

$$\sin \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \dots$$

ATKINSON SCIENCE

$$e^{i\pi} = -1$$
$$\frac{u}{u_\tau} = \frac{1}{\kappa} \ln \frac{y u_\tau}{\nu} + C$$
$$E_b = \sigma T^4$$

THEORY GUIDE

Glaser Method

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13 October 2020

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1 Introduction

BS EN ISO 5250, Ref. [1], states that designers of buildings should assess the risk of surface condensation, mould growth and interstitial condensation using the methods described in BS EN ISO 13788, Ref. [2]. The assessment method for interstitial condensation in BS EN ISO 13788 is often referred to as the *Glaser* method. The movement of water vapour through a building component is assumed to be due to the diffusion of vapour through the stationary air contained in the open pores of the component. Important phenomena such as capillary suction and air movement are not considered. Nor are variations in material properties with moisture content or the hygroscopic moisture capacity of materials. Consequently, the method is limited to cases in which these phenomena can be considered negligible. The method should be regarded as an assessment tool, rather than an accurate prediction tool.

The method is based on monthly mean values of internal and external environmental conditions, and during each month the diffusion of vapour is assumed to have reached a steady state. Mean monthly external conditions should be derived using the methods described in BS EN ISO 15927-1, Ref. [3] or in national standards. *CIBSE Guide A*, 2015, Ref. [4], gives mean monthly temperature and relative humidity values for three locations in the United Kingdom (*CIBSE Guide A*, 2015, Table 7.10, p. 7-14). In the UK the monthly mean internal temperature is usually taken to be fixed at 20°C. BS EN ISO 13788:2012 describes a method of determining the monthly mean internal humidity by categorising buildings into *climate classes* based on the likely amount of excess humidity in the building. The method is described in Section 6 of this report and also in *Climate Classes: Theory Guide*, 2020, Ref. [5], which can be downloaded from the Atkinson Science web site.

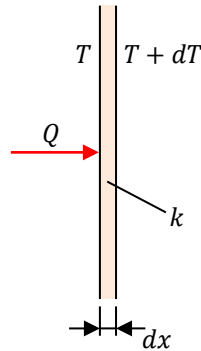
This guide begins by describing the principles of heat conduction and vapour diffusion and introduces the equations that are used in the Glaser method. It then presents a method of determining the internal relative humidity based on climate classes. The guide describes how condensation and evaporation are dealt with in the Glaser method and presents a number of sample calculations which show how the Glaser method is used to assess the risk of interstitial condensation.

2 Heat conduction

2.1 Steady one-dimensional heat conduction

We begin by considering the steady one-dimensional flow of heat flow through a plane layer of thickness dx , as shown in Figure 1.

Figure 1 Heat flow through a plane layer



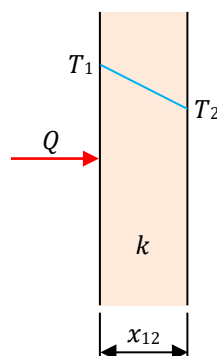
One face is maintained at temperature T [K] and the other at $T + dT$. We find that the rate of heat flow Q [W] is proportional to the area of flow A [m²] and to the temperature difference dT across the layer, and inversely proportional to dx [m]. We can write

$$Q = -kA \left(\frac{dT}{dx} \right) \quad (2.1)$$

which is *Fourier's law*. The negative sign occurs because the flow of heat is in the direction of decreasing temperature and k is assumed to be positive. The constant k [W m⁻¹ K⁻¹] is called the *thermal conductivity* of the material.

A wall is made up of successive plane layers. If k is constant and the heat flow through the wall is steady, then Q in each layer must be constant. From (2.1), (dT/dx) in each layer must also be constant and so the temperature profile is linear, as shown in Figure 2.

Figure 2 Heat flow through a wall



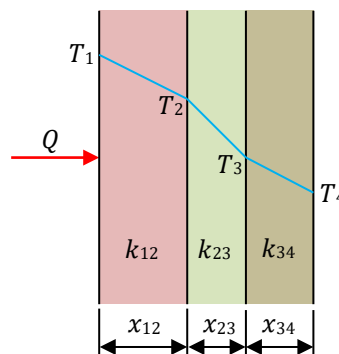
Integrating (2.1) gives the heat flow in terms of the surface temperatures T_1 and T_2 :

$$Q = -kA \frac{T_2 - T_1}{x_{12}} \quad (2.2)$$

2.2 Steady one-dimensional heat conduction through a composite wall

In buildings, walls may be made up of many different materials. Figure 3 shows a composite wall. The temperatures at the surfaces are T_1 and T_4 , and the temperatures at the interfaces are T_2 and T_3 .

Figure 3 Heat flow through a composite wall



If the heat flow is steady, then the heat flow through each slab must be the same and we can write

$$q = \frac{Q}{A} = -k_{12} \frac{T_2 - T_1}{x_{12}} = -k_{23} \frac{T_3 - T_2}{x_{23}} = -k_{34} \frac{T_4 - T_3}{x_{34}} \quad (2.3)$$

The temperature difference across the composite wall is

$$-(T_4 - T_1) = -(T_2 - T_1) - (T_3 - T_2) - (T_4 - T_3) \quad (2.4)$$

Substituting the heat flux equations (2.3) into the right-hand side of (2.4) gives

$$-(T_4 - T_1) = q \left(\frac{x_{12}}{k_{12}} + \frac{x_{23}}{k_{23}} + \frac{x_{34}}{k_{34}} \right) \quad (2.5)$$

Rearranging (2.5) gives a heat flow equation for the wall as a whole:

$$q = -U(T_4 - T_1) \quad (2.6)$$

where

$$\frac{1}{U} = \frac{x_{12}}{k_{12}} + \frac{x_{23}}{k_{23}} + \frac{x_{34}}{k_{34}} \quad (2.7)$$

U is the overall heat transfer coefficient or thermal transmittance of the wall.

In general, for any number of slabs the thermal transmittance is given by

$$\frac{1}{U} = \sum \frac{\Delta x}{k} \quad (2.8)$$

2.3 Boundary layers

On both sides of the wall there will be a thin layer of air which will provide resistance to heat flow. This thermal resistance is usually specified in terms of a convection heat transfer coefficient h [$\text{W m}^{-2} \text{K}^{-1}$]. When the resistance of the boundary layers is considered, the thermal transmittance of the wall is given by

$$\frac{1}{U} = \frac{1}{h_i} + \sum \frac{\Delta x}{k} + \frac{1}{h_e} \quad (2.9)$$

where h_i is the convection heat transfer coefficient on the internal surface of the wall and h_e is the coefficient on the external surface.

For an external wall, BS EN ISO 13788:2012 recommends $1/h_e = 0.04 \text{ K m}^2 \text{ W}^{-1}$; for an internal surface with the heat flow in the horizontal direction, BS EN ISO 13788:2012 recommends $1/h_i = 0.13 \text{ K m}^2 \text{ W}^{-1}$ (BS EN ISO 13788:2012, p. 6).

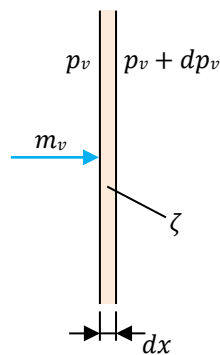
3 Vapour diffusion

3.1 Steady one-dimensional vapour diffusion

Most building materials have open pores containing moist air. If there is a difference in vapour concentration across the material, then vapour will diffuse through the air in the direction from high concentration to low concentration.

We begin by considering the steady one-dimensional diffusion of vapour through a plane layer of thickness dx , as shown in Figure 4.

Figure 4 Vapour diffusion through a plane layer



The mass flux of vapour is usually modelled by

$$m_v = -\frac{1}{10^6 \zeta} \frac{dp_v}{dx} \quad (3.1)$$

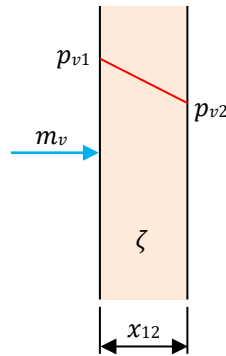
where m_v [$\text{g s}^{-1} \text{m}^{-2}$] is the mass flux (mass flow rate per unit area) of vapour, ζ [$\text{MN s g}^{-1} \text{m}^{-1}$] is the vapour resistivity, p_v [Pa] is the pressure of the vapour in the air-vapour mixture, and x [m] is the direction of diffusion. The negative sign occurs because the flow of vapour is in the direction of decreasing vapour pressure and ζ is assumed to be positive.

A wall is made up of successive plane layers. If ζ is constant and the flow of vapour through the wall is steady, then m_v in each layer must be constant. From (3.1), (dp_v/dx) in each layer must also be constant and so the vapour pressure profile is linear, as shown in Figure 5.

Integrating (3.1) gives the mass flow of vapour in terms of the surface vapour pressures p_{v1} and p_{v2} :

$$m_v = -\frac{1}{10^6 \zeta} \frac{p_{v2} - p_{v1}}{x_{12}} \quad (3.2)$$

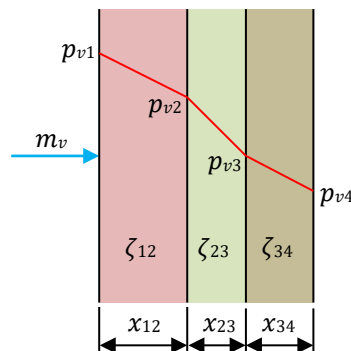
Figure 5 Vapour diffusion through a wall



3.2 Steady one-dimensional vapour diffusion through a composite wall

Figure 6 shows a composite wall. The vapour pressures at the surfaces are p_{v1} and p_{v4} , and the vapour pressures at the interfaces are p_{v2} and p_{v3} .

Figure 6 Vapour diffusion through a composite wall



If the mass flow of vapour is steady, then the mass flow through each slab must be the same and we can write

$$m_v = -\frac{1}{10^6 \zeta_{12}} \frac{p_{v2} - p_{v1}}{x_{12}} = -\frac{1}{10^6 \zeta_{23}} \frac{p_{v3} - p_{v2}}{x_{23}} = -\frac{1}{10^6 \zeta_{34}} \frac{p_{v4} - p_{v3}}{x_{34}} \quad (3.3)$$

The difference in vapour pressure across the composite wall is

$$-(p_{v4} - p_{v1}) = -(p_{v2} - p_{v1}) - (p_{v3} - p_{v2}) - (p_{v4} - p_{v3}) \quad (3.4)$$

Substituting the vapour flux equations (3.3) into the right-hand side of (3.4) gives

$$-(p_{v4} - p_{v1}) = m_v 10^6 (\zeta_{12} x_{12} + \zeta_{23} x_{23} + \zeta_{34} x_{34}) \quad (3.5)$$

Rearranging (3.5) gives a vapour flux equation for the wall as a whole:

$$m_v = -\frac{(p_{v4} - p_{v1})}{10^6 Z} \quad (3.6)$$

where

$$Z = \zeta_{12}x_{12} + \zeta_{23}x_{23} + \zeta_{34}x_{34} = z_{12} + z_{23} + z_{34} \quad (3.7)$$

The term z [MN s g^{-1}] for each slab in (2.7) is called the *vapour resistance* of the slab:

$$z = \zeta \Delta x \quad (3.8)$$

The sum of the terms Z [MN s g^{-1}] is called the *overall vapour resistance* of the wall.

In general, for any number of slabs the overall vapour resistance is

$$Z = \sum z = \sum \zeta \Delta x \quad (3.9)$$

Note that the vapour resistivity ζ is a property of the material of the slab, but the vapour resistance z depends on the thickness of the slab.

3.3 Boundary layers

By convention the vapour resistance of the boundary layers on each side of the wall is assumed to be zero.

