Ventilation of the Cavities in Timber Framed Walls
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Summary

This report reviews the available guidance on the need to ventilate the cavity between the cladding and the sheathing of timber framed walls. In the UK at present there is a division between the Scottish and Northern Ireland Building Regulations which say that perpend ventilators should be installed at the top and bottom of a wall, and the English and Wales Regulations, BS520 and NHBC and TRAD recommendations, which say that ventilators are needed only at the bottom.

If ventilators are installed at top and bottom, it is possible that a wall could be considered ‘slightly ventilated’ in BS EN ISO 6946, this would mean that the thermal resistance of normal cavities would be halved when U-values are calculated, and the thermal benefits of low emissivity breather membranes eliminated.

The material collected and the analysis in this report has demonstrated that there is very little information about the ventilation and airflow likely in the wall cavities of ‘real’ houses. No work at all seems to have been carried out on walls with brick claddings. Some work on timber claddings in test rigs and environmental chambers in Scandinavia and North America suggests that wet walls will dry faster when ventilated, however the benefits of ventilation to dry walls may be limited.

Modelling of the risks of interstitial condensation and the drying rates of wet walls using severe UK conditions shows that, when the ventilation of a cavity is increased from zero up to a level where there is no further change:

If no VCL is present, ventilating the cavity will not affect the risk of severe interstitial condensation.

If an incomplete VCL is present, ventilating the cavity behind brick cladding will reduce the amount of condensation, however ventilating the cavity behind timber cladding will make little difference.

If there is a complete VCL, there will be no condensation whether the cavity is ventilated or not.

Wet sheathing behind brick cladding will dry faster if the cavity is ventilated; ventilation does not increase the drying rate of wet sheathing behind timber cladding.
If there are no rain impacts on external walls, the moisture content of external cladding is determined by the ambient relative humidity and is little affected by ventilating the cavity.

Cladding that has been wetted by rain impacts, will dry slightly faster if the cavity is ventilated, however the difference is not dramatic.

Although it is not known what the ventilation rates in wall cavities in real buildings actually are, the values needed to make a difference in behind brick cladding, ~ 10 ach, imply such small air speeds, ~ .003 m/s, that it is difficult to envisage that they would not be achieved in practice even with ventilators only at the base of the wall.

At present the following recommendations could be suggested.

With brick cladding:

It is necessary to install ventilators only at the base of the wall.

However, if there is any reason to believe that the wall is at high risk of moisture damage; either from the interior if it has a high internal moisture load, or from the outside, if it is in an area of very severe driving rain, ventilators at the top and bottom will give extra protection.

With timber cladding

Ventilation at the base alone will be sufficient in areas which are not exposed to high levels of driving rain. Ventilators top and bottom should be installed in highly exposed areas.
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1 Introduction

There is currently a difference between the Scottish and English requirements/recommendations for ventilation of the cavity between the sheathing and cladding in timber framed walls. This difference extends to other important guidance documents, BS5250:2002 and BR262 (the relevant sections of each document are contained in Section 3). The guidance is:

the SBSA Domestic Technical Handbook and BR262 both recommend a ventilated cavity

Approved Document C and BS5250:2002 both recommend a vented cavity

The difference between these two types of cavity is defined in BS5250:2002:

3.30 vented air space: cavity or void that has openings to the outside air placed so as to allow some limited, but not necessarily through, movement of air

3.31 ventilated air space: cavity or void that has openings to the outside air placed so as to promote through movement of air

Ventilation of the cavity has benefits in reducing the risk of moisture damage within a wall, as a result of either interstitial condensation or rain penetration. However the thermal resistance of a ventilated cavity is considered to be lower than an unventilated cavity, especially if low emissivity materials are used. This reduction in resistance can be sufficient to raise the wall U-value over the threshold required by regulations.

This report discusses the role of ventilation within the cavities of timber framed walls, reviews the current guidance and the information available from Europe and North America. It presents the results of a model of heat and mass transfer within timber framed walls which has been used to analyze the effect of cavity ventilation on the risk of condensation and the potential for wet structures to dry.

Little information is available on the actual ventilation rates found in the wall cavities of real buildings. Some measurements have been carried out in test rigs in environmental chambers, however it is extremely dubious whether these are at all representative of conditions in reality.
2 Timber Framed Walls

2.1 Structure and composition

A timber framed wall consists of a number of layers, from the inside:

- the internal lining, usually plasterboard,
- a vapour control layer (VCL) which should be complete, and as airtight as possible; this can be a polythene sheet, with overlaps, between the insulation and plasterboard, or foil backed plasterboard with taped joints;
- insulation, usually mineral wool, between the studs;
- sheathing plywood or OSB;
- a breather membrane, which allows water vapour to diffuse through, but which repels liquid water;
- the cavity;
- the external cladding which is usually either brick or timber boarding.

In recent years, in a relatively small number of buildings, the sheathing has been replaced by cross bracing. This will effectively eliminate any interstitial condensation risks, but not affect the possibility of damage from moisture ingress. As this type of wall is uncommon and is at no greater risk of moisture damage, it will not be considered separately.

As the structural components, the studs and sheathing, are of timber which is vulnerable to decay it is necessary to protect them from water, which could come from interstitial condensation or rain ingress from the outside.

2.2 Interstitial condensation

The thermal resistance ($R_t$) and vapour resistance ($R_v$) of each of the layers of a typical timber framed wall, with brick cladding, assuming that the VCL is absent or bypassed, are shown in Table 1.

<table>
<thead>
<tr>
<th>Description</th>
<th>$D$</th>
<th>$\lambda$</th>
<th>$R_v$</th>
<th>$R_t$</th>
<th>$R_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside - Rsi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.130</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>12</td>
<td>0.167</td>
<td>45.0</td>
<td>0.072</td>
<td>0.54</td>
</tr>
<tr>
<td>VCL*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Glassfibre</td>
<td>100</td>
<td>0.040</td>
<td>10.0</td>
<td>2.500</td>
<td>1.0</td>
</tr>
<tr>
<td>Plywood sheathing</td>
<td>12</td>
<td>0.143</td>
<td>450</td>
<td>0.084</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Table 1 - Thermal and moisture properties of timber framed wall with ineffective VCL
*Thin membranes are assumed to have no thermal resistance and a vapour resistance defined directly rather than calculated from the resistivity and thickness.

