Calculating space heating and cooling demand within the Home Energy Model

A technical explanation of the methodology

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Acknowledgements

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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

Related technical documents

Space heating and cooling demand is the amount of thermal energy that needs to be provided to the space (heating demand) or removed from the space (cooling demand) in order to achieve a desired temperature. This is dependent on many factors including fabric heat loss, ventilation and infiltration heat loss, thermal mass, etc. Details of how these factors are modelled are covered in the following papers:

- HEM-TP-03 External conditions
- HEM-TP-05 Fabric heat loss
- HEM-TP-06 Ventilation and infiltration
- HEM-TP-07 Thermal mass
- HEM-TP-08 Solar gains and shading
- HEM-TP-17 Controls

The core HEM can be used with a variety of heating and cooling periods and temperature settings and this document relates only to the way the core HEM uses these parameters, which may come from user inputs or from wrappers. For further information on space heating and cooling demand assumptions made within the FHS assessment wrapper, please see:

- HEMFHS-TP-01 FHS occupancy assumptions (for metabolic gains)
- HEMFHS-TP-02 FHS space heating and cooling assumptions
- HEMFHS-TP-04 FHS appliances assumptions (for gains from appliances, cooking and lighting)

Code implementation

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

src/core/project.py (for response of the heating/cooling system and recording of unmet demand)

src/core/space_heating_demand/internal_gains.py *src/core/space_heating_demand/thermal_bridge.py*

src/core/space_heating_demand/ventilation_element.py (for summer ventilation to avoid overheating)

src/core/space_heating_demand/zone.py

Methodology

1. Overview

This calculation is based on BS EN ISO 52016-1:2017, which defines procedures for calculating internal temperatures and space heating and cooling demand. The calculation of unmet demand is additional to the procedures in the standard but follows naturally. The calculation of the additional summer ventilation requirement to avoid overheating is also additional but follows the same principles as the space cooling demand calculation from the standard.

2. Zone heat balance

The heat losses and solar gains for each zone of the building are calculated independently (i.e. the zones are thermally uncoupled, as per Option C in BS EN ISO 52016-1:2017 section 6.4.6). At present zero heat is assumed to flow between different zones of the building. This may be an area for future development (see Future development section).

Each zone in the building is represented by a heat flow network (see Figure 1) consisting of one node representing the internal air linked to nodes representing the internal surfaces of the building elements, which are themselves linked to each other to account for radiative heat transfer between them. The internal surface nodes are also linked to nodes representing other layers of each building element: each transparent building element is represented by two nodes (for the internal and external surfaces) and each of the other building elements is represented by five nodes. Each node has an associated heat capacity and each of the connections between the nodes has an associated heat transfer coefficient. The boundary conditions at the external surface node of each element depend on whether the building element is adjacent to ground, outside air, thermally conditioned space or thermally unconditioned space.