4 Properties of materials

4.1 Air cavities

Air cavities can be categorised as ventilated or unventilated. The criteria to distinguish between the two types are set out in BS EN ISO 6946:2017, Ref. [6]. BS EN ISO 13788:2012 states that if the air cavity is well ventilated to the outside then no account should be taken of the materials between the air cavity and the outside; the inner face of the air cavity should become the external boundary (BS EN ISO 13788:2012, p. 10) and the convection heat transfer coefficient should be the value for an internal surface.

If the air cavity is unventilated then its thermal resistance ($\Delta x/k$ term in (2.9)) is given in Table 3.3, p. 3-6 of *CIBSE Guide A*, 2015.

Air cavities are assumed to have no vapour resistance (*CIBSE Guide A*, 2015, p. 7-18).

4.2 Membranes and foils

Membranes and foils are thin materials and they are usually classified by their vapour resistance z rather than by their thickness Δx and vapour resistivity ζ . Their thermal resistance ($\Delta x/k$ term in (2.9)) is usually taken to be zero.

Some materials such as metal foils effectively prevent the passage of water vapour and therefore have an infinite vapour resistance z . However, a finite value of z is required for each material in the calculation method. BS EN ISO 13788:2012, recommends using a vapour resistance factor $\mu (= \zeta_{Mat}/\zeta_{Air})$ of 100,000 (BS EN ISO 13788:2012, p. 10). In the United Kingdom the vapour resistivity of stationary air ζ_{Air} is taken to be $5 \text{ MN s g}^{-1} \text{ m}^{-1}$.

5 Relations for air-water vapour mixtures

The atmosphere is a mixture of air and water vapour. The atmospheric or barometric pressure is equal to the partial pressure of the dry air in the mixture and the partial pressure of the water vapour:

$$p = p_a + p_v \quad (6.1)$$

where p [Pa] is the atmospheric pressure, p_a [Pa] is the partial pressure of the dry air, and p_v [Pa] is the partial pressure of the water vapour. The partial pressure of the water vapour is often simply called the *vapour pressure*.

The *saturation vapour pressure* p_{vSat} [Pa] is the highest pressure that the water vapour can have before it becomes saturated and condensation begins. The saturation vapour pressure depends on the temperature of the vapour and thus the temperature of the mixture. *CIBSE Guide A*, 2015 gives the following approximate relations between the saturation vapour pressure and the temperature for use in calculations of surface and interstitial condensation:

$$T \geq 0 \quad p_{vSat} = 610.5 \text{ Exp} \left(\frac{17.269 \times T}{237.3 + T} \right) \quad (6.2)$$

$$T < 0 \quad p_{vSat} = 610.5 \text{ Exp} \left(\frac{21.875 \times T}{265.5 + T} \right) \quad (6.3)$$

The temperature T is in °C and p_{vSat} is in Pa. As the temperature falls the saturation vapour pressure falls and eventually the vapour in the mixture becomes saturated and condensation occurs. The temperature at which saturation occurs is known as the *dew point*.

Equations (6.2) and (6.3) can be inverted to give the *dew point* T_d [C] from the vapour pressure p_v [Pa]:

$$p_v \geq 610.5 \text{ Pa} \quad T_d = \frac{237.3 \ln \left(\frac{p_v}{610.5} \right)}{17.269 - \ln \left(\frac{p_v}{610.5} \right)} \quad (6.4)$$

$$p_v \geq 610.5 \text{ Pa} \quad T_d = \frac{265.5 \ln \left(\frac{p_v}{610.5} \right)}{21.875 - \ln \left(\frac{p_v}{610.5} \right)} \quad (6.5)$$

The relative humidity ϕ [%] is the ratio of the vapour pressure p_v [Pa] to the saturation vapour pressure p_{vSat} [Pa] at the same temperature, expressed as a percentage:

$$\phi = \frac{p_v}{p_{vSat}} \times 100\% \quad (6.6)$$

When ϕ is 100% the vapour is saturated and condensation occurs.

6 Environmental conditions

The Glaser method of calculating interstitial condensation is based on monthly mean values of internal and external environmental conditions. During each month the conduction of heat and diffusion of vapour is assumed to have reached a steady state. BS EN ISO 13788:2012 states that mean monthly external conditions should be derived using the methods described in BS EN ISO 15927-1 or in national standards. *CIBSE Guide A*, 2015 gives mean monthly temperature and relative humidity values for three locations in the United Kingdom (*CIBSE Guide A*, 2015, Table 7.10, p. 7-14). In the UK the monthly mean internal temperature is usually taken to be fixed at 20°C.

BS EN ISO 13788:2012 describes a method of determining the monthly mean internal humidity by categorising buildings into *climate classes* based on the likely amount of excess humidity in the building. The amount of moisture per unit volume in the space is assumed to be greater than that outside by $\Delta m_v/V$ [kg m⁻³], where Δm_v [kg] is the excess mass of moisture in the space and V [m³] is the volume of the space. The vapour pressure in the space will be greater than that outside by

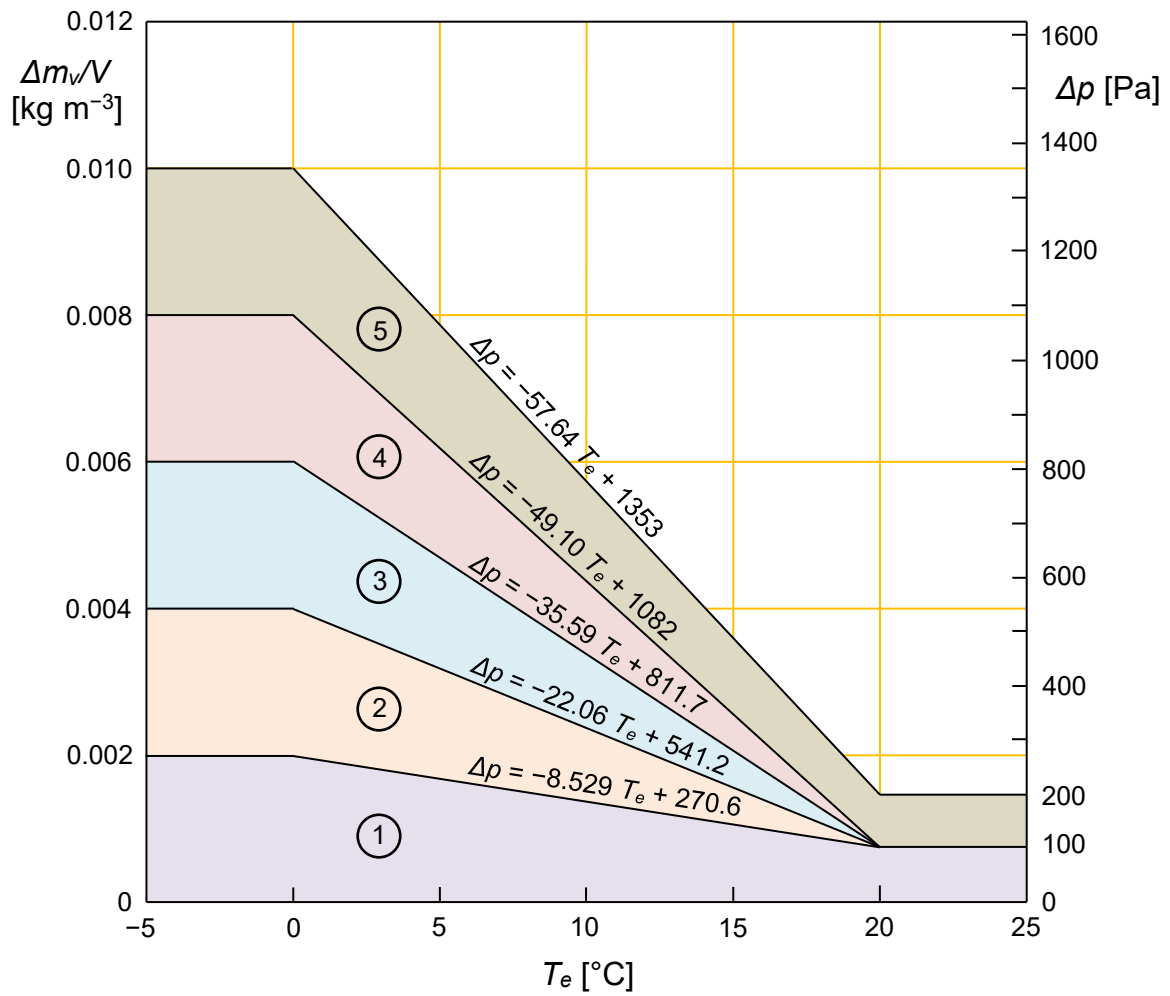
$$\Delta p_v [\text{Pa}] = p_{v i} - p_{v e} = \frac{\Delta m_v}{V} R_v T_i$$

where R_v is the specific gas constant for water vapour (= 461.5 J kg⁻¹ K⁻¹). Since $T_i = 20^\circ\text{C}$,

$$\Delta p_v [\text{Pa}] = \frac{\Delta m_v}{V} R_v T_i = 461.5 \times 293.15 \times \frac{\Delta m_v}{V} = 135290 \frac{\Delta m_v}{V}$$

The excess moisture is assumed to be related to occupancy. However, the method accounts for the likelihood that windows will be opened in summer when outside and inside temperatures are similar. The chart in Figure 7 gives the moisture excess $\Delta m_v/V$ [kg m⁻³] and the vapour pressure excess Δp_v [Pa] in terms of the climate class and the outside temperature T_e [°C].

Figure 7 Excess moisture in terms of climate class and outdoor temperature



BS EN ISO 13788:2012 gives examples of buildings in each climate class. These are reproduced in Table 1.

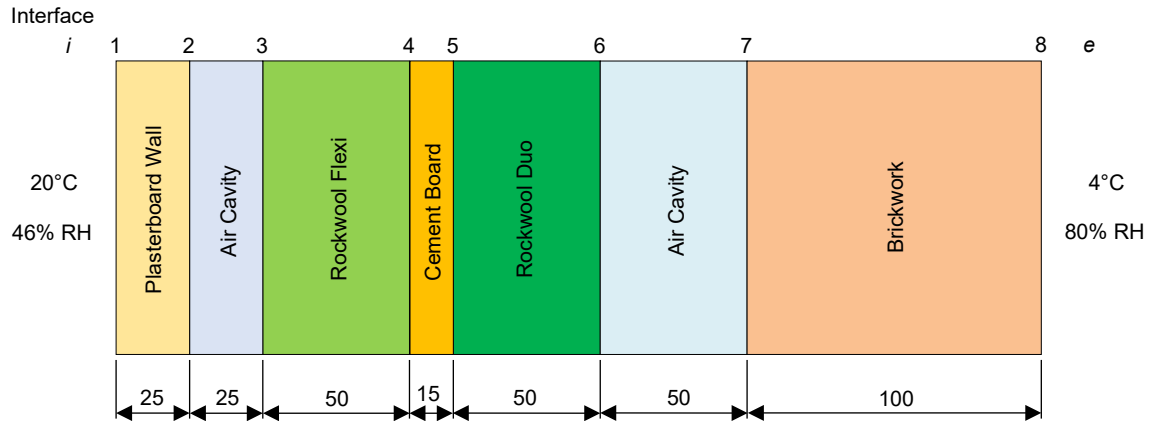
Table 1 Typical buildings in each climate class from BS EN ISO 13788:2012

Climate class	Building
1	Unoccupied buildings, storage of dry goods
2	Offices, dwellings with normal occupancy and ventilation
3	Buildings with unknown occupancy
4	Sports halls, kitchens, canteens
5	Special buildings, e.g. laundry, brewery, swimming pool

7 Example 1

The external wall of an apartment block is constructed as shown in Figure 8. Calculate the temperature, vapour pressure and saturation vapour pressure through the wall. Also calculate the heat flux and the mass flux of vapour through the wall.

