Modelling controls 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)](#).

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 explain the calculation methodology in detail. New documents will be added, and the content amended, when necessary to ensure documentation is sufficiently comprehensive. This will usually, but not always, occur alongside the release of a new version of HEM.

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 and government response

What: The [Home Energy Model consultation](#) introduces the overhaul to the SAP methodology and sought views on the approach taken by the new Home Energy Model. The [Home Energy Model consultation](#) summarises the feedback to the consultation and the actions taken subsequently in development, ahead of the initial release of HEM.

Audience: The Home Energy Model consultation will be of interest to those seeking a general introduction to HEM and its role in government policy on domestic energy performance.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model core engine has been published as a [Git repository](#). Note the reference code for official HEM wrappers is published separately.

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.

Related content

This paper sets out the methodology for modelling controls within the Home Energy Model core engine. These may include controls for heating systems, cooling systems or hot water systems. The control methodology may vary according to the system type.

For information on control assumptions within the FHS assessment wrapper, please see:

- HEMFHS-TP-02 FHS space heating and cooling demand assumptions
- HEMFHS-TP-03 FHS domestic hot water assumptions

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

hem_core/controls/time_control.py

hem_core/cooling_systems/air_conditioning.py

hem_core/heating_systems/boiler.py

hem_core/heating_systems/elec_storage_heater.py

hem_core/heating_systems/emitters.py

hem_core/heating_systems/heat_battery.py

hem_core/heating_systems/heat_network.py

hem_core/heating_systems/heat_pump.py

hem_core/heating_systems/instant_elec_heater.py

hem_core/heating_systems/storage_tank.py

hem_core/project.py

Methodology

1. Overview

Systems requiring control (e.g. heating and hot water systems) can refer to one or more Control objects (containing schedules) that are defined as separate objects in the inputs to the core engine. As a minimum, these Control objects will define whether a system is on or off during a particular timestep, but some types of control objects may also define numeric setpoints. Note: in this context "on" means the system is ready to provide heat, but actual operation will also depend on demand on the system (e.g. a heat pump providing water heating which is "on" will not operate if the hot water cylinder is still above the minimum hot water temperature). In some cases, additional controls that are specific to the system, such as backup heating controls for heat pumps, are defined as part of the relevant system object instead of a control object.

For hot water systems with storage (e.g. an immersion heater supplying a hot water cylinder) the control is expressed as a numeric value at each timestep. The schedule must be defined as a SetpointTimeControl or a CombinationTimeControl that gives a numeric schedule. For standard storage tanks, numeric schedules for the minimum and maximum hot water temperatures are required. For SmartHotWaterTanks, the numeric schedules denote the minimum and maximum state of charge.

For space heating and cooling systems, a Control object defining a numeric setpoint schedule must be referenced (see the descriptions of SetpointTimeControl and CombinationTimeControl below). The relevant setpoint defined for each timestep is then used in the calculation of space heating/cooling demand at that timestep. If no setpoint has been set for a particular timestep (i.e. a null value is specified in the setpoint schedule) then the heating or cooling demand will be zero.

For space heating and cooling systems with storage, an additional Control object may be referenced so that input to the storage is controlled on a different schedule than output from the storage. For example, with a storage heater the input would typically be on at night when electricity is available at off-peak rates, whereas the output would typically be on during the day.

2. Control schedule object types currently implemented

2.1 OnOffTimeControl

This defines a Boolean value for each timestep of the simulation, which determines whether the system is on or off.

2.2 SetpointTimeControl

This defines a numeric value for each timestep of the simulation, which is used to determine demand. Null values may also be provided in which case demand for that timestep will be zero and the system will be off (it is important to differentiate between times when there is no demand because the setpoint has been reached and times when there is no demand because the system is off as this may affect standby power requirements for some systems).

Additional inputs can be provided on an optional basis, to set minimum or maximum setpoints which will be applied to all timesteps (i.e. if any of the setpoints in the specified schedule fall below the specified minimum or above the specified maximum, then the minimum or maximum temperature will be used instead, respectively). This allows for setback temperatures to be defined independently of the main setpoint schedule. Any null values will be overwritten with the maximum or minimum value (whichever has been provided) and the system is assumed to be always on. If both minimum and maximum values have been provided, then there is a further input to specify which should be used when the main schedule contains a null value.

An "advanced start" duration can also be specified to define how long before the specified heating period the system should switch on. This is intended for use with systems with a low capacity and/or a high degree of thermal inertia (e.g. heat pump with wet distribution) to avoid situations in which demand at the start of the heating period cannot be met (efficiently or at all) due to the system taking time to warm up.

