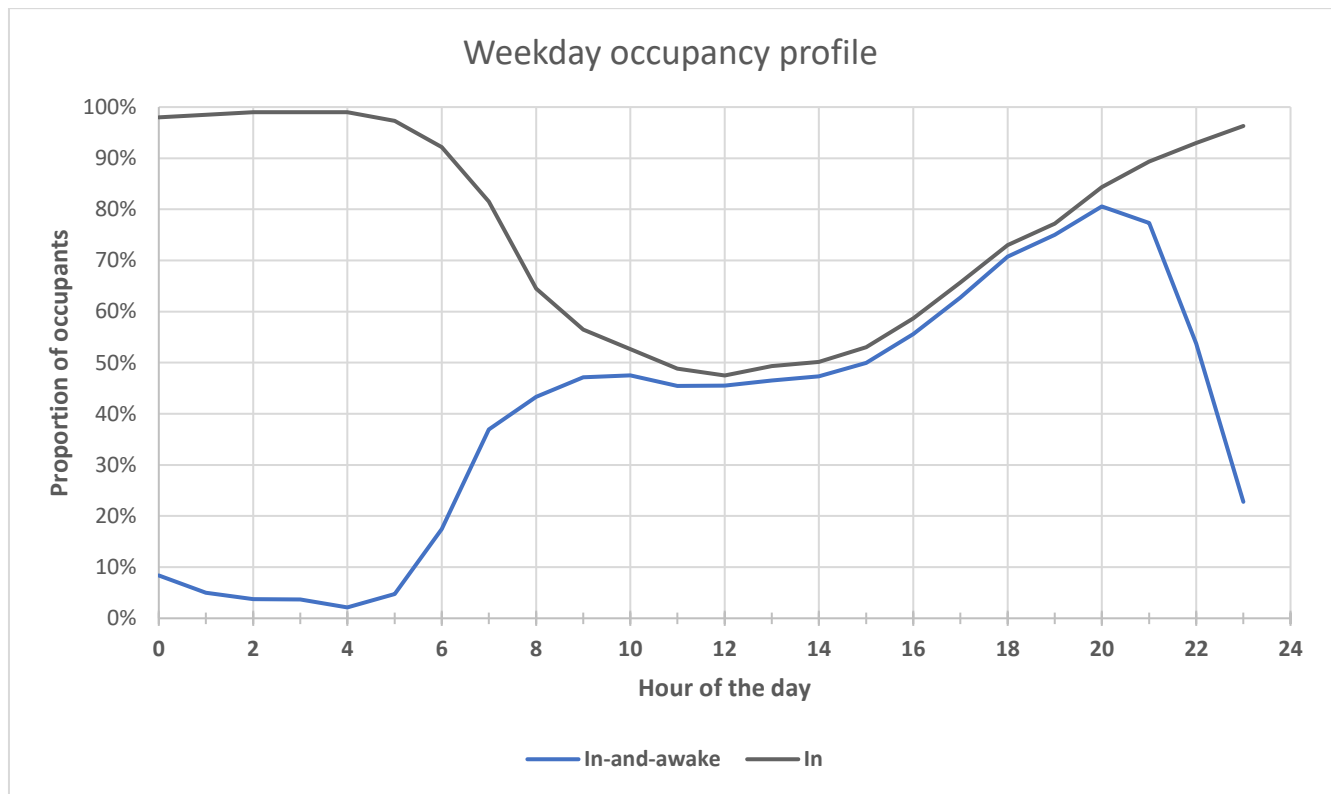


Figure 1 – Weekday occupancy profile based on ONS data.