In the absence of a VCL, the highest vapour resistance layer, the sheathing, is on the cold side of the highest thermal resistance layer, the insulation – see the highlighted layers in Table 1. If the VCL is perfect, no condensation will occur. Alternatively, if the VCL is omitted or bypassed by major gaps, severe interstitial condensation will occur on the relatively impermeable sheathing plywood. In practice the true situation will lie somewhere between these extremes, with small gaps in the VCL allowing some water vapour to reach the sheathing. This will diffuse through the sheathing and breather membrane, into the cavity and thence to the outside by a combination of diffusion through the outer cladding and convection, provided there is some air movement through the cavity. The accumulation and evaporation of condensate on the sheathing will depend on the balance between thermal and vapour properties of the materials and the degree of air motion through the cavity.

It is important to note that, if warm moist air can move from the inside of the house through the structure to the outside there will be very severe condensation within the wall. Although the inner lining will not be airtight, unless a perfect VCL has been installed, the sheathing can be assumed to be reasonably air tight, limiting air transport through the wall.

Table 2 shows the percentage of the thermal and vapour resistance that is outside the cavity for three cases: with brick cladding and no VCL, with timber cladding and no VCL and with timber cladding and a complete VCL. With both cladding types, over 90% of the thermal resistance of the wall is inside the cavity. With timber cladding in the absence of a VCL, 90% of the vapour resistance is inside the cavity; with an intact VCL this rises to over 99%. Also shown in the table are the temperature and vapour pressure in an unventilated cavity, calculated assuming 20°C/60% RH inside and 0°C/95%RH outside. With no VCL, condensation occurring on the sheathing limits the amount of water vapour reaching the cavity.

With timber cladding the conditions inside an unventilated cavity are very close to outside, suggesting that cavity ventilation will not make a dramatic difference to the cavity environment.
Table 2 – Percentage of thermal and vapour resistance outside cavity and temperature and vapour pressure in an unventilated cavity assuming 20°C/60% indoors and 0°C/95% outside – condensation occurring on sheathing when no VCL

<table>
<thead>
<tr>
<th></th>
<th>Brick No VCL</th>
<th>Timber No VCL</th>
<th>Timber VCL= 200MNs/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of total thermal resistance outside cavity</td>
<td>8.5</td>
<td>5.8</td>
<td>5.8</td>
</tr>
<tr>
<td>% of total vapour resistance outside cavity</td>
<td>42.3</td>
<td>9.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Cavity temperature: °C</td>
<td>1.7</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Cavity vapour pressure: Pa</td>
<td>660</td>
<td>600</td>
<td>583</td>
</tr>
<tr>
<td>External temperature and VP</td>
<td>0/580</td>
<td>0/580</td>
<td>0/580</td>
</tr>
</tbody>
</table>

2.3 Rain penetration

Most cladding systems allow some driving rain to enter the cavity, through the mortar joints between the brickwork or around the laps of boarding. This will usually run down the inner face of the cladding and be drained at the bottom, however in very high winds water can be sprayed across the cavity onto the breather membrane, which should prevent the water from reaching the sheathing ply. Also if a house is exposed to heavy driving rain during construction, before the breather membrane and cladding are installed, the sheathing may absorb large amounts of water.

2.4 Ventilation

Some degree of air movement within the cavity of a timber framed wall may be necessary to aid the evaporation of any water that wets the sheathing plywood from inside or outside. In a ventilated cavity, as defined in BS5250, with openings at top and bottom, there will be a continuous stream of air through the cavity that will allow more rapid drying than in a vented cavity in which air is moving in and out through one opening.

The important question is how much air movement is necessary in any situation? It is possible to say that there should be more air movement in:

- buildings with totally impermeable claddings;
- buildings in areas exposed to high levels of driving rain;
- buildings exposed to high internal humidities.
However little specific information is available on the need for ventilation in the cavities of ‘normal’ timber framed houses in typical urban or suburban situations.
3  Current Guidance

The sections below summarize the guidance on the provision of ventilation in the cavities of timber framed walls available from various sources within the UK.

3.1  SBSA Domestic Technical Handbook

3.10.5 Wall constructions (framed)

Framed wall of timber studs and dwangs, with a vapour permeable sheathing to the framing covered with a breather membrane. Masonry external cladding of 100 mm thick clay brick or block, concrete or calcium silicate brick or block, dense in-situ concrete, lightweight concrete or autoclaved aerated concrete, with an externally ventilated cavity of 50 mm but not more than 100 mm wide between the cladding and the framing, the cavity ventilated to the outside by means of one open perpend joint for at least every 1.2 m run at the top and bottom of the wall. Masonry cladding rendered or unrendered externally. Insulation applied as an infill to the framing. The framing lined internally with a vapour control layer and plasterboard.

3.2  Approved Document C 2004

Framed external walls

5.17 Any framed external wall will meet the requirement if the cladding is separated from the insulation or sheathing by a vented and drained cavity with a membrane that is vapour open, but resists the passage of liquid water, on the inside of the cavity (see Diagram 11).
3.3 Northern Ireland Technical Booklet C

2.6 Framed walls

(a) Framed wall of timber studs and noggings with a vapour permeable sheathing material over the framing and covered with a breather membrane having a vapour resistance of not more than 0.6 MNs/g.

Masonry external leaf at least 100 mm thick of bricks or blocks of clay, calcium silicate, concrete or cast stone, with a ventilated cavity between the cladding and sheathing material.

The cavity shall be uniform in width and shall be not less than 50 mm wide and not greater than 100 mm wide. The cavity shall be ventilated by means of open perpend joints at the top and bottom of the wall. There shall be at least one open perpend joint for every 1.2 m length of wall.

External render optional.

Glass or rock fibre insulation applied as an infill to the framing.

