Conventions for U-value calculations

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BR 443
2019 Edition

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Acknowledgements:
Graeme Hannah (BRE); David Kelly (BRE); Sean Doran (BRE); Magdalena Arent (BRE); John Henderson (BRE); Steve Abnett (BRE); Bob Richardson (NFRC); Carlton Jones (MCRMA); Duncan King (CPA); David Roy (MCRMA); Guy Lewis (Structuraltimber); Jim Hooker (SPRA); Lauren Fairley (TIMSA); Lee Davies (MCRMA); Lewis Taylor (TRADA); Liz Wynder (NHBC); Mark Magennis (Xtratherm); Mark Stevenson (Kingspan); Mel Price (IMA); Malcolm Macleod (NHBC); Nick Burton (Steel-Window-Association); Nick Boulton (TTF); Paul Newman (Kingspan); Paul Cribbens (NHBC); Philip Lever (Aggregate, CBA); Richard Milward (Jablite); Rob Warren (Celotex); Sam Dave (Innovare systems); Steve Chaytor (NHBC); Stephen Wise (Knaufinsulation).

First published 2002
Second edition 2006
Third edition 2019

This document is published in memory of **Brian Anderson [1948-2016]**, the author of the 2002 and 2006 editions of this document.

Dr Brian Anderson was the lead author for the original BR 443 – Conventions for U-values, and the newly published revised version has been shaped by his initial input at the technical scoping stage prior to his unexpected passing in 2016.

Brian's contribution to the industry was huge, and with his expertise he guided, informed and enabled both government and generations of engineers, architects, builders, teachers and students to understand and construct better performing homes. He led the development and maintenance of BREDEM, and later SAP (the methodology by which we assess the compliance of domestic dwellings against the Energy Performance of Buildings Directive) and authored a range of more than 30 technical publications and papers to support this.

He also played a leading role in the preparation of European standards for thermal insulation and thermal performance, including chairing the committees for BSI (British Standards Institution) that co-ordinate the UK input to the CEN (European Committee for Standardisation) 'Thermal performance of buildings and building components', and playing a strategic role within CEN to ensure consistency and compatibility of various standards. The sum of Brian's work has had a profound, lasting and positive impact on us all – enabling the UK to measure and reduce household fuel use and provide a mechanism for reducing the nation's carbon emissions and addressing fuel poverty.

Brian was recognised and held in the highest esteem by those who knew him or of his work. He was admired and respected by colleagues and clients alike, based on his deep knowledge and experience, positive attitude and polite manner. He was a quiet and unassuming gentleman who had a passion for his work. His passing has been an enormous loss to both BRE and industry, and BRE are proud to publish the revised BR 443 in honour of his great contribution to the built environment.

CONTENTS

1 Introduction

1.1 General

This BRE report, BR443 (2019), is an update to the 2006 edition, primarily reflecting changes in British, European and International standards.

Calculation methods for the determination of heat transfer through building elements between internal and external environments are based on standards that were developed in the European Committee for Standardisation (CEN) and the International Organisation for Standardisation (ISO) and published as British Standards.

Since publication of the previous edition of this document, European standards specifying calculation methods for thermal properties have been amended, replacing the previous British standards BS EN ISO 6946, BS EN ISO 10211, BS EN ISO 10456, BS EN ISO13370, and BS EN ISO 13789 in addition to many other standards.

Earlier versions of this publication included references to the standards which were applicable at the time of publication. This document uses references to BS EN ISO standards which were published from 2017.

The guidance in this document is concerned with the calculated U-values of new building elements – walls, roofs, floors, windows and doors.

Guidance is given on:

- thermal conductivity of materials (section 3);
- various issues that commonly arise when undertaking U-value calculations (section 4);
- various types of construction element, identifying which of the issues mentioned in section 4 apply to which construction type (sections 7 to 14).

It does not reproduce the details of the calculation methods, for which the reader is referred to the relevant British Standards and other reference documents (see References and further reading).

In existing buildings the calculation of the thermal resistance (R-value) or thermal transmittance (U-value) can be difficult for the following reasons:

- materials traditionally used in buildings may not be homogeneous and their thermal conductivity values may not be available;
- establishing the exact composition and dimensions of layers of materials requires destructive methods, which will not always be possible.

Generic U-values for various elements of existing domestic buildings can be obtained from SAP (the Standard Assessment Procedure for energy Rating of dwellings); see also section 13 of this document.

1.2 The use of U-values in calculating heat transfer

The transmission heat transfer coefficient through the building elements separating the conditioned (e.g. heated or cooled) space and the external environment can be calculated either directly by numerical methods using the modelling rules given in BS EN ISO 10211 or, alternatively, according to Formula (1) given in BS EN ISO 13789.

The formula applies to all the building components, separating the internal and the external environments.

$$H_d = \sum(A_i \times U_i) + \sum(L_k \times \Psi_k) + \sum\chi_j \quad (1)$$

where:

- H_d - the direct heat transfer coefficient between the heated or cooled space and the exterior through the building envelope, in W/K;
- A_i - the area of element i of the building envelope, in m2 (the dimensions of windows and doors are taken as the dimensions of the aperture in the wall);
- U_i - the thermal transmittance (U-value) of element i of the building envelope, in W/m²K;
- L_k - the length of linear thermal bridge k, in m;
- Ψ_k - the linear thermal transmittance of thermal bridge k, in W/m·K;
- χ_j - the point thermal transmittance of point thermal bridge j, in W/K.

Where details of the thermal bridges are not known, for example in existing buildings, the second and third terms on the right-hand side of Formula (1) may be replaced by a default allowance for thermal bridges (H_{tb}).

This document provides conventions which can be used for the calculation of the rate of heat loss through individual components of the envelope of a building. In most cases the thermal properties of a building component are represented by its thermal transmittance, U-value (in W/m^{2}K). The U-value multiplied by the area of the component gives the rate of heat loss through the component per unit of temperature difference between inside and outside.

Repeating thermal bridges (which occur at fixed intervals in the element, such as timber studding) are taken into account in the calculation of the U-value of the component and no further allowance is needed.

Linear thermal transmittances (Ψ-values) arise at junctions between different components and point thermal transmittances of point thermal bridges (χ) occur where insulation is discretely penetrated; both are calculated by numerical modelling.

Sections 1.3, 1.4 and 2.5 give further details on the calculations methods.

1.3 Calculation methods for the determination of thermal transmittance (U-values).

Thermal transmittance, U-value, is calculated by the methods in:

- BS EN ISO 6946 for building components and building elements , excluding doors, windows and other glazing units, curtain walls, components involving heat transfer through the ground and air permeable components. The calculation method applies to components consisting of thermally homogeneous layers which may include air layers.

In essence, the method given in BS EN ISO 6946 is based on the relationship:

$$U = 1/R_{tot}$$

where:

U - U-value (W/m²ᐧK) of the building element

R_{tot} - Total thermal resistance of the building element (m²K/W)

For components consisting of homogeneous layers:

$$R_{tot} = R_{si} + R_1 + R_2 + \ldots R_n + R_{se}$$

where:

R_{si} - internal surface resistance

R_n - design thermal resistance of each layer (including air spaces)

R_{se} - external surface resistance

and thermal resistances of each layer is calculated as:

$$R = d/\lambda$$

where:

d - thickness of homogeneous layer (m)

λ - design thermal conductivity of the material in the layer (W/m·K).

For components consisting of homogeneous and inhomogeneous layers:

$$R_{tot} = (R_{tot,upper} + R_{tot,lower})/2$$

$R_{tot,upper}$ - the upper limit of total thermal resistance

$R_{tot,lower}$ - the lower limit of total thermal resistance

Both $R_{tot,upper}$ and $R_{tot,lower}$ are calculated in accordance with BS EN ISO 6946.

Calculation of surface resistances for surfaces with high emissivity (e.g reflective surfaces), thermal resistance of airspaces, thermal resistance of tapered layers are given in the Annexes to the standard.

The corrections to the calculated total thermal resistance are given in Appendix F of the standard.

This standard also provides approximate procedures to be used for elements containing inhomogeneous layers, including the effect of metal fasteners by means of . Other cases where insulation is bridged by metal are subject to other standards.

- BS EN ISO 13370 for calculation of heat transfer coefficients and heat flow rates for building elements in thermal contact with the ground, including slab-on-ground floors, suspended floors and basements.

- The transmission heat loss through a component is modified if there is an unheated space between the internal and external environments. One method of allowing for this is given in BS EN ISO 13789.

- BS EN ISO 10077-1 for windows and doors; the thermal transmittance of roof windows and other projecting windows can be calculated according to this standard, provided that the thermal transmittance of their frame sections is determined by measurement or by numerical calculation. Thermal transmittance can also be determined by measurement in accordance with BS EN ISO 12567-1 or BS EN ISO 12567-2.

- BS EN ISO 12631 for curtain walls. See also section 13.

These methods are appropriate for demonstrating compliance with building regulations for the conservation of fuel and power, namely Part L of the Building Regulations for England [1], Part L of the Building Regulations for Wales [2], Section 6 of the Building (Scotland) Regulations [3], and Part F of the Building Regulations (Northern Ireland) [4].

However, it is essential for designers to be fully conversant with the Building Regulations requirements applicable at the time of calculation, and the means of compliance, and to be aware of any proposed amendments that may be relevant to design work already in hand. This is very important since the designer may be asked to provide evidence of the details used for the calculations.

Where compliance is expressed in terms of whole-building performance, such as CO_2 emissions, U-values obtained by the methods referred to in this document should be used for the relevant calculations by the Standard Assessment Procedure (SAP) [5] for dwellings or by the Simplified Building Energy Model (SBEM) [6] for other buildings.

Party/separating walls (the walls which divide a building into separate premises) can give rise to heat transmission to the external environment via thermal bypass if the wall is of a cavity construction. There is no available method for calculating such losses; see section 7 for more details.

1.4 Calculation methods for the determination of linear thermal transmittance (Ψ) and the point thermal transmittance (χ).

Thermal bridges fall into three categories:

(a) repeating thermal bridges (which occur at fixed intervals in the element such as roof timber joists or rafters, beam and block floor with beams at fixed intervals, mortar joints and mullions in curtain walling, battens or plaster dabs of wall drylining systems) where the additional heat flow due to the bridging is included in the determination of the U value of the building element containing these bridges, as indicated in these conventions;

(b) non-repeating thermal bridges, which arise at junctions between different components (e.g. junctions of floor and roof with the external wall and details around window and door openings) and also when thermal bridges occur at different intervals (e.g. beams of a beam and block floor, located at variable intervals. The additional heat flows due to these types of thermal bridges are determined separately. They can be calculated by two-dimensional thermal modelling.

(c) the point thermal transmittance of a point thermal bridge, χ, occurs where insulation is discretely penetrated and can be calculated by three-dimensional thermal modelling.

Non-repeating thermal bridges need to be included in the total heat transmission coefficient of a building. This is done by means of a linear thermal transmittance for the junction, which represents the additional heat flow per unit length and temperature difference that is not accounted for in the U-values of the plane building elements containing the thermal bridge.

The linear thermal transmittance value, *Ψ,* associated with additional heat loss via junctions and areas around openings (see section 2.5), is calculated according to BS EN ISO 10211.
For further information see IP 1/06 [7]. For the conventions used for numerical calculation of linear thermal bridges refer to BR 497 [10].

The publications on Accredited Construction Details [8] helps to demonstrate that a provision has been made to eliminate all reasonably avoidable thermal bridge in the insulation layers (so far as the detail apply).

Accredited Construction Details (Scotland) [9] with the calculated *Ψ*-values for a range of junctions, give examples of details for buildings in which the thermal bridging effects are limited to a reasonable level.

According to the conventions used for numerical calculation of linear thermal bridges, BR 497 [10], the influence of point thermal bridges, χ, occurring as a result of the intersection of linear thermal bridges or where insulation is discretely penetrated is insignificant and can be ignored, so the point thermal bridges can be omitted from the calculation of the total heat transfer.

If, however, there are significant point thermal bridges, then the point thermal transmittances should be calculated in accordance with BS EN ISO 10211 or taken from tables or catalogues prepared in accordance with BS EN ISO 14683.

1.5 U-values obtained by in-situ measurement

While calculated U-values are acceptable for Building Regulations and most other purposes, direct in-situ measurement of U-values is also possible for other (non-regulatory) purposes.

BS ISO 9869-1:2014 "Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter method" provides the description of a method which allows the U-values of walls in existing dwellings to be established by in-situ measurements.

The approach given in BS ISO 9869-1:2014, is based on assuming that mean values of heat flow rate and temperatures over a reasonably long period of time (minimum 72 hours) give an estimate of the steady-state condition, but this may give erroneous results in certain cases. The procedures apply only where a defined number of measurements are undertaken for a development at different times to calculate an average U-value figure.

BS ISO 9869-2:2018 "Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance - Part 2: Infrared method for frame structure dwelling" describes the infrared method for measuring the thermal resistance and thermal transmittance of opaque building elements on existing buildings. The method uses an infrared camera to measure the thermal transmittance (U-value) of a frame structure dwelling with light thermal mass, typically with a daily thermal capacity (calculated according to BS EN ISO 13786) below 30 kJ/(m^2K). This method is useful for screening tests to identify defective areas of building elements. The U-value of building elements in the steady state can be obtained by this method from the averages of the observed values over a certain period of time.

The heat transfer of the outer surface of building elements depends strongly on the outdoor wind velocity and varies with time, making it difficult to measure or estimate the density of the heat flow through building elements. Therefore, according to BS ISO 9869-2, the internal surface temperature is observed with an infra-red camera only at night. This condition is applied because the outdoor air temperature and room temperature are relatively stable at night, temperature is unaffected by sunlight, and heat transmission through building elements is in a relatively steady state condition due to the relatively low thermal mass of the dwellings under consideration. Although the method in this standard is only applied to low thermal capacity building elements, e.g. timber-framed construction, the U-value of building elements for the steady state condition should be estimated statistically.

When the U-value is high, the U-value obtained by this method can be determined accurately. However, when the U-value is low, the heat flow through the building element is also low, making it difficult to achieve a reliable result.

2 U-value calculation: numerical methods and simplified methods

The basic U-value calculation is intended for use with a building element which consists solely of plane, parallel, uniform layers: the heat flow through such an element is directly from inside to outside in a straight line, and all that is needed to obtain the U-value is a simple sum of the thermal resistances of each layer.

Virtually all practical building components, however, have non-uniformities, whether they be joints between masonry units, timber joists with insulation between them, all other types of structural members separated by infill panels, glazing within a frame, etc. The consequence of non-uniformities, or the presence of any layers that are not plane and parallel, is that the heat no longer travels in straight lines. This affects the total heat transfer through the element and needs to be allowed for in the determination of the U-value.

2.1 Numerical methods of establishing U-values

The term “numerical method” or “numerical analysis” is used in this guide to indicate a detailed computer calculation that allows for multi-dimensional (non-uniform) heat flow.

The general case involves variations in heat flow in all three dimensions, and would be invoked for analysis of 3-way corners between building elements, for instance.

For the purposes of U-values, however, it is almost always the case that the construction is uniform in one direction or that 3-dimensional effects do not significantly affect the overall U-value. (The corners of a window frame represent an example of the latter.) In consequence, 2-dimensional analysis – much easier to visualise and to represent within computer software – is appropriate for most cases of U-value determination. There are cases, however, which need to be treated in a 3-dimensional way, such as point fixings.

Various mathematical techniques can be employed, including finite element analysis, finite differences, and boundary integral methods. Software packages based on any of these techniques are suitable for numerical analysis provided that they conform with BS EN ISO 10211 and, in the case of windows and doors, BS EN ISO 10077-2.

Numerical analysis provides the most precise results, and is always a permissible alternative. Many cases, however, can be treated by simplified methods for which the calculation procedures are much easier to carry out.

It is important that numerical analysis is carried out using appropriate software and by persons who have adequate experience of undertaking this type of calculation according to BR497.

2.2 Simplified methods of establishing U-values

Simplified methods are normally used for U-value calculations where they are appropriate for the construction of the element concerned; the British Standards and other calculation methods define the scope of validity of the methods they describe.

The method defined in BS EN ISO 6946 is often applicable for calculations of U-values for walls, roofs and suspended floors. Known also as the Combined Method, it involves calculation of the upper limit and the lower limit of the thermal resistance of the element. . Any non-uniform layer is to be treated as a bridged layer when using this calculation method. The standard calculates the U-value of the component from the arithmetic mean of these two limits. While the true result always lies somewhere between the limits, the equal weighting can be an inadequate approximation when the difference between the limits is large. The standard requires that the ratio of the upper limit to the lower limit does not exceed 1.5. When the ratio exceeds 1.5 a numerical method must be used.

The principal exclusion in the scope of BS EN ISO 6946 is when an insulation layer, or part of an insulation layer, is penetrated by a metal component: other techniques should be used in those cases. However, point fixings, i.e. discrete fixing points as opposed to fixing rails, are not excluded.

Wall ties, fixing screws and similar can be handled by application of the U-value correction given in Annex F of BS EN ISO 6946, even though made of metal.

Other simplified methods include BS EN ISO 13370 for ground floors and BS EN ISO 10077-1 for windows and doors.

For information on BRE software for calculations according to these standards, see the website www.brebookshop.com.

2.3 Numerical and simplified methods used together

For constructions that cannot be handled by the methods in BS EN ISO 6946, the U-value can be calculated by numerical analysis. There are two possibilities:

1) use numerical analysis to calculate the U-value of the whole element;

2) use numerical analysis to calculate the thermal resistance of the layer or layers containing the metal component, and then use the result in a calculation according to BS EN ISO 6946. That is usually the best course when the component is sold as a separate product, as the numerical calculation needs to be done only once.

Similarly, for floors, it may be appropriate to use numerical analysis to obtain the thermal resistance of the floor deck, and then use that resistance in a calculation according to BS EN ISO 13370 to allow for the effect of the ground.

