Calculating ductwork and pipework heat losses 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

This paper sets out the methodology for heat losses affecting pipework and ductwork within the Home Energy Model core engine.

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

src/core/pipework.py

src/core/ductwork.py

1. Methodology

A home will usually have some kind of pipework and may also have some ductwork. Pipes may carry domestic hot water, cold water, or a heating fluid, and the pipe may be at a different temperature to its surroundings. Similarly, ductwork may carry warm or cold air which may be at a different temperature to its surroundings. Where such temperature differences occur, there will also be heat transfer, causing heat losses.

1.1 Sources used to develop methodology

- CIBSE Guide C Reference data, Section 3 Heat Transfer.
- CIBSE Guide B2 Ventilation and ductwork, Section 2.3.5.4 Airflow in ducts.
- BS 5422:2009 Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range –40 °C to +700 °C
- BS EN ISO 12241:2022 Thermal insulation for building equipment and industrial installations. Calculation rules

1.2 Key assumptions made in the absence of sources

For calculation of the internal heat transfer coefficient in pipes, the following is assumed. Water flow rate is assumed to be 0.2 m/s which is the lowest velocity stated in CIBSE Guide C, Table 3.32. Pipe diameter is assumed to be 20 mm. Hot water temperature is assumed to be 50°C. The associated convective film heat transfer coefficient from Table 3.32 was selected based on these values for water flow rate, pipe diameter and water temperature, and this is set as the default for the Home Energy Model.

For calculation of the internal heat transfer coefficient in ducts, the following is assumed. CIBSE Guide B, 2.3.5.4, ‘Airflow in ducts’ states the recommended maximum velocity for domestic air ducts is 3 m/s. This value is used to determine the internal surface heat transfer co-efficient of the duct, and this is set as the default for the Home Energy Model. Note that air duct velocities in use may be lower than 3 m/s, which means the internal surface heat transfer may be lower for some ventilation systems.

Pipes and ducts are assumed to be cylindrical. For rectangular pipes and ducts, the width can be used as a substitute for the diameter.

For hot water distribution pipework, at present it is assumed all stranded heat is lost from the pipework within one timestep.

1.3 Data inputs

The following data inputs are required to calculate the heat loss from ductwork or pipework.

- location, whether inside or outside
- internal diameter of the duct/pipe, in metres
- external diameter of the duct/pipe, in metres
- length of duct/pipe, in metres
- thermal conductivity of the insulation, in W / m·K
- thickness of the insulation, in metres
- whether the surface is reflective or not (boolean input)
- whether the duct/pipe is carrying air or water (in effect, whether it is a duct or a pipe)

1.3.1 Location of ducts and pipes

The location of the following can be specified to be located either outside with external air temperatures, or inside with internal air temperatures:

- Ducts
- Distribution pipework

Location has not currently been implemented for primary pipework.

1.3.2 Types of pipework

The following types of pipework can be represented in the Home Energy Model:

- Primary pipework (between heat source and hot water or thermal storage)
- Distribution pipework (pipework carrying hot water to tapping points)

Space heating pipework is not represented, since it is assumed that all heat losses provide beneficial heat to the dwelling. Space heating pipework is instead considered to be part of the heat emitter system.

1.4 Calculation methodology

1.4.1 Calculation of surface resistances

The linear exterior surface resistance of a pipe or duct, $R_{l,se}$, is calculated as

$$R_{l,se} = \frac{1}{h_{se} \cdot duct\ or\ pipe\ circumference\ including\ insulation}$$

where h_{se} is the exterior surface heat transfer co-efficient.

The same calculation is used for the interior surface resistance $R_{l,si}$, substituting the interior heat transfer co-efficient h_{si} for h_{se} , and using the internal circumference. The interior surface heat transfer coefficient is used for calculating the interior surface resistance, and the exterior surface heat transfer coefficient is used for calculating the exterior surface resistance. See Annex A for values of the surface heat transfer coefficients. This calculation is taken from 4.1.4 BS 12241:2022, 4.1.4 'External surface resistance'.

Default values of the internal and external heat transfer coefficients are not included in BS 12241. However, these values are available in CIBSE Guide C, and so have been selected for use in the calculations of surface resistances of pipes and ducts in the Home Energy Model. There are four possible values, depending on whether the insulation has a reflective surface or not, whether it is the internal or external surface, and whether it is a duct or a pipe.

