Modelling electric storage heaters within the Home Energy Model

A technical explanation of the methodology

December 2023

Acknowledgements

This methodology has been developed for the Department for Energy Security & Net Zero by a consortium led by the Building Research Establishment (BRE), including AECOM, Sustenic, University of Strathclyde's Energy Systems Research Unit, Kiwa Ltd., Loughborough University Enterprises Limited, Chris Martin and John Tebbit.

Quality assurance has been undertaken by a consortium led by Etude, including Levitt Bernstein, Julie Godefroy Sustainability, and UCL.

Document reference: HEM-TP-13

Document version: v1.0

Issue date: 13/12/23

Home Energy Model version: HEM v0.24

Any enquiries regarding this publication should be sent to us at: homeenergymodel@energysecurity.gov.uk

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

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

elec_storage_heater.py

Overview

Electric storage heaters are room heaters which typically use off-peak electricity to heat up a high thermal mass core, then release this heat later when space heating is required. Their use is long-established in the UK and they have historically been a helpful technology in terms of smoothing the load on the national grid.

The main factors determining their performance are their storage capacity, their ability to retain heat and their ability determine the correct amount of heat to store each night relative to the next day’s requirement.

This paper sets out the methodology used to determine the energy performance of storage heaters within the Home Energy Model core engine.

Methodology

The Home Energy Model’s (HEM’s) electric storage heater model focusses on modelling the energy balance of two components of the heater, the core and the case, making use of a mixture of empirical performance data and physical modelling. It is intended that the necessary empirical data will come from the product characteristics database (PCDB) (or future equivalent), such that the user would simply select the product from a list and the correct performance data would be imported.

The objective of this model is to predict the overall electricity input and heat output of a storage heater under various conditions such as room temperature, air flow rate, heating rate, and others.

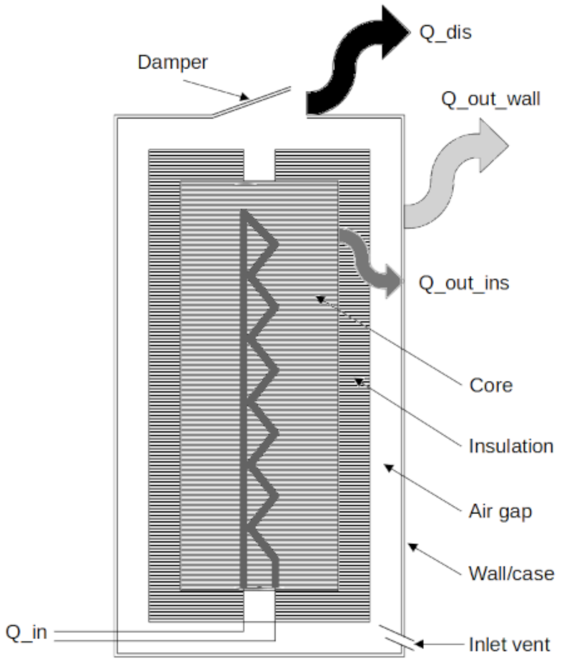

Figure 1 – Diagram of a storage heater

1. Governing equations

The governing equations of the model describe the energy balance of the core and case (referred as 'wall' in the equations) of the electric storage heater. The equations relating to the temperature of the core and case are defined and used in differential form, as follows.

Temperature variation in the core of the heater:

$$\frac{\mathrm{dT_{core}}}{\mathrm{dt}} = \left(\frac{1}{\mathrm{mass}} * \mathrm{c_{pcore}}\right) * (\mathrm{Q_{in}} - \mathrm{Q_{out\_ins}} - \mathrm{Q_{dis}})$$

Temperature variation in the case of the heater:

$$\frac{dT_{\mathrm{wall}}}{dt} = \frac{1}{\mathrm{thermal\_mass\_wall}} * (Q_{\mathrm{out\_ins}} - \mathrm{Q_{out\_wall}})$$

Where:

$\mathrm{T_{core}}$ is the temperature of the core of the storage heater [°C].

T_{wall} is the temperature of the wall (case) of the storage heater [°C].

mass refers to the mass of the core element of the heater [kg]

thermal_mass_wall represents thermal mass of the storage heater wall [Wh / K]

c_{pcore} denotes the specific heat capacities of the core material [J/kg/K]

Q_{in} represents the electrical energy input to the core of the heater [Wh]

Q_{out_ins} represents the heat transfer from the core, through the insulation to the case [Wh]

Q_{dis} represents the heat transfer from the core to the air passing through the heater and into the room [Wh], and

Q_{out_wall} represents the heat transfer from the case to the room [Wh]

1.1 Heat Transfer equations

The heat transfer to the room due to air passing through the heater (when damper is open and the fan is potentially on), Q_{dis}, is determined based on the temperature difference between the core and the room air. The heat transfer rate is calculated as follows:

$$Q_{dis} = h * A * (Tcore - Tair)$$

Where $Q_{dis}$is the rate of heat transfer, h is the convective heat transfer coefficient, A is the surface area between the heater core and the air and Tair is the temperature of the room air.

Because the convective heat transfer coefficient, h, depends on a complex relationship between various factors including the physical properties of air such as its density, viscosity, and thermal conductivity, as well as flow conditions like velocity, turbulence, and orientation relative to the surface, we have chosen to determine the value of 'h * A' (hereafter referred to as the heat loss parameter) experimentally for each electric storage heater type, storing performance properties in the PCDB (or future equivalent). It is expected that there will be a strong correlation between ‘h’ and the difference in temperature between the heater's core and the room air, which is to be captured during the lab test. The specification of this lab test will be formalised in due course, but we envisage a full charge / discharge test which determines the heat output characteristics over the full range of charge levels. In this test the performance of electric storage heaters can be characterised in ‘on’ mode (with damper open and potentially fan assistance) by measuring the mass flow of air leaving the unit, the temperature of the air being discharged from the unit, the core temperature and the ambient air temperature:

$$h * A = mass\_flow\_air * (c_p * \left(T_{out_{safe}} - Tair\right))/(T_{core} - T_{air})$$

where c_p is the specific heat capacity of air [J/kg/K].