If a setback or advanced start period are specified, then the heating/cooling system will attempt to meet the target temperature but if it cannot do so then no unmet demand will be recorded (i.e. unmet space heating/cooling demand is only recorded for the setpoints specified by the main schedule). See HEM-TP-04 Space heating and cooling demand for how unmet demand is calculated.

2.3 ChargeControl

Like the OnOffTimeControl, this defines a schedule of when heating is on/off, but it also provides additional information to define a schedule of target charge levels per time-step. This is used to define the charge level for storage heaters or heat batteries (as a proportion of the total storage capacity). It is intended to be used to control the energy input to such systems, rather than to define their output.

See Section 3.8 Electric storage heater and Section

3.9 Heat battery for further information on the options for ChargeControl.

2.4 OnOffCostMinimisingTimeControl

This generates a Boolean schedule based on a cost schedule and a desired number of operating hours per day (this does not have to be an integer number of hours). For each day of the simulation, the control will pick the required number of timesteps to meet this number of operating hours, prioritising the lowest-cost timesteps. For example, if the inputs state that 7 hours of operation are required and the timestep is half-hourly, then the 14 timesteps with the lowest cost in each day will be selected. The cost schedule can be based on any metric that needs to be minimised (e.g. financial cost, CO_2 emissions, primary energy).

2.5 CombinationTimeControl

This generates a schedule based on a combination of different control types (as defined above). The CombinationTimeControl object will generate a Boolean schedule, and may also generate a numeric schedule depending on the combination of controls specified. The CombinationTimeControl requires an operator (AND, OR, XOR, NOT, MAX, MIN, MEAN) and reference to the individual controls which are combined to define an overall control object. Multiple operators of any type can be combined within the CombinationTimeControl to provide the logic for the overall control. For example, the logic could specify that control 1 AND (control 2 OR control 3) needs to be on for the system to be on.

For a Boolean schedule, the value for each timestep of each control in the combination is compared to determine whether the system is on or off. For example, if the operator is defined as AND in the CombinationTimeControl object, the value of each individual control needs to be on at the relevant timestep for the system to be on. If the operator is defined as OR, at least one of the individual controls needs to be on at a given timestep for the system to be on.

For a numeric schedule, the combination of different controls is used to determine the numeric value for each timestep. For example, if all the individual controls are numeric and the operator is set to MAX, the CombinationTimeControl would generate a schedule by selecting the maximum temperature from the range at each timestep.

Individual controls of a Boolean and numeric schedule can be combined in the CombinationTimeControl object with the AND operator to define a schedule which sets each value as the setpoint where the Boolean value is true AND a numeric value is specified.

A Logic table for a CombinationTimeControl object which generates a schedule from a set of combined controls is shown in Table 1. The table shows example criteria for different combinations of control types (Boolean, Numeric, mixed) for when the system is on, when heating/cooling is required in the period, or a setpoint value is defined. 'ctrl 1' and 'ctrl 2' represent two individual controls which are combined and N/A denotes particular combinations of controls and operators which are incompatible.

Table 1: Logic table for CombinedTimeControl and criteria for control combinations

Value	Operator	Combined controls		
		Boolean	Numeric	Boolean (ctrl 1) & Numeric (ctrl 2)
System is ON	AND	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2
	OR	ctrl 1 OR ctrl 2	ctrl 1 OR ctrl 2	ctrl 1 OR ctrl 2
	XOR	ctrl 1 XOR ctrl 2	ctrl 1 XOR ctrl 2	ctrl 1 XOR ctrl 2
	MIN	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2
	MAX	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2
	MEAN	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2	ctrl 1 AND ctrl 2
System is in required period (numeric only)	AND	N/A	ctrl 1 AND ctrl 2	ctrl 1 is true AND ctrl 2 in period
	OR	N/A	ctrl 1 OR ctrl 2	N/A
	XOR	N/A	ctrl 1 XOR ctrl 2	N/A
	MIN	N/A	ctrl 1 AND ctrl 2	N/A
	MAX	N/A	ctrl 1 AND ctrl 2	N/A
	MEAN	N/A	ctrl 1 AND ctrl 2	N/A
Setpoint value (numeric only)	AND	N/A	N/A	ctrl 2 IF ctrl 1 is true else Null
	OR	N/A	N/A	N/A
	XOR	N/A	N/A	N/A
	MIN	N/A	MIN(ctrl 1, ctrl 2)	N/A
	MAX	N/A	MAX(ctrl 1, ctrl 2)	N/A
	MEAN	N/A	MEAN(ctrl 1, ctrl 2)	N/A

3. System-specific controls

3.1 Storage tank

Each heat source supplying the storage tank or smart hot water tank must also have a reference to a control schedule object defining two numeric schedules. For a storage tank this is to define the minimum and maximum temperature and for a SmartHotWaterTank this is for the minimum and maximum state of charge.

