Conventions for U-value calculations

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Contents

1 Introduction

Calculation methods for the determination of U-values of building elements 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.

These methods are appropriate for demonstrating compliance with building regulations for the conservation for fuel and power, namely Part L of the Building Regulations for England & Wales, Section 6 of the Building (Scotland) Regulations, and Part F of the Building Regulations (Northern Ireland)[1,2,3]. 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)[4] for dwellings or by the Simplified Building Energy Model (SBEM)[5] for other buildings.

This publication provides guidance on the use of the calculation methods by:

- indicating the method or methods of calculation that are appropriate for different construction elements;
- providing additional information about using the methods;
- providing data relevant to typical UK constructions.

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*).

While calculated U-values are acceptable for Building Regulations and most other purposes, direct measurement of U-values is also possible and, indeed, test results should be preferred when available provided that the values have been obtained in accordance with the appropriate measurement standards*.

The guidance in this document is concerned with the U-values of building elements – walls, roofs, floors, windows and doors. It is complementary to the information in Accredited Construction Details[6] which deals with the junctions between building elements and around openings.

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 12).

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* The measurement standards for the U-value of building components are BS EN ISO 8990 for walls, roofs, and floor decks (ie excluding effects of the ground), BS EN ISO 12567-1 for windows and doors, and BS EN ISO 12567-2 for rooflights.

2 Numerical methods and simplified methods

U-value calculation is at its simplest for 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, other types of structural member separated by infill panels, glazing within a frame, and so on. 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. That 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

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 (3-D) effects do not significantly affect the overall U-value. (The corners of a window frame represent an example of the latter.) In consequence, 2-D 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-D way (eg 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. A guidance document is in preparation[7].

2.2 Simplified methods

Simplified methods are normally used for U-value calculations where they are appropriate for the construction of the element concerned: the British Standard 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. Known also as the Combined Method, it involves calculation of the upper limit of thermal resistance of the element and the lower limit of thermal resistance. 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 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 (ie 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 D 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.bre.co.uk/uvalues.

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:

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

(ii) 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.

2.4 Thermal bridging at junctions and around openings

Thermal bridges fall into two categories:

(i) repeating thermal bridges (eg timber joists or rafters, mortar joints and mullions in curtain walling) where the additional heat flow due to the bridging is to be included in the determination of the U-value of the building element containing these bridges, as indicated in these conventions;

(ii) non-repeating thermal bridges (eg junctions of floor and roof with the external wall, and details around window and door openings) where the additional heat flow due to this type of thermal bridge is determined separately.

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. Linear thermal transmittance has the symbol Ψ and units W/m·K. For further information see BRE IP 1/06[8]. The publication on Accredited Construction Details[6] gives examples of details for constructions typical of dwellings in which the thermal bridging effects are limited to a reasonably low level.

3 Thermal properties of materials and products

3.1 Declaration of thermal properties of products

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

In other cases the declaration of thermal properties should correspond to minimum thermal performance – in other words the thermal resistance should be at least that declared, or the thermal conductivity or thermal transmittance should be not more than that declared. 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 production has thermal performance at least equal to the declared value).

The standards for the measurement of thermal conductivity and thermal resistance are BS EN 12664, BS EN 12667 and BS EN 12939.

3.2 Values for use in calculations

Where possible, use values of thermal conductivity, λ, for specific products declared by the manufacturer in accordance with section 3.1. Generally use the nominal thickness of products in calculations except where the thickness is constrained by the construction (eg compressible insulation in a fixed width).

Further guidance for specific materials and products in 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 as given in Section 3 of CIBSE Guide A[9]. If measured data are not available, the thermal conductivity should be obtained from the mean density using the data in the CIBSE Guide.

Mortar conductivity is given in the CIBSE Guide as:

Outer leaves	0.94 W/m·K
Inner leaves	0.88 W/m·K

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

Outer leaves	0.77 W/m·K
Inner leaves	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	2.3 W/m·K
Concrete screed	1.15 W/m·K

Further information can be obtained from manufacturers or Section 3 of CIBSE Guide A.

3.5 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 production 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 (see www.timsa.org.uk for contact details; the Thermal Insulation Manufacturers and Suppliers Association also produce a guide listing many insulation products).

Harmonised standards are in the process of being developed for in-situ insulation materials, and new standards involving the same rules for λ-declarations are now being published.

3.6 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^2)	0.21 W/m·K
Higher density (up to 900 kg/m^2); eg acoustic or fire resistant board	0.25 W/m·K

3.7 Structural timber

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

Prefabricated timber frame wall panels (typical density 460–480 kg/m^2)	0.12 W/m·K
All other softwood (including joists, site-assembled panels, window frames (typical density 500 kg/m^2)	0.13 W/m·K
Hardwood (typical density 700 kg/m^3)	0.18 W/m·K

3.8 Metals and alloys

Thermal conductivity values for commonly used metals and alloys are:

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

3.9 Thermal conductivity of other materials

For materials other than those mentioned in the preceding sub-sections, in the absence of product-specific values provided by the manufacturer on the basis on thermal conductivity tests (see 3.1), use the thermal conductivity data given in BS EN 12524*.

3.10 Reflective foil products

3.10.1 Bubble sheet with aluminium foil facing

The thermal resistance of bubble sheet with foil facings consists of the resistance of the bubble 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†. 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 bubble sheet is used in the cavity of a masonry wall. U-value calculations should take account only of airspaces actually present. See also section 4.8.

