Modelling heat emitters within the Home Energy Model

A technical explanation of the methodology

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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

This paper sets out the methodology for modelling heat emitters within the core Home Energy Model. Other relevant papers on the core Home Energy Model include:

- HEM-TP-04 Space heating and cooling demand
- HEM-TP-12 Heat pump methodology
- HEM-TP-14 Boiler methodology
- HEM-TP-17 Controls

For further information on relevant assumptions made within the FHS assessment wrapper, please see HEMFHS-TP-02 FHS space heating and cooling demand assumptions.

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

src/core/heating_systems/emitters.py

Methodology

This document provides a description of how wet heat emitters (radiators, underfloor heating) are modelled in the Home Energy Model (HEM). The emitters are heated by a heat source (e.g. a heat pump or boiler) via water flowing in a circuit and then emit heat into the dwelling. Their heat output is determined by the emitter characteristics and the temperature difference between the emitters and the surrounding air. Their responsiveness is also dependent on the thermal mass of the emitter system.

The space heating demand is calculated for each zone and becomes an input to the emitter calculation for that zone, which calculates the energy required from the heat source (e.g., heat pump) given the emitter properties. The final emitter temperature and output is then calculated, which is limited by the maximum emitter temperature and the maximum output of the heat source. The final emitter temperature is then stored to become the initial emitter temperature in the next timestep, and the emitter output is returned to the space heating calculation so that the resultant temperature of the zone can be calculated.

Allowance for the pre-heating of emitters or use of setback temperatures is dealt with by the controls module where specified and is therefore included in the space heating demand for the timestep that is input to the emitter calculation. See HEM-TP-17 Controls.

1. Flow and return temperatures and maximum emitter temperature

The emitter module requires the Eco-design control class (I to VIII)[1] to be specified and the flow and return temperature depend on the class of the controller used:

- For controllers without weather compensation (classes I, IV, V and VIII), the flow temperature is assumed to be fixed at the design flow temperature.
- For weather compensating controllers (classes II, III, VI and VII) the flow temperature is dependent on the outside temperature. The minimum flow temperature is also required (the maximum, or design, flow temperature is entered regardless) along with the outside air temperatures at which the maximum and minimum flow temperatures will be set.

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[1] These classes are fully defined on page 16 of this document from the Official Journal of the European Union - https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014XC0703(01). In brief they are: Class I - On/off Room Thermostat. Class II - Weather compensator control, for use with modulating heaters. Class III - Weather compensator control, for use with on/off output heaters. Class IV - TPI10 room thermostat, for use with on/off output heaters. Class V - Modulating room thermostat, for use with modulating heaters. Class VI - Weather compensator and room sensor, for use with modulating heaters. Class VII - Weather compensator and room sensor, for use with on/off output heaters. Class VIII – Multi-sensor room temperature control, for use with modulating heaters.

> Linear interpolation is used to calculate the flow temperature based on the outdoor temperature.

The return temperature in Celsius is assumed to be 6/7th of the flow temperature in Celsius; for flow temperatures above 70˚C this is capped at 60˚C return temperature. This assumption originated from an old MCS heat pump sizing guide.

The maximum achievable temperature of the emitter is calculated as the average of the target flow temperature and return temperature.

2. Energy input from heat source

Note: If the space heating demand on the emitters is zero, then the emitters will be cooling down or at steady state with the heating off. In this case, the calculation skips this step and goes straight to the calculation of emitter temperature and output achieved.

2.1 Emitter temperature required to meet space heating demand

Energy demand is converted into power output required by dividing by timestep. The calculated power output is therefore the power needed to achieve the set point within the current timestep.

The following equation (taken from the ASHRAE Handbook 2020 page 644) gives the power output achieved for a given emitter temperature:

$$power\ output\ (kW) = c\ (T_E(t) - T_{rm}(t-1))^n \qquad (1)$$

where:

$T_E(t)$ is the mean emitter temperature in timestep t.