Figure 8 External wall



The thickness, thermal conductivity and vapour resistivity of each slab in the wall are given in Table 2.

Table 2 Properties of materials

Slab	Δx [mm]	k [W m ⁻¹ K ⁻¹]	$\Delta x/k$ [K m ² W ⁻¹]	ζ [MN s g ⁻¹ m ⁻¹]
Plasterboard wall	25	0.21	-	60
Air cavity	25	-	0.18	0
Rockwool Flexi	50	0.038	-	5
Cement board	15	0.23	-	250
Rockwool Duo	50	0.035	-	5.9
Air cavity	50	-	0.18	0
Brickwork	100	0.84	-	23

Interface temperatures and heat flux

The overall heat transfer coefficient for the wall U is given by (2.9)

$$\begin{aligned} \frac{1}{U} &= \frac{1}{h_i} + \sum \frac{\Delta x}{k} + \frac{1}{h_e} \\ &= \frac{1}{7.7} + \frac{0.025}{0.21} + 0.18 + \frac{0.05}{0.038} + \frac{0.015}{0.23} + \frac{0.05}{0.035} + 0.18 + \frac{0.1}{0.84} + \frac{1}{25} \\ &= 3.578 \text{ m}^2 \text{ K W}^{-1} \end{aligned}$$

and so $U=0.2795 \text{ W m}^{-2} \text{ K}^{-1}$.

The heat flux q is

$$q = -U(T_e - T_i) = -0.2795 \times (4 - 20) = 4.472 \text{ W m}^{-2}$$

The heat flux through the boundary layers and the slabs is the same. For the internal boundary layer

$$q = -h_i(T_1 - T_i)$$

so

$$T_1 = T_i - \frac{q}{h_i} = 20 - \frac{4.472}{7.7} = 19.42^\circ\text{C}$$

Across the plasterboard

$$q = -k_{12} \frac{T_2 - T_1}{x_{12}}$$

so

$$T_2 = T_1 - q \frac{x_{12}}{k_{12}} = 19.42 - 4.472 \times \frac{0.025}{0.21} = 18.89^\circ\text{C}$$

Similarly, for the other slabs

$$T_3 = T_2 - q \frac{x_{23}}{k_{23}} = 18.89 - 4.472 \times 0.18 = 18.08^\circ\text{C}$$

$$T_4 = T_3 - q \frac{x_{34}}{k_{34}} = 18.08 - 4.472 \times \frac{0.05}{0.038} = 12.20^\circ\text{C}$$

$$T_5 = T_4 - q \frac{x_{45}}{k_{45}} = 12.20 - 4.472 \times \frac{0.015}{0.23} = 11.91^\circ\text{C}$$

$$T_6 = T_5 - q \frac{x_{56}}{k_{56}} = 11.91 - 4.472 \times \frac{0.05}{0.035} = 5.52^\circ\text{C}$$

$$T_7 = T_6 - q \frac{x_{67}}{k_{67}} = 5.49 - 4.472 \times 0.18 = 4.71^\circ\text{C}$$

$$T_8 = T_7 - q \frac{x_{78}}{k_{78}} = 4.71 - 4.472 \times \frac{0.1}{0.84} = 4.18^\circ\text{C}$$

For the external boundary layer

$$T_e = T_8 - \frac{q}{h_o} = 4.18 - \frac{4.472}{25} = 4^\circ\text{C}$$

as expected.

Interface saturation vapour pressures

The saturation vapour pressure at the interfaces can be calculated from (6.2). In the living space

$$p_{vSat\ i} = 610.5 \text{ Exp} \left(\frac{17.269 \times T_i}{237.3 + T_i} \right) = 610.5 \text{ Exp} \left(\frac{17.269 \times 20}{237.3 + 20} \right) = 2336.9 \text{ Pa}$$

Similarly, for the interfaces

$$T_1 = 19.42^\circ\text{C}, p_{vSat\ 1} = 2254.2 \text{ Pa}$$

$$T_2 = 18.89^\circ\text{C}, p_{vSat\ 2} = 2180.7 \text{ Pa}$$

$$T_3 = 18.08^\circ\text{C}, p_{vSat\ 3} = 2073.5 \text{ Pa}$$

$$T_4 = 12.20^\circ\text{C}, p_{vSat\ 4} = 1420.1 \text{ Pa}$$

$$T_5 = 11.91^\circ\text{C}, p_{vSat\ 5} = 1393.1 \text{ Pa}$$

$$T_6 = 5.52^\circ\text{C}, p_{vSat\ 6} = 903.8 \text{ Pa}$$

$$T_7 = 4.71^\circ\text{C}, p_{vSat\ 7} = 854.5 \text{ Pa}$$

$$T_8 = 4.18^\circ\text{C}, p_{vSat\ 8} = 823.1 \text{ Pa}$$

and outside

$$T_e = 4^\circ\text{C}, p_{vSat\ e} = 812.8 \text{ Pa}$$

Interface vapour pressures and vapour mass flux

The overall vapour resistance of the wall Z is given by (3.9)

$$\begin{aligned} Z &= \sum \zeta \Delta x \\ &= 60 \times 0.025 + 0 + 5 \times 0.05 + 250 \times 0.015 + 5.9 \times 0.05 + 0 + 23 \times 0.1 \\ &= 8.095 \text{ MN s g}^{-1} \end{aligned}$$

The vapour pressure in the living space $p_{v\ i}$ is

$$p_{v\ i} = \frac{\phi_i p_{vSat\ i}}{100} = \frac{46 \times 2336.9}{100} = 1075.0 \text{ Pa}$$

and the vapour pressure outside is

$$p_{v\ e} = \frac{\phi_e p_{vSat\ e}}{100} = \frac{80 \times 812.8}{100} = 650.2 \text{ Pa}$$

The vapour mass flux m_v is given by

$$m_v = -\frac{(p_{ve} - p_{vi})}{10^6 Z} = -\frac{650.2 - 1075.0}{10^6 \times 8.095} = 52.48 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1075.0 \text{ Pa}$$

The mass flux through each slab is the same and equal to m_v . Across the plasterboard

$$m_v = -\frac{1}{10^6 \zeta_{12}} \frac{p_{v2} - p_{v1}}{x_{12}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_v \zeta_{12} x_{12} \\ &= 1075.0 - 10^6 \times 52.48 \times 10^{-6} \times 60 \times 0.025 = 996.3 \text{ Pa} \end{aligned}$$

Similarly, for the other slabs

$$p_{v3} = p_{v2} - 10^6 m_v \zeta_{23} x_{23} = 996.3 - 10^6 \times 52.48 \times 10^{-6} \times 0 \times 0.025 = 996.3 \text{ Pa}$$

$$p_{v4} = p_{v3} - 10^6 m_v \zeta_{34} x_{34} = 996.3 - 10^6 \times 52.48 \times 10^{-6} \times 5 \times 0.05 = 983.2 \text{ Pa}$$

$$p_{v5} = p_{v4} - 10^6 m_v \zeta_{45} x_{45} = 983.2 - 10^6 \times 52.48 \times 10^{-6} \times 250 \times 0.015 = 786.4 \text{ Pa}$$

$$p_{v6} = p_{v5} - 10^6 m_v \zeta_{56} x_{56} = 786.4 - 10^6 \times 52.48 \times 10^{-6} \times 5.9 \times 0.05 = 770.9 \text{ Pa}$$

$$p_{v7} = p_{v6} - 10^6 m_v \zeta_{67} x_{67} = 770.9 - 10^6 \times 52.48 \times 10^{-6} \times 0 \times 0.05 = 770.9 \text{ Pa}$$

$$p_{v8} = p_{v7} - 10^6 m_v \zeta_{78} x_{78} = 770.9 - 10^6 \times 52.48 \times 10^{-6} \times 23 \times 0.1 = 650.2 \text{ Pa}$$

There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v8} = 650.2 \text{ Pa}$$

which is the value we expected.

The calculated values of T , p_{vSat} and p_v are listed in Table 3 and plotted on charts in Figures 9 and 10.

Table 3 Calculated temperatures and vapour pressures at interfaces

Interface	T [C]	p_{vSat} [Pa]	p_v [Pa]
<i>i</i>	20	2336.9	1075.0
1	19.42	2254.2	1075.0
2	18.89	2180.7	996.3
3	18.08	2073.5	996.3
4	12.20	1420.1	983.2
5	11.90	1393.1	786.4
6	5.52	903.8	770.9
7	4.71	854.5	770.9
8	4.18	823.1	650.2
<i>e</i>	4	812.8	650.2

Figure 9 Chart of calculated temperature

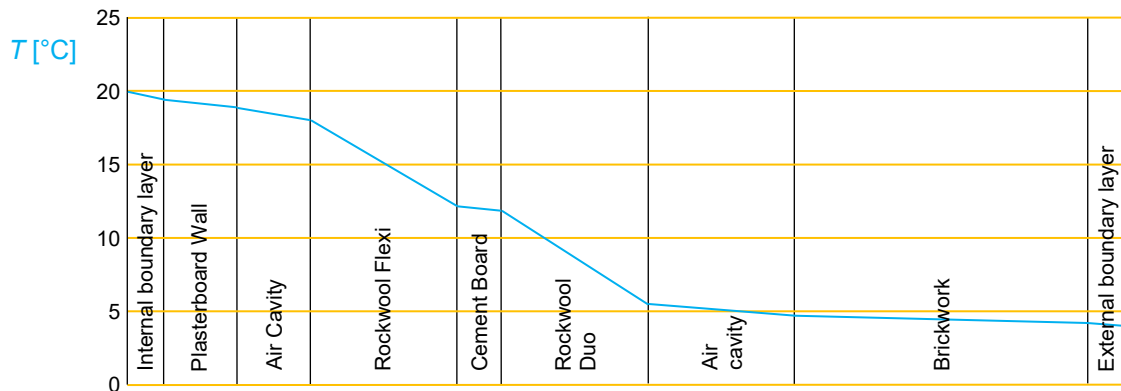
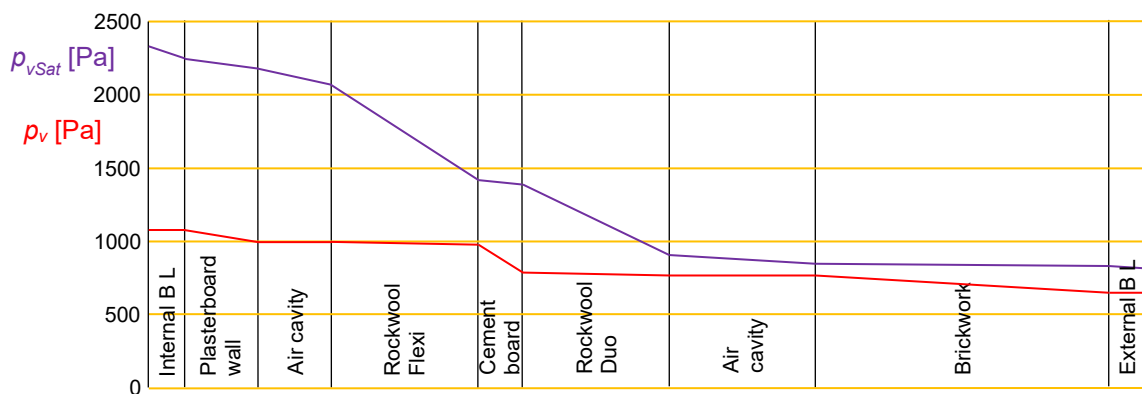


Figure 10 Chart of calculated vapour pressure and saturation vapour pressure



The vapour pressure is always below the saturation vapour pressure so there is no condensation in the wall.