3.10.2 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 either side 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 by an EU national accreditation service. 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, the test should be undertaken with an airspace on either side of the product, and the quoted result should be the thermal resistance of the assembly consisting of the product and the two airspaces. This resistance is then included in a calculation according to BS EN ISO 6946 along with the other components making up the complete structure. 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 4.8.

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

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

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* BS EN 12524 will be superseded by the revised version of BS EN ISO 10456 (publication expected 2007).

† A British Standard for the measurement of emissivity is in preparation.

4 Issues concerned with U-value calculations

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

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 assumed. 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

4.2 Mortar joints in masonry construction

Include mortar joints in the calculation for both inner and outer leaves of walls by treating the masonry leaf as a bridged layer.

The joints may be disregarded, however, if the difference in thermal resistance between 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; that applies to almost all brickwork, and to most walls built with dense masonry units.

Otherwise include the mortar joints in the calculation. 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 from –

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

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 voids filled with insulation. These units may be treated by:

(i) calculating the thermal resistance of the block by the Combined Method of BS EN ISO 6946, using surface resistance of zero on both sides, then

(ii) 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 (i). The mortar joints are allowed for in this second calculation.

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

4.4 Foam-faced blocks

Using foam-faced blocks, where the insulation covers the block face, there will be gaps in the insulation at the mortar joints. Take account of this in U-value calculations by treating the face insulation as a bridged layer, using a thermal resistance of 0.1 m^2K/W for the air gaps and a fraction equal to that of the mortar joints.

4.5 Timber fraction for timber-framed walls

4.5.1 Conventional timber studs

(i) For timber frame construction which conforms with the designs in Accredited Construction Details[6], additional heat loss at corners, window surrounds, between floors etc is limited and the associated timbers are not counted as part of the timber fraction. This is comparable with masonry construction where items such as lintels and cavity closers are not counted.

The **default fraction** for timber frame is:

0.15 (15%)

This is based on 38 mm timbers at 600 mm centres for one-storey and two-storey buildings, and reducing centres on the lower floors of three, four and five-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 section (i), all the following conditions are met:

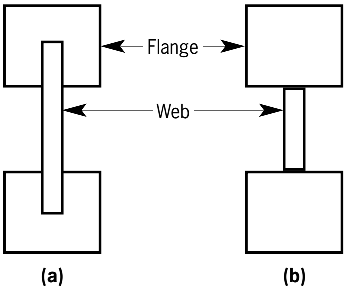
- there is a single top plate as part of the external wall panels;
- the sole plate is below finished floor level;
- there are no mid-height, full depth noggings in external walls;
- the studs at junctions where internal walls meet external walls, and any noggings for fittings and fixtures, are no more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

(iii) In particular cases the timber fraction can be calculated using the following guidelines*:

- 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)†;
- include all timbers (eg noggings and intermediate floor joists) that are not insulated behind.

4.5.2 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; that is, the calculations can be based on geometry (b) (see left) rather than (a).



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 section 4.8))

If the thermal conductivities differ by more than 20%, base the calculation on (a) using five layers.

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	Fraction corresponding to conditions of:	
	4.5.1 (i)	4.5.1 (ii)
Flanges, 38 mm wide	0.15	0.125
Flanges, 48 mm wide	0.17	0.145
Webs, 8 to 10 mm wide	0.04	0.04

In other cases calculate the fraction using the guidelines in 4.5.1 (iii).

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* This basis can also be used for SIPS and light steel frame.

† 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.

4.6 Timber fraction 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. The following data apply for typical situations.

4.6.1 Ceiling joists

Trussed rafters – 35 mm joists at 600 mm centres (35 / 600)	0.058
50 mm joists at 400 mm centres (50 / 400)	0.125
Add for additional timbers (noggings, loft hatch etc)	1% (0.01)

In the absence of specific information, use the following default fraction (based on 48 mm timbers at 600 mm centres:

Default fraction for ceiling joists (48 / 600 + 0.01)	0.09

4.6.2 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 = 38 / 400 + 38 / 3000):

Default fraction for floor joists	0.11

4.7 Plasterboard wall lining

For thermal conductivity of plasterboard see section 3.6.

4.7.1 Plasterboard on dabs

The following data apply to plaster dabs:

Fraction of plaster dabs	0.20
Thermal conductivity of plaster dabs	0.43 W/m·K
Thickness of plaster dabs	15 mm
Thermal resistance of 15 mm airspace	0.17 m^2K/W

4.7.2 Plasterboard on battens

The following 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
Batten thickness (typical)	22 mm
Thermal resistance of 22 mm airspace	0.18 m^2K/W

For proprietary metal channel systems and similar, refer to manufacturer’s data for the equivalent thermal resistance.

4.8 Airspace resistance

4.8.1 Unventilated airspaces, normal (high) emissivity

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. An airspace for which the thickness (in the heat flow direction) is less than one-tenth of its width or height is also treated as an air layer; examples include the space between the battens in a dry-lined wall, or the space under tiles on a pitched roof. Calculations of airspace 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*.

An unventilated air layer is treated as if it were a homogeneous layer of given thermal resistance. Table 2 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 wall constructions normally have a resistance of:

0.18 m^2K/W

One exception is a cavity behind external tile-hanging or similar; this is a well-ventilated cavity for which the rules in clause 5.3 of BS EN ISO 6946 apply. Data for this case are given in 4.8.6.