Internal finish of plasterboard on a vapour control layer of at least 125 μm (500 gauge) polyethylene

3.4 BS5250:2002 Code of practice for control of condensation in buildings

Definitions

3.30 vented air space
cavity or void that has openings to the outside air placed so as to allow some limited, but not necessarily through, movement of air

3.31 ventilated air space
cavity or void that has openings to the outside air placed so as to promote through movement of air

8.3.5 Timber framed walls
Because of the risk of interstitial condensation occurring on the inner surface of the cladding, it is essential that the construction be vented, preferably by a cavity. If the cladding is of high vapour resistance material, e.g. metal or plastic, a
drained cavity is essential. Where the cladding also functions as the sheathing, a vented airspace is recommended. If this is not possible, the cladding should have as low a vapour resistance as possible or have open joints at horizontal laps.

3.5 BR262 – Thermal Insulation Avoiding risks

3.20(f) Ensure that a clear cavity is maintained behind the cladding and that it is drained and ventilated (Figure 42).

3.6 NHBC

NHBC Standards up to 1992 (Practice Note 5 - on designing timber framed buildings) recommended ventilation of the cavity between the sheathing and cladding at both high and low level.

In 1992 Practice Note 5 was made into Chapter 6.2 - 'External timber framed walls' and at the same time the wording was amended to say, 'the cavity should be ventilated although it is not necessary to provide through ventilation. Where wall areas are divided by horizontal cavity barriers ventilation openings should be provided to each section, preferably at the top, although it may be
aesthetically preferable to place the lowest ventilation slots below the lowest timber.'

At the time of Practice Note 5 the England & Wales Building Regulations required a fire barrier at each floor level. Timber framed buildings were basically two storey and therefore had one barrier at first floor level. The cavity ventilation at both high level (eaves) and low level (DPC) meant that each cavity, above and below the horizontal cavity barrier, was vented at either high or low level but not both levels.

When the England & Wales Building Regulations dropped the requirement for horizontal cavity barriers at intermediate floor level the ventilation requirements was clarified by stating the (enlarged) cavity still only requires venting at one level not both.

3.7 TRADA

Chapter 9 of the TRADA guide to walling\(^5\), which covers cladding, states that the cavity should be vented, as opposed to ventilated, and recommends that that advice in regulations or from guarantors should be followed. They feel that in one or two storey housing, the top of the cavity will not be sealed so that ventilators only at the base will allow a through flow of air.

3.8 Summary

The majority opinion is that ventilators are necessary only at the base of walls, with the Scottish and Northern Irish Regulations standing out from the rest in requiring ventilators top and bottom. The decision to include this requirement was made in the late 1980s, when BRE was preparing the first draft of Thermal Insulation: Avoiding Risks, BR262, which recommended ventilators top and bottom. This document was designed to contain best practice, ‘belt and braces’ advice to be followed by anyone wishing to avoid any problems as insulation levels were increased. The guidance was not therefore subject to the same cost effectiveness considerations as might go into decisions to include issues in the Building Regulations. However when the relevant sections of the Scottish and Northern Ireland Regulations were being drafted at the time, it was felt that this point was worth including. It seems that the feeling was that, while including ventilators top and bottom would not cause any problems, and it might give added protection in some circumstances, no work was done to justify the need for this provision.
4 Ventilation of Cavities

4.1 Sources of ventilation

The cavity between the cladding and sheathing in a timber framed wall is about 50mm wide in the case of brick cladding, and somewhat narrower behind timber. Although the cavity extends the full height and width of the wall, horizontal fire barriers break up the cavity at each floor. If ventilation openings are provided at the top and bottom of the cavity air will move in and out of these driven by two forces.

Wind forces on a house set up a complex pattern of pressure differences over the external walls. Because the wind speed increases with height, when the wind is blowing more or less towards a wall the positive pressure at the top of the wall will be more than at the base, so air will flow in the upper and out of the lower ventilators. This flow will reverse if the wind is blowing along the wall, because the venturi effect will suck air out of the upper ventilators more than out of the lower ones. The distribution of pressures along a wall may reverse, so that flow is upwards at one end and downwards at the other. If the wind is on the other side of the house the relative flows will depend on the roof pitch and eaves overhang.

If the temperature of the air in the cavity is warmer than outside, air will flow in the lower ventilators and out the upper ones. In a wall built to the current insulation standards, the temperature difference from cavity to outside will be small in the winter, so the stack driven flows may be negligible. Flows may be more significant in the summer when solar gain could heat the cladding and cavity 10 - 20°C above the outside air.

If the cavity has ventilators at the base and is assumed to be totally sealed at the top, air movement will be much more limited. If the wind blows obliquely along a wall, there may be flow in through the ventilators at one end and out at the other. More significant flows will occur due to diurnal temperature changes; as the air in the cavity warms up during the day it will expand and move out of the ventilators and conversely move back in again as it cools and contracts overnight. This process has been defined as ‘venting’ in BS5250:2002, where it is distinguished from ‘ventilation’ which implies a through flow of air. Although air moves in this venting process only in and out of the ventilators at the base the wall, it will affect conditions in the whole cavity. Temperature differences between the sheathing and cladding caused by heat loss from the house in winter or solar gain in the summer lead to a circulation of air within the cavity, with air rising up the warmer side and falling on the colder side.

In practice it is unlikely that the top of a cavity is totally sealed so that even if ventilators are installed only at the base of a wall, there will still be some through flow of air through the cavity.
4.2 The air speeds associated with cavity ventilation

It is conventional to express ventilation rates of buildings in terms of air changes per hour (ach), the volume flow of air through the room in m$^3$/h divided by the room volume in m$^3$. Values in occupied rooms are typically about 0.5 to 1.5 ach and values in a ventilated loft about 5 – 10 ach. It is useful to translate this concept into the type of ventilation likely with a wall cavity.

Consider a square metre of wall with a cavity w metres wide. The volume of the cavity is w m$^3$, therefore if the flow of air through it is Q m$^3$/h, the ventilation rate is Q/w ach. The cross sectional area of the cavity is also w m$^2$ so that the flow speed of air through it is Q/w m/h. This means that the flow speed in m/h is equal to the ventilation rate in ach.

In other words the flow speeds needed to achieve reasonable ventilation rates will be extremely low; 20 ach requires only 20 m/h, or in more usual units, 20/3600 = 0.0055 m/s, a barely discernable movement of air. These very low flows are reasonable if we consider the parallel situation of ventilating a house by removing the front and back walls completely.

