Modelling hot water storage tanks within the Home Energy Model

A technical explanation of the methodology

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Contents

Background to the Home Energy Model

What is the Home Energy Model?

The [Home Energy Model (HEM)](#) is a calculation methodology designed to assess the energy performance of homes, which will replace the government's [Standard Assessment Procedure (SAP)](#).

The Home Energy Model is still under development and its first version will be implemented alongside the [Future Homes Standard (FHS)](#) in 2025. We are publishing information about the model while it is still at a formative stage to enable industry to participate in the ongoing development process.

Where can I find more information?

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

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

What: This document is one of a suite of [technical documents](#), which go into further detail on the methodology and the validation exercises that have been carried out. We intend to update and produce further technical documentation throughout the model development process.

Audience: The technical documentation will be of interest to those who want to understand the detail of how the Home Energy Model works and how different technologies are treated.

The Home Energy Model consultation

What: The [Home Energy Model consultation](#), which explains the overhaul to the SAP methodology and seeks views on the approach taken by the new Home Energy Model.

Audience: The Home Energy Model consultation will be of interest to those who want to understand the proposed changes to the SAP methodology and wider SAP landscape.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model and the Home Energy Model: FHS assessment has been published as [a Git repository](#). This code is identical to that sitting behind the consultation tool. We are currently considering whether the open-source code could serve as the approved methodology for regulatory uses of the Home Energy Model.

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

Related Content

Hot water storage tanks (also known as hot water cylinders) store hot water for later use after being heated by a heat source such as an immersion heater, boiler or heat pump. The performance of a storage tank depends on its volume, heat losses, the pattern of hot water draw-offs and the control arrangements of heat sources (temperature setpoints and timing).

This paper sets out the methodology for modelling storage tanks within the Home Energy Model core engine. For information on relevant assumptions made in the FHS assessment wrapper, please see HEMFHS-TP-03 FHS domestic hot water assumptions.

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

src/core/heating_systems/storage_tank.py

Methodology

1. Overview

The Home Energy Model (HEM) storage tank model is a 4-layer tank model based on Method A from [BS EN 15316-5:2017](). Hot water is drawn off from the top of the tank and replaced by fresh cold water at the bottom which is then heated in the tank by one or more heat sources. It is assumed that the water is stratified by temperature.

An example of the storage tank in relation to the heat source, and primary/secondary pipework can be seen in Figure 1 below.
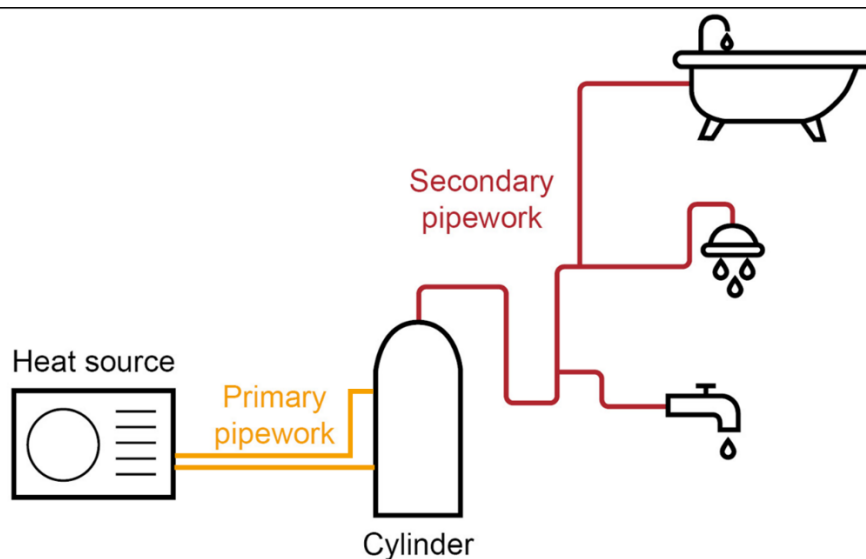

Figure 1 – Storage tank in relation to the heat source, and primary/secondary pipework

The setpoint temperature and minimum hot water temperature (i.e., the minimum allowable temperature of the hot water provided) are specified in the inputs or a wrapper and the tank model is initialised with the water at the setpoint temperature specified. For each heat source, the location within the tank of the heater and the location of the thermostat controlling it are also inputs, but where there are several heat sources, the order of the heaters and the order of the corresponding thermostats must be the same (i.e., the lowest heater in the tank must be controlled by the lowest thermostat, etc.).

Thermal losses from the tank are based on a user-entered value for the losses under standard test conditions (according to BS 1566 or BS EN 12897) in kWh/day. Note that this means that changing just the volume of the tank in the inputs does not change the calculated thermal losses.