4.8.2 Unventilated airspaces, low emissivity surface

A low-emissivity surface (eg 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.

Low emissivity has no effect on the U-value if not adjacent to an airspace in the construction.

For 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)	0.44 m^2K/W
Low-emissivity surface, heat flow upwards (roof applications)	0.34 m^2K/W
Low-emissivity surface, heat flow downwards (floor applications)	0.50 m^2K/W

Use higher airspace resistances only if given in a certificate issued by a certification body accredited by an EU national accreditation service. Testing of emissivity should be done on the finished product after any lamination process.

Notes

(i) Values for heat flow horizontal should be used for applications where the heat flow direction is within ±30° of the horizontal plane (ie 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.

(ii) If the facing is not of low emissivity over its whole surface (eg 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. Thus in a wall application, if 9% of the surface is overprinted, the appropriate cavity resistance is $1 / (0.09 / 0.18 + 0.91 / 0.44) = 0.39$ m^2K/W.

(iii) The value for heat flow downwards is not applicable to a 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. See section 9.2.

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* 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.

4.8.3 Small airspaces

Small airspaces include voids in masonry blocks and similar components. Calculate their thermal resistance using Annex B of BS EN ISO 6946.

4.8.4 Roof spaces

Table 3 of BS EN ISO 6946 gives values of thermal resistance for ventilated roof spaces above an insulated ceiling; these values incorporate the resistance of the pitched roof construction but not R_{se}. When using the table referred to, the value of R_{se} should be taken as 0.04 m^2K/W (and not from section 4.8.6) since the values in the table include the effect of the ventilated roof space.

4.8.5 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 them should be made in U-value calculations.

4.8.6 Ventilated airspaces

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:

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

4.9 Corrections to thermal transmittance

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

- air gaps in insulation;
- mechanical fasteners penetrating an insulation layer;
- precipitation 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 ΔU, or formulae for calculating it, are given in Annex D of BS EN ISO 6946.

BS EN ISO 6946 permits the corrections due to wall ties, air gaps etc to be omitted if the 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, it 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.

4.9.1 Corrections due to air gaps

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

Level 0 $\Delta U = 0.00$
There must be no gaps 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 $\Delta U = 0.01$
A correction for air gaps is needed if:

- 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 $\Delta U = 0.04$
Air gaps as in Level 1, and also air circulation possible on the warm 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 D 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).

4.9.2 Wall ties

The effect of wall ties is negligible in an uninsulated cavity, and in any cavity if plastic ties are used.

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. The following indicates typical data:

Thermal conductivity	
mild steel	50 W/m·K
stainless steel	17 W/m·K
Cross-section	
double triangle types (4 mm diameter)	12.5 mm^2
vertical twist types (20 mm × 4 mm)	80 mm^2
Density (at 900 mm × 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

4.9.3 Fixing screws and other discrete fixings

Use the procedure in Annex D of BS EN ISO 6946 to obtain ΔU for fixings. The correction is applicable to fixing screws that pass through insulation.

For flat roofs, fixings comprise:

(i) fixings for insulation boards – the type of fixings and the density of fixings depend on the product and data should be obtained from manufacturer's specifications;

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

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

The method of correction given in BS EN ISO 6946 does not apply when both ends of the fixing are in contact with metal sheets: for these cases see the guidance in section 4.10.

4.9.4 Windposts and masonry support brackets

Where windposts or masonry support brackets* 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 support brackets. The corrected U-value is:

$$U = U_0 + (L\,\Psi / A)$$

where U_0 is the U-value of the wall without the windposts or masonry support brackets, L is the total length of windposts or masonry support brackets, and A is the total area of the wall.

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 [7]). That calculation needs be done only once for a given design of windpost and penetrated insulation thickness.

In the absence of a detailed calculation, the value $\Psi = 0.18$ 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 section 4.9.2), no additional correction is needed for windposts that do not penetrate the insulation.

4.9.5 Rainscreen cladding

Make no allowance in U-value calculations for the effect of the rainscreen cladding itself because the space behind is fully ventilated. The effect of brackets or rails fixing the cladding to the wall behind needs to be allowed for if the brackets or rails penetrate an insulation layer or part of an insulation layer.

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 detailed 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 section 4.8.6). For further information see the Council for Aluminium in Building/Centre for Windows and Cladding Technology (CWCT/CAB) Guide on the thermal assessment of non-traditional construction[10].

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* Also known as masonry support angles.

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

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

(ii) **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 (eg 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 (see also reference [7]). That calculation needs to be done only once for a given design of rail and penetrated insulation thickness. The U-value of the wall allowing for the fixing rail is:

$$U = U_0 + (L\,\Psi / A)$$

where U_0 is the U-value of the wall without the fixing rails, L is the total length of rail and A is the total area of the wall.

(iii) **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 (eg 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:

$$U = U_0 + n\,\chi$$

where U_0 is the U-value of the wall without the fixing rails and n is the number of brackets per square metre of wall.

(iv) **Default increment to the U-value**
If numerically calculated results are not available, the U-value calculated without brackets, U_0, is increased by 0.30 W/m^{2}K, so that:

$$U = U_0 + 0.30$$

4.9.6 Inverted roofs

A correction should be applied to the U-value as set out in BS EN ISO 6946 Annex D.

