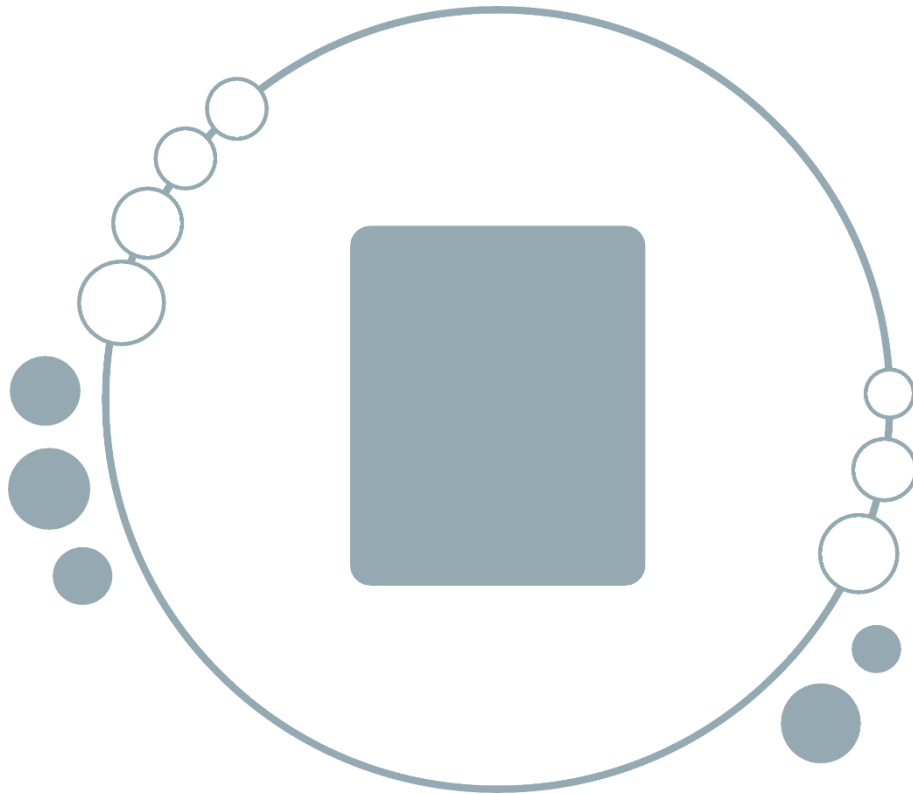




Modelling Infiltration and Ventilation within the Home Energy Model

A technical explanation of the methodology

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Background to the Home Energy Model

What is the Home Energy Model?

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

Ventilation of dwellings is required to provide fresh air, but this leads to heat loss as warm air leaves the dwelling and is replaced with colder air from outside. The rate of this heat loss depends on the rate of air flow and the temperature difference between incoming and outgoing air. Air flow may be intentional, to provide adequate ventilation via passive or mechanical means, or unintentional, due to air leakage through the fabric of the building.

For more information on how the ventilation and infiltration heat loss is accounted for in the space heating and cooling demand calculations, see HEM-TP-01 General summary of core calculation and HEM-TP-04 Space heating and cooling demand.

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

[src/hem_core/space_heat_demand/ventilation.py](#)

[src/hem_core/space_heat_demand/zone.py](#)

[src/hem_core/project.py](#)

Methodology

1. Overview

The methodology for calculating airflow and heat loss through ventilation and infiltration in the Home Energy Model (HEM) is primarily based on BS EN 16798-7:2017. HEM considers various components:

- Envelope leakage (infiltration) – see 2. *Ventilation – Uncontrolled / Infiltration*
- Vents – see 3. *Ventilation – Vents*
- Mechanical ventilation systems (such as mechanical extract, supply, and balanced systems) – see 4. *Ventilation – Mechanical Ventilation*
- Window openings – see 5. *Ventilation – Windows*

To model ventilation and infiltration in dwellings, HEM accounts for:

- Wind-driven pressure: external wind creates pressure variations across the building envelope, which influence airflow through openings.
- Stack effect: temperature differences between the interior and exterior of the dwelling cause density differences between air inside and outside the dwelling, which leads to pressure variations between openings at different heights.

HEM then determines the internal pressure that would lead to a balance between incoming and outgoing air flows and uses this to calculate the air flow through each opening and subsequently the overall air change rate.

HEM calculates the ventilation for the entire dwelling all at once instead of using zones. This is because if the zones are treated entirely independently (with no air flow between them), then cross-ventilation (and possibly stack effect) is not fully accounted for and would likely lead to an underestimation of ventilation rates. If the zones are treated as separate but connected (i.e. with air flow between them) that requires details around the internal layout of the dwelling, size and positioning of internal doors etc. which would increase input complexity and would require solving for several internal pressure values simultaneously, thus increasing the calculation complexity.

1.1 Mass balance principle

The methodology calculates air inflows and outflows by considering various pathways through which air enters and leaves a building. Fresh air can enter through vents, envelope leakage, open windows, or mechanical ventilation systems (such as supply-only¹ or balanced systems). Similarly, air exits the building through vents, envelope leakage, open windows, or mechanical ventilation systems (such as extract-only or balanced systems).

