BS EN ISO 13788:2012

BSI Standards Publication

Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods (ISO 13788:2012)

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National foreword

This British Standard is the UK implementation of EN ISO 13788:2012. It supersedes BS EN ISO 13788:2002 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/540, Energy performance of materials components and buildings.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Foreword

This document (EN ISO 13788:2012) has been prepared by Technical Committee ISO/TC 163 "Thermal performance and energy use in the built environment" in collaboration with Technical Committee CEN/TC 89 “Thermal performance of buildings and building components” the secretariat of which is held by SIS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2013, and conflicting national standards shall be withdrawn at the latest by June 2013.

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This document supersedes EN ISO 13788:2001.

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Endorsement notice

The text of ISO 13788:2012 has been approved by CEN as a EN ISO 13788:2012 without any modification.

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 13788 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods* in cooperation with CEN/TC 89, *Thermal performance of buildings and building components*.

This second edition cancels and replaces the first edition (ISO 13788:2001), which has been technically revised.

Introduction

Moisture transfer is a very complex process and the knowledge of moisture transfer mechanisms, material properties, initial conditions and boundary conditions is often limited. Therefore this International Standard lays down simplified calculation methods, which assume that moisture transport is by vapour diffusion alone and use monthly climate data. The standardization of these calculation methods does not exclude use of more advanced methods. If other sources of moisture, such as rain penetration or convection, are negligible, the calculations will normally lead to designs well on the safe side and if a construction fails a specified design criterion according to this procedure, more accurate methods may be used to show that the design will pass.

This International Standard deals with:

a) the critical surface humidity likely to lead to problems such as mould growth on the internal surfaces of buildings,

b) interstitial condensation within a building component, in:

   — heating periods, where the internal temperature is usually higher than outside;

   — cooling periods, where the internal temperature is usually lower than the outside;

   — cold stores, where the internal temperature is always lower than outside.

c) an estimate of the time taken for a component, between high vapour resistance layers, to dry, after wetting from any source, and the risk of interstitial condensation occurring elsewhere in the component during the drying process.

This International Standard does not cover other aspects of moisture, e.g. ground water and ingress of precipitation.

In some cases, airflow from the interior of the building into the structure is the major mechanism for moisture transport, which can increase the risk of condensation problems very significantly. This International Standard does not address this issue; where it is felt to be important, more advanced assessment methods should be considered.

The limitations on the physical processes covered by this International Standard mean that it can provide a more robust analysis of some structures than others. The results will be more reliable for lightweight, airtight structures that do not contain materials that store large amounts of water. They will be less reliable for structures with large thermal and moisture capacity and which are subject to significant air leakage.

Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods

1 Scope

This International Standard gives simplified calculation methods for:

a) The internal surface temperature of a building component or building element below which mould growth is likely, given the internal temperature and relative humidity. The method can also be used to assess the risk of other internal surface condensation problems.

b) The assessment of the risk of interstitial condensation due to water vapour diffusion. The method used does not take account of a number of important physical phenomena including:

- the variation of material properties with moisture content;
- capillary suction and liquid moisture transfer within materials;
- air movement from within the building into the component through gaps or within air spaces;
- the hygroscopic moisture capacity of materials.

Consequently, the method is applicable only where the effects of these phenomena can be considered to be negligible.

c) The time taken for water, from any source, in a layer between two high vapour resistance layers to dry out and the risk of interstitial condensation occurring elsewhere in the component during the drying process.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6946:2007, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

ISO 9346, *Hygrothermal performance of buildings and building materials — Physical quantities for mass transfer — Vocabulary*

ISO 15927-1, *Hygrothermal performance of buildings — Calculation and presentation of climatic data — Part 1: Monthly means of single meteorological elements*

3 Terms and definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9346 and the following apply.

3.1.1
monthly mean temperature
mean temperature calculated from hourly values or the daily maximum and minimum temperature over a month

3.1.2
temperature factor at the internal surface
difference between the temperature of the internal surface and the external air temperature, divided by the difference between the internal operative temperature and the external air temperature, calculated with a surface resistance at the internal surface R_{si}:

$$f_{R_{si}} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e}$$

Note 1 to entry: The operative temperature is taken as the arithmetic mean value of the internal air temperature and the mean radiant temperature of all surfaces surrounding the internal environment.

Note 2 to entry: Methods of calculating the temperature factor in complex constructions are given in ISO 10211.

3.1.3
design temperature factor at the internal surface
minimum acceptable temperature factor at the internal surface:

$$f_{R_{si,min}} = \frac{\theta_{si,min} - \theta_e}{\theta_i - \theta_e}$$

3.1.4
minimum acceptable temperature
lowest internal surface temperature before mould growth may start

3.1.5
mean annual minimum temperature
mean of the lowest temperature recorded in each year of a set of at least ten years' data

3.1.6
internal moisture excess
rate of moisture production in a space divided by the air change rate and the volume of the space:

$$\Delta \mathrm{v} = \mathrm{v}_i - \mathrm{v}_e = \mathrm{G} / (\mathrm{n} \cdot V)$$

3.1.7
water vapour diffusion-equivalent air layer thickness
thickness of a motionless air layer which has the same water vapour resistance as the material layer in question: $s_d = \mu \cdot d$

3.1.8
relative humidity
ratio of the vapour pressure to the saturated vapour pressure at the same temperature:

$$\varphi = \frac{p}{p_{sat}}$$

3.1.9
critical surface humidity
relative humidity at the surface that leads to deterioration of the surface, specifically mould growth

3.1.10
heating period
external climate that leads to risk of condensation when a building is being heated, so that the internal temperature and vapour pressure are higher than outside

3.1.11
cooling period
external climate that leads to risk of condensation when a building is being cooled, so that the internal temperature and vapour pressure are lower than outside

3.2 Symbols and units

Symbol	Quantity	Unit
D	water vapour diffusion coefficient in a material	m^2/s
D_0	water vapour diffusion coefficient in air	m^2/s
G	internal moisture production rate	kg/h
M_a	accumulated moisture content per area at an interface	kg/m^2
R	thermal resistance	$m^2 \cdot K/W$
R_v	gas constant for water vapour = 462	$Pa \cdot m^3/(K \cdot kg)$
T	thermodynamic temperature	K
U	thermal transmittance of component or element	$W/(m^2 \cdot K)$
V	internal volume of building	m^3
Z_p	water vapour diffusion resistance with respect to partial vapour pressure	$m^2 \cdot s \cdot Pa/kg$
Z_v	water vapour diffusion resistance with respect to humidity by volume	s/m^2
d	material layer thickness	m
f_{Rsi}	temperature factor at the internal surface	-
$f_{Rsi,min}$	design temperature factor at the internal surface	-
g	density of water vapour flow rate	$kg/(m^2 \cdot s)$
n	air change rate	h^{-1}
p	water vapour pressure	Pa
q	density of heat flow rate	W/m^2
s_d	water vapour diffusion-equivalent air layer thickness	m
t	time	s
w	moisture content mass by volume	kg/m^3
δ_p	water vapour permeability of material with respect to partial vapour pressure	$kg/(m \cdot s \cdot Pa)$
δ_0	water vapour permeability of air with respect to partial vapour pressure	$kg/(m \cdot s \cdot Pa)$
v	humidity of air by volume	kg/m^3
Δv	internal moisture excess, $v_i - v_e$	kg/m^3
Δp	internal vapour pressure excess, $p_i - p_e$	Pa
φ	relative humidity	-
λ	thermal conductivity	$W/(m \cdot K)$
μ	water vapour resistance factor	-
θ	Celsius temperature	°C
$\theta_{si,min}$	minimum acceptable surface temperature	°C

3.3 Subscripts

an	annual	m	mean
c	condensation	n	interface
cr	critical value	s	surface
e	external air	sat	value at saturation
ev	evaporation	se	external surface
eq	equivalent (outside temperature)	si	internal surface
i	internal air	T	total over the whole component or element
min	minimum value		

4 Input data for the calculations

4.1 Material and product properties

For the calculations, design values shall be used. Design values in product or material specifications or the tabulated design values given in the standards referred to in Table 1 may be used.

Table 1 — Material and product properties

Property	Symbol	Design values
Thermal conductivity Thermal resistance	λ R	Obtained or determined in accordance with ISO 10456.
Water vapour resistance factor Water vapour diffusion-equivalent air layer thickness	μ s_d	Obtained from ISO 10456 or determined in accordance with ISO 12572.

Thermal conductivity, λ, and water vapour resistance factor, μ, are applicable to homogenous materials and thermal resistance, R, and water vapour diffusion-equivalent air layer thickness, s_d, apply primarily to composite products or products without well-defined thickness.

For air layers, R is taken from ISO 6946 and s_d is assumed to be 0,01 m, independent of air layer thickness and inclination.

4.2 External boundary conditions

4.2.1 Location

Unless otherwise specified, the external conditions used shall be representative of the location of the building, taking account of altitude where appropriate.

NOTE Unless other information is available (for example in national standards), it can be assumed that temperature falls by 1 K for every 200 m increase in altitude.

4.2.2 Time period for climatic data

For the calculation of the risk of surface mould growth or the assessment of structures for the risk of interstitial condensation, monthly mean values, derived using the methods described in ISO 15927-1, or in national standards, shall be used.

In the absence of national data or standards, the mean monthly temperatures shall be those likely to occur once in 10 years, obtained from local climate records. If these data are not available, 2 K may be subtracted from the monthly mean temperatures for an average year for calculations in a heating climate, or 2 K added to the monthly mean temperatures for an average year in a cooling climate.

For calculations of the risk of surface condensation on low thermal inertia elements such as windows and their frames, the average, taken over several years, of the lowest daily mean temperature in each year shall be used in the absence of any national standards.

4.2.3 External temperature

The following temperatures shall be used for the calculations.

a) For calculations of walls exposed to the outside, the external air temperature as specified in 4.2.1 and 4.2.2 shall be used.

b) For calculation of solid ground floors or walls below the ground, incorporate 2 m of soil below the floor in the calculation. The monthly mean temperatures in the ground below this may be estimated with the following steps:

— Take the twelve monthly mean external air temperatures: θ_m

— Average these to give the annual mean external air temperature: θ_{an}

— For each month calculate the average of the θ_m and θ_{an}: $(\theta_{an}+\theta_m)/2$

— Displace the calculated values by one month, so the January value becomes February etc.