The alternative viewpoint is that reasonable air speeds will lead to very large ventilation rates. Studies in Denmark have measured 0.2 m/s in a wall cavity - see Section 5; this implies a ventilation rate of 720 ach.

4.3 Effect of cavity ventilation on the thermal performance of a wall

Heat transfer across cavities in buildings is a complex process, made up of a combination of conduction in still air, convection from air movement within the cavity and radiation between the cavity sides. For practical calculations of wall U-values it is assumed in BS EN ISO 6946:1997$^6$ and CIBSE Guide A3 that the heat transfer can be replaced by a standard thermal resistance, which depends on the direction of heat flow. For unventilated cavities with high emissivity surfaces and with horizontal heat flow, i.e. in walls, the standard resistance, for cavity widths between 25 and 100mm, is 0.18 m$^2$K/W (Table 2 of BS EN ISO 6946).

In this context it is important to consider what constitutes an unventilated or a ventilated cavity; BS EN ISO 6946 states:
An air layer having no insulation layer between it and the external environment but with small openings to the external environment shall also be considered as
an unventilated air layer, if these openings are not arranged so as to permit air flow through the layer and they do not exceed:
- 500 mm$^2$ per m length for vertical air layers
- 500 mm$^2$ per m$^2$ of surface area for horizontal air layers.

The standard defines a slightly ventilated cavity as:

A slightly ventilated air layer is one in which there is provision for limited air flow through it from the external environment by openings within the following ranges:
- > 500 mm$^2$ but < 1 500 mm$^2$ per m length for vertical air layers
- > 500 mm$^2$ but < 1 500 mm$^2$ per m$^2$ of surface area for horizontal air layers.

The design thermal resistance of a slightly ventilated air layer is one half of the corresponding value in Table 2.

Therefore if a wall cavity is considered to be slightly ventilated, the thermal resistance of the cavity is reduced from 0.18 m$^2$K/W to 0.09 m$^2$K/W. This could make a difference between meeting or not meeting the required U-value in marginal cases. This effect will be more important if the cavity has one low emissivity surface, such as the aluminised breather membranes that are currently being introduced. If the emissivity of one surface is less than 0.2 and the cavity is unventilated, the cavity resistance can be taken as 0.44 m$^2$K/W (or 0.31 m$^2$K/W if with one metal surface of unknown emissivity); this is a significant improvement over the high emissivity and can result in walls meeting the U-value requirement without the need to increase insulation and stud width. However if the cavity is slightly ventilated, its resistance falls back to 0.22 m$^2$K/W (or 0.16 m$^2$K/W for unknown emissivity) losing much of the benefit of the expensive, low emissivity membrane.

The effect of these changes on the U-value of a timber framed wall with brick or timber cladding calculated with the BRE U-value calculator is shown in Table 3. In each case it is assumed that the wall includes 140mm of insulation ($\lambda = 0.04$ W/mK), with a 15% timber fraction.

<table>
<thead>
<tr>
<th></th>
<th>High emissivity</th>
<th>Low emissivity</th>
<th>Emissivity $\leq$ 0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>102mm brick cladding</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unventilated cavity</td>
<td>0.301</td>
<td>0.289</td>
<td>0.278</td>
</tr>
<tr>
<td>Slightly ventilated cavity</td>
<td>0.310</td>
<td>0.303</td>
<td>0.298</td>
</tr>
<tr>
<td><strong>12mm timber cladding</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unventilated cavity</td>
<td>0.306</td>
<td>0.293</td>
<td>0.282</td>
</tr>
<tr>
<td>Slightly ventilated</td>
<td>0.315</td>
<td>0.308</td>
<td>0.302</td>
</tr>
</tbody>
</table>
Changing from an unventilated to a slightly ventilated cavity increases the U-value by 3% for high emissivity materials. This increase rises to over 7% if the emissivity of one surface is less than 0.2.

The cavity in a wall, built to the England & Wales requirements, with ventilators only at the bottom, would certainly be considered unventilated. If ventilators are installed to the current Scottish requirement, with: *the cavity ventilated to the outside by means of one open perpend joint for at least every 1.2 m run at the top and bottom of the wall.*, the degree of ventilation will depend on the size of the individual ventilators.

For the ventilators, installed top and bottom every 1.2 m, to be smaller than the BS6946 threshold of 500mm$^2$/m of wall, they must individually be smaller than $500 \times 1.2 / 2 = 300$mm$^2$. This is the same as a gap 5mm wide and 60mm high. Two manufacturers of ‘weepvents’ on the internet quote open sizes as 390mm$^2$ and 220mm$^2$ respectively. If the first of these were used, top and bottom, the wall should be regarded as slightly ventilated, if the second were used the wall could be regarded as unventilated. If no proprietary ventilators were used and it was assumed that each open perpend at top and bottom, every 1.2 m, was $10 \times 65$mm, this implies an area of $650 \times 2 / 1.2 = 1083$ mm$^2$/m of wall, so that the wall would certainly be classified as slightly ventilated.
Available information on cavity ventilation and its effects

Very little information is available on the degree of air movement through wall cavities in practice. An extensive literature search and contacts with building research organisations around the world has found no measurements of air movement behind brick claddings or studies of the performance of this type of wall. Some measurements of air flows behind timber claddings in test rigs, but not real buildings, have been carried out in North America and Scandinavia. A number of experiments have been carried out in test chambers to determine the drying rate of wet sheathing plywood, when air is blown through the cavity. These tests and their results are summarized below.

Measurements with tracer gas and hot wire anemometers in 25 mm cavities, open top and bottom, in a test rig in Denmark\(^7\) found air speeds in the range 0.12 – 0.22 m/s under light winds between 1 and 3 m/s. Moisture measurements in dry walls and in walls that had been deliberately wetted suggested that a wall that was very wet from, for example rain penetration or exposure to heavy rain during construction, would dry faster if it was ventilated. However, if a dry wall was ventilated the sheathing and cladding became wetter than in an unventilated wall, because of moist air entering at times when the wall was cold due to night sky radiation. This was confirmed by the development of a theoretical model.