3.1.1 Standard Storage Tank

The StorageTank module has the following control inputs for each heat source:

- Position of the thermostat controlling that heat source
- Position of the heat source input
- Minimum hot water temperature schedule (not needed when heat source is solar thermal)
- Maximum hot water temperature schedule

3.1.2 Smart hot water tank

The SmartHotWaterTank module has the following control inputs:

- For each heat source:
  - Position of the heat source input
  - Minimum state of charge schedule (not needed when heat source is solar thermal)
  - Maximum state of charge schedule
- Maximum set point temperature schedule
- Lowest water temperature that is considered usable (a single figure for the entire simulation)

3.2 Immersion heater and PV diverter

For an immersion heater, see section 3.1 Storage tank which defines the inputs required

If the immersion heater is fed by a PV diverter, then this is assumed to operate whenever there is excess generated electricity available with no restrictions on time of day. A separate SetpointTimeControl schedule or a CombinationTimeControl that gives a numeric schedule must be input for the maximum temperature (for a standard storage tank) or the maximum state of charge (for a smart hot water tank) when energy is being diverted.

3.3 Boiler

For a combi boiler, water heating is assumed to be available at all times.

For a boiler heating a storage tank, see section 3.1 Storage tank which defines the inputs required

For space heating, the heating setpoints are defined by a numeric schedule (see above).

In addition to the above, boiler performance will also be affected by flow and return temperature when there is presence of weather compensating controls – the flow and return temperatures are determined in the emitter calculation as the methodology is common to all systems with wet distribution (see section 3.6 Systems with wet distribution).

3.4 Heat pump

For water heating, see section 3.1 Storage tank which defines the inputs required that are specific to water heating.

For space heating, the heating setpoints are defined by a numeric schedule (see the descriptions of SetpointTimeControl and CombinationTimeControl above).

Other heat pump control inputs common to both space and water heating are:

- Modulating vs. On/off control
- Backup control type, one of:
    - "None" -- backup heater disabled or not present
    - "TopUp" -- when heat pump has insufficient capacity, backup heater will supplement the heat pump
    - "Substitute" -- when heat pump has insufficient capacity, backup heater will provide all the heat output, and heat pump will switch off
- Time after which the backup heater will activate if demand has not been satisfied

In addition to the above, heat pump performance will also be affected by flow and return temperature when there is presence of weather compensating controls – the flow and return temperatures are determined in the emitter calculation as the methodology is common to all systems with wet distribution (see section 3.6 Systems with wet distribution).

For hybrid heat pumps, there is also the option of entering a cost schedule which will determine when the boiler operates instead of the heat pump. A cost value can be provided for each timestep.

3.5 Heat network / Heat interface unit

For an HIU providing hot water directly, hot water is assumed to be available at all times.

For an HIU heating a storage tank, see section 3.1 Storage tank which defines the inputs required.

For space heating, the heating setpoints are defined by a numeric schedule (see the descriptions of SetpointTimeControl and CombinationTimeControl above.

3.6 Systems with wet distribution

The design/maximum flow temperature must be entered in all cases, but additional flow temperature inputs are required for weather compensating controls. The emitter module requires the Ecodesign control class (I to VIII) to be specified and for those classes (II, III, VI and VII) which include weather compensation, the minimum flow temperature is also required along with the outside air temperatures at which the maximum and minimum flow temperatures will be set. The actual flow temperature (and implicitly, the return temperature, which is calculated from the flow temperature) at each timestep is then interpolated based on these inputs. The flow/return temperature will then affect the efficiency of the heat source (e.g. boiler, heat pump).

3.7 Direct electric heater

The heating setpoints are defined by a numeric schedule (see the descriptions of SetpointTimeControl and CombinationTimeControl above).

3.8 Electric storage heater

A schedule from the input file (contained in the ChargeControl input object – see 2.3 ChargeControl) determines the times at which electric storage heaters are allowed to be charged (e.g. off-peak hours) and the maximum charge level allowed for each time-step. Subject to this maximum, the extent to which they actually need to be charged is then determined by specific logic for one of the following control logic types: manual, automatic or predictive (see below for descriptions). This is specified in the ChargeControl input object.

Using this logic, a target charge level is determined for each timestep. If the current state of charge is below the target charge level the storage heater will be charged towards the target level, limited by the maximum charge rate.