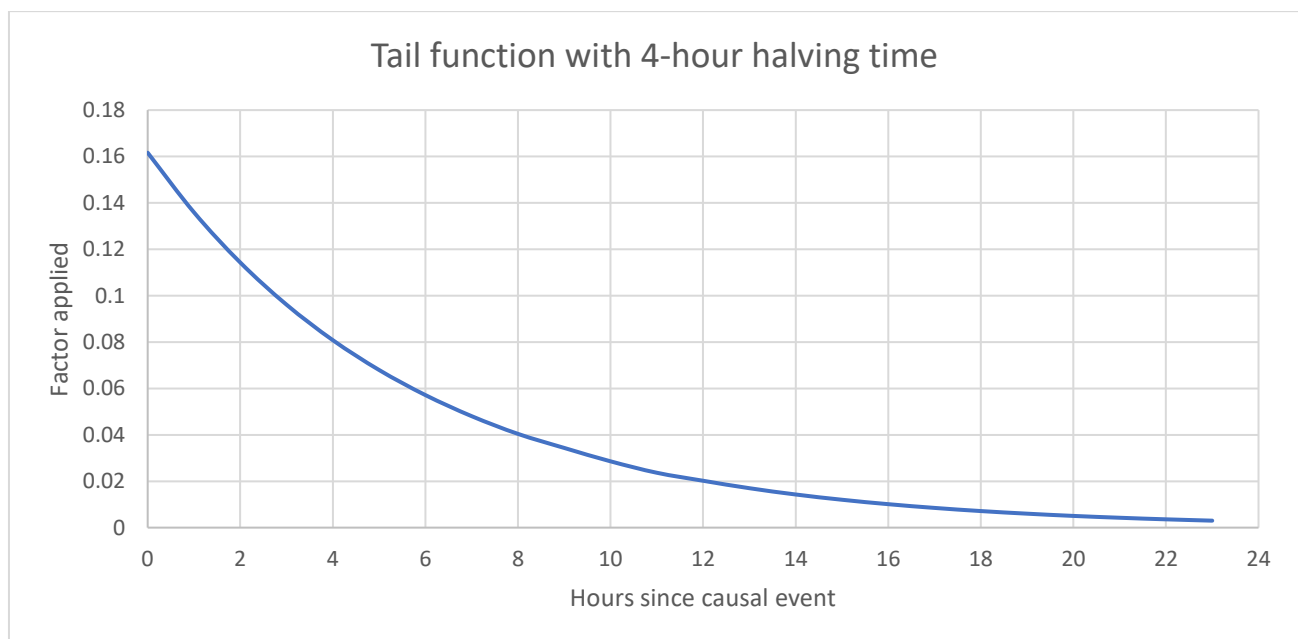


Figure 2 – Tail function to be applied to occupancy profile.

This was then applied¹⁰ to the 24-hour profile of in-and-awake data to give an adjusted profile. The impact of applying a tail function of this type, with a 4-hour halving time, to the in-and-awake occupancy rate is shown in Figure 3.

¹⁰ Each hourly figure was spread over the following 24 hours according to the tail function then the total for each hour was summed.

The choice of a 4-hour halving time is an estimate based on a working group's experience that, during the heating season, clothes left to dry on a rack indoors typically take about a day to dry to an acceptable level – consistent with the graph. In practice this time would vary with case-specific factors, like air circulation in the specific location.

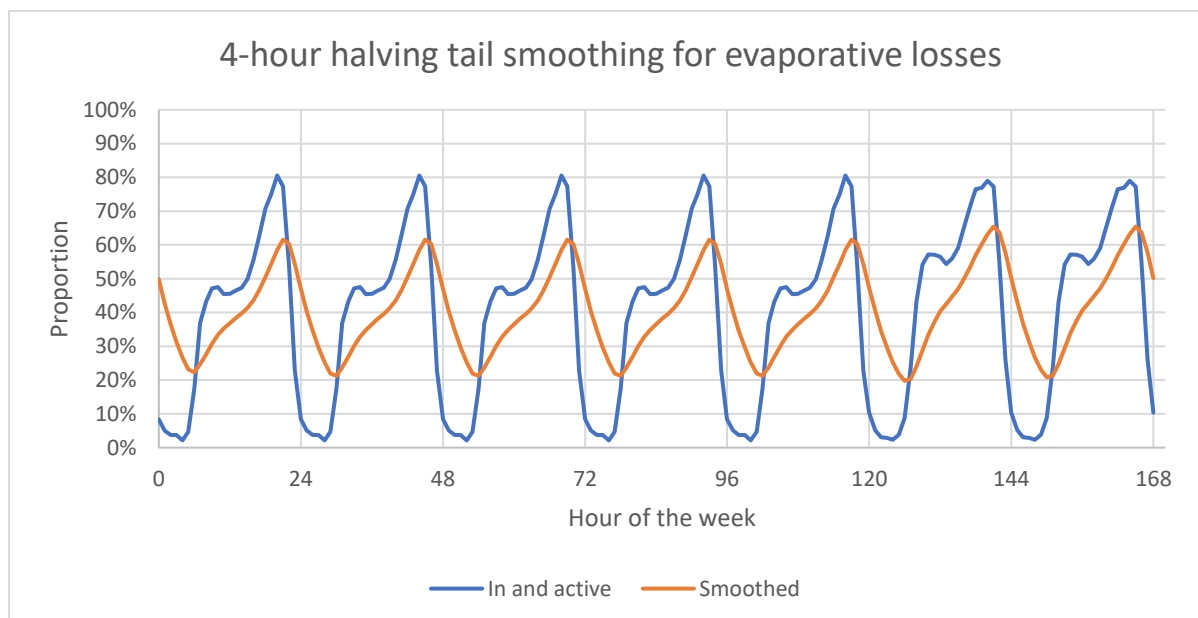


Figure 3 – Impact of smoothing occupancy profile (before and after)

There is a slightly different profile on the last two days shown in figure 3 as these are based on the weekend ONS profile data.