4.9.7 Loft hatches

An uninsulated loft hatch increases the roof U-value by typically 9% at the insulation level of $U = 0.16$ W/m^{2}K, 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

4.9.8 Recessed light fittings

For recessed light fittings in an insulated ceiling 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:

$$\Delta U = f(2.0 - U_{\text{roof}})$$

where f is the fraction of the total ceiling area with removed insulation and U_{roof} is the U-value of the roof before application of the correction.

4.9.9 Items that may be disregarded in U-value calculations

The following are usually disregarded when establishing U-values of constructional elements:

- service penetrations (eg plumbing passing through an external wall);
- passive stack ventilators and extract fans;
- trickle vents (see section 11);
- louvres or ventilators for the purposes of providing air for combustion appliances where these are in accordance with manufacturer's instructions or required by building regulations.

4.10 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. The MCRMA Guide[11] 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 Z-spacer systems*.

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

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

4.11 Light steel-framed walls

Light steel frame is a 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 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. 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.

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* 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.

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.

The unheated space is assigned an effective thermal resistance, R_u, and is included in the U-value calculation as if it were a homogeneous layer with the stated effective thermal resistance. For further details see Appendix A.

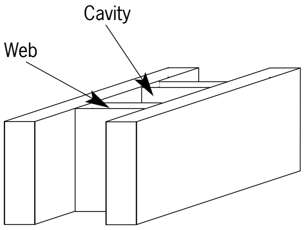
The effect of attached garages and conservatories is not included in the U-value.

6 Expression of results

The final result 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.

7 U-values for walls

Unless otherwise noted below, the U-value 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 (see section 4)
Masonry solid wall Brick or block	Include mortar joints in calculation (see section 4.2) For the brick or block, select exposed λ (except with an external insulation or cladding system when the protected value applies) Air gaps for internal insulation between battens (see section 4.9.1)
Masonry cavity wall Unfilled	Include mortar joints in calculation (see section 4.2) Cavity resistance is 0.18 m^{2}K/W Dry-lining (see section 4.7) Air gaps for internal insulation between battens (see section 4.9.1) Reflective foil insulation in cavity (see section 3.10)
Full cavity fill – injected (after building)	Include mortar joints in calculation (see section 4.2) Wall ties (see section 4.9.2) Dry-lining (see section 4.7) Air gaps for internal insulation between battens (see section 4.9.1)
Full cavity fill – slabs (during building)	Include mortar joints in calculation (see section 4.2) Air gaps correction (see section 4.9.1) Wall ties (see section 4.9.2) Dry-lining (see section 4.7) Air gaps for internal insulation between battens (see section 4.9.1)
Partial cavity fill	Include mortar joints in calculation (see section 4.2) Air gaps correction (see section 4.9.1) Wall ties (see section 4.9.2) Include cavity resistance for the unfilled part of the cavity (see section 4.8) Correction for wall ties applies to the insulation layer only (not to the remaining unfilled cavity) Dry-lining (see section 4.7) Air gaps for internal insulation between battens (see section 4.9.1) Foam-faced blocks (see section 4.4)
Diaphragm wall 	Insulation can be in the 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 section 4.8) 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 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 section 4.7) Air gaps for internal insulation between battens (see section 4.9.1)

Wall type	Issues (see section 4)
Timber frame wall Insulation between solid timber studs (clear cavity)	Timber fraction (see 4.5.1) Air gaps – correction level 0 or 1 (see section 4.9.1) 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 section 4.8)
Insulation between I-beam studs (clear cavity)	I-beam fraction (see section 4.5.2) Other issues as for timber frame with insulation between solid timber studs
Warm frame and hybrid*	Timber fraction (see section 4.5.1) Air gaps – correction level 0 or 1 (see section 4.9.1) Correction for wall ties (see section 4.9.2) 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 Cavity resistance included for masonry cladding; other claddings are disregarded (see section 4.8)
Steel frame wall Warm frame, cold frame and hybrid*	Calculation method (see section 4.11) Air gaps – correction level 0 or 1 (see section 4.9.1) Warm frame and hybrid, correction for wall ties (see section 4.9.2) 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 Cavity resistance included for masonry cladding; other claddings are disregarded (see section 4.8)
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 section 4.10)
Twin skin metal cladding Site-assembled	Numerical analysis is needed to allow for the effect metal elements (eg spacer systems) that fully or partly penetrate the insulation, and to take account of profiled sheets (see section 4.10). The data in IP 10/02 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
Curtain wall	The average U-value of the façade should be obtained. Methods of calculation are given in prEN 13947. For further guidance see the CWCT/CAB Guide[10]
Rainscreen cladding	See section 4.9.5
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 section 4.5.1 (ii)). Connectors joining the outer and inner leafs are treated in the same way as wall ties (if plastic, the U-value correction is negligible)

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* Hybrid framed constructions have both insulation between the studs and an insulation layer on the outside or inside of the frame.

† 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.

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 permanently airtight.