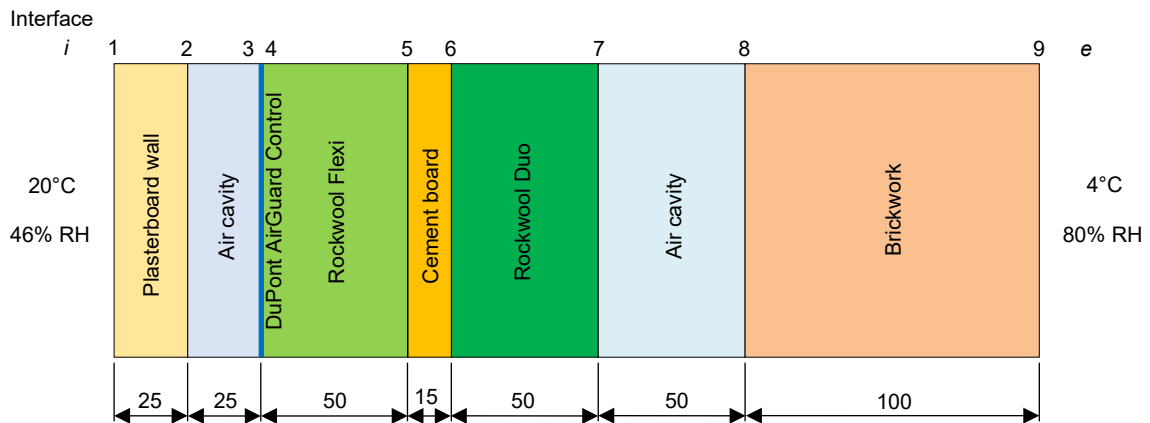
BS EN ISO 13788:2012 recommends that slabs with a thermal resistance $\Delta x/k$ greater than $0.25 \text{ m}^2 \text{ K W}^{-1}$ are subdivided into separate layers, each with a thermal resistance no greater than $0.25 \text{ m}^2 \text{ K W}^{-1}$. Each layer should then be treated as a separate material and the calculation should include the interfaces between them (see BS EN ISO 13788:2012, p. 10). In Example 1, the slab of Rockwool Flexi has a thermal resistance of $1.32 \text{ m}^2 \text{ K W}^{-1}$ and the slab of Rockwool Duo has a thermal resistance of $1.43 \text{ m}^2 \text{ K W}^{-1}$. However, there is no condensation in either slab, so subdividing the slabs would not have changed the solution.

8 Example 2

Repeat Example 1, but with a DuPont AirGuard Control vapour control layer added to the warm side of the Rockwool Flexi insulation.

The external wall with vapour control layer is shown in Figure 11.

Figure 11 External wall with vapour control layer



The properties of the materials in the wall are given in Table 4.

Table 4 Properties of materials

Slab	Δx [mm]	k [W m ⁻¹ K ⁻¹]	$\Delta x/k$ [K m ² W ⁻¹]	ζ [MN s g ⁻¹ m ⁻¹]	z [MN s g ⁻¹]
Plasterboard wall	25	0.21	-	60	-
Air cavity	25	-	0.18	0	-
DuPont AirGuard	-	-	-	-	10
Rockwool Flexi	50	0.038	-	5	-
Cement board	15	0.23	-	250	-
Rockwool Duo	50	0.035	-	5.9	-
Air cavity	50	-	0.18	0	-
Brickwork	100	0.84	-	23	-

Membranes such as the DuPont AirGuard Control vapour control layer are assumed to have negligible thermal resistance. Consequently, there will be no change to the calculated interface temperatures and the heat flux and Figure 9 will still represent the temperature variation through the wall. The saturation vapour pressure depends only on the temperature, so there will be no change to the calculated interface saturation vapour pressures either and the purple curve in Figure 10 will still represent the variation in saturation vapour pressure through the wall.

The vapour control layer adds a large vapour resistance to the wall, so the overall vapour resistance Z , the vapour mass flux m_v , and the interface vapour pressures p_v must be recalculated.

The overall vapour resistance of the wall Z is

$$\begin{aligned} Z &= \sum \zeta \Delta x \\ &= 60 \times 0.025 + 0 + 10 + 5 \times 0.05 + 250 \times 0.015 + 5.9 \times 0.05 + 0 + 23 \times 0.1 \\ &= 18.095 \text{ MN s g}^{-1} \end{aligned}$$

The vapour mass flux m_v is given by

$$m_v = -\frac{(p_{ve} - p_{vi})}{10^6 Z} = -\frac{650.2 - 1075.0}{10^6 \times 18.095} = 23.48 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1075.0 \text{ Pa}$$

The mass flux through each component is the same and equal to m_v . Across the plasterboard

$$m_v = -\frac{1}{10^6 \zeta_{12}} \frac{p_{v2} - p_{v1}}{x_{12}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_v \zeta_{12} x_{12} \\ &= 1075.0 - 10^6 \times 23.48 \times 10^{-6} \times 60 \times 0.025 = 1039.8 \text{ Pa} \end{aligned}$$

Similarly, for the other components

$$p_{v3} = p_{v2} - 10^6 m_v \zeta_{23} x_{23} = 1039.8 - 10^6 \times 23.48 \times 10^{-6} \times 0 \times 0.025 = 1039.8 \text{ Pa}$$

$$p_{v4} = p_{v3} - 10^6 m_v \zeta_{34} x_{34} = 1039.8 - 10^6 \times 23.48 \times 10^{-6} \times 10 = 805.0 \text{ Pa}$$

$$p_{v5} = p_{v4} - 10^6 m_v \zeta_{45} x_{45} = 805.0 - 10^6 \times 23.48 \times 10^{-6} \times 5 \times 0.05 = 799.2 \text{ Pa}$$

$$p_{v6} = p_{v5} - 10^6 m_v \zeta_{56} x_{56} = 799.2 - 10^6 \times 23.48 \times 10^{-6} \times 250 \times 0.015 = 711.1 \text{ Pa}$$

$$p_{v7} = p_{v6} - 10^6 m_v \zeta_{67} x_{67} = 711.1 - 10^6 \times 23.48 \times 10^{-6} \times 5.9 \times 0.05 = 704.2 \text{ Pa}$$

$$p_{v8} = p_{v7} - 10^6 m_v \zeta_{78} x_{78} = 770.9 - 10^6 \times 23.48 \times 10^{-6} \times 0 \times 0.05 = 704.2 \text{ Pa}$$

$$p_{v9} = p_{v8} - 10^6 m_v \zeta_{89} x_{89} = 704.2 - 10^6 \times 23.48 \times 10^{-6} \times 23 \times 0.1 = 650.2 \text{ Pa}$$

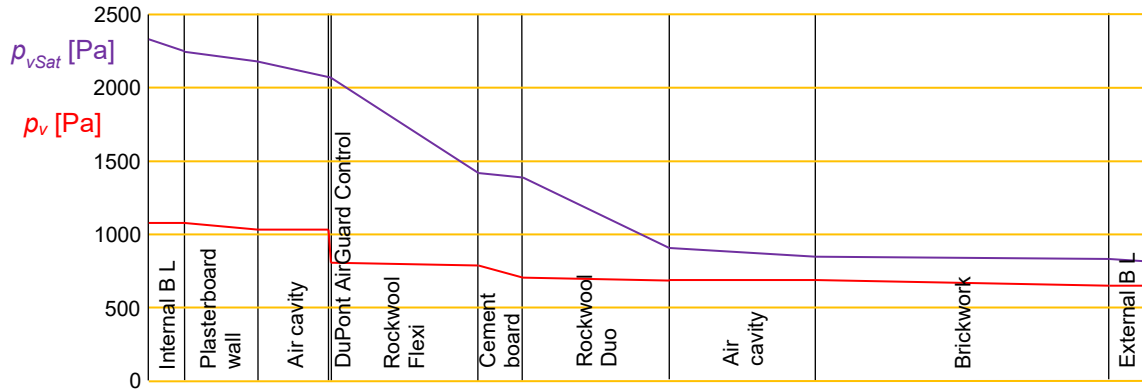
There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v9} = 650.2 \text{ Pa}$$

which is the value we expected.

The calculated values of p_v are plotted in Figure 12 along with the previously calculated values of p_{vSat} .

Figure 12 Chart of calculated vapour pressure and saturation vapour pressure



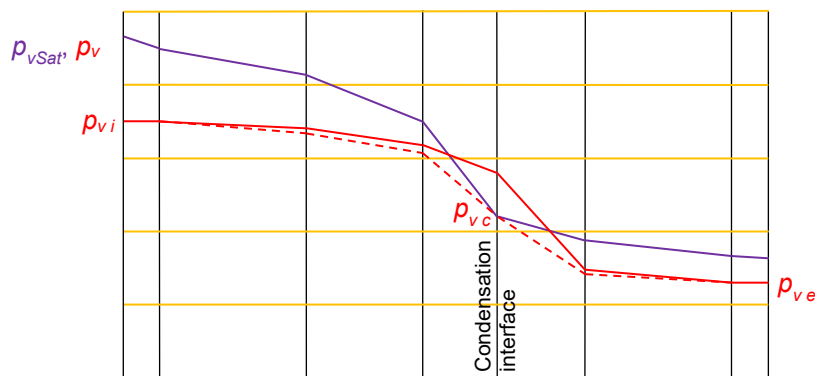
The vapour control layer reduces the amount of moisture reaching the cold part of the wall, making condensation even less likely.

9 Condensation

If the calculated vapour pressure exceeds the saturation vapour pressure at any interface then condensation is said to occur. The vapour mass flow through the structure will no longer be constant but will fall as vapour is lost through condensation. BS EN ISO 13788:2012 sets out the steps needed to determine the vapour mass flow in the structure when condensation occurs and the rate of condensation at the affected parts of the structure.

Any interface where the calculated vapour pressure exceeds the saturation vapour pressure is called a *condensation interface*. At condensation interfaces the calculated vapour pressure must be set equal to the saturation vapour pressure at the interface.

Figure 13 Vapour pressure profile with one condensation interface



In Figure 13, there are now three interfaces on which the vapour pressure is fixed: the two interfaces in the air inside and outside the structure and the condensation interface. The fixed vapour pressure values on these interfaces are p_{vi} , p_{ve} and p_{vc} , respectively. p_{vi} and p_{ve} are fixed by the monthly mean environmental conditions and p_{vc} is fixed by the calculated temperature at the condensation interface. The vapour pressures on the other interfaces must be recalculated so that they are consistent with these fixed vapour pressures.

The vapour mass flow m_{v1} [$\text{g s}^{-1} \text{m}^{-2}$] between interface i and interface c is

$$m_{v1} = -\frac{(p_{vc} - p_{vi})}{10^6 Z_1} \quad (9.1)$$

where Z_1 [MN s g^{-1}] is the overall vapour resistance between interface i and interface c :

$$Z = \sum_{i \rightarrow c} z = \sum_{i \rightarrow c} \zeta \Delta x \quad (9.2)$$

The vapour mass flow m_{v2} [$\text{g s}^{-1} \text{m}^{-2}$] between interface c and interface e is

$$m_{v2} = -\frac{(p_{ve} - p_{vc})}{10^6 Z_2} \quad (9.3)$$

where Z_2 [MN s g^{-1}] is the overall vapour resistance between interface c and interface e :

$$Z = \sum_{c \rightarrow e} z = \sum_{c \rightarrow e} \zeta \Delta x \quad (9.4)$$

The vapour mass flow m_{v1} will be larger than the mass flow m_v calculated originally and m_{v2} will be smaller, because of the drop in vapour pressure imposed at the condensation interface. The difference

$$\Delta m_v [\text{g s}^{-1} \text{m}^{-2}] = m_{v2} - m_{v1} \quad (9.5)$$

is the condensation rate at the condensation interface. Δm_v is negative, indicating that vapour is being lost through condensation. BS EN ISO 13788:20012 assumes that the diffusion of vapour through the structure is slow and that the rate of condensation is constrained by the rate at which vapour diffuses to and from the condensation site.