The difference caused by applying the tail function is most obvious at night, where the in-and-awake rate falls close to zero, but the smoothed data falls much more gradually, reaching a minimum of just over 20% in the morning. This gives the intended behaviour – that moisture generated during the day continues to generate evaporative losses during the night.

Cold water losses

Losses to incoming cold water are directly linked to the volume of water used, so it is assumed this would also reduce when people are out or asleep. Therefore, basing this profile on the in-and-awake occupancy dataset is again assumed to be suitable. It will take time for cold water to warm up towards room temperature, a 'tail' of the sort described for evaporative losses was also applied here. In the case of cold water in uninsulated copper pipes, this is likely to warm up quite quickly; but due to their larger volume and compact shape, cold water entering toilet cisterns will take longer.

A simple heat loss model was developed in a spreadsheet to consider likely warm up times. It was assumed cold water pipework was made up of uninsulated 15mm copper pipe¹¹. Heat

¹¹ The length of pipework can be ignored for this purpose – the time taken is independent in the length assumed, for the chosen calculation method.

transfer from air to pipework was based on the 2021 ASHRAE Handbook methodology, assuming a cold-water temperature of 10°C and room air temperature of 20°C. The toilet cistern was modelled as a rectangular box made up of sides with a U-value of 5 and a total volume of 8l but only assumed to be filled $\frac{3}{4}$ full for calculating the heat capacity. The results of these models are shown in Figures 4 and 5. Note the substantial differences in the scale of the time axes of the two graphs.