1.4.2 Calculation of thermal resistance of cylindrical insulation

The insulation around a duct or a pipe is assumed to be in the shape of a hollow cylinder. The linear thermal resistance, R_l, of a hollow cylinder of insulation in is calculated as:

$$R_l = \frac{\ln \frac{D_e}{D_i}}{2\pi\lambda}$$

Where D_e is the outer diameter of the insulation and D_i is the inner diameter of the insulation, both in metres, and λ is the thermal conductivity of the insulation.

1.4.3 Calculation of linear thermal transmittance

The linear thermal transmittance is the heat loss per metre of duct/pipe length, in units of W/m. It is calculated from the reciprocal of the sum of component linear thermal transmittances:

linear thermal transmittance = 1 / (interior linear surface resistance + insulation linear thermal resistance + exterior linear surface resistance)

1.4.4 Calculation of energy loss

The heat loss rate of a duct or pipe is:

$$\Phi_l = U_l \cdot L \cdot (T_i - T_a)$$

Where Φ_l is the heat loss rate in watts, U_l is the linear thermal transmittance, L is the length of duct or pipe, T_i is the temperature inside the duct or pipe, and T_a is the ambient room temperature. (From BS 12241:2022, 4.1.6 ‘Heat flow rate’)

The linear thermal transmittance of the duct or pipe is multiplied by the length of the duct/pipe, which is then multiplied by the temperature difference (*e.g.* temperature of air/water in the duct/pipe minus the room temperature) to give the instantaneous heat loss rate. This is then multiplied by the duration over which the pipework is hot in each timestep to calculate the energy loss.

1.4.5 Distribution pipework

The total hot water distribution pipework length should be calculated as the sum of all lengths of pipework from the hot water source to a tapping point (i.e. tap, bath or shower), hence if a pipe is shared for multiple tapping points the length of shared pipe should be duplicated and added for each tapping point.

For a hot water draw-off event, heat loss is calculated for the duration of the draw-off. Stranded heat is calculated differently, see below.

1.4.6 Calculation of stranded heat in pipework

In addition to this, where pipework is in use intermittently, there will be stranded heat remaining after the flow through the pipe has ceased. This can be very significant in some cases (e.g. where small draw-offs are made from domestic hot water outlets), so the amount of stranded energy is also calculated and included in the pipework loss total for each time step. Stranded heat is calculated using the energetic content of the remaining hot water in the entire run of the pipework, using the difference between the hot water temperature and the average internal air temperature. Stranded heat is allocated to the timestep in which the water draw-off occurs. At present it is assumed all stranded heat is lost from the pipework. We may be able to refine this in future.

1.4.7 Internal heat gains

Losses from pipework that is inside the conditioned part of the dwelling are assumed to contribute to internal heat gains.

2. Verification of methodology

BS 5422 Table 13 lists indicative thickness of insulation to control heat loss for ductwork carrying warm air, assuming a horizontal duct at 35°C, with a 600 mm vertical sidewall in still air at 15 °C. These values were calculated by the standards authors according to BS EN ISO 12241:1998.

To verify that the Home Energy Model methodology follows BS EN ISO 12241, the results from Home Energy Model ductwork calculations were compared to BS 5422 Table 13, and were found to be in agreement. Note that it was not an exact comparison because it compared rectangular ducts to the cylindrical duct as used in the Home Energy Model. This verification is included in the unit tests for the module.

3. Validation of methodology

The calculation methodology in BS 12241:2022 is very widely used, and it is assumed that other applications of the methodology have validated it in a generic sense. However, there remains a possibility that are aspects of pipework and ductwork heat losses that are not fully considered when it is applied to modelling home energy consumption. For this reason, it may be worth considering empirical validation of the heat losses in a laboratory setting, with an experimental design that replicates ducts or pipes in a dwelling. Another option is the use of computational fluid dynamics modelling for an intermodel comparison.

4. Limitations in the Consultation Version

Ducts and pipes also have fixings where they are fixed to a surface. Often these fixings cause thermal bridges and therefore there will be additional heat losses. Thermal bridges may also occur due to gaps in insulation. Thermal bridging is not currently modelled.