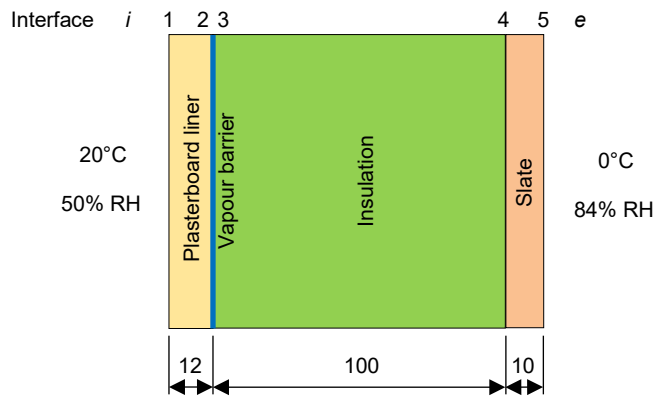
We can determine the amount of condensate that will build up at the condensation interface over the assessment month. February represents a period of $60 \times 60 \times 24 \times 28 = 2,419,200$ seconds, so for February the total amount of condensate M_c [g m^{-2}] is

$$M_c [\text{g m}^{-2}] = 2,419,200 \times \Delta m_v \quad (9.6)$$

10 Example 3

A flat roof is constructed as shown in Figure 14. Determine whether condensation will occur in the structure. The monthly mean environmental conditions in Figure 14 are for February.

Figure 14 Flat roof



The properties of the materials in the roof are given in Table 5.

Table 5 Properties of materials

Slab	Δx [mm]	k [W m ⁻¹ K ⁻¹]	$\frac{\Delta x}{k}$ [K m ² W ⁻¹]	ζ [MN s g ⁻¹ m ⁻¹]	z [MN s g ⁻¹]
Plasterboard liner	12	0.16	-	50	-
Vapour barrier	-	-	-	-	5,000
Insulation	100	0.03333	-	750	-
Slate	10	0.2	-	2,500,000	-

Interface temperatures and heat flux

The overall heat transfer coefficient for the wall U is given by (2.9)

$$\begin{aligned} \frac{1}{U} &= \frac{1}{h_i} + \sum \frac{\Delta x}{k} + \frac{1}{h_e} \\ &= \frac{1}{7.7} + \frac{0.012}{0.16} + \frac{0.100}{0.03333} + \frac{0.010}{0.20} + \frac{1}{25} \\ &= 3.295 \text{ m}^2 \text{ K W}^{-1} \end{aligned}$$

and so $U=0.3035 \text{ W m}^{-2} \text{ K}^{-1}$.

The heat flux q is

$$q = -U(T_e - T_i) = -0.3035 \times (0 - 20) = 6.070 \text{ W m}^{-2}$$

The heat flux through the boundary layers and the slabs is the same. For the internal boundary layer

$$q = -h_i(T_1 - T_i)$$

so

$$T_1 = T_i - \frac{q}{h_i} = 20 - \frac{6.070}{7.7} = 19.21^\circ\text{C}$$

Across the plasterboard liner

$$q = -k_{12} \frac{T_2 - T_1}{x_{12}}$$

so

$$T_2 = T_1 - q \frac{x_{12}}{k_{12}} = 19.21 - 6.070 \times \frac{0.012}{0.16} = 18.76^\circ\text{C}$$

Across the vapour barrier

$$T_3 = T_2 = 18.76^\circ\text{C}$$

For the other slabs

$$T_4 = T_3 - q \frac{x_{34}}{k_{34}} = 18.76 - 6.070 \times \frac{0.100}{0.03333} = 0.55^\circ\text{C}$$

$$T_5 = T_4 - q \frac{x_{45}}{k_{45}} = 0.55 - 6.070 \times \frac{0.010}{0.2} = 0.24^\circ\text{C}$$

For the external boundary layer

$$T_e = T_5 - \frac{q}{h_e} = 0.24 - \frac{6.070}{25} = 0^\circ\text{C}$$

as expected.

Interface saturation vapour pressures

The saturation vapour pressure at the interfaces can be calculated from (6.2). In the living space

$$p_{vSat i} = 610.5 \text{ Exp} \left(\frac{17.269 \times T_i}{237.3 + T_i} \right) = 610.5 \text{ Exp} \left(\frac{17.269 \times 20}{237.3 + 20} \right) = 2336.9 \text{ Pa}$$

Similarly, for the interfaces

$$T_1 = 19.21^\circ\text{C}, p_{vSat 1} = 2225.2 \text{ Pa}$$

$$T_2 = 18.76^\circ\text{C}, p_{vSat 2} = 2162.9 \text{ Pa}$$

$$T_3 = 18.76^\circ\text{C}, p_{vSat 3} = 2162.9 \text{ Pa}$$

$$T_4 = 0.55^\circ\text{C}, p_{vSat 4} = 635.2 \text{ Pa}$$

$$T_5 = 0.24^\circ\text{C}, p_{vSat 5} = 621.4 \text{ Pa}$$

and outside

$$T_e = 0^\circ\text{C}, p_{vSat e} = 610.5 \text{ Pa}$$

Interface vapour pressures and vapour mass flux

The overall vapour resistance of the wall Z is given by (3.9)

$$\begin{aligned} Z &= \sum \zeta \Delta x \\ &= 50 \times 0.012 + 5,000 + 750 \times 0.100 + 2,500,000 \times 0.010 \\ &= 30,075.6 \text{ MN s g}^{-1} \end{aligned}$$

The vapour pressure in the living space p_{vi} is

$$p_{vi} = \frac{\phi_i p_{vSat i}}{100} = \frac{50 \times 2336.9}{100} = 1168.4 \text{ Pa}$$

and the vapour pressure outside is

$$p_{ve} = \frac{\phi_e p_{vSat e}}{100} = \frac{84 \times 610.5}{100} = 512.8 \text{ Pa}$$

The vapour mass flux m_v is given by

$$m_v = -\frac{(p_{ve} - p_{vi})}{10^6 Z} = -\frac{512.8 - 1168.4}{10^6 \times 30,075.6} = 0.02180 \times 10^{-6} \text{ g s}^{-1}\text{m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1168.4 \text{ Pa}$$

The mass flux through each slab is the same and equal to m_v . Across the plasterboard liner

$$m_v = -\frac{1}{10^6 \zeta_{12}} \frac{p_{v2} - p_{v1}}{x_{12}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_v \zeta_{12} x_{12} \\ &= 1168.4 - 10^6 \times 0.02180 \times 10^{-6} \times 50 \times 0.012 = 1168.4 \text{ Pa} \end{aligned}$$

Similarly, for the other slabs

$$p_{v3} = p_{v2} - 10^6 m_v \zeta_{23} x_{23} = 1168.4 - 10^6 \times 0.02180 \times 10^{-6} \times 5,000 = 1059.4 \text{ Pa}$$

$$p_{v4} = p_{v3} - 10^6 m_v \zeta_{34} x_{34} = 1059.4 - 10^6 \times 0.02180 \times 10^{-6} \times 750 \times 0.100 = 1057.8 \text{ Pa}$$

$$p_{v5} = p_{v4} - 10^6 m_v \zeta_{45} x_{45} = 1057.8 - 10^6 \times 0.02180 \times 10^{-6} \times 2,500,000 \times 0.010 = 512.8 \text{ Pa}$$

There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v5} = 512.8 \text{ Pa}$$

which is the value we expected.

The calculated values of T , p_{vSat} and p_v are listed in Table 6.

Table 6 Calculated temperatures and vapour pressures at interfaces

Interface	T [C]	p_{vSat} [Pa]	p_v [Pa]
<i>i</i>	20	2336.9	1168.4
1	19.21	2225.2	1168.4
2	18.76	2162.9	1168.4
3	18.76	2162.9	1059.4
4	0.55	635.2	1057.8
5	0.24	621.4	512.8
<i>e</i>	0	610.5	512.8

At interface 4, between the insulation and the slate, the calculated vapour pressure p_v is greater than the saturation vapour pressure p_{vSat} , so there will be condensation at this interface.

11 Example 4

Calculate the condensation rate in Example 3 and the amount of condensate built up over the assessment month.

The vapour pressure cannot exceed the saturation vapour pressure, so the vapour pressure at the condensation interface must be set equal to the saturation vapour pressure at the interface. Then the vapour pressures either side, up to the fixed vapour pressures p_{vi} and p_{ve} , must be recalculated.

The overall vapour resistance Z_1 [MN s g^{-1}] between interface i and interface c is

$$Z_1 = \sum_{i \rightarrow c} z = \sum_{i \rightarrow c} \zeta \Delta x = 50 \times 0.012 + 5,000 + 750 \times 0.100 = 5,075.6 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v1} [$\text{g s}^{-1} \text{ m}^{-2}$] between interface i and interface c is

$$m_{v1} = -\frac{(p_{vc} - p_{vi})}{10^6 Z_1} = -\frac{635.2 - 1168.4}{10^6 \times 5,075.6} = 0.10505 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1168.4 \text{ Pa}$$

The mass flux through each slab up to interface c is the same and equal to m_{v1} . Across the plasterboard liner

$$m_{v1} = -\frac{1}{10^6 \zeta_{12}} \frac{p_{v2} - p_{v1}}{x_{12}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_{v1} \zeta_{12} x_{12} \\ &= 1168.4 - 10^6 \times 0.10505 \times 10^{-6} \times 50 \times 0.012 = 1168.4 \text{ Pa} \end{aligned}$$

Similarly, for vapour barrier

$$p_{v3} = p_{v2} - 10^6 m_{v1} \zeta_{23} x_{23} = 1168.4 - 10^6 \times 0.10505 \times 10^{-6} \times 5,000 = 643.1 \text{ Pa}$$

and for the insulation

$$p_{v4} = p_{v3} - 10^6 m_{v1} \zeta_{34} x_{34} = 643.1 - 10^6 \times 0.10505 \times 10^{-6} \times 750 \times 0.100 = 635.2 \text{ Pa}$$

which is what we expect.

The overall vapour resistance Z_2 [MN s g^{-1}] between interface c and interface e is

$$Z_1 = \sum_{i \rightarrow c} z = \sum_{i \rightarrow c} \zeta \Delta x = 2,500,000 \times 0.010 = 25,000 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v2} [$\text{g s}^{-1} \text{ m}^{-2}$] between interface c and interface e is

$$m_{v2} = -\frac{(p_{ve} - p_{vc})}{10^6 Z_2} = -\frac{512.8 - 635.2}{10^6 \times 25,000} = 0.004896 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

The mass flux through each slab up to interface e is the same and equal to m_{v2} . Across the slate

$$m_{v2} = -\frac{1}{10^6 \zeta_{45}} \frac{p_{v5} - p_{vc}}{x_{45}}$$

so

$$\begin{aligned} p_{v5} &= p_{vc} - 10^6 m_{v2} \zeta_{45} x_{45} \\ &= 635.2 - 10^6 \times 0.004896 \times 10^{-6} \times 2,500,000 \times 0.010 = 512.8 \text{ Pa} \end{aligned}$$

There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v5} = 512.8 \text{ Pa}$$

which is the value we expected.