Roof type	Issues (see section 4)
Pitched roof Insulation at ceiling level	U-value is calculated for the ceiling (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 (eg 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 3 of BS EN ISO 6946 Loft hatch; recessed light fitting – add correction (see sections 4.9.7 and 4.9.8)
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 a 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
Flat roof	Insulation between joists to be treated as a bridged layer Insulation between, below and above joists to be treated as separate layers Air gaps correction (see section 4.9.1) Fixing nails (see section 4.9.3) Treat tapered insulation layers as in Annex C of BS EN ISO 6946
Inverted roof	Calculate the correction for precipitation by EN ISO 6946 (see section 4.9.6). Ignore the effect of ballast etc. In the case of a ‘green’ roof, ignore the effect of soil, vegetation etc

Roof type	Issues (see section 4)
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 section 4.10)
Twin skin metal cladding (site-assembled)	Numerical analysis is needed to allow for the effect metal elements (eg spacer systems) that fully or partly penetrate the insulation, and to take account of profiled sheets (see section 4.10). The data in IP 10/02 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*)	The issues are those for pitched roof, insulation at rafter level. Determine the timber fraction for each case according to the construction of the panel (see section 4.5.1 (iii))

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* SIPS for roofs are 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

U-values for floors next to the ground and for basements should take account of the buffering effect of the ground itself. Suitable methods for doing this are given in BS EN ISO 13370*. Very large floors can have low U-values without all-over insulation (see section Appendix 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. Walls to other spaces that can reasonably be assumed to be heated to the same temperature (eg the separating wall to an adjacent house) should not be included in the perimeter.

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;
- hardcore 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 (eg vinyl or carpets) are not included in the calculation; but it is permissible to include them if their properties are adequately defined.

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* If numerical analysis is used to model heat flow through the ground, the conditions of BS EN ISO 10211 apply as regards the dimensions of ground to be included in the model. As this makes the geometrical model rather large, it is recommended that numerical analysis is limited to the construction elements themselves using the formulae in BS EN ISO 13370 to allow for the effect of the ground.

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 $R_{si} = 0.17$ m^{2}K/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 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.

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*;
- 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 m^2, so the opening per perimeter length is 0.003 m^2/m for one air brick per metre, or 0.0015 m^2/m for one air brick per 2 metres. The latter is the minimum for suspended timber floors in building regulations and also for suspended concrete floors.

The calculation of the overall U-value of the floor involves combining U-values representing the floor (from the inside environment to the underfloor 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 m^{2}K/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 footnote 3 of clause 6.2.4 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.

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* This is the average wind speed over the heating season and not the design wind speed for, for example, wind loading (which is usually much higher).

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; that is, 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 (15) of BS EN ISO 13370, using d_g in place of d_t in equation (10) or (11)*.

Floor height above ground

The floor height above ground affects 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 three bricks) can be used if this height has not been specified.

Depth of underfloor void below ground

If it varies, use an average. Assume a value of 300 mm unless specified otherwise†.

9.2.1 Suspended timber floor

Insulation between joists is treated as a bridged layer.

9.2.2 Suspended beam-and-block floor

The beam-and-block construction constitutes a bridged layer for the purposes of U-value calculation. The beam fraction varies and should be determined for the case concerned. 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 4.8.

9.2.3 Concrete beam floor with polystyrene between the beams or below the beams, or both

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 section 4.8).

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.

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[*] These equation numbers are those in the 1998 edition of the standard. In the draft revision ISO/DIS 13370:2005 they are equations (8), (B.4) and (B.5) respectively.

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

9.3 Floor exposed on underside

Surface resistance for inside surface	0.17 m^2K/W
Surface resistance for outside surface	0.04 m^2K/W

Calculations can usually be done according to BS EN ISO 6946.

10 U-values for basements

U-values can be obtained from the Approved Document for Basements[15] or 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, calculate the wall resistance R_w using $R_{si} = 0.13$ m^{2}K/W (for horizontal heat flow) and $R_{se} = 0$, 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.

11 U-values for windows, roof windows and rooflights

The U-value is that of the complete window or rooflight, including the frame. Frame materials include timber, plastics, aluminium, steel, and combinations of metal and plastic or metal and wood.

Obtain U-values for windows preferably either by measurement in a hot box according to BS EN ISO 12567-1 or by numerical calculation using software conforming with BS EN ISO 10077-2. Measurements for roof windows and rooflights are covered by BS EN ISO 12567-2. The British Fenestration Rating Council (www.bfrc.org) operates a scheme of approved simulators for calculations according to BS EN ISO 10077-2.

Simplified calculations using the methods in BS EN 673 and BS EN ISO 10077-1 are permissible alternatives which yield more approximate results. For further guidance see the CWCT/CAB Guide[10].

For a more detailed discussion of the assessment methods, see *A route map to Part L*[16].

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, in the case of dwellings, a U-value can be established to represent all the windows using a standard window 1.48 m high by 1.23 m wide, with a central vertical divider, and one opening light and one fixed light. Details of the standard window are given in Glass and Glazing Federation (GGF) Data Sheet 2.2[17].

11.1 Roof windows and rooflights

U-values of roof windows and rooflights are usually quoted for the window or rooflight in the vertical plane. This allows comparison of different products that could be used at different inclinations. However, for the purposes for calculating heat losses from buildings, U-values should relate to the plane of the component as installed in the building. This can be done by calculating the U-value of rooflights and roof windows, allowing for the angle of the roof in respect of both surface resistances and gas space resistances (see BS EN ISO 10077-1 and BS EN 673). Alternatively the following adjustments can be made to U-values assessed for the component in the vertical plane:

Inclination of roof	U-value adjustment (W/m^{2}K)	
	Twin skin or double glazed	Triple skin or triple glazed
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 > 20°	+ 0.4	+ 0.2
≤ 20° (treated as horizontal)	+ 0.5	+ 0.3

In the case of rooflights mounted on an upstand, the area of the rooflight is that of the opening in the roof. The heat loss associated with the upstand should be quoted as a linear thermal transmittance (ie the additional heat loss due to the upstand that is not included in either the U-value of the roof or the U-value of the rooflight) per unit temperature difference and per unit length of upstand (expressed in W/m·K).

