Technical Note No 48

U-values of windows

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 U-values of windows
TN 49 U-values of curtain walls

Introduction

This Technical Note introduces the reader to the assessment of energy transfer through windows in terms of overall U-values of windows.

Limits on window U-values to comply with the Building Regulations are described in Technical Note 47.

Windows

The basic parts of a window are the glazing, the frame, the weather strips and sealants, and the hardware.

For the purpose of heat transfer through windows, these parts can be categorised into two, ignoring the hardware:

- Frame including weather strips and sealants, and
- Glazing unit including single or multiple glass panes and spacer bar and sealant at the unit edge.

The components affecting the energy transfer through a window are: frame, glass, and the spacer bar.

Energy transfer through windows

Energy transfers through windows due to:

- Temperature difference between the warm and cold environments;
- Air leakage;
- Solar radiation.

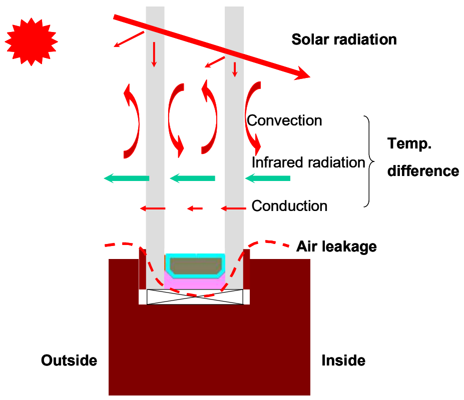

Figure 1 Energy transfer through window during heating season

The following part of this technical note deals only with the heat transfer due to temperature difference, which is measured in terms of U-value.

Heat transfer due to temperature difference

Heat transfer through a window, as shown in Figure 2, can be divided into three parts:

- One-dimensional heat transfer through glazing, Q_g, represented by centre pane U-value of glazing, U_g;
- Two-dimensional heat transfer through frame, Q_f, represented by frame U-value excluding edge effect, U_f;
- Two-dimensional heat transfer due to the interaction of the frame, the glass, and the spacer, Q_{edge}, known as the edge effect, represented by linear thermal transmittance, Ψ.

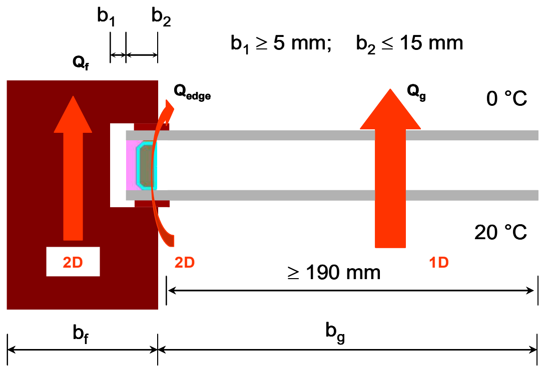

Figure 2 Heat transfer through window

Environmental conditions

Heat transfer through windows is assessed under the typical environmental conditions:

External temperature, T_e	0 °C
External surface resistance, R_{se}	0.04 m²K/W
Internal temperature, T_i	20 °C
Internal surface resistance, R_{si}	
Surface parallel to glazing	0.13 m²K/W
Surface perpendicular to glazing	0.20 m²K/W

Centre pane U-value of glazing, U_g

Heat transfers through glazing by convection, long-wave radiation, and conduction as shown in Figure 3.

BS EN 673 specifies the method of calculating the centre pane U-value of glazing, U_g.

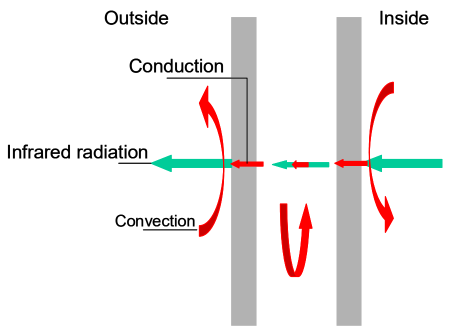

Figure 3 Heat transfer through insulating glass unit during heating season

Typical centre pane U-values of glazing for vertical orientation can be found in Table C.2 in Annex C of BS EN ISO 10077-1:2000.