¹ Note: HEM does not currently model supply-only mechanical ventilation (a.k.a. positive input ventilation) but this could be added in future without changing the fundamental structure of the calculation described here.

To solve for the internal reference pressure, and therefore the airflow at each individual airflow path, the model sets up a system of nonlinear airflow equations representing the mass balance principle. This requires that the mass of incoming air equals the mass of outgoing air for the ventilation zone. By solving these equations iteratively, the model identifies the value of the internal reference pressure ($p_{z,ref}$) that ensures balanced airflow across all airflow paths.

$$\begin{aligned}
 & q_{m;V;lea;in}(p_{z,ref}) + q_{m;V;lea;out}(p_{z,ref}) \\
 & + q_{m;V;vent;in}(p_{z,ref}) + q_{m;V;vent;out}(p_{z,ref}) \\
 & + q_{m;V;SUP;dis} + q_{m;V;ETA;dis} \\
 & + q_{m;V;arg;in}(p_{z,ref}) + q_{m;V;arg;out}(p_{z,ref}) \\
 & = 0
 \end{aligned}$$

Equation 1 – Implicit mass balance formula for determining internal reference pressure and air mass flow rates (eq. 67 from BS EN 16798-7:2017)

- $q_{m;V;lea;in/out}$ is the mass flow rate of air entering and leaving the dwelling (respectively) through envelope leakage. See section 2. *Ventilation – Uncontrolled / Infiltration*.
- $q_{m;V;vent;in/out}$ is the mass flow rate of air entering and leaving the dwelling (respectively) through vents (include trickle vents and air bricks but does not include passive stack vents). See section 3. *Ventilation – Vents*.
- $q_{m;V;SUP/ETA;dis}$ is the mass flow rate of air supplied to/extracted from the dwelling (respectively) by mechanical ventilation systems. See section 4. *Ventilation – Mechanical Ventilation*.
- $q_{m;V;arg;in/out}$ is the mass flow rate of air entering and leaving the dwelling (respectively) through window openings. See section 5. *Ventilation – Windows*.

By convention, the mass of air entering and leaving the dwelling are positive and negative respectively. The calculated air mass flow rates are used to calculate the dwelling's heat loss.

The total volume of air entering the building is calculated in eq. 68 from BS EN 16798-7:2017 as:

$$q_{V;tot;in} = \frac{q_{m;V;tot;in}}{\rho_{a,e}}$$

Equation 2 - Total volume of air entering the building

Where:

- $q_{m;V;tot;in}$ is the total mass of air entering the building
- $\rho_{a,e}$ is the density of the external air

The total air change rate is then calculated by summing the total volume of air entering the building and dividing by the total dwelling volume. Section 6. *Calculation of ventilation and*

infiltration heat loss explains how the total air change rate calculated from solving the mass balance equation is used to calculate the dwelling's heat loss from ventilation and infiltration.

1.2 Calculating Airflow rate from Pressure Difference

The method for calculating the volumetric flow rate from an airflow path ($q_{V,path,i}$) in HEM can be summarised with this equation²:

$$q_{V,path,i} = C_{path,i} \cdot \text{sign}(\Delta p_{path,i}) \cdot |\Delta p_{path,i}|^{n_{path,i}}$$

Equation 3 - Volumetric flow rate from an airflow path

Where:

- $C_{path,i}$: The flow coefficient (varies for the type of flow path³).
- $\text{sign}()$: a function that returns either +1 or -1, to determine the direction of the airflow where conventionally, air entering the dwelling is positive and air leaving the dwelling is negative.
- $\Delta p_{path,i}$: The pressure difference across the airflow path (Pa).
- $n_{path,i}$: The flow exponent for the airflow path (varies for the type of flow path⁴), which describes the relationship between airflow rate and pressure difference.

The pressure difference ($\Delta p_{path,i}$) between the inside and outside of the dwelling governs the airflow through the airflow path and is defined in Section 6.4.2.4 of BS EN 16798-7:2017 (equation 4), as:

$$\Delta p_{path,i} = p_{e,path,i} - p_{z,path,i}$$

Equation 4 - Pressure difference between inside and outside of the dwelling

Where $p_{e,path,i}$ is the external pressure and $p_{z,path,i}$ is the internal pressure. Note that the calculated pressure difference applies to leakage paths, vent openings (including with fans – see *Section 4 – Mechanical Ventilation*) and window openings.

The external pressure ($p_{e,path,i}$), influenced by wind speed and stack effect, is calculated in Section 6.4.2.4 of BS EN 16798-7:2017 equation 5, as:

$$p_{e,path,i} = \rho_{a,ref} \cdot \frac{T_{e,ref}}{T_e} \cdot (0.5 \times C_{p,path,i} \cdot u_{site}^2 - h_{path,i} \cdot g)$$

Equation 5 - External pressure

Where:

² This equation is a generalisation of equations 53, 58 and 62 from BS EN 16798-7:2017.

³ Windows and Vents derive this using a discharge coefficient, an equivalent area and $n_{path,i}$, Leaks derive this value from an envelope leakage test. See equations 54, 59, and B.4 from BS EN 16798-7:2017 respectively.