12 U-values for doors

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

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.

For further details see GGF Data Sheet 2.2[17].

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:

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

Assess industrial doors (roller-shutter types etc) either by testing or by using numerical analysis.

Appendix A

Elements adjacent to an unheated space

The data in this Appendix are the same as that in SAP 2005[4].

The procedure for treatment of U-values of elements adjacent to unheated space is described in BS EN ISO 6946 and BS EN ISO 13789.

BS EN ISO 6946 gives a simplified procedure where the unheated space is treated as if it was an additional homogeneous layer.

BS EN ISO 13789 gives more precise procedures for the calculation of heat transfer from a building to the external environment via unheated spaces, and may be used when a more accurate result is required.

The following procedure may be used for typical structures (no measurements are needed of the construction between the unheated space and the external environment; just select the appropriate value of R_u from Tables A1 to A3 (on this page to page 33):

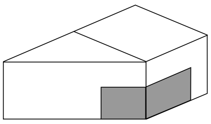
$$U = \frac{1}{\frac{1}{U_0} + R_u}$$

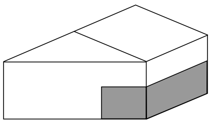
where U is the resultant U-value of the element adjacent to an unheated space (W/m^{2}K), U_o is the U-value of the element between heated and unheated spaces calculated as if there were no unheated space adjacent to the element (W/m^{2}K), and R_u is the effective thermal resistance of unheated space from the appropriate table.

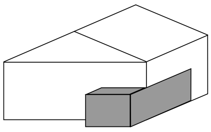
Integral garages

The U-value of elements between the dwelling and an integral garage should be adjusted using R_u from Table A1 or Table A2. Attached garages (not integral) should be disregarded.

Table A1 R_u for integral single garages*





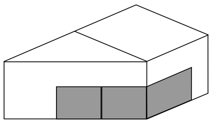


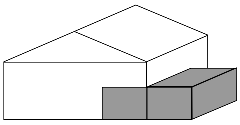
Garage type	Elements between garage and dwelling	R_u for a single garage Inside†	Outside‡
Single, fully integral	Side wall, end wall and floor	0.68	0.33
Single, fully integral	One wall and floor	0.54	0.25
Single, partially integral, displaced forward	Side wall, end wall and floor	0.56	0.26

* Single garage is garage for one car.

† Insulated envelope of dwelling goes round outside of garage.

‡ Walls separating garage from dwelling are external walls.





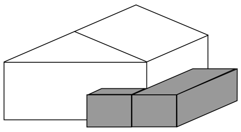


Table A2 R_u for integral double garages[*]

Garage type	Elements between garage and dwelling	R_u for a double garage	
		Inside[†]	Outside[‡]
Double, fully integral	Side wall, end wall and floor	0.59	0.28
Double, half integral	Side wall , halves of garage end wall and floor	0.34	N/a
Double, partially integral, integral displaced forward	Part of garage side wall, half of end wall and some floor	0.28	N/a

[*] Double garage is garage for two cars.
[†] Insulated envelope of dwelling goes round outside of garage.
[‡] Walls separating garage from dwelling are external walls.

Stairwells and access corridors in flats

Stairwells and access corridors are not regarded as parts of the dwelling. If they are heated they are not included in the calculation. If unheated, the U-value of walls between the dwelling and the unheated space should be modified using the following data for R_u.

Figure A1 shows examples of access corridors in flats.

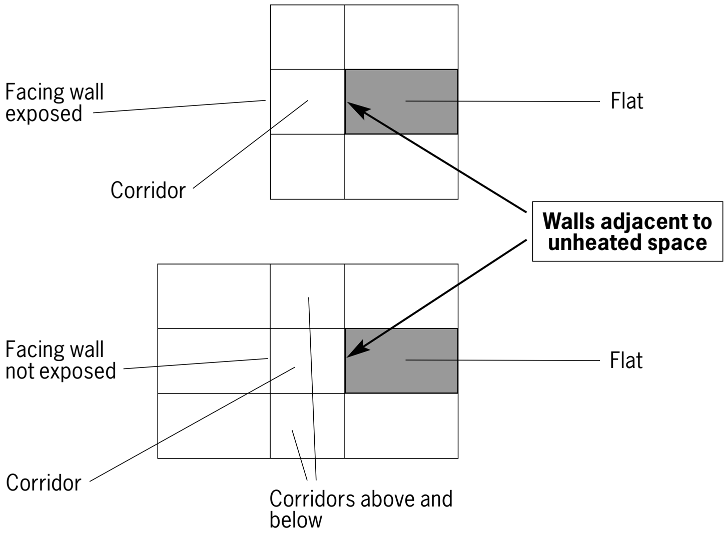


Figure A1 Access corridors

Table A3 gives recommended values of R_u for common configurations of access corridors and stairwells.