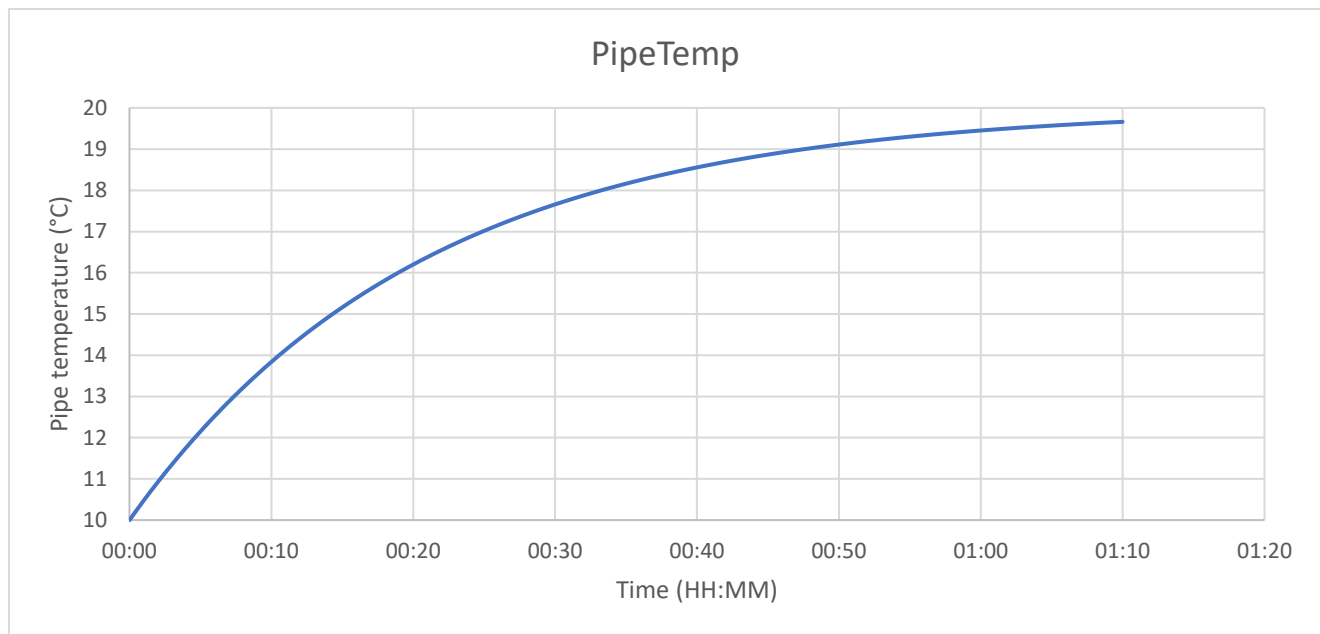


Figure 4 – Modelled warm-up profile of water in uninsulated 15mm pipework

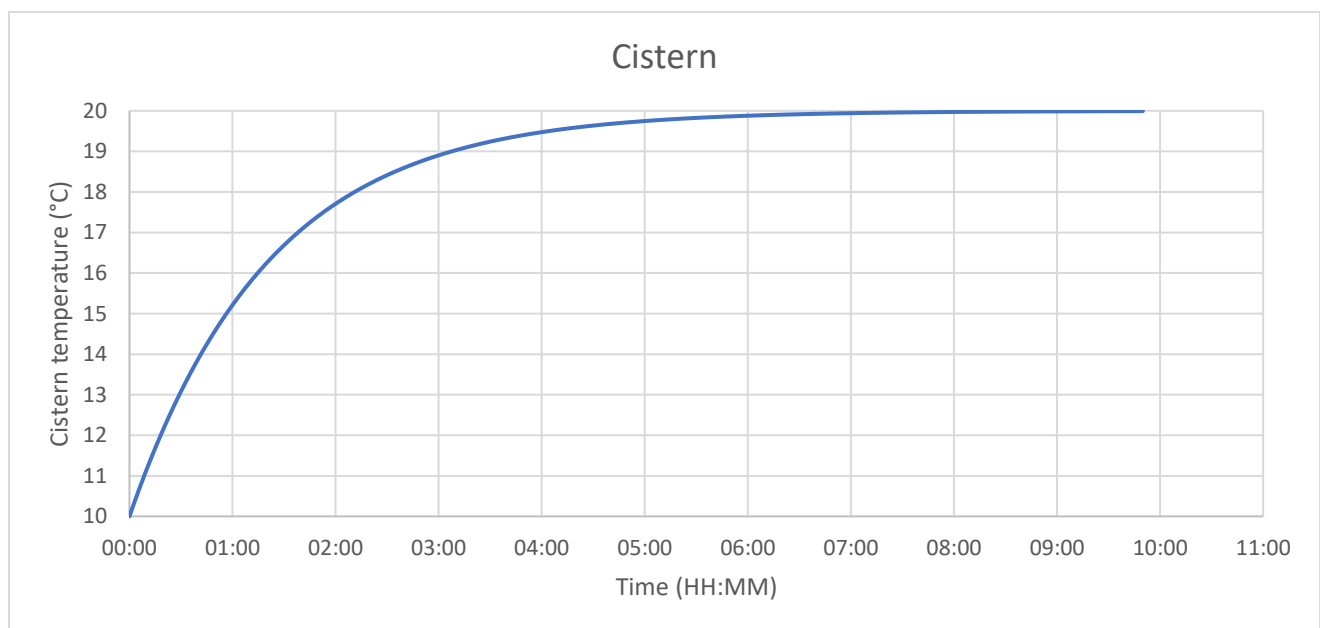


Figure 5 – Modelled warm-up profile of water in a toilet cistern

The modelled halving times for heat loss (i.e. where the temperature has risen halfway to the ambient air temperature) for pipework and a toilet cistern were about 14 minutes and 57

minutes, respectively. Toilet flushing is the single largest user of cold¹² water in homes¹³, so weighting more heavily towards this halving time by using a figure of 45 minutes gives the adjusted profile shown in Figure 6.

