Thermal Transmittance around Edge of Vacuum Glazing

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Abstract. The main objective of the calculations thermal performance properties of the edge of vacuum glazing was the quantification of the heat flow around edge of glazing. Additional heat flow around edge of glazing is expressed by means linear thermal transmittance. Linear thermal transmittance of the junction between edge vacuum glazing and wooden frame or wooden-aluminium frame was calculated by using a two dimensional (2D) numerical calculations. Edge sealing of vacuum glazing is assumed by means solder glass with Indium metal strip, so it is metal-based edge seal. In vacuum glazing the edge seal acts as a thermal bridge between the glass sheets. Heat flows from the glass sheet on the warm side through the edge seal to the sheet on the cold side, not only does it increase the overall thermal performance of the glazing, but also it causes temperature variation (decrease surface temperatures) and stress in the edge region.

1. Introduction
The main objective of the calculations thermal performance properties of the edge of vacuum glazing was the quantification of the heat flow around edge of glazing. Additional heat flow around edge of glazing is expressed by means linear thermal transmittance. Linear thermal transmittance of the junction between glazing and wooden frame was calculated by using a two dimensional (2D) numerical calculations.

At present, vacuum glass is used in different kinds of buildings such as office building, building group, exhibition center and showrooms, library, greenhouse, house and apartment, many of which were “world first” or “world greatest”.

A different fabrication method of vacuum glazing using a indium alloy edge seal technique was developed at the University of Ulster (UU) [1], and in China [2]. Vacuum glazing samples incorporating two tempered or heat-strengthened glass of 5 mm thick were produced with the center of glazing U-value of 0.58 W.m2.K⁻¹.

2. Description of vacuum glazing
The vacuum glazing consists of two glass panes separated by a vacuum layer which is 0.2 mm wide. The glass sheets are separated by small circular metal pillars with diameter of about 0.25 mm and spaced 40 mm apart. There is a low-emission layer on the inner part of the glazing, which reduces heat loss by radiation.
According to the description from Beijing Synergy Vacuum Glazing Technology Co., Ltd., vacuum glazing has a dimension of 978 mm x 578 mm and structure (Figure 1):

\[ T5 + V + TL5 \]

where

- T is tempered or heat-strengthened glass of 5 mm thick;
- V is vacuum layer of 0.15 to 0.2 mm thick;
- TL is tempered or heat-strengthened low-E glass of 5 mm thick.

Solar factor (g-value) of glazing = 0.638;
Light-transmission factor \( n_V = 0.79 \);
The edge of the vacuum glazing is 10 to 12 mm wide;
Amount of pillars (supporting profiles) 13 x 24 = 312 for vacuum glazing area of 0.565 m² (Figure 2);
Declared value of glass thermal transmittance \( U_g = 0.58 \text{ W.m}^2\text{K}^{-1} \).

These properties were stated by the manufacturer based on the calculation in Window 7 by Canadian Standard NFRC 100-2010.

Figure 1. Vacuum glazing – section (not to scale) [3]

Figure 2. Vacuum glazing – support pillar field – view

Synergy Vacuum Glazing Technology uses infrared edge sealing technology [2]. The technology of making tempered vacuum glass in rapid step infrared heating furnace and edge sealing by infrared glass solder was first proposed in Chinese and American patents [5]. In recent years, a Chinese company not only developed low-melting-point and lead-free glass solder which can heat up rapidly by absorbing infrared, but also designed and manufactured step infrared continuous heating furnace
with 6 minutes a beat. The edge of glass is sealed at a relatively fast speed where the temperature of glass center is 30-50 ºC lower than the edge. The technology not only decreased the anneal extent of tempered glass, but also reduced electricity consumption and production. Model of the edge of vacuum glazing (Figure 2) is based on thermal conductivity of applied materials. Solder glass 1 W/(m·K) and Indium 83.7 W/(m·K).

\[ \lambda = 1 \text{ W/(m·K)} \]

\[ \lambda_{ekv} = 0.0063 \text{ W/(m·K)} \]

\[ \lambda = 83.7 \text{ W/(m·K)} \]

Figure 3. Model of edge of vacuum glazing (not to scale)

3. Method for testing heat flow around edge of glazing
In general, the thermal transmittance or U-value of the window or door product or assembly is calculated as a function of the thermal transmittance of the components and their geometrical characteristics, plus the thermal interactions between the components.

EN ISO 10077-1 [6] provides a calculation method to obtain the thermal transmittance of windows and pedestrian doors consisting of glazed and/or opaque panels fitted in a frame. EN ISO 10077-2 [7] specifies the method for numerical calculation of the thermal transmittance of frames \( U_f \) and the linear thermal transmittance \( \Psi \). The \( \Psi \) value describes the heat loss caused by fitting the glass unit in the frame (or mullion/transom). The amount of this \( \Psi \) value varies depending on the spacer used in the insulating glass unit. A distinction is made between conventional spacers and thermally improved spacers. The calculation of the thermal transmittance of frame profiles, and the linear thermal transmittance according to EN ISO 10077-2 is carried out using a two dimensional numerical method.