⁴ Windows and vents use a value of 0.5 for this exponent, taken as a suggested default from section B.3.2.2 in BS EN 16798-7:2017.

- $\rho_{a,ref}$: reference air density.
- T_e and $T_{e,ref}$: external and reference air temperatures⁵ respectively.
- $C_{p,path,i}$: wind pressure coefficient for the airflow path.
- u_{site} : reference wind speed at site at zone level.
- $h_{path,i}$: height of the airflow path above the ground level.
- g : gravitational constant.

The calculation of airflow rates for the individual airflow paths for vents (designed apertures for air exchange), leaks in the ventilation zone (unintended openings such as cracks and gaps)⁶, and window openings, uses wind pressure coefficients to evaluate the impact of wind pressure on each specific path.

For airflow paths less than 15m above the ground, these coefficients are taken from AIVC Guide 5: Ventilation Modelling Data Guide⁷ Tables F1-F3, which cover one- to three-storey buildings in three shielding classes, equivalent to those in BS EN 16798-7:2017. The assumed ratio of depth to width is 1:1 (i.e. a square footprint). Coefficients are defined for each possible angle of wind to a given façade, in increments of 45 degrees.

Table 1: Example wind pressure coefficients for wall paths of <15m height and “open” shielding

Wind angle	0° (windward)	45°	90°	135°	180° (leeward)	225°	270°	315°
Pressure coefficient	0.7	0.35	-0.5	-0.4	-0.2	-0.4	-0.5	0.35

Above 15m in height, the shielding class is assumed to be “exposed”, and the values are taken for mid-rise buildings with a footprint ratio of 1.5:1 (AIVC Guide 5 Figure F1)⁸.

The above assumes that the dwelling is cross-ventilated. There are no AIVC values for the situation where cross-ventilation is not possible. In this case, AIVC wind angles with positive coefficients are taken to be “Windward” and AIVC wind angles with negative coefficients are taken to be “Leeward”. Substituting these values from Table B.8 in EN 16798-7 for each wind angle results in the following table (used for all heights and shield classes):

⁵ (293.15K) A constant used to adjust for temperature effects on air density. Taken from Table 11 in BS EN 16798-7:2017.

⁶ HEM models the overall dwelling leakage as individual air flow paths distributed across the dwelling, enabling them to be modelled in the same way as a vent or window.

⁷ Orme, M. and Leksmono, N. (2002) 'Appendix F - Wind Pressure Coefficient Data' in *AIVC Guide 5: Ventilation Modelling Data Guide*. International Energy Agency, pp. 63-66. <https://www.aivc.org/resource/gu-5-ventilation-modelling-data-guide> The same source figures are also available in AIVC Technical Note 44. Table B.7 in BS EN 16798-7:2017 also provides default values for these coefficients, but these are highly conservative and use a simpler angular distribution of 60 degree ranges.

⁸Figure F1 from 'Appendix F - Wind Pressure Coefficient Data' in *AIVC Guide 5: Ventilation Modelling Data Guide*.

Table 2: Wind pressure coefficients for façades of non-cross ventilated zone

Wind angle	0° (windward)	45°	90°	135°	180° (leeward)	225°	270°	315°	Roof
Pressure coefficient	0.05	0.05	-0.05	-0.05	-0.05	-0.05	-0.05	0.05	0

Note that HEM additionally adjusts u_{site} for height of the airflow path above the ground level, see section 1.3 *Wind speed reduction*.

The internal pressure at the height of the airflow path is influenced by the reference pressure ($p_{z,ref}$) at the ventilation zone's floor level, adjusted for the height of the path is defined in Section 6.4.2.4 of BS EN 16798-7:2017 equation 6, as:

$$p_{z,path,i} = p_{z,ref} - \rho_{a,ref} \cdot h_{path,i} \cdot g \cdot \frac{T_{e,ref}}{T_z}$$

Equation 6 - Internal pressure

where T_z is the internal air temperature.

Where the methodology requires the internal temperature (e.g. to calculate stack effect), it uses the volume-weighted average of the zone temperatures from the previous timestep.

1.3 Wind speed reduction

HEM applies a correction to the raw wind speed from the weather file to account for local conditions, which may be quantified through the following parameters (defined in BS EN ISO 15927-1:2003):

- A topography coefficient, which accounts for the increase in mean wind speed over isolated hills and escarpments and is related to the wind velocity upwind to the hill.
- A roughness coefficient, which accounts for the variability of mean wind speed at the site due to the site's height above the ground and the roughness of the terrain.

The wind speed correction is based on the following equation from BS 16798-7:2017, 6.4.2.2:

$$u_{site} = u_{10} \frac{C_{rgh,site} \times C_{top,site}}{C_{rgh,met} \times C_{top,met}}$$

Equation 7 - Wind speed correction

- u_{10} (m/s) is the wind velocity from the weather file assumed to be measured 10m above ground level,
- $C_{rgh,site}$ is the roughness coefficient at building site,

- $C_{top,site}$ is the topography coefficient at building site,
- $C_{rgh,met}$ is the roughness coefficient at height of 10m for meteorological station,
- $C_{top,met}$ is the topography coefficient for local conditions at the meteorological station.