The original calculated values of T , p_{vSat} and p_v and the recalculated values of p_v are listed in Table 7.

Table 7 Recalculated vapour pressures at interfaces

Interface	T [C]	p_{vSat} [Pa]	p_v Original [Pa]	p_v Recalc. [Pa]
i	20	2336.9	1168.4	1168.4
1	19.21	2225.2	1168.4	1168.4
2	18.76	2162.9	1168.4	1168.4
3	18.76	2162.9	1059.4	643.1
4	0.55	635.2	1057.8	635.2
5	0.24	621.4	512.8	512.8
e	0	610.5	512.8	512.8

The rate of condensation is

$$\begin{aligned} \Delta m_v [\text{g s}^{-1} \text{ m}^{-2}] &= m_{v2} - m_{v1} \\ &= (0.004896 - 0.10505) \times 10^{-6} = -0.10015 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2} \end{aligned}$$

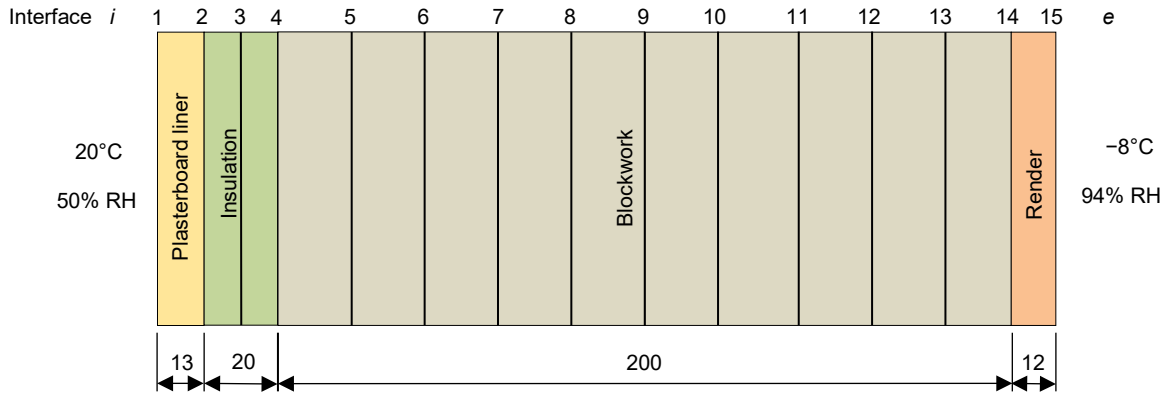
The condensation rate is negative because vapour is being lost. The assessment month is February, so from (9.6) the amount of condensate built up over the month M_c [g m^{-2}] is

$$\begin{aligned} M_c &= 2,419,200 \times \Delta m_v \\ &= 2,419,200 \times 0.10015 \times 10^{-6} = 0.2423 \text{ g m}^{-2} \end{aligned}$$

12 Example 5

A wall is constructed as shown in Figure 15. Determine whether condensation will occur in the structure. The monthly mean environmental conditions in Figure 15 are for February.

Figure 15 Blockwork wall



The blockwork and the insulation have a thermal resistance $\Delta x/k$ greater than $0.25 \text{ m}^2 \text{ K W}^{-1}$, so the insulation has been divided into two layers and the blockwork has been divided into ten layers.

The properties of the materials in the wall are shown in Table 8.

Table 8 Properties of materials

Slab	Δx [mm]	k [W m ⁻¹ K ⁻¹]	ζ [MN s g ⁻¹ m ⁻¹]
Plasterboard liner	13	0.5652	40
Insulation	20	0.04	5
Blockwork	200	0.08	70
Render	12	0.8	40

Interface temperatures and heat flux

The profile of temperature in each slab will always be a straight line, so we can ignore the subdivisions when we calculate the temperature profile in the wall. The overall heat transfer coefficient for the wall U is given by (2.9)

$$\begin{aligned} \frac{1}{U} &= \frac{1}{h_i} + \sum \frac{\Delta x}{k} + \frac{1}{h_e} \\ &= \frac{1}{7.7} + \frac{0.013}{0.5652} + \frac{0.020}{0.04} + \frac{0.200}{0.08} + \frac{0.012}{0.80} + \frac{1}{25} \\ &= 3.208 \text{ m}^2 \text{ K W}^{-1} \end{aligned}$$

and so $U=0.3117 \text{ W m}^{-2} \text{ K}^{-1}$.

The heat flux q is

$$q = -U(T_e - T_i) = -0.3117 \times (-8 - 20) = 8.729 \text{ W m}^{-2}$$

The heat flux through the boundary layers and the slabs is the same. For the internal boundary layer

$$q = -h_i(T_1 - T_i)$$

so

$$T_1 = T_i - \frac{q}{h_i} = 20 - \frac{8.729}{7.7} = 18.87^\circ\text{C}$$

Across the plasterboard liner

$$q = -k_{1 \rightarrow 2} \frac{T_2 - T_1}{x_{1 \rightarrow 2}}$$

so

$$T_2 = T_1 - q \frac{x_{1 \rightarrow 2}}{k_{1 \rightarrow 2}} = 18.87 - 8.729 \times \frac{0.013}{0.5652} = 18.67^\circ\text{C}$$

Similarly, for the other slabs

$$T_4 = T_2 - q \frac{x_{2 \rightarrow 4}}{k_{2 \rightarrow 4}} = 18.67 - 8.729 \times \frac{0.020}{0.04} = 14.30^\circ\text{C}$$

$$T_{14} = T_4 - q \frac{x_{4 \rightarrow 14}}{k_{4 \rightarrow 14}} = 14.30 - 8.729 \times \frac{0.200}{0.08} = -7.52^\circ\text{C}$$

$$T_{15} = T_{14} - q \frac{x_{14 \rightarrow 15}}{k_{14 \rightarrow 15}} = -7.52 - 8.729 \times \frac{0.012}{0.8} = -7.65^\circ\text{C}$$

For the external boundary layer

$$T_e = T_{15} - \frac{q}{h_e} = -7.65 - \frac{8.729}{25} = -8^\circ\text{C}$$

as expected.

Interface saturation vapour pressures

The saturation vapour pressure at the interfaces can be calculated from (6.1) and (6.2). These are listed Table 9.

Table 9 Saturation vapour pressure through wall

Interface	T [C]	p_{vSat} [Pa]
<i>i</i>	20	2336.9
1 (Start of plasterboard)	18.87	2177.9
2 (Start of insulation)	18.67	2150.8
3	16.48	1874.2
4 (Start of blockwork)	14.30	1629.2
5	12.12	1412.9
6	9.94	1222.4
7	7.75	1054.1
8	5.57	907.2
9	3.39	778.6
10	1.21	666.4
11	-0.97	563.4
12	-3.16	469.1
13	-5.34	389.7
14 (Start of render)	-7.52	322.7
15	-7.65	319.0
<i>e</i>	-8	309.4

Interface vapour pressures and vapour mass flux

Assuming there is no condensation, the profile of vapour pressure in each slab will always be a straight line, so we can ignore the subdivisions when we calculate the vapour pressure profile in the wall. The overall vapour resistance of the wall *Z* is given by (3.9)

$$\begin{aligned}
 Z &= \sum \zeta \Delta x \\
 &= 40 \times 0.013 + 5 \times 0.020 + 70 \times 0.200 + 40 \times 0.012 \\
 &= 15.1 \text{ MN s g}^{-1}
 \end{aligned}$$

The vapour pressure in the living space p_{vi} is

$$p_{vi} = \frac{\phi_i p_{vSat i}}{100} = \frac{50 \times 2336.9}{100} = 1168.4 \text{ Pa}$$

and the vapour pressure outside is

$$p_{ve} = \frac{\phi_e p_{vSat e}}{100} = \frac{94 \times 309.4}{100} = 290.8 \text{ Pa}$$

The vapour mass flux m_v is given by

$$m_v = -\frac{(p_{ve} - p_{vi})}{10^6 Z} = -\frac{290.8 - 1168.4}{10^6 \times 15.1} = 58.12 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1168.4 \text{ Pa}$$

The mass flux through each slab is the same and equal to m_v . Across the plasterboard liner

$$m_v = -\frac{1}{10^6 \zeta_{1 \rightarrow 2}} \frac{p_{v2} - p_{v1}}{x_{1 \rightarrow 2}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_v \zeta_{1 \rightarrow 2} x_{1 \rightarrow 2} \\ &= 1168.4 - 10^6 \times 58.12 \times 10^{-6} \times 40 \times 0.013 = 1138.2 \text{ Pa} \end{aligned}$$

Similarly, for the other slabs

$$p_{v4} = p_{v2} - 10^6 m_v \zeta_{2 \rightarrow 4} x_{2 \rightarrow 4} = 1138.2 - 10^6 \times 58.12 \times 10^{-6} \times 5 \times 0.020 = 1132.4 \text{ Pa}$$

$$p_{v14} = p_{v4} - 10^6 m_v \zeta_{4 \rightarrow 14} x_{4 \rightarrow 14} = 1132.4 - 10^6 \times 58.12 \times 10^{-6} \times 70 \times 0.200 = 318.7 \text{ Pa}$$

$$p_{v15} = p_{v14} - 10^6 m_v \zeta_{14 \rightarrow 15} x_{14 \rightarrow 15} = 318.7 - 10^6 \times 58.12 \times 10^{-6} \times 40 \times 0.012 = 290.8 \text{ Pa}$$

There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v15} = 290.8 \text{ Pa}$$

which is the value we expected.

The calculated values of T , p_{vSat} and p_v are listed in Table 10.

Table 10 Vapour pressure through the wall

Interface	T [C]	p_{vSat} [Pa]	p_v [Pa]
<i>i</i>	20	2336.9	1168.4
1 (Start of plasterboard)	18.87	2177.9	1168.4
2 (Start of insulation)	18.67	2150.8	1138.2
3	16.48	1874.2	1135.3
4 (Start of blockwork)	14.30	1629.2	1132.4
5	12.12	1412.9	1051.0
6	9.94	1222.4	969.7
7	7.75	1054.1	888.3
8	5.57	907.2	806.9
9	3.39	778.6	725.6
10	1.21	666.4	644.2
11	-0.97	563.4	562.8
12	-3.16	469.1	481.4
13	-5.34	389.7	400.1
14 (Start of render)	-7.52	322.7	318.7
15	-7.65	319.0	290.8
<i>e</i>	-8	309.4	290.8

The calculated vapour pressure p_v is greater than the saturation vapour pressure p_{vSat} , at interfaces 12 and 13 in the blockwork, so there will be condensation at these interfaces.

13 Example 6

Calculate the condensation rate and the amount of condensate built up over the month at the two condensation interfaces in Example 5.

The vapour pressure cannot exceed the saturation vapour pressure, so the vapour pressure at the two condensation interface must be set equal to the saturation vapour pressure at the interfaces. Then the vapour pressures either side, up to the fixed vapour pressures p_{vi} and p_{ve} , must be recalculated.