Table A3 R_u **for common configurations of stairwells and access corridors**

Elements between stairwell or corridor and dwelling	Heat loss from corridor through:	R_u
Stairwells		
Facing wall exposed		0.82
Facing wall not exposed		0.90
Access corridors		
Facing wall exposed,		
corridors above and below	facing wall, floor and ceiling	0.28
corridor above or below	facing wall, floor or ceiling	0.31
Facing wall not exposed,		
corridors above and below	floor and ceiling	0.40
corridor above or below	floor or ceiling	0.43

Room in roof

In the case of room-in-roof construction where the insulation follows the shape of the room, the U-value of the walls of the room-in-roof construction is calculated by the procedure described above using thermal resistance R_u from Table A4. The same applies to the ceiling of the room below.

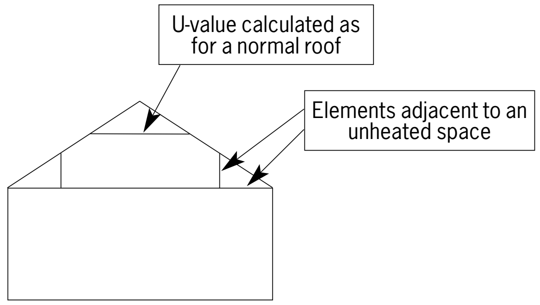


Figure A2 Room in roof

Table A4 R_u **for a room in roof adjacent to an unheated loft space**

Area (Figure A2)	Element between dwelling and unheated loft space	R_u for elements
Room built into a pitched roof insulated at ceiling level	Insulated wall of room in roof	0.50
	Insulated ceiling of room below	0.50

If the insulation follows the slope of the roof, the U-value should be calculated in the plane of the slope.

Other cases

In other cases R_u should be calculated using the following the formula

$$R_u = \frac{A_i}{\sum(A_e \times U_e) + 0.33nV}$$

where A_i and A_e are the areas of internal and external elements (m^2), excluding any ground floor, U_e is the U-value of external walls (W/m^2K), n is the air change rate (ach) of unheated space, and V is the volume of unheated space (m^3).

Typical values of the air change rate in unheated spaces are given in Table A5. The default value of $n = 3$ ach should be used if the airtightness of the unheated space is not known.

Table A5 Typical air change rates for unheated spaces

Airtightness 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 or permanent ventilation openings	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

Appendix B

U-values of uninsulated floors

Figure B1 shows the dimensions of rectangular solid ground floors that have 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.

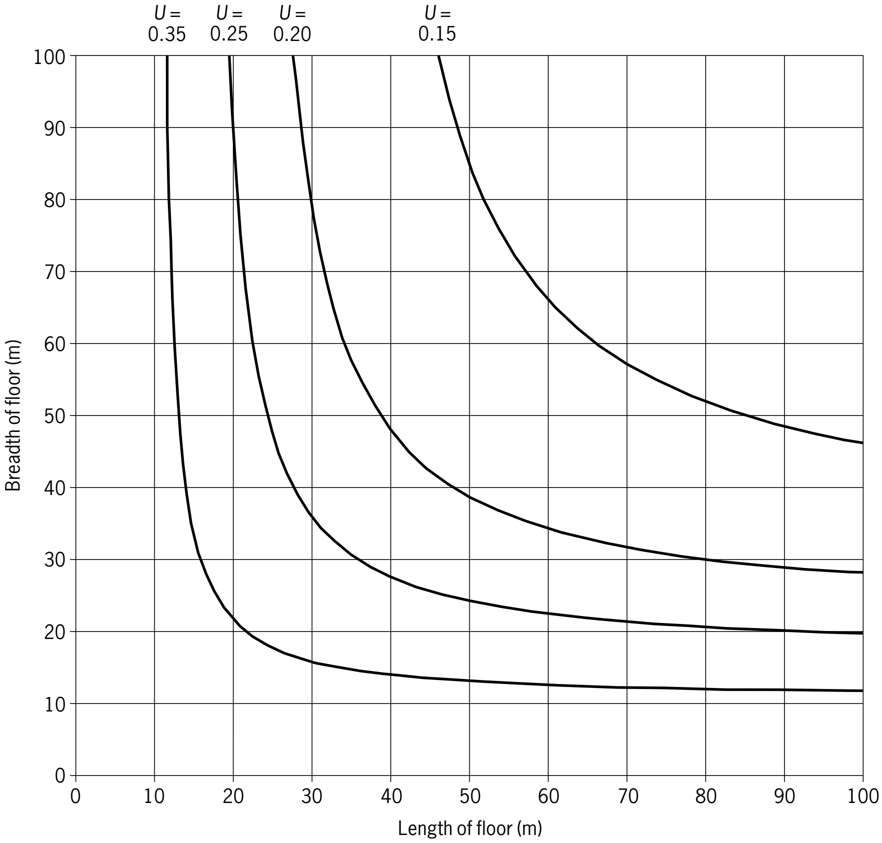


Figure B1 U-value of uninsulated rectangular ground floors

References and further reading

[1] Office of the Deputy Prime Minister (now the Department for Communities and Local Government). The Building Regulations 2000 (as amended) Approved Documents L1A, L1B, L2A and L2B, 2006 Edition, available from www.communities.gov.uk.