For inputs $C_{top,site}$, $C_{rgh,met}$, and $C_{top,met}$, a default value of '1' is used, defined in section B.3.4.2 from BS EN 16798-7:2017.

The roughness coefficient at building site ($C_{rgh,site}$) is calculated with the following equation which accounts for terrain class and height above ground (BS EN ISO 15927-1:2003 section 7.2.2):

$$C_{rgh,site} = K_R \times \ln \left(\frac{z}{z_0} \right)$$

Equation 8 - Roughness coefficient at building site

where

- K_R , the terrain factor, and z_0 , the roughness height, are terrain dependent (Table 3).
- z is the height above ground, taken as the distance between the ground and the lowest part of the ventilated zone. z cannot be lower than the minimum height above ground associated with each terrain class (z_{min} , in Table 3).

Table 3: K_R , z_0 and z_{min} for available terrain types, extracted from BS EN ISO 15927-1:2003 section 7.2.2.

Terrain	K_R	z_0	z_{min}
Open water	0.17	0.01	2
Open field	0.19	0.05	4
Suburban	0.22	0.3	8
Urban	0.24	1.0	16

2. Ventilation – Uncontrolled / Infiltration

HEM expects the entry of the details of an infiltration pressure test⁹ of the dwelling. This includes the test result (i.e. envelope air tightness index, in units of m³/h.m²), test reference pressure (e.g. 50Pa or 4Pa) and the envelope (reference) area. The test data is used to

⁹ This measurement is assumed to have been conducted under the current approved airtightness methodology (BS EN ISO 9972:2015, Method 3, as described in CIBSE TM23, 2020. This means that all openings, vents etc. that have been provided for the purpose of ventilation should be closed (but not sealed), except if no closing mechanism exists in which case temporary sealing may be used. This differs from other methodologies (e.g. Passivhaus) where openings, vents etc. should be tested in the state they would be in during normal operation (e.g. trickle vents would be open). The AP50 (m³/h.m²) result, or equivalent for the applicable reference pressure, is the one needed in HEM.

calculate an overall leakage coefficient, C_{leak} , for the dwelling in accordance with section B.3.3.15 from BS EN 16798-7:2017:

$$C_{leak} = q_{V,\Delta p_{leak;ref}} \times \frac{A_{leak}}{\Delta p_{leak;ref}^{n_{leak;ref}}}$$

Equation 9 - Leakage coefficient

Where:

- $q_{V,\Delta p_{leak;ref}}$ is the envelope airtightness index of the ventilation zone.
- A_{leak} is the reference area of the envelope airtightness index.
- $\Delta p_{leak;ref}$ is the reference pressure for the envelope airtightness index.
- $n_{leak;ref}$ is the air flow coefficient through leaks (defaulted to 0.677 in section B.3.3.14).

The overall dwelling leakage coefficient is then used to calculate a leakage coefficient for the facades, $C_{leak;fde}$, (external walls) and the roof, $C_{leak;roof}$, using equations B.5 and B.6 from BS EN 16798-7:2017, respectively:

$$C_{leak;fde} = C_{leak} \times \frac{A_{fde}}{A_{fde} + A_{roof}}$$

Equation 10 - Leakage coefficient for facades

$$C_{leak;roof} = C_{leak} \times \frac{A_{roof}}{A_{fde} + A_{roof}}$$

Equation 11 - Leakage coefficient for roof

Where:

- A_{fde} is the surface area of the façades of the ventilation zone.
- A_{roof} is the surface area of the roof of the ventilation zone.

HEM models the overall dwelling leakage as five air flow paths, distributed across the dwelling with four in the facades and one in the roof (in accordance with section B.3.3.16 from BS EN 16798-7:2017), to estimate how air leaks into and out of various sections of the envelope.

Table 4 outlines the locations of the five leak air flow paths based on the total height of the ventilation zone of the dwelling, along with the proportion of the associated leakage coefficient that it receives. Leaks are not assigned to any particular building elements; instead they are defined such that in any given timestep they are located slightly offset from the windward/leeward sides of the building, as specified in Table 4 (with windward and leeward orientations as defined in section 1.2 Calculating Airflow rate from Pressure Difference¹⁰). Therefore, HEM does not account for differences in the sheltering of different orientations i.e. it does not differentiate between external walls and party walls when assigning air leakage. The

¹⁰ The selection of the pressure coefficients for 45° and 135° angles to normal, rather than 0° and 180° for directly windward and leeward, is based on validation testing which indicates this mitigates against excessive leakage estimates in the absence of a more refined treatment of leak placement (see Future Development section).

pressure coefficients applicable to façades at different orientations than the two selected are not applied to leaks (but are used for other types of flow path).

HEM then treats these leaks as individual airflow paths to calculate the airflow in and out of each leak at each timestep using the internal reference pressure.

