Part
6.B Worked examples of U-value calculations using the combined method

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contents

part

6.B

Worked examples of U-value calculations using the Combined Method

6.B.0 Introduction

For *building* elements which contain repeating thermal bridges, such as timber ceiling ties or joists between insulation in a roof or floor, timber studs in a wall, or mortar joints in lightweight blockwork, the effect of thermal bridges should be taken into account when calculating the *U-value*. The calculation method, known as the Combined Method, is set out in BS EN ISO 6946 and the following examples illustrate the use of the method for typical wall, roof and floor designs. Although computer software is the most usual choice for *U-value* calculations these examples explain the principles of the combined method and may be useful as a means of selection and checking the accuracy of software.

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In cases where the ceiling ties, studs or joists in roof, wall or floor *constructions* project beyond the surface of the insulation the depths of these components should be taken to be the same as the thickness of insulation for the purposes of the *U-value* calculation (as specified in BS EN ISO 6946).

It is acceptable to ignore non-metal wall ties, cavity trays and movement joints. The calculation should take account of metal wall ties and other metal fixings, air gaps between and around insulation slabs, and any metal members that bridge an insulation layer.

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Conductivity values for common *building* materials can be obtained from the CIBSE Guide A Section 3 or from BS EN 12524: 2000 (to be replaced by BS EN ISO 10456). For specific insulation products, however, data should be obtained from manufacturers. Table 6.A.18 (Part 6.A) gives typical thermal conductivities for some common *construction* materials.

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The procedure in this Part does not address elements containing metal connecting paths. For establishing *U-values* for light steel frame *construction*, BRE Digest 465 may be used. For built-up sheet metal walls and roofs, the following may be used:

www.steel-sci.org

- BRE IP 10/02, Metal cladding: assessing the thermal performance of built-up systems which use Z-spacers;
- P312 Metal Cladding: *U-value* calculation: Assessing thermal performance of built-up metal roof and wall cladding systems using rail and bracket spacers, Steel Construction Institute 2002.

For curtain walling, the reader is directed to the CWCT publication ‘Thermal assessment of window assemblies, curtain walling and non-traditional building envelopes’ (2006).

For ground floors and basements the reader is directed to Part 6.C.

6.B.1 The procedure

The *U-value* is calculated by applying the following steps:

a. Calculate the upper resistance limit (R_{upper}) by combining in parallel the total resistances of all possible heat-flow paths (i.e. sections) through the plane *building* element.

b. Calculate the lower resistance limit (R_{lower}) by combining in parallel the resistances of the heat flow paths of each layer separately and then summing the resistances of all layers of the plane *building* element.

c. Calculate the *U-value* of the element from U = 1 / R_T,

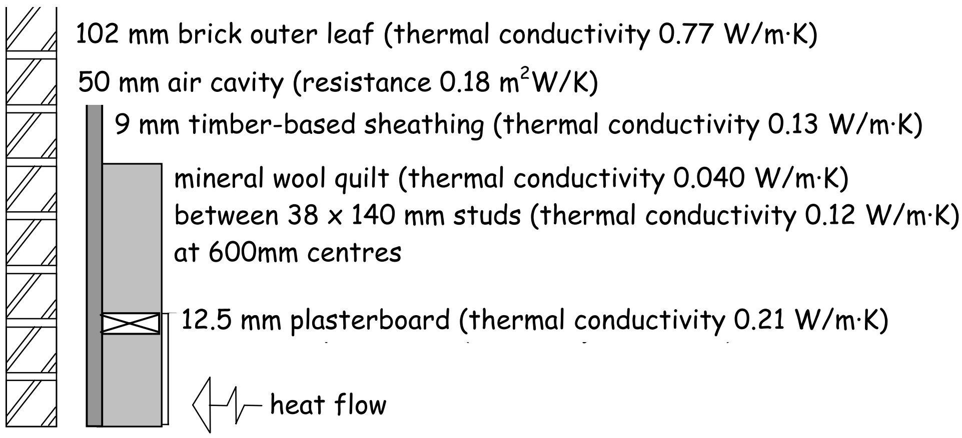
where $$R_T = \frac{R_{upper} + R_{lower}}{2}$$

d. Where appropriate, add a correction for air gaps and mechanical fasteners (including wall ties) as described in BS EN ISO 6946 Annex D.

