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Standard U-values

This digest provides information which enables U-values for walls and roofs to be calculated on the basis of standard assumptions, in accordance with the CIBS Guide, Section 3, 'Thermal properties of building structures'. This new edition includes a table of thermal conductivities of some building materials but omits the Table of U-values for wall and roof constructions that were included in the earlier edition.

The calculation of heat losses from ground floors is described in Digest 145; and from dwellings in general in Digest 190; some data relating to windows are included in Digest 140.

Introduction

The thermal transmittance or U-value of a wall, roof or floor of a building is a measure of its ability to conduct heat out of the building; the greater the U-value, the greater the heat loss through the structure. The total heat loss through the building fabric is found by multiplying U-values and areas of the externally exposed parts of the building, and multiplying the result by the temperature difference between inside and outside.

In the past, U-values have been obtained by a variety of methods — by measurement, by adjustment of measured values, or by calculation from thermal resistances of component parts. As a result, different sources often quoted different values for the same construction. In fact, the U-value of a structure does vary to some extent from one situation to another; among other things it depends on the moisture content of the component materials, the wind speed and the internal conditions. The results obtained by measurement depend on conditions during tests and differ from one another as well as from calculated values based on arbitrary assumptions about the conditions of exposure. Although all these methods give values that are accurate enough for heat loss calculation, difficulties arise when regulations require that the U-value should not exceed a stated value.

Standard U-values are needed for comparing different constructions on a common basis or for meeting a stated figure specified by a client or by regulations.

Basis of the standard U-values

Standard U-values are calculated from the resistances of the component parts, which in turn are based on standard assumptions about moisture contents of materials, rates of heat transfer to surfaces by radiation and convection, and airflow rates in ventilated airspaces. The effects of any heat bridging through the structure also have to be taken into account in a standard manner. The standard assumptions are as far as possible typical of practical conditions although they cannot be expected to agree in every case as conditions vary between one situation and another.

Measured U-values cannot be accepted as standard because it is only on rare occasions that the conditions of the test agree precisely with the standard assumptions.

Explanation of terms used

Thermal conductivity (λ) is a measure of a material's ability to transmit heat; it is expressed as heat flow in watts per square metre of surface area for a temperature difference of 1K per metre thickness and may be expressed as: $\frac{Wm}{m^2K}$ but thickness over area $\frac{m}{m^2}$ cancels to $\frac{1}{m}$ and the expression is normally given as *W/m.K*).

Thermal resistivity ($1/\lambda$) is also a property of a material, independent of thickness; it is the reciprocal of conductivity, ie *(m.K)/W*.

When the thickness of a material is known, its actual **thermal resistance** (*R*) can be calculated by dividing its thickness in metres by its thermal conductivity. The resistance is expressed in $(m^2K)/W$.

Thermal transmittance (*U*) is a property of an element of a structure comprised of given thicknesses of material and is a measure of its ability to transmit heat under steady flow conditions. It is defined as the quantity of heat that will flow through unit area, in unit time, per unit difference of temperature between inside and outside environment. It is calculated as the reciprocal of the sum of the resistances of each layer of the construction and the resistances of the inner and outer surfaces and of any air space or cavity. It is given in $W/(m^2K)$.

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To summarise the foregoing: a property of any material is its thermal conductivity (λ); the reciprocal of this is resistivity ($1/\lambda$). For material of known thickness, the resistance (R) can be calculated (thickness/conductivity) and from the resistances of the various layers comprising a construction and the resistances of cavities, and of inner and outer surfaces, the U-value can be calculated.

For a simple structure without heat bridging, the thermal transmittance coefficient U is expressed at:

$$U = 1/(R_{si} + R_{so} + R_{cav} + R_1 + R_2 \ldots\ldots)$$

where R_{si} = internal surface resistance (see Table 1)

R_{so} = internal surface resistance (see Table 2)

R_{cav} = resistance of any cavity within the building element (see Tables 3 and 4)

R_1, R_2 = resistance of slabs of material

Table 1 Internal surface resistance R_{si}

Building element	Surface emissivity*	Heat flow	$(m^2K)/W$
Walls	High	Horizontal	0·12
	Low	Horizontal	0·30
Ceilings or roofs, flat or pitched	High	Upward	0·10
Floors	Low	Upward	0·22
Ceilings and floors	High	Downward	0·14
	Low	Downward	0·55

Table 2 Standard outside resistance R_{so}

Building element	Surface emissivity*	Surface resistance R_{so} $(m^2K)/W$
Wall	High	0·06
	Low	0·07
Roof	High	0·04
	Low	0·05

*Emissivity should be taken as 'high' for all normal building materials including glass, other than unpainted metallic surfaces such as aluminium or galvanised steel, which should be regarded as 'low'.

Notes

For any part of a building, freely exposed on the underside to an open space, the same values as for roofs should be used.

The values given are applicable to any orientation.

Resistance of cavities (R_{cav}) The thermal resistance of airspaces, such as cavities in hollow wall constructions, depends mainly on the following factors:

1 Thickness of the airspace (its dimension through the thickness of the wall) — resistance increases with the thickness up to a maximum at about 20 mm.