3.8.1 Manual

In the case of manual control, the target charge level for each time-step is as specified in the input file. No further modification is made, meaning it will attempt to reach the maximum charge level whenever charging is scheduled.

3.8.2 Automatic

Where automatic charging is selected, charging cuts-off once a threshold internal room temperature is reached[1], so that in warmer weather the unit will charge less. This cut-off temperature is set in the input file, via the ChargeControl input object, and can be varied across the year, if desired.

A variant of this is also allowed for, where the charge level is determined as a function of the external temperature (i.e. a weather compensation control). In this case the input file must include the details of temperature points at which zero and maximum charging are reached and the model will interpolate in between to determine the target charge level. Intermediate temperatures/charge levels can be defined if needed to model non-linear compensation.

3.8.3 Predictive

When predictive[2] control is used, an estimate is made of the heat expected to be required over the next 24 hours to determine the appropriate target charge level. Such a prediction can either be backward looking (based on the previous day's heat demand) or forward looking (based on predicted weather for the following day) but at the time of writing only the forward looking method has been implemented. This works by calculating the heating degree-hours for the previous 24 hours and comparing this with the heat requirement for that period. The heating degree-hours for the following 24 hours are then calculated and used to predict the following day's heat requirement on a proportional basis, after subtracting any heat left in the storage heaters at the start of the charging period.

This is recalculated on a rolling 24-hour basis. Since this is driven by weather data the model already has, no additional inputs are needed. An additional parameter 'temp_charge_cut' can be used to further limit that charge by preventing further charging once the room temperature reaches a threshold point specified in the input file.

The options above are consistent with BS EN 15500-1-2017 Section 5.2.4.4, which states that 'the storage of the heat can be controlled by indoor temperature and/or by the precalculated demand according to the outdoor temperature'. The standard does not give details of how this should be done.

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[1] It can start again if the room temperature falls, although this is unlikely in practice.
[2] This is currently referred to as control type 'HHRSH' in the HEM code, since it has only been used with high heat retention storage heaters to date.

3.8.4 CELECT

While this can be entered as a distinct control type in HEM, it is currently treated no differently to a normal automatic control. In future, this may be updated[3].

3.9 Heat battery

The home energy model supports two distinct types of heat battery: dry-core heat batteries and phase-change material (PCM) heat batteries. The energy input to either type of heat battery is specified via a ChargeControl object which specifies when the heat battery can charge (e.g. off-peak hours) and the target charge level (as a proportion of the total storage capacity). When the schedule allows charging, the battery attempts to charge to the target level, at a rate limited by the power of the heat source.

PCM heat batteries only support the 'Heat Battery' ChargeControl logic type at present, though the current implementation uses this as a simple on/off control rather than utilising the predictive functionality. Dry-core heat batteries support 'Heat Battery' (including the predictive capability) and 'Manual' logic types.

3.9.1 Heat Battery

The 'Heat Battery' ChargeControl logic type implements predictive charging functionality. This is functionally the same as the 'HHRSH' control described in Section 3.8.3 Predictive, which is used for electric storage heaters. Each of these use the same predictive algorithm that estimates tomorrow's heating demand based on heating degree hours calculated from past demand and external temperature forecasts. The only difference is that the 'temp_charge_cut' input is not used (and is not required) for heat batteries, since this parameter is only relevant to room heaters that need to stop charging if the room temperature becomes too high. Heat batteries don't directly heat rooms during charging, so room temperature is not relevant to the charging decision.

3.10 Instantaneous point-of-use water heater

This is assumed to be available all the time, so there are no control inputs.

3.11 Air conditioning

The cooling setpoints are defined by a numeric schedule (see the descriptions of SetpointTimeControl and CombinationTimeControl above.)

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[3] This control type is present in SAP, but it is not believed to be in active use at this time so has not been prioritised for inclusion in HEM.

Future development

The current set of control options in the Home Energy Model can handle most of the typical situations for controls within a home. However, as the Home Energy Model becomes more widely used, there may be requests to add further control options to handle additional situations. For example, there may be some settings for heat pumps which are not currently modelled. Additional control options could be added as and when they are required. There are a number of standards which provide a method to define the control of systems in buildings. Relevant standards include:

EN 12098-1 – Controls for heating systems part 1

EN 12098-3 – Controls for heating systems part 3

EN 15500-1 – Control for heating, ventilating and air conditioning applications part 1

ISO 52120-1 – Contribution of building automation, controls and building management

ISO 52127-1 – Building management system

Future work could seek to align the HEM methodology with one or several of these standards.