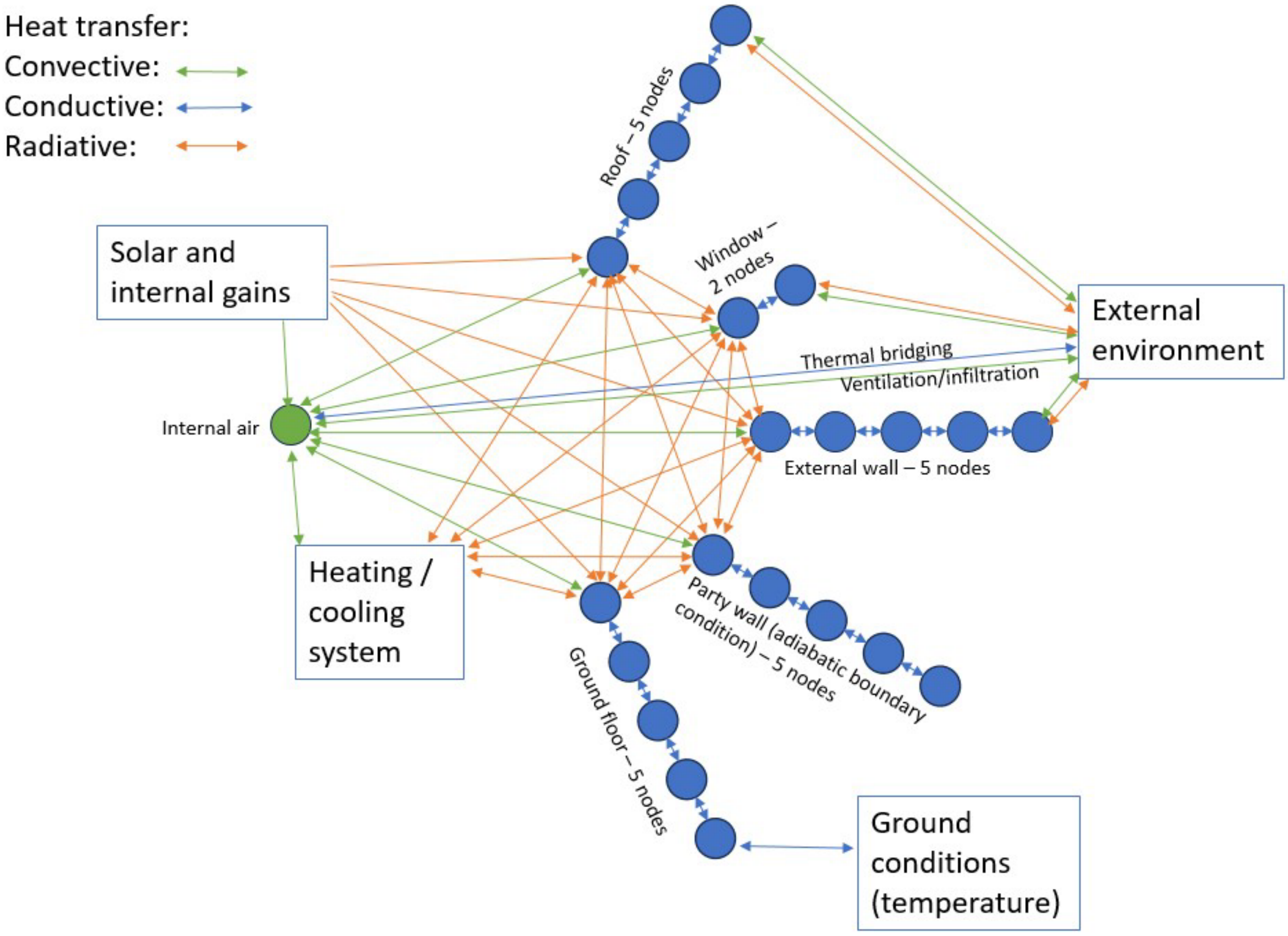

Figure 1 – Example of a heat flow network for a zone containing one roof, one window, one external wall, one party wall and one ground floor.

The core heat balance equations for each node are based on BS EN ISO 52016-1:2017 section 6.5.6, which are solved simultaneously at each timestep to calculate the temperature of each node at that timestep. The temperatures of the internal air and internal surfaces of each zone of the building are then used to calculate the operative temperature (defined as the average of the internal air temperature and the area-weighted mean radiant temperature of internal surfaces) in each zone, upon which the space heating/cooling demand is based. The inputs to the heat balance equations are:

- Final node temperatures from the calculation at the previous timestep – see Annex A for how these are initialised before the first timestep.
- Heat capacity of each node – see HEM-TP-07 Thermal mass.
- Heat transfer coefficient between each pair of connected nodes and at the external boundary of the dwelling – see HEM-TP-05 Fabric heat loss.
- Ventilation heat transfer coefficient (based on flow rate and temperature of supply air) – see HEM-TP-06 Ventilation and infiltration.
- Thermal bridging heat transfer coefficient (sum over all thermal bridges) – see section 4.

- Internal gains, made up of:
    - Gains profiles (e.g., for metabolic gains and gains from appliances, cooking and lighting) specified in inputs (or set in a wrapper) – see section 3.
    - Gains from hot water distribution, storage and primary pipework – see HEM-TP-11 Hot water storage tanks and HEM-TP-10 Ductwork and pipework losses.
    - Gains from ventilation fans – see HEM-TP-06 Ventilation and infiltration.
- Solar gains – see HEM-TP-08 Solar gains and shading.
- Heating/cooling system output – see section 5 and section 6.
- Boundary conditions at external surfaces (e.g., for an external wall: external air temperature, solar radiation absorbed) – see HEM-TP-03 External conditions and HEM-TP-05 Fabric heat loss.

3. Internal gains

Internal gains profiles can be specified by the user and/or by a wrapper. There are two broad types of gains profile: “internal gains” and “appliance gains”, the latter of which can include, for example, profiles for lighting, cooking and other appliances. An “internal gains” profile simply specifies the internal gains to be used in the calculation at each timestep, whereas an “appliance gains” profile specifies energy consumption at each timestep and a “gains fraction” which is the proportion of the energy consumption that becomes internal gains.

In addition to user-input internal gains, the core model also calculates internal gains from systems within the building, such as ventilation fans and hot water pipes.

The gains from each source are summed at each timestep and the sum becomes an input to the heat balance equations. Internal gains are summed for the whole dwelling and are assumed to be divided between zones in proportion to their floor area.