4. Calculations for vacuum glazing
The thermal transmittance of the frame section, \( U_f \), is defined as follows. In the calculation model the glazing is replaced by an insulation panel with thermal conductivity \( \lambda = 0.035 \text{ W/(m·K)} \) inserted into the frame, with clearance \( b_1 \) not less than 5 mm. The overlap \( b_2 \) is equal to that of the glazing which the insulation panel replaces. The length of the panel shall be at least 190 mm measured from the most protruding part of the frame, ignoring any protruding gasket(s). The opposite end of the panel is considered as an adiabatic boundary. The frame model shall contain all materials used in manufacturing the window except the glazing or opaque panel, which is replaced by the insulation panel. The thickness \( d \) of the insulation panel shall be of the glazing or opaque panel being replaced;

To calculate the two-dimensional thermal conductance of the section consisting of the frame and the glazing including the spacer effect, the frame section with a projected frame width, \( b_f \), and thermal transmittance \( U_f \) is completed by glazing with thermal transmittance \( U_g \) and length \( b_g \) (Figure 4). The value of the linear thermal transmittance, \( \Psi \), is defined by Equation (1).

\[ \Psi = L^{2D}_{\Psi} - U_f b_1 - U_g b_g \]  

(1)

where 
\[ \Psi \] is the linear thermal transmittance, expressed in W/(m·K);
\[ L^{2D}_{\Psi} \] is thermal conductance of the section shown in Figure 4, expressed in W/(m·K);
\[ U_f \] is the thermal transmittance of the frame section, expressed in W/(m²·K);
\[ U_g \] is the thermal transmittance of the central area of the glazing, expressed in W/(m²·K);
is the projected width of the frame section, expressed in m;

\( b_g \) is the visible width of the glazing, expressed in m.

**Figure 4.** Schematic of profile section with glazing installed [7]

5. **Calculations vacuum glazing in wooden frame**

Calculation of linear thermal transmittance was by means Therm program [8]. Results of calculations are in Table 1. In the first column are results for wooden frame I4 taken from EN ISO 10077-2. In this frame was installed calibration panel with thermal conductivity \( \lambda = 0.035 \text{ W/(m·K)} \) inserted into the frame, with clearance \( b_1 \) in order to obtain \( U_f \) value for glazing with \( d_g = 10.2 \text{ mm} \) (for vacuum glazing). This is in second column in Table 1. In the third column are results for calculation of linear thermal transmittance of vacuum glazing. Here we have from Table 1:

- \( U_f = 1.56 \text{ W/(m}^2\text{·K)} \) and \( b_f = 110 \text{ mm} \)
- \( U_g = 0.58 \text{ W/(m}^2\text{·K)} \) and \( b_g = 190 \text{ mm} \)
- \( L_2D = 0.3042 \text{ W/(m·K)} \).

For linear thermal transmittance according equation (1) is

\[
\Psi = 0.3046 - 1.56 \times 0.110 - 0.58 \times 0.19 = 0.023 \text{ W/(m·K)}
\]  

(2)

6. **Calculations vacuum glazing in wooden-aluminium frame**

The wood-aluminium window has a dimension of 800 x 1,200 mm, the surface of the window \( A_{sp} = 0.96 \text{ m}^2 \) (Figure. 5). The frame construction of the wood-aluminium window is based on the wooden profile IV88.

**Figure 5.** Window with vacuum glazing - section
Table 1. Results of calculations of thermal transmittance $VG$ in wooden frame

| Calibration and comparison results from EN ISO 10077-2 | Results for frame with calibration panel with $d_g = 10.2$ mm | Results for vacuum glazing $d_g = 10.2$ mm |
|-------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------|
| $d_g = 28$ mm                                          | $d_g = 10.2$ mm                                               | $d_g = 10.2$ mm                             |
| $U_f = 1.36$ W/(m$^2$.K)                              | $U_f = 1.56$ W/(m$^2$.K)                                      | $U_f = 1.56$ W/(m$^2$.K)                   |
| $L^{2D} = 0.346$ W/(m.K)                              | $L^{2D} = 0.586$ W/(m.K)                                      | $L^{2D} = 0.3046$ W/(m.K)                  |

Figure 1.4: $d_g = 28$ mm

Table 2. Results of calculations of thermal transmittance $VG$ in wooden-aluminium frame

| Results for frame with calibration panel $d_g = 10.2$ mm | Results for vacuum glazing $d_g = 10.2$ mm |
|----------------------------------------------------------|---------------------------------------------|
| $d_g = 10.2$ mm                                          | $d_g = 10.2$ mm                             |
| $U_f = 1.286$ W/(m$^2$.K)                               | $U_f = 1.286$ W/(m$^2$.K)                   |
| $L^{2D} = 0.5615$ W/(m.K)                               | $L^{2D} = 0.2942$ W/(m.K)                   |
| $U_g = 0.58$ W/(m$^2$.K)                                | $U_g = 0.58$ W/(m$^2$.K)                    |

$U_g = 0.58$ W/(m$^2$.K) $L^{2D} = 0.2942$ W/(m.K)
Here we have from Table 2:

\[ U_f = 1.286 \text{ W/(m}^2\text{.K)} \text{ } \text{and} \text{ } b_f = 115 \text{ mm} \\
U_g = 0.58 \text{ W/(m}^2\text{.K)} \text{ } \text{and} \text{ } b_g = 190 \text{ mm} \\
L^{2b} = 0.2942 \text{ W/(m.K).} \\

For linear thermal transmittance according equation (1) is

\[ \Psi' = 0.2942 - 1.286 \times 0.115 - 0.58 \times 0.19 = 0.036 \text{ W/(m.K)} \]

(3)

7. Conclusions

The edge area of vacuum glazing using solder glass and indium alloy edge seal has linear thermal transmittance

\[ \Psi' = 0.023 \text{ W/(m.K)} \text{ for wooden frame,} \\
\Psi' = 0.036 \text{ W/(m.K)} \text{ for wooden-aluminium frame.} \\

These values should be used if thermal performance of window with vacuum glazing is expressed according system of European standards EN ISO 10077-1 and EN ISO 10077-2.

Acknowledgement

The authors express thanks to Ministry of Education SR for financial support of the projects VEGA 1/0113/19 and APVV-16-0126.

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