$T_{rm}(t-1)$ is the final internal air temperature achieved in the room/zone in the previous timestep, this is used to avoid a circularity in the calculation.

c and n are constants from the characteristic equation of emitters derived from BS EN 442 tests[2].

Equation (1) is rearranged to solve for the emitter temperature:

$$T_E(\mathrm{t}) = \left(\frac{power\ output}{c}\right)^{1/n} + T_{rm}(t-1) \qquad (2)$$

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[2] Note that c is referred to as k_m in BS EN 442, but the equations are in different units. Therefore, k_m must be divided by 1,000 to give c, so that equation (1) gives a result in kW rather than W. Also note that c and n must be entered as aggregated values for the entire emitter system in the zone rather than for each individual emitter. This assumes that all the emitters are of broadly the same type and have the same n value. Please see Heat Emitter Input Estimator for more details on how to calculate the c and n values. This workbook can be found in the documentation area of the consultation tool.

Entering the power output required into equation (2) gives the emitter temperature required to meet space heating demand.

2.2 Energy input required to meet space heating demand

The energy input required from the heat source will include the energy needed to warm the emitters up to the required temperature when accounting for their thermal mass and the energy needed to increase the temperature of the room as demanded (i.e., the space heating demand).

Equation (3) gives the energy required to warm the emitters:

$$energy\ required\ to\ warm\ up\ emitters = K_E\ \times (T_E(t) - T_E(t-1)) \qquad (3)$$

where:

$T_E(t)$ is the emitter temperature in timestep t.

$T_E(t-1)$ is the emitter temperature at the previous timestep.

K_E is the thermal mass of the emitters.

Entering the required emitter temperature into equation (3) gives the energy required to warm the emitters to the required temperature. Note that if the emitter temperature is already above the required temperature, then the result of equation (3) will be negative.

Equation (4) gives the total energy required to meet the space heating demand:

$$energy\ req.from\ heat\ source = energy\ req.to\ heat\ zone +\ energy\ req.to\ warm\ up\ emitters$$
(4)

However, this calculation of the energy input required is not limited by the maximum emitter temperature (see next section).

2.3 Energy input required to reach maximum emitter temperature

The energy input provided by the heat source must be limited so that the emitter temperature does not exceed its maximum. Calculating this limit requires dividing the timestep into two periods:

1. The time during which the emitters are warming up or cooling down to the required temperature.
2. The time during which the emitters maintain the maximum temperature.

The heat source power output during the first period is determined as follows:

- If the emitters are already above the maximum temperature[3], then the power input from the heat source during this period is zero.
- If the emitters are below the maximum temperature, then the power input from the heat source during this period is the maximum power output of the heat source (calculated by the relevant heat source module, e.g., heat pump module). Note that this will be reduced if the heat source has already allocated some output to higher-priority services.

Then, the time required to reach the maximum emitter temperature is calculated by iteratively solving the following differential equation (derivation in Annex A) using the power input figure determined above:

$$\frac{d\Delta T}{dt} = \frac{power\ input - c \times (\Delta T)^n}{K_E} \quad (5)$$

where ΔT is the difference between the emitter temperature and the room temperature.

If the emitters do not reach the maximum temperature during the timestep, then the warm-up/cool-down period lasts for the entire timestep and there is no power input associated with the second period. If the emitters do reach the maximum temperature during the timestep, then the power input required to maintain this temperature during the second period is calculated using equation (1).

The energy input required so that the emitters reach the maximum temperature is therefore the sum of the energy input for the two periods described above. This can be calculated by multiplying the length of each period by the power input in that period.

2.4 Energy input from heat source

The energy input required from the heat source is therefore the lower of:

- Energy input required to meet space heating demand.
- Energy input required to reach maximum emitter temperature.

The energy input required from the heat source is passed to the relevant heat source module (e.g. the heat pump module) along with the flow and return temperatures (which may affect the efficiency of the heat source). The heat source module then calculates the energy that can be provided to the emitters (which is returned to the emitter module) and the associated fuel consumption required (which is stored for later).

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[3] Note that the maximum temperature may vary between timesteps, as it is based on the flow and return temperatures which may be variable due to weather compensation.