The method for calculating the airflow rate for each leak is described in section

1.2 Calculating Airflow rate from Pressure Difference.

Table 4: Leakage coefficient distribution

Height of Leak	$C_{leak,fde}$ distribution	$C_{leak,roof}$ distribution
At 0.25 times the ventilation zone height	25% to the 45° façade	
	25% to the 135° facade	
At 0.75 times the ventilation zone height	25% to the 45° façade	
	25% to the 135° facade	
At the full ventilation zone height		100% to roof

3. Ventilation – Vents

HEM expects the entry of each vent and treats each as an individual air flow path where the air flow rate is calculated at each timestep. Vents include trickle vents and air bricks but not passive stack vents.

The method for calculating the airflow rate for each vent is described in *Section*

1.2 Calculating Airflow rate from Pressure Difference, and depends on the equivalent area of the opening. A larger opening allows for more air to enter or exit the dwelling through that opening. All vents are assumed to be adjustable and fully closeable when entered in HEM (additional comments on this assumption are provided in the *Future Developments* section). This is modelled via a vent opening position variable (between zero and one, where zero means the vents are fully closed, and one means the vents are fully open) which is multiplied by the equivalent area of each vent.

Note that the vent opening position is an input to the main ventilation calculation, but the ventilation module also provides functionality to determine the vent opening ratio that would lead to a particular target air change rate, by running the calculation iteratively (see section 3.1 *Vent adjustment*). To understand how this functionality fits into the overall space heating calculation, see *HEM-TP-01*.

3.1 Vent adjustment

It is assumed that occupants may adjust openings to avoid air change rates that are too low or too high. To allow this behaviour to be modelled, HEM can accept two optional schedules containing minimum and maximum target air change rates (if running the calculation with a wrapper, predefined control schedules could be used) and an optional initial vent opening position input. If the opening position of vents input is not specified, it is defaulted to 1, meaning that vents begin the simulation fully open.

If one or both schedules are not specified, none of the targets associated with the unspecified schedules will be applied for any timestep. If a schedule is present but contains timesteps where an air change rate target has not been entered (i.e. values set to null), then no target is applied in those timesteps. This allows the user to specify limits for certain timesteps and have no targets for others.

For timesteps where any target air change rates are entered, the following vent opening and closing functionality can operate. If the air change rate in the dwelling, calculated with vents in the same position as the previous timestep, is between the minimum and maximum thresholds specified, the vents remain in the same position. If it is not within the thresholds, then whichever threshold it is closer to becomes the target air change rate for an iterative solver (e.g. if the maximum air change rate threshold is set to 0.7 but the calculated air change rate for the current vent opening position is 0.75, then 0.7 becomes the target air change rate). The solver will then adjust all the vents to attempt to hit that target air change rate. If opening or closing the vents to their maximum would still not allow the respective threshold to be met, they are simply opened or closed to their fullest extent (vent opening position set to one or zero).

4. Ventilation – Mechanical Ventilation

HEM models the provision of mechanical ventilation of several types, each described in its own subsection as follows:

- 4.1 Intermittent mechanical extract ventilation (Intermittent MEV)¹¹
- 4.2 Continuous centralised mechanical extract ventilation (Continuous cMEV)
- 4.3 Continuous decentralised mechanical extract ventilation (Continuous dMEV)
- 4.4 Balanced mechanical ventilation with heat recovery (MVHR)¹²

The method to calculate the airflow rate from mechanical ventilation systems is largely the same for all system types, with the type of system determining whether air is supplied or extracted. Balanced systems such as MVHR both supply and extract air, extract-only systems such as Continuous cMEV only extract air. In each timestep a system is active, it will supply

¹¹ Note that in Part F this is referred to as natural ventilation with background ventilators and intermittent extract fans. Note also that the naming of this type of ventilation in this document is not intended to imply that intermittent extract fans are the dominant cause of air flow – it is likely that wind or stack driven air flow will be the most significant component.

¹² Note that balanced mechanical ventilation without heat recovery can be modelled as MVHR with heat recovery efficiency of zero.

and/or extract air at a volume flow rate calculated by multiplying together the *design air flow rate*¹³, *control and system factors*¹⁴ and a *pressure derating factor*¹⁵, given by Equation 12.

$$k \times \Delta p_{path,i}$$

Equation 12: Pressure derating factor for mechanical ventilation paths

Where k is the flow change coefficient for the system type (see Table 5)¹⁶ and $\Delta p_{path,i}$ is as defined in Equation 4.

Table 5: Flow change coefficients for different mechanical ventilation types

System type	Flow change coefficient (l/s.Pa)
MVHR	0.5
Continuous cMEV	0.5
Continuous dMEV	0.1
Intermittent dMEV	0.5
Positive input ventilation ¹⁷	0.1

4.1 Intermittent mechanical extract ventilation (Intermittent MEV)

Each individual intermittent mechanical extract fan must be entered separately into HEM. The inputs include the required design air flow rate to be extracted from the ventilation zone and the specific fan power (see section 7. *Mechanical ventilation electricity consumption*). As with all types of MEV systems, Intermittent MEV systems will only extract air from the dwelling.

In addition, Intermittent MEV systems operate based on a control schedule, which contains the proportion of each timestep that the system is running for and is a calculation input (or if running the calculation with a wrapper, a predefined control schedule could be used).