6.B.2 Timber framed wall example

In this example there is a single bridged layer in the wall, involving insulation bridged by timber studs. The *construction* consists of outer leaf brickwork, an air cavity, 9 mm timber-based sheathing, 38 x 140 mm timber framing with 140 mm of mineral wool quilt insulation between the timber studs and plasterboard 12.5 mm thick. See additional notes at end of example.

Section through Timber framed wall



(Total thickness: 313.5 mm; *U-value*: 0.30 W/m²K)

The thicknesses of each layer, together with the thermal conductivities of the materials in each layer, are shown below. The internal and external surface resistances are those appropriate for wall *constructions*. Layer 4 is thermally bridged and two thermal conductivities are given for this layer, one for the unbridged part and one for the bridging part of the layer. For each homogeneous layer and for each section through a bridged layer, the thermal resistance is calculated by dividing the thickness (in metres) by the thermal conductivity.

Calculation of thermal resistance (timber frame)

Layer	Material	Thickness (mm)	Thermal conductivity (W/m·K)	Thermal resistance (m^2K/W)
	external surface	-	-	0.040
1	outer leaf brick	102	0.77	0.132
2	air cavity	50	-	0.180
3	sheathing	9	0.13	0.069
4(a)	mineral wool quilt between timber studs	140	0.040	3.500
4(b)	timber framing occupying 15% of the wall area	140	0.12	1.167
5	plasterboard	12.5	0.21	0.060
	internal surface	-	-	0.130

Both the upper and the lower limits of thermal resistance are calculated by combining the alternative resistances of the bridged layer in proportion to their respective areas, as illustrated below. The method of combining differs in the two cases.

Upper resistance limit

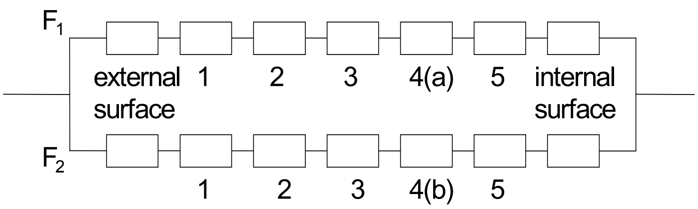
When calculating the upper limit of thermal resistance, the *building* element is considered to consist of two thermal paths (or sections). The upper limit of resistance is calculated from:

$$R_{upper} = \frac{1}{\frac{F_1}{R_1} + \frac{F_2}{R_2}}$$

where F_1 and F_2 are the fractional areas of the two sections (thermal paths) and R_1 and R_2 are the total resistances of the two sections.

The method of calculating the upper resistance limit is illustrated conceptually below:

Conceptual illustration of how to calculate the upper limit of thermal resistance



Resistance through the section containing insulation	External surface resistance	= 0.040
	Resistance of bricks	= 0.132
	Resistance of air cavity	= 0.180
	Resistance of sheathing	= 0.069
	Resistance of mineral wool (85%)	= 3.500
	Resistance of plasterboard	= 0.060
	Internal surface resistance	= 0.130
	Total (R_1)	= 4.111 m²K/W

Fractional area F_1 = 0.85 (85%)

Resistance through the section containing timber stud	External surface resistance	= 0.040
	Resistance of bricks	= 0.132
	Resistance of air cavity	= 0.180
	Resistance of sheathing	= 0.069
	Resistance of timber framing (15%)	= 1.167
	Resistance of plasterboard	= 0.060
	Internal surface resistance	= 0.130
	Total (R_2)	= 1.778 m²K/W

Fractional area F_2 = 0.15 (15%)

