Technical Note No 47

Overall building envelope U-values

This Technical Note is one of four on the effect of building envelope performance on energy use in buildings. The series comprises:

TN 46 Introduction to building envelope energy transfer
TN 47 Overall building envelope U-values
TN 48 Energy loss through windows
TN 49 U-values of curtain walls

Introduction

This Technical Note introduces the reader to the assessment of overall U-values for complete building envelopes or assemblies of components forming part of the building envelope.

Building envelope is here considered in the application of commercial and public buildings and large buildings divided into many separate dwellings. Buildings of this type are covered by Approved Document L2 of the Building Regulations (England and Wales). An appendix gives equivalent values for Scotland and Northern Ireland. Similar considerations apply to other types of building and to buildings that have to comply with a different regulatory regime.

Energy use within a building will also depend on any solar gain and radiant losses through transparent areas of the envelope. These are covered in TN48 and TN49.

Effect of building envelope conduction

Energy use in buildings is heavily governed by energy transfer through the building envelope. Reducing the energy lost by conduction through the building envelope is an important aspect in the design of energy efficient buildings.

Calculation of the amount of energy lost by conduction through the building envelope is an important part of any method of assessment or compliance checking procedure.

Heat transfer by conduction is calculated using U-values (TN46).

Effect of air leakage

Air leakage through the building envelope is a major contributory factor to the rate of energy loss through the building envelope (TN46).

Currently non-domestic buildings in the UK are required to achieve an air leakage rate of 10 m^3/m^2hr. For buildings that achieve lower air leakage rates it is possible to balance energy savings from improved sealing against greater conduction losses/gains associated with higher U-values.

Assessing energy efficiency of buildings

The Building Regulations (England and Wales) give three methods for showing compliance. All of these methods require knowledge of the overall U-value of the building envelope or of separate zones of the building envelope.

The 'Elemental method' allows assessment of compliance of the building envelope alone. This method is based on:

a) U-values of the building envelope elements

b) Limits on the type, position and extent of glazing

It is possible to trade-off the effect of high U-values for some elements of the building envelope against lower U-values for other elements.

Note that the elemental method also accounts for the method of air conditioning and ventilation and for solar gains.

The greatest limitation of this method is the limit on the areas of glazing.

The 'whole-building method' relies on a carbon performance rating (CPR) for the whole building. Based on either the primary fuel consumption or the carbon emissions, the CPR must be below certain limits depending on the class of building and method of conditioning the internal environment.

This method gives greater flexibility to the building designer and takes account of solar gains. These may be beneficial during the heating cycle but solar gains may require the provision of larger cooling plants and lead to greater energy use for cooling.

It will often be necessary to use this method or the 'carbon emissions calculation method' to show the full benefits of more highly glazed walls such as some curtain walls.

The 'carbon emissions calculation method' requires a building to produce no greater carbon emissions than would be the case for a building complying with the elemental method.

This method also gives greater design flexibility and has the same advantages as the 'whole-building' method. The carbon emissions calculation method is described in CIBSE TM32.

U-values of assemblies of components

Whatever the individual U-values of the components, an overall U-value of an assembly can be established for the purposes of calculating energy use, and/or showing compliance with the Building Regulations.

The primary concern of the Building Regulations (England and Wales) is to limit the total amount of energy used in any building. They set limits on the U-values of different elements of the building envelope and limit the use of particular elements such as windows.

The Regulations give an upper limit for the U-value for different elements and also standard U-values that are used to establish a notional building.

Table 1 shows the upper limits for U-values, and also the U-values and allowable areas used to define the notional building (see below).

The area of glazing in an actual building is also controlled in order to limit solar gain. Those allowable areas are different from and additional to the allowable areas shown in Table 1.

No U-values or allowable areas are given for curtain walling. The U-value of an actual curtain wall depends on the proportion of vision area in the wall and achievable U-values vary widely, TN49. For a fully glazed curtain wall the U-values could reasonably be taken as those for metal framed windows. The allowable area of curtain walling is not relevant as no curtain walling is included in the notional building, see below.

Element	Poorest allowable U-value	Standard U-value	Allowable area at standard U-value
Pitched roof with insulation between rafters	0.35	0.20	N/A
Pitched roof with insulation between joists	0.35	0.16	N/A
Flat roof or roof with integral insulation	0.35	0.25	N/A
Walls, including basement walls	0.70	0.35	N/A
Floors, including ground floors and basement floors	0.25	0.25	N/A
Windows, roof windows and personnel doors, glazing in metal frames	3.3 *(Part L1 only)*	2.2	15-40
Windows, roof windows and personnel doors, glazing in wood or PVC frames	3.3	2.0	15-40
Rooflights		2.2	20
Vehicle access and similar large doors		0.7	N/A
Unheated space		0.35	N/A
Display windows, shop entrance doors and similar glazing	N/A	N/A	N/A