— If necessary, more detailed calculation of ground temperature may be carried out with the methods in ISO 13370.

c) For calculations of suspended floors algorithms for the calculation of monthly subfloor temperatures from the internal and external monthly temperatures are given in Annex E of ISO 13370

d) For calculations of roofs the monthly mean equivalent outside temperature, $\overline{\theta_{eq}}$, which takes account of solar gain and cooling by long wave radiation, should be used; $\overline{\theta_{eq}}$ can be calculated using the methodology given in ISO 13790. As a simplified case, $\overline{\theta_{eq}}$ can be taken by subtracting 2 K from every monthly mean external air temperature.

4.2.4 External humidity

4.2.4.1 External air

To define the external air humidity conditions, use vapour pressure, p_e.

Monthly mean vapour pressure may be calculated from the mean temperature and relative humidity using Formula (1).

$$\overline{p_e} = \overline{\varphi_e}\, p_{sat}\left(\overline{\theta_e}\right) \qquad (1)$$

For calculations of the risk of surface condensation on low thermal inertia elements such as windows and their frames, the external relative humidity corresponding to the temperatures defined in 4.2.2 shall be used.

NOTE In some climates the relative humidity associated with the mean annual minimum temperature can be assumed to be 0,85.

4.2.4.2 Humidity conditions in the ground

Assume saturation ($\varphi = 1$).

4.3 Internal boundary conditions

4.3.1 Internal air temperature

Use values according to the expected use of the building.

NOTE Annex A gives a method for estimating internal air temperature from the external temperature.

4.3.2 Internal humidity

The internal air humidity can be either

a) obtained from

$$p_i = p_e + \Delta p \quad (2)$$

Take values of Δp according to the expected use of the building.

Δp may be derived from the internal moisture excess, Δv, using

$$\Delta p = \Delta v \, R_v \, T_i = \frac{G}{nV} R_v \, T_i \quad (3)$$

Values of Δp for a range of building types may be found in Appendix A.

or

b) given as a monthly mean value φ_i when the internal relative humidity is known.

NOTE Annex A gives a method for estimating internal relative humidity from the external air temperature.

c) given as a constant φ_i when the internal relative humidity is kept constant e.g. by air-conditioning.

4.4 Surface resistances

4.4.1 Heat transfer

The value of R_{se} shall be taken as 0,04 m^2·K/W.

For condensation or mould growth on opaque surfaces, an internal surface thermal resistance of 0,25 m^2·K/W shall be taken to represent the effect of corners, furniture, curtains or suspended ceilings, if there are no national standards.

The values of R_{si} given in Table 2 shall be used for the assessment of interstitial condensation, or surface condensation on windows and doors.

Table 2 — Internal thermal resistances for the assessment of interstitial condensation, or surface condensation on windows and doors

Direction of heat flow	**Thermal resistance** m2·K/W
Upwards	0,10
Horizontal	0,13
Downwards	0,17

4.4.2 Water vapour transfer

The surface water vapour resistance is assumed to be negligible in the calculations in accordance with this International Standard.

5 Calculation of surface temperature to avoid critical surface humidity

5.1 General

This clause specifies a method to design the building envelope to prevent the adverse effects of critical surface humidity, e.g. mould growth.

NOTE Surface condensation can cause damage to unprotected building materials that are sensitive to moisture. It can be accepted temporarily and in small amounts, e.g. on windows and tiles in bathrooms, if the surface does not absorb the moisture and adequate measures are taken to prevent its contact with adjacent sensitive materials.

There is a risk of mould growth when monthly mean surface relative humidities are above a critical relative humidity, $\varphi_{si,cr}$, which should be taken as 0,8 unless more specific information is available from National Regulations or elsewhere.

5.2 Determining parameters

Besides the external climate (air temperature and humidity), three parameters govern surface condensation and mould growth:

a) the “thermal quality” of each building envelope element, represented by thermal resistance, thermal bridges, geometry and internal surface resistance. The thermal quality can be characterized by the temperature factor at the internal surface, f_{Rsi} ;

  NOTE ISO 10211 gives a method for calculating weighting factors, when there is more than one inside boundary temperature.

b) the internal moisture supply;

c) internal air temperature and the heating system and its settings.

5.3 Design for avoidance of mould growth, corrosion or other moisture damage

To avoid mould growth the monthly mean relative humidity at the surface should not exceed a critical relative humidity φ_{sicr}, which should be taken as 0,8 unless more specific information is available from National Regulations or elsewhere. Other criteria, e.g. $\varphi_{sicr} \leq 0{,}6$ to avoid corrosion, can be used if appropriate.

The principal steps in the design procedure are to determine the internal air humidity and then, based on the required relative humidity at the surface, to calculate the acceptable saturation humidity by volume, v_{sat}, or vapour pressure, p_{sat}, at the surface. From this value, a minimum surface temperature and hence a required “thermal quality” of the building envelope (for a given internal air temperature and expressed by f_{Rsi}) is established.

For each month of the year, go through the following steps:

a) define the external temperature in accordance with 4.2.3;

b) define the external humidity in accordance with 4.2.4;

c) define the internal temperature in accordance with national practice;

d) use the procedure defined in 4.3.2 to obtain the internal relative humidity;

e) with a maximum acceptable relative humidity at the surface, $\varphi_{si} = \varphi_{sicr}$, calculate the minimum acceptable saturation vapour pressure, p_{sat}

$$p_{sat}(\theta_{si}) = \frac{p_i}{\phi_{sicr}} \tag{4}$$

f) determine the minimum acceptable surface temperature, $\theta_{si,min}$, from the minimum acceptable saturation vapour pressure calculated in e);

NOTE The temperature as a function of saturation vapour pressure can be found from Formula (E.3) or Formula (E.4). Another option is to prepare a table or a graph, based on Formulae (E.1) and (E.2), indicating the relationship between p_{sat} and θ_i to find θ from p_{sat}.

g) from the minimum acceptable surface temperature, $\theta_{si,min}$, assumed internal air temperature, θ_i (see 4.3.1) and external temperature, θ_e, the minimum temperature factor, $f_{Rsi,min}$, is calculated according to the Formula in 3.1.3.

The month with the highest required value of $f_{Rsi,min}$ is the critical month. The temperature factor for this month is $f_{Rsi,max}$ and the building element shall be designed so that $f_{Rsi,max}$ is always exceeded, i.e. $f_{Rsi} > f_{Rsi,max}$.

Examples of this procedure are given in Annex B.

For a given building design effective values of f_{Rsi} can be derived:

— for plane elements, from $f_{Rsi} = 1 - R_{si}\,U$;

— where multidimensional heat flow occurs, from a finite element or similar programme in accordance with ISO 10211.

5.4 Design for the limitation of surface condensation on low thermal inertia elements

The assessment of surface condensation on low thermal inertia elements such as, for example, windows and their frames, which show fast response to temperature changes, requires a different procedure.

Condensation on the inside surface of window frames can be an inconvenience if the water runs onto adjacent decorations, and can cause corrosion in metal frames or rot in wooden ones by penetrating joints, e.g. between the frame and glass. Because of their impermeable surface finish, mould growth is rarely a problem on window frames. The maximum acceptable relative humidity at the frame surface is therefore $\varphi_{si} = 1$.

Some intermittent condensation on window frames may be acceptable, however the procedure specified below will limit this.

a) Define the external temperature as the average, taken over several years, of the lowest daily mean temperature in each year.

b) Define the internal temperature according to national practice.

c) Use the procedure defined in 4.3.2 to obtain the internal relative humidity.

d) With a maximum acceptable relative humidity at the internal surface, $\varphi_{si} = 1{,}0$, calculate the minimum acceptable vapour pressure, p_{sat}

$$p_{sat}(\theta_{si}) = p_i \tag{5}$$

e) Determine the minimum acceptable surface temperature, $\theta_{si,min}$, from the minimum acceptable saturation vapour pressure.

NOTE 1 The temperature as a function of saturation vapour pressure can be found from Formula (E.3) or Formula (E.4). Another option is to prepare a table or a graph, based on Formulae (E.1) and (E.2) indicating the relationship between p_{sat} and θ_i to find θ from p_{sat}.

f) From the minimum acceptable surface temperature $\theta_{si,min}$, assumed internal air temperature, θ_i (see 4.3.1) and external temperature, θ_e, the required temperature factor of the building element, $f_{Rsi,min}$, is calculated according to the Formula in 3.1.3.

Owing to the complex form and variety of materials used in window frames and the interactions between the glass, frame and wall containing the window, heat flows and surface temperatures cannot, generally, be calculated by simple one dimensional methods. Care therefore needs to be taken linking the minimum acceptable surface temperature of the frame to the internal and external air temperatures.

Two, or if necessary three, dimensional finite element calculations on complete window systems including the glazing, give surface temperatures that can be scaled to any combination of internal or external temperatures. Calculations carried out with an insulation material, such as expanded polystyrene, substituted for the glazing, used to obtain an equivalent thermal transmittance of the frame, do not give accurate surface temperatures.

NOTE 2 Details of appropriate calculation methods are given in ISO 10077-2.

Various simplified methods have been developed to allow the calculation of realistic thermal transmittances of complete windows taking account of multi-dimensional heat flows through the frame and the spacer between the panes of double glazing. While these will give accurate heat flows, surface temperatures will be seriously in error and they should not be used to estimate the risk of condensation.

6 Calculation of interstitial condensation

6.1 General

This clause gives a method to establish the annual moisture balance and to calculate the maximum amount of accumulated moisture due to interstitial condensation. The method is an assessment rather than an accurate prediction tool. It is suitable for comparing different constructions and assessing the effects of modifications. It does not provide an accurate prediction of moisture conditions within the structure under service conditions.

6.2 Principle

Starting with the first month in which any condensation is predicted, the monthly mean external conditions are used to calculate the amount of condensation or evaporation in each of the 12 months of a year. The accumulated mass of condensed water at the end of those months when condensation has occurred is compared with the total evaporation during the rest of the year. One-dimensional, steady-state conditions are assumed. The only effect of air movement considered is the presence of a continuous air cavity, which is well ventilated to the outside as defined in ISO 6946. The effect of air movement through the building component is not considered.

Moisture transfer is assumed to be pure water vapour diffusion, described by the following equation:

$$g = \frac{\delta_0}{\mu}\frac{\Delta p}{d} = \delta_0 \frac{\Delta p}{s_d} \tag{6}$$

where $\delta_0 = 2 \times 10^{-10}$ kg/(m·s·Pa).

NOTE 1 δ_0 depends on temperature and barometric pressure, but these influences are neglected in this International Standard.