3 Thermal properties of materials and products

3.1 Declaration of thermal properties of thermal insulation products

All types of insulation materials may have a degree of incostintency in their thermal conductivity, depending on the manufacturing process, moisture content and the raw materials.

Where products are covered by a harmonised European standard (EN) or a European Technical Assessment (ETA), product declarations should conform to the requirements of the EN or ETA.

An estimate of 90/90 is a reasonable basis for such declarations (meaning that, at a statistical confidence level of 90%, at least 90% of the factory production of insulation material has thermal performance at least equal to, or better than the declared value).

The standards for the laboratory measurement of thermal conductivity for masonry materials having a thermal resistance of not less than 0.1 m²·K/W and thermal conductivity up to 2.0 W/m·K are BS EN 12664, BS EN 12667 and BS EN 12939.

BS EN 13172 specifies the procedures and the criteria for the evaluation of the conformity of a thermal insulating product with the relevant European product specification. BS EN 13162 to BS EN 13171 give methods to ensure that the declared thermal conductivity relates to 90% of the factory production within a 90% confidence level.

Some of the standards mentioned in this section are being revised.

3.2 Thermal values for use in calculations

Wherever possible, use thermal conductivity (λ) declared by the manufacturer; otherwise use tabulated design values of thermal conductivity for specific products from BS EN ISO 10456.
In the case of inverted roof insulation refer to clause 4.8.6.

Generally use the nominal thickness of products in calculations, except where the thickness is constrained by the construction (e.g. compressible insulation in a fixed width); in that case the thickness of the insulation as installed should be used.

Further guidance for specific materials and products is given in the following sections.

3.3 Masonry

Declared values of thermal conductivity for masonry units, when based on measurements, should be referred to the mean density of the product as described in BS EN 1745, and adjusted to the appropriate moisture content in Section 3 of CIBSE Guide A [11].

If measured data are not available, the thermal conductivity should be obtained from the mean density using the data in the CIBSE Guide or the tabulated data in BS EN 1745 which specifies procedures for the determination of thermal properties of masonry and masonry products.

Mortar conductivity is given in the CIBSE Guide A as:

Outer leaves (of a cavity wall):	λ=**0.94 W/m·K**
Inner leaves (of a cavity wall):	λ=**0.88 W/m·K**

Unless otherwise specified, **brick thermal conductivity** should be taken as

Outer leaves (of a cavity wall):	λ=**0.77 W/m·K**
Inner leaves (of a cavity wall):	λ=**0.56 W/m·K**

See also section 4.2

3.4 Concrete beams and concrete screeds

In the absence of specific information the following should be used:

Reinforced concrete beam (1% steel)	λ= **2.30 W/m·K**
Concrete screed (density 1800 kg/m^3)	λ= **1.15 W/m·K**

Further information can be obtained from manufacturers or Section 3 of CIBSE Guide A and BS EN ISO 10456.

3.5 Stone

In the absence of specific information the following should be used:

Limestone (density 2000 kg/m^3)	λ= **1.40 W/m·K**
Sandstone or granite (density 2600 kg/m^3)	λ= **2.30 W/m·K**
Artificial stone (density 1750 kg/m^3)	λ= **1.30 W/m·K**
Pumice (density 400 kg/m^3)	λ= **0.12 W/m·K**

Further information can be obtained from manufacturers or from Section 3 of CIBSE Guide A and BS EN ISO 10456.

3.6 Insulation materials

Many insulation materials are covered by harmonised product standards. The standards concerned are listed in *References and further reading*. The procedures for establishing declared λ-values include:

- 90% of the factory production of insulation material has thermal conductivity not exceeding the declared value;
- for foamed plastic materials blown other than by air, the declared value represents the average over 25 years.

Data on thermal properties of insulation products should be sought from manufacturers.

3.7 Gypsum plasterboard

Like many materials, the thermal conductivity of gypsum plasterboard depends on density. The following are representative values:

Standard wallboard (density up to 700 kg/m^3):	λ=**0.21 W/m·K**
Higher density (up to 900 kg/m^3), e.g. acoustic or fire resistant board:	λ=**0.25 W/m·K**

3.8 Timber, structural timber and timber-based sheathing

The thermal conductivity of timber is dependent upon species, density and moisture content. For design purposes the following values are recommended:

Timber/softwood, e.g. joists, window frames (typical density 500 kg/m^3)	λ= **0.13 W/m·K**
Timber/hardwood (typical density 700 kg/m^3)	λ= **0.18 W/m·K**
Prefabricated timber frame wall panels (typical density 460-480 kg/m^3)	λ= **0.12 W/m·K**
Plywood (typical density 500 kg/m^3)	λ= **0.13 W/m·K**
Oriented strand board, OSB, (typical density 650 kg/m^3)	λ= **0.13 W/m·K**
Particleboards, fibreboard (typical density 600 kg/m^3)	λ= **0.14 W/m·K**

3.9 Metals and alloys

Thermal conductivity values for commonly used metals and alloys are:

Mild steel (including galvanised steel)	λ=**50 W/m·K**
Stainless steel	λ=**17 W/m·K**
Aluminium (typical alloy)	λ=**160 W/m·K**

3.10 Reflective foil products

Reflective (low emissivity at the appropriate wavelength) surfaces are utilized in a number of ways to enhance the thermal performance of insulating products.

BS EN 16012 describes a set of procedures for using existing standardized test and calculation methods to determine thermal performance of reflective insulation products.

Reflective foil products include:

Type 1: Typically foam insulation with aluminium foil facing on each side, mineral wool faced with aluminium foil, or multi-foil insulation product which is stitched or sealed only at the edges and substantially flat with parallel faces;

Type 2: Typically bubble-foil insulation with reflective surfaces, with a regular geometry and parallel faces;

Type 3: Typically multi-foil insulation with reflective surfaces, with irregular thickness, and with parallel faces that are not flat and may have stitching;

Type 4: A thin film or sheet, less than 2 mm thickness, used singly or in multiple layers, which makes use of a low emissivity surface to increase the thermal resistance of adjacent or enclosed air space(s), but which has no significant thermal resistance of its own.

Multi-foil insulation products comprise two or more layers of heat reflecting foil and several internal layers of insulation (e.g. sheets of low density insulation materials).

3.10.1 Thermal resistance of foam or mineral wool insulation with aluminium foil facing

The thermal resistance of foam or mineral wool insulation with foil facings consists of the resistance of the insulation sheet and the resistance of air spaces on either one side of it or both sides, where the resistance of the airspace(s) takes account of the emissivity of the surfaces.

Product performance should be determined in terms of the thermal resistance of the core, measured according to BS EN 12664 or BS EN 12667, and the emissivity of the surfaces according to BS EN 16012[a].

Where the product is to be fixed by battens, the bridging effect of the battens should be included in the calculation using the method of upper and lower limits of thermal resistance as defined in BS EN ISO 6946.

Similarly, the effect of wall ties is included when foam or mineral wool insulation is used in the cavity of a masonry wall. U-value calculations should take account only of airspaces actually present. See also 4.7.

3.10.2 Thermal resistance of bubble-foil and multi-foil insulation

Multi-foil insulation comprises products that consist of several layers of foil separated by other materials. They are intended for applications with an airspace on one side or both sides and the overall thermal performance includes the effect of low-emissivity surfaces facing these airspaces.

The U-value of constructions that include multi-foil insulation should be based on performance data for the product concerned, measured by a Notified Body accredited for thermal testing.

Product performance can be established either from measurement of the thermal resistance of the core according to BS EN 12664 or BS EN 12667 together with the emissivity of the surfaces, or in a hot box apparatus conforming with BS EN ISO 8990.

In the case of the "hot box" test, the test is undertaken with an airspace on both sides of the product, and the test result is the thermal resistance of the assembly consisting of the product and the two airspaces. The purpose of the test is to establish the product's 'core' resistance, i.e. the total measured resistance minus the adjacent cavity resistances (calculated according to BS EN ISO 6946). It is the declared core resistance and declared surface emissivity(s) that are then used in BS EN ISO 6946 calculations, along with the other components making up the complete structure.

If the construction has only one airspace, the thermal resistance determined by test is corrected to deduct the resistance of one airspace. With the hot-box test described, and where the product is to be fixed by battens, the bridging effect of the battens should be included in the calculation using the method of upper and lower limits of thermal resistance as defined in BS EN ISO 6946.

Similarly, the effect of wall ties is included when multi-foil insulation is used in the cavity of a masonry wall. U-value calculations should take account only of airspaces actually present. See also section 4.7.

Alternatively, the battens can be included in the construction under test. In situations where battens compress the multi-foil product and/or modify the shape of the product between battens, these effects cannot be dealt with other than by hot-box measurement.

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[a] Annex D in BS EN 16012

Where the effect of battens is included in the hot-box measurement, the result applies only to the specific batten dimensions and spacing used in the hot-box test. BS EN 16012 generally requires at least three tests to establish a design core resistance value.

The thermal resistance of an airspace depends on heat flow direction, and certified values should indicate the applications for which test results are valid.

In the absence of the correctly measured resistance of multi-foil insulation and adjacent airspace according to BS EN Standards, use:

Total thermal resistance of multi-foil insulation and adjacent airspaces	R=**1.7**[b,c] **m^2 K/W**

3.10.3 Thickness of multi-foil insulation and adjacent air cavity

Refer to BBA Information Bulletin No 3 "Reflective foil insulation – Conventions for U value calculations"[d], which sets out dimensional conventions to assist in the calculations of U-values for elements incorporating reflective foil insulation, including:

Product thickness (uncompressed) – as declared by supplier; measured at 25Pa according to BS EN 16012.

Product thickness (compressed) – as zero (unless R-value was robustly determined, or testing the product under pressure 20 kPa;

Thickness of air cavity adjacent to reflective foil insulation – depending on the installation, the convention is that 30% of multi-foil insulation will open up in the adjacent rafter cavity and fill 70% of the adjacent cavity below due to the effect of gravity.

3.10.4 Reflective breather membranes, vapour control layers, air barriers.

Reflective breather membrane may improve U-values without changing wall thickness.

The thermal resistance of an air space with a low emissivity surface is calculated according to Annex D of BS EN ISO 6946. Emissivity of the reflective surface (e.g. foil) should be sourced from third party certification.

See also section 4.7.2 of this document.

Refer to BBA Information Bulletin No 5 "Reflective breather membranes in timber framed walls – thermal performance claims"[e] confirming that hot box measurement (BS EN ISO 8990) and calculation (BS EN ISO 6946) agree very well.

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[b] The thermal performance of multi-foil insulation. T I Ward, S M Doran, BRE, July 2005 http://webarchive.nationalarchives.gov.uk/20150601181604/https://www.planningportal.gov.uk/uploads/br/multi-foil-insulation_july2005.pdf

[c] BCA Technical Guidance Note 6. Use of multi-foil insulation products and compliance with Regulation 7 and Building Regulation Requirement L1

[d] BBA Information Bulletin No 3 "Reflective foil insulation – Conventions for U value calculations", 2010

[e] The BBA Information Bulletin No 5 "Reflective breather membranes in timber framed walls – thermal performance claims", 2015

4 Details of U-value calculations

The lists of constructional types given here and later in this document identify issues that need to be considered for each type.

4.1 Surface resistance

Although surface resistance is affected by emissivity, the maintenance of a low-emissivity surface adjacent to the internal or external environment cannot generally be achieved.

Surface resistances used for calculations should be those applicable to normal (high) emissivity as given in BS EN ISO 6946, namely:

Heat flow direction	Element type	R_{si}	R_{se}
Horizontal	Wall, window	0.13	0.04
Upwards	Roof	0.10	0.04
Downwards	Floor	0.17	0.04

Where R_{si} internal surface resistance and R_{se} is external surface resistance, m^2K/W.

The surface resistances apply to surfaces in contact with still air; no surface resistance applies to surfaces in contact with another material.

The values under “horizontal” apply to heat flow directions ±30° from the horizontal plane.

For further details refer to BS EN ISO 6946.

See also 4.7.3 and 4.7.4 for surface resistance of well and slightly ventilated airspaces.

4.2 Mortar joints in masonry construction

The mortar joints in a masonry construction may be disregarded if the difference in thermal resistance between the bridging material and the bridged material is less than 0.1 m^2K/W.

For normal mortar this means that the joints can be disregarded when the thermal conductivity of the masonry units is greater than 0.5 W/m·K and the thickness of the blocks or bricks is not more than 105 mm: this applies to almost all brickwork, and to most walls built with dense masonry units.

Otherwise, include mortar joints in the calculation for inner and/or outer leaves of walls, by treating the masonry leaf concerned as a bridged layer.

The fraction of mortar is as follows:

- For blocks of face area 440 × 215 mm with 10 mm joints, fraction = 0.067
- For other cases the fraction is calculated using the equation:

$$fraction = 1 - \frac{(block\ length) \times (block\ height)}{(block\ length + joint\ thickness) \times (block\ height + joint\ thickness)} + 0.001$$

in which the term 0.001 allows for half blocks at corners, etc.

4.3 Voided masonry units

Masonry units can have voids, which can be air voids or filled with insulation. These units may be treated by:

1) Calculating the thermal resistance of the block by the Combined Method of BS EN ISO 6946, using a surface resistance of zero on both sides, then

2) Using the result in a calculation of the U-value of a wall containing such masonry units, treating in this case the masonry units as homogeneous elements with thermal resistance as calculated in step 1). The mortar joints are allowed for in this second calculation.

The result from step 1) may be quoted in technical literature describing the properties of the masonry unit, allowing users to calculate U-values of wall constructions via step 2).

4.4 Timber fraction for timber-framed walls

4.4.1 Conventional timber studs

(i) For timber frame construction, additional heat losses at corners, window surrounds, between floors, etc., are not counted as part of the timber fraction.

The **default fraction** for timber frame is

0.15 (15%)

This is based on 38 mm timbers at 600 mm centres for 1-storey and 2-storey buildings, and reducing centres on the lower floors of 3-, 4- and 5-storey buildings of 400 mm and 300 mm centres.

(ii) A **lower fraction** of

0.125 (12.5%)

can be used if, in addition to the criteria of (i), all the following conditions are met:

- there is a single top plate as part of the external wall panels
- the sole plate is below finished floor level
- there are no mid-height full depth noggings in external walls
- the studs at junctions where internal walls meet external walls, and any noggings for fittings and fixtures, are no more than 38 mm deep and have continuous wall insulation behind them.

(iii) The timber fraction can be calculated using the following guidelines:[f]

- exclude timbers that are outside the wall area used for heat loss calculations (so that the timbers included are those between the finished internal faces of external or party walls, and between the inside level of the ground floor and the underside of the ceiling of the top floor);
- exclude a zone around windows and doors of 50 mm at the sill and each jamb and 175 mm at the top (lintel zone);[g]

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[f] This basis can also be used for SIPS and light steel frame.
[g] The additional heat loss associated with the timbers around doors and windows is allowed for in the linear thermal transmittances that apply to the perimeter of the window or door.

- include all timbers (e.g. noggings and intermediate floor joists) that are not insulated behind.

4.4.2 I-beam studs

I-beam studs consist of flanges and a web, usually made of wood-based materials. Provided that the thermal conductivity of the material used for the flanges does not differ by more than 20% from that of the web, the penetration of the web into the flanges can be disregarded for the purposes of U-value calculations according to BS EN ISO 6946, and the calculations can be based on geometry (b) rather than (a).

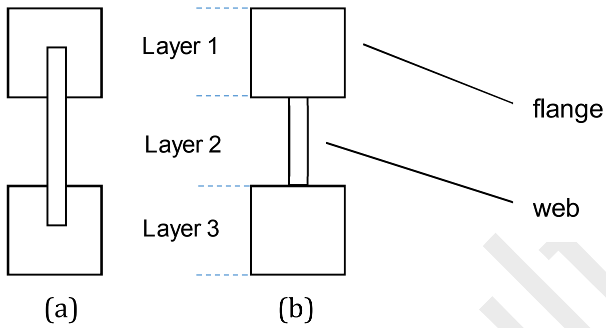

Figure 1. I-beam studs

Shape (b) is treated as three separate layers for the calculation of the upper and lower resistance limits. It is assumed that the thermal insulation is sufficiently flexible to occupy the space on either side of the web (for rigid boards, assume the space is an airspace (see 4.7).

If the thermal conductivities differ by more than 20%, base the calculation on (a), using five layers, where the flanges are split into two layers, of which one penetrated by the web and the other not.

Thermal conductivity values for materials commonly used for I-beams are:

Softwood:	0.13 W/m·K
Timber strand:	0.15 W/m·K
OSB:	0.13 W/m·K
Structural fibreboard:	0.13 W/m·K

The fractions can be taken from the following table:

Component	
Flanges, 38 mm wide (at 600 mm): 38/600 + 0.01=	0.073 (7.3%)
Flanges, 47 mm wide (at 400 mm): 47/400 + 0.01=	0.128(12.8%)
Flanges, 47 mm wide (at 600 mm): 47/600 + 0.01 =	0.088 (8.8%)
Webs, 8 to 10 mm wide (at 400 mm)	0.025 (2.5%)
Webs, 8 to 10 mm wide (at 600 mm)	0.017 (1.7%)
Note: 1% added for additional timbers (accounted above by adding 0.01)	

In other cases calculate the fraction using the guidelines in 4.4.1 (iii).