2 Surface emissivity — commonly used building materials have a high emissivity and radiation accounts for about two-thirds of the heat transfer through an airspace with high emissivity surfaces. Lining the airspace with low emissivity material such as aluminium foil increases the thermal resistance by reducing radiation.

3 Direction of heat flow — a horizontal airspace offers higher resistance to downward than to upward heat flow, because downward convection is small.

4 Ventilation — airspace ventilation provides an additional heat flow path but because air movement in such conditions is very variable, estimates for this are necessarily approximate. Ventilation may be either deliberate, for example, ventilated cavity walls, or fortuitous, as in sheeted constructions with gaps between sheets.

Standard values for various airspaces, unventilated and ventilated, are given in Tables 3 and 4. The small amount of ventilation required to avoid condensation in roof spaces does not significantly affect the airspace resistance and, where this is the only ventilation provided, data for unventilated airspace should be used. Similarly, the data in Table 3 are applicable to the airspace in a cavity wall that is ventilated only to normal standards.

Table 3 Standard thermal resistance of unventilated airspaces

Type of airspace		Thermal resistance* $(m^2K)/W$	
Thickness	Surface emissivity	Heat flow— horizontal or upwards	Heat flow downwards
5 mm	High	0·11	0·11
	Low	0·18	0·18
20 mm or more	High	0·18	0·21
	Low	0·35	1·06
High emissivity planes and corrugated sheets in contact		0·09	0·11
Low emissivity multiple foil insulation with airspace on one side		0·62	1·76

*Including internal boundary suface

Materials As explained previously the resistance (R) of a material is equal to its thickness divided by its thermal conductivity λ. Values of λ for insulating materials can be obtained from the CIBS *Guide*. These materials are intended for use in dry situations and their thermal conductivity in air-dry condition is appropriate.

For the materials commonly used for masonry walling — brick, lightweight concrete, dense concrete — there is a relationship between bulk dry density and thermal conductivity, but the effect of moisture must also be considered. Table 5 sets out for a range of dry densities some average thermal conductivities at moisture contents appropriate to solid brickwork and concrete, protected from rain and exposed to rain as, for example, in the inner and outer leaves respectively of cavity walling.

If available, however, measured λ-values should be used for calculating standard U-values. The tests should have been made on specimens at a fairly low moisture content and should be adjusted, using Table 6, to the standard moisture content appropriate to the conditions of use, as indicated by the column headings of Table 5.

Table 4 Standard thermal resistance of ventilated airspaces

(Airspace thickness, 20 mm minimum)	Thermal resistance* $(m^2K)/W$
Airspace between asbestos-cement or black painted metal cladding with unsealed joints, and high emissivity lining	0·16
As above, with low emissivity surface facing airspace	0·30
Loft space between flat ceiling and unsealed asbestos-cement or black metal cladding pitched roof	0·14
As above with aluminium cladding instead of black metal, or with low emissivity upper surface on ceiling	0·25
Loft space between flat ceiling and unsealed tiled pitched roof	0·11
Loft space between flat ceiling and pitched roof lined with felt or building paper	0·18
Airspace between tiles and roofing felt or building paper on pitched roof	0·12
Airspace behind tiles on tile-hung wall	0·12

*including internal boundary surface

Table 5 Thermal conductivity of masonry materials

Bulk dry density	Thermal conductivity $W/(m.K)$		
kg/m^3	Brickwork protected from rain: 1%*	Concrete protected from rain: 3%*	Brickwork or concrete exposed to rain: 5%*
200	0·09	0·11	0·12
400	0·12	0·15	0·16
600	0·15	0·19	0·20
800	0·19	0.23	0·26
1000	0·24	0·30	0·33
1200	0·31	0·38	0·42
1400	0·42	0·51	0·57
1600	0·54	0·66	0·73
1800	0·71	0·87	0·96
2000	0·92	1·13	1·24
2200	1·18	1·45	1·60
2400	1·49	1·83	2·00

*Moisture content expressed as a percentage by volume

Table 6 Moisture factors, for use with Table 5

Moisture content (% by volume)	1	3	5	10	15	20	25
Moisture factor	1·3	1·6	1·75	2·1	2·35	2.55	2.75