Table 1 U-values of building elements from Part L2 of the Building Regulations (England and Wales) *(See Appendix A for values to be used in Scotland and Northern Ireland)*

Acceptable U-values and areas of curtain walling will depend on:

- Other aspects of the building envelope when using the 'elemental method'
- All aspects of energy transfer and energy use when using the 'whole building method' or 'carbon emissions calculation method

U-value of an entire façade

Energy loss through a facade or any zone of a façade can be calculated by summing the energy loss through the individual elements. The heat flow is:

$$Q = \Delta t \times \sum U_{element} \times A_{element}$$

The U-value of a zone is calculated as:

$$U_{zone} = \frac{Q}{\Delta t \times A_{zone}} = \frac{\sum U_{element} \times A_{element}}{\sum A_{element}}$$

This method of calculation is called the area-weighted method for calculating U-values.

Consider a façade zone comprising 30 percent glazing with U-value 2.8 W/m^{2}K and 70 percent wall with U-value 0.28 W/m^{2}K. The overall U-value of the zone is given by:

$$U_{zone} = \frac{2.8 \times 0.3 + 0.28 \times 0.7}{0.3 + 0.7}$$

$$U_{zone} = 1.04 \ \textbf{W/m}^2\textbf{K}$$

Selection of components to achieve the required overall U-value

Acceptable U-values of components such as windows will depend on the area of windows as a fraction of the total area under consideration.

For windows in a wall with a U-value of 0.35 W/m^{2}K the following combinations all achieve the same overall U-value of 1.09 W/m^{2}K as sometimes required by Part L2 of the Building Regulations (England and Wales):

Window U-value (W/m^{2}K)	Window area (%)
1.83	50
2.20	40
2.46	35
2.82	30
3.31	25

Table 2 Window U-values and areas

Note that:

1 There is no upper limit to window U-values given in Part L2. However, Part L1 limits window U-values to 3.3 w/ m^{2}K.

2 Reducing the window area of a façade will give rise to greater use of energy for lighting. This may not be beneficial when calculating energy use using the 'whole building method' or the 'carbon emissions calculation method'.

3 The window area may have to be limited to reduce the adverse effect of solar gain.

Calculation of overall building envelope U-value

To calculate an overall U-value for a building envelope the area-weighted method may be applied. All relevant elements of the building envelope must be included. The relevant elements are all those in contact with both the internal and external environments.

When applying the weighted-area method to calculate heat loss (gain) it is established practice to take the area of an element as it is measured on the inside of the building. All warm (cold) surfaces are included in the area, including the surface of wall behind a floor or ceiling void.

Energy transfer is the product of area, U-value and the temperature difference between the internal and external environments. Elements that are not in direct contact with the external environment, for instance walls of an atrium and the inner skins of double facades require particular consideration (see below).

Floor slabs in contact with the external environment must be included in the overall U-value calculation but not floor slabs in direct contact with the ground. Whilst energy may be transferred through floors in contact with the ground, and in this sense they are part of the building envelope, the U-value of a floor slab in contact with the ground should not be combined with the U-values of other parts of the building envelope. The external environment of the ground is not comparable with that outside an exposed floor slab, wall or roof.

Example 1

Consider the building shown in Figure 1, comprising wall and roof zones as shown in Table 3.

For this building envelope the overall U-value is given by:

$$U_{overall} = \frac{\sum U \times A}{\sum A} = \frac{780}{1000} = 0.78 \text{ W/m}^2\text{K}$$

Note that the U-value shown for the window area is an area-weighted average calculated as:

$$U_{average} = \frac{\sum U_{window} \times A_{window}}{\sum A_{window}}$$

Some windows may have higher U-values if others have lower U-values.

The overall U-value may be used to calculate annual energy use due to conduction losses for use in the 'whole building method' or 'carbon emissions calculation method'. The annual energy loss will depend on the internal and external temperatures. Calculation requires knowledge of the number of degree-heating days (TN46).

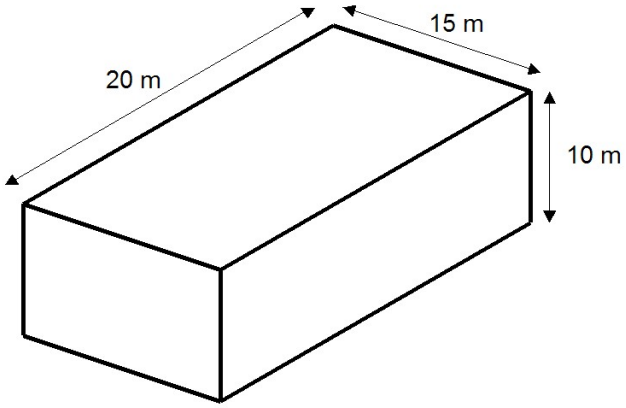

Figure 1 Building dimensions for example 1
(All dimensions are internal)