2. Calculation steps

The initial calculation steps can be summarised as follows:

1. The energy stored in each layer of the tank before any hot water is drawn off is calculated using the minimum available temperature of the water as a baseline (i.e., water at the cold feed temperature is considered as having zero stored energy)

2. The volume and associated energy of domestic hot water to be withdrawn from the tank is calculated:

    a. The volume demanded is an input to the storage tank module at each timestep (see HEM-TP-09 Energy for domestic hot water).

    b. The calculation iterates over the layers in the tank model, starting from the top layer:

        i. If the water in the layer is below the minimum hot water temperature, it is assumed that no more water will be withdrawn from the tank. In this case, the tank cannot provide enough hot water above the minimum hot water temperature and so the remaining demand is assumed to be unmet. The associated energy is reported as unmet demand.

        ii. If the water in the layer is at or above the minimum hot water temperature, the volume withdrawn from the layer to satisfy the energy requirement is calculated. If the volume that would be withdrawn is greater than the volume of the layer, then the remaining energy demand is passed on to the next layer down, unless the current layer is the last one in which case the remaining demand is reported as unmet demand.

3. The temperature of each layer of the storage tank after hot water has been withdrawn is calculated (see Figure 2 for example):

    a. The volume withdrawn from the top layer of the tank is replaced with the same volume of water from the next layer down (and so on for other layers). If the volume withdrawn was greater than the volume of a single layer, then the water is replaced from lower layers or ultimately by cold water added to the bottom of the tank. The temperature of the water in each layer is then recalculated based on a volume-weighted average of the temperatures of the layers from which the water was drawn (or the cold feed temperature, if relevant).

    b. There is an assumed error in the standard in equation (9) as a volume and temperature are added instead of multiplied. The following is used instead:

$$\vartheta_{sto;vol;i} = \frac{\vartheta_{sto;vol;i-1} \times V_{sto;use;W} + \vartheta_{sto;vol;i} \times (V_{sto;vol;i} - V_{sto;use;W})}{\vartheta_{sto;vol;i}}$$

4. (Step 4 from the standard relates to the withdrawal of energy for space heating and is currently not implemented)

5. (Step 5 from the standard relates to the withdrawal of energy for space heating and is currently not implemented)

The following calculation steps are then executed for each heat source supplying heat to the tank, starting from the heat source closest to the bottom of the tank:

6. The maximum energy input from the heat source is calculated:

    a. If, in the relevant timestep, the tank is being held at the setpoint (see S11P-022 Controls) then the minimum hot water temperature is set to be the same as the setpoint temperature (for this step in the calculation only).

    b. If the temperature of the tank at the relevant thermostat position is above the minimum hot water temperature, then there is no demand, and the potential energy input is set to zero.

    c. If the temperature of the tank at the relevant thermostat position is below the minimum hot water temperature, the maximum energy contribution from the heat source, accounting for primary losses, if any (see section on primary circuit losses), is calculated and used to calculate the temperatures at each layer that would result, assuming at this stage that all of the energy stays in the layer that it is provided to (note that at this stage the layer temperatures may be calculated to be higher than the setpoint temperature). If the heat source controls specify that the heat source is off during the relevant timestep, then the maximum energy contribution from the heat source will be set to zero.

7. The temperatures at each layer are recalculated, accounting for mixing due to convection:

    a. Tank layers are assumed to mix (and their temperatures are averaged) when the temperature of the water in a layer is higher than the temperature of the water in the layer above. The calculation iterates over all the layers until the temperature in each layer is lower than or equal to the temperature of the layer above.

    b. There is an assumed error in the standard in equation (12) as a volume and temperature are added instead of multiplied. The following is used instead:

    $$\vartheta_{sto;vol,i} = \vartheta_{sto;vol,i+1} = \frac{\vartheta_{sto;vol,i} \times V_{sto;vol,i} + \vartheta_{sto;vol,i+1} \times V_{sto;vol,i+1}}{V_{sto;vol,i} + V_{sto;vol,i+1}}$$

8. Thermal losses and the final temperature of each layer are calculated (see Figure 2 for example):

    a. Thermal losses are calculated based on the daily loss under standard test conditions and the temperatures calculated in the previous calculation step or the setpoint temperature, whichever is lower.

    b. Equation (13) in the standard implicitly assumes an hourly timestep, but HEM explicitly adds a multiplication by the timestep in hours to facilitate variation in the calculation timestep.

c. Thermal losses that have already been accounted for in the calculation for previous heat sources are subtracted to avoid double-counting.

d. There is an assumed error in the standard in equation (14) where the formula adds values instead of multiplying. The following is used instead:

$$\Delta\vartheta_{sto;vol,i} = \frac{Q_{sto;vol,i}}{\rho_w \times C_{p;w} \times V_{sto;vol,i}}$$

e. The final value of the temperature is reduced by the thermal losses and is capped to the setpoint temperature.