Rectangular ducts are approximated to be cylindrical ducts. This may cause a small variation in the heat loss predictions.

Location, internal or external, cannot be specified for primary pipework.

Sometimes pipework is embedded into walls, and heat transfer then occurs directly to the surrounding material. This is not currently modelled, and heat losses may differ in this situation.

For stranded heat in pipework, it is assumed that all heat is lost between hot water usage events. Hot water usage may be over-estimated if the occupant does not fully draw-off all the stranded water, and the occupant later makes use of the stranded water before it cools off fully.

Where the duct or pipe is enclosed, for example between floor and ceiling, or is boxed in, its ambient temperature may be higher than the room temperature. This may result in overestimation of heat losses.

The mean temperature of the heating water in primary pipework may be lower than the flow temperature from the heat source, since the return temperature is lower than the flow temperature. The mean temperature is not currently calculated, and the flow temperature is used instead.

Similarly, mean temperature of the hot water in DHW distribution pipework may be lower than the heat source (for instantaneous heating) or lower than the stored hot water if it is stored, since heat is lost in the distribution pipework, and the stored hot water may not always be at its maximum setpoint. The mean temperature is not calculated, and a default temperature of 52°C is currently used instead.

Secondary circulation pipework is not modelled (hot water pumped in a loop to reduce time waiting for hot water from taps).

The Part L regulations currently state that space heating pipes in voids should be insulated. Currently this is not modelled, and such pipework is instead considered to be part of the heat emitter system, with all heat losses being utilised as space heating. There is also a lack of evidence about the effect of pipework losses in voids such as an intermediate floor, and how this may affect heat loss into each zone.

5. Future development

The following may result in improved calculations:

- Modelling of thermal bridging
- Modelling of embedded pipes
- Modelling of re-used stranded hot water
- Calculation of mean water temperatures in primary pipework and hot water distribution pipework
- Modelling of rectangular ductwork if this is considered likely to be found in homes
- Modelling the insulation effect of boxed-in pipework
- Adding location to primary pipework to capture pipework that might be located outside the thermal envelope

The following are additional features that may cover some types of pipework not currently modelled:

- Secondary circulation pipework, including energy used in the circulation pump
- Space heating flow and return pipework where they pass through a void such as an intermediate floor

There is another BS EN standard which handles pipework energy performance in buildings. This is BS EN 15316-3:2017. *Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies. Part 3: Space distribution systems (DHW, heating and cooling).* This standard could be used as a reference to improve the modelling of pipework in the Home Energy Model. The accuracy of heat loss predictions could be validated by either laboratory testing or the use of computational fluid dynamics modelling.

Other references which may be useful for further development include the following:

- The *NHBC Standards Chapter 8.1 Internal services, Pipe Insulation requirements for space heating and hot water systems in new dwellings*, TECHNICAL GUIDANCE 8.1/35 provide more detail about how the pipework insulation requirements are applied to new homes.
- BPEC (British Plumbing Employers Council) provide a free textbook online for the BPEC Level 2 Diploma in Plumbing Foundation. This contains details and diagrams of hot water plumbing systems, and can help to ensure that realistic plumbing systems are modelled in the Home Energy Model. See Section 7 – F/602/2884 Understand and apply domestic hot water system installation and maintenance techniques

Annex A – Surface heat transfer coefficients

Surface heat transfer coefficient for type of surface	**W / m2 K**
h_{se} Exterior surface of duct or pipe: high emissivity non-reflective surface (convective and radiative combined) From CIBSE Guide C, Table 3.25	10
h_{se} Exterior surface of duct or pipe: low emissivity reflective surface (convective and radiative combined) From CIBSE Guide C, Table 3.25	5.7
h_{si} Inner surface of air duct, at air flow velocity of approximately 3 m/s (This includes the convective fraction only, since there is no radiative heat transfer to the outer surface. Therefore, this takes the value for a low-emissivity outside surface as an equivalent for convective only internal surface) From CIBSE Guide C, Table 3.25. Note that CIBSE Guide B, 2.3.5.4, ‘Airflow in ducts’ states the recommended maximum velocity for domestic air ducts is 3 m/s	15.5
h_{si} Inner surface of pipe, at water flow of approximately 0.2 m/s, and water temperature of 50°C From CIBSE Guide C, Table 3.32	1500

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