Zone	Area (m^2)	Opaque area (%)	U-value (W/m^2K)	$U \times A$ (W/K)	Window area (%)	U-value (W/m^2K)	$U \times A$ (W/K)	$\sum U \times A$ (W/K)
Wall 1	15 x 10 = 150	100	0.30	45	0	-	0	45
Wall 2	20 x 10 = 200	50	0.35	35	50	2.8	280	315
Wall 3	15 x 10 = 150	100	0.30	45	0	-	0	45
Wall 4	20 x 10 = 200	50	0.35	35	50	2.8	280	315
Roof	20 x 15 = 300	100	0.20	60	-	-	0	60
	Total 1000						**Total**	780

Table 3 Fabric properties for example 1.

Notional building

When applying the 'elemental method' or 'carbon emissions calculation method' it is necessary to set a benchmark against which to assess the energy efficiency of a proposed building. The Part L2 of the Building Regulations (England and Wales) defines a notional building for use with the 'elemental method'. CIBSE TM32 defines targets for the 'carbon emissions calculation method'. Any proposed building must be designed to be as energy efficient or better.

The notional building is defined by the standard U-values given in Table 1 and the allowable areas of elements are shown in Table 4.

Building type	Windows and doors as percentage of the area of exposed wall	Rooflights as percentage of area of roof
Residential buildings (where people temporarily or permanently reside)	30	20
Places of assembly, offices and shops	40	20
Industrial and storage buildings	15	20
Vehicle access doors and display windows **and similar glazing**	As required	

Table 4 Allowable areas of elements in the building envelope
(Other allowable areas apply to the limitation of solar gain)

When calculating the overall energy use of the notional building it is only allowable to take into account roof lights up to 10 per cent of the roof area in excess of any rooflights in the proposed building, up to a maximum of 20 per cent rooflights in the notional building. If a roof will actually contain 5 per cent rooflights then the notional building will contain 15 per cent rooflights.

For the building shown in Figure 1 the notional building will be defined as four walls each with 40 per cent glazing (assuming it is an office building) and a roof with 10 per cent rooflights (assuming they will not be included in the actual building).

The appropriate fabric properties are shown in Table 5.

The overall U-value of the building envelope (excluding the floor) is then given by:

$$U_{overall} = \frac{\sum U \times A}{\sum A} = \frac{896.5}{1000} = 0.90 \text{ W/m}^2\text{K}$$

It can be seen that the U-value of the notional building is greater than that of the building proposed in example 1 which therefore complies with Part L of the Building Regulations (England and Wales).

The overall U-value of 0.90 W/m^{2}K is used when calculating the annual energy use as an input to the 'Carbon emission calculation method' or the 'Whole building method'.

Zone	Area (m^2)	Opaque area (%)	U-value (W/m^{2}K)	$U \times A$ (W/K)	Window area (%)	U-value (W/m^{2}K)	$U \times A$ (W/K)	$\sum U \times A$ (W/K)
Wall 1	15 x 10 = 150	60	0.35	31.5	40	2.2	132	163.5
Wall 2	20 x 10 = 200	60	0.35	42	40	2.2	176	218
Wall 3	15 x 10 = 150	60	0.35	31.5	40	2.2	132	163.5
Wall 4	20 x 10 = 200	60	0.35	42	40	2.2	176	218
Roof	20 x 15 = 300	90	0.25	67.5	10	2.2	66	133.5
	Total 1000						**Total**	896.5

Table 5 Fabric properties for the notional building in Example 1.

Note that the overall U-value of the proposed building may be greater than that for the notional building if other aspects of the proposed buildings lead to greater efficiency than required by the notional building. This may arise from:

- The use of more efficient heating and/or cooling systems
- Reduced air leakage
- Improved shading or the use of higher performance glazing to reduce solar gain

Single wall

When considering only a single wall, without any knowledge of the other walls and roof, it is necessary to assume the worst conditions for those other elements of the building and consider only a notional wall. This will often lead to a more onerous U-value requirement for the wall.

Assuming, for an office, a wall with 40 per cent glazed area the required overall U-value for the wall will be:

$$U = 0.4 \times 2.2 + 0.6 \times 0.35 = 1.09 \text{ W/m}^2\text{K}.$$

Energy gains from reducing air leakage

Air leakage through the building envelope gives rise to a loss of conditioned air and gives rise to an energy loss (TN44).

Air leakage through one square metre of the building envelope at a rate of 10 m^3/m^2hr at 50 Pa gives rise to an average rate of energy loss of 0.172 W/m^2K.