Tests in an environmental chamber at Penn State University in the USA\(^8\) showed that blowing air through wetted wall assemblies increased the drying rate, but concluded that this would not necessarily apply in real buildings exposed to the outside air.

Detailed studies in test rigs exposed to the outside air at the University of Waterloo, Ontario\(^9\), demonstrated that deliberately wetted timber framed walls, with timber cladding, dried faster when ventilated than when unventilated. The role of ventilation in preventing water vapour being driven into the structure by solar gain in summer, was felt to be very important.

Tests in an environmental chamber at Tampere University in Finland\(^10\) investigated the effect of material permeability on the drying rate of wet sheathing and timber cladding. However ventilation was not investigated, though it was mentioned that this would affect the results.
6 Modelling the effects of cavity ventilation on moisture performance

6.1 Available models

To model the hygrothermal performance of a timber framed wall with a ventilated cavity between the cladding and the sheathing, it is necessary to take account of a number of effects:

A) conduction of heat and diffusion of moisture through the materials;

B) transport of heat and moisture through the structure by air movement from within the building to outside;

C) transport of heat and moisture from out of the cavity by air motion to the outside;

D) storage of heat and moisture within the materials.

Models are available which allow for some, but not all, of these effects:

BRECON, the BRE condensation prediction tool that was based on BS5250:1989 allows for A) and C); this has been extended to carry out hourly calculations over a year, forming a model called BRECON-Y.

ICOND, the BRE model which complies with BS5250:2002 and BS EN ISO 13788:2001 allows for only A).

MATCH and WUFI, the sophisticated non steady state models now available, allow for only A) and D).

ROOFCOND the roof condensation model developed in the recently completed Pil Project ‘Improved thermal and moisture performance of pitched roofs’ could be modified to apply to walls and would allow for A), B) and C) but not D).

To provide the best estimate of the effect of cavity ventilation on the risks of interstitial condensation and the drying potential of wet sheathing plywood, the following procedure was adopted:

BRECON-Y was used to calculate hourly values of the cavity temperature and vapour pressure and the condensation on the sheathing as a function of the cavity ventilation and the effective resistance of the VCL.

The calculated cavity temperature and vapour pressure were used as external boundary conditions in MATCH to investigate the drying rates of wet sheathing plywood as a function of cavity ventilation.

This involves a number of assumptions:

The external data were taken from the EU Test Reference Year (TRY) for Eskdalemuir. As this site is about 350 m above sea level in the Southern...
Uplands, it represents a much more severe climate than in most of the populated areas of Scotland. However, as the TRYs were developed for use in calculation of the long term energy use in buildings, they cover the mean conditions. A mean year at Eskdalemuir will be representative of a once in twenty years severe year at Aberdeen, which is more appropriate for studies of moisture damage.

The internal conditions are assumed to be constant at 20°C and 60% relative humidity all year. This imposes a severe moisture load on the wall, that could be thought typical of a poorly ventilated house occupied by a large family.

It is assumed for simplicity that the cavity ventilation rate is independent of the wind speed and temperature differences. In any case, as discussed in section 4.1, the variation of cavity ventilation with these driving forces is extremely complicated and not well understood.

As noted above, if there were movement of warm, humid air from the inside of the building through the structure to the outside, this would dominate heat and moisture transport and the formation of condensation. However, in a timber framed wall, even if, as is likely, the inner plasterboard lining and VCL are not air tight, the sheathing plywood and breather membrane, which are not penetrated by services will be. It has therefore been assumed that no air is flowing from the inside of the house to the cavity.

BRECON-Y assumes that there is no heat and moisture storage in the fabric of the wall. This is a reasonable assumption for a timber framed wall, where the mass of the components is relatively small compared to a masonry wall.

As noted in Section 5, little information about the actual ventilation rates or air flows in cavities is available. The modeling has therefore investigated the effect of varying the ventilation rate from zero up to a level where no more change is apparent.

### 6.2 BRECON-Y

The interstitial condensation prediction methods contained in both BS5250:1989 and in BS5250:2002 (by reference to BS EN ISO 13788:2001), are based on the same physical assumptions. The difference between them is that, while the 1989 method calculates only the accumulation over 60 days of winter weather and provides no guidance as to how to interpret the results, the 2002 version calculates the monthly accumulation and evaporation over a year and provides definite criteria for assessing the results.

The BRE package BRECON was based on the BS5250:1989 procedure, and was extended to include the effect of ventilating a cavity within the structure. This has been further extended to include the input of a year of hourly external temperatures and humidities, so that the hourly accumulation and evaporation of condensation can be calculated. Because, as noted above, it is based on the
same physics, this extended version could be considered to comply with BS EN ISO 13788:2001 and therefore with BS5250:2002. To produce a realistic picture of the accumulation and evaporation of condensate over a winter, the calculation starts at the beginning of July and proceeds until the end of June the next year.

As shown in the Appendix the temperature within the cavity can be determined by the balance between heat transfer by conduction from the inside of the house into the cavity (H_{in}) and the sum of heat transfer by conduction (H_{out}) and ventilation out of the cavity (H_{vent}). Similarly the cavity vapour pressure is determined by the balance between water vapour diffusing into the cavity (D_{in}) and that leaving by diffusion (D_{out}) and ventilation (D_{vent}) – see Figure 1.

This model is being extended to take account of evaporation of moisture from the wet cladding into the cavity.

\[
H_{in} = H_{out} + H_{vent}
\]
\[
D_{in} = D_{out} + D_{vent}
\]

**Figure 1 – Assumed heat and moisture flows into and out of the cavity of a timber framed wall**

The thermal resistance (R_t) and vapour resistance (R_v) of each of the layers of a typical timber framed wall, with either brick or timber cladding, assuming that the VCL is absent or bypassed, are shown in Table 4.