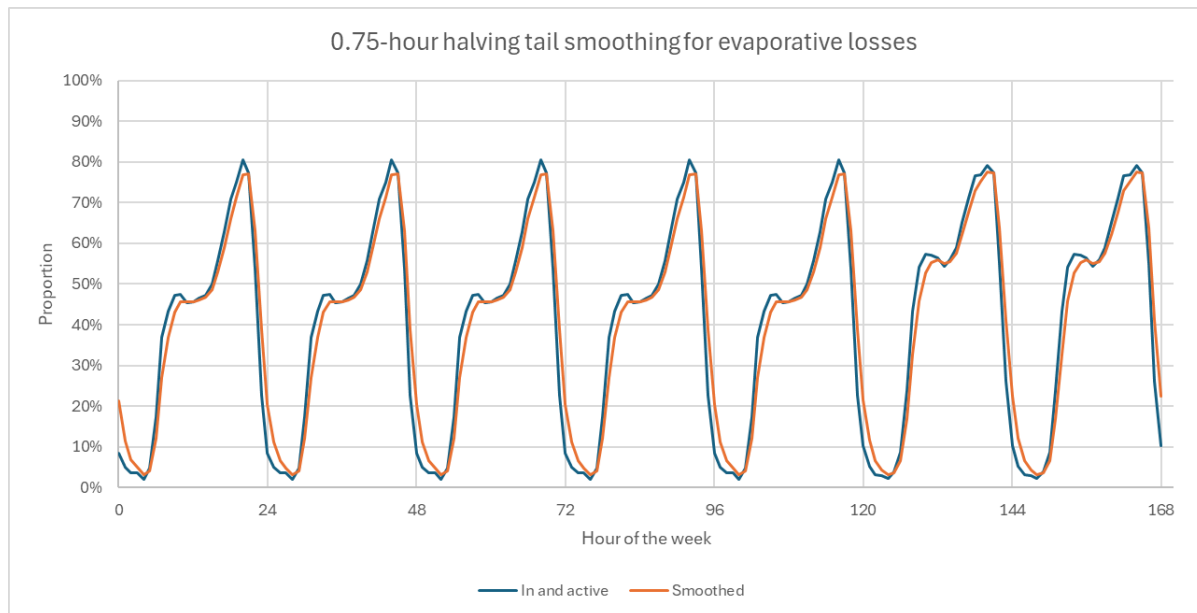


Figure 6 – Impact of smoothing on occupancy profile (before and after)

This makes a fairly subtle difference to the in-and-active profiles (much less than the 4-hour halving smoothing profile applied for evaporative losses), but it reduces peaks slightly and shows some non-negligible differences during in the night.

Applying profiles to the average losses

Multiplying the time-of-day profiles described above by the flat/average figures for evaporative and cold-water losses based on PHPP (25 and 20 W/person), does not yet give the correct outcome (since the average of the ‘in-and-active’ data is not 1). This is because the PHPP figure already have inherent assumptions about occupancy that we would result in double counting. Therefore, before application of each profile, the proportions were rescaled to give an average of 1.

A further subtlety relates to the fact that the weekend occupancy profile is different from the weekday profile. Because smoothing used, the factor for any given time depends to some extent on the occupancy profile for each point in the previous 24 hours. This means the smoothed profile is different on Monday from Tuesday, for example, because Monday contains

¹² Total water use is higher for showers, but the ‘hot’ component of that is out of scope of this work because this is included in the calculation of hot water energy directly – where it is assumed water is directly heated from cold.

¹³ According to the EST’s At Home With Water report:

https://energysavingtrust.org.uk/sites/default/files/reports/AtHomewithWater%287%29.pdf?utm_source=chatgpt.com

the tails of Sunday's different activity profile. To allow for these intraday differences, a full week's set of profiles is provided in the data files used by the FHS wrapper code (*cold_water_loss_profile.csv* and *evap_loss_profile.csv*).

Finally, the 24-hourly values (based on there being 24 values in the ONS data) are interpolated to give the 48 half-hourly figures needed when using a 30-minute timestep.

The final data tables incorporating these adjustments are shown in Appendix A, with graphs shown here (Figures 7 and 8). These values are applicable directly to the flat loss figures.

The FHS wrapper calculates the evaporative and cold-water losses for each half hour of the year and writes these to the input file that is sent to HEM's core calculation.