4.5 Timber fractions for other elements

In general the fraction can be calculated as the timber width divided by the spacing interval, allowing for any additional cross pieces, for example:

35 mm joists at 600 mm centres: (35 / 600) + 0.01=	0.068 (7%)
50 mm joists at 400 mm centres: (50 / 400) + 0.01=	0.135 (14%)
Note: 1% added for additional timbers (accounted above by adding 0.01)	

The following data applies for typical situations:

4.5.1 Ceiling joists

In the absence of specific information use the following default fraction (based on 47 mm timbers at 400 mm centres):

Default fraction for ceiling joists: (47 / 400) + 0.01=	0.128 (13%)

4.5.2 Doubled-up timbers

Joists/rafters/studs at 600 mm centres may be inconsistently spaced and as a result may feature doubled-up timbers based on 47 mm timbers at 600 mm centres:

Default fraction for doubled ceiling joists (2 × 47) / 600 + 0.01	0.167 (17%)

4.5.3 Suspended timber floor

The fraction should allow for noggings. In the absence of specific information use the following default fraction (based on 38 mm timbers at 400 mm centres plus a nogging every 3 metres), for example:

Default fraction for floor joists (38 / 400) + (38 / 3000)	0.108 (11%)

4.6 Plasterboard wall lining (unventilated).

The airspace between the plasterboard and a wall is assumed to be unventilated in all three cases below. For thermal conductivity of plasterboard see section 3.7.

4.6.1 Plasterboard on dabs

The following default data apply to plaster dabs:

Fraction of plaster dabs	**0.20 (20%)**
Thermal conductivity of plaster dabs	λ=**0.43 W/m·K**
Thickness of plaster dabs	**15 mm**
Thermal resistance of 15 mm airspace	R=**0.17 m²K/W**

4.6.2 Plasterboard on battens (47mm at 600mm centres)

The following default data apply to the typical configuration of 47 mm timber battens at 600 mm centres plus top and bottom rail for room height 2400 mm:

Timber fraction (47 / 600) + 2 (47 / 2400) =	**0.118 (12%)**
Batten thickness (typical)	**22 mm**
Thermal resistance of 22 mm airspace	R=**0.18 m²K/W**

4.6.3 Plasterboard on battens (47mm at 400mm centres)

The following default data apply to the typical configuration of 47 mm timber battens at 400 mm centres plus top and bottom rail for room height 2400 mm:

Timber fraction (47 / 400) + 2 (47 / 2400) =	**0.157 (16%)**
Batten thickness (typical)	**22 mm**
Thermal resistance of 22 mm airspace	R=**0.18 m²K/W**

In the case of plasterboard on battens, for proprietary metal channel systems and similar, refer to manufacturer's data for the equivalent thermal resistance.

The air layer between the plasterboard and a wall is assumed to be unventilated in all three cases (refer to section 4.7).

4.7 Airspace resistance

In BS EN ISO 6946 the term "airspace" includes both air layers (which have a width and length both 10 times the thickness, with thickness measured in the heat flow direction) and air voids (which have a width or length comparable to the thickness).

If the thickness of the air layer varies, its average value is used to calculate the thermal resistance.

Airspaces can be treated as media with thermal resistance because the radiation and convection heat transfer across them is approximately proportional to the temperature difference between the bounding surfaces. Calculations of air layer resistance for normal building applications should be based on a mean temperature of 10°C and a temperature difference across the airspace of 5 K[h].

BS EN ISO 6946 uses the term "air layer" to denote a cavity or other airspace that extends over the whole area of the element, such as the cavity in a cavity wall, the space between the battens in a dry-lined wall, or the space under tiles on a pitched roof.

Air layers are differentiated as unventilated, slightly ventilated and well ventilated.

An **unventilated air layer** is one in which there is no provision for the movement of air through it.

An air layer having no insulation between it and the external environment, but with small openings to the external environment, shall also be considered as an unventilated air layer if these openings are not arranged so as to permit air flow through the layer and they do not exceed

- 500 mm² per metre of length (in the horizontal direction) for vertical air layers, and
- 500 mm² per square metre of surface area for horizontal air layers.

NOTE Drain openings (weep holes) in the form of open vertical joints in the outer leaf of a masonry cavity wall usually conform to the above criteria and so are not regarded as ventilation openings.

A **slightly ventilated air layer** is one in which there is provision for limited air flow through it from the external environment by openings of area, within the following ranges:

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[h] The airspace between panes of glass in a double glazed unit is an exception for which a higher temperature difference is used, as specified in BS EN 673. Airspaces in hollow window frames need special treatment as described in BS EN ISO 10077-2.

- >500 mm^2 but <1500 mm^2 per metre of length (in the horizontal direction) for vertical air layers, and
- >500 mm^2 but <1500 mm^2 per square metre of surface area for horizontal air layers.

A **well-ventilated air layer** is one for which the openings between the air layer and the external environment are equal to or exceed:

- 1500 mm^2 per metre of length (in the horizontal direction) for vertical air layers, and
- 1500 mm^2 per square of metre of surface area for horizontal air layers.

The guidance on how these types of air space are treated is given in BS EN ISO 6946.

4.7.1 Unventilated airspaces, normal (high) emissivity

An unventilated air layer is treated as if it were a homogeneous layer of given thermal resistance. Table 8 of BS EN ISO 6946 gives thermal resistance values for unventilated air layers (cavities that extend over the whole area of the element).

Cavities in unventilated masonry wall constructions normally have:

Thermal resistance (unventilated cavity)	R=**0.18 m^{2}K/W**

Note, that wall constructions (e.g. timber framed walls) may require cavities to be drained or vented to allow some limited, but not necessarily through movement of air; for example for timber framed walls there is a requirement set by NHBC standards [15] to provide an air opening equivalent to an open brick joint every 1.2m of wall length. This would result in an air opening of at least 10mm by 70 mm every 1.2 metres, resulting in opening areas of approximately 580mm^2 per metre of length (in the horizontal direction) for vertical air layers, making such a cavity slightly ventilated. The U-value is therefore calculated for a slightly ventilated cavity according to BS EN ISO 6946.

Another exception is a cavity behind external tile-hanging or similar: this is a well-ventilated cavity for which the rules in clause 6.9.4 of BS EN ISO 6946 apply. Data for this case are given further in 4.7.3.

4.7.2 Resistance of unventilated airspaces with low emissivity surface

A low-emissivity surface, such as aluminium foil, reduces the radiation transfer across an airspace, so that the airspace has a higher thermal resistance compared to one bounded by surfaces of normal (high) emissivity.

A low emissivity surface has no effect on the U-value if not adjacent to an air space in the construction.

The thermal resistance of an air space with a low emissivity surface can be calculated according to Annex D of BS EN ISO 6946. Note that the emissivity of less than ε=0.2 should be used for calculating the thermal resistance of an air space only where given in a certificate issued by a certification body accredited by an EU national accreditation service.

According to BS EN 15976, the measurement range of the apparatus for measurement of emissivity is limited to values between 0.02 and 0.94. This means that the minimum measured emissivity value is 0.02, therefore the declared emissivity cannot be less than 0.02.

Determining emissivity should be carried out on the finished product (e.g. insulation board) by using test methods BS EN ISO 15976 (which specifies the method to determine the emissivity) and BS EN ISO 16012 (which describes a set of procedures for using existing standardized test and calculation methods to determine the declared thermal performance of reflective insulation products).

Notes

1. The thermal resistance values for horizontal heat flow should be used for applications where the heat flow direction is within ±30° of the horizontal plane, i.e. in the case of a roof for roof pitch greater than 60°. The heat flow direction is considered as upwards for roof pitches of 60° or less.

2. The value for heat flow downwards is not applicable to a low-emissivity surface facing the underfloor space of a suspended floor. This space is ventilated and should be handled by the procedures in BS EN ISO 13370.

3. If the facing is not of low emissivity over its whole surface, for example because of overprinting, the thermal resistance should be adjusted by weighting the inverse of the thermal resistance for normal emissivity and for low emissivity in proportion to the relative areas. For example, in a wall application, if 9% of the surface is overprinted, e.g. the cavity has a high emissivity ε=0.2 and R=0.18 m^2K/W, with the remaining 91% having low emissivity ε=0.2 and R=0.44 m^2K/W**,** the the average cavity resistance is: 1/(0.09/0.18+0.91/0.44)=0.39 m^2K/W.

When the calculated resistance is not available for products with low-emissivity surface (e.g. foil-faced products with the foil adjacent to an unventilated airspace of width at least 25 mm), the thermal resistance of the airspace may be taken as:

Low-emissivity surface, heat flow horizontal (wall applications, ε=0.2)	R=**0.44 m^2K/W**
Low-emissivity surface, heat flow upwards (roof applications, ε=0.2)	R=**0.34 m^2K/W**
Low-emissivity surface, heat flow downwards (floor applications, ε=0.2)	R=**0.50 m^2K/W**

Where ε is the emissivity value.

The thermal resistance for unventilated cavities larger than 25 mm will remain unchanged with respect to the thickness of the cavity if the same emissivity value is used, but for cavities smaller than 25 mm the resistance will decrease as the thickness of the cavity decreases; the smaller the unventilated air gap the smaller the resistance. For example for a wall air cavity of 20mm (ε=0.2) the resistance is still close to that for 25mm, but for a wall air cavity of 10 mm (ε=0.2) the resistance is 0.29 m^2K/W, and for a wall air cavity of 5mm (ε=0.2) the resistance is 0.17 m^2K/W.

Theoretically, the calculation of thermal resistance can be done for an air gap of any thickness, even for a very small gap. However, the regulatory requirements for the minimum permitted width of air gaps or cavities should be taken into account when designing the construction of the wall, e.g. minimum required air gaps for walls in areas of high exposure; such requirements are not the subject of this document. Also, it should be noted that very thin air gaps have very small resistances, therefore making the benefits of low emissivity surface negligible.

4.7.3 Surface resistance of ventilated air spaces

The air in well ventilated airspaces is taken as being at the temperature of the external air. Accordingly the resistance of the airspace and that of all layers between it and the external environment are disregarded. However, as the cladding provides protection from wind, the external surface resistance is greater than its normal value of 0.04 m^2K/W.

The following are the indicative resistances of ventilated air spaces calculated according to Annex C of BS EN ISO 6946.

High-emissivity surface (ε=0.9), heat flow horizontal (wall applications)	R_{se} = **0.13 m^2K/W**
High-emissivity surface (ε=0.9), heat flow upwards (roof applications)	R_{se} = **0.10 m^2K/W**
Low-emissivity surface (ε=0.2), heat flow horizontal (wall applications)	R_{se} = **0.29 m^2K/W**
Low-emissivity surface (ε=0.2), heat flow upwards (roof applications)	R_{se} = **0.17 m^2K/W**

4.7.4 Slightly ventilated airspaces

The effect of ventilation depends on the size and distribution of the ventilation openings. The procedure is given in EN ISO 6946.

4.7.5 Resistance of small airspaces (up to 0.3 m thickness in components other than glazing).

Small airspaces include voids in masonry blocks and similar components. Calculate the thermal resistance of air voids using Annex D of BS EN ISO 6946. See also 4.3.

4.7.6 Resistance of roof spaces

Table 9 of BS EN ISO 6946 gives values of thermal resistance for ventilated roof spaces above an insulated ceiling: these values incorporate the thermal resistance of the ventilated roof space and the thermal resistance of the (pitched) roof construction, but they do not include the external surface resistance R_{se}. When using the table referred to, the value of R_{se} should be taken as 0.04 m^2K/W.

The resistance of roof spaces in Table 9 of BS EN ISO 6946 range from 0.06 m^2K/W for a tiled roof with no felt, boards or similar to 0.3 m^2K/W for roofs lined with boards and felt. The data in Table 9 of BS EN ISO 6946 apply to naturally ventilated roof spaces above heated buildings; if mechanically ventilated, use the detailed procedure in BS EN ISO 13789.

4.7.7 Resistance of profiled metal decks

Profiled metal sheets used for roofing decks usually result in small airspaces between the insulation and the metal sheet at each profiled section. The effect of these airspaces on the U-value of an insulated roof is very small, because of lateral heat conduction in the metal sheets. No allowance for these should be made in U-value calculations.

4.8 Corrections to thermal transmittance (ΔU)

U-values need to be corrected where relevant to allow for the effect of:

- air gaps in insulation;
- mechanical fasteners penetrating an insulation layer;
- precipitation, water storage or root damage on inverted roofs (roofs in which the insulation is placed on top of the waterproof layer).

The U-value is first calculated without taking account of these effects, and then a correction ΔU is added to obtain the final U-value.

Values of corrections, or formulae for calculating them, are given in Annex F of BS EN ISO 6946.

BS EN ISO 6946 permits the corrections due to wall ties, air gaps, etc. to be omitted if the total corrections amount to less than 3% of the uncorrected U-value of the element. The 3% relates to the total corrections. For example, if there are both wall ties and air gaps, the 3% threshold applies to the sum of the ΔU values from each cause. (In most cases, the correction will need to be calculated in order to establish whether this criterion applies.)

When comparing U-values, such as for altered elements when upgrading existing buildings, it is recommended that the ΔU correction is included in the U-value in all cases.

4.8.1 Corrections for air gaps

Annex F of BS EN ISO 6946 recognises three levels of correction for air gaps in an insulation layer. The levels are:

Level 0: ΔU = 0.00
There must be no air voids within the insulation, or where only minor air voids are present, they must have no significant effect on the thermal transmittance, e.g. gaps not exceeding 5 mm width penetrating the insulation layer. This applies for double layer insulation, and for single layer boards with lapped or sealed joints or with dimensional tolerances such that no gap will exceed 5 mm.

Level 1: ΔU = 0.01
A correction for air gaps is needed if air gaps bridge between the cold and warm sides of the insulation, but not causing air circulation between the cold and warm side of insulation, and

- the sum of the length or width tolerance and the dimensional stability of the insulation boards is more than 5 mm, or
- the squareness tolerance of the insulation boards, batts or slabs is more than 5 mm.

Level 2: ΔU = 0.04
Air gaps as in Level 1, and also air circulation is possible between the warm and cold side of the insulation layer. It applies, for example, to partial cavity fill with insulation boards if the boards are not affixed to the inner leaf.

Level 1 is the default and should be assumed unless the conditions applying to Level 0 are fulfilled. For further guidance see Annex F of BS EN ISO 6946.

Corrections for air gaps apply to walls and roofs, but not to floors (because convection is suppressed when the heat flow direction is downwards).

4.8.2 Wall ties

The effect of wall ties may be negligible in an uninsulated cavity, and in any cavity if specialist ties are used (BS EN ISO 6946 permits the corrections due to wall ties to be omitted if the corrections amount to less than 3% of the uncorrected U-value of the wall; specialist wall ties have thermal conductivity less than 1 W/m·K and therefore have very little effect on the calculated U-value). Otherwise the effect of wall ties needs to be considered.

The correction requires knowledge of the thermal conductivity of the ties, their cross-sectional area, and the number per square metre of wall.

Information including the number, size and location of wall ties, which affect the structural performance of a product or which co-ordinate with other components, should be declared and must be obtained from the specifiers of wall tie design.

The following indicates typical thermal conductivity (λ) data:

mild steel	λ=**50 W/m·K**
stainless steel	λ=**17 W/m·K**

For wall ties made of non-steel material refer to the detail obtained from the manufacturer.

For further details refer to BS EN 845-1.

In the absence of the exact details, the following typical details can be used:

Cross-section (typical size for ties)	
double triangle types (4 mm diameter)	**12.5 mm^2**
vertical twist types (20 mm by 4 mm)	**80 mm^2**

Density (at 900 mm by 450 mm centres) for walls up to 15 m in height and leaf thickness of at least 90 mm (a higher density is required if the height is greater or either leaf is thinner)	**2.5 per m^2**

4.8.3 Corrections for mechanical fasteners (fixing screws and other fixings).

In cases where fixing screws pass through the insulation layer use the procedure in Annex F of BS EN ISO 6946 to obtain ΔU for fixings.

BS EN ISO 6946 (Annex F.3) offers two options for calculating corrections for mechanical fasteners:

a) Detailed calculation, where the effect of mechanical fasteners can be assessed in accordance with BS EN ISO 10211 in order to obtain the point thermal transmittance for one fastener. The total correction to the calculated U-value is the point thermal transmittance (χ) for one fastener multiplied by the number of fasteners per square metre;

b) Approximate procedure in BS EN ISO 6946 (Annex F.3.2) which can be used when the effect of mechanical fasteners, calculated by other methods, is not available. This procedure is applicable when the fastener fully penetrates the insulation layer and for the recessed fasteners.

For flat roofs, fixings comprise:

1) fixings for insulation boards: the type of fixings and the density of fixings depends on the insulation product and data should be obtained from the insulation manufacturer's specifications; and

2) fixings for mechanically fixed membranes (as opposed to bonded systems): the density of fixings depends on exposure and data should be obtained from the membrane manufacturer's specifications.

The fixings correction also applies to insulation over rafters of a pitched roof. Again, information should be obtained from the insulation manufacturer's specifications.

No correction need be applied in the case of fixings in a flat roof where the metal part of the composite fastener is recessed by at least 50% of the length of the fixing and the density of fixings does not exceed 15 fixings per square metre. The method of correction given in BS EN ISO 6946 does not apply when both ends of the metallic fixing are in direct contact with metal sheets, including composite panels bounded by metal sheets. For these cases see the guidance in section 4.9.

4.8.4 Windposts and masonry support brackets

Where windposts or masonry support brackets[i] penetrate an insulation layer (usually cavity insulation), their effect should be taken into account by adjusting the U-value of the wall using a linear thermal transmittance, Ψ, for the windposts or masonry support brackets. The corrected U-value is:

$$U = U_0 + \frac{\sum (L_{windposts} \times \Psi)}{A} \tag{2}$$

where:

U_o - the U-value of the wall without the windposts or masonry support brackets, in W/m²K;
L - the total length of windposts or masonry support brackets, in m;
Ψ - the linear thermal transmittance of thermal bridge, in W/m·K;
A - the total area of the wall, in m².

To determine the linear thermal transmittance, a 2-D numerical calculation is undertaken on a section through the wall containing the windpost or masonry support bracket. The boundaries of the model should be at quasi-adiabatic positions. The result is compared with a calculation in which the windpost or masonry support bracket is omitted, so as to obtain a linear thermal transmittance, Ψ, as described in BS EN ISO 10211 (see also reference [10]). The calculation needs to be done only once for a given design of windpost and penetrated insulation thickness.