<table>
<thead>
<tr>
<th>Description</th>
<th>d (mm)</th>
<th>λ (W/m·K)</th>
<th>r_v (MN·s/g·m)</th>
<th>R_t (m²K/W)</th>
<th>R_v (MN·s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rsi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasterboard</td>
<td>12</td>
<td>0.167</td>
<td>45.0</td>
<td>0.072</td>
<td>0.54</td>
</tr>
<tr>
<td>VCL*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glassfibre</td>
<td>100</td>
<td>0.040</td>
<td>10.0</td>
<td>2.500</td>
<td>1.0</td>
</tr>
<tr>
<td>Plywood sheathing</td>
<td>12</td>
<td>0.143</td>
<td>450</td>
<td>0.084</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Breather membrane*  |  |  | 0.40
Cavity  | 50  |  | 0.180
Brick or Timber  | 102  | 0.752  | 50  | 0.136  | 5.1
Rse  | 0.25  | 60  | 0.048  | 0.72

*Thin membranes are assumed to have no thermal resistance and a vapour resistance defined directly rather than calculated from the resistivity and thickness.

In the absence of a VCL the highest vapour resistance layer, the sheathing, is on the cold side of the highest thermal resistance layer, the insulation. Condensation is likely on the inside of the sheathing.

6.2.1 Brick Cladding

As an example of the data output, Figure 2 shows the total accumulated condensate on the sheathing, in a wall with brick cladding, over the year, as a function of VCL vapour resistance, Rvb, assuming no ventilation in the cavity. The large amounts predicted with no VCL would not, of course, remain on the surface of plywood, most would run down, and some would soak in.

![Figure 2](image.png)

Figure 2 – Accumulated condensation on the sheathing of a wall with brick cladding as a function of the VCL vapour resistance in MNs/g assuming no cavity ventilation

Figure 3 shows the effect of increasing the cavity ventilation rate, Ncav, with no VCL present; there is a slight fall in peak condensate with a small amount of ventilation, but no further benefit as ventilation increases.
Figure 3 - Accumulated condensation on the sheathing of a wall with brick cladding as a function of the cavity ventilation rate assuming no VCL.

Figure 4 and Figure 5 summarize the condensation risks in a wall with brick cladding. Figure 4 shows the peak accumulation of condensate on the sheathing (the high point of the curves in Figure 2), as a function of cavity ventilation rate and VCL vapour resistance. Figure 5 shows the number of hours in each year when there is at least 20g/m² of condensate on the sheathing; this threshold has no particular significance, it is chosen to eliminate the large number of nights in summer when there are small amounts of condensate.
These figures show that, with brick cladding:

If there is no VCL, there will be severe condensation on the sheathing, as expected. Some ventilation to the cavity will lower the condensation accumulation and duration slightly, but more ventilation brings no further benefits. This is because, besides removing water vapour from the cavity, increasing the amount that can diffuse through the sheathing, ventilation of the cavity also cools the sheathing, increasing the potential for condensation.

If there is a partially complete VCL, the condensation accumulation is greatly reduced and ventilating the cavity provides some further reduction.

6.2.2 Timber Cladding

Timber cladding has both a lower thermal resistance and a lower vapour resistance than brick cladding – see Table 4. This means that the cavity and therefore the sheathing will be colder behind timber than behind brick cladding, but also there will be more possibility for water vapour to diffuse out of the system with timber cladding.

Figure 6 shows the calculated cavity temperatures and vapour pressures in walls with brick and timber cladding and with no VCL (Rvb=0) and with a partially
effective VCL (Rvb=10). Obviously the presence or absence of a VCL does not affect the cavity temperature. Temperatures are about 0.5°C colder in the cavity behind timber compared to brick cladding. Also, and very significantly, the cavity vapour pressure behind the timber is much lower than behind brick with no cavity ventilation. This means that, while the brick cavity vapour pressure falls rapidly as some ventilation is provided, there is little change in the timber cavity.

![Graph showing cavity temperature and vapour pressure](image)

**Figure 6 – Calculated annual mean cavity temperature and vapour pressure in walls with brick and timber cladding as a function of cavity ventilation rate with two VCL resistivities**

This difference between the two types is reinforced by Figure 7, which shows the annual condensate peak, in walls with no VCL and a partial VCL. As before 4000 has been subtracted from the condensate values when no VCL is present. This shows that in both cases, ventilating the cavity behind brick cladding does have some small effect, however ventilating a cavity behind timber cladding has virtually no effect on the condensation on sheathing behind timber cladding.
Figure 7 – Peak accumulation of condensate on the sheathing of walls with brick and timber cladding as a function of cavity ventilation rate and VCL resistance, Rvb, in MNs/g (values for Rvb= 0 reduced by 4000 to bring them onto scale)

The effect of cavity ventilation on condensation on the sheathing in walls with timber cladding is much less marked than with brick cladding. This finding, which tends to support the work done in Scandinavia and North America, is essentially because the relatively low vapour resistance of timber cladding, compared to brick, means that vapour pressures in the cavity are closer to outside even with no ventilation.

6.3 MATCH modelling

To investigate the effect of cavity ventilation on the moisture content of the sheathing plywood, a series of calculations were carried out using the advanced software MATCH. In this case the timber framed wall was truncated, by removing the external cladding, and hourly values of the cavity temperature and vapour pressure, calculated with BRECON-Y for different cavity ventilation rates, were used as the external boundary conditions. The solar gains normally included in MATCH calculations were turned off by setting the surface emissivity equal to zero and the reflectivity equal to one. The internal conditions were assumed to be equal to 20°C and 60% RH as before. No VCL was included in the wall in any of the simulations.

Two types of models were used:
A) Calculation of the “normal” sheathing moisture content over a year starting in July
B) Calculations of the rate of drying of saturated sheathing over two months starting in September.

Figure 8 shows the moisture content of the outer two mm of plywood behind brick cladding with cavity ventilation rates equal to 0, 10 and 30 ach. The sheathing is about 2% dryer with both ventilated cavities compared to the unventilated case.