4. Thermal bridging

There are two broad types of thermal bridge in the model: linear thermal bridges and point thermal bridges. For each linear thermal bridge, the linear thermal transmittance (Ψ-value) and length are entered by the user. The heat transfer coefficient for the linear thermal bridge is then calculated by multiplying these together. For each point thermal bridge, the heat transfer coefficient is entered directly. The heat transfer coefficients for each thermal bridge are summed to an overall thermal bridging heat transfer coefficient which is then entered into the heat balance equations.

5. Heating and cooling demand

To calculate the space heating and cooling demand, the heat balance equations are first solved for the case where no active heating or cooling is being provided, then the resulting “free” operative temperature achieved is compared to the target heating and cooling (setpoint/setback) temperature(s) for the timestep. Note that cooling setpoints must always be higher than heating setpoints for the same timestep.

If the comparison indicates that the operative temperature would be below the heating setpoint in the absence of heating being provided, then there is space heating demand. To calculate this, the heat balance equations are solved again, this time assuming a heating system output of 10 kW per m2 floor area (this is an arbitrarily high figure used to set up an interpolation). The calculation then interpolates between the operative temperatures achieved at these two points (i.e., for heating system outputs of 0 and 10 kW per m2 floor area) to find the heating system output required to meet the desired operative temperature. This figure is the space heating demand for the timestep.

The calculation for cooling demand is similar to the calculation of space heating demand, but with an additional step. This additional step checks to see if the cooling can be provided by opening windows rather than with the use of an active cooling system (this calculation is described in a later section of this document and may use a setpoint which is lower than the active cooling setpoint). If, after checking for the impact of window opening, the comparison indicates that the operative temperature would be above the active cooling setpoint in the absence of active cooling being provided, then there is space cooling demand. In this case, the heat balance equations are solved again assuming a cooling system capacity of 10 kW per m2 floor area (again, this is an arbitrarily high figure used to set up an interpolation). The calculation then interpolates between the operative temperatures achieved at these two points (i.e., for cooling system outputs of 0 and 10 kW per m2 floor area) to find the cooling system output required to meet the desired operative temperature. This figure is the space cooling demand for the timestep.

If the comparison of the “free” operative temperature with the setpoints indicates that no heating or cooling is required, then the node temperatures already calculated with no active heating or cooling provided are taken as the final node temperatures for the timestep.

6. Response of heating/cooling system and unmet demand

The calculated space heating demand becomes an input to the heating system calculation, which will calculate how much of the demand the system can meet. If the heating system is able to meet the demand within the timestep this is the heating system output reported for the timestep. If it is unable to do so, the shortfall is calculated. Some systems (e.g., electric heat pumps) may have a built-in backup heater, in which case some or all of the shortfall may be met by this. Any remaining shortfall is reported as unmet demand. The temperature of each node at the end of the timestep is calculated by solving the heat balance equations again using the heating system output that the relevant heating system calculation indicates can be provided. This means that where some of the heating demand was unmet a lower operative temperature than the required setpoint temperature would be calculated. The final node temperatures achieved then become the starting temperatures in the next timestep.

Similarly, when demand is for space cooling rather than space heating, the space cooling demand becomes an input to the cooling system calculation, which will calculate how much of the demand the system can meet. If the cooling system is able to meet the demand within the timestep this is the level of cooling reported for the timestep. If it is unable to do so, the shortfall is calculated and reported as unmet demand. The temperature of each node at the end of the timestep is calculated by solving the heat balance equations again using the amount of cooling that the relevant cooling system calculation indicates can be provided. This means that where some of the cooling demand was unmet a higher temperature than the required setpoint temperature would be calculated. The final node temperatures achieved then become the starting temperatures in the next timestep.

7. Additional summer ventilation to avoid overheating

If no window opening is assumed, HEM calculates very high indoor temperatures during the summer under certain circumstances. In practice, occupants will take action (e.g. opening windows) to increase ventilation to disperse excess heat and so reduce the risk/extent of overheating[1]. To address this, the HEM incorporates an additional algorithm to model the impact of such window opening.

7.1 Maximum cooling potential from additional ventilation

It is assumed that a user of HEM would have information on the maximum equivalent opening areas of windows (i.e. equivalent areas of all windows assuming they are opened to their fullest extent). This data should be available from the Part O compliance process.

Based on this, the algorithm estimates ventilation rates from opening windows using the simple methods in CIBSE Guide A (Tables 4.25 and 4.26) under two scenarios: cross-ventilation (i.e. openings on opposite facades) or single-sided ventilation. The Guide shows how to calculate ventilation for stack and wind dominated conditions, as well as providing the criterion that HEM uses to determine which of these conditions prevails for each timestep.

HEM assigns each zone to one of the simple scenarios from the Guide as follows:

1. Assign the total maximum equivalent area of all openings in the zone in proportion to the area of each opening.

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[1] The infiltration rate is likely to fall under these conditions because wind speeds will generally be low. The HEM calculation of infiltration should reflect this as it is tailored to the hourly wind speed.