The air flow rate for each fan is calculated for the proportion of each timestep when the system is active, by multiplying the value from the control schedule by the design air flow rate.

¹³ This is the design air flow rate to be supplied to or extracted from the ventilation zone by the system

¹⁴ The default for the control factor for residential buildings is taken from Table B.4. from BS EN 16798-7:2017, the associated system factor is selected from Table B.5, with an assumed ventilation effectiveness of 100% (i.e. no pressure derating) is taken from section B.3.3.7. This results in an overall required outdoor air flow rate for the ventilation system of 1.1 multiplied by the design outdoor air flow rate.

¹⁵ This is a departure from BS EN 16798-7:2017, which assumes the rate of airflow is fixed in mechanical ventilation systems.

¹⁶ The coefficients in Table 5 are derived from laboratory test data (unpublished) measuring flow rates at different pressure differentials, for typical fans of different MEV systems within the PCDB.

¹⁷ Although this value has been set, positive input ventilation systems have not yet been fully implemented in HEM.

4.2 Continuous centralised mechanical extract ventilation (Continuous cMEV)

Continuous centralised MEV systems extract air continuously from the dwelling and are entered into HEM as a single system, rather than by entering each fan or duct endpoint individually. The inputs include the required design air flow rate to be extracted from the ventilation zone and the specific fan power (see section 7. *Mechanical ventilation electricity consumption*). As with all types of MEV systems, Continuous cMEV systems will only extract air from the dwelling.

Unlike intermittent systems, Continuous cMEV systems operate constantly and therefore do not require a control schedule.

4.3 Continuous decentralised mechanical extract ventilation (Continuous dMEV)

Each individual decentralised mechanical extract ventilation (dMEV) fan should be entered separately into HEM. The inputs include the required design air flow rate to be extracted from the ventilation zone and the specific fan power (see section 7. *Mechanical ventilation electricity consumption*). As with all types of MEV systems, Continuous dMEV systems will only extract air from the dwelling.

As with Continuous cMEV systems and unlike intermittent systems, Continuous dMEV systems operate constantly and therefore do not require a control schedule.

4.4 Balanced mechanical ventilation with heat recovery (MVHR)

Balanced MVHR systems supply and extract air simultaneously, while recovering heat from extracted air, and the supply and extract parts are entered as a single system in HEM. The inputs include the required design air flow rate to be supplied and extracted from the ventilation zone, the specific fan power (see section 7. *Mechanical ventilation electricity consumption*) and the heat recovery efficiency.

Technically, the MVHR system usually supplies air at a higher temperature than the outside air (as long as internal air is at a higher temperature than external air), i.e.:

$$T_s = T_e + \eta \times (T_z - T_e)$$

Equation 13 - Supply air temperature from MVHR system

Where:

- T_s is the supply air temperature
- T_e is the external air temperature
- T_z is the internal air temperature
- η is the MVHR heat recovery efficiency

However, calculating this requires the internal air temperature, which depends on the air change rate and supply temperature, thus introducing a circularity in the calculation. Given that the ventilation heat loss is directly proportional to both the air flow rate and the temperature difference (see section 6. *Calculation of ventilation and infiltration heat loss*), the air flow rate used in the heat loss calculation can be adjusted to account for the heat recovery effect using an equivalent flow rate of external air, thus avoiding the circularity. For example, if the MVHR system recovers 85% of the energy from outgoing air, then this means that it has reduced the temperature difference between internal air and incoming air by 85%, which is the equivalent of reducing the air flow rate by 85% while keeping the original temperature difference. This equivalence can be summarised by the equation below:

$$\begin{aligned} & constants \times (temperature\ difference \times (1 - efficiency)) \times air\ flow\ rate \\ & = constants \times temperature\ difference \times (air\ flow\ rate \times (1 - efficiency)) \end{aligned}$$

Equation 14 - Adjusting air flow rate for heat loss calculation

Note that adjusting the air flow rate instead of the temperature difference is only valid when calculating heat loss, and the adjusted air flow rate should not be used in any other context (e.g. the mass balance in Equation 1).

Losses from MVHR ductwork are calculated based on the length and diameter of ducts subject to heat transfer and the duct insulation properties as illustrated in Figure 1. The calculation of total resistance of duct insulation is based on the same principles as the equivalent calculation for hot water pipework and is described in HEM-TP-10 Ductwork and pipework losses.

Ductwork in HEM can be of circular or rectangular cross-section and there is no limit to the number of ducts that can be specified (ducts of the same type are assumed to be connected in series, e.g. heat loss from all intake ducts will be summed when intake ducts are relevant).

The heat loss for each duct is:

$$duct_heat_loss = length \times (temp_inside_duct - temp_outside_duct) / total_resistance$$

Equation 15 - Heat loss for each duct

The ductwork losses are then accounted for in the main space heating calculation by adding them to or subtracting them from the internal gains. Note that in the case of an MVHR unit outside the thermal envelope of the building, it is the supply and extract ducts that are subject to heat transfer, whereas in the case of an MVHR unit inside the thermal envelope, it is the intake and exhaust ducts that are subject to heat transfer (see Figure 1).