The centre pane U-value of glazing varies with glass orientation. Table 1 shows the difference in centre pane U-value of an insulating glass unit when it is in horizontal orientation with upwards heat transfer and in vertical orientation with horizontal heat transfer.

Insulating glass unit (6-16-6)		U_g (W/m²K) Vertical	Horizontal
Hard	Air	1.7	2.4
Low-E	90% Argon	1.5	2.1
Soft	Air	1.4	2.1
Low-E	90% Argon	1.2	1.8

Table 1 Centre pane U-value of glazing

For slope glazing, the centre pane U-value of glazing can be calculated according to BS EN 673.

Frame U-value, U_f

Heat transfers through frames mainly by conduction through the solid material. Some heat transfer also occurs by convection and radiation in air cavities in the frame.

BS EN ISO 10077-2:2003 specifies the two-dimensional numerical method of assessing frame U-value, U_f, excluding the edge effect.

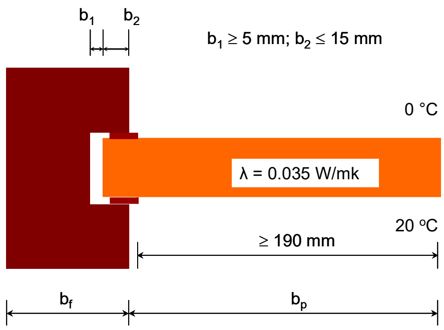

Figure 4 Frame section with insulation panel

To assess the heat transfer through the frame excluding the edge effect, an insulation panel with thermal conductivity of 0.035 W/mK is used in place of the glazing unit. A two-dimensional numerical simulation is carried out to assess the heat transfer, Q_1, through the frame and the insulation panel as shown in Figure 4, over a length of 1 m perpendicular to the section plane.

The frame U-value, U_f, excluding the edge effect is:

$$U_f = \frac{L_f^{2D} - U_p b_p}{b_f}; \qquad L_f^{2D} = \frac{Q_1}{\Delta T}$$

Where:

- b_p = length of the insulation panel from the solid edge of the frame, in m;
- b_f = width of the solid frame excluding gaskets, in m;
- Q_1 = rate of heat transfer through the frame and the insulation panel, in W/m;
- L^{2D}_f = two-dimensional thermal conductance of the frame section and the insulation panel, in W/mK;
- ΔT = temperature difference, in K;
- U_p = centre panel U-value, in W/m²K;
- U_f = frame U-value, in W/m²K.

Linear thermal transmittance, Ψ

Due to the interaction of the frame, the glass panes, and the spacer, some heat transfers laterally along the glass panes and the frame, then through the edge of the frame and the spacer bar towards the cold side.

The linear thermal transmittance, Ψ, describes the extra heat transfer due to the interaction of the frame, glass and the spacer bar.

A two-dimensional computer simulation is carried out to assess the heat transfer, Q_2, through the frame with glazing unit in use, as shown in Figure 5, over a depth of 1 m perpendicular to the section plane.

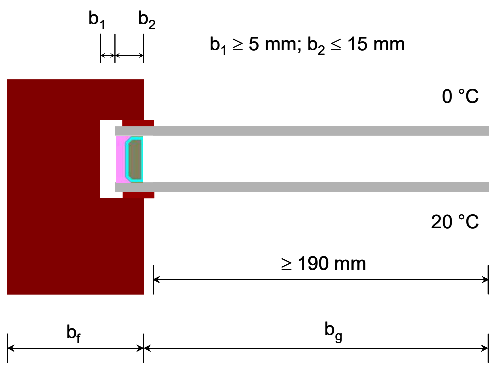

Figure 5 Frame section with insulating glass unit

The linear thermal transmittance is:

$$\Psi = \frac{L_\Psi^{2D} - U_f b_f - U_g b_g}{l}; \qquad L_\Psi^{2D} = \frac{Q_2}{\Delta T}$$

Where:

- U_g = centre pane U-value of glazing, in W/m²K;
- b_g = width of the glass from the solid edge of the frame, in m;
- Q_2 = rate of heat transfer through the frame and the glazing unit in use, in W/m;
- L^{2D}_Ψ = two-dimensional thermal conductance of the frame section and the glazing unit in use, in W/mK;
- l = length of glazing edge perpendicular to the cross section, in m (l = 1m with glazing at one side; l = 2m with glazing at both sides).