9. The energy required from the heat source to reach the final temperature, accounting for thermal losses and primary losses (see section on primary circuit losses), is calculated and becomes an input to the relevant heating system module.

3. Example

The following graphs show the temperatures calculated in steps 3 and 8 over a 24 hour calculation period for an example tank. In this example:

- The heater is in layer 1 (the bottom layer) and is controlled by a thermostat in layer 2.

- The setpoint temperature is 60°C and the minimum hot water temperature is 52°C.

- For the first 7 hours of the day, the controls have been set to maintain the setpoint temperature continuously.
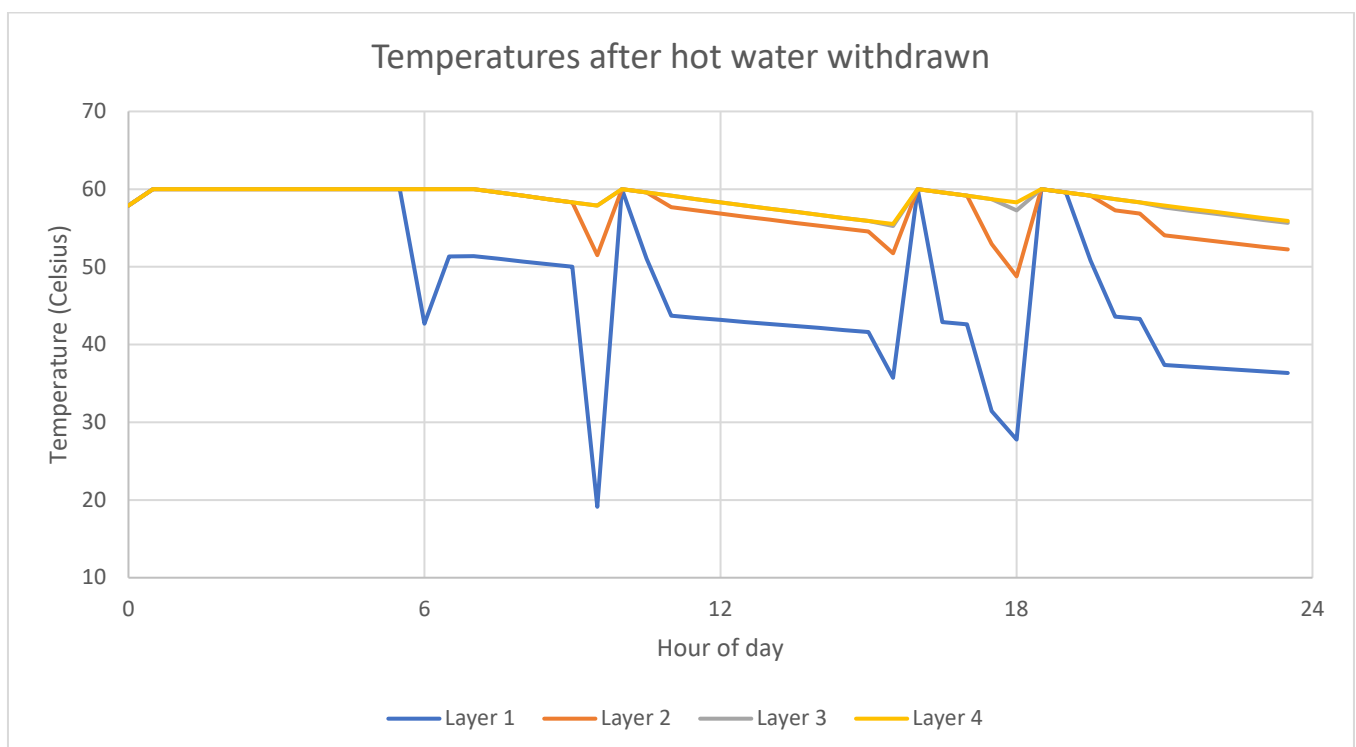
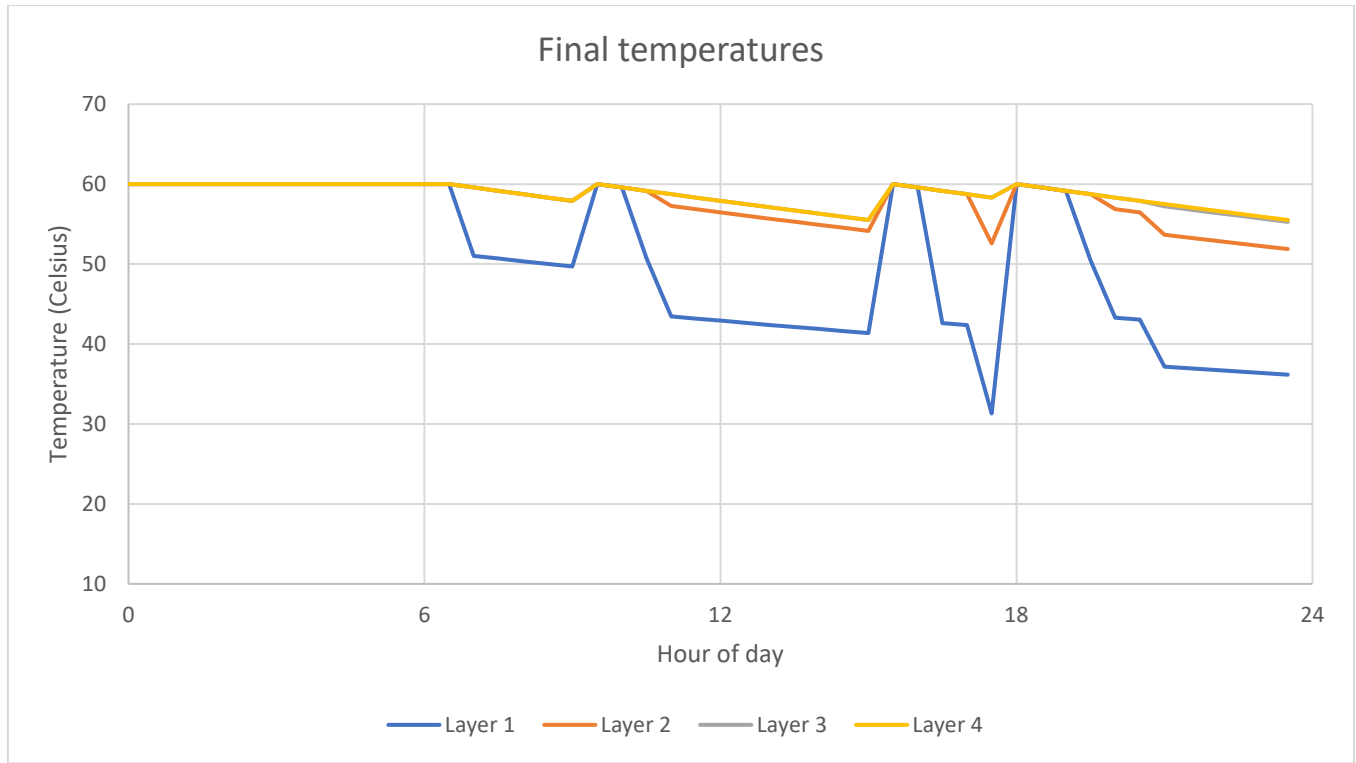**Figure 2 – Temperature of tank layers after hot water is drawn off in each timestep over 24 hours.**