In the absence of a detailed calculation the value Ψ = 0.18 W/m·K may be used.

Provided that the wall U-value is corrected for the effect of wall ties passing through cavity insulation (see 4.8.2), no additional correction is needed for windposts that do not penetrate the insulation.

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[i] Also known as masonry support angles

4.8.5 Rainscreen cladding

The space behind rainscreen cladding should normally be fully ventilated, so the cladding itself is not included in the U-value calculation. The effect of brackets or rails fixing the cladding to the wall behind must be taken into account, but only if the brackets or rails penetrate an insulation layer or part of an insulation layer.

In general, the options are:
1. Detailed calculation for the whole wall;
2. A 2-dimensional numerical calculation when cladding is fixed to the wall by rails;
3. A 3-dimensional numerical calculation when cladding is fixed to the wall by discrete brackets;
4. Use a default correction.

As the effect of fixing brackets or rails on the U-value of the wall can be large, even when a thermal break pad is included, their contribution to the overall U-value needs to be assessed by a numerical calculation. The calculation model should omit the cladding but include the fixing rails or brackets to their full length. The external surface resistance should be taken as 0.13 m^2K/W (rather than 0.04 m^2K/W) to allow for the sheltering effect of the cladding (see 4.7.3).

Methods for establishing U-values of walls with rainscreen cladding are:

a) Detailed calculation for the whole wall.
The U-value of the whole wall, inclusive of all fixing arrangements, is assessed by numerical calculation conforming to BS EN ISO 10211. The result applies only to the wall as calculated: any variations need to be re-assessed.

b) Using a linear thermal transmittance for a fixing rail that penetrates an insulation layer
A 2-D numerical calculation is undertaken on a section through the wall containing the fixing rail. The boundaries of the model should be at adiabatic positions, for example mid-way between two rails. The result is compared with a calculation in which the rail is omitted, so as to obtain a linear thermal transmittance, Ψ, as described in BS EN ISO 10211. That calculation needs to be done only once for a given design of rail and penetrated insulation type and thickness.

The U-value of the wall allowing for the fixing rail is

$$U = U_0 + \frac{\sum (L_{rail} \times \Psi)}{A} \tag{3}$$

where:
U_o - the U-value of the wall without the fixing rails calculated according to BS EN ISO 6946, in W/m^2K;
L_{rail} - the total length of rai, in m;
Ψ - the linear thermal transmittance of thermal bridge, in W/m·K;
A - the total area of the wall, in m^2.

c) Using a point thermal transmittance for a discrete fixing bracket that penetrates an insulation layer
A 3-D numerical calculation is undertaken on a section through the wall containing a representative fixing bracket. The boundaries of the model should be at quasi-adiabatic positions, for example mid-way between two brackets. The result is compared with a

calculation in which the brackets are omitted, so as to obtain a point thermal transmittance, χ, as described in BS EN ISO 10211. That calculation needs to be done only once for a given design of bracket and penetrated insulation thickness.

The U-value of the wall is then calculated as:

$$U = U_0 + \frac{\sum (n \times \chi)}{A} \quad (4)$$

where:

U_o - the U-value of the wall, without the brackets calculated according to BS EN ISO 6946, in W/m²K;
n - the number of brackets per square metre of wall;
χ - the point thermal transmittance of point thermal bridge, in W/K;
A - the total area of the wall, in m².

Alternatively, use of a simple method for determining U-values for metal roof and wall cladding including rail and bracket spacers allows the calculation of U-values for such cladding without the need for complex numerical analysis software. See section 4.9.

d) Default increment to the U-value

If calculated results are not available, the U-value calculated without brackets, U_0, is increased by a conservative default value of 0.30 W/m²K which takes account of both linear and point thermal bridges, so that:

$$U = U_0 + 0.30 \text{ W/m}^2\text{K} \quad (5)$$

where:

U_o - the U-value of the wall, without the corrections, calculated according to BS EN ISO 6946, in W/(m²K).

4.8.6 Inverted roofs

Inverted roofs have their waterproofing layer beneath the thermal insulation instead of above it as in other forms of roofing.

Calculation of thermal transmittance (U-value) should be carried out in accordance with BS EN ISO 6946 as for other roofs; the correction given in Annex F.4 of BS EN ISO 6946 allows for the effect of precipitation on the roof permeating through the joints in the insulation boards to the surface of the waterproof membrane and remaining on the surface of the waterproof membrane for potentially extended periods.

Thermal conductivity. European Technical Approval Guideline[j] (ETAG) 031-1, which sets out performance requirements for inverted roof insulation kits - advises that the design (not the declared) thermal conductivity for insulation should be used due to the special nature of the inverted roof application and the insulation being exposed to rainwater.

Rainwater cooling. Rainwater, which is able to reach the waterproofing layer on an inverted roof will absorb heat from the underlying structure and affect the thermal performance of a roof system.

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[j] https://www.eota.eu/en-GB/content/etags-used-as-ead/26/

Therefore, the initial U-value of an inverted roof system (based on design thermal conductivity) must also be corrected by adding a rainwater correction factor. A correction should be applied to the U-value as set out in BS EN ISO 6946 Annex F4.

The corrected U-value of an inverted roof will be dependent on the amount of rainfall reaching the roof (factor *p*) - which means it will be location specific; it will also depend on the proportion of rainwater that can reach the waterproof layer, drainage factor (*f*) and factor for increased heat loss caused by rainwater flowing on the waterproof layer (*x*).

Seasonal average rainfall (*p)* can be found at the UK Met Office website[k].

Refer to BBA General No 4[l], which gives detailed guidance on establishing "*p*", gives the formula for calculating the correction to the U-value and recommends the following values of the drainage factor, *f* , without the need for testing (these may be conservative and improved values determined by carrying out a test on a specific construction might be preferred).

Drainage factor (*f*)	
Roof gardens, green roofs and parking decks with cast concrete finish	0.5
Insulation with rebated or tongue and groove joints and open covering (e.g. gravel/paving)	0.75
Insulation with butt edged joints and open covering (e.g. gravel/paving)	1.0

According to BS EN ISO 6946, for a single layer of extruded polystyrene (XPS) insulation, or other insulating materials suitable for water immersion (as accredited by a national accreditation service) above the membrane with butt joints and open covering such as gravel (considered to be giving the highest ΔU), the drainage factor multiplied by the factor for increased heat loss caused by rainwater flowing on the membrane ($f{\cdot}x$) expressed in (W·day)/(m²·K·mm) is equal 0.04. Values lower than 0.04 can apply for roof constructions that give less drainage through the insulation. In these cases, where the effect of the measures is documented in independent reports, values smaller than 0.04 can be used.

The correction value for thermal transmittance ($f{\cdot}x$) determined in accordance with ETAG31-1. According to ETAG31-1, without the need for testing the following ($f{\cdot}x$) values can be used:

Drainage factor multiplied by the factor for increased heat loss caused by rainwater ($f{\cdot}x$)	
Roof gardens, green roofs and parking decks with cast concrete finish	0.02
Insulation with rebated or tongue and groove joints and open covering (e.g. gravel/paving)	0.03
Insulation with butt edged joints and open covering (e.g. gravel/paving)	0.04

For values lower than above the $f{\cdot}x$ values shall be determined in accordance with Appendix C of ETAG 31-1.

The U-value calculation should not include any gravel/paving layer and the correction may be ignored if it is less than 3% of the uncorrected U-value. See also section 8 of this document.

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[k] https://www.metoffice.gov.uk/public/weather/climate/

[l] BBA General Information Bulletin No 4 (2018 or later). Inverted roofs – Drainage and U-value corrections.

4.8.7 Loft hatches

An uninsulated loft hatch increases the roof U-value by typically 9% at the insulation level of the roof U = 0.16 W/m²K, but moderate insulation reduces this substantially.

When a loft hatch is present, obtain the overall U-value of the roof as an area-weighted average of the U-value of the main roof area and the area comprising the loft hatch. As an alternative, a correction ΔU can be included for loft hatches using the following table (which is based on insulation of the loft hatch with thermal conductivity 0.040 W/m·K).

Insulation thickness on loft hatch (mm)	ΔU
0	0.015
25	0.006
50	0.003

4.8.8 Recessed light fittings

For recessed light fittings in an insulated ceiling (e.g. ceiling insulation in pitched roofs) where the insulation in the vicinity of the light fitting has been removed to allow the dissipation of heat, either obtain the overall U-value of the roof as an area-weighted average, or add a correction, ΔU, to the U-value of the roof according to:

$$\Delta U = f\,(2.0 - U_{roof}) \qquad (6)$$

where:

f - fraction of the total ceiling area with removed insulation

U_{roof} - U-value of roof before application of the correction, in W/m²K.

4.9 Metal-faced roofing and wall cladding

The U-value of metal-clad walls and roofs needs to take account of joints between panels and any metallic components within the insulation, including through fixings.

Refer to MCRMA Technical Paper No. 18 [17] which sets out the principles and contains information on how to carry out the calculations.

The data given in BRE IP 10/02 [12] can be used as an alternative for wall or roof Z-spacer systems.[m]

Refer to IP 10/02 for details of the parameters used. The information paper also describes a method for determining thermal performance of insulated double-skin metal roof or wall systems in the UK, incorporating Z-spacers.

4.9.1 Rail-and-bracket systems

The method given in Steel Construction Institute (SCI) Technical Note P312 [13] can be used as an alternative for rail-and-bracket systems.

For built-up wall or roofing system using rails and brackets, divide the insulation into two layers, one corresponding to the rails and one corresponding to the brackets.

The rails are included in the construction table as bridging for that part of the insulation.

[m] Z-spacer systems are not usually used for new construction but may be found in existing construction.

The brackets are allowed for by a Δ U correction calculated from the number of brackets per m^2 and their cross-sectional area and thermal conductivity.

Calculate the bridging fraction for the rails from the rail thickness and the rail spacing. The calculation basis is set out in SCI Technical Information Sheet P312.

4.9.2 Compression of insulation by profile ribs

The correction applies to built-up rail & bracket or Z-spacer systems, where the insulation is compressed by shallow profile ribs of the inner liner.

The correction is valid if the rib depth does not exceed 25 mm and the ribs (centre to centre) are at least 250 mm apart. If these conditions are not fulfilled, including the case of deeper-profiled outer liners, measure the insulation thickness at its thinnest point, i.e. ignoring any insulation that spills into the ribs.

The correction is calculated as a ΔU term according to the formula given in BRE IP 10/02 or SCI Info Sheet P312. The correction does not apply if the insulation is not compressed by the profile ribs.

4.10 Light steel-framed walls

Light steel framing system consisting of cold-formed, galvanised steel C or Z-sections. Insulation can be provided as follows:

- between the metal studs only – cold frame;
- between the metal studs and on the outside of the studs – hybrid;
- outside the metal studs only – warm frame.

The methodology set out in BS EN ISO 6946 can only be used for light steel framing when all the insulation is placed outside of the steel sections (warm frame). Where the steel framing bridges some or all of the insulation (cold frame or hybrid) this type of construction is outside the scope of BS EN ISO 6946 and can be subject to numerical modelling. However, BRE Digest 465 [14] describes an adaptation of the BS EN ISO 6946 method that is suitable for obtaining the U-value for light steel frame constructions where the metal bridges the insulation.

For light steel frame construction, the studs are included in the construction table as a bridged layer. The fraction includes any noggings as well as the studs, but based on the central web of the studs.

For a warm frame, i.e. insulation outside the frame and none between the studs, the normal calculation according to EN ISO 6946 applies, including the fixings for the insulation.

For a cold frame (insulation only between studs) and hybrid (insulation between studs and outside the frame), the basis in Digest 465 is used. Give the stud spacing (centre-to-centre), the stud depth (usually the same as in the construction table, but the noggins depth if that is greater), and indicate whether the flange width (the flanges of the studs that form the C- or Z-sections) is greater than 50 mm.

Insulation inside the frame and none between the studs should be treated as warm frame. Insulation between studs and inside the frame should be treated as hybrid.

4.11 **Timber building kits**

Guidelines given in ETAG 007-2012 cover those industrially prepared timber-based building kits, marketed as a building, that are made of pre-designed and prefabricated main building parts intended for production in series. The main building parts of the kits are floor, wall and roof structures. These building parts may be assembled at the factory into larger entities, e.g. volumetric units.
Thermal resistance (R-value) and the corresponding thermal transmittance (U value) of each of the main building parts in a kit shall be calculated according to EN ISO 6946.

For insulation products, the declared thermal conductivity according to harmonized product standards or according to an ETA for a special insulation product shall be used for calculations. For other components the design thermal conductivity values for materials according to EN ISO 10456 can be used.

For walls made of logs, the calculations can be based on an assumed homogeneous wood section where the thickness is equal to the maximum log thickness for rectangular logs. For round logs the area-equal thickness may be used. The effects of seals or cracks are neglected.
Thermal transmittance of windows and doors in the external envelope which are included in the kit shall be declared separately.

5 Elements adjacent to an unheated space

For elements adjacent to an unheated space (sometimes called semi-exposed elements), the effect of the unheated space can be incorporated into the U-value of the element.

Examples of unheated spaces include garages, stairwells, store rooms and conservatories.

The heat transfer from a building to the external environment via unheated spaces is calculated according to ISO 13789.

Alternatively, when the external envelope of the unheated space is not insulated, 6.10.2 and 6.10.3 of BS EN ISO 6946 provide simplified procedures, treating the unheated space as a thermal resistance.

The thermal transmittance between the internal and external environments can be obtained by treating the unheated space together with its external construction components as if it were an additional homogeneous layer with thermal resistance, R_u.

$$R_u = \frac{A_i}{\sum (A_e \times U_e) + 0.33 \times n \times V} \qquad (7)$$

where:

- A_i - the total area of all elements between the internal environment and the unheated space, in m²;
- A_e - the area of element k between the unheated space and the external environment, in m²;
- U_e - the thermal transmittance of element k between the unheated space and the external environment, in W/m²·K;
- n - the ventilation rate of the unheated space, in air changes per hour;
- V - the volume of the unheated space, in m³.

Typical values of the air change rate (n) in unheated spaces are given in Tabl 1. A default value of n = 3.0 ach should be used if the airtightness of the unheated space is not known.

Table 1. Typical air change rates for unheated spaces

Air tightness type	**n** (air changes per hour)
No doors or windows, all joints between components well-sealed, no ventilation openings provided	0.1
All joints between components well-sealed, no ventilation openings provided	0.5
All joints well-sealed, small openings provided for ventilation	1.0
Not airtight due to some localised open joints or permanent ventilation openings	3.0
Not airtight due to numerous open joints, or large or numerous permanent ventilation openings	10.0

6 Expression of results and areas to which U-values apply

6.1 Expression of the U-value results

The resulting calculated U-values should be rounded to two significant figures (to two decimal places if the value is less than 1.0, one decimal place if more than 1.0). Round to the nearest value, with 1 to 4 being rounded downwards, and 5 to 9 being rounded upwards.

6.2 Areas for which calculated U-values apply

For the calculation of heat losses, the calculated U-value is multiplied by the area of the heat loss element. The areas of building elements which are heat loss elements, are measured between the finished internal faces of the external elements of building, or of separating walls and floors in the case of a building containing separate premises.

Internal partitions and intermediate floors of the same premises are disregarded when establishing heat loss areas.

The area of windows, roof windows and doors is the area of the opening in the wall[n]. For rooflights see section 11.

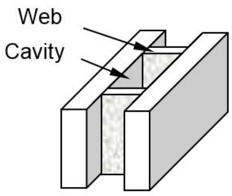
Note that in the case of window surrounds and similar, the U-value of the plane wall applies up to the edge of the window opening in the wall.

[n] The area of a window, as used to establish the thermal transmittance of the window, can be slightly larger than the aperture in the wall. The effect of any differences in area is incorporated in the Ψ-values for the junctions between walls and window, see BS EN ISO 13789.

7 U-values for walls

Unless otherwise noted below, the U-values of walls can be calculated using BS EN ISO 6946. Usually there are bridged layers, so that the calculation proceeds by way of the upper and lower limits of resistance. For other components, U-values should be obtained by numerical analysis if the procedures of BS EN ISO 6946 are not applicable.