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[16] Kent R. *A route map to Part L* (consultation document of July 2004), Issue 2, available from the British Fenestration Rating Council, www.bfrc.org.

[17] Glass and Glazing Federation. Window and door system U-values: provision of certified data. *Data Sheet* 2.2. London, GGF, 2002.

British Standards Institution

Calculation methods

BS EN ISO 6946*	Building components and building elements – Thermal resistance and thermal transmittance – Calculation method
BS EN ISO 10077-1*	Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: Simplified method
BS EN ISO 10077-2	Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames
BS EN ISO 10211-1*	Thermal bridges in building construction – Heat flows and surface temperatures – Part 1: General calculation methods
BS EN ISO 10211-2*	Thermal bridges in building construction – Heat flows and surface temperatures – Part 2: Linear thermal bridges
BS EN ISO 10456*	Building materials and products – Procedures for determining declared and design thermal values
BS EN ISO 13370*	Thermal performance of buildings – Heat transfer via the ground – Calculation methods
BS EN ISO 13789*	Thermal performance of buildings – Transmission heat loss coefficient – Calculation method
ISO 15099	Thermal performance of windows, doors and shading devices – Detailed calculations
BS EN 673	Glass in building – Determination of thermal transmittance (value) – Calculation method
BS EN 1745	Masonry and masonry products – Methods for determining design thermal values
BS EN 12524	Building materials and products – Hygrothermal properties – Tabulated design values
prEN 13947	Thermal performance of curtain walling – Calculation of thermal transmittance

* These standards are presently under review. The revised versions, expected to be published in early 2007, might have slightly different titles. The two parts of ISO 10211 are being combined into one. The data in EN 12524 are being incorporated into ISO 10456, and the revision version of ISO 10456 will supersede EN 12524.

Measurement methods

BS EN 12664	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	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	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 8990	Thermal insulation – Determination of steady-state thermal transmission properties – Calibrated and guarded hot box
BS EN ISO 12567-1	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	Thermal performance of windows and doors – Determination of thermal transmittance by hot box method – Part 2: Roof windows and other projecting windows

Insulation product standards

Factory-made products:

BS EN 13162	Thermal insulation products for buildings – Factory made mineral wool (MW) products – Specification
BS EN 13163	Thermal insulation products for buildings – Factory made products of expanded polystyrene – Specification
BS EN 13164	Thermal insulation products for buildings – Factory made products of extruded polystyrene foam (XPS) – Specification

BS EN 13165	Thermal insulation products for buildings – Factory made rigid polyurethane foam (PUR) products – Specification
BS EN 13166	Thermal insulation products for buildings – Factory made products of phenolic foam (PF) – Specification
BS EN 13167	Thermal insulation products for buildings – Factory made cellular glass (CG) products – Specification
BS EN 13168	Thermal insulation products for buildings – Factory made wood wool (WW) products – Specification
BS EN 13169	Thermal insulation products for buildings – Factory made products of expanded perlite (EPB) – Specification
BS EN 13170	Thermal insulation products for buildings – Factory made products of expanded cork (ICB) – Specification
BS EN 13171	Thermal insulation products for buildings – Factory made wood fibre (WF) products – Specification

In-situ-formed products (prENs are draft standards):

BS EN 14063-1	Thermal insulation materials and products – In-situ formed expanded clay lightweight aggregate products (LWA) – Part 1: Specification for the loose-fill products before installation
prEN 14063-2	Thermal insulation materials and products – In-situ formed expanded clay lightweight aggregate products (LWA) – Part 2: Specification for the installed products
prEN 14064-1	Thermal insulation products for buildings – In-situ formed loose-fill mineral wool (MW) products – Part 1: Specification for the loose-fill products before installation
prEN 14064-2	Thermal insulation products for buildings – In-situ formed loose-fill mineral wool (MW) products – Part 2: Specification for the installed products
prEN 14315-1	Thermal insulation 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
prEN 14315-2	Thermal insulation 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	Thermal insulation products for buildings – In-situ thermal insulation formed from expanded perlite (EP) products – Part 1: Specification for the bonded and loose-fill products before installation
prEN 14316-2	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	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
prEN 14317-2	Thermal insulation products for buildings – In-situ thermal insulation formed from exfoliated vermiculite (EV) products – Part 2: Specification for the installed products
prEN 14318-1	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
prEN 14318-2	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
prEN 15100-1	Thermal insulation products for buildings – In-situ formed urea formaldehyde foam (UF) products – Part 1: Specification for the foam system before installation
prEN 15100-2	Thermal insulation products for buildings – In-situ formed urea formaldehyde foam (UF) products – Part 2: Specification for the installed products
prEN 15101-1	Thermal insulation products for buildings – In-situ formed loose-fill cellulose products – Part 1: Specification for the loose-fill products before installation
prEN 15101-2	Thermal insulation products for buildings – In-situ formed loose-fill cellulose products – Part 2: Specification for the installed products

Further reading

Doran S M. Timber frame dwellings. Conservation of fuel and power: AD L1A guidelines. *BRE Special Digest* SD2:2006. Garston, BRE Press, 2006.

Doran S M. Masonry walls and beam-and-block floors. U-values and building regulations. *BRE Special Digest* 4. Garston, BRE Press, 2003. (New edition due later in 2006.)

BRE. *Part L explained. The BRE guide.* BRE Report BR 489. Garston, BRE Press, 2006.