The overall vapour resistance Z_1 [MN s g^{-1}] between interface i and interface 12 is

$$Z_1 = \sum_{i \rightarrow 12} z = \sum_{i \rightarrow 12} \zeta \Delta x = 40 \times 0.013 + 5 \times 0.020 + \frac{8}{10} \times 70 \times 0.200 = 11.82 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v1} [$\text{g s}^{-1} \text{ m}^{-2}$] between interface i and interface 12 is

$$m_{v1} = -\frac{(p_{v12} - p_{vi})}{10^6 Z_1} = -\frac{469.1 - 1168.4}{10^6 \times 11.82} = 59.16 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1168.4 \text{ Pa}$$

The mass flux through each slab up to interface 12 is the same and equal to m_{v1} . Across the plasterboard liner

$$m_{v1} = -\frac{1}{10^6 \zeta_{1 \rightarrow 2}} \frac{p_{v2} - p_{v1}}{x_{1 \rightarrow 2}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_{v1} \zeta_{1 \rightarrow 2} x_{1 \rightarrow 2} \\ &= 1168.4 - 10^6 \times 59.16 \times 10^{-6} \times 40 \times 0.013 = 1137.6 \text{ Pa} \end{aligned}$$

Similarly, for the insulation

$$\begin{aligned} p_{v4} &= p_{v2} - 10^6 m_{v1} \zeta_{2 \rightarrow 4} x_{2 \rightarrow 4} \\ &= 1137.6 - 10^6 \times 59.16 \times 10^{-6} \times 5 \times 0.020 = 1131.7 \text{ Pa} \end{aligned}$$

and for the blockwork up to interface 12

$$\begin{aligned} p_{v12} &= p_{v4} - 10^6 m_{v1} \zeta_{4 \rightarrow 12} x_{4 \rightarrow 12} \\ &= 1131.7 - 10^6 \times 59.16 \times 10^{-6} \times \frac{8}{10} \times 70 \times 0.200 = 469.1 \text{ Pa} \end{aligned}$$

which is what we expect.

The overall vapour resistance Z_2 [MN s g⁻¹] between interface 12 and interface 13 is

$$Z_2 = \sum_{i \rightarrow 12} z = \sum_{i \rightarrow 12} \zeta \Delta x = \frac{1}{10} \times 70 \times 0.200 = 1.40 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v2} [g s⁻¹ m⁻²] between interface 12 and interface 13 is

$$m_{v2} = -\frac{(p_{v13} - p_{v12})}{10^6 Z_2} = -\frac{389.7 - 469.1}{10^6 \times 1.40} = 56.71 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

The overall vapour resistance Z_3 [MN s g⁻¹] between interface 13 and interface e is

$$Z_3 = \sum_{13 \rightarrow e} z = \sum_{13 \rightarrow e} \zeta \Delta x = \frac{1}{10} \times 70 \times 0.200 + 40 \times 0.012 = 1.88 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v3} [g s⁻¹ m⁻²] between interface 13 and interface e is

$$m_{v3} = -\frac{(p_{ve} - p_{v13})}{10^6 Z_3} = -\frac{290.8 - 389.7}{10^6 \times 1.88} = 52.61 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

The mass flux through each slab up to interface e is the same and equal to m_{v3} . Across the blockwork between interface 13 and interface 14:

$$m_{v3} = -\frac{1}{10^6 \zeta_{13 \rightarrow 14}} \frac{p_{v14} - p_{v13}}{x_{13 \rightarrow 14}}$$

so

$$\begin{aligned} p_{v14} &= p_{v13} - 10^6 m_{v3} \zeta_{13 \rightarrow 14} x_{13 \rightarrow 14} \\ &= 389.7 - 10^6 \times 52.61 \times 10^{-6} \times \frac{1}{10} \times 70 \times 0.200 = 316.1 \text{ Pa} \end{aligned}$$

Similarly, for the render

$$\begin{aligned} p_{v15} &= p_{v14} - 10^6 m_{v3} \zeta_{14 \rightarrow 15} x_{14 \rightarrow 15} \\ &= 316.1 - 10^6 \times 52.61 \times 10^{-6} \times 40 \times 0.012 = 290.8 \text{ Pa} \end{aligned}$$

There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v15} = 290.8 \text{ Pa}$$

which is the value we expected.

The original calculated values of T , p_{vSat} and p_v and the recalculated values of p_v are listed in Table 11. The recalculated values of p_v at interface 3 and interfaces 5 to 11 (highlighted in blue) are obtained by linear interpolation.

Table 11 Recalculated vapour pressure through the wall

Interface	T [C]	p_{vSat} [Pa]	p_v Original [Pa]	p_v Recalc. [Pa]
i	20	2336.9	1168.4	1168.4
1 (Start of plasterboard)	18.87	2177.9	1168.4	1168.4
2 (Start of insulation)	18.67	2150.8	1138.2	1137.6
3	16.48	1874.2	1135.3	1134.6
4 (Start of blockwork)	14.30	1629.2	1132.4	1131.7
5	12.12	1412.9	1051.0	1048.9
6	9.94	1222.4	969.7	966.1
7	7.75	1054.1	888.3	883.2
8	5.57	907.2	806.9	800.4
9	3.39	778.6	725.6	717.6
10	1.21	666.4	644.2	634.7
11	-0.97	563.4	562.8	551.9
12	-3.16	469.1	481.4	469.1
13	-5.34	389.7	400.1	389.7
14 (Start of render)	-7.52	322.7	318.7	316.1
15	-7.65	319.0	290.8	290.8
e	-8	309.4	290.8	290.8

The rate of condensation at interface 12 is

$$\begin{aligned} \Delta m_v [\text{g s}^{-1} \text{m}^{-2}] &= m_{v2} - m_{v1} \\ &= (56.71 - 59.16) \times 10^{-6} = -2.45 \times 10^{-6} \text{ g s}^{-1} \text{m}^{-2} \end{aligned}$$

The condensation rate is negative because vapour is being lost. The assessment month is February, so from (9.6) the amount of condensate built up over the month M_c [g m^{-2}] is

$$\begin{aligned} M_c &= 2,419,200 \times \Delta m_v \\ &= 2,419,200 \times 2.45 \times 10^{-6} = 5.927 \text{ g m}^{-2} \end{aligned}$$

The rate of condensation at interface 13 is

$$\begin{aligned} \Delta m_v [\text{g s}^{-1} \text{m}^{-2}] &= m_{v3} - m_{v2} \\ &= (52.61 - 56.71) \times 10^{-6} = -4.10 \times 10^{-6} \text{ g s}^{-1} \text{m}^{-2} \end{aligned}$$

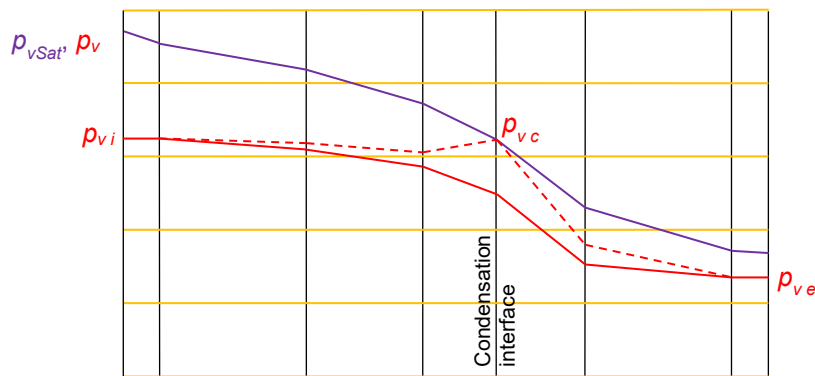
and the amount of condensate built up over the month M_c [g m^{-2}] is

$$M_c = 2,419,200 \times 4.10 \times 10^{-6} = 9.919 \text{ g m}^{-2}$$

14 Evaporation

According to BS EN ISO 13788:2012, if there is condensate accumulated from previous months at an interface, then the vapour pressure at the interface must be set equal to the saturation vapour pressure. Again, BS EN ISO 13788:2012 assumes that the diffusion of vapour is slow. Consequently, the evaporation of vapour at the interface will always be able to maintain the vapour pressure at the saturation vapour pressure until there is no condensate left. In Figure 16 there is one condensation interface.

Figure 16 Evaporation with one condensation interface



In Figure 16, there are three interfaces on which the vapour pressure is fixed: the two interfaces in the air inside and outside the structure and the condensation interface. The fixed vapour pressure values on these interfaces are $p_{v i}$, $p_{v e}$ and $p_{v c}$, respectively. $p_{v i}$ and $p_{v e}$ are fixed by the monthly mean environmental conditions and $p_{v c}$ is fixed by the evaporation at the interface. The vapour pressures on the other interfaces must be recalculated so that they are consistent with these fixed vapour pressures.

The vapour mass flow $m_{v 1}$ [$\text{g s}^{-1} \text{m}^{-2}$] between interface i and interface c is

$$m_{v 1} = -\frac{(p_{v c} - p_{v i})}{10^6 Z_1} \quad (14.1)$$

where Z_1 [MN s g^{-1}] is the overall vapour resistance between interface i and interface c :

$$Z = \sum_{i \rightarrow c} z = \sum_{i \rightarrow c} \zeta \Delta x \quad (14.2)$$

The vapour mass flow m_{v2} [$\text{g s}^{-1} \text{m}^{-2}$] between interface c and interface e is

$$m_{v2} = -\frac{(p_{ve} - p_{vc})}{10^6 Z_2} \quad (14.3)$$

where Z_2 [MN s g^{-1}] is the overall vapour resistance between interface c and interface e :

$$Z = \sum_{c \rightarrow e} z = \sum_{c \rightarrow e} \zeta \Delta x \quad (14.4)$$

The difference in vapour mass flow

$$\Delta m_v [\text{g s}^{-1} \text{m}^{-2}] = m_{v2} - m_{v1} \quad (14.5)$$

is the evaporation rate at the condensation interface. Δm_v is positive, indicating that vapour is being added through evaporation.

We can determine the amount of condensate that will evaporate at the condensation interface over the assessment month. June represents a period of $60 \times 60 \times 24 \times 31 = 2,678,400$ seconds, so for June the total amount of condensate that evaporates M_c [g m^{-2}] is

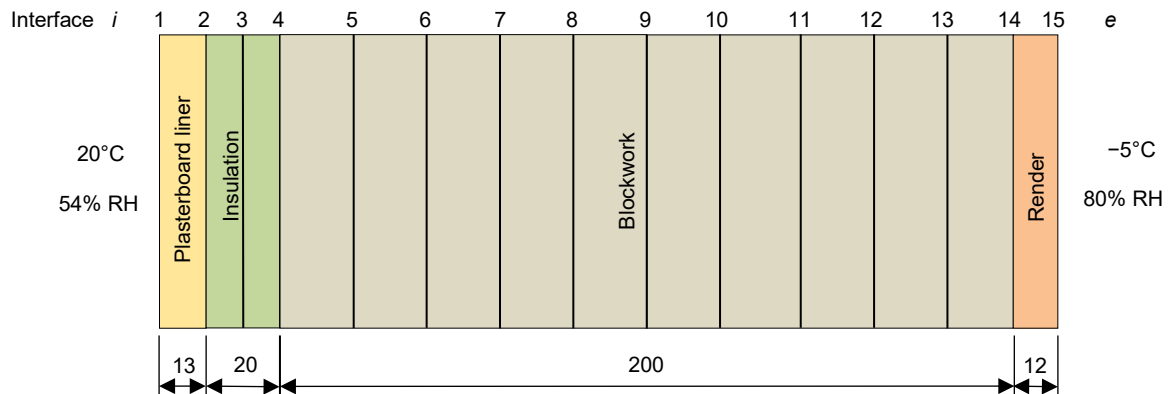
$$M_c [\text{g m}^{-2}] = 2,678,400 \times \Delta m_v \quad (14.6)$$

According, to BS EN ISO 13788:2012, if the amount of condensate left over at the end of the month is a negative value, then the amount of condensate can be set to zero. Alternatively, one can use the evaporation rate Δm_v to calculate the time for the accumulated condensate to reach zero and then divide the month into two sections, with and without condensate at the interface.

15 Example 7

Repeat Examples 5 and 6, but for the month of March. Figure 17 shows the blockwork wall and the monthly mean environmental conditions for March. Examples 5 and 6 show that there is condensate at interfaces 12 and 13 at the end of February.