Wall type	Issues
Masonry solid wall Brick or block	Include mortar joints in calculation if required: see 4.2 For the brick or block select exposed λ (except with an external insulation or cladding system when the protected value applies) Plasterboard wall lining (dry-lining): see 4.6 Air gaps for internal insulation between battens: see 4.8.1
Masonry cavity wall Unfilled	Include mortar joints in calculation if required: see 4.2 Cavity resistance is 0.18 m^2K/W Plasterboard wall lining (dry-lining): see 4.6 Air gaps for internal insulation between battens: see 4.8.1 Reflective foil insulation in cavity: see 3.10
Full cavity fill – injected (post-construction)	Include mortar joints in calculation if required: see 4.2 Wall ties: see 4.8.2 Plasterboard wall lining (dry-lining): see 4.6 Air gaps for internal insulation between battens: see 4.8.1
Full cavity fill - slabs (during building)	Include mortar joints in calculation if required: see 4.2 Air gaps correction: see 4.8.1; Wall ties: see 4.8.2 Plasterboard wall lining (dry-lining): see 4.6 Air gaps for internal insulation between battens: see 4.8.1
Partial cavity fill	Include mortar joints in calculation if required: see 4.2 Air gaps correction: see 4.8.1 Wall ties: see 4.8.2 Include cavity resistance for the unfilled part of the cavity (see 4.7) Correction for wall ties applies to the insulation layer only (not to the remaining unfilled cavity) If wall ties are non-metal (e.g. plastic), the U-value correction is negligible) Plasterboard wall lining (dry-lining): see 4.6 Air gaps for internal insulation between battens: see 4.8.1

Wall type	Issues
Diaphragm wall  	Insulation can be located in the wall cavities, on the internal surface or on the external surface. In any of these cases the webs are treated as a thermal bridge: for the thermal resistance of air-filled voids see 4.7. If insulation partially fills the voids, leaving residual airspaces, divide the webs into two layers, one in line with the insulation and one in line with the residual airspace. The thermal conductivity of the masonry should correspond to ‘exposed’ from the damp proof membrane (dpm) outwards and to ‘protected’ on the inside of the dpm (except with external insulation systems, when all the masonry is protected) Dry-lining: see 4.6 Air gaps for internal insulation between battens: see 4.8.1
Timber frame wall Insulation between solid timber studs (clear cavity)	Timber fraction: see 4.4.1 Air gaps – correction level 0 or 1: see 4.8.1 No correction for wall ties If insulation partially fills the space between the studs, leaving residual airspaces, divide the studs into two layers, one in line with the insulation and one in line with the residual airspace Cavity resistance included for masonry cladding; other claddings are disregarded: see 4.7 Cavity ventilation: see 4.7.1
Insulation between I-beam studs (clear cavity)	I-beam fraction: see 4.4.2 Other issues as for timber frame with insulation between solid timber studs
Warm frame and hybrid[o]	Timber fraction: see 4.4.1 Air gaps – correction level 0 or 1: see 4.8.1 Correction for wall ties: see 4.8.2 If wall ties are non-metal (e.g. plastic), the U-value correction is negligible) For hybrid, if insulation partially fills the space between the studs, leaving residual airspaces, divide the studs into two layers, one in line with the insulation and one in line with the residual airspace Cavity resistance included for masonry cladding; other claddings are disregarded: see 4.7
Separating/party walls in dwellings	There is no available method of calculating U-values of separating/party walls; the U-value depends on the presence of insulation and/or effective edge sealing. Refer to the Building Regulations documents for separating/party wall U-values.

[o] Hybrid framed constructions have both insulation between the studs and an insulation layer on the outside or inside of the frame

Wall type	Issues
Light steel frame wall Warm frame, cold frame and hybrid frame	For the appropriate calculation method see 4.10 Air gaps – correction level 0 or 1 (see 4.8.1) Warm frame and hybrid, correction for wall ties: see 4.8.2 For hybrid, if insulation partially fills the space between the studs, leaving residual airspaces, divide the studs into two layers, one in line with the insulation and one in line with the residual airspace (see BRE Digest 465). Cavity resistance included for masonry cladding; other claddings are disregarded: see 4.7
Metal-faced composite panel (factory-assembled)	Numerical analysis is needed to take account of joints between panels, if it is thinner at joints or if metal fully or partly penetrates insulation, and to take account of profiled sheets: see 4.9.
Twin skin metal cladding (site-assembled)	Numerical analysis is needed to allow for the effect of metal elements (such as spacer systems) that fully or partly penetrate the insulation, and to take account of profiled sheets: see 4.9. The data in IP 10/02 [4] can be used as an alternative for Z-spacer systems, and the method in SCI P312 [13] can be used as an alternative for rail-and-bracket systems.
Curtain wall	The average U-value of the façade should be obtained. Methods of calculation are given in BS EN ISO 12631. See also section 12 of this document.
Rainscreen cladding	See 4.8.5.
SIPS (structural insulated panel systems)	The thermal resistance of the panel is usually calculated separately, and this resistance is used in a calculation by the method of BS EN ISO 6946. Determine the bridging fraction for each case according to the construction of the panel (see guidance in 4.4.1 (iii). Connectors joining the outer and inner leafs are treated in the same way as wall ties (if plastic, the U-value correction is negligible).

8 U-values for roofs

Except where otherwise noted below, the U-value of roofs can be calculated using BS EN ISO 6946. Usually there are bridged layers, so that the calculation proceeds by way of the upper and lower limits of resistance. For other components U-values should be obtained by numerical analysis if the procedures of BS EN ISO 6946 are not applicable.

Disregard a suspended ceiling for the purposes of U-value calculation, unless it is designed to be permanent and airtight.

Roof type	Issues
Pitched roof insulation at ceiling level	The U-value is calculated at the ceiling level (not for the sloping roof). The timber joists and the insulation to be treated as bridged layer. If there are two or more layers of insulation, consider each layer separately (e.g. bridged timber insulation layer; then continuous insulation layer). Select correction “level 1” for air gaps if insulated between joists only; correction “level 0” if a second layer covers the joists and any gaps in the first layer. All construction elements above insulation layer are collectively assigned a single thermal resistance given in Table 9 of BS EN ISO 6946. Loft hatch; recessed light fitting – add correction, see 4.8.7 and 4.8.8.
insulation at rafter level, ceiling follows line of roof slope	The U-value is calculated for the sloping surface of the sloping roof. It is the area of the sloping roof that is used in heat loss calculations. Treat insulation between, above and below rafters as separate layers for the calculation. Insulation between rafters is treated as a bridged layer. Select correction “level 1” for air gaps if insulated between rafters only; correction “level 0” if a second layer, either above or below, covers the rafters and any gaps in the first layer. If there is an insulated flat ceiling near the top of the pitch, calculate its thermal resistance as for roof insulated at a ceiling level. If there is an uninsulated decorative flat ceiling (near the top of the pitch), disregard it and assess the roof as if there were no flat ceiling.
Insulation at rafter level, flat ceiling	Multiply the thermal resistance of the insulated roof structure by the cosine of the pitch of the roof. Take the thermal resistance of the roof void between rafters and ceiling as 0.16 m^2K/W. The area of the flat ceiling is used for heat loss calculations. Treat insulation between, above and below rafters as separate layers for the calculation. Insulation between rafters is treated as a bridged layer. Select correction level 1 for air gaps if insulated between rafters only; correction level 0 if a second layer, either above or below, covers the rafters and any gaps in the first layer.

Roof type	Issues
Flat roof	Insulation between joists to be treated as a bridged layer. Insulation between, below and above joists to be treated as separate layers. The U-value calculated by the procedure given in BS EN ISO 6946 needs to be corrected by using procedure given in Annex F.4 of this standard, where relevant, to take into the account effect of air voids, mechanical fasteners penetrating insulation layer and precipitation for inverted roofs. Correction for air void (voids within the insulation layer or between the insulation and the adjucent layer): see 4.8.1 of this document or Annex F.2 in BS EN ISO 6946. Correction for mechanical fasteners and fixing screws: see 4.8.3 or Annex F.3 in BS EN ISO 6946. Treat tapered insulation layers as in Annex E of BS EN ISO 6946. Consideration should be made to avoid the risk of condensation. Refer to BS 6229 for more information on various types of flat roofs.
Inverted roof	a) Calculate the initial U-value of an inverted roof system according to BS EN ISO 6946, based on design thermal conductivity of insulation layer. Ignore the effect of gravel/paving layers. b) Calculate the correction for precipitation by EN ISO 6946 apepndix F.4 and apply correction factor to the U-value calculated in step a). See section 4.8.6 for more details. A correction for rainwater cooling should be applied to the calculated U-value as set out in BS EN ISO 6946 Annex F.4 for all types of inverted roofs. The correction for precipitation applies to heated buildings; for cooled buildings it does not apply.
"Green" roof (inverted)	Proceed with the calculation as for other types of roof (e.g. inverted roof, flat roof) disregarding the landscaping elements. In the case of an inverted 'green' roof, the **design** thermal conductivity value of the landscaping element can only be permitted if given in a certificate issued by a certification body accredited by a national accreditation service. Refer to BS 6229.
"Blue" roof (inverted)	There is no currently available method for calculation of additional cooling effect for inverted "blue" roofs; it is expected that the correction to the U-value will be greater than for inverted roofs Refer to BS 6229.

Roof type	Issues
Other types of roofs, e.g. "Green" or "Blue" roofs which are not inverted	For other types of roofs (refer to "The GRO Green Roof Code"[p]) which are not inverted roofs, the calculations should exclude all types of roof gardens until the methodology has been defined. For all types of 'green' roof, the design thermal conductivity value of the landscaping element can only be permitted if given in a certificate issued by a certification body accredited by a national accreditation service. Refer to BS 6229 for more information.
Metal-faced composite panel (factory assembled)	Numerical analysis is needed to take account of joints between panels, if it is thinner at joints or if metal fully or partly penetrates insulation, and to take account of profiled sheets: see 4.9.
Twin skin metal cladding (site-assembled)	Numerical analysis is needed to allow for the effect metal elements (such as spacer systems) that fully or partly penetrate the insulation, and to take account of profiled sheets: see 4.9. The data in IP 10/02 [12] can be used as an alternative for Z-spacer systems, and the method in SCI P312 [13] as an alternative for rail-and-bracket systems.
SIPS (structural insulated panel systems)[q]	The issues are similar to those for pitched roof, insulation at rafter level. Determine the timber fraction for each case according to the construction of the panel (see 4.4.1 (iii)).

[p] The GRO Green Roof Code; Green Roof Code of Best Practice for the UK

[q] Composite panel systems with facings of timber-based material, incorporating rigid insulation that contributes to the overall strength of the panel; they can be mounted on purlins or they can span directly between walls.

9 U-values for floors

Suitable methods for calculating U-values for floors are given in BS EN ISO 13370, which provides methods of calculation of heat transfer coefficients and heat flow rates for building elements in thermal contact with the ground, including slab-on-ground floors, suspended floors and basements.

U-values for floors next to the ground and for basements should take account of the buffering effect of the ground itself.

Very large floors can have low U-values without all-over insulation (see Annex B).

Unlike components above ground, heat transfer through floors varies over the area of the floor, being greatest at the edge of the floor and least in the middle. The techniques in BS EN ISO 13370 are based on the average of this variation and provide a U-value that is representative of the floor as a whole. The avoidance of cold bridging at the edges of a floor usually requires separate consideration in addition to the U-value.

The U-value for floors (including basement floors) depends on the exposed perimeter and the area of the floor. The perimeter should include the length of all exposed walls bounding the heated space and also any walls between the heated space and an unheated space – the floor losses are calculated as if the unheated space were not present.

Since the floor U-value decreases as the ratio of perimeter to area decreases, in order to cover the case of buildings of different sizes, the U-value can be obtained for the smallest intended building. Then all buildings to be considered will have the resulting U-value or better.

Walls to other spaces that can reasonably be assumed to be heated to the same temperature, such as the separating wall to an adjacent dwelling, should not be included in the perimeter.

Thermal conductivity of ground:

Type of soil	λ_{ground}
Clay/silt	1.5 W/m²K
Sand/gravel	2.0 W/m²K
Rock	3.5 W/m²K

The ground type in the UK is most commonly clay.

Use techniques such as BS EN ISO 6946 to take account of bridged layers in the floor construction. Obtain U-values by numerical analysis if the procedures of BS EN ISO 6946 are not applicable.

9.1 Slab-on-ground floor (ground-bearing floor slabs)

Slab-on-ground floors include raft construction: the criterion is that the floor construction is essentially in contact with the ground over its whole area, without a ventilated space below.

The U-value is determined by the method in BS EN ISO 13370. The standard covers the cases of insulation over the whole floor area, where only edge insulation is provided (including low-density foundations), and a combination of both all-over insulation and edge insulation.

The calculation requires the thermal resistance, R_f, of the floor construction. The standard gives guidance as follows:

- R_f includes the thermal resistance of any all-over insulation layers above, below or within the slab;
- R_f includes the thermal resistance of any floor covering but a thin floor covering may be neglected;
- the thermal resistance of dense concrete slabs may be neglected;
- hard-core below the slab should not be included.

It is recommended for most calculations that dense floor slabs ($\rho \geq 1800$ kg/m^3) and floor coverings such as vinyl or carpets are not included in the calculation; but it is permissible to include them if their properties are adequately defined.

Slab-on-ground floors usually do not have bridged layers. If a floor does have a bridged layer, calculate R_r as follows:

(i) use the method of BS EN ISO 6946 with R_{si} = 0.17 m²K/W (downwards heat flow) and R_{se} = 0;

(ii) subtract R_{si} from the total thermal resistance so calculated to obtain R_f (this is so as not to count R_{si} twice since this quantity appears separately in the formulae in BS EN ISO 13370);

(iii) insert R_f into the relevant formula in BS EN ISO 13370 to obtain the U-value of the floor allowing for the effect of the ground.

If desired or if necessary, numerical analysis can be used in place of step (i).

Edge insulation*:* First calculate the U-value of the floor without edge insulation but including any insulation over the whole floor area. The effect of edge insulation (e.g. vertical perimeter strip) of a slab-on-ground floor is then applied as a correction to this U-value. Low-density foundation blocks are treated as vertical edge insulation. The thermal conductivity of foundation blocks should allow for their moisture content in this application: thermal conductivity of 0.25 W/m·K is recommended for foundation blocks of autoclaved aerated concrete.

Edge insulation is insulation applied at the edge of the floor.

It can be:

- horizontal: laid horizontally around the edge of the building, either inside (so providing thicker insulation at the edges of a floor with all-over insulation);

- vertical: placed vertically below ground, against or as part of the wall foundations.

If both horizontal and vertical edge insulation are present, then according to BS EN ISO 13370 only the one that has the greatest effect on the floor U-value is included in the calculation.

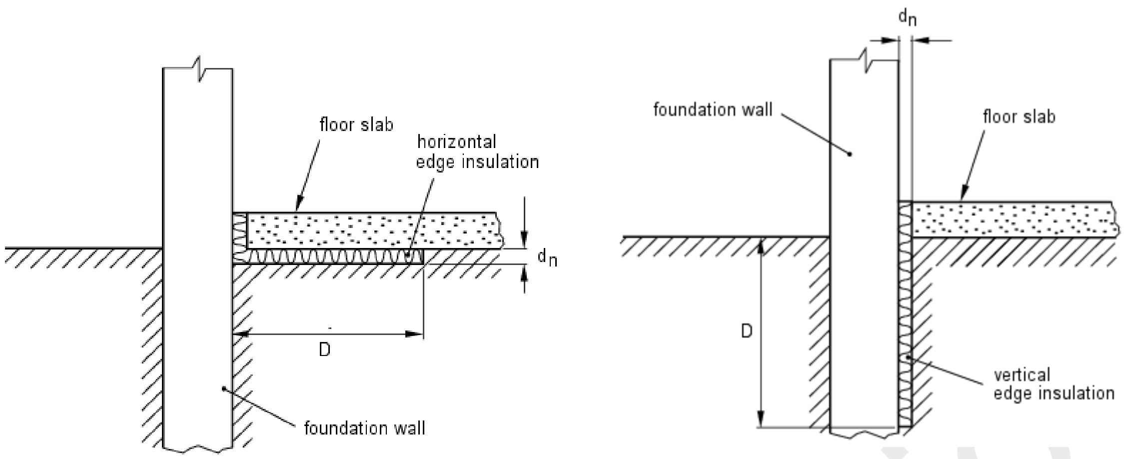


Figure 2. Horizontal and vertical floor insulation

Key:

D is the depth of vertical insulation, measured from outside ground level, mm
d_n is the thickness of the edge insulation, mm

Low-density concrete blocks used for the foundations count as edge insulation (enter the appropriate thermal conductivity for the blocks when they are below ground level as λ for the edge insulation):

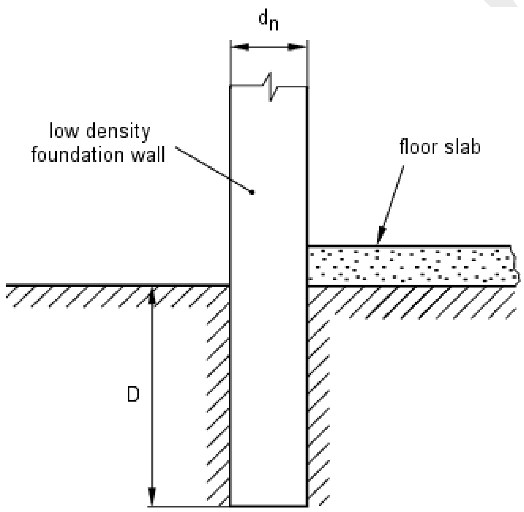


Figure 3. Low density concrete blocks

9.2 Suspended floors

Suspended floors have a ventilated void below the floor. The ventilation rate of the void is calculated from:

- the mean wind speed, the average over the heating season at 10 m height; in the absence of specific information use the UK average of 5 m/s[r];
- thermal resistance of solum: usually zero (a value greater than zero applies only if the solum is specifically insulated); do not include concrete, hardcore, etc.
- the wind shielding factor: values are given in BS EN ISO 13370 for sheltered, average and exposed locations; unless a local U-value is specifically required use the shielding factor for average exposure (0.05);
- the area of ventilation openings per length of exposed perimeter. The open area in a typical air brick is 0.003 m², so the opening per perimeter length is 0.003 m²/m for one air brick per metre, or 0.0015 m²/m for one air brick per 2 metres. The latter is the minimum for suspended timber floors in building regulations guidance, and also for suspended concrete floors.

Additional suspended floor parameters include the calculated temperature in the underfloor space, calculated according to Annex G of EN ISO 13370. The internal and external temperatures are approximate.

The calculation of the overall U-value of the floor involves combining U-values representing the floor (from the inside environment to the under-floor void), and the heat transfer from the underfloor space to the outside (by conduction through the ground and the walls of the underfloor void and by ventilation of the underfloor void).

The U-value of the floor deck can usually be calculated by the method of BS EN ISO 6946, allowing for any bridged layers and using surface resistance values of 0.17 m²K/W at both the upper and lower surfaces of the floor. If parts of joists or other floor beams have insulation between them such that the lower surface of the floor deck is non-planar, the surface should be made planar for the purposes of the calculation according to clause 6.7.2.4 of BS EN ISO 6946.