Once the heat transfer to the room due (Q_{dis}) is calculated, the mass flow of air required to pass through the core and, in the case of fan-assisted units, the mass flow of core air mixed with room temperature air (to avoid exceeding a safe supply temperature), is calculated to determine the amount of fan energy required to deliver Q_{dis} safely into the room:

$$mass\_flow\_air = Q_{dis}/(c_p * \left(T_{out\_safe} - T_{air}\right))$$

The value of mass_flow_air [kg/s] is dependent on the specific electric storage heater unit and will be determined by the temperature difference between the safe supply temperature from the heater and the room temperature, (T_{out_safe} - T_{air}).

The following data sets "labs_tests_400" and "lab_tests_400_fan" contain lists of temperature differences between the core and the room, and corresponding heat loss parameter characteristics for two illustrative products[1] – the latter one being fan-assisted. The labs_tests_400 list is used to evaluate the heating performance of the electric storage heater when it reaches approximately 400°C and discharges heat, reducing its core temperature in the process.

For the demonstration version of HEM software being made available for the consultation, the data for the illustrative fan assisted unit is always used when storage heaters are selected by the user. When HEM comes into formal use, the user would select the actual product used from a list contained in the PCDB (or future equivalent).

```
labs_tests_400 = [
        [ 324.91, 1.77 ],
        [ 286.52, 1.58 ],
        [ 254.93, 1.4 ],
        [ 228.63, 1.25 ],
        [ 206.41, 1.13 ],
        [ 187.41, 1.02 ],
        [ 171.03, 0.92 ],
        [ 156.79, 0.83 ],
        [ 144.29, 0.75 ],
        [ 133.25, 0.68 ],
        [ 123.42, 0.62 ],
        [ 114.57, 0.6 ],
        [ 106.36, 0.6 ],
        [ 98.73, 0.6 ],
        [ 91.65, 0.6 ],
        [ 85.07, 0.6 ]]
```

```
labs_tests_400_fan = [
        [ 270.15, 5.03 ],
        [ 202.2, 5.03 ],
        [ 151.33, 5.03 ],
        [ 113.24, 5.03 ],
        [ 84.73, 5.03 ],
        [ 63.39, 5.03 ],
        [ 47.42, 5.03 ],
        [ 35.47, 5.03 ],
        [ 26.53, 5.03 ],
        [ 19.84, 5.03 ],
        [ 14.84, 5.03 ],
        [ 11.1, 5.03 ],
        [ 8.31, 5.03 ],
        [ 6.22, 5.03 ],
        [ 4.66, 5.02 ],
        [ 3.49, 5.03 ],
        [ 2.62, 5.02 ]]
```

1.2 Energy transfer from case to room, Q_{out_wall}

The energy transfer in the time step to the room from the heater wall (case) has been modelled as if it behaves like a normal emitter, using the same exponential discharging equation applied for other emitters (e.g. radiators) in HEM:

$$Q_{out\_wall} = c * (T_{wall} - T_{air})^n$$

c and n will be product specific, so will also form part of the PCDB (or future equivalent) record.

[1] These are derived from real product data kindly supplied by a manufacturer, so should be realistic. However, in practice performance will differ considerably from product to product.

1.3 Energy transfer from core to case, Q_{out_ins}

The energy transfer in the time step from the storage heater core to the case of the unit is described by the following formula:

$$Q_{out\_ins} = U_{core\_wall} * A * (T_{core} - T_{wall})$$

Where:

A is the area of the surface separating the core and the case [m2]

U_{core_wall} is the U-value for the combined layers separating the core from the case (insulation layer and air gap) [W/m2K]

$$U_{core\_wall} = 1/(\frac{1}{U_{ins}} + R_{air})$$

The air layer is characterised by a thermal resistance (R_{air}), which will vary depending on whether the air is relatively still or is flowing. This is set to one of two values:

R_{air_on}, when the damper is open and there's convection through the air gap [m2K/W]

R_{air_off}, when the damper is off and the air is still or slowly moving inside the case [m2K/W].

Typical values are assumed at 0.17 m2K/W when the damper is OFF/closed and 0.07 m2K/W when the damper is ON/open.

1.4 Electric energy input to core, Q_{in}

The electrical energy input to the core, electric_charge(t, T_{core}), is determined based on the control system logic. For the simple control system so far implemented, the unit is assumed to charge if the following three condition are met:

- The time falls within the off-peak period for the selected electricity tariff
- The temperature of the core is less than or equal to the target temperature (T_{core_target} or T_{core_max})
- The room temperature is less than or equal to the room temperature cut-off value. (This is effectively a simple automatic charge control, increasingly limiting the amount of charge stored as the weather warms up.)

When active, the electrical energy input is set to a constant value as per the charging power rating of the unit (from the PCDB (or future equivalent) record). When the core temperature reaches the target temperature, the unit switches off the charging process and keeps throttling the power in to maintain the target temperature for as long as the charging process is allowed (e.g. the remainder of the off-peak hours). Further control options are likely to be added in future.

Future development

Further development of the control options is anticipated, including for controls capable of responding to variable time of day pricing and emissions factors, and the availability of renewable energy generated on site (e.g. PV).

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