The upper limit of resistance is then:

$$R_{upper} = \frac{1}{\frac{F_1}{R_1} + \frac{F_2}{R_2}} = \frac{1}{\frac{0.850}{4.111} + \frac{0.150}{1.778}} = 3.435 \text{ m}^2\text{K/W}$$

Lower resistance limit

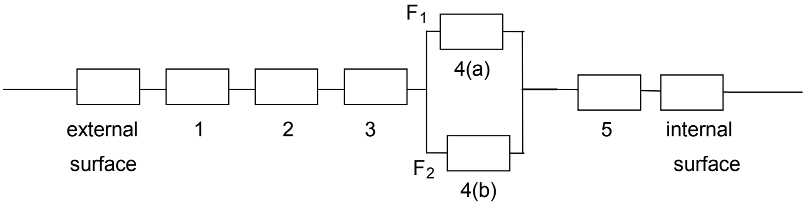
When calculating the lower limit of thermal resistance, the resistance of a bridged layer is determined by combining in parallel the resistances of the unbridged part and the bridged part of the layer. The resistances of all the layers in the element are then added together to give the lower limit of resistance.

The resistance of the bridged layer is calculated using:

$$R = \frac{1}{\frac{F_{insul}}{R_{insul}} + \frac{F_{timber}}{R_{timber}}}$$

The method of calculating the lower limit of resistance is illustrated conceptually below.

Conceptual illustration of how to calculate the lower limit of thermal resistance



The lower limit of resistance is then obtained by adding up the resistances of all the layers:

External surface resistance	= 0.040
Resistance of bricks	= 0.132
Resistance of air cavity	= 0.180
Resistance of sheathing	= 0.069
Resistance of bridged layer = $\dfrac{1}{\dfrac{0.850}{3.500}+\dfrac{0.150}{1.167}}$	= 2.692
Resistance of plasterboard	= 0.060
Internal surface resistance	= 0.130
Total (R_{lower})	= 3.304 m²K/W

Total resistance of wall (not allowing for air gaps around the insulation)

The total resistance of the wall is the average of the upper and lower resistance limits:

$$R_T = \frac{R_{upper} + R_{lower}}{2} = \frac{3.435 + 3.304}{2} = 3.369 \text{ m}^2\text{K/W}$$

Correction for air gaps

If there are small air gaps penetrating the insulating layer a correction should be applied to the *U-value* to account for this. The correction for air gaps is ΔU_g where

$\Delta U_g = \Delta U'' \times (R_I / R_T)^2$

and where R_I is the thermal resistance of the layer containing gaps, R_T is the total resistance of the element and ΔU" is a factor which depends upon the way in which the insulation is installed. In this example R_I is 2.692 m²K/W, R_T is 3.369 m²K/W and ΔU" is 0.01 (i.e. correction level 1). The value of ΔU_g is then:

ΔU_g = 0.01 x (2.692 / 3.369)² = **0.006 W/m²K**

U-value of the wall

The effect of air gaps or mechanical fixings should be included in the *U-value* unless they lead to an adjustment in the *U-value* of less than 3%.

$U = 1 / R_T + \Delta U_g$ (if ΔU_g is not less than 3% of $1 / R_T$)

$U = 1 / R_T$ (if ΔU_g is less than 3% of $1 / R_T$)

In this case ΔU_g = 0.006 W/m²K and $1 / R_T$ = 0.297 W/m²K. Since ΔU_g is less than 3% of $(1 / R_T)$,

$U = 1 / R_T = 1 / 3.369 =$ **0.30 W/m²K.**

Notes:

1 The timber fraction in this particular example is 15%. This corresponds to 38mm wide studs at 600mm centres and includes full-depth dwangs, etc. and the effects of additional timbers at junctions and around openings.

2. In this example correction level 1 is appropriate. This is because air gaps are likely to exist, in some cases, between the insulation and the timber framing.