Alternatively the U-values of the floor may be calculated by numerical analysis (in which case there is no need to approximate non-planar surfaces). Calculate the overall U-value using BS EN ISO 13370.

Edge insulation: For suspended floors the effect of edge insulation is applied to the heat transfer through the ground and not to the whole floor construction, i.e. the edge insulation is included in the calculation sequence before the thermal resistance of the floor deck. It is done by applying the correction for edge insulation (as for slab-on-ground floors) to U_g as calculated by equation (10) of BS EN ISO 13370, using d_g in place of d_f in equation (D.5) or (D.6).

Floor height above ground: Floor height above ground is the average distance from outside ground level to the top of the suspended floor construction. The floor height above ground affects the calculation of the heat transfer from the underfloor void to the outside. If it varies around the building, use the average value. A default value of 225 mm (the height of 3 bricks or one block) can be used if this height has not been specified.

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[r] This is the average wind speed over the heating season and not the design wind speed for e.g. wind loading (which is usually much higher).

Depth of underfloor void below ground: If this varies, use an average. Assume a value of 300 mm unless specified otherwise[s]. The depth of the underfloor void below ground level does not affect the result unless it is greater than 0.5 m (and its effect is slight for greater depths).

9.2.1 Suspended timber floor

Insulation between joists is treated as a bridged layer, where insulation is bridged by timber.

9.2.2 Suspended beam-and-block floor

The beam-and-block construction constitutes a bridged layer for the purposes of U-value calculation in accordance with BS EN ISO 6946 and BS EN ISO 13370, or numerical analysis.

The beam fraction varies and should be determined for the case concerned. The thermal performance depends on the finished floor system (type of blocks, beams, applied layers above and/or below the structural floor etc.).

Round or oval voids in blocks can be replaced by rectangular voids having the same cross-sectional area for the purpose of U-value calculations. For airspace resistances see 4.7

If numerical calculation is used to establish the floor U-value and the distance between the beams varies the area weighted average U-value can be used.

9.2.3 Concrete beam floor with polystyrene layers

Use the calculation method in BS EN ISO 13370, together with BS EN ISO 6946 or numerical analysis.

The thermal resistance of the floor deck can be calculated using BS EN ISO 6946 where the deck has plane upper and lower surfaces. If that is not the case the lower resistance limit cannot be defined and the thermal resistance of the floor deck should be obtained by numerical analysis. In either case, BS EN ISO 13370 is then used to allow for the resistance of the ground.

9.2.4 Solid suspended floor – precast concrete planks

Material between the planks is treated as a bridged layer. Cylindrical hollow chambers can be replaced by rectangular chambers of the same cross-sectional area for the purposes of the U-value calculation – for airspace resistance see 4.7.

9.2.5 Solid suspended floor – composite steel and concrete

This type of floor consists of a profiled metal sheet with poured concrete on top. If the floor insulation is of even thickness, the floor U-value can be calculated by BS EN ISO 6946 using the average thickness of the concrete layer. If the insulation is below the floor and profiled to match the metal sheet, obtain the U-value by numerical analysis.

9.3 Floor fully exposed to external air on underside

For this type of floor (e.g. a floor above a passage or entrance to the building, or ventilated communal garege below the building) calculations can usually be done according to BS EN ISO 6946.

Surface resistance for inside surface:	**0.17 m²K/W**
Surface resistance for outside surface:	**0.04 m²K/W**

[s] Unless greater than 500 mm the void depth does not affect the U-value when calculated by BS EN ISO 13370.

10 U-values for basements and swimming pools

U-values can be calculated using BS EN ISO 13370.

BS EN ISO 13370 gives methods for floors and walls of heated basements, and for the U-value of an unheated basement (not forming part of the living space).

The wall thickness used in the U-value calculations for basements is that of the walls of the building above ground level.

10.1 Heated basements

The calculation of the U-value of a basement floor is similar to that of a slab-on-ground floor, but allowing for the average depth of the basement. The guidance for slab-on-ground floors given in section 9.1 applies also to basement floors.

In the calculation of the U-value of a basement wall, include all layers in the construction of the basement wall, including any masonry layer, while omitting backfill on the outside of the wall. Surface resistances are allowed for separately in the formulae in BS EN ISO 13370. However, if the wall construction contains bridged layers or a U-value correction applies, calculate the wall resistance R_w using R_{si} = 0.13 m^{2}K/W (for horizontal heat flow) and R_{se} = 0, apply any U-value correction so that R_w is modified to account the correction, then subtract 0.13 from the result.

10.2 Unheated basements

An unheated basement will normally have insulation within the floor deck between the heated space and the basement. Calculate the U-value of the floor deck as for other suspended floors.

The calculation of the overall U-value of an unheated basement includes the U-values of the basement floor and walls. The latter are calculated in the same way as for a heated basement. Also needed is the average ventilation rate of the basement. In the absence of specific information use the default value of 0.3 air changes per hour given in BS EN ISO 13370.

10.3 Swimming pools

Building Regulations guidance may have different approaches in different countries; refer to [1], [2], [3] or [4].

11 U-values for windows, roof windows and rooflights

There are four categories that need to be considered separately for establishing U-values:

- windows;
- roof windows;
- out-of-plane rooflights;
- in-plane rooflights.

Window is unit made of flat glass fitted into a frame; it is fitted into an opening in the wall of a building for the admission of light and air. Glazing can be single, double, triple, etc., with gaps in between which can be filled with air, argon or other gases; the surface of the glass may have low emissivity coating. Frame materials include: timber, plastics, aluminium, steel, and combinations of metal and plastic or metal and wood.

Roof window is a window, which is incorporated as part of the design of a roof. A roof window is installed in the same plane as the surrounding roof, with a minimum pitch of 15 degrees. This is as opposed to a rooflight which is installed on an upstand, and so is not in the same plane as the surrounding roof.

Out-of-plane rooflight is a unit made of translucent material, e.g. glass, GRP (glass reinforced polyester), polycarbonate or other thermoplastics, which protrudes above the plane of the roof upon which it is installed. It can be installed on a flat roof or pitched roof; where installed on a pitched roof it is likely to be fitted 'out of plane' with the level of the tiling. This category of glazed units may be profiled such as a dome, barrel vault, pyramid, ridge light or just flat. The roof light would also require a manufacturer's upstand or builder's kerb, protruding at least 150mm from the finished waterproofing level, which has to be waterproofed using the appropriate materials.

In-plane continuous rooflight is a translucent unit manufactured of GRP (glass reinforced polyester), polycarbonate or other thermoplastics, made to the same profile shape as the metal or fibre cement roof sheet, and simply replaces the opaque sheet of the profiled sheeted roof construction by an in-plane rooflight, typically used on large span commercial and industrial roofs at very low pitch (less than 15 degrees).

Refer to NARM website[t] for more information on the different types of rooflights.

Note that for windows and roof windows the U-value is established in vertical position, but for both out-of-plane and in-plane roof lights, the U-value is established in the horizontal position.

11.1 Calculation methods for windows and roof windows

The U-value is that of the complete window or roof window, including the glazing and the frame. The U-value of a window depends on the U-value of the glazing or other translucent material (centre-pane U-value), the U-value of the frame and the linear thermal transmittance of the junction between glazing and frame (which includes the effect of glazing spacers).

[t] https://www.narm.org.uk/downloads/guidance

Methods for establishing U-values of windows and roof windows:

a) measurement of a complete product in a hot box according to BS EN ISO 12567-1(for windows) or BS EN ISO 12567-2 (for roof windows);

b) numerical calculations of U-values by using the methods in BS EN ISO 10077-1. This calculation method is an alternative to the hot box test method specified in BS EN ISO 12567-1 (for windows) and BS EN ISO 12567-2 (for roof windows).

   The calculation is based on combining four components of the overall thermal transmittance:

   - for elements containing glazing, the thermal transmittance of the glazing calculated using BS EN 673 for establishing the U-value of centre pane glazing for vertical or angled planes, or measured according to BS EN 674 or BS EN 675;

   - for elements containing opaque panels, the thermal transmittance of the opaque panels, calculated according to BS EN ISO 6946 and/or numerical method in BS EN ISO 10211;

   - linear thermal transmittance of the frame and frame/glazing junction, calculated according to BS EN ISO 10077-2.

   The preferred methods for establishing values of thermal transmittance of window frames are numerical calculation methods (e.g. finite element, finite difference, boundary element) in accordance with ISO 10077-2. If no other information is available, the values derived from the tables and graphs in Annex F of BS EN ISO 10077-1 can be used for vertical windows in the calculations for the corresponding frame types.

   The thermal transmittance of **roof windows** can be calculated according to BS EN ISO 10077-1, provided that the thermal transmittance of their frame sections is determined by measurement or by numerical calculation using software conforming with BS EN ISO 10077-2 (but not from tables of default values given in the EN ISO 10077-1 because these tables are for vertical windows only).

   The calculation method for frames given in BS EN ISO 10077-2 applies to vertical frame profiles, but it is an acceptable approximation for horizontal frame profiles (sills and head sections) and for frames used in roof windows. However, in some cases the hot box method is preferred if physical and geometrical data is not available or a frame profile has a complicated geometrical shape;

c) simplified calculations of U-values by using the methods in BS EN ISO 10077-2, thermal transmittance of the glazing calculated using BS EN 673, pre-calculated U-values of frames given in Annex F and default ψ-values of typical combinations of frames given in Annex G of BS EN ISO 10077-1 are permissible alternatives to establishing U-values, which yield rather approximate results.

d) Pre-calculated U-values for typical vertical windows are given in Annex H of BS EN ISO 10077-1. It gives U-values calculated by the method in the standard using linear thermal transmittances from the Annex G of the standard for normal types of glazing spacer bars and for spacer bars with improved thermal performance.

The British Fenestration Rating Council[u] operates a scheme of approved simulators for calculations according to BS EN ISO 10077-2.

Methods a) and b) are suitable for comparison of different windows and roof windows (e.g. for the purposes of the Regulations compliance).

Methods c) and d) can be used for energy calculation only, when the specific measured or calculated information is not available.

Trickle vents are often provided in windows. While their presence affects heat transfer in practice, ventilation is regarded as a separate issue to transmission heat losses, so do not include the trickle vents in U-value determination.

Specifically:
- in hot box tests, the trickle vents should be closed and sealed with tape to ensure no air transfer;
- perform calculations as if the trickle vents were not present.

As the thermal performance of glazing and frame are generally different, the U-value of a window depends on its size and configuration. U-values should be based on the actual windows to be used in the building. Alternatively a U-value can be established to represent all the windows in a dwelling using a standard window 1.48 m high by 1.23 m wide. Details of the standard window are available from Glass and Glazing Federation (GGF).

11.2 Calculation of U-values for windows with secondary glazing

The U-value of windows with secondary glazing is obtained using the procedure for a "double window" in BS EN ISO 10077-1 clause 6.4.2.1.2, provided that the space between the main window and the secondary glazing is unventilated and the thermal transmittance of their frame sections is determined by measurement or by numerical calculation.

If either of the gaps between the frames exceeds 3 mm and measures have not been taken to prevent excessive air exchange with external air, the method does not apply.

11.3 Calculation of U-values for windows with closed shutters or blinds

A shutter on the outside of a window introduces an additional thermal resistance, resulting from both the air layer enclosed between the shutter and the window, and the shutter itself. The thermal transmittance of a window with closed shutter is calculated as given in section 6.4.2.2 of BS EN ISO 10077-1. The thermal transmittance of their frame sections is determined by measurement or by numerical calculation.

BS EN 13125 specifies the classification criteria of shutters and internal and external blinds in relation with their air permeability for the calculation of additional thermal resistance given by these products according to EN ISO 10077-1.

BS EN 13125 applies to shutters and blinds fitted to a window, a French window or a curtain walling with a roughly constant thickness of air layer between 15 mm and 300 mm (shutters and blinds parallel to the window or to the façade). This standard gives indicative values of correction

[u] www.bfrc.org

to the thermal resistance, ΔR, for different classes of shutters and external blinds, e.g. ΔR=0.08 $m^2 \cdot K/W$ for shutters and blinds with very high air permeability. If the shutters or blinds are fitted in a way that there is an excessive air exchange with external air, the method does not apply.

11.4 Adjustments to U-values for inclined roof windows (for energy calculations)

U-values of roof windows which are mounted in-plane with the sloping roof are obtained by measurements or numerical modelling given in section 11.1 and are usually tested or modelled and quoted in the vertical position. This allows comparison of different window and roof window products that could be mounted at different inclinations (e.g. for the purposes of the Regulations compliance).

However, for the purposes of calculations such as heat losses from buildings, energy efficiency calculations or building energy demand (e.g. SAP, SBEM), the U-values should relate to the inclination of the component as installed in the building. Note, that the U-value of a roof window in the inclined position will be higher than the U-value for the same rooflight in a vertical position.

If the U-value of a roof window in the inclined position, obtained by methods described in section 11.1, is not available, but is available for the roof window in the vertical position, the following indicative adjustments (as set out in Table 2) can be made to convert U-values assessed for the roof window component (including window frame) in the vertical plane into the U-value for the inclined position.

Table 2. Indicative adjustments to roof window U-values from vertical to inclined position

Inclination of roof or inclination of in-plane roof window	U-value adjustment (W/m^2K) (from vertical to inclined position)	
	Twin skin or double glazed roof window	Triple skin or triple glazed roof window
70° or more (treated as vertical)	0.0	0.0
< 70° and > 60°	+ 0.2	+ 0.1
≤ 60° and > 40°	+ 0.3	+ 0.2
≤ 40° and > 30°	+ 0.4	+ 0.2
30° or less (treated as horizontal)	+ 0.5	+ 0.3

Notes:

1) The U-value adjustments should not be used for establishing U-values of inclined roof windows for the purposes other than the purposes of energy calculations (SAP, SBEM).
2) Adjusted U-values are not suitable for the assessment of compliance criteria or comparison with other products.
3) Use the adjustments only if the actual data for roof window is obtained by measurement or numerical calculation for the vertical position.
4) The adjusted U-value is applicable to the opening in the roof for roof-windows fitted in-plane of the sloping roof (but not to rooflights on upstands or kerbs).
5) The U-value adjustments are applicable for the whole windows (not just glazing) with wooden, PVC or Aluminium frames.

11.5 Out-of-plane rooflights (roof lights on upstands or kerbs)

11.5.1 Components of out-of-plane rooflights

Many rooflights are “out-of-plane rooflights” that sit proud of the plane of the roof (typically mounted on upstands or kerbs where any glazing layer projects beyond the outside surface of the building envelope). There are differences between the area of the opening in the roof and the surface area of a rooflight-and-upstand assembly which could be quite significant, e.g. for a dome or pyramid rooflight mounted on an upstand or kerb.

The components of the rooflight are shown below, although the configurations may vary considerably.

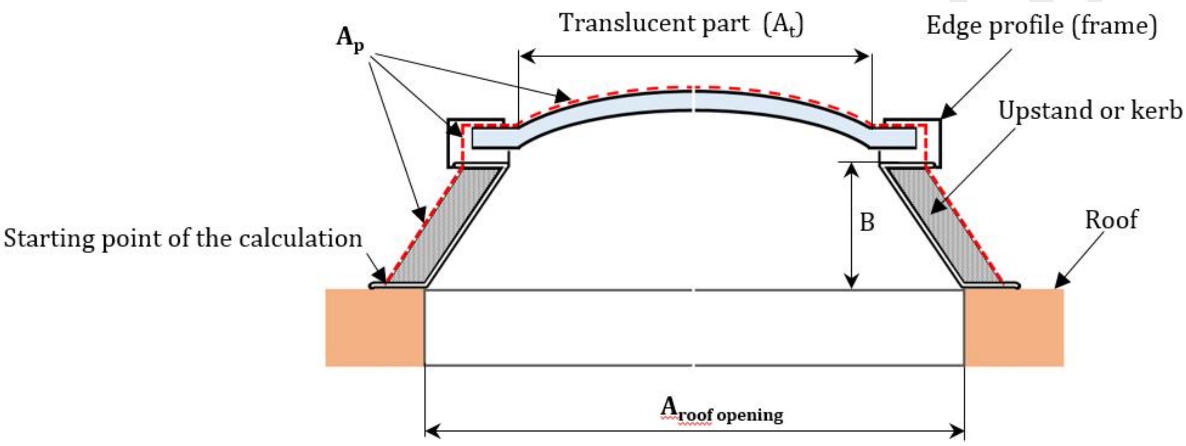

Figure 4: Roof light on upstand

Key:

- A_t - the outer exposed surface area of the translucent part
- A_p - the outer developed product surface area of the rooflight calculated in accordance with Annex D of BS EN 1873
- B - height of upstand or kerb
- $A_{roof\ opening}$ - the area of the opening in the roof

Note that according to BS EN 1873 the thermal transmittance U-value is determined in a horizontal position and is calculated in reference to the outer developed surface area.

Annex D of BS EN 1873 specifies the method for determination of U-values for all parts of rooflights (including upstand, edge profile, junction part and the translucent part including mineral glass). It also specifies methods of determining linear thermal bridges for junctions that occur between the upstand and the edge profile and the edge profile and the translucent part.

The calculation of U-values for the components requires input of values for internal and external resistance which are quoted in BS EN ISO 6946 (shown in section 4.1 of this document). According to BS EN ISO 6946, the values under “horizontal” apply to heat directions ±30º from the horizontal plane.

11.5.2 Rooflights with the upstands as an integral part of the product

Some rooflights might be manufactured with the upstands forming an integral part of the product.

If an upstand is an integral part of the product, the U-value of the complete product should be evaluated in a horizontal position according to BS EN 1873 or measured in a hot box according to BS EN ISO 12567-2 where the product is tested in a horizontal position.

According to BS EN 1873, the U-value of a product established in a horizontal position and determined in reference to the external surface is declared in the Declaration of Performance; this value should be used for the compliance criteria and comparison of the rooflights.