U-value of window

BS EN ISO 10077-1:2000 specifies the method of calculating U-values of windows with or without opaque areas. The basic formula is:

$$U_w = \frac{\sum U_g A_g + \sum U_p A_p + \sum U_f A_f + \sum \Psi_g l_g + \sum \Psi_p l_p}{A_w}$$

- A_g / A_p = smaller visible projected area of glass/opaque panel seen from both sides ignoring overlapping of gaskets;
- A_f = larger projected area of frame seen from both sides;
- l_g / l_p = larger perimeter of visible glass/ opaque panel seen from both sides;
- A_w = projected area of the window.

Note that if the U-values of frames are calculated according to BS EN 10077-2, the projected areas of glazing/opaque panel, and the frames used in the formula above should be taken as the projected areas viewed from inside the building.

According to the formula given above, there are two ways to calculate the overall U-values of windows:

- **Simplified method**: Calculate U_w according to BS EN ISO 10077-1:2000 using default frame U-value, U_f, and linear thermal transmittance, Ψ, given in Annex D and Annex E respectively;

- **Detailed method**: Calculate U_w according to BS EN ISO 10077-2:2003 using frame U-value, U_f, and the linear thermal transmittance, Ψ, from the results of two-dimensional computer simulations.

The simplified method only gives indicative U-values of windows. It is suitable at the early design stage. Indicative U-values of windows with different combinations of glazing and frame can be found in Annex D of BS EN ISO 10077-1.

Calculation of the overall U-values of windows by coupling the default linear thermal transmittance from BS EN ISO 10077-1:2000 with frame U-values from computer simulation results according to BS EN ISO 10077-2:2003 is not permitted. These methods are entirely different and results should not be combined. The linear thermal transmittance values for insulating glass units do not apply to the edge of opaque panels, particularly insulated panels, which may have much higher values of the linear thermal transmittance (cf. CWCT document – The effect of edge details on heat transfer through insulated panels).

Example of window U-value calculation

A window of the type recommended for Building Regulations calculation is shown in Figure 6. The window comprises 3-chamber PVC-U frames with steel reinforcement and a 4/16/4 double glazed unit with a centre pane U-value of glass 1.15 W/m²K. The geometry of the window is:

A_{fAA} = 0.223 m² l_{gAA} = 2.21m
A_{fBB} = 0.141 m² l_{gBB} = 2.67m
A_{fCC} = 0.142 m² l_{gCC} = 2.42m
A_g = 1.314 m²

Simplified method

By using the simplified method, the default frame U-value and linear thermal transmittance can be found in BS EN ISO 10077-1 Table D.1 and Table E.1 respectively as follows:

U_f = 2.0 W/m²K,
Ψ = 0.06 W/mK,
The indicative U-value is therefore:
U_w = 1.88 W/m²K

Detailed method

By using the detailed method, the frame U-values and linear thermal transmittances are obtained from computer simulations.

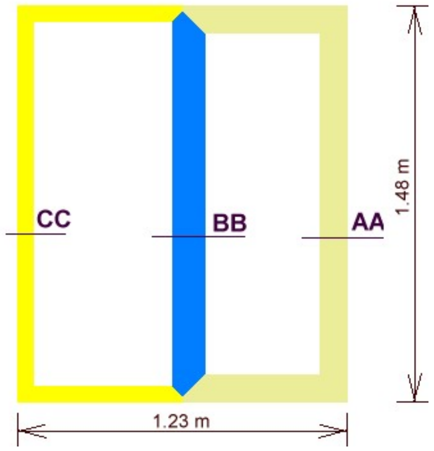

Figure 6 Window elevation

U_{fAA} = 1.80 W/m²K Ψ_{gAA} = 0.076 W/mK
U_{fBB} = 1.66 W/m²K Ψ_{gBB} = 0.081 W/mK
U_{fCC} = 1.85 W/m²K Ψ_{gCC} = 0.068 W/mK