3. BS EN ISO 6946 states that if the insulation is installed in such a way that no air circulation is possible on the warm side of the insulation then ΔU" is set to 0.01 W/m²K. If, on the other hand, air circulation is possible on the warm side then it should be set to 0.04 W/m²K. The possible correction levels and correction factors are summarised as follows:

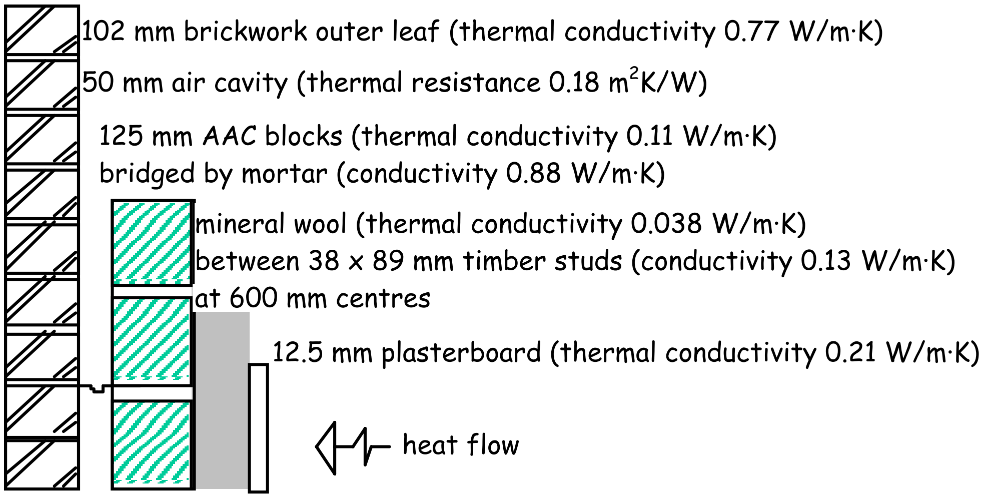
Correction for air gaps

Description of air gap	**Correction level**	**ΔU" W/m²K**
Insulation installed in such a way that no air circulation is possible on the warm side of the insulation. No air gaps penetrating the entire insulation layer.	0	0.00
Insulation installed in such a way that no air circulation is possible on the warm side of the insulation. Air gaps may penetrate the insulation layer.	1	0.01
Air circulation possible on the warm side of the insulation. Air gaps may penetrate the insulation.	2	0.04

6.B.3 Cavity wall with lightweight masonry leaf and insulated dry-lining example

In this example there are two bridged layers - insulation bridged by timber and lightweight blockwork bridged by mortar. The *construction* consists of outer leaf brickwork, a clear cavity, 125 mm AAC blockwork, 38 x 89 mm timber studs (600 mm centre-to-centre spacing) with insulation between the studs and one sheet of 12.5 mm plasterboard. See additional notes at end of example.

Section through wall with two bridged layers



(Total thickness: 378.5 mm; *U-value*: 0.30 W/m²K)

The thicknesses of each layer, together with the thermal conductivities of the materials, are shown below, with appropriate internal and external surface resistances, these being, for a wall, 0.13 m²K/W and 0.04 m²K/W. Layers 3 and 4 are both thermally bridged and two thermal conductivities are given for each layer to reflect the bridged part and the bridging part in each case. For each homogeneous layer and for each section through a bridged layer the thermal resistance is calculated by dividing the thickness (expressed in metres) by the thermal conductivity.

Calculation of thermal resistance (cavity wall)

Layer	Material	Thickness (mm)	Thermal conductivity (W/m·K)	Thermal resistance (m²K/W)
	external surface	-	-	0.040
1	outer leaf brick	102	0.77	0.132
2	air cavity	50	-	0.180
3(a)	AAC blocks (93.3%)	125	0.11	1.136
3(b)	mortar (6.7%)	(125)	0.88	0.142
4(a)	mineral wool (88.2%)	89	0.038	2.342
4(b)	timber studs (11.8%)	(89)	0.13	0.685
5	plasterboard	12.5	0.21	0.060
	internal surface	-	-	0.130

Both the upper and lower limits of thermal resistance are calculated by combining the alternative resistances of the bridged layer in proportion to their respective areas, as illustrated below. The method of combining differs in the two cases.