Note: no default adjustments from vertical to horizontal or vice versa should be applicable for the purpose of Regulations Compliance or comparison of out-of-plane rooflights with other glazing products.

For the energy calculations (SAP, SBEM), the U-value applicable for the roof opening assuming the U-value of the product (U_p) is available, given that the area of roof opening ($A_{roof\_opening}$) and the surface area of out-of-plane rooflight calculated according to BS EN 1873 (A_p) are also available:

$$U_{roof\_opening} = \frac{A_p \times U_p}{A_{roof\_opening}} \tag{9}$$

where:

$U_{roof\ opening}$ is the thermal transmittance of the rooflight associated with the area of the opening in the roof.

U_p is the thermal transmittance of a complete rooflight evaluated according to BS EN 1873 or measured to 12567-2, applicable to the outer surface area of the product;

A_p is the outer developed product surface area of the rooflight (including translucent part edge profile and upstand, but only if the upstand is an integral part of the product);

$A_{roof_{opening}}$ is the plane area of the product (the area of the opening in the roof).

11.5.3 Rooflights mounted on upstands or kerbs which are supplied or built separately.

Rooflights may be mounted on kerbs or upstands, which are separate products supplied by different manufacturers or assembled on site rather than being an integral part of the product. In such case U-values and Ψ-values of components are determined separately.

The U-value of out-of-plane rooflights with separate upstands or kerbs can be determined by these methods:

a) The thermal transmittance of a rooflight including a translucent part and edge profile (without an upstand or kerb) determined by hot box measurement in accordance with the test method given in BS EN ISO 12567-2. This U-value is used for the compliance and comparison of the rooflights with other glazing products. Note: in accordance with the test method given in BS EN ISO 12567-2 and BS EN 1873 the test specimen on the test rig is fixed in a horizontal position.

b) Thermal transmittance of rooflight components determined by calculation.
An alternative to measurement could be the procedures specified in BS EN ISO 10077-1, BS EN ISO 10077-2 (but not from tables of default values given in the EN ISO 10077-1) and BS EN 673. Although the method in BS EN ISO 10077-2 basically applies to vertical frame profiles, it is an acceptable approximation for horizontal frame profiles.

The U-value for rooflights, where the translucent part is made of plastics (e.g. polycarbonate), can be determined by calculation in accordance with BS EN 1873. According to BS EN 1873 for roof lights, calculation shall be done for the roof light mounted horizontally.

Note: no default adjustments from vertical to horizontal or vice versa should be applicable for the purpose of Regulations Compliance or comparison of out-of-plane rooflights with other glazing products.

The Linear thermal bridge occurring at the junction between the upstand and the roof is not accounted for and needs to be considered separately. According to BS EN 1873, Ψ -value of 0.35 W/(m·K) is a conservative value for Ψ for each thermal bridge (e.g. between the upstand and the edge profile, between the translucent part and the edge profile and between the translucent part and the junction with another adjacent rooflight).

Thermal bridges between the upstand and the roof are considered separately.

According to BS EN 1873, the U-value of a roof light supplied without an upstand, established in a horizontal position and determined in reference to the external surface, is the value that is declared in the Declaration of Performance; this value should be used for the compliance criteria and comparison of the rooflights.

In the case of rooflights mounted on an upstand or builders kerb, only **for the purpose of energy calculations**, the area of the rooflight is the opening in the roof (i.e. projected area); and the U-value associated with the area of roof opening can be calculated using the following formula:

$$U_{roof\_opening} = \frac{\sum A_p \times U_p + \sum A_u \times U_u + \sum L_{p;u} \times \Psi_{p;u} + \sum L_{u;r} \times \Psi_{u;r}}{A_{roof\_opening}} \qquad (10)$$

where:

A_p - product surface area (calculated according to BS EN 1873), m²

U_p - U-value of the product (determined according to BS EN 1873), W/m²K

A_u - surface area of upstand or kerb, m²

U_u - U-value of upstand of kerb, W/m²K

$L_{p;u}$ - the length of thermal bridge between the product and upstand or kerb, m

$L_{u;r}$ - the length of thermal bridge between the upstand or kerb and the roof, m

$\Psi_{p;u}$ - the linear thermal transmittance between the product and upstand or kerb, W/m·K

$\Psi_{u;r}$ - the linear thermal transmittance between the upstand or kerb and roof, W/m·K

$A_{roof\_opening}$ - area of roof opening, m²

11.6 Lantern- or box-style rooflights kerb or upstand

Figure 5 gives an example of a lantern-style rooflight. The configuration of lantern-style rooflights can vary significantly.

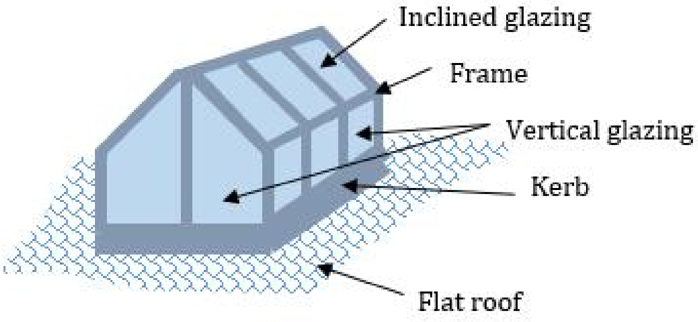

Figure 5: Lantern-type rooflight

A lantern type rooflight includes vertical and inclined glazing. Such rooflights are normally assembled on site.

Note that this method requires the calculation of U-values of individual sections; these can be obtained by measurement according to BS EN ISO 12567-1 (as windows or rooflights) or by numerical calculation using software conforming with BS EN ISO 10077-2. This method is an alternative to the hot box test method specified in BS EN ISO 12567-1.

U-values of frames are calculated according to BS EN ISO 10077-2.

U-value of glazing calculated according to BS EN ISO 673; for the inclined sections the U-value should be related to the inclination.

For declaring the U-value or the compliance of individual sections with the Building Regulations, refer to the U-values of individual sections (including frames) tested/calculated in the intended mounting position.

For the heat loss calculations (SAP, SBEM) use the following formula to calculate U-value applicable to the roof opening.

$$U = \frac{\sum_{i=1}^{i=n} A_t \times U_t + \sum_{i=1}^{i=n} A_f \times U_f + \sum A_u \times U_u + \sum_{i=1}^{i=n} L_{t;f} \times \Psi_{t;f} + \sum_{i=1}^{i=n} L_{f;f} \times \Psi_{f;f} + \sum L_{f;u} \times \Psi_{f;u} + \sum L_{u;r} \times \Psi_{u;r}}{A_{roof\_opening}} \quad (11)$$

where:

A_t - area of each glazed, translucent or opaque section (not including frame), m²

A_f - area of frame associated with each section, m2

A_u - area of upstand or builders kerb, m²

U_t - U-value of each glazed, translucent or opaque section (not including frame) ,W/m²K

U_f - U-value of frame associated with each section, W/m²K
U_u - U-value of upstand of kerb, W/m²K
$L_{t;f}$ - length of thermal bridge between translucent part and frame, over which $\Psi_{t;f}$ applies, m
$L_{f;f}$ - length of thermal bridge between frames of sections, over which $\Psi_{f;f}$ applies, m
$L_{f;u}$ - length of thermal bridge between sections and upstand or kerb, over which $\Psi_{f;u}$ applies, m
$L_{u;r}$ - length of thermal bridge between upstand or kerb and a roof, over which $\Psi_{u;r}$ applies, m
$\Psi_{t;f}$ - the linear thermal transmittance between translucent parts and frames, W/m·K
$\Psi_{f;f}$ - the linear thermal transmittance of the thermal bridge between frames of sections, W/m·K
$\Psi_{f;u}$ - the linear thermal transmittance frames and upstand or kerb, W/m·K
$\Psi_{u;r}$ - the linear thermal transmittance between the upstand and a roof, W/m·K
$A_{roof\_opening}$ - area of roof opening, m²

For heat loss calculations (e.g. SAP, SBEM), the linear thermal bridge between the non-traditional glazing and adjacent building elements should be calculated by numerical modelling.

If there are junctions between sections of the non-traditional glazing, the linear thermal bridge needs to be accounted for in the U-value of the whole glazing product or added separately.

11.7 In-plane continuous rooflights

In-plane contunious rooflights may consist of single-skin sheets or factory assembled units made of several sheets of translucent materials.

In-plane rooflights made of single profiled transparent or translucent sheets that fit into the plane of a profiled sheeted roof (typically profiled metal or fibre cement) replacing one or more of the opaque sheets, have poor insulating properties and do not profide adequate thermal insulation required for conditioned buildings.

Factory assembled continuous in-plane rooflights which could be with or without load bearing profiles, consist of several layers of translucent material which can provide level of insulation required by the Building Regulations for the conditioned buildings.

Since each layer of translucent material in the factory assembled rooflight may have different configurations and some layers may have different load-bearing profiles, the effect of the profile on the surface area should therefore not be considered, and the U-value should be based on the plan area of the rooflight (opening in the roof).

Factory-assembled continuous in-plane rooflights can be tested to BS EN ISO 12567-2 where the product is tested in a horizontal position.

Calculation of the thermal insulation characteristics is performed as described in BS EN ISO 6946, EN 673, BS EN ISO 10211, or BS EN ISO 10077-1.

The declared thermo-physical properties of the constituent materials, which will be necessary for any such calculations, shall either be as measured according to the relevant standards or alternatively be assigned a value according to BS EN ISO 10456.

For the declaration of the U-value, for compliance and for the comparison with other rooflights products, the U-value obtained by the testing in horizontal position should be used.

Note: no default adjustments from vertical to horizontal or vice versa should be applicable for the purpose of Regulations Compliance or comparison of out-of-plane rooflights with other glazing products.

For the energy calculations, the U-value of in-plane continuous rooflight is calculated as follows:

$$U = \frac{\sum A_p \times U_p + \sum L_{p;r} \times \Psi_{p;r}}{A_{roof\_opening}} \tag{12}$$

where:

- A_p - product area (developed area of in-plane rooflight), m²
- U_p - U-value of the product (includes translucent part and edge profile, if present), W/m²K
- $L_{p;r}$ - the length of thermal bridge between the inplane rooflight and the roof, m
- $\Psi_{p;r}$ - the linear thermal transmittance between the in-plane rooflight and roof, W/m·K
- $A_{roof\_opening}$ - area of roof opening (the same as product area), m²

12 Curtain walls

Curtain walls include structural frames, and window assemblies fixed to mullions and transoms. The average U-value of the façade should be obtained for the representative reference elements. Methods of calculation are given in BS EN ISO 12631 and include:
— the single assessment method, and
— the component assessment method.

The single assessment method is based on detailed computer calculations of the heat transfer through a complete construction including mullions, transoms, and filling elements (e.g. glazing unit, opaque panel). This method can be used for any curtain walling system.

The component assessment method divides the representative element into areas of different thermal properties, e.g. glazing units, opaque panels and frames. By area weighting the U-values of these elements with additional correction terms describing the thermal interaction between these elements (Ψ-values), the overall façade U-value can be calculated. This method can be used for curtain walling systems such as unitised systems, stick systems and patent glazing. Structural silicone glazing, rain screens and structural glazing are excluded from the component assessment method.

U-values for centre pane glazing can be measured or assessed according to BS EN ISO 673.

U-values of mullions and transoms can be established according to BS EN ISO 10077-2:2017.

U-values of panels can be established by using methods given in BS EN ISO 6946:2017.

The calculation includes thermal bridges for glazing-to-frame and panel-to-frame.

Thermal bridging (ψ-value) is calculated as given in BS EN ISO 10211:2017 (detailed calculation) or BS EN ISO 14683:2017 (Simplified method and default values).

13 Dynamic transparent building elements

Dynamic transparent building elements are elements with thermal and/or solar properties that vary with the condition of the external environment, either in a passive way or due to a control.

An example of a dynamic transparent building element would be a transparent façade element with movable blinds and vents, switchable glazing, thermally insulated shutetrs, PV-integrated glazing.

In the case where ventilation through the dynamic transparent element takes place, the dynamic building element is taken into account in the effective U-value and g-value.

Refer to Annex G in BS EN ISO 52016-1 which gives procedures for the calculations of dynamic properties of dynamic transparent elements.

A separate standard covering more detailed procedures on dynamic transparent elements and adaptive building facades is in preparation.

14 U-values for doors

Obtain the U-value for the complete door set and not just the door leaf.

For the purposes of heat demand calculations (SAP, SBEM) for fully glazed doors establish the U-value on the basis of doors with dimensions:

- for single doors: 1.0 m wide and 2.0 m high;
- for double doors and patio doors: 2.0 m wide and 2.0 m high.

The U-value of a solid wooden door and frame may be taken as 3.0 W/m^{2}K.

The U-value of a composite door without glazing can be calculated by the methods in BS EN ISO 6946 provided that:

a) the internal and external facings of any panels within the door are of material of thermal conductivity, *(λ),* less that 0.5 W/m·K, and

b) the thermal conductivity, *(λ),* of any bridging material at the edges of panels within the door or at the edges of the door is less than 0.5 W/m·K.

In other cases it is necessary to allow for a linear thermal transmittance term for the edges of panels within the door or for the edges of the door, or both (as specified in BS EN ISO 10077-1). For a partially glazed door, assess the glazing by BS EN ISO 10077-1 or -2.

The U-value of doors can also be obtained by testing according to BS EN ISO 12567-1 or by numerical analysis (see 2.1). This includes industrial doors (roller-shutter types etc.).

15 U-values of existing (old) walls, roofs and floors in dwellings

U-values of existing (old) walls, roofs or floors might be difficult to determine due to difficulties with establishing the exact construction and thermal properties of materials of the elements.

The sources of U-values for the existing (old) building elements are given below. These U-values can be used in the absence of the calculated values, e.g. for the purposes of heat loss calculation or SAP software for the purposed of issuing EPCs for existing dwellings. However these values should not be used for new buildings, and are not applicable for buildings other than dwellings.

15.1 Existing (old) walls in dwellings.

Refer to SAP Specification [5] Appendix S to obtain default U-values for different wall types for dwellings built at different times from pre-1900 onwards.

15.2 Existing (old) roofs in dwellings.

The U-value for a pitched roof with an insulated ceiling should, where possible, be based on the observed thickness of the loft insulation. Refer to SAP Specification [5] Appendix S to obtain default U-values for different types of roofs, including pitched roofs insulated at ceiling and rafter levels, flat roof and thatched roof.

15.3 Existing (old) floors in dwellings.

Refer to Figure B.1 of this document, which shows the dimensions of rectangular solid ground floors without insulation. These U-values are approximate and can be used only if no other information is available.

Refer to SAP Specification [5] Appendix S for generic U-values of ground floors in dwellings.

16 Heat capacity

The heat capacity of a building element is a measure of how much heat the element is able to store. This is calculated from the properties of the materials making up the building element. Heat capacity is part of calculation of energy demand for buildings and is often calculated by U-value calculators as an additional feature.

The calculation methods are given in BS EN ISO 13786; two methods are defined in the standard for calculating heat capacity:

- a detailed calculation (clause 8 of BS EN ISO 13786);
- a simplified calculation by the effective thickness method (Annex C of BS EN ISO 13786).

The simplified calculation is often carried out in parallel with the U-value calculation by U-value calculators.

Heat capacity per unit area, kappa (κ) in kJ/m²K, for a construction element can be calculated from:[v]

$$\kappa = 10^{-6} \times \Sigma \, (d_j \times \rho_j \times c_j) \tag{13}$$

where:

d_j - the thickness of each layer (mm)
ρ_j - density of each layer (kg/m³)
c_j - specific heat capacity of each layer (J/kg·K)

The summation is over all layers in the element, starting at the inside surface and stopping at whichever of these conditions occurs first (which may mean part way through a layer):

- half way through the component (e.g. wall)
- an insulation layer (thermal conductivity <= 0.08 W/m·K)
- total thickness of 100 mm.

The heat capacity of a building component is calculated first without taking account of the surface resistance, using the most suitable of the conditions given above. Account of surface resistances is then taken into the account in accordance with section C3 of BS EN ISO 13786.

Air layers are included in the calculation of heat capacity; use the thermal resistance of air cavity (which depends on the thickness of the cavity and is calculated according to BS EN ISO 6946; see section 4.7 of this document for the detaild of calculating resistance of air layers), and the following parameters:

Density of air	ρ=**1.0 kg/m³**

Use typical heat capacity for other materials (see BS EN ISO 10456 and CIBSE Guide) for:

[v] This simplified calculation is acceptable for SAP calculations. A detailed method is given in ISO 13786, Thermal performance of building components – Dynamic thermal characteristics – Calculation methods.

Specific heat capacity of air	c_p=**1000 J/(kg·K)**
Brick, concrete and stone	c_p=**840 J/(kg·K)**
Gypsum, plasters and renders, plasterboard	c_p=**840 J/(kg·K)**
Glass	c_p=**750 J/(kg·K)**
PU foam, rigid	c_p=**1800 J/(kg·K)**
Timber	c_p=**1600 J/(kg·K)**
Plywood	c_p=**1700 J/(kg·K)**
Mineral wool, expanded and extruded polystyrene	c_p=**1450 J/(kg·K)**

See BS EN ISO 10456 and CIBSE Guide A for more design values for specific heat capacity of insulation and masonry materials.