The U-value of the window is therefore:

U_w = 1.63 W/m²K

Common error

By coupling the frame U-values from computer simulation results with the default Ψ value 0.06 W/mK from BS EN ISO 10077-1. The window U-value will be:

U_w = 1.57 W/m²K

This gives a lower U-value for the window, hence over-estimates the thermal performance of the window.

The reason for the over-estimation by this method is that BS EN ISO 10077-1 generally gives lower Ψ values based on outdated thermal performance of frames and glazing units, i.e., higher frame U-values and centre pane U-values of glazing at the time of publishing the standard. With the development of frames and glazing units, their thermal performance is much improved resulting in lower frame U-values and centre pane U-values of glazing in practice nowadays. On the other hand, the higher performance of improved frames and glazing enhances the thermal bridging effect due to the interaction between the frames, the glasses, and the spacers, leading to higher Ψ values. Computer simulation gives more realistic and up-to-date frame U-values, and Ψ values. By combining the frame U-value from computer simulation results and the default Ψ values from BS EN ISO 10077-1, part of the heat transfer through the window is neglected leading to a lower U-value for the windows.

Influence of general geometry

The area of the frame as a proportion of the total window area affects the U-values of windows. In general, with the same glazing unit and framing system, the larger the window, the lower the U-value of the window will be. Indicative U-values of windows with different proportions of frame area are given in Table F.1 and F.2 in Annex F of BS EN ISO 10077-1.

For a casement window with an insulating glass unit with a centre pane glass U-value of 1.5 W/m²K, and a frame of U-value 2.6 W/m²K, the U-value of the window is 2.0 W/m²K when the fraction of frame area is 30 per cent. The U-value of the window is reduced to 1.9 W/m²K when the fraction of frame area is decreased to 20 per cent.

The thickness of the frame perpendicular to the plane of the glazing also affects the thermal performance of windows. Increasing the thickness of a frame tends to increase the length of the heat transfer path but usually also increases the exposed surface area. For frames made of insulating materials (e.g. PVC or timber) the effect of the increased thickness is to introduce more thermal resistance by lengthening the heat transfer path than is lost by increasing the exposed surface area. The U-value of the frame therefore decreases, but not in proportion to the increase in thickness.

For conductive frame materials (e.g. metals) the increase in thermal resistance caused by lengthening the heat transfer path is usually negligible compared to the reduction in thermal resistance caused by the increased surface area, and the frame U-value may increase. For a metal frame the U-value is best reduced by introducing a better thermal break, or by combining the metal frame with a less conductive material such as timber or PVC (composite windows).

Combined energy rating

Taking into account solar gain and heat transfer due to air leakage, the total energy transfer through a window can be expressed in the form of an overall energy rating.

The British Fenestration Rating Council (BFRC) gives the formula for calculating the overall energy rating for domestic windows as:

$$DWER = 218.6 g_w - 68.5 \times (U_W + 0.0165 L_{50})$$

Where

DWER = domestic window energy rating, in kWh/m²/year;
$g_w = 0.9 \times g_\perp \times$ *fraction area of visible glass,*
= window solar factor,
$g_\perp$ = normal solar factor of the glazing unit,
U_w = overall thermal transmittance of the window, in W/m²K,
L_{50} = air leakage factor measured at 50 Pa, in m³/h/m².

U_w and L_{50} in the formula are calculated or measured based on the window type recommended for Building Regulation calculation with a width of 1.23 m and a height of 1.48 m.

The weighting coefficients in the formula are determined by the national climate conditions in the U.K.

Detailed information can be found at web site: http://www.bfrc.org.