Upper resistance limit

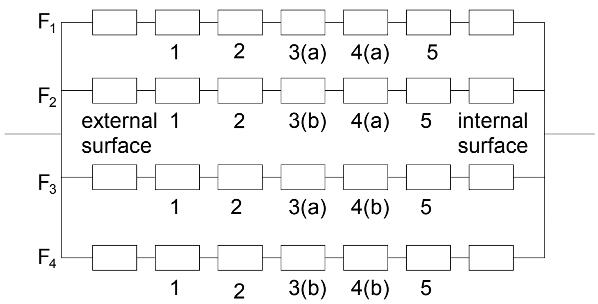
When calculating the upper limit of thermal resistance, the *building* element is considered to consist of a number of thermal paths (or sections). In this example there are four sections (or paths) through which heat can pass. The upper limit of resistance, R_{upper}, is given by

$$R_{upper} = \frac{1}{\frac{F_1}{R_1} + \frac{F_2}{R_2} + \frac{F_3}{R_3} + \frac{F_4}{R_4}}$$

where F_1, F_2, F_3 and F_4 are the fractional areas of sections 1, 2, 3 and 4 respectively and R_1, R_2, R_3 and R_4 are the corresponding total thermal resistances of the sections.

A conceptual illustration of the method of calculating the upper limit of resistance is shown in the figure below:

Conceptual illustration of how to calculate the upper limit of thermal resistance



Resistance through section containing AAC blocks and mineral wool

External surface resistance	= 0.040
Resistance of bricks	= 0.132
Resistance of air cavity	= 0.180
Resistance of AAC blocks (93.3%)	= 1.136
Resistance of mineral wool (88.2%)	= 2.342
Resistance of plasterboard	= 0.060
Internal surface resistance	= 0.130
Total thermal resistance (R_1)	= 4.020 m^2K/W

Fractional area F_1 = 0.823 (93.3% x 88.2%)

Resistance through the section containing mortar and mineral wool

External surface resistance	= 0.040
Resistance of bricks	= 0.132
Resistance of air cavity	= 0.180
Resistance of mortar (6.7%)	= 0.142
Resistance of mineral wool (88.2%)	= 2.342
Resistance of plasterboard	= 0.060
Internal surface resistance	= 0.130
Total thermal resistance (R_2)	= 3.026 m^2K/W

Fractional area F_2 = 0.059 (6.7% x 88.2%)

Resistance through section containing AAC blocks and timber

External surface resistance	= 0.040
Resistance of bricks	= 0.132
Resistance of air cavity	= 0.180
Resistance of AAC blocks (93.3%)	= 1.136
Resistance of timber (11.8%)	= 0.685
Resistance of plasterboard	= 0.060
Internal surface resistance	= 0.130
Total thermal resistance (R_3)	= 2.363 m²K/W

Fractional area F_3 = 0.110 (93.3% x 11.8%)

Resistance through section containing mortar and timber

External surface resistance	= 0.040
Resistance of bricks	= 0.132
Resistance of air cavity	= 0.180
Resistance of mortar (6.7%)	= 0.142
Resistance of timber (11.8%)	= 0.685
Resistance of plasterboard	= 0.060
Internal surface resistance	= 0.130
Total thermal resistance (R_4)	= 1.369 m²K/W

Fractional area F_4 = 0.008 (6.7% x 11.8%)

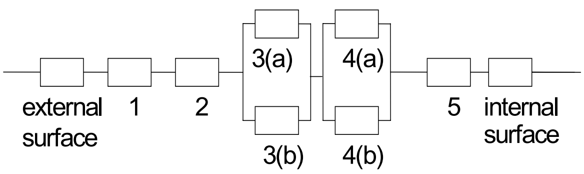
Combining these resistances we obtain:

$$R_{upper} = \frac{1}{\frac{F_1}{R_1}+\frac{F_2}{R_2}+\frac{F_3}{R_3}+\frac{F_4}{R_4}} = \frac{1}{\frac{0.823}{4.020}+\frac{0.059}{3.026}+\frac{0.110}{2.363}+\frac{0.008}{1.369}} = 3.617\ m^2K/W$$