The density of heat flow rate is given by:

$$q = \lambda \frac{\Delta \theta}{d} = \frac{\Delta \theta}{R} \tag{7}$$

NOTE 2 The thermal conductivity, λ, and the thermal resistance, R, are assumed constant and the specific heat capacity of the materials not relevant. For parallel sided homogeneous materials, $R = d/\lambda$. Heat sinks/sources due to phase changes are neglected.

NOTE 3 Calculation methods according to this principle are often called "Glaser methods". More advanced methods are specified in EN 15026.

6.3 Limitation of sources of error

There are several sources of error caused by the simplifications described in 6.2.

a) The thermal conductivity depends on the moisture content, and heat is released/absorbed by condensation/evaporation. This will change the temperature distribution and saturation values and affect the amount of condensation/drying.

b) The use of constant material properties is an approximation.

c) Capillary suction and liquid moisture transfer occur in many materials and this may change the moisture distribution.

d) Air movements within building materials, gaps, joints or air spaces may change the moisture distribution by moisture convection. Rain or melting snow may also affect the moisture conditions.

e) The real boundary conditions are not constant over a month.

f) Most materials are at least to some extent hygroscopic and can absorb water vapour.

g) One-dimensional moisture transfer is assumed.

h) The effects of solar and long-wave radiation are neglected except for roofs.

NOTE Due to the many sources of error, this calculation method is less suitable for certain building components and climates. Neglecting moisture transfer in the liquid phase normally results in an overestimate of the risk of interstitial condensation.

This International Standard is not intended to be used for building elements where there is airflow through or within the element or where rain water is absorbed.

6.4 Calculation

6.4.1 Material properties

Divide the building element into a series of parallel-sided homogeneous layers and define the material properties of each layer and the surface coefficients in accordance with 4.4.1 and 4.4.2. Each layer in multi-layer products or components, including any products with facings or coatings, shall be treated as an individual layer, taking full account of their respective thermal and moisture vapour transmission properties. Calculate the thermal resistance, R, and the water vapour diffusion-equivalent air layer thickness, s_d, of each individual layer of the building element. It is recommended that elements with a thermal resistance greater than 0,25 $m^2 \cdot K/W$ are subdivided into a number of notional layers each with thermal resistance not exceeding 0,25 $m^2 \cdot K/W$; these subdivisions are treated as separate material layers with interfaces between them in all calculations.

If the element contains a layer which is well ventilated to the outside, as defined in 5.3.4 of ISO 6946:2007, take no account of all material layers between the cavity and outside.

Some materials, such as sheet metals, effectively prevent the passage of any water vapour and therefore have an infinite value of μ. However, as a finite value of μ for a material is required for the calculation procedure, a value of 100 000 should be taken for these materials. This can lead to the prediction of negligibly small amounts of condensation, which should be disregarded as due to the inaccuracy of the calculation method.

Calculate the accumulated thermal resistance and the water vapour diffusion-equivalent air layer thickness from the outside to each interface *n*.

$$R'_{\mathrm{n}} = R_{\mathrm{se}} + \sum_{j=1}^{n} R_j \tag{8}$$

$$s'_{\mathrm{d},n} = \sum_{j=1}^{n} s_{\mathrm{d},j} \tag{9}$$

The total thermal resistance and the water vapour diffusion-equivalent air layer thickness are given by Formulae (10) and (11):

$$R'_{\mathrm{T}} = R_{\mathrm{si}} + \sum_{j=1}^{N} R_j + R_{\mathrm{se}} \tag{10}$$

$$s'_{\mathrm{d,T}} = \sum_{j=1}^{N} s_{\mathrm{d},j} \tag{11}$$

6.4.2 Boundary conditions for interstitial condensation

Define internal and external temperature and humidity according to 4.2.

If the element contains a layer which is well ventilated to the outside, assume the temperature and vapour pressure in the cavity are the same as outside air. Assume the outside surface thermal resistance is the same as the value for inside appropriate to the direction of heat flow, as defined in Table 2.

6.4.3 Starting month

Starting with any month of the year (the trial month), calculate the temperature, saturated vapour pressure and vapour distributions through the component as specified in 6.4.4 and 6.4.5. Determine whether any condensation is predicted.

If no condensation is predicted in the trial month, repeat the calculation with successive following months until either:

a) no condensation has been found in any of the 12 months, then report the component as free from condensation; or

b) a month is found with condensation, this is the starting month.

If condensation is predicted in the trial month, repeat the calculation with successively earlier months until either:

c) condensation is predicted in all 12 months; then, starting in any month, calculate the total annual accumulation of condensation as specified in 6.4.4, 6.4.5 and 6.4.6; or

d) a month is found with no condensation; then take the following month as the starting month.

NOTE In climates outside the tropics, with well defined seasons, choosing a trial month two or three months before the coldest period of the year will normally allow the starting month to be found rapidly.

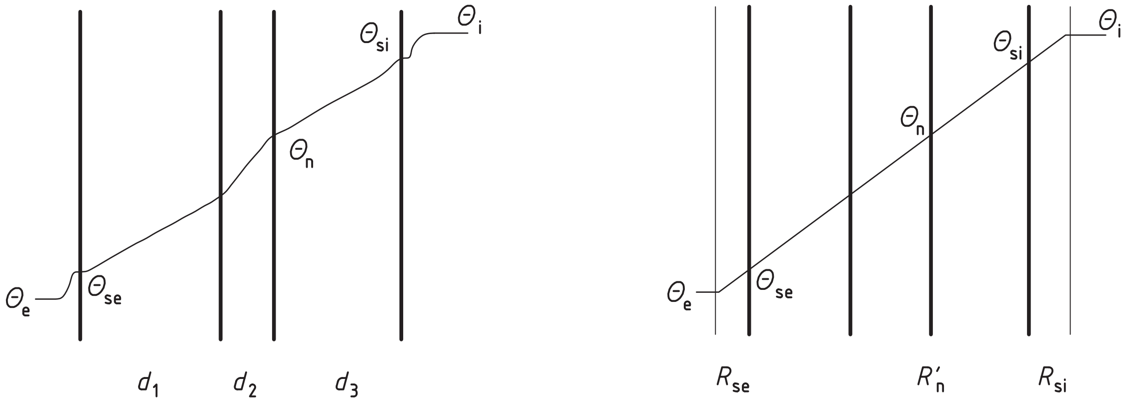
If a starting month has been determined, carry out the calculations specified in 6.4.4, 6.4.5 and 6.4.6 for each month of the year, starting with the starting month.

6.4.4 Temperatures and saturated vapour pressure distribution

Calculate the temperature at each interface between materials according to:

$$\theta'_n = \theta_e + \frac{R'_n}{R'_T}(\theta_i - \theta_e) \quad (12)$$

The temperature distribution in each layer is linear given the assumption of steady-state conditions, see Figure 1.



(a) Plotted against the width of each layer **(b) Plotted against thermal resistance of each layer**

Figure 1 — Temperature distribution in a multi-layer building element

Calculate the saturation vapour pressure from the temperature at each interface between material layers.

NOTE Expressions for saturation vapour pressure as a function of temperature are given in Annex E.

6.4.5 Vapour pressure distribution

Draw a cross section of the building element with the thicknesses of each layer equivalent to its water vapour diffusion-equivalent air layer thickness, s_d, see Figure 2. Draw straight lines joining the saturation vapour pressures at each interface between materials.

If there is no accumulated condensate from the previous month, draw the vapour pressure profile as a straight line between the internal and external vapour pressure (p_i and p_e). If this line does not exceed the saturation pressure at any interface, condensation does not occur; see Figure 2, in which the water vapour pressure in the building component is lower at every point in the component than the vapour saturation pressure.

The vapour flow rate through the building element may be calculated as:

$$g = \delta_0 \frac{p_i - p_e}{s'_{d,T}} \quad (13)$$

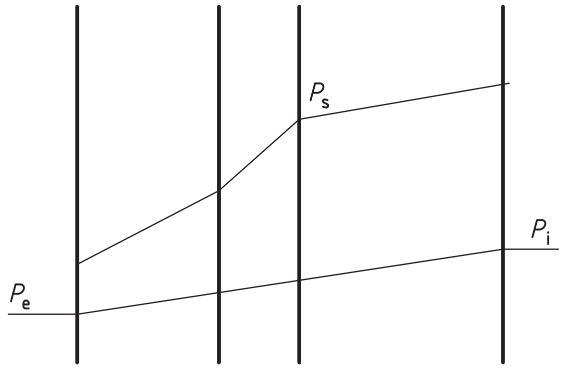


Figure 2 — Water vapour diffusion in a multi-layer building element without any interstitial condensation

If the vapour pressure exceeds the saturation pressure at any interface, assume that the local value of the vapour pressure is equal to the saturation pressure and redraw the vapour pressure as a series of lines which touch, but do not exceed the saturation vapour pressure profile at as few points as possible, see examples in Figures 3 and 4. These points are the condensation interfaces.

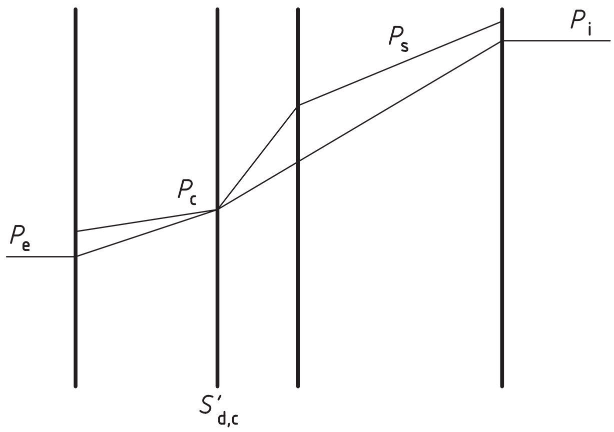


Figure 3 — Water vapour diffusion with interstitial condensation in one interface plane

6.4.6 Condensation rate

The rate of condensation is the difference between the amount of moisture transported to and the amount of moisture transported from the condensation interface:

$$g_c = \delta_0 \left(\frac{p_i - p_c}{s'_{d,T} - s'_{d,c}} - \frac{p_c - p_e}{s'_{d,c}} \right) \quad (14)$$

In a building component with **more than one** condensation interface, maintain a record of the amount of condensation in each interface.