3. Emitter temperature and output achieved

If the emitter temperature required to meet the space heating demand is higher than the maximum temperature, and if the calculations described above determined that the maximum emitter temperature could be reached within the timestep, then the final emitter temperature achieved is taken to be the maximum emitter temperature.

Otherwise, the temperature of the emitters at the end of the timestep is calculated by iteratively solving equation (5) using the power input actually provided by the heat source. If there was no space heating demand, then the power input is zero.

At present, the calculation assumes a constant power output from the heat source over the timestep. It does not account for overshoot/undershoot followed by stabilisation of emitter temperature, meaning that the end emitter temp may not be exactly the same as the target calculated in step 3. This also neglects possible priority of other services provided by the heat source (such as domestic hot water), which could cause intermittent operation or delayed start, although the running of higher-priority services is still accounted for by reducing the maximum power output of the heat source to the emitters. In practice, the error that this introduces into the calculation is small.

If the final emitter temperature calculated is less than the internal air temperature (taken from the previous timestep to avoid circularity) then the final emitter temperature is set to the internal air temperature.

Once the final emitter temperature has been obtained, the energy output by the emitters can be calculated by rearranging equation (4) to give the equation below:

$$energy\ output = energy\ provided\ by\ heat\ source - energy\ used\ to\ warm\ up\ emitters \quad (6)$$

where the energy used to warm up emitters is calculated by entering the final emitter temperature into equation (3).

The energy output by the emitters is then returned to the space heating calculation so that the final zone temperature can be calculated.

Future development

The emitter calculation is currently done on a per-zone basis, treating the emitters in each zone as independent from each other when in reality they may be on the same circuit and therefore not separately controlled. This is an area for potential future development.

Only one (aggregated) value for the constants from the characteristic equation of emitters can be entered per zone, which means that the model implicitly assumes that all emitters in a zone have the same n value (effectively, HEM models one large emitter per zone which is the sum of all the actual emitters). Adding the ability to model a set of emitters with different characteristics is an area for potential future development.

Consideration may be given to adding emitters to the Product Characteristics Database (PCDB) (or equivalent) so that users can simply select the appropriate product.

Annex A – Derivation of differential equation for emitter temperature

A differential equation for change rate of emitter temperature was derived, to be solved iteratively to calculate the emitter temperatures.

Heat balance equation for emitters (conservation of energy):

$$\frac{K_E \times \left(T_E(t) - T_E(t-1)\right)}{timestep} = power\ input\ (W) - power\ output(W)$$

where:

$T_E(t)$ is mean emitter temperature at the current timestep.

$T_E(t-1)$ is mean emitter temperature at the previous timestep.

K_E is thermal mass of emitters.

Power output from emitter (equation from 2020 ASHRAE Handbook p644, equation 1):

$$power\ output\ (kW) = c \times (T_E(t) - T_{rm})^n$$

where:

T_E is the mean emitter temperature.

T_{rm} is the air temperature in the room/zone.

c and n are constants from the characteristic equation of emitters (e.g., derived from BS EN 442 tests)

Substituting power output equation into heat balance equation gives:

$$\frac{K_E \times (T_E(t) - T_E(t-1))}{timestep} = power\ input - c \times (T_E(t) - T_{rm})^n$$

Rearranging gives:

$$\frac{T_E(t) - T_E(t-1)}{timestep} = \frac{power\ input - c \times (T_E(t) - T_{rm})^n}{K_E}$$

which gives the differential equation as timestep goes to zero:

$$\frac{dT_E}{dt} = \frac{power\ input - \ c\ \times\ (T_E - \ T_{rm})^n}{K_E}$$

If T_{rm} is assumed to be constant over the time period, then the rate of change of T_E is the same as the rate of change of ΔT, where:

$$\Delta T = \ T_E - \ T_{rm}$$

Therefore, the differential equation can be simplified to an expression in terms of ΔT:

$$\frac{d\Delta T}{dt} = \frac{power\ input - \ c\ \times (\Delta T)^n}{K_E}$$

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