![Figure 8 – Moisture content of the outer 2mm of sheathing plywood behind brick cladding with three cavity ventilation rates](image)

Figure 9 shows the moisture content of the inner two mm of the sheathing ply, which confirms the BRECON-Y results shown above; with no VCL there is severe condensation on the sheathing, ventilation of the cavity reduces the amount slightly but does not solve the problem.
Figure 9 – Moisture content of the inner 2mm of sheathing plywood behind brick cladding with three cavity ventilation rates

Figure 10 and Figure 11 show the same information for sheathing behind timber cladding. As might be expected from Figure 6, ventilating the cavity makes little difference to the sheathing moisture content.
Figure 11 - Moisture content of the inner 2mm of sheathing plywood behind timber cladding with three cavity ventilation rates

Figure 12 shows the effect of cavity ventilation on the drying rate of sheathing plywood that has been wetted to 50% moisture content behind brick cladding. Provision of cavity ventilation increases the drying rate and lowers the final moisture content.

Figure 12 – Drying of the outer 2mm of sheathing plywood behind brick cladding with and without cavity ventilation
Figure 13 shows the same information for sheathing behind timber cladding; as before cavity ventilation makes no difference to the drying rate or the final moisture content.

Figure 13 - Drying of the outer 2mm of sheathing plywood behind timber cladding with and without cavity ventilation
7 Effectiveness of ventilation for drying timber cladding

7.1 Without rain impacts
The moisture content of brick and especially timber cladding will depend much more on the outside temperature and humidity and impacts of driving rain than on moisture diffusing from the inside. In the absence of rain impacts the timber will settle to a moisture content determined by its hygroscopic properties and the presence of any surface coatings. Assuming, as a worst case that no surface coating is present, the moisture content will be similar to that shown in Figure 14. These curves, known as sorption isotherms have been measured using standardised methods for many types of material. While there are small variations with temperature, relative humidity is the main determining parameter.

![Figure 14 – Moisture content of softwood as a function of relative humidity at 20°C](image)

The monthly mean relative humidity in a cavity behind timber cladding, with no ventilation and with 50 ach is shown, together with the external relative humidity on Figure 15. Figure 16 shows timber moisture content calculated from the mean of the cavity and external relative humidity, using the curve shown in Figure 14.

This shows that, if rain impact is ignored, cavity ventilation will make little difference to the moisture content of timber cladding.
Figure 15 – Monthly mean external relative humidity and cavity relative humidity behind timber cladding, with no cavity ventilation and with cavity ventilation at 50 ach.

Figure 16 – Timber cladding moisture content with no cavity ventilation and with cavity ventilation at 50 ach.
7.2 With rain impacts
In the real world, especially in Scotland, there are significant impacts of driving rain on external walls. These will raise the cladding moisture content above the hygroscopic region shown in Figure 14. After any surface water has rapidly run off, the cladding will subsequently dry, by evaporation, to the hygroscopic moisture content corresponding to the ambient relative humidity.

The rate of evaporation and therefore drying will depend on:
- the moisture content of the timber;
- the humidity of the adjacent air, and
- the transfer of moisture through the surface boundary layer.

Ventilation will lower the cavity vapour pressure and increase the rate of evaporation. Also, increased air movement over the internal surface of the cladding will lower the surface resistance and promote evaporation. However, as discussed above, the velocities within ventilated cavities will be very small and may have a negligible effect on the evaporation. Values for the surface transfer coefficient are quoted as a function of air speed in CIBSE Guide A, however these are said to be invalid below 1 m/s and are designed to apply to external surfaces. Further work is needed in this area.

To provide an estimate of drying rates, MATCH was used to calculate the rate of drying of timber cladding that had been wetted to 40% moisture content, with unventilated and ventilated cavities, using the conditions from Figure 15, in January and June. The results, in Figure 17, show that ventilation does encourage slightly faster drying, however the difference is not dramatic.
Figure 17 – Drying of timber cladding after being wetted to 40% moisture content – with and without cavity ventilation in January and June

To assess the longer term performance of timber cladding, Figure 18, shows the daily moisture content over a year with a range of cavity ventilation rates from 0 to 200 ach. It is assumed that once every three months there is a severe episode of driving rain which instantaneously raises the cladding moisture content to 40%.
Figure 18 – Daily average timber cladding moisture content as a function of cavity ventilation rate assuming that there is a driving rain episode which raises the cladding moisture content to 40% once every three months

These results are summarised in Table 5 which shows the annual mean moisture content and the percentage of time that the moisture content is over 24%

Table 5 – Annual mean cladding moisture content and % of time moisture content is over 24%

<table>
<thead>
<tr>
<th>Ncav : ach</th>
<th>Annual mean moisture content %</th>
<th>% of time mc &gt;24%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24.3</td>
<td>33.4</td>
</tr>
<tr>
<td>50</td>
<td>23.4</td>
<td>28.5</td>
</tr>
<tr>
<td>100</td>
<td>23.3</td>
<td>27.1</td>
</tr>
<tr>
<td>150</td>
<td>23.3</td>
<td>27.4</td>
</tr>
<tr>
<td>200</td>
<td>23.4</td>
<td>27.4</td>
</tr>
</tbody>
</table>

Providing some limited ventilation lowers the moisture content slightly, however any further additional ventilation brings no further improvement.
8 Discussion and conclusions

The material collected and the analysis in this report has demonstrated that there is very little information about the ventilation and airflow likely in the wall cavities between the sheathing and cladding in timber framed walls in ’real’ houses. No work at all seems to have been carried out on walls with brick claddings. Some work on timber claddings in test rigs and environmental chambers in Scandinavia and North America suggests that wet walls will dry faster when ventilated, however the benefits of ventilation to dry walls may be limited.

Modelling of the risks of interstitial condensation and the drying rates of wet walls using severe UK conditions shows that, when the ventilation of a cavity is increased from zero up to a level where there is no further change:

If no VCL is present, ventilating the cavity will not affect the risk of severe interstitial condensation.

If an incomplete VCL is present, ventilating the cavity behind brick cladding will reduce the amount of condensation, however ventilating the cavity behind timber cladding will make little difference.

If there is a complete VCL, there will be no condensation whether the cavity is ventilated or not.

Wet sheathing behind brick cladding will dry faster if the cavity is ventilated; ventilation does not increase the drying rate of wet sheathing behind timber cladding.

If there are no rain impacts on external walls, the moisture content of external cladding is determined by the ambient relative humidity and is little affected by ventilating the cavity.