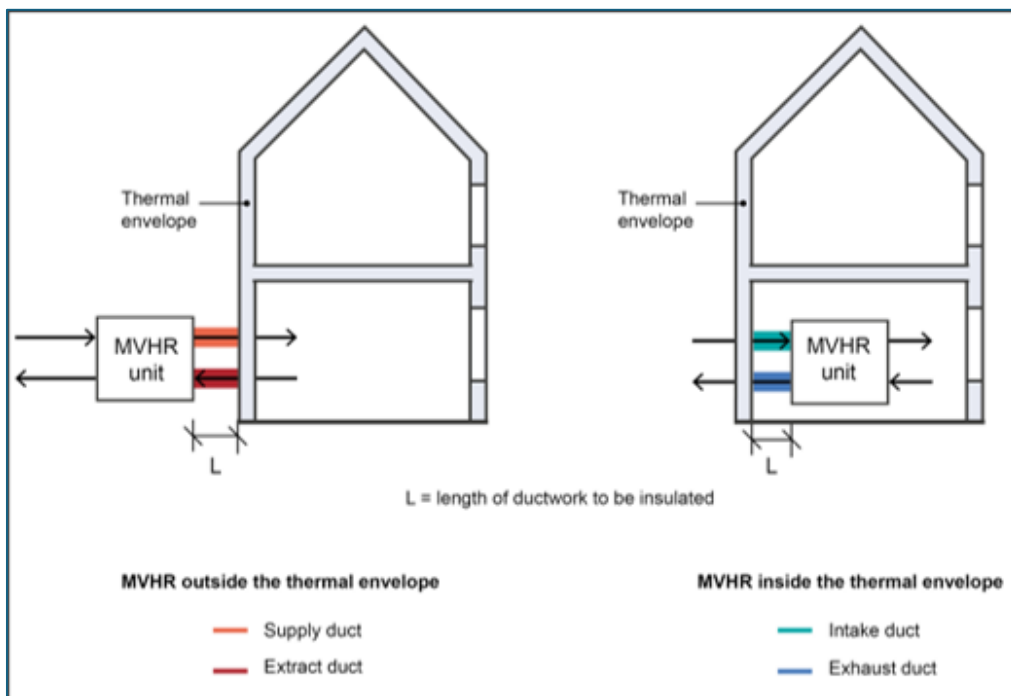


Figure 1 – The section of duct that needs to be insulated depends on the location of the MVHR unit. The length of insulated ducts subject to internal to external temperature difference should be entered in the HEM.

Energy consumption by fans is also calculated (see section 7. *Mechanical ventilation electricity consumption*) and for MVHR it is assumed that half of this energy adds to internal gains in the dwelling. This is based on the following assumptions:

- Energy consumed by fans supplying air to the dwelling heats the incoming air and therefore contributes to internal gains, while the energy consumed by fans extracting air from the building is exhausted along with the extracted air
- Energy consumption by fans is divided equally (half each) between the supply and extract fans.

5. Ventilation – Windows

HEM expects the entry of window dimensions as a whole, and additionally any openable areas. Each openable window part is treated as an individual air flow path where the air flow rate for each window part, delimited by a division, is calculated at each timestep. While not explicitly mentioned, an assumption has been inferred from equations that use window divisions and parts in BS EN 16798-7:2017 and the *Demo EN 16798-7/ Natural vent excel spreadsheet from EPC Centre* that the number of window divisions is always one less than the number of window parts.

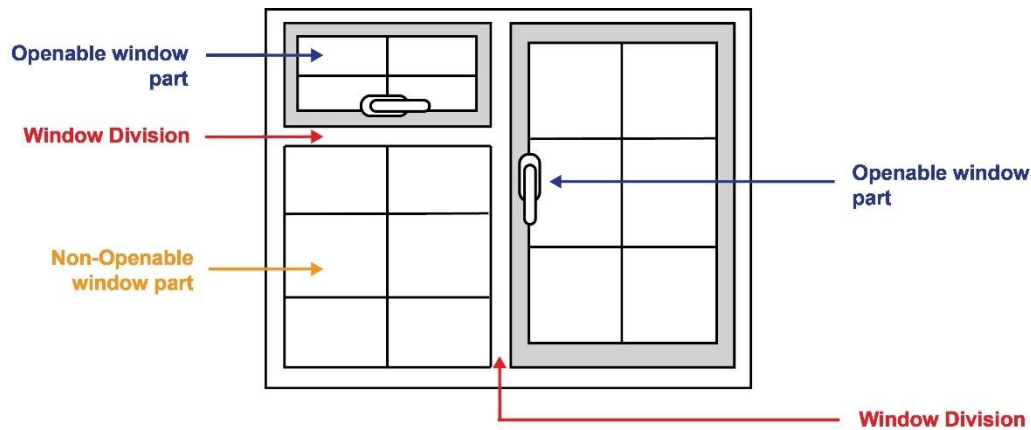


Figure 2 – An example window configuration, highlighting various components relevant to airflow and ventilation calculations.