Part L2 of the Building Regulations (England and Wales) requires buildings to have a whole building air leakage rate of 10 m^3/m^2hr or less. This may be assumed as the acceptable air leakage rate for the notional building. If a lower air leakage rate can be achieved (and demonstrated by a whole building air leakage test on completion) then it may be possible to use building envelope components with poorer U-values than allowed by the 'elemental method'.

Using the 'carbon emissions calculation method' the energy saved through reduced air leakage can be used to balance energy lost through the building envelope by conduction.

Taking the notional building of Table 5, the total surface area of the building envelope is 1000 m^2. If the building can be constructed to have a whole building air leakage rate of 8 m^3/m^2hr this will be 2 m^3/m^2hr less than the allowable air leakage of 10 m^3/m^2hr. The rates of energy use are shown in Table 6.

Notional building	Rate of energy use (W/K)
Conduction losses	896.5
Air leakage losses	177.0
Total	1073.5

Proposed building	Rate of energy use (W/K)
Conduction losses	896.5
Air leakage losses	137.6
Total	1034.1

Table 6 Effect of air leakage losses

This is equivalent to a reduction in the rate of energy use of 39.4 W/K

The proposed building with tighter construction could now have conduction losses of 930.9 W/K and still comply with Part L2 of the Building Regulations (England and Wales).

Example 2

Taking the building shown in Figure 1 and constructing the longer walls with curtain walling of U-value 3.0 W/m^2K. The fabric properties are as shown in Table 7.

The overall U-value is now:

$$U = \frac{1350}{1000} = 1.35 \text{ W/m}^2\text{K}$$

and this is acceptable provided the building is subject to a whole building air leakage test and achieves an air leakage rate of 8 m^3/m^2hr or less.

Zone	Area (m^2)	Opaque area (%)	U-value (W/m^2K)	$U \times A$ (W/K)	Curtain wall area (%)	U-value (W/m^2K)	$U \times A$ (W/K)	$\sum U \times A$ (W/K)
Wall 1	15 x 10 = 150	100	0.30	45	0	-	0	45
Wall 2	20 x 10 = 200	0	-	0	100	3.0	600	600
Wall 3	15 x 10 = 150	100	0.30	45	0	-	0	45
Wall 4	20 x 10 = 200	0	-	0	100	3.0	600	600
Roof	20 x 15 = 300	100	0.20	60	-	-	0	60
	Total 1000						**Total**	1350

Table 7 Revised fabric properties for example 1

Double skin walls and atria

If the components of the building envelope do not have surfaces in contact with the internal and external environments the temperature difference across them will be lower than the full temperature between the internal and external environments.

This may occur where:

- An atrium is at a lower temperature than the shops or offices opening on to it
- The internal skin of a double skin façade is not in contact with the external environment

Energy transfer through these areas of the envelope will depend on the actual temperature drop across the zone and it is necessary to calculate the temperature within the atrium or the plenum between the inner and outer skins of a double skin façade.

Avoidance of condensation

Where U-values of components are significantly greater than the standard U-values shown in Table 1 a condensation check should be carried out. This also applies to small components such as aluminium mullions and transoms.

References

Building Regulations (England and Wales): Part L2, Conservation of fuel and power in buildings other than dwellings (2002 edition), http://www.odpm/gov.uk/

Building Regulations (Scotland): Part J, Conservation of fuel and power, http://www.scotland.gov.uk/build_regs/sect-j.pdf.

Building Regulations (Northern Ireland): Part F, Conservation of fuel and power, http://www.buildingcontrol.org/bcni/legislation/regulations.asp.

TN46 Introduction to building envelope energy transfer, CWCT, 2004.

TN48 Energy loss through curtain walls, CWCT 2004.

TN50 Solar gain and solar shading, CWCT 2004.

TN51 Environmental control glasses, CWCT 2004.

CIBSE TM32: Guidance for the use of the carbon emissions calculation method, CIBSE 2003, ISBN: 1903287413.

BS EN ISO 13789: 1999, Thermal performance of buildings – Transmission heat loss coefficient – Calculation method.

Appendix A - Building Regulations Scotland and Northern Ireland

Allowable U-values used in this Technical Note are those included in the Part L2 of the Building Regulations (England and Wales). In Scotland the appropriate values are given in Schedule J.

In Northern Ireland the appropriate values are given in Schedule F. Table A shows the values used in each case.

Component	England and Wales	Scotland	Ireland
Pitched roof with insulation between rafters	0.20	0.20	
Pitched roof with insulation between joists	0.16	0.16	?
Flat roof or roof with integral insulation	0.25	0.25	?
Walls	0.35	0.30	?
Windows (metal)	2.20	2.20	?
Windows (timber and plastic)	2.00	2.00	?

Table A Standard U-values in different Building Regulations

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