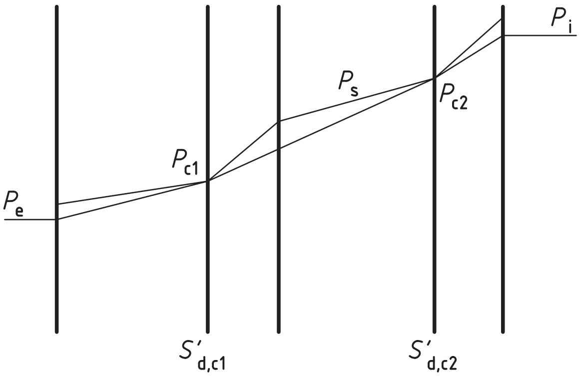


Figure 4 — Water vapour diffusion with interstitial condensation in two interface planes

The rate of condensation is calculated for each condensation interface from the difference in slope between successive straight lines, that is, in the case of two condensation interfaces (see Figure 4).

At interface c1:

$$g_{c1} = \delta_0 \left(\frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} - \frac{p_{c1} - p_e}{s'_{d,c1}} \right) \tag{15}$$

At interface c2:

$$g_{c2} = \delta_0 \left(\frac{p_i - p_{c2}}{s'_{d,T} - s'_{d,c2}} - \frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} \right) \tag{16}$$

6.4.7 Evaporation

When there is condensate, accumulated from previous months, at one or more interfaces, the vapour pressure shall be equal to the saturation pressure and the vapour pressure profile shall be drawn as straight lines between the values representing internal vapour pressure, condensation interfaces and external vapour pressure, see Figure 5. If the vapour pressure values exceed the saturation values at any interface, redraw the vapour pressure lines as specified in 6.4.4.

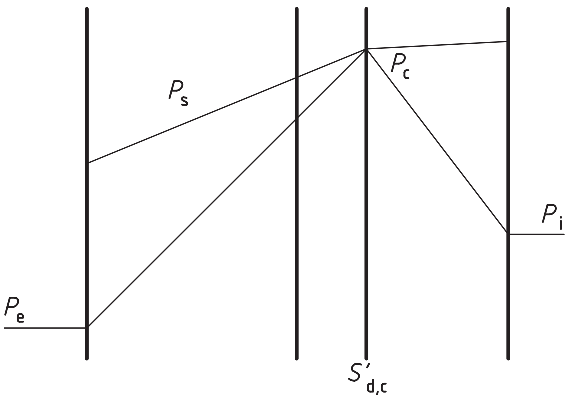


Figure 5 — Evaporation from an interface in the building component

The rate of evaporation is calculated as

$$g_{ev} = \delta_0 \left(\frac{p_i - p_c}{s'_{d,T} - s'_{d,c}} - \frac{p_c - p_e}{s'_{d,c}} \right) \tag{17}$$

NOTE The expressions for the rate of evaporation and condensation are the same. By convention, condensation occurs if the expression is positive and evaporation if the expression is negative.

In a building component with **more than one** condensation interface the rate of evaporation is calculated for each interface separately, see Figure 6.

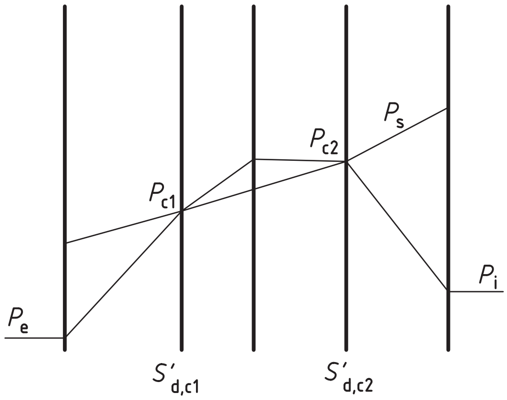


Figure 6 — Evaporation from a building component, when condensation has occurred in two interfaces

The rates of evaporation, for two evaporation interfaces, are calculated as (see Figure 6):

At interface c1:

$$g_{ev1} = \delta_0 \left(\frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} - \frac{p_{c1} - p_e}{s'_{d,c1}} \right) \tag{18}$$

At interface c2:

$$g_{ev2} = \delta_0 \left(\frac{p_i - p_{c2}}{s'_{d,T} - s'_{d,c2}} - \frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} \right) \tag{19}$$

If the accumulated amount of condensate at an interface at the end of the month is calculated as a negative value, either set it to zero or 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.

6.4.8 Evaporation and condensation

In a building component with more than one condensation interface there could be months with condensation in one interface and evaporation in another, see Figure 7.

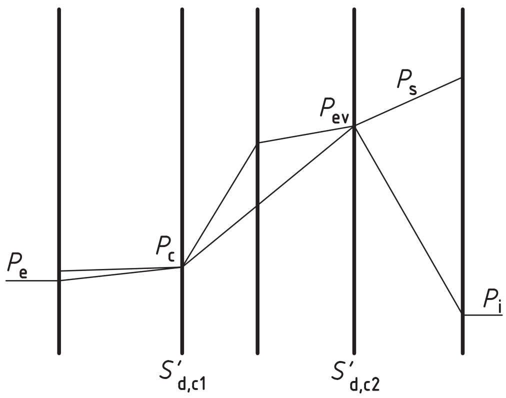


Figure 7 — Evaporation in one interface and condensation in another in a building component, where condensation has occurred in two interfaces

The rate of condensation, g_c, or evaporation, g_{ev}, are calculated for each interface separately:

Condensation between layer 1 and 2:

$$g_c = \delta_0 \left(\frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} - \frac{p_{c1} - p_e}{s'_{d,c1}} \right) \tag{20}$$

Evaporation between layer 3 and 4:

$$g_{ev} = \delta_0 \left(\frac{p_i - p_{c2}}{s'_{d,T} - s'_{d,c2}} - \frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} \right) \tag{21}$$

Examples of interstitial condensation calculations are given in Annex C.

6.5 Criteria used to assess building components

Report the results of the calculations according to a), b) or c) as applicable.

a) No condensation predicted at any interface in any month.

In this case report the structure as being free of interstitial condensation.

b) Condensation occurs at one or more interfaces during some months but, for each interface concerned, there is no net accumulation over the year as all the condensate is predicted to evaporate again.

In this case report the maximum amount of condensation that occurred at each interface, and the month during which the maximum occurred. Also, the risk of water run-off or degradation of building materials and deterioration of thermal performance as a consequence of the calculated maximum amount of moisture shall be considered according to regulatory requirements and other guidance in product standards.

NOTE If the maximum accumulation of condensate exceeds 200 g/m^2 the risk of run-off from non-absorbent materials will be very high.

c) Condensation at one or more interfaces does not completely evaporate.

In this case report that the structure has failed the assessment, and state the maximum amount of moisture that occurred at each interface together with the amount of moisture remaining after twelve months at each interface.

7 Calculation of drying of building components

7.1 General

This clause gives a method to establish the drying potential of building components, especially those bounded by high vapour resistance layers such as foils, membranes or coatings with $s_d > 2$ m, that have shown no harmful condensation with the procedure specified in Clause 6, under the imposed internal and external climate. It also assesses the risk of interstitial condensation, at another location within the component, caused by the water evaporating from a wetted layer.

NOTE Material layers may have become wet by built-in moisture, rain impact during construction, a leak from services, a defect in a waterproof layer or a previous interstitial condensation problem that has been rectified.

The method should be regarded as an assessment rather than as an accurate prediction tool. It is suitable for comparing different constructions and assessing the effects of modifications.

7.2 Principle

The procedure assumes that there is an excess moisture content of 1 kg/m^2 concentrated at the centre of a specified layer. The monthly mean external conditions are used to calculate the amount of evaporation in each of the twelve months of a year. This year is repeated until the excess moisture content of the specified layer reaches zero. This time in months is reported as the length of time that the structure will take to dry out completely. At the same time the risk of condensation at other interfaces, caused by the evaporated excess moisture, is evaluated.

7.3 Specification of the method

a) Specify the material layer assumed to have been wetted;

b) Divide that layer into two equal parts, with an interface between them;

c) Introduce 1 kg/m^2 of moisture at that interface.

Carry out the interstitial condensation procedure specified in 6.4.4 to 6.4.8, starting with the appropriate month and repeating the monthly calculations until either all the excess moisture has dried out or ten years have been calculated.

7.4 Criteria used to assess drying potential of building components

Report the results of the calculations according to a), b) or c) as applicable.

a) Drying out within ten years without condensation in other layers.

   In this case report the drying out time in months and estimate the risk of degradation to the layer containing the excess moisture.

b) Drying out within ten years with temporary condensation in other layers.

   In this case report the drying out time in months and the maximum amount of condensation that occurred at each interface, and the month during which the maximum occurred. Also, the risk of water run-off or degradation of building materials and deterioration of thermal performance as a consequence of the calculated maximum amount of moisture shall be considered according to regulatory requirements and other guidance in product standards.

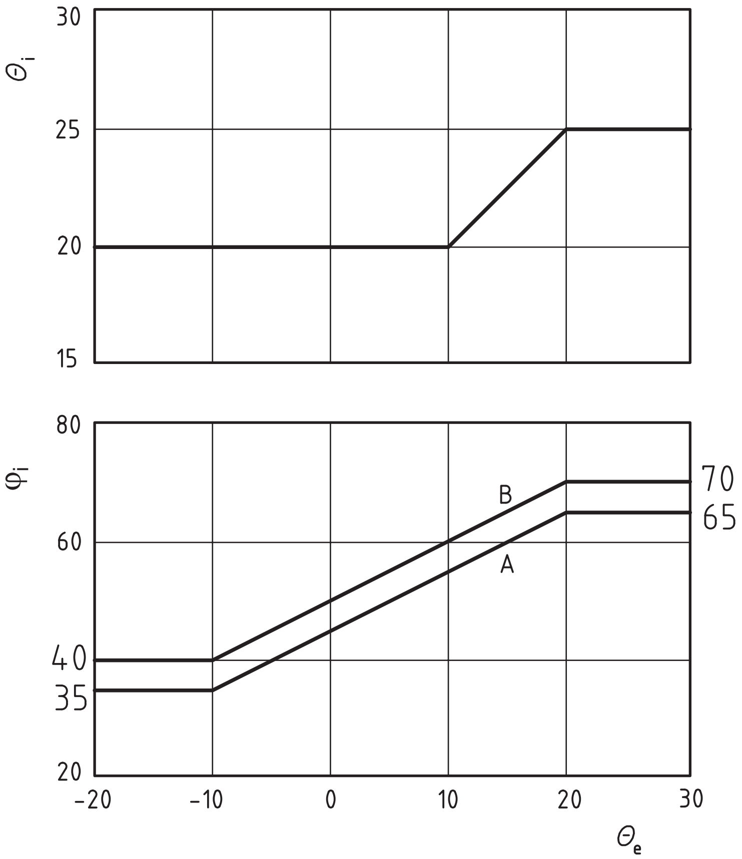
c) Drying time exceeds ten years.