17 Appendix A: Glossary/definitions

basement
usable part of a building that is situated partly or entirely below ground level

blue roof
roof designed to attenuate the rate at which rainwater is drained from the roof and is allowed to enter the drainage system

building element
major part of a building (e.g. wall, roof or floor)

building component
building element or a part of it

declared thermal value
expected value of a thermal property of a building material or product assessed from measured data at reference conditions of temperature and humidity, given for a stated fraction and confidence level, and corresponding to a reasonable expected service lifetime under normal conditions

design thermal conductivity
value of thermal conductivity of a building material or product under specific external and internal conditions, which can be considered as typical of the performance of that material or product when incorporated in a building component

design thermal resistance
value of thermal resistance of a building product under specific external and internal conditions, which can be considered as typical of the performance of that product when incorporated in a building component

discrete; discretely
specific, one off, random

cavity wall tie
device for connecting a masonry leaf across a cavity to another masonry leaf or to a structural frame to resist tension and compression forces while allowing limited differential movement in the plane of the wall

cavity width
distance between the cavity faces of the masonry leaves of a cavity wall, measured perpendicular to the plane of the wall

conditioned space
heated and/or cooled space

edge profile
any frame or profile necessary to fix and/or open the translucent part of the rooflight

emissivity
emissivity of a material (usually written ε) is the ratio (proportion) of the energy radiated by a surface relative to the energy radiated by a blackbody at the same temperature. It is a measure of a material's ability to radiate heat

fixing
device (e.g. a nail, screw, screw/plug, anchor or bolt) used to connect ancillary components to masonry or to supporting structures to resist tension and shear forces

"green" roof
a "green" roof or living roof is a roof of a building consisting of the structural deck and all the layers on it that are partially or completely covered with vegetation and/or a growing medium planted over a waterproofing membrane.

transmission heat transfer coefficient (heat loss)
heat flow rate due to thermal transmission through the fabric of a building, divided by the difference between the environment temperatures on either side of the construction

internal dimension
dimension measured from wall to wall and floor to ceiling inside a room of a building
inverted roof
a roof in which the thermal insulation is placed above the waterproofing layer.

linear thermal transmittances (Ψ-values)
arise at junctions between different components

material
piece of a product irrespective of its delivery form, shape and dimensions, without any facing or coating

noggings
wooden pieces fitted between the principal timbers of timber-framed wall

product
final form of a material ready for use, of given shape and dimensions and including any facings or coatings

point thermal transmittance of point thermal bridge (χ)
occurs where insulation is discretely penetrated by fixings

reflective surface or low emissivity surface
surface which has a low emissivity at the appropriate wavelength within the temperature range found in building elements

reflective insulation
insulation product which has one or both external face(s) comprising a reflective surface

rooflights (out-of-plane, projecting)
product, where any layer of glazed product is mounted out-of-plane of the roof (projects beyond the outside surface of the building envelope)

roof windows (in-plane with roof)
any framed glazed product installed in plane with a sloped or horizontal building envelope

SIPS
SIPS for walls are composite panel systems incorporating rigid insulation that contributes to the overall strength of the panel. The facings can be timber, OSB, plasterboard or concrete.

slab on ground
floor construction directly on the ground over its whole area

steady-state condition of a system or process
is the condition that does not change in time; broadly it is a condition that changes only negligibly over a specified time

suspended floor
floor construction in which the lowest floor is held off the ground, resulting in an air void between the floor and the ground. This air void, also called underfloor space or crawl space, may be ventilated or unventilated, and does not form part of the habitable space

18 Appendix B: U-values of uninsulated floors

Figure B.1 shows the dimensions of rectangular solid ground floors that have indicative U-values of 0.15, 0.20, 0.25 and 0.35 W/m^{2}K without insulation of the floor slab. Edge insulation of the floor will usually be needed to avoid thermal bridging at the perimeter. It is intended only as a guide: floor U-values should be calculated for particular cases on the basis of the floor construction and the building dimensions.

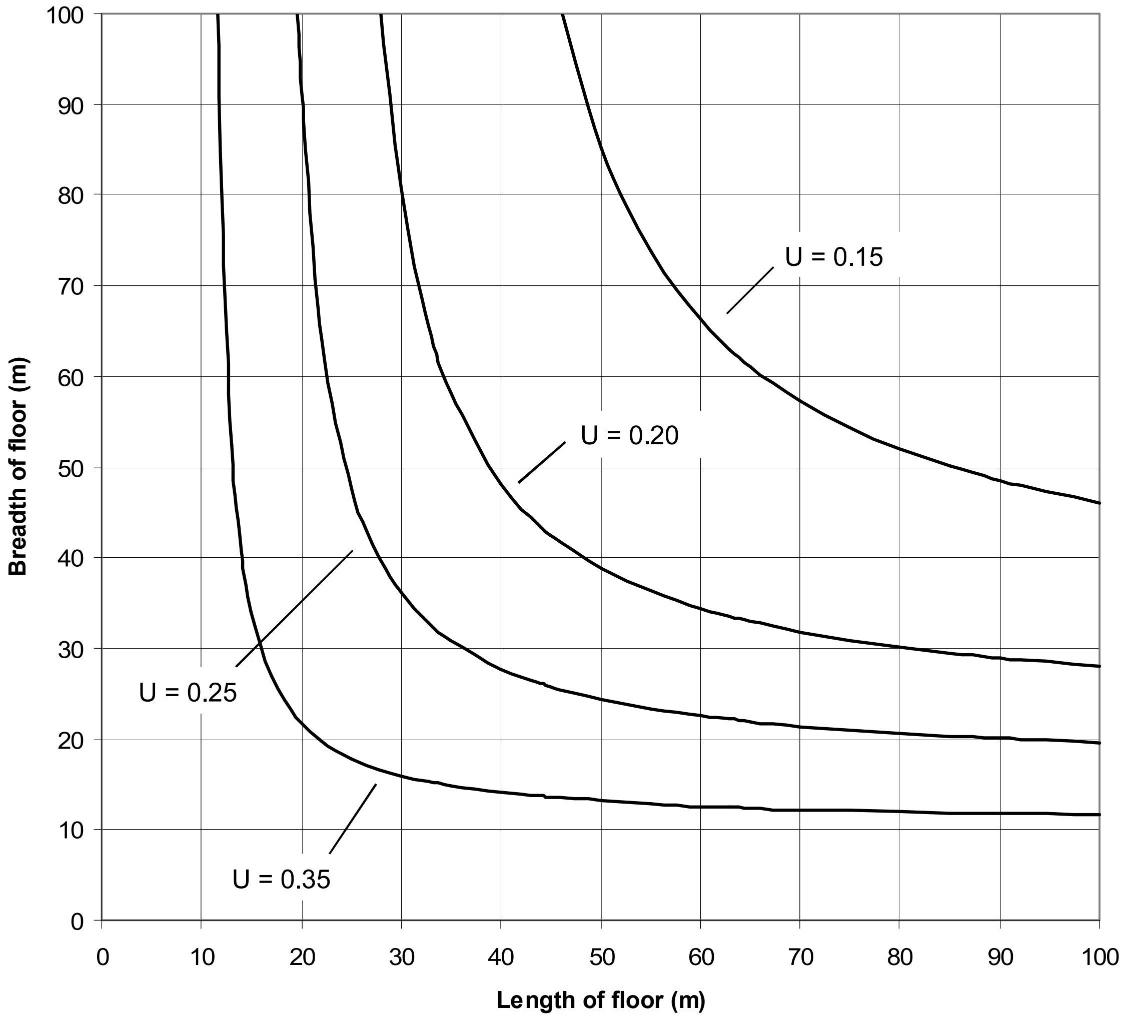

Figure B1 U-value of uninsulated rectangular ground floors

19 References and further reading

[1] The Building Regulations Approved Documents L1A, L1B, L2A and L2B for use in England, from https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l

[2] The Building Regulations Approved Documents L1A, L1B, L2A and L2B for use in Wales, obtainable from https://gov.wales/topics/planning/buildingregs/approved-documents/part-l-energy/?lang=en

[3] The Building (Scotland) Regulations: Domestic Handbook and Non-domestic Handbook, obtainable from http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/publications/pubtech

[4] The Building Regulations (Northern Ireland): Technical Booklets F1 and F2, obtainable from http://www.buildingcontrol-ni.com/regulations/technical-booklets

[5] SAP: The Government's Standard Assessment Procedure for Energy Rating of Dwelling.

[6] UK's National Calculation Method for Non Domestic Buildings, http://www.uk-ncm.org.uk/

[7] Ward T I. Information Paper IP 1/06 *Assessing the effect of thermal bridging at junctions and around openings*, BRE, 2006

[8] 2006 Department for Communities and Local Government. Accredited Construction Details, 2007, obtainable from www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/bcassociateddocuments9/acd

[9] Accredited Construction Details (Scotland) 2015, obtainable from http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/techhandbooks

[10] Ward T I., Hannah G., Sanders C. *Conventions for calculating temperature factors and linear thermal transmittance (BR 497 2nd edition)*. BRE, 2016

[11] *CIBSE Guide A*, 2018 Edition. Chartered Institution of Building Services Engineers, 2018

[12] Ward T I. Information Paper IP 10/02 *Metal cladding: assessing the thermal performance of built-up systems that use 'Z' spacers*. BRE, 2002

[13] Technical Note P312, *Metal cladding: U-value calculation: Assessing the thermal performance of built-up metal roof and wall cladding systems using rail & bracket spacers*, Steel Construction Institute, 2002

[14] Digest 465 *U-values for light steel frame construction.* BRE, 2002

[15] NHBC Standards http://www.nhbc.co.uk/Builders/ProductsandServices/TechZone/nhbcstandards/

[16] Glazing Manual Data Sheet 2.2, *Window and door system U-values: provision of certified data,* Glass and Glazing Federation, 2014

[17] MCRMA Technical Paper No. 18 Conventions for calculating U-values, f-values and ψ-values for metal cladding systems using two- and three-dimensional thermal calculations. November 2006.

Relevant Standards

Calculation methods

BS EN ISO 6946:2017	Thermal performance of buildings and building components. Thermal resistance and thermal transmittance. Calculation methods
BS EN ISO 10077-1:2017	Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Part 1: General
BS EN ISO 10077-2:2017	Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Part 2: Numerical methods for frames
BS EN ISO 10211:2017	Thermal bridges in building construction. Heat flows and surface temperatures. Detailed calculations
BS EN ISO 13370:2017	Thermal performance of buildings. Heat transfer via the ground. Calculation methods
BS EN ISO 13786:2017	Thermal performance of building components. Dynamic thermal characteristics. Calculation methods
BS EN ISO 13789:2017	Thermal performance of buildings. Transmission and ventilation heat transfer coefficients. Calculation method
BS EN ISO 10456:2007	Building materials and products. Hydrothermal properties. Tabulated design values and procedures for determining declared and design values
ISO 15099:2003 (R10) Ed1	Thermal performance of windows, doors and shading devices. Detailed calculations
BS EN 673:2011	Glass in building. Determination of thermal transmittance (U-value) – Calculation method
EN 674:2011	Glass in building — Determination of thermal transmittance (U value) — Guarded hot plate method
EN 675:2014	Glass in building — Determination of thermal transmittance (U value) — Heat flow meter method
BS EN 1745:2012	Masonry and masonry materials. Methods for determining design thermal values
BS EN 13125:2001	Shutters and blinds — Additional thermal resistance — Allocation of a class of air permeability to a product
BS EN ISO 12631:2017	Thermal performance of curtain walling – Calculation of thermal transmittance
BS EN ISO 52016-1:2017	Energy performance of buildings. Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads. Calculation procedures
ISO/TR 52016-2:2017	Energy performance of buildings. Energy needs for heating and cooling, Internal temperatures and sensible and latent heat loads. Explanation and justification of ISO 52016-1 and ISO 52017-1

EN 12898*	Glass in building — Determination of the emissivity
BS EN 845-1:2013+A1:2016*	Specification for ancillary components for masonry. Wall ties, tension straps, hangers and brackets

Measurement methods

BS EN ISO 8990:1996	Thermal insulation. Determination of steady-state thermal transmission properties. Calibrated and guarded hot box
BS EN ISO 1946-1:1999*	Thermal performance of building products and components – Specific criteria for the assessment of laboratories measuring heat transfer properties – Part 1: Common criteria.
BS EN ISO 1946-2:1999*	Thermal performance of building products and components – Specific criteria for the assessment of laboratories measuring heat transfer properties – Part 2: Measurement by guarded hot plate method.
BS EN ISO 1946-3:1999*	Thermal performance of building products and components – Specific criteria for the assessment of laboratories measuring heat transfer properties – Part 3: Measurement by heat flow meter method.
BS EN ISO 1946-4:2000*	Thermal performance of building products and components – Specific criteria for the assessment of laboratories measuring heat transfer properties – Part 4: Measurement by hot box method.
BS EN 12664:2001	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Dry and moist products of medium and low thermal resistance
BS EN 12667:2001	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance
BS EN 12939:2001	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Thick products of high and medium thermal resistance
BS EN ISO 12567-1:2010	Thermal performance of windows and doors. Determination of thermal transmittance by hot box method. Part 1: Complete windows and doors
BS EN ISO 12567-2:2005	Thermal performance of windows and doors. Determination of thermal transmittance by hot box method. Part 2: Roof windows and other projecting windows
ISO 8301:1991 Ed1	Thermal insulation. Determination of steady-state thermal resistance and related properties. Heat flow meter apparatus
BS 8202-1:1995	Coatings for fire protection of building elements. Code of practice for the selection and installation of sprayed mineral coatings
BS EN 15976:2011	Flexible sheets for waterproofing — Determination of emissivity
BS EN 16012:2012+A1:2015	Thermal insulation for buildings — Reflective insulation products — Determination of the declared thermal performance

BS ISO 9869-1:2014	Thermal insulation —Building elements — In-situ measurement of thermal resistance and thermal transmittance Part 1: Heat flow meter
BS ISO 9869-2:2018	Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance — Part 2: Infrared method for frame structure dwelling
BS EN 12412-2:2003	Thermal performance of windows, doors and shutters. Determination of thermal transmittance by hot box method. Frames

Additional standards

BS EN 845-1:2013+A1:2016	Specification for ancillary components for masonry. Part 1: Wall ties, tension straps, hangers and brackets
BS EN 1873	Prefabricated accessories for roofing — Individual rooflights of plastics — Product specification and test methods
EN ISO 10456:2007	Building materials and products — Hydrothermal properties — Tabulated Design values and procedures for determining declared and design thermal Values
BS EN 410:2011	Glass in building —Determination of luminous and solar characteristics of glazing
BS 6229:2018	Flat roofs with continuously supported coverings. Code of practice

Factory-made products:

BS EN 13162:2012+A1:2015	Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification
BS EN 13163:2012+A2:2016	Thermal insulation products for buildings. Factory made products of expanded polystyrene (EPS). Specification
BS EN 13164:2012+A1:2015	Thermal insulation products for buildings. Factory made products of extruded polystyrene foam (XPS). Specification
BS EN 13165:2012+A2:2016	Thermal insulation products for buildings. Factory made rigid polyurethane foam (PUR) products. Specification
BS EN 13166:2012+A2:2016	Thermal insulation products for buildings. Factory made products of phenolic foam (PF) products. Specification
BS EN 13167:2012+A1:2015	Thermal insulation products for buildings. Factory made cellular glass (CG) products. Specification
BS EN 13168:2012+A1:2015	Thermal insulation products for buildings. Factory made wood wool (WW) products. Specification
BS EN 13169:2012+A1:2015	Thermal insulation products for buildings. Factory made products of expanded perlite (EPB) products. Specification
BS EN 13170:2012+A1:2015	Thermal insulation products for buildings. Factory made products of expanded cork (ICB). Specification

BS EN 13171:2012+A1:2015	Thermal insulation products for buildings. Factory made wood fibre (WF) products. Specification

In-situ-formed products:

BS EN 14063-1:2004	Thermal insulation products for buildings. In-situ formed expanded clay lightweight aggregate products. Part 1: Specification for the loose-fill products before installation
BS EN 14063-2:2013	Thermal insulation products for buildings. In-situ formed expanded clay lightweight aggregate products. Part 2: Specification for the installed products
BS EN 14064-1:2010	Thermal insulation products for buildings. In-situ formed loose-fill mineral wool (MW) products. Part 1: Specification for the loose-fill products before installation
BS EN 14064-2:2010	Thermal insulation products for buildings. In-situ formed loose-fill mineral wool (MW) products. Part 2: Specification for the installed products
BS EN 14315-1:2013	Thermal insulating products for buildings. In-situ formed sprayed rigid polyurethane (PUR) and polyisocyanurate (PIR) foam products. Part 1: Specification for the rigid foam spray system before installation
BS EN 14315-2:2013	Thermal insulating products for buildings. In-situ formed sprayed rigid polyurethane (PUR) and polyisocyanurate (PIR) foam products. Part 2: Specification for the installed insulation products
BS EN 14316-1:2004	Thermal insulation products for buildings. In-situ thermal insulation formed from expanded perlite (EP) products. Part 1: Specification for bonded and loose-fill products before installation
BS EN 14316-2:2007	Thermal insulation products for buildings. In-situ thermal insulation formed from expanded perlite (EP) products. Part 2: Specification for the installed products
BS EN 14317-1:2004	Thermal insulation products for buildings. In-situ thermal insulation formed from exfoliated vermiculite (EV) products. Part 1: Specification for bonded and loose-fill products before installation
BS EN 14317-2:2007	Thermal insulation products for buildings. In-situ thermal insulation formed from exfoliated vermiculite (EV) products. Part 2: Specification for the installed products
BS EN 14318-1:2013	Thermal insulating products for buildings. In-situ formed dispensed rigid polyurethane (PUR) and polyisocyanurate (PIR) foam products. Part 1: Specification for the rigid foam dispensed system before installation
BS EN 14318-2:2013	Thermal insulating products for buildings. In-situ formed dispensed rigid polyurethane (PUR) and polyisocyanurate (PIR) foam products. Part 2: Specification for the installed insulation products
BS EN 15101-1:2013	Thermal insulation products for buildings. In-situ formed loose fill cellulose (LFCI) products. Specification for the products before installation

BS EN 15101-2:2013	Thermal insulation products for buildings. In-situ formed loose fill cellulose (LFCI) products. Specification for the installed products

(*These Standards are currently under review)