Table 7 Thermal conductivities (λ) of some building materials

Material	Condition (if known)	Bulk density	λ
		kg/m^3	$W/(m.K)$
Asbestos-cement sheet	C	1600	0·40
Asbestos insulating board	C	750	0.12
Asphalt, roofing	dry	1600–2325	0·43 – 1·15
Brickwork, *see* Table 5			
Concrete, *see* Table 5			
Cork granules, raw	dry	115	0·052
Corkboard		145	0.042
Fibre insulating board	C	260	0.050
Hardboard, medium		600	0·08
standard		900	0.13
Metals:			
aluminium alloy, typical		2800	160
copper, commercial		8900	200
steel, carbon		7800	50
Mineral fibre (glass or rock)			
mat or quilt	dry	1220	0.04
semi-rigid felted mat	dry	130	0.036
loose, felted slab or mat	dry	180	0.042
Perlite, loose granules	dry	65	0·042
plaster	C	600	0·19
Plasterboard, gypsum		950	0·16
perlite		800	0·18
Plaster, gypsum		1280	0·46
lightweight		400 – 960	0·079 – 0·30
sand/cement	C	1570	0.53
Plastics, cellular			
expanded polystyrene	dry	15	0·037
	dry	25	0.034
polyurethane foam (aged)	dry	30	0·026
pvc flooring	dry		0·40
Plastics, solid			
epoxy glass fibre	dry	1500	0·23
polystyrene	dry	1050	0.17
Stone, *see* Table 5			
Timber, across grain			
softwood	C		0·13
hardwood			0·15
plywood	C	530	0·14
Vermiculite loose granules		100	0·065
Wood chipboard	C	800	0·15
Woodwool slab	C	500	0.085
	C	600	0.093

C conditioned to constant weight at 20°C and 65% rh

Notes

Some of the figures in this table are representative values to be used in the absence of precise information. Materials commonly used as thin membranes are not included. The contribution to overall insulation made by a membrane is due largely to the forming of additional airspaces, the resistance of the actual material being too low to be significant.

The thermal resistance of roofing tiles and slates should be neglected because of the airflow through the units; the resistance of this portion of the structure is allowed for in the values for ventilated airspaces given in Table 4.

Heat bridging

A metal or other high conductivity member bridging a structure increases the heat loss. In simple cases, the thermal resistance can be found by calculating separately the thermal transmittances of the different portions of the construction and combining them in proportion to their relative areas.

Multi-webbed bridges occur in components such as slotted blocks and perforated bricks. For these, calculation should be by three-dimensional analysis or by the combined method in the CIBS *Guide*.

The calculation of U-values

Table 7 sets out the thermal conductivities (from the CIBS *Guide*) of a range of building materials and, in conjunction with Tables 1–6, enables U-values to be calculated for a wide range of constructions.

Example 1

To find the U-value of an unplastered 'one-brick' solid wall, built of bricks of 1700 kg/m^3 density.

From Table 1, R_{si} = 0·12 *(m^{2}K)/W*

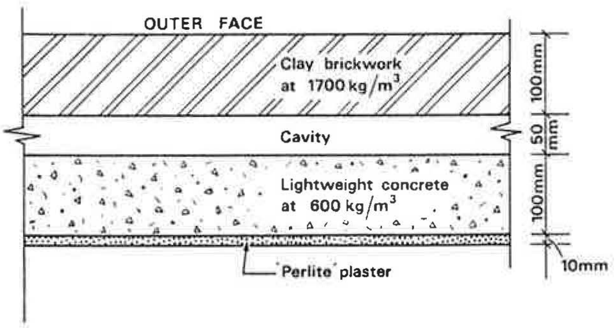
From Table 2, R_{so} = 0·06 *(m^{2}K)/W*

$$R_{brick} = \frac{\text{thickness in metres}}{\lambda\text{-value}} = \frac{0{\cdot}215}{0{\cdot}84} = 0{\cdot}26$$

$$U = \frac{1}{0{\cdot}12+0{\cdot}06+0{\cdot}26} = \frac{1}{0{\cdot}44} = 2{\cdot}3\ W/(m^2K)$$

Example 2

Calculate U-value of wall shown below.



$$U = \frac{1}{R_{si} + R_{so}\ R_{cav} + R_1 + R_2 + R_3}$$

From Table 1, R_{si} = 0.12 *(m^{2}K)/W*

From Table 2, R_{so} = 0·06

From Table 3, R_{cav} = 0·18

From Table 5,

(outer leaf) R_1 $= \frac{0{\cdot}10}{0{\cdot}84} = 0{\cdot}12$

(inner leaf) R_2 $= \frac{0{\cdot}10}{0{\cdot}19} = 0{\cdot}53$

From Table 7,

(plaster) R_3 $= \frac{0{\cdot}01}{0{\cdot}19} = 0{\cdot}05$

1.06

$$U = \frac{1}{1{\cdot}06} = 0.94\ W/(m^2K)$$

The CIBS *Guide* lists standard U-values for a selection of external wall and roof constructions. These constructions, or any others for which a U-value is already known, may be varied and the effect of the variation calculated by the following procedures:

1 Find the reciprocal of the U-value (= total resistance of the construction).
2 Deduct from this the resistance of any layers that are to be omitted.
3 Add the resistance of any layers that are to be added.
4 Find the reciprocal of the new total resistance (= the U-value).

Example 3

Calculate the effect of filling with polyurethane foam the cavity in Example 2.

U-value of the original construction 0·94 *W/(m^{2}K)*

(1)	1/0·94		= 1·06
(2)	Deduct R_{cav}		0·18
			0·88
(3)	Add R_{fill}	$\frac{0{\cdot}050}{0{\cdot}026}$	= 1·92
			2.80
(4)	$U = 1/2{\cdot}80$		= 0·36 *W/(m^{2}K)*

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