Annex A
(informative)

Internal boundary conditions

A.1 'Continental' and tropical climates

In the absence of well-defined - controlled, measured or simulated - internal air conditions, a simplified approach to determine the internal temperature and humidity for heated buildings (only dwellings and offices) based on the external air temperature may be used. The internal air conditions are derived from entering the daily mean of the external air temperature into the graphs in Figure A.1. The internal air humidity level is selected according to the expected occupancy of the building.



Key

θ_i internal temperature, expressed in °C

φ_i internal relative humidity, expressed in %

θ_e external temperature, expressed in °C

A normal occupancy

B high occupancy

Figure A.1 — Daily mean internal air temperature and humidity in dwellings and office buildings depending on the daily mean external air temperature

A.2 Maritime climates

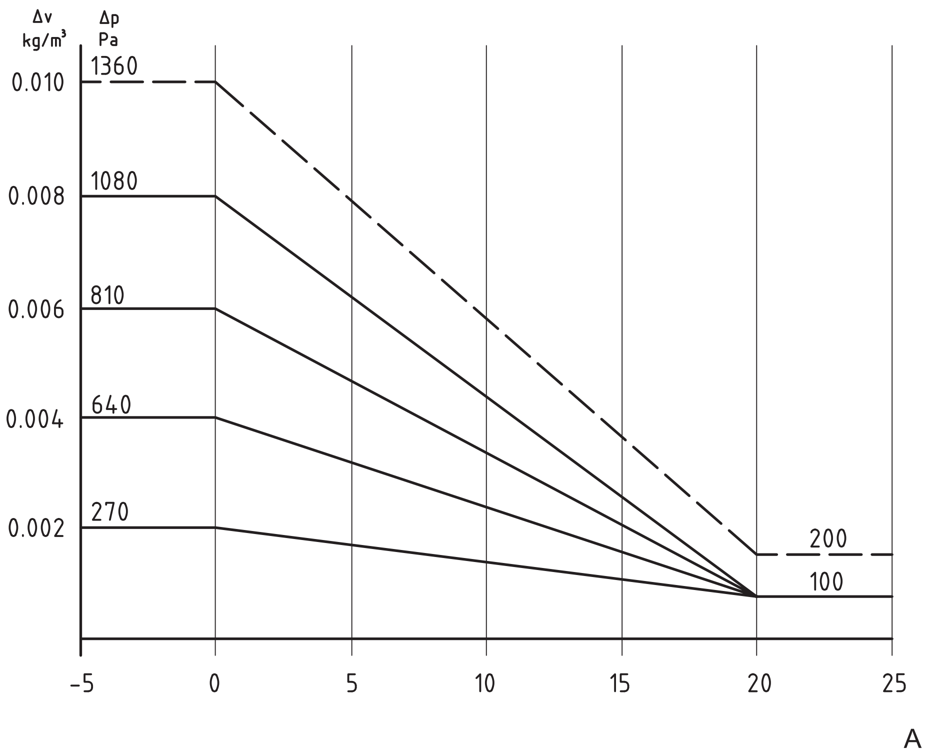
Internal humidity load can be described by five humidity classes. Figure A.2 shows limit values of Δ*v* and Δ*p* for each class. For the calculations, it is recommended that the upper limit value for each class is used unless the designer can demonstrate that conditions are less severe. The data in Figure A.2 are derived from buildings in Western Europe. Measured data may be used to derive values applicable to other climates.

Table A.1 gives some guidance regarding selection of humidity class.

Table A.1 — Internal humidity classes

Humidity 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

Wherever possible measured data should be used for the analysis of buildings in class 5, with high internal humidities. The dotted line on Figure A.2 gives suggested values that could be used in the absence of other data.



Key

A monthly mean outdoor temperature, expressed in °C

Figure A.2 — Variation of internal humidity classes with external temperature

Annex B
(informative)

Examples of calculation of the temperature factor at the internal surface to avoid critical surface humidity

B.1 Example 1, using the internal conditions defined in Annex A

a) The monthly mean external temperature, θ_e, and relative humidity, φ_e, for the location of the building are defined (columns 1 and 2 in Table B.1).

b) The monthly internal temperature, θ_i, and relative humidity, φ_i, are derived from the external temperature using the lines in Figure A.1, assuming high occupancy (columns 3 and 4 in Table B.1). The internal saturated vapour pressure, $p_{sat}(\theta_i)$, is calculated from the internal temperature using Formula (E.1) or Formula (E.2), where appropriate, and multiplied by the internal relative humidity to give the internal vapour pressure, p_i, (column 5 in Table B.1).

c) The minimum acceptable saturation vapour pressure, $p_{sat}(\theta_{si})$, is calculated using Formula (4) as specified in 5.3e) and the minimum acceptable surface temperature, $\theta_{si,min}$, calculated from Formula (E.3) or Formula (E.4) to give the values in columns 6 and 7 of Table B.1.

d) The internal and external temperatures are used to calculate f_{Rsi} with the Formula in 3.1.2

to give the values shown in column 8 of Table B.1.

With the conditions assumed in Table B.1, January is the critical month and $f_{Rsi,max}$ = 0,622.

Table B.1 — Calculation of $f_{Rsi,max}$ in a high occupancy building

Month	1	2	3	4	5	6	7	8
	θ_e °C	φ_e	θ_i °C	φ_i	p_i Pa	$p_{sat}(\theta_{si})$ Pa	$\theta_{si,min}$ °C	f_{Rsi}
January	2,4	0,92	20,0	0,52	1 225	1 531	13,3	0,622
February	2,8	0,88	20,0	0,53	1 234	1 542	13,5	0,620
March	4,5	0,85	20,0	0,55	1 274	1 592	13,9	0,609
April	6,7	0,80	20,0	0,57	1 325	1 656	14,6	0,591
May	9,8	0,78	20,0	0,60	1 397	1 747	15,4	0,547
June	12,6	0,80	21,3	0,63	1 585	1 981	17,4	0,547
July	14,0	0,82	22,0	0,64	1 691	2 114	18,4	0,549
August	13,7	0,84	21,9	0,64	1 668	2 085	18,2	0,548
September	11,5	0,87	20,8	0,62	1 505	1 882	16,5	0,546
October	9,0	0,89	20,0	0,59	1 379	1 724	15,2	0,561
November	5,0	0,91	20,0	0,55	1 285	1 607	14,1	0,606
December	3,5	0,92	20,0	0,54	1 250	1 563	13,7	0,616

B.2 Example 2, assuming a constant internal relative humidity

In the case of an air conditioned building, where the temperature and relative humidity are controlled at 20 °C and 0,50:

a) The monthly mean external temperature, θ_e, and internal temperature, θ_i, and relative humidity, φ_i, are defined for the building under investigation (columns 1, 2 and 3 in Table B.2).

b) The internal saturated vapour pressure, $p_{sat,i}$, is derived from the temperature using Formula (E.1) or Formula (E.2) or Table E.1; this is combined with the internal relative humidity, to give the internal vapour pressure, p_i, shown in column 4 of Table B.2.

c) The minimum acceptable saturation vapour pressure, $p_s(\theta_{si})$, is calculated using Formula (9) as specified in 5.3e) and the minimum acceptable surface temperature, $\theta_{si,min}$, calculated from Formula (E.3) or Formula (E.4) to give the values in columns 5 and 6 of Table B.2.

d) The Formula in 3.1.2

is used to calculate f_{Rsi} giving the values shown in column 7 of Table B.2.

With the conditions assumed in Table B.2, January is the critical month and $f_{Rsi,max}$ = 0,581.

Table B.2 — Calculation of $f_{Rsi,max}$ using controlled internal humidity

Month	1	2	3	4	5	6	7
	θ_e °C	θ_i °C	φ_i	p_i Pa	$p_{sat}(\theta_{si})$ Pa	$\theta_{si,min}$ °C	f_{Rsi}
January	2,4	20	0,5	1 168	1 461	12,6	0,581
February	2,8	20	0,5	1 168	1 461	12,6	0,571
March	4,5	20	0,5	1 168	1 461	12,6	0,524
April	6,7	20	0,5	1 168	1 461	12,6	0,445
May	9,8	20	0,5	1 168	1 461	12,6	0,277
June	12,6	20	0,5	1 168	1 461	12,6	0,003
July	14,0	20	0,5	1 168	1 461	12,6	-0,229
August	13,7	20	0,5	1 168	1 461	12,6	-0,171
September	11,5	20	0,5	1 168	1 461	12,6	0,132
October	9,0	20	0,5	1 168	1 461	12,6	0,330
November	5,0	20	0,5	1 168	1 461	12,6	0,508
December	3,5	20	0,5	1 168	1 461	12,6	0,553

B.3 Example 3, with a known moisture supply and constant ventilation rate

a) The monthly mean external temperature, θ_e, and relative humidity, φ_e, for the location of the building are defined (columns 1 and 2 in Table B.3).

b) The monthly external saturated vapour pressure, $p_{sat,e}$, calculated from the temperature using Formula (E.1) or Formula (E.2), where appropriate, or Table E.1, and the relative humidity are used to calculate the external vapour pressure, p_e, (column 3 in Table B.3).

c) The internal moisture supply vapour pressure excess, Δv, is calculated from the assumed air change rate, n, moisture production rate, G, and volume of the building, V, and converted into a vapour pressure excess, Δp, using Formula (E.6). This is added to pe to give the internal vapour pressure (columns 5 and 6 of Table B.3).

d) The minimum acceptable saturation vapour pressure, $p_{sat}(\theta_{si})$, is calculated using Formula (9) as specified in 5.3e) and the minimum acceptable surface temperature, $\theta_{si,min}$, calculated from Formula (E.3) or Formula (E.4) to give the values in columns 8 and 9 of Table B.3.

e) The Formula in 3.1.2

is used to calculate f_{Rsi} giving the values shown in column 10 of Table B.3.

With the conditions assumed in Table B.3, August is the critical month and $f_{Rsi,max}$ = 0,832.