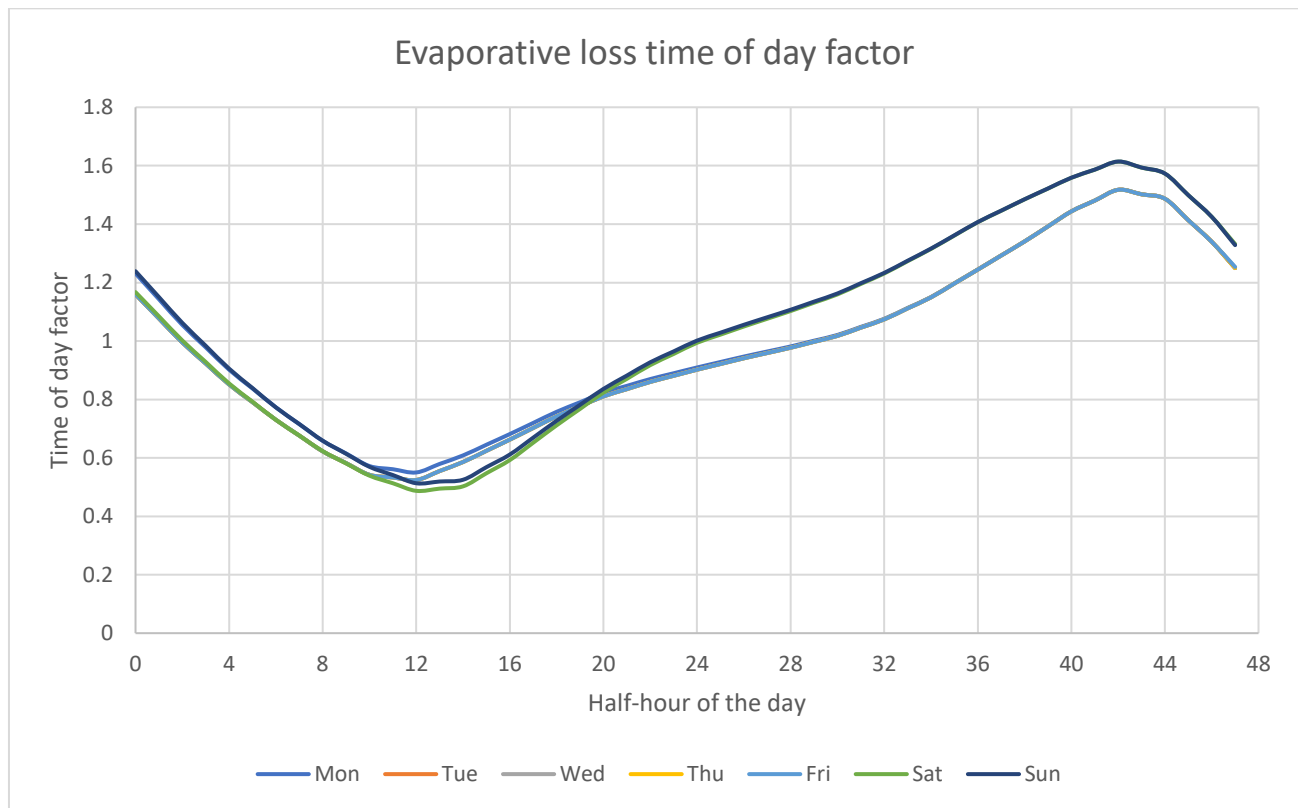


Figure 7 – Final evaporative loss time-of-day profile used for FHS wrapper.

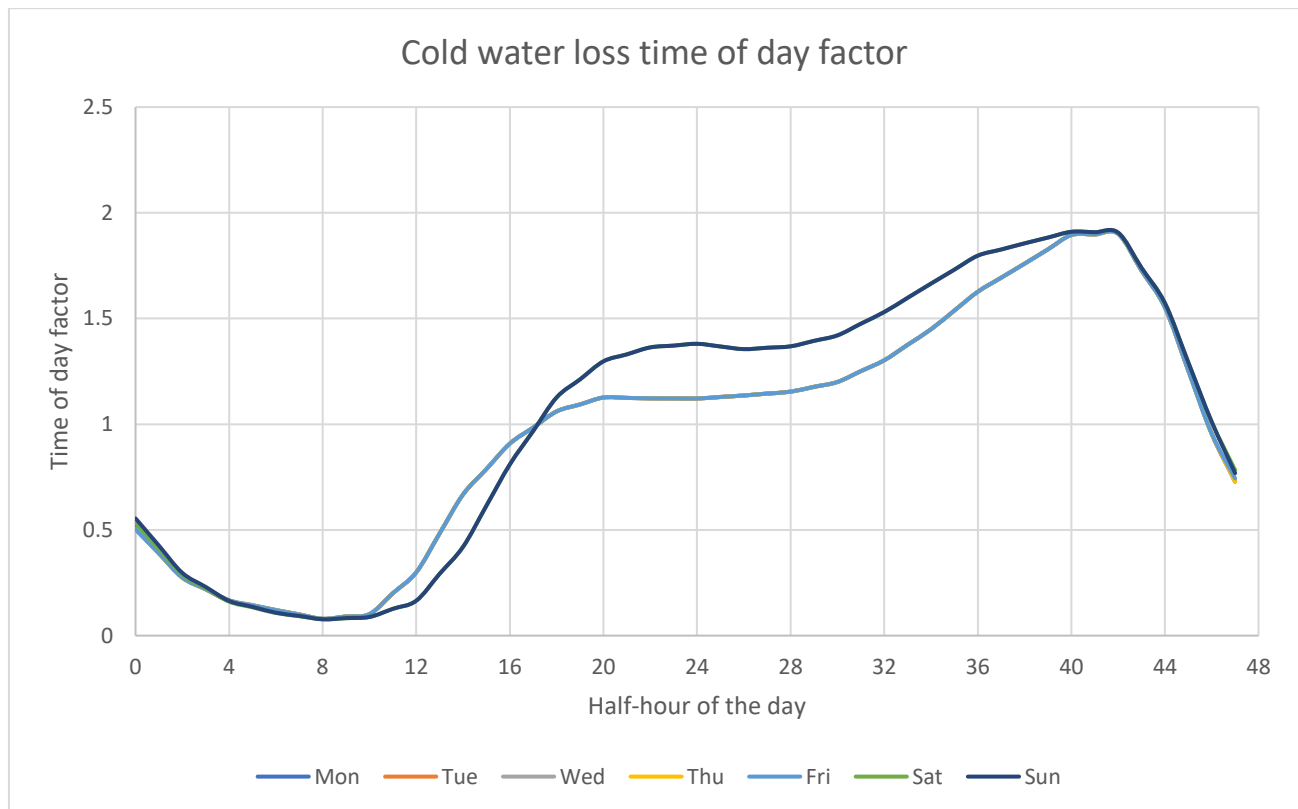


Figure 8 – Final cold water loss time-of-day profile used for FHS wrapper.