Cladding that has been wetted by rain impacts, will dry slightly faster if the cavity is ventilated, however the difference is not dramatic.

Although it is not known what the ventilation rates in wall cavities in real buildings actually are, the values needed to make a difference in behind brick cladding, ~ 10 ach, imply such small air speeds, ~ .003 m/s, that it is difficult to envisage that they would not be achieved in practice even with ventilators only at the base of the wall.

At present the following recommendations could be suggested.

With brick cladding:

It is necessary to install ventilators only at the base of the wall.
However, if there is any reason to believe that the wall is at very high risk of moisture damage, either from the interior if it has a high internal moisture load, or from the outside, if it is in an area of very severe driving rain, ventilators at the top and bottom will give extra protection.

With timber cladding

Ventilation at the base alone will be sufficient in areas which are not exposed to high levels of driving rain. Ventilators top and bottom should be installed in highly exposed areas.
BS5250:2002 British Standard Code of Practice for avoiding condensation in buildings, BSI 2002

BRE: Thermal Insulation avoiding risks  BRE Report BR262


Approved Document C 2004, Site preparation and resistance to contaminants and moisture, ODPM 2004

TRADA Guide to Timber framed Construction TRADA.


Kakela, P 2004, Drying rate of timber framed external wall structures in Nordic Climate

BS 5250 1989, British Standard Code of Practice for avoiding condensation in buildings, BSI 1989

1) BS EN ISO 13788 - Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods

2) BS EN ISO 12571:2000, Hygrothermal performance of building materials and products :Determination of hygroscopic sorption properties

Appendix - Background to BRECON-Y

Under steady state conditions the heat balance within a cavity which is ventilated to the outside air is made up of:
Conduction from the inside through the inner leaf =
Conduction to the outside through the outer leaf + Ventilation to the outside

or
\[
A \left( \frac{T_i - T_c}{R_{ri}} \right) = A \left( \frac{T_c - T_e}{R_{re}} \right) + Q \rho c (T_c - T_e) \tag{1}
\]

\(T_i\) is the internal air temperature in °C
\(T_e\) is the external air temperature in °C
\(T_c\) is the cavity air temperature in °C
\(R_{ri}\) is the thermal resistance from the inside to the ventilated cavity in m\(^2\)K/W
\(R_{re}\) is the thermal resistance from the ventilated cavity to outside in m\(^2\)K/W
\(A\) is the wall area in m\(^2\)
\(Q\) is the air flow rate through the cavity in m\(^3\)/s
\(\rho\) is the density of air in kg/m\(^3\)
\(c\) is the specific heat of air in J/kg°C

Similarly, the vapour balance is made up from:
Diffusion from the inside through the inner leaf =
Diffusion to the outside through the outer leaf + Ventilation to the outside

or
\[
A \left( \frac{p_i - p_c}{R_{vi}} \right) = A \left( \frac{p_c - p_e}{R_{ve}} \right) + Qk(p_c - p_e) \tag{2}
\]

where
\(p_i\) is the internal vapour pressure in Pa
\(p_e\) is the external vapour pressure in Pa
\(p_c\) is the cavity vapour pressure in Pa

\(R_{vi}\) is the vapour resistance from the inside to the ventilated cavity in Ns/g
\(R_{ve}\) is the thermal resistance from the ventilated cavity to outside in Ns/g
k is a constant relating vapour pressure in Pa to moisture content in g/m$^3$
k = 2.17/T$_k$, where T$_k$ is the absolute temperature of the air

When condensation is occurring on the inside of the sheathing, the vapour pressure at that point is then constrained to the SVP at the sheathing temperature, equation (2) then becomes:

$$A \left( \frac{ps(T_{sh}) - p_c}{R_{vi} - R_{vs}} \right) = A \left( \frac{p_c - p_e}{R_{ve}} \right) + Qk(p_c - p_e)$$ (3)

Where $ps(T_{sh})$ is the SVP at the sheathing temperature in Pa

$R_{vs}$ is the vapour resistance from the inside to the sheathing in Ns/g

Since $Q = nV$ and $A = V/w$ $Q = nwA$

where: $n$ is the ventilation of the cavity in air changes per second
$V$ is the volume of the cavity in m$^3$
$w$ is the width of the cavity in m

$$\left( \frac{T_i - T_c}{R_{ti}} \right) = \left( \frac{T_c - T_e}{R_{te}} \right) + nw\rho w(T_c - T_e)$$ (4)

and

$$\left( \frac{P_i - P_c}{R_{vi}} \right) = \left( \frac{P_c - P_e}{R_{ve}} \right) + nk(p_c - p_e)$$ (5)

or with condensation occurring:

$$\left( \frac{ps(T_{sh}) - p_c}{R_{vi} - R_{vs}} \right) = \left( \frac{p_c - p_e}{R_{ve}} \right) + nk(p_c - p_e)$$ (6)

giving the following equations for the temperature and vapour pressure in the cavity

$$T_c = \frac{T_i + Rd \left( \frac{1}{R_{ti}} + nw\rho w \right) T_e}{1 + Rd \left( \frac{1}{R_{te}} + nw\rho w \right)}$$ (8)
\[ P_c = \frac{P_e + R_v \left( \frac{1}{R_v} + nwk \right) P_e}{1 + R_v \left( \frac{1}{R_v} + nwk \right)} \]

(9)

or with condensation occurring

\[ P_c = \frac{p_s(T_{sh}) + (R_v - R_{vs}) \left( \frac{1}{R_{ve}} + nwk \right) P_e}{1 + (R_v - R_{vs}) \left( \frac{1}{R_{ve}} + nwk \right)} \]

(10)

The sheathing temperature \( T_{sh} \) and vapour pressure \( p_{sh} \) are given by

\[ T_{sh} = \frac{T_i (R_{ti} - R_{ts}) + R_{ts} T_c}{R_{ti}} \]

(11)

\[ p_{sh} = \frac{p_i (R_v - R_{vs}) + R_{vs} P_c}{R_{vi}} \]

(12)

\( R_{ts} \) is the thermal resistance from the inside to the sheathing in m\(^2\)K/W,
\( R_{vs} \) is the vapour resistance from the inside to the sheathing in Ns/g.