Table B.3 — Calculation of $f_{Rsi,max}$ using a constant ventilation rate

Month	1	2	3	4	5	6	7	8	9	10
	θ_e °C	φ_e	p_e Pa	n h^{-1}	Δp Pa	p_i Pa	$p_{sat}(\theta_{si})$ Pa	$\theta_{si,min}$ °C	θ_i °C	f_{Rsi}
January	2,8	0,92	687,0	0,5	433	1 120	1 400	12,0	20	0,534
February	2,8	0,88	657,1	0,5	433	1 090	1 363	11,6	20	0,510
March	4,5	0,85	715,6	0,5	433	1 149	1 436	12,4	20	0,507
April	6,7	0,80	784,7	0,5	433	1 218	1 522	13,3	20	0,493
May	9,8	0,78	944,5	0,5	433	1 378	1 722	15,2	20	0,525
June	12,6	0,80	1166,6	0,5	433	1 600	1 999	17,5	20	0,663
July	14,0	0,82	1310,1	0,5	433	1 743	2 179	18,9	20	0,812
August	13,7	0,84	1316,2	0,5	433	1 749	2 186	18,9	20	0,830
September	11,5	0,87	1179,9	0,5	433	1 613	2 016	17,6	20	0,722
October	9,0	0,89	1021,2	0,5	433	1 454	1 818	16,0	20	0,637
November	5,0	0,91	793,4	0,5	433	1 226	1 533	13,4	20	0,558
December	3,5	0,92	721,9	0,5	433	1 155	1 444	12,4	20	0,542

NOTE G = 0,4 kg/h, V = 250 m^3.

B.4 Example 4, with a known moisture supply and variable ventilation rate

In practice, buildings are ventilated less in colder weather. If a relationship between the air change rate and temperature is known or can be assumed, the values of f_{Rsi} can be calculated as in example 3 but using the variable air change rate in step 3).

The values in Table B.4 were calculated assuming that $n = 0,2 + 0,04\ \theta_e$. With these conditions, January is the critical month and $f_{Rsi,max}$ = 0,718.

Table B.4 — Calculation of $f_{Rsi,max}$ using a variable ventilation rate

Month	1	2	3	4	5	6	7	8	9	10
	θ_e °C	φ_e	p_e Pa	n h^{-1}	Δp Pa	p_i Pa	$p_{sat}(\theta_{si})$ Pa	$\theta_{si,min}$ °C	θ_i °C	f_{Rsi}
January	2,8	0,92	683	0,31	694	1 377	1 722	15,2	20	0,718
February	2,8	0,88	657	0,31	694	1 351	1 689	14,9	20	0,701
March	4,5	0,85	709	0,38	570	1 279	1 599	14,0	20	0,614
April	6,7	0,80	788	0,47	463	1 251	1 564	13,7	20	0,524
May	9,8	0,78	941	0,59	366	1 307	1 634	14,3	20	0,445
June	12,6	0,80	1 162	0,70	308	1 470	1 837	16,2	20	0,483
July	14,0	0,82	1 302	0,76	285	1 587	1 984	17,4	20	0,563
August	13,7	0,84	1 317	0,75	290	1 607	2 008	17,6	20	0,615
September	11,5	0,87	1 183	0,66	328	1 511	1 889	16,6	20	0,601
October	9,0	0,89	1 017	0,56	387	1 404	1 755	15,5	20	0,587
November	5,0	0,91	788	0,40	542	1 330	1 662	14,6	20	0,641
December	3,5	0,92	719	0,34	637	1 356	1 695	14,9	20	0,692

NOTE G = 0,4 kg/h, V = 250 m^3.

Annex C
(informative)

Examples of calculation of interstitial condensation

C.1 Environmental conditions

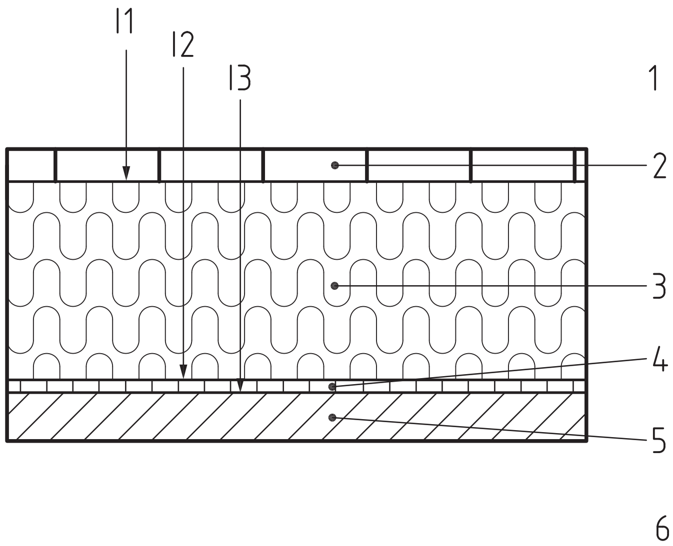
Table C.1 shows the external and internal environmental conditions used in the two examples in C.2 and C.3. The internal conditions are derived from the external conditions using the lines in Figure A.1, assuming low and high occupancy.

Table C.1 — External and internal conditions used for analysis

Month	External		Internal Normal occupancy		Internal High occupancy	
	θ_e °C	φ_e	θ_i °C	φ_i	θ_i °C	φ_i
January	-1	0,85	20,0	0,39	20,0	0,49
February	0	0,84	20,0	0,40	20,0	0,50
March	4	0,78	20,0	0,44	20,0	0,54
April	9	0,72	20,0	0,49	20,0	0,59
May	14	0,68	22,0	0,54	22,0	0,64
June	18	0,69	24,0	0,58	24,0	0,68
July	19	0,73	24,5	0,59	24,5	0,69
August	19	0,75	24,5	0,59	24,5	0,69
September	15	0,79	22,5	0,55	22,5	0,65
October	10	0,83	20,0	0,50	20,0	0,60
November	5	0,88	20,0	0,45	20,0	0,55
December	1	0,88	20,0	0,41	20,0	0,51

C.2 Example 1: Building component with condensation in one interface plane

In this example, the flat roof with an impermeable weather proofing layer over the insulation, shown in Figure C.1 is analysed using the internal and external climates shown in Table C.1 and the material properties shown in Table C.2.



Key

1 external air
2 weatherproofing 0,01 m
3 insulation 0,10 m
4 vapour check
5 liner 0,012 m
6 internal air

Figure C.1 — Materials for flat roof in example 1

Table C.2 — Material properties for flat roof

	d m	R m²·K/W	μ	s_d m
External resistance	–	0,04	–	–
Weatherproofing	0,010	0,05	500 000	5 000
Insulation	0,100	3	150	15
Vapour check	–	–	–	1 000
Liner	0,012	0,075	10	0,12
Internal resistance	–	0,10	–	–

NOTE The material properties shown in the examples refer to generic material types, not specific materials.

The three interfaces at the intersections between the material layers shown in Figure C.1 are analysed. At the beginning of the calculation, it is assumed that the accumulated moisture content, M_a, in all three interfaces is zero.

Using the environmental data for normal occupancy in Table C.1, November is determined as the starting month as described in 6.4.3, 6.4.4 and 6.4.5, with the vapour pressure exceeding the saturated vapour pressure at interface 1, the interface between the insulation and weatherproofing. The rate of condensation, g_c, is calculated from Formula (14). This makes up the accumulated moisture content, M_a, at the end of November shown in the third column of Table C.3.

This procedure is then repeated using the environmental conditions for each month from Table C.1. In each month, no condensation is predicted at interfaces 2 and 3. As shown in Table C.3, the rate of condensation at interface 1 rises to a peak in the coldest month of January and then falls towards zero in March.

Table C.3 — Monthly condensation rate and accumulation at interface 1

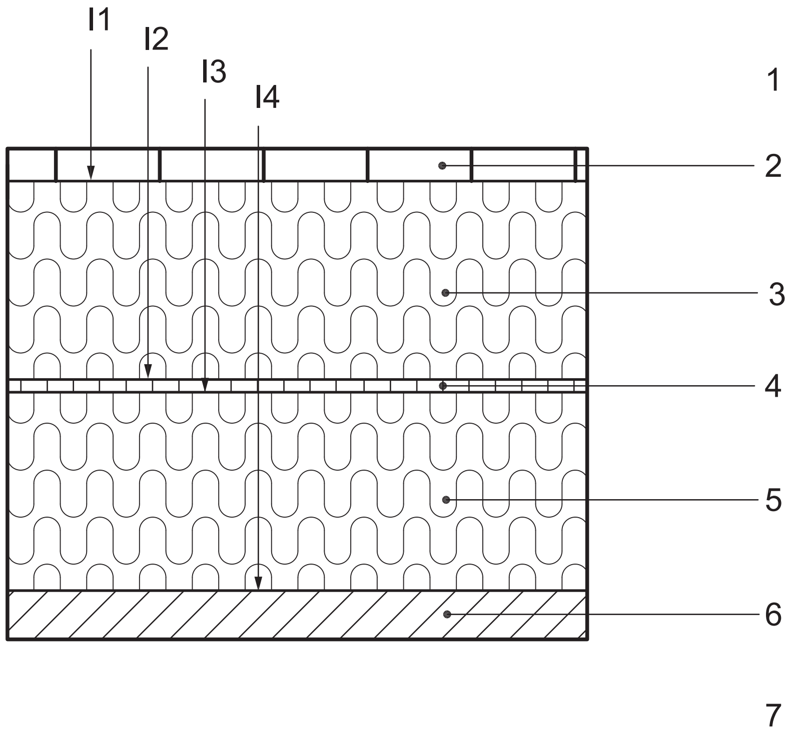
Month	Normal occupancy		High occupancy	
	g_c kg/m^2	M_a kg/m^2	g_c kg/m^2	M_a kg/m^2
October	0	0	0,00005	0,00005
November	0,00006	0,00006	0,00018	0,00023
December	0,00013	0,00019	0,00026	0,00049
January	0,00015	0,00035	0,00028	0,00077
February	0,00013	0,00048	0,00024	0,00101
March	0,00008	0,00055	0,00020	0,00120
April	-0,00005	0,00050	0,00007	0,00127
May	-0,00016	0,00034	-0,00002	0,00125
June	-0,00025	0,00009	-0,00010	0,00115
July	-0,00028	0	-0,00012	0,00103
August	0	0	-0,00011	0,00092
September	0	0	-0,00002	0,00090

From April onwards, the rate of condensation becomes negative, i.e. evaporation is occurring as specified in 6.4.6, and the accumulated moisture falls until it is close to zero in June. During July, the accumulated moisture dries out, and is set to zero.