Future work

There remains a good deal of uncertainty in this area both regarding the level of losses and how they vary over the day and year. Should suitable data become available, the level and time-of-day profile, and possibly the whole calculation approach, should be reassessed.

Annex A – Tables of time of use factors

Table A1 - Evaporative losses time of day factor

Half hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	1.2311	1.1595	1.1595	1.1595	1.1595	1.1673	1.2389
1	1.1430	1.0771	1.0771	1.0771	1.0771	1.0846	1.1505
2	1.0549	0.9947	0.9947	0.9947	0.9947	1.0019	1.0621
3	0.9783	0.9229	0.9229	0.9229	0.9229	0.9283	0.9837
4	0.9017	0.8511	0.8511	0.8511	0.8511	0.8547	0.9053
5	0.8373	0.7906	0.7906	0.7906	0.7906	0.7924	0.8390
6	0.7728	0.7302	0.7302	0.7302	0.7302	0.7301	0.7727
7	0.7155	0.6763	0.6763	0.6763	0.6763	0.6766	0.7158
8	0.6582	0.6224	0.6224	0.6224	0.6224	0.6230	0.6589
9	0.6152	0.5821	0.5821	0.5821	0.5821	0.5811	0.6141
10	0.5721	0.5419	0.5419	0.5419	0.5419	0.5391	0.5693
11	0.5611	0.5331	0.5331	0.5331	0.5331	0.5131	0.5412
12	0.5501	0.5242	0.5242	0.5242	0.5242	0.4872	0.5131
13	0.5793	0.5550	0.5550	0.5550	0.5550	0.4949	0.5191
14	0.6084	0.5858	0.5858	0.5858	0.5858	0.5025	0.5252
15	0.6450	0.6242	0.6242	0.6242	0.6242	0.5475	0.5684
16	0.6816	0.6626	0.6626	0.6626	0.6626	0.5925	0.6116
17	0.7196	0.7023	0.7023	0.7023	0.7023	0.6520	0.6693
18	0.7577	0.7421	0.7421	0.7421	0.7421	0.7115	0.7271
19	0.7903	0.7763	0.7763	0.7763	0.7763	0.7675	0.7815
20	0.8229	0.8105	0.8105	0.8105	0.8105	0.8235	0.8360
21	0.8464	0.8352	0.8352	0.8352	0.8352	0.8705	0.8816
22	0.8698	0.8600	0.8600	0.8600	0.8600	0.9174	0.9272
23	0.8896	0.8809	0.8809	0.8809	0.8809	0.9557	0.9643
24	0.9094	0.9018	0.9018	0.9018	0.9018	0.9939	1.0014
25	0.9280	0.9214	0.9214	0.9214	0.9214	1.0217	1.0284
26	0.9467	0.9409	0.9409	0.9409	0.9409	1.0496	1.0554
27	0.9640	0.9589	0.9589	0.9589	0.9589	1.0761	1.0812
28	0.9814	0.9770	0.9770	0.9770	0.9770	1.1026	1.1070
29	1.0010	0.9973	0.9973	0.9973	0.9973	1.1311	1.1348
30	1.0206	1.0175	1.0175	1.0175	1.0175	1.1595	1.1626
31	1.0483	1.0457	1.0457	1.0457	1.0457	1.1953	1.1979
32	1.0760	1.0739	1.0739	1.0739	1.0739	1.2311	1.2331
33	1.1133	1.1116	1.1116	1.1116	1.1116	1.2731	1.2747
34	1.1505	1.1494	1.1494	1.1494	1.1494	1.3152	1.3164
35	1.1977	1.1968	1.1968	1.1968	1.1968	1.3609	1.3618
36	1.2449	1.2443	1.2443	1.2443	1.2443	1.4066	1.4072
37	1.2930	1.2925	1.2925	1.2925	1.2925	1.4456	1.4462
38	1.3411	1.3407	1.3407	1.3407	1.3407	1.4847	1.4851
39	1.3925	1.3921	1.3921	1.3921	1.3921	1.5216	1.5221
40	1.4440	1.4436	1.4436	1.4436	1.4436	1.5585	1.5590
41	1.4809	1.4805	1.4805	1.4805	1.4805	1.5862	1.5866
42	1.5178	1.5174	1.5174	1.5174	1.5174	1.6139	1.6143
43	1.5024	1.5021	1.5021	1.5021	1.5021	1.5934	1.5937
44	1.4871	1.4869	1.4869	1.4869	1.4869	1.5729	1.5731
45	1.4134	1.4133	1.4133	1.4133	1.4133	1.4990	1.4991
46	1.3398	1.3398	1.3398	1.3398	1.3398	1.4251	1.4251
47	1.2496	1.2496	1.2496	1.2496	1.2535	1.3320	1.3281