Figure 17 Blockwork wall



The properties of the materials in the wall are shown in Table 12.

Table 12 Properties of materials

Slab	Δx [mm]	k [W m ⁻¹ K ⁻¹]	ζ [MN s g ⁻¹ m ⁻¹]
Plasterboard liner	13	0.5652	40
Insulation	20	0.04	5
Blockwork	200	0.08	70
Render	12	0.8	40

Interface temperatures and heat flux

From Example 5, the overall heat transfer coefficient for the wall U is 0.3117 W m⁻² K⁻¹.

The heat flux q is

$$q = -U(T_e - T_i) = -0.3117 \times (-5 - 20) = 7.793 \text{ W m}^{-2}$$

The heat flux through the boundary layers and the slabs is the same. For the internal boundary layer

$$q = -h_i(T_1 - T_i)$$

so

$$T_1 = T_i - \frac{q}{h_i} = 20 - \frac{7.793}{7.7} = 18.99^\circ\text{C}$$

Across the plasterboard liner

$$q = -k_{1 \rightarrow 2} \frac{T_2 - T_1}{x_{1 \rightarrow 2}}$$

so

$$T_2 = T_1 - q \frac{x_{1 \rightarrow 2}}{k_{1 \rightarrow 2}} = 18.99 - 7.793 \times \frac{0.013}{0.5652} = 18.81^\circ\text{C}$$

Similarly, for the other slabs

$$T_4 = T_2 - q \frac{x_{2 \rightarrow 4}}{k_{2 \rightarrow 4}} = 18.81 - 7.793 \times \frac{0.020}{0.04} = 14.91^\circ\text{C}$$

$$T_{14} = T_4 - q \frac{x_{4 \rightarrow 14}}{k_{4 \rightarrow 14}} = 14.91 - 7.793 \times \frac{0.200}{0.08} = -4.57^\circ\text{C}$$

$$T_{15} = T_{14} - q \frac{x_{14 \rightarrow 15}}{k_{14 \rightarrow 15}} = -4.57 - 7.793 \times \frac{0.012}{0.8} = -4.69^\circ\text{C}$$

For the external boundary layer

$$T_e = T_{15} - \frac{q}{h_e} = -4.69 - \frac{7.793}{25} = -5^\circ\text{C}$$

as expected.

Interface saturation vapour pressures

The saturation vapour pressure at the interfaces can be calculated from (6.1) and (6.2). These are listed Table 13. The temperatures at interface 3 and interfaces 5 to 13 (highlighted in blue) in Table 13 have been calculated by linear interpolation.

Table 13 Saturation vapour pressure through wall

Interface	T [C]	p_{vSat} [Pa]
<i>i</i>	20	2336.9
1 (Start of plasterboard)	18.99	2194.8
2 (Start of insulation)	18.81	2170.3
3	16.86	1919.5
4 (Start of blockwork)	14.91	1694.6
5	12.96	1493.0
6	11.02	1192.3
7	9.07	1152.9
8	7.12	1009.6
9	5.17	882.3
10	3.22	769.3
11	1.27	669.3
12	-0.67	577.7
13	-2.62	490.9
14 (Start of render)	-4.57	416.2
15	-4.67	412.7
<i>e</i>	-5	401.2

Interface vapour pressures

The vapour pressure in the living space p_{vi} is

$$p_{vi} = \frac{\phi_i p_{vSat i}}{100} = \frac{54 \times 2336.9}{100} = 1261.9 \text{ Pa}$$

and the vapour pressure outside is

$$p_{ve} = \frac{\phi_e p_{vSat e}}{100} = \frac{80 \times 401.2}{100} = 321.0 \text{ Pa}$$

There is condensate at interfaces 12 and 13 so the vapour pressure must be set equal to the saturation vapour pressure at these interfaces. Then the vapour pressures either side, up to the fixed vapour pressures p_{vi} and p_{ve} , can be calculated.

The overall vapour resistance Z_1 [MN s g^{-1}] between interface i and interface 12 is

$$Z_1 = \sum_{i \rightarrow 12} z = \sum_{i \rightarrow 12} \zeta \Delta x = 40 \times 0.013 + 5 \times 0.020 + \frac{8}{10} \times 70 \times 0.200 = 11.82 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v1} [$\text{g s}^{-1} \text{ m}^{-2}$] between interface i and interface 12 is

$$m_{v1} = -\frac{(p_{v12} - p_{vi})}{10^6 Z_1} = -\frac{577.6 - 1261.9}{10^6 \times 11.82} = 57.89 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

There is no vapour resistance across the boundary layers, so at the inner surface of the wall

$$p_{v1} = p_{vi} = 1261.9 \text{ Pa}$$

The mass flux through each slab up to interface 12 is the same and equal to m_{v1} . Across the plasterboard liner

$$m_{v1} = -\frac{1}{10^6 \zeta_{1 \rightarrow 2}} \frac{p_{v2} - p_{v1}}{x_{1 \rightarrow 2}}$$

so

$$\begin{aligned} p_{v2} &= p_{v1} - 10^6 m_{v1} \zeta_{1 \rightarrow 2} x_{1 \rightarrow 2} \\ &= 1261.9 - 10^6 \times 57.89 \times 10^{-6} \times 40 \times 0.013 = 1231.8 \text{ Pa} \end{aligned}$$

Similarly, for the insulation

$$\begin{aligned} p_{v4} &= p_{v2} - 10^6 m_{v1} \zeta_{2 \rightarrow 4} x_{2 \rightarrow 4} \\ &= 1231.8 - 10^6 \times 57.89 \times 10^{-6} \times 5 \times 0.020 = 1226.0 \text{ Pa} \end{aligned}$$

For the blockwork up to interface 12

$$\begin{aligned} p_{v12} &= p_{v4} - 10^6 m_v \zeta_{4 \rightarrow 12} x_{4 \rightarrow 12} \\ &= 1226.0 - 10^6 \times 57.89 \times 10^{-6} \times \frac{8}{10} \times 70 \times 0.200 = 577.7 \text{ Pa} \end{aligned}$$

which is what we expect.

The overall vapour resistance Z_2 [MN s g⁻¹] between interface 12 and interface 13 is

$$Z_2 = \sum_{i \rightarrow 12} z = \sum_{i \rightarrow 12} \zeta \Delta x = \frac{1}{10} \times 70 \times 0.200 = 1.40 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v2} [g s⁻¹ m⁻²] between interface 12 and interface 13 is

$$m_{v2} = -\frac{(p_{v13} - p_{v12})}{10^6 Z_2} = -\frac{490.9 - 577.7}{10^6 \times 1.40} = 62.00 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

The overall vapour resistance Z_3 [MN s g⁻¹] between interface 13 and interface e is

$$Z_3 = \sum_{13 \rightarrow e} z = \sum_{13 \rightarrow e} \zeta \Delta x = \frac{1}{10} \times 70 \times 0.200 + 40 \times 0.012 = 1.88 \text{ MN s g}^{-1}$$

The vapour mass flux m_{v3} [g s⁻¹ m⁻²] between interface 13 and interface e is

$$m_{v3} = -\frac{(p_{ve} - p_{v13})}{10^6 Z_3} = -\frac{321.0 - 490.9}{10^6 \times 1.88} = 90.37 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2}$$

The mass flux through each slab up to interface e is the same and equal to m_{v3} . Across the blockwork between interface 13 and interface 14:

$$m_{v3} = -\frac{1}{10^6 \zeta_{13 \rightarrow 14}} \frac{p_{v14} - p_{v13}}{x_{13 \rightarrow 14}}$$

so

$$\begin{aligned} p_{v14} &= p_{v13} - 10^6 m_{v3} \zeta_{13 \rightarrow 14} x_{13 \rightarrow 14} \\ &= 490.9 - 10^6 \times 90.37 \times 10^{-6} \times \frac{1}{10} \times 70 \times 0.200 = 364.4 \text{ Pa} \end{aligned}$$

Similarly, for the render

$$\begin{aligned} p_{v15} &= p_{v14} - 10^6 m_{v3} \zeta_{14 \rightarrow 15} x_{14 \rightarrow 15} \\ &= 364.4 - 10^6 \times 90.37 \times 10^{-6} \times 40 \times 0.012 = 321.0 \text{ Pa} \end{aligned}$$

There is no vapour resistance across the boundary layers, so away from the outer wall

$$p_{ve} = p_{v15} = 321.0 \text{ Pa}$$

which is the value we expected.

Evaporation rate and amount of condensate cleared

The rate of evaporation at interface 12 is

$$\begin{aligned} \Delta m_v [\text{g s}^{-1} \text{ m}^{-2}] &= m_{v2} - m_{v1} \\ &= (62.00 - 57.89) \times 10^{-6} = 4.11 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2} \end{aligned}$$

The evaporation rate is positive because vapour is being added to the existing vapour in the material. The assessment month is March, so from (14.6) the amount of condensate evaporated over the month M_c [g m^{-2}] is

$$\begin{aligned} M_c &= 2,678,400 \times \Delta m_v \\ &= 2,678,400 \times 4.11 \times 10^{-6} = 11.01 \text{ g m}^{-2} \end{aligned}$$

The rate of evaporation at interface 13 is

$$\begin{aligned} \Delta m_v [\text{g s}^{-1} \text{ m}^{-2}] &= m_{v3} - m_{v2} \\ &= (90.37 - 62.00) \times 10^{-6} = 28.37 \times 10^{-6} \text{ g s}^{-1} \text{ m}^{-2} \end{aligned}$$

and the amount of condensate evaporated over the month M_c [g m^{-2}] is

$$M_c = 2,678,400 \times 28.37 \times 10^{-6} = 75.99 \text{ g m}^{-2}$$

At the end of February there was 5.927 g m^{-2} of condensate at interface 12 and 9.919 g m^{-2} of condensate at interface 13. The evaporation in March will easily clear all of the condensate at both interfaces.

16 Further information

16.1 Vapour resistance units converter

In this report we have used the vapour resistivity ζ [$\text{MN s g}^{-1} \text{m}^{-1}$] to characterise the resistance of a material to the diffusion of vapour. The vapour resistivity is just one set of units by which the resistance can be measured. Some of the different sets of units are material properties, like the vapour resistivity, while others apply to a given thickness of material. There are also sets of units for the permeability of the material to the diffusion of vapour. These are inversely proportional to the resistivity of the material.

On the Atkinson Science web site you can find a vapour resistance units converter that you can use to convert from one set of units of vapour resistance or permeability to another:

<https://atkinsonscience.co.uk/WebApps/Construction/VapResUnitsConverter.aspx>

On the same web page there is a user guide and a theory guide that you can download.

16.2 Climate classes web application

Also on the Atkinson Science web site you can find a climate classes web application:

<https://atkinsonscience.co.uk/WebApps/Construction/ClimateClasses.aspx>

The user selects the location and climate class of the building from drop-down lists and the application returns the monthly mean relative humidity inside the building based on an internal temperature of 20°C. On the same web page there is a user guide and a theory guide that you can download.

16.3 Two- and three-dimensional vapour diffusion

A fundamental assumption of the Glaser method is that the diffusion of vapour is one-dimensional. The method is strictly only valid when applied to planar structures. The diffusion of vapour will then be normal to the inner and outer surfaces over most of the structure.

At a right-angled joint there will be diffusion in two orthogonal directions, rendering the Glaser method invalid. However, it is possible to extend the method to two- and three-dimensions by employing a computational fluid dynamics (CFD) program. On the Atkinson Science web site you will find case studies in which we have used a CFD program to calculate vapour diffusion in a roof junction, a canopy junction and a balcony junction:

<https://atkinsonscience.co.uk/Services/Condensation.aspx>

17 References

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