Figure 3 – Final temperature of tank layers in each timestep over 24 hours, accounting for both hot water draw-off and heating.

4. Primary pipework losses

At the start of a heating event (a timestep where there is energy input to the tank where there was no energy input in the previous timestep), the energy of water in the primary pipework is subtracted from the maximum output of the relevant heat source in step 6 and is included in the demand on the heat source in step 9. This represents the energy used to heat up the primary pipework at the start of the heating event.

During a heating event (any timestep where there is energy input to the tank), energy lost from primary pipework is calculated assuming that the flow temperature is maintained for the whole timestep, and this is subtracted from the maximum output of the relevant heat source in step 6 and is included in the demand on the heat source in step 9. It is also added to internal gains (the model currently assumes that all primary pipework is inside the thermal envelope of the dwelling).

At the end of a heating event (a timestep where there is no energy input to the tank but there was energy input in the previous timestep), the energy of water in primary pipework is added to

the internal gains. This represents the loss of the energy that was used to heat up the primary pipework at the start of the heating event.

For details of how the pipework losses are calculated based on the pipework characteristics, see HEM-TP-10 Ductwork and pipework losses.

Future development

Currently, the ability to vary the setpoint temperature over time (e.g., to model sterilisation cycles) is limited. This may be incorporated in future versions. The current model is also restricted to having a single setpoint for all heat sources; this could be changed in the future to reflect system setups that use different setpoints for different heat sources (e.g., the setpoint for a PV diverter may be higher than the setpoint for a boiler, so that more surplus PV-generated energy may be diverted and stored).

The number of layers in the tank model may also be increased in the future to provide more granularity regarding the tank temperature and positioning of thermostats and heaters. BS EN 15316-5:2017 supports a model with up to 24 layers.

The current primary pipework loss calculation produces figures that are higher than would be expected. Therefore, the assumptions made around flow temperature and running time may be revised in the future.

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