2. Find the orientation of the largest opening and the height of the highest and lowest openings.
3. Determine the orientation of each opening relative to the largest, and group them into three groups:
    a. Same side as largest opening (difference in orientation < 45 degrees)
    b. Opposite side to largest opening (difference in orientation >= 135 degrees)
    c. Adjacent side to largest opening (not same or opposite side)
4. If there are no openings opposite the largest, assume there is no cross-ventilation; otherwise assume there is.
5. Assign openings to high and low groups based on whether they are closest to the highest or lowest opening.
6. If all openings are the same height, assume there is no stack ventilation; otherwise assume there is.

The maximum additional ventilation is then calculated for each zone using the calculations from the relevant scenario from the Guide (selected as described above), based on the maximum equivalent opening areas, the wind speed and external air temperature from the weather data, and the internal air temperature (as calculated assuming no window opening, to avoid introducing a circularity in the calculation),

7.2 Required additional ventilation

If the comparison of the “free” operative temperature to the window opening setpoint indicates that additional ventilation is required, then there is an additional step in the cooling demand calculation to see if sufficient cooling can be provided by opening windows to keep the operative temperature below the active cooling setpoint (a lower temperature setpoint for window opening than active cooling can be set, in which case window opening may be assumed even if the temperature does not exceed the active cooling setpoint).

The level of additional ventilation that would be required to keep the temperature at the window opening setpoint is calculated in a similar way to the calculation of active cooling demand. The ventilation rate and operative temperatures that would result from the maximum additional ventilation (see above) from window opening are calculated, and an interpolation is performed to determine how much additional ventilation is required for cooling. The lower of the required additional ventilation and the maximum additional ventilation is then used to calculate if additional ventilation from window opening would keep the operative temperature below the active cooling setpoint. If it would, then the node temperatures calculated with the window opening are taken as the final node temperatures for the timestep. If it is calculated that the maximum additional ventilation from window opening is insufficient to keep the operative temperature below the active cooling setpoint, then it is assumed that the windows will remain shut (to keep actively cooled air inside the dwelling) and there is no additional ventilation for cooling purposes.

7.3 Limitations

The approach to modelling summer ventilation to avoid overheating is limited in several ways. Each zone is modelled independently so the model implicitly assumes there is no air flow between zones. In reality, occupants are likely to leave internal doors open when internal temperatures are high to allow for greater cross-ventilation, so the model probably underestimates the potential for cooling via cross-ventilation. Conversely, the model assumes that air can flow freely between windows in the same zone, when in reality occupants may have closed internal doors between them. The model also does not account for the effect of wind direction on the cooling potential.

The arrangement of windows in each zone is assigned to one of the simplified cases from CIBSE Guide A, but these may not be particularly representative of some arrangements, which is likely to introduce a degree of inaccuracy to the model.

The model also assumes that all windows are equally openable, which may not be the case.

Future development

Modelling of inter-zone heat transfer, via either a fully coupled or simplified calculation, may be added in the future. The calculation could also be changed so that internal gains are entered per-zone rather than for the whole dwelling.

The development of a more sophisticated ventilation model (see HEM-TP-06 Ventilation and infiltration) would allow for a better representation of additional summer ventilation to avoid overheating, which could allow, for example, modelling of air flow between zones and the effect of wind direction. This calculation could also be changed to ask for the equivalent areas on a per-window basis rather than assuming that the total maximum equivalent area is divided equally between all the windows.

It should be possible in future to adapt the calculation to allow for several heating systems heating the same zone, each with their own setpoint. This would most likely involve calculating demand for the system with the highest setpoint, then calculating the demand for the system with the next highest setpoint, accounting for the output of the first system, and so on for subsequent systems. A similar adaptation could also be made to allow for several cooling systems, starting with the system with the lowest setpoint.

Other potential changes are likely to be to the individual components that feed into the space heating and cooling demand and are covered in the relevant documents on each component.

Annex A – Initialisation of node temperatures

The calculation described in this document depends on the final node temperatures from the calculation at the previous timestep, which are not available for the first timestep. Therefore, in order to initialise the node temperatures for the first timestep, the calculation requires an additional input for the desired starting operative temperature for each zone. Initially, the node temperatures are all set to the average of the starting operative temperature and the external air temperature for the first timestep. Then, the space heating/cooling demand is calculated (using the same external air temperature data for the first timestep) and the node temperatures are recalculated assuming that the required space heating/cooling demand can be provided in full. This process is then repeated until there are two consecutive iterations where all the node temperatures are the same (to within a relative tolerance of 10^{-8}). Each iteration uses a timestep of one year (but without varying the external conditions) as this requires fewer iterations to converge on a solution and gives the same initial temperatures (to approximately five significant figures) as using an hourly or half-hourly timestep.

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