Lower resistance limit

When calculating the lower limit of thermal resistance, the resistance of a bridged layer is determined by combining in parallel the resistances of the unbridged part and the bridged part of the layer. The resistances of all the layers in the element are then added together to give the lower limit of resistance. A conceptual illustration of the method of calculating the lower limit of resistance is shown below:

Conceptual illustration of how to calculate the lower limit of thermal resistance



The resistances of the layers are added together to give the lower limit of resistance. The resistance of the bridged layer consisting of AAC blocks and mortar is calculated using:

$$R_{first} = \frac{1}{\frac{F_{blocks}}{R_{blocks}} + \frac{F_{mortar}}{R_{mortar}}}$$

and the resistance of the bridged layer consisting of insulation and timber is calculated using:

$$R_{second} = \frac{1}{\frac{F_{insul}}{R_{insul}} + \frac{F_{timber}}{R_{timber}}}$$

The lower limit of resistance is then obtained by adding together the resistances of all the layers:

External surface resistance	= 0.040
Resistance of bricks	= 0.132
Resistance of air cavity	= 0.180
Resistance of first bridged layer $R_{first} = \frac{1}{\frac{0.933}{1.136} + \frac{0.067}{0.142}}$	= 0.773
Resistance of second bridged layer $R_{second} = \frac{1}{\frac{0.882}{2.342} + \frac{0.118}{0.685}}$	= 1.821
Resistance of plasterboard	= 0.060
Internal surface resistance	= <u>0.130</u>
Total (R_{lower})	= <u>3.136</u> m²K/W

Total resistance of wall

The total resistance of the wall is the average of the upper and lower resistance limits:

$$R_T = \frac{R_{upper} + R_{lower}}{2} = \frac{3.636 + 3.136}{2} = 3.376 \text{ m}^2\text{K/W}$$

Correction for air gaps between the timber studs

Since the insulation is entirely between studs (i.e. there is no continuous layer of insulation) a correction should be applied to the *U-value* in order to account for air gaps. The overall *U-value* of the wall should include a term ΔU_g, where

$$\Delta U_g = \Delta U'' \times (R_I / R_T)^2$$

and where $\Delta U'' = 0.01$ (referred to in BS EN ISO 6946 as correction level 1), R_I is the thermal resistance of the layer containing the gaps and R_T is the total resistance of the element. ΔU_g is therefore:

$$\Delta U_g = 0.01 \times (1.820 / 3.386)^2 = 0.003 \text{ W/m}^2\text{K}$$

U-value of the wall

The effect of air gaps or mechanical fixings should be included in the *U-value* unless they lead to an adjustment in the *U-value* of less than 3%.

$U = 1 / R_T + \Delta U_g$ (if ΔU_g is not less than 3% of $1 / R_T$)

$U = 1 / R_T$ (if ΔU_g is less than 3% of $1 / R_T$)

In this case $\Delta U_g = 0.003$ W/m²K and $1 / R_T = 0.296$ W/m²K. Since ΔU_g is less than 3% of $(1 / R_T)$,

$U = 1 / 3.376 = 0.30$ W/m²K.

Notes:

1. For *buildings* where sound resisting *separating floors* and *separating walls* are provided, this *construction* may not provide appropriate resistance to flanking sound transmission.
2. Since the cavity wall ties do not penetrate any insulation no correction need be applied to the *U-value* to take account of them.
3. In the above calculation it is assumed that the dwangs do penetrate the whole of the insulation. If the dwangs do not penetrate the whole of the insulation thickness they can be excluded as part of the timber percentage used in the calculation.