The method for calculating the airflow rate for each window part is described in the section *Methodology*

1. **Overview** in this document, and proportional to the ratio of window opening (how open the window is). The value for the ratio of window opening is a value between zero (fully closed) and one (fully open) which is the ratio of the window's free area in the current timestep to the window's maximum free area. A larger window opening ratio allows for more air to enter or exit the dwelling. Note that the window opening ratio is an input to the ventilation calculation, which may be run more than once, with different values for this input. To understand how this fits into the overall calculation of air change rate and cooling demand, see HEM-TP-01 and HEM-TP-04 respectively.

5.1 Window opening adjustment

If no window opening is assumed, HEM calculates very high indoor temperatures during the summer under certain circumstances. *Section 8. Additional summer ventilation to avoid overheating in HEM-TP-04 Space heating and cooling demand* describes how HEM incorporates an additional algorithm to model the impact of window opening in response to high indoor temperatures.

Note there are also two window control schedules, one for adjustability and one for openability:

- **Adjustability:** This is a schedule of window opening setpoints. If the value is null for a given timestep, this means that the windows are not adjustable, and the assumption is that windows are closed if not adjustable (see Future development section for suggested improvements to this assumption). This control schedule is defined on a whole-dwelling basis.
- **Openability:** This is a simple Boolean schedule which defines whether the window can be opened or not. This control schedule is defined separately for each window.

Furthermore, due to the whole dwelling model used for ventilation instead of using thermal zones, there is additional logic laid out in section 2.2. *Space heating and cooling calculation structure*, step 5. in *HEM-TP-01 General summary of core calculation*.

6. Calculation of ventilation and infiltration heat loss

The total air change rate calculated from solving the mass balance equation is used in the calculation of the ventilation heat loss coefficient which is a variable in the zone balance equations (see *HEM-TP-04 Space heating and cooling demand*):

$$q_v = \frac{\text{air changes per hour} \times \text{zone volume}}{3600}$$

$$h_{ve} = \rho_{air} \times c_{air} \times q_v$$

Equation 16 – Ventilation heat loss coefficient

Where:

- q_v is the air flow rate in m³/s
- 3600 is the number of seconds in an hour.
- h_{ve} is the ventilation heat loss coefficient (a variable in the zone heat balance equations, see *HEM-TP-04*) in W/K.
- ρ_{air} is the density of air in kg/m³.
- c_{air} is the heat capacity of air in J/(kg.K).

Note that the ventilation heat loss coefficient (h_{ve}) is calculated for each timestep, as it depends on the air change rate calculated at each timestep.

7. Mechanical ventilation electricity consumption

In the case of mechanical ventilation systems, when fans are running, they are assumed to run at a single energy consumption rate determined by their specific fan power. We note that this may not reflect mechanical ventilation systems with more sophisticated control arrangements.

Then HEM calculation software does not apply any adjustments to account for in-situ differences in specific fan power. The specific fan power input should reflect the specific fan power expected for the specific installation (with the specific ductwork arrangement installed etc.) rather than an idealised scenario. Therefore, any adjustments required to the specific fan power must be made before entering it into the model.

Future development

The currently assumed distribution of leaks (Table 4) does not account for differences in the sheltering of different orientations e.g. it does not differentiate between external walls and party walls. This could lead to excessive heat losses for some typologies (e.g. flats or houses which have facades that are backed by another flat, building or structure) and may be an excessive simplification, particularly for a half-hourly model. Additional functionality is planned to apportion leaks to specific exposed façades (rather than dynamically placing them relative to wind direction) based on each façade's contribution to the total exposed area of the ventilation zone. This would mean that infiltration would e.g. reduce in timesteps where the windward and/or leeward façades are not exposed.

In addition, HEM may in future amend the infiltration pressure test result, based on empirical research showing it can exaggerate the level of infiltration when performed on dwellings with significant party wall area (such as mid-terraces and flats). A correction factor would be added based on the proportion of envelope area which faces other occupied volumes.

Passive and hybrid ducts (including chimneys) are currently not modelled in HEM, and BS EN 16798-7:2017 section 6.4.3.3.3 does not specify how to calculate the pressure losses in ductwork, simply stating "*A method can be defined at national level to calculate the pressure drop through the ductwork*". Without a method for calculating this, the implicit formula in section 6.4.3.3.5 equation 30, cannot be solved. Therefore, in order to model passive and hybrid ducts in HEM a solution from outside the standard will be needed (development of this is ongoing).

While the additional ventilation from combustion appliances can be calculated from BS EN 16798-7:2017, heating from these appliances is not currently modelled and therefore until such aspects of combustion appliances can be modelled, they are not yet included in the ventilation calculation.

Positive input ventilation (where air is drawn into the dwelling from the exterior or loft space, but not actively extracted), is planned to be added to HEM in a future update.

HEM assumes that, when applying the vent opening logic, all vents are adjustable when in reality, this is not always the case. Future iterations of HEM could be updated to allow the specification of vents which are not adjustable, which would then be treated as fixed openings and excluded from the vent adjustments described in section 3.1 *Vent adjustment*.

HEM treats null values in the 'Adjustability' control schedule, for the window opening and closing logic, as causing windows to close if not adjustable. This could be modified in future versions of HEM so that this instead causes the windows to be left in the same position that they were in the previous timestep.