If high occupancy is assumed, condensation starts in October and the rate again rises to a peak in January. Evaporation starts in May, but all the condensate has not evaporated by September.

C.3 Example 2: Building component with condensation in two interfaces

In this example a flat roof with an extra 100 mm of insulation added below the vapour control layer shown in Figure C.2 is analysed using the material properties shown in Table C.4 and the high occupancy internal and external climates shown in Table C.1.



Key

1 external air
2 weatherproofing, 0,01 m
3 insulation, 0,10 m
4 vapour check
5 insulation, 0.01 m
6 liner, 0,012 m
7 internal air

Figure C.2 — Materials for roof in example 2

Table C.4 — Material properties for insulated flat roof

	d m	*R* $m^2 \cdot K/W$	μ	s_d m
External resistance	–	0,04	–	–
Weatherproofing	0,010	0,05	500 000	5 000
Insulation	0,100	3	150	15
Vapour check	–	–	–	1 000
Insulation	0,100	3	150	15
Liner	0,012	0,075	10	0,12
Internal resistance	–	0,10	–	–

The four interfaces at the intersections between the material layers shown in Figure C.2 are analysed. At the beginning of the calculation, it is assumed that the accumulated moisture content, M_a, in all four interfaces is zero.

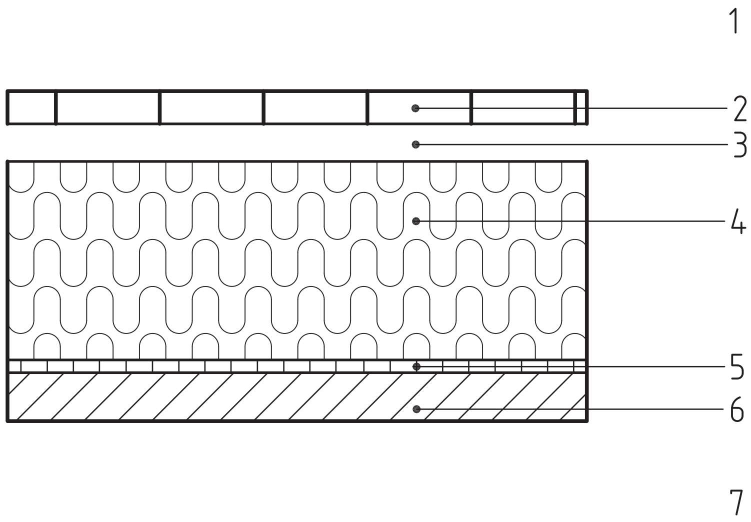
Using the environmental data in Table C.1, December is determined as the starting month as described in 6.4.3, 6.4.4 and 6.4.5, with the vapour pressure exceeding the saturated vapour pressure at interface 1, the interface between the weather proofing and outer layer of insulation, and at interface 3 between the inner layer of insulation and the vapour control layer. The rate of condensation, g_c, is calculated from Formulae (20) and (21). Condensation persists at interface 1 throughout the year, however at interface 3 the accumulation of condensate peaks in March; evaporation takes place in April and May with complete drying by the end of May.

Table C.5 — Monthly condensation rates and accumulation within the insulated wall

Month	Interface 1		Interface 3	
	g_c kg/m^2	M_a kg/m^2	g_c kg/m^2	M_a kg/m^2
December	0,00022	0,00022	0,04734	0,04734
January	0,00022	0,00043	0,06722	0,11456
February	0,00019	0,00063	0,05209	0,16665
March	0,00020	0,00083	0,01139	0,17804
April	0,00015	0,00098	-0,06451	0,11352
May	0,00012	0,00110	-0,12130	0
June	0,00009	0,00119	0	0
July	0,00009	0,00129	0	0
August	0,00010	0,00139	0	0
September	0,00013	0,00152	0	0
October	0,00016	0,00168	0	0
November	0,00020	0,00188	0	0

C.4 Example 3: Building component containing a well ventilated cavity

The flat roof, shown in Figure C.3 contains a well ventilated cavity between the weather proofing layer and the insulation. In this case, as specified in 6.4.1, the weather proofing layer is not included in the analysis and the external surface thermal resistance is made equal to the internal resistance, giving the material properties shown in Table C.6.



Key

1 external air
2 weatherproofing, 0,01 m
3 well ventilated cavity
4 insulation, 0,10 m
5 vapour check
6 liner, 0,012 m
7 internal air

Figure C.3 — Materials for ventilated flat roof in example 3

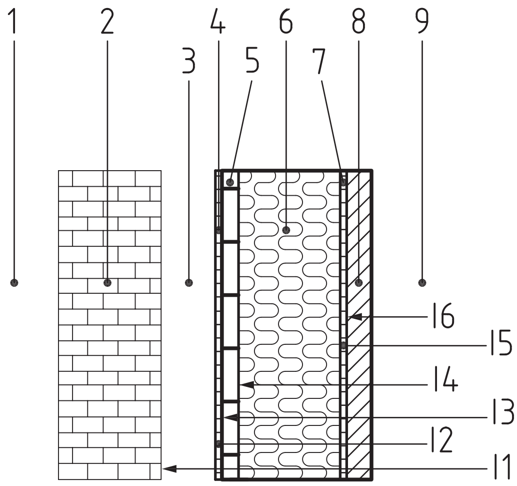
Table C.6 — Material properties for flat roof including well ventilated cavity

	d m	*R* $m^2 \cdot K/W$	*μ*	s_d M
External resistance	–	0,10	–	–
Insulation	0,100	3	150	15
Vapour check	–	–	–	1 000
Liner	0,012	0,075	10	0,12
Internal resistance	–	0,10	–	–

Analysis of this structure with the climates shown in Table C.1 does not predict condensation in any month.

C.5 Example 4: Building component in a warm humid climate

In this example the timber framed wall shown in Figure C.4 is analysed using the material properties shown in Table C.7.



Key

1 external air
2 brick, 0,105 m
3 unventilated cavity, 0,05 m
4 permeable membrane
5 plywood, 0,012 m
6 insulation, 0,140 m
7 vapour control layer
8 plasterboard, 0,0125 m
9 internal air

Figure C.4 — Materials for timber framed wall in example 4

Table C.7 — Material properties for timber framed wall

	d m	*R* $m^2 \cdot K/W$	*μ*	s_d m
External resistance	–	0,04	–	–
Brick	0,105	0,136	8	0,84
Unventilated cavity	0,050	0,18	–	–
Permeable membrane	–	–	–	0,2
Plywood	0,012	0,092	90	1,1
Insulation	0,140	3,5	1,4	0,2
Vapour control layer	–	–	–	50
Plasterboard	0,0125	0,06	12	0,15
Internal resistance	–	0,13	–	–

Analysis using the external and internal climates in Table C.1, shows that no condensation is predicted in any month, as would be expected from the presence of the vapour control layer on the inside of the insulation.

If the component is assumed to be part of an air conditioned building in a hot humid climate, and is analysed using the climate data shown in Table C.8, condensation is predicted to occur on interface 5 between the insulation and the vapour control layer, during July, August and September, the hottest months of the year (see Table C.9).

Table C.8 — External and internal conditions in a hot humid climate

Month	External		Internal	
	θ_e °C	φ_e	θ_i °C	φ_i
January	8,0	63,0	20,0	40,0
February	8,0	63,4	20,0	40,0
March	11,0	64,4	20,0	40,0
April	15,5	69,2	20,0	40,0
May	19,5	76,9	20,0	40,0
June	21,5	84,1	20,0	40,0
July	26,0	85,4	20,0	40,0
August	27,0	82,8	20,0	40,0
September	25,0	80,2	20,0	40,0
October	20,0	70,5	20,0	40,0
November	15,5	68,8	20,0	40,0
December	10,5	66,4	20,0	40,0

Table C.9 — Monthly condensation rate and accumulation at interface 5

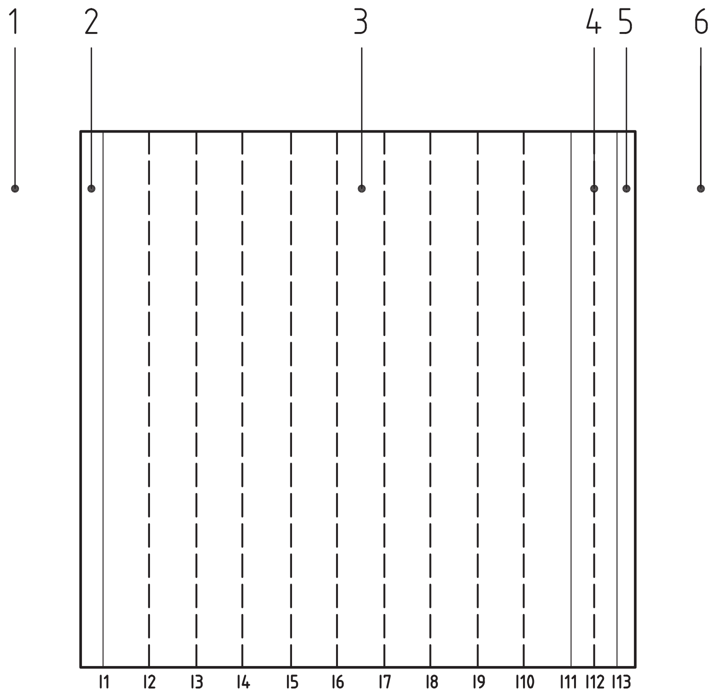
Month	Interface 5	
	g_c kg/m^2	M_a kg/m^2
July	0,0941	0,0941
August	0,1158	0,2100
September	0,0211	0,2311
October	-0,1701	0,0610
November	-0,2563	0,0000
December	0,0000	0,0000
January	0,0000	0,0000
February	0,0000	0,0000
March	0,0000	0,0000
April	0,0000	0,0000
May	0,0000	0,0000
June	0,0000	0,0000

C.6 Example 5: Division of a layer with high thermal resistance

In this example, a wall built from lightweight blockwork with internal insulation is analysed. The material properties of each layer are shown in Table C.10. Both the blockwork and the insulation have a thermal resistance greater than 0,25 m^{2}K/W, so the blockwork is divided into ten layers and the insulation into two to give the interfaces shown in Figure C.5.