Table A2 - Cold water losses time of day factor

Half hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	0.5256	0.5032	0.5032	0.5032	0.5032	0.5324	0.5547
1	0.4044	0.3888	0.3888	0.3888	0.3888	0.4102	0.4258
2	0.2833	0.2744	0.2744	0.2744	0.2744	0.2880	0.2969
3	0.2255	0.2193	0.2193	0.2193	0.2193	0.2243	0.2305
4	0.1677	0.1642	0.1642	0.1642	0.1642	0.1606	0.1641
5	0.1446	0.1421	0.1421	0.1421	0.1421	0.1338	0.1363
6	0.1215	0.1201	0.1201	0.1201	0.1201	0.1071	0.1085
7	0.1007	0.0997	0.0997	0.0997	0.0997	0.0920	0.0930
8	0.0799	0.0793	0.0793	0.0793	0.0793	0.0769	0.0775
9	0.0909	0.0905	0.0905	0.0905	0.0905	0.0825	0.0829
10	0.1020	0.1017	0.1017	0.1017	0.1017	0.0882	0.0884
11	0.2008	0.2007	0.2007	0.2007	0.2007	0.1267	0.1269
12	0.2997	0.2996	0.2996	0.2996	0.2996	0.1652	0.1653
13	0.4837	0.4837	0.4837	0.4837	0.4837	0.2927	0.2927
14	0.6678	0.6678	0.6678	0.6678	0.6678	0.4201	0.4201
15	0.7880	0.7880	0.7880	0.7880	0.7880	0.6150	0.6150
16	0.9082	0.9082	0.9082	0.9082	0.9082	0.8099	0.8099
17	0.9844	0.9844	0.9844	0.9844	0.9844	0.9684	0.9684
18	1.0605	1.0605	1.0605	1.0605	1.0605	1.1268	1.1268
19	1.0934	1.0934	1.0934	1.0934	1.0934	1.2121	1.2121
20	1.1263	1.1263	1.1263	1.1263	1.1263	1.2974	1.2974
21	1.1244	1.1244	1.1244	1.1244	1.1244	1.3303	1.3303
22	1.1226	1.1226	1.1226	1.1226	1.1226	1.3633	1.3633
23	1.1221	1.1221	1.1221	1.1221	1.1221	1.3718	1.3718
24	1.1217	1.1217	1.1217	1.1217	1.1217	1.3803	1.3803
25	1.1288	1.1288	1.1288	1.1288	1.1288	1.3677	1.3677
26	1.1359	1.1359	1.1359	1.1359	1.1359	1.3551	1.3551
27	1.1449	1.1449	1.1449	1.1449	1.1449	1.3618	1.3618
28	1.1540	1.1540	1.1540	1.1540	1.1540	1.3684	1.3684
29	1.1768	1.1768	1.1768	1.1768	1.1768	1.3943	1.3943
30	1.1996	1.1996	1.1996	1.1996	1.1996	1.4202	1.4202
31	1.2510	1.2510	1.2510	1.2510	1.2510	1.4753	1.4753
32	1.3023	1.3023	1.3023	1.3023	1.3023	1.5304	1.5304
33	1.3756	1.3756	1.3756	1.3756	1.3756	1.5977	1.5977
34	1.4489	1.4489	1.4489	1.4489	1.4489	1.6650	1.6650
35	1.5377	1.5377	1.5377	1.5377	1.5377	1.7310	1.7310
36	1.6264	1.6264	1.6264	1.6264	1.6264	1.7971	1.7971
37	1.6929	1.6929	1.6929	1.6929	1.6929	1.8263	1.8263
38	1.7594	1.7594	1.7594	1.7594	1.7594	1.8555	1.8555
39	1.8271	1.8271	1.8271	1.8271	1.8271	1.8828	1.8828
40	1.8949	1.8949	1.8949	1.8949	1.8949	1.9101	1.9101
41	1.8978	1.8978	1.8978	1.8978	1.8978	1.9081	1.9081
42	1.9007	1.9007	1.9007	1.9007	1.9007	1.9060	1.9060
43	1.7266	1.7266	1.7266	1.7266	1.7266	1.7394	1.7394
44	1.5524	1.5524	1.5524	1.5524	1.5524	1.5727	1.5727
45	1.2536	1.2536	1.2536	1.2536	1.2536	1.2919	1.2919
46	0.9548	0.9548	0.9548	0.9548	0.9548	1.0111	1.0111
47	0.7290	0.7290	0.7290	0.7290	0.7436	0.7829	0.7683