Improving U-values of windows

A range of technologies is available to improve the thermal performance of windows. It is important to realise that the improvements are not necessarily cumulative. In some cases, the technologies are mutually exclusive and the use of one technology will prevent the use of another.

Frame technology

As the frame is only a small part of the window, a reduction in the frame U-value of 0.1 W/m2K will result in a much smaller reduction in the overall window U-value.

The greatest improvements in window U-values can be achieved with the use of higher performance glazing units, combined with warm edge glazing technology.

Gas filling

Inert gas filling is an effective way to reduce heat transfer through insulating glass units due to its low thermal conductivity, high heat capacity, and high viscosity.

Argon filling gives good thermal performance but cannot be carried out for some warm edge spacers.

Krypton filling gives good thermal performance for narrower than usual cavities.

Unless otherwise specified, for gas filled insulating glass units, a nominal gas concentration of 90 per cent should be assumed. Increasing the gas concentration will make little difference to centre pane U-value of insulating glass unit where argon is used; but will be more significant for krypton.

Warm edge spacer

When insulating glass units are used the high conductivity of conventional aluminium spacer bars leads to lower internal surface temperatures at the edge of the insulating glass unit. This in turn leads to heat transfer laterally in the glass from the centre of the pane to the edge and increases the heat loss through the unit.

Warm edge spacers use metal or other materials with lower thermal conductivity to replace conventional aluminium spacer bars. They improve the thermal performance of windows by increasing the minimum internal surface temperature, hence reducing the risk of surface condensation.

The most commonly used warm edge spacer bars are:

- Stainless steel;
- Thermoplastic;
- Thermally-broken metal;
- Foam rubber;
- Reinforced butyl sealant.

Using warm edge spacers generally increases the minimum surface temperature by as much as 3.5°C and reduces the U-value of windows by as much as 0.2 W/m^2K.

DTI PII research project - *Assessing the heat loss at insulating glass sealed unit edge* - studies the thermal performance of windows with different combination of frame, glazing, and spacer bars. Details may be found on the CWCT web site: http://www.cwct.co.uk.

Gas filling requires the use of a perimeter glazing unit sealant which has a low rate of gas leakage, which in turn may preclude the use of some warm edge glazing technologies which are not compatible with those sealant materials.

Low-E coated glass

Using hard Low-E coated (ε_n = 0.15) glass is currently common practice.

Using soft low-E coatings (ε_n = 0.02 ~0.04) can improve the thermal performance of insulating glass units significantly. However the glass sheet has a shorter shelf-life prior to being made into an insulating glass unit. It is not possible to toughen glass after application of some soft low-E coating. The glass can be toughened before application of the coating, but this may affect cost and availability.

Triple insulating glass units

Triple insulating glass units give good thermal performance but the weight will increase by up to 50 per cent compared to double insulating glass units. The additional thickness may also require modification to the frames.

High performance film IGU

These insulating glass units incorporate one or more optically clear films with a low-e coating suspended within the cavity between glass panes. The thin film reduces convection and infrared radiation within the cavity, thus improving the thermal performance of the insulating glass unit without increasing the weight of the unit significantly. These units are a relatively recent development in North America.

Notation

A	Projected area	m^2
Q	Rate of heat flow	W/m
U	U-value	W/m^2K
Ψ	Linear thermal transmittance	W/mK
b	Width	m
l	Perimeter of glazing	m
l	Depth of glazing edge	m
ΔT	Temperature difference	°C
g	Solar factor	
L_{50}	Air leakage factor measured at 50 Pa	$m^3/h/m^2$
R_{SE}	External surface resistance	m^2K/W
R_{SI}	Internal surface resistance	m^2K/W
T_E	External temperature	°C
T_I	Internal temperature	°C
BFRC Rating	Domestic window energy rating	$kWh/m^2/year$

Subscription

f	Frame
p	Panel
$\perp$	Normal
g	Glass
w	Window
1,2	Numbers referring to simulations

References

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TN 47 *Overall building envelope U values*, CWCT 2005.

TN49 *Energy transfer through curtain walls*, CWCT, in preparation.

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