Table C.10 — Material properties for wall

	d m	R m²·K/W	μ	s_d m
External resistance	–	0,04	–	–
Render	0,012	0,015	8	0,096
Blockwork	0,275	2,500	10	2,75
Insulation	0,020	0,500	1	0,02
Liner	0,013	0,023	8	0,10
Internal resistance	–	0,13	–	–



Key

1 external air
2 render, 0,012 m
3 blockwork, 0,275 m
4 insulation, 0,02 m
5 liner, 0,013 m
6 internal air

Figure C.5 — Materials for wall in example 5, subdivisions of material layers shown as dashed lines

If the external and internal climate data shown in Table C.11 is used to analyse the structure, condensation is predicted at interfaces 2 and 3 within the blockwork, see Table C.12.

Table C.11 — External and internal climates used for analysis

Month	External		Internal	
	θ_e °C	φ_e	θ_i °C	φ_i
January	-10	0,95	20	0,49
February	-8	0,94	20	0,50
March	-5	0,80	20	0,54
April	0	0,82	20	0,59
May	13	0,68	22	0,64
June	18	0,69	24	0,68
July	19	0,73	24,5	0,69
August	19	0,75	24,5	0,69
September	14	0,79	22,5	0,65
October	7	0,83	20	0,60
November	1	0,88	20	0,55
December	-4	0,95	20	0,51

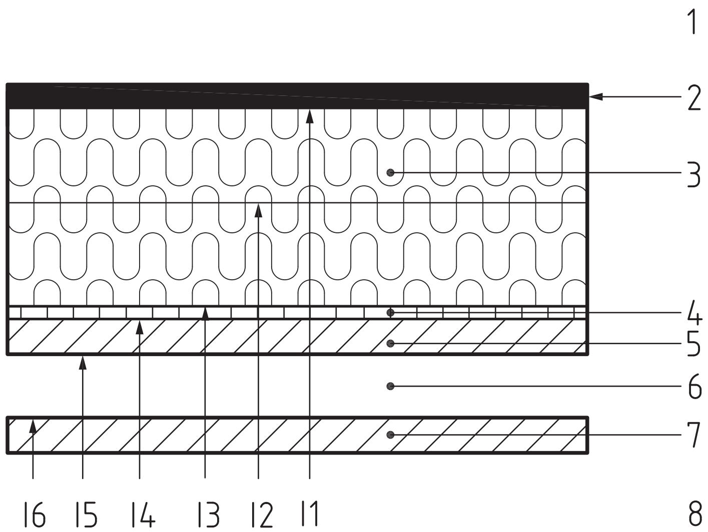
Table C.12 — Monthly condensation and accumulation rates at interfaces 2 and 3

Month	Interface 2		Interface 3	
	g_c kg/m^2	M_a kg/m^2	g_c kg/m^2	M_a kg/m^2
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
January	0,0249	0,0249	0,0249	0,0249
February	0,0056	0,0306	0,0057	0,0306
March	-0,0109	0,0196	-0,0109	0,0196
April	-0,0931	0	-0,0932	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0

Annex D
(informative)

Example of the calculation of the drying of a wetted layer

In this example, it is assumed that the insulation, layer 3 in the flat roof shown in Figure D.1, has been wetted by precipitation during construction before the outer weatherproof membrane was installed. The material properties for each layer are shown in Table D.1. If the component is analysed, using the external and high occupancy internal climates shown in Table C.1, without the wetted insulation, no condensation is predicted at any interface.



Key

1 external air
2 membrane
3 insulation
4 vapour check
5 roof deck
6 unventilated cavity
7 liner
8 inside air

Figure D.1 — Flat roof with wetted insulation at layer 3

Table D.1 — Material properties for flat roof

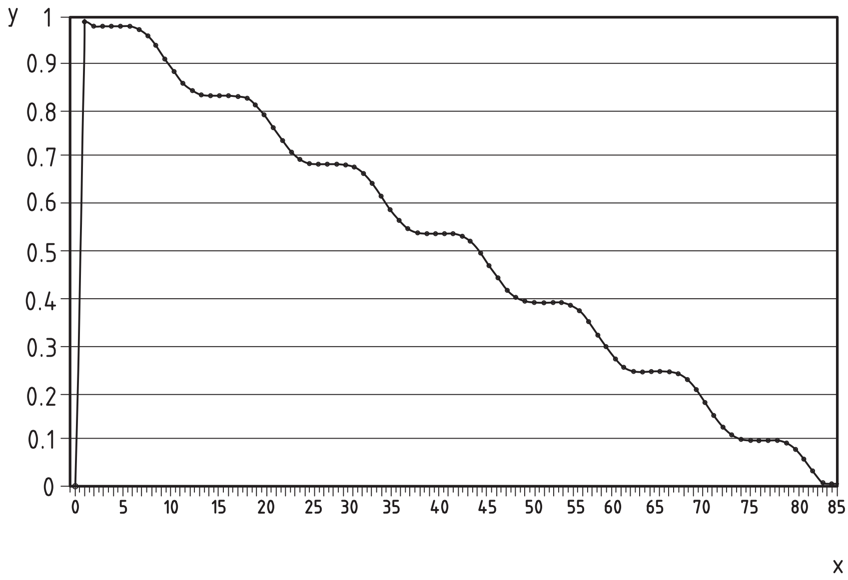
	d mm	R m²K/W	μ	s_d m
External resistance	–	0,04	–	–
Membrane	0,002	0,008	6 000	12,0
Insulation	0,200	5,0	1,0	0,2
Vapour check	–	–	–	75,0
Roof deck	0,019	0,146	10,0	0,19
Air layer	0,100	0,160	–	–
Liner	0,012	0,06	12,0	0,15
Internal resistance	–	0,1	–	–

The insulation layer is divided into two and it is assumed that there is excess moisture content of 1 kg/m² at the notional interface, I2, at the centre of the layer.

Analysis of the condensation and evaporation rates at each interface, with the procedure specified in 6.4.4 to 6.4.8 using the external and high occupancy internal climates shown in Table C.1, starting in September, shows that all the excess moisture at interface 2 moves to interface 1, within the first month (see Table D.2) Evaporation from interface 1 then takes place, until the amount of excess moisture reaches zero after 83 months (see Figure D.2).

Table D.2 — Monthly condensation rate and accumulation at interfaces 1 and 2

	Interface 2		Interface 1	
	g_c kg/m²	M_a kg/m²	g_c kg/m²	M_a kg/m²
	–	1,0	–	0,0
September	-1,382	0,0	0,99128	0,99128
October	0,0	0,0	-0,00845	0,98284
November	0,0	0,0	-0,00208	0,98075
December	0,0	0,0	-0,00013	0,98063
January	0,0	0,0	-0,00007	0,98056
February	0,0	0,0	-0,00073	0,97983
March	0,0	0,0	-0,00521	0,97462
April	0,0	0,0	-0,01266	0,96195
May	0,0	0,0	-0,02254	0,93942
June	0,0	0,0	-0,02820	0,91121
July	0,0	0,0	-0,02735	0,88386
August	0,0	0,0	-0,02539	0,85848



Key

x months

y condensate, expressed in kg/m^2

Figure D.2 — Amount of condensate at interface 1

Annex E
(informative)

Relationships governing moisture transfer and water vapour pressure

E.1 Water vapour saturation pressure as a function of temperature

The following empirical formulae give the saturated vapour pressure of water as a function of temperature

$$p_{sat} = 610{,}5\,e^{\frac{17{,}269\,\theta}{237{,}3+\theta}} \quad \text{for } \theta \geq 0\ °C \tag{E.1}$$

$$p_{sat} = 610{,}5\,e^{\frac{21{,}875\,\theta}{265{,}5+\theta}} \quad \text{for } \theta < 0\ °C \tag{E.2}$$

These may be inverted to allow the calculation of the temperature corresponding to any saturated vapour pressure.

$$\theta = \frac{237{,}3 \log_e\left(\dfrac{p_{sat}}{610{,}5}\right)}{17{,}269 - \log_e\left(\dfrac{p_{sat}}{610{,}5}\right)} \quad \text{for } p_{sat} \geq 610{,}5\ \text{Pa} \tag{E.3}$$

$$\theta = \frac{265{,}5 \log_e\left(\dfrac{p_{sat}}{610{,}5}\right)}{21{,}875 - \log_e\left(\dfrac{p_{sat}}{610{,}5}\right)} \quad \text{for } p_{sat} < 610{,}5\ \text{Pa} \tag{E.4}$$

Table E.1 — Saturated vapour pressure and humidity by volume

θ °C	P_{sat} Pa	v_{sat} kg/m^3	θ °C	P_{sat} Pa	v_{sat} kg/m^3
-20	103	0,00088	11	1 312	0,00999
-19	113	0,00096	12	1 402	0,01064
-18	124	0,00105	13	1 497	0,01132
-17	137	0,00115	14	1 598	0,01204
-16	150	0,00126	15	1 704	0,01280
-15	165	0,00138	16	1 817	0,01360
-14	181	0,00151	17	1 937	0,01444
-13	198	0,00165	18	2 063	0,01533
-12	217	0,00180	19	2 196	0,01626
-11	237	0,00196	20	2 337	0,01725
-10	259	0,00213	21	2 486	0,01828
-9	283	0,00232	22	2 642	0,01937
-8	309	0,00252	23	2 808	0,02051
-7	338	0,00274	24	2 982	0,02171
-6	368	0,00298	25	3 166	0,02297
-5	401	0,00324	26	3 359	0,02430
-4	437	0,00351	27	3 563	0,02568
-3	475	0,00381	28	3 778	0,02714
-2	517	0,00413	29	4 003	0,02866
-1	562	0,00447	30	4 241	0,03026
0	611	0,00484	31	4 490	0,03194
1	656	0,00518	32	4 752	0,03369
2	705	0,00555	33	5 027	0,03552
3	757	0,00593	34	5 316	0,03744
4	813	0,00634	35	5 619	0,03945
5	872	0,00678	36	5 937	0,04155
6	935	0,00724	37	6 271	0,04374
7	1 001	0,00773	38	6 621	0,04603
8	1 072	0,00825	39	6 987	0,04843
9	1 147	0,00880	40	7 371	0,05092
10	1 227	0,00938			

E.2 Vapour pressure and humidity by volume

Vapour pressure and humidity by volume are related by Formula (E.5):

$$p = v\, R_v\, T \qquad \text{(E.5)}$$

where

R_v is the gas constant for water = 462 Pa.m³/(K.kg);

T is the absolute temperature in kelvins.

The difference between internal and external water vapour pressure Δp is calculated as:

$$\Delta p = \Delta v \, R_v \, \frac{(T_i + T_e)}{2} = \frac{G}{nV} R_v \, \frac{(T_i + T_e)}{2} \qquad \text{(E.6)}$$

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