Thermal Performance of Window with Vacuum Glazing. Case Study

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Abstract. This document deals with the determination of thermal transmission properties of wood-aluminium window with vacuum glazing. Test measurements are performed with guarded hot-box method at defined temperature difference. They describe how the support pillars influence temperature distribution on the surface and how the edge vacuum glazing influence the heat flow through window. The deformation of the temperature field due to support pillars is surprisingly small and its range is from 0.40 K to 0.51 K with temperature difference on both sides of approximately 33 K. Decrease of internal surface temperature from the middle of glass to the edge is about 18.92 °C – 12.37 °C = 6.55 K, and so it is considerable effect. The effect of the edge on the glazing is not explicitly quantified in the term of heat flow in this document, but is implicitly documented by means of surface temperature. Thermography was used to check if there are touching points between glasses where distance is from 0.15 to 0.2 mm. The vacuum glazing measured in this work was a sample, which was fabricated in Asian producer. The window was tested two years after delivery from the producer.

1. Introduction

Multiple glazing with three or more panes along with low-emission layers and gas with very low thermal conductivity (krypton or argon) can achieve heat-transfer coefficients $U_g$ below 1.0 W.m$^{-2}$.K$^{-1}$ [1]. Comparable values can be reached by the creation of vacuum layers between two glass panes where the pressure will be less than 0.1 Pa. This eliminates heat transfer by conduction and heat flow.

The concept of vacuum glazing was first introduced in 1913 by Zoller F [2]. In 1995, Simko T M [3] improved the design and the manufacture of vacuum glazing. The glass sheets were separated by the support pillars. Since then many international efforts focused on vacuum glazing research and development [4, 5]. Jianzheng T [6] summarize newest technology highlights on vacuum glass in China. But meanwhile there are also challenges for vacuum glass industry, for example lack of understanding of the characteristics of tempered vacuum glass, high cost of glass, lack of certified testing standards of product quality.

At present, vacuum glass is used in different kinds of buildings such as office building, building group, exhibition spaces and showrooms, library, greenhouse, house and apartment, many of which were “world first” or “world greatest”. Vacuum glazing was not a standard product at the time and it was first presented in Slovakia in 2016. At the Coneco Trade Fair in Bratislava, a gold-plated wood-aluminium window with a vacuum glazing was awarded for excellent thermal and acoustic properties.
Two years after delivery from an Asian supplier, we verified the $U_v$ value of the vacuum glazing and the $U_w$ value of the window with built-in vacuum glazing. At defined temperature difference in hot-box were study surface temperature irregularities.

2. **Description of vacuum glazing and window frame**

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. Vacuum glazing has a dimension of 978 mm x 578 mm and has composition (Figure 1):

$$T5 + V + TL5$$

where T is tempered or heat strengthened glass of 5 mm thickness,

V is a vacuum layer of thickness of 0.15 to 0.2 mm;

TL tempered or heat strengthened low-E glass of 5 mm thickness.

Solar factor (g-value) of glazing = 0.638;
Light transmittance factor $\tau_V = 0.79$;
The edge of the vacuum glazing has the width of 10 to 12 mm;
Number of pillars (supporting profiles) 13 x 24 = 312 for a vacuum glazing area of 0.565 m$^2$;

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

The wood-aluminium window has a dimension of 800 x 1,200 mm, the surface of the window $A_w = 0.96$ m$^2$ (Figure 2). The frame construction of the wood-aluminium window is based on the wooden profile IV88 (Figure 3), which was designed for a pre-assembled window. The vacuum glazing measurement in the hot box corresponds to a frame construction without thermal insulation materials and to $U_f = 1.286$ W.m$^{-2}$.K$^{-1}$ [7].

For the measuring of $U_f$ according to EN 12412-2 [8], the glazing is replaced by an insulation panel with thermal conductivity $\lambda = 0.035$ W.m$^{-1}$.K$^{-1}$, which is inserted into the frame. The thickness of the insulation panel shall be the same as of that the glazing. Different $U_f$ values are measured for different glazing applications by triple glazing, double glazing or vacuum glazing. We use the frame with $U_f = 1.286$ W.m$^{-2}$.K$^{-1}$ for vacuum glazing testing in the window.

3. **Verification method**

The verification of the heat transfer coefficient of the window and of the vacuum glazing was performed by a hot-box method (Figure 4) according to STN EN ISO 12 567-1 [9]. Measurement of the thermal transmittance of the vacuum glazing was also performed alternately by heat flow meter.

Measurements were made to ensure that the air permeability of the test specimen did not affect the measurement – by sealing of the joints inside and outside. Measurement of the thermal transmittance of the window and the vacuum glazing was performed under the same condition as the calibration procedure, it was done with an average temperature of 10 °C and with a air temperature difference $\Delta \theta = (20 \pm 2)$ K, which is recommended in [9].
4. Method for testing thermal irregularities

The verification of internal and external surface temperatures and the heat transfer coefficient of the window and the vacuum glazing was performed by a hot-box method according to [STN EN ISO 12 567-1, 2010]. For testing thermal irregularities in surface temperatures was used air temperature difference between hot and cold side of the specimen:

\[ 33 \text{ K for } 22^\circ \text{C inside and } -11^\circ \text{C outside air temperatures}. \]

Internal and external temperatures are measured by PT1000 sensors. They are evenly spaced over the vacuum glazing area and located opposite on the hot and cold side (Figure 5).
Figure 5. Temperature sensors on the cold side

Surface temperatures at 22 and -11 °C

- Internal surface temperature

Location of temperature sensors from midle to edge

Figure 6. Temperature distribution at 33 K difference; p – pillar

The difference between the temperature on internal surface of the support pillar and the midpoint of the support pillar (Figure 6) is

\[ 19.43 \, ^\circ\text{C} - 18.92 \, ^\circ\text{C} = 0.51 \, \text{K} \]

The irregularity of the internal surface temperature due to support pillars is approximately 0.51 K in the central glazing area. Temperature difference between central area of glazing and edge of glazing is

\[ 18.92 \, ^\circ\text{C} - 12.37 \, ^\circ\text{C} = 6.55 \, \text{K} \]

It is significant that the internal surface temperature drops from the centre of the glazing to the edge.
5. Infrared thermography
The point thermal bridge disturbs this uniformity by reducing the surface temperatures on the indoor surface and increasing the surface temperatures on the outdoor surface. Thermography is used to check if there are touching points between glasses where distance is from 0.15 to 0.2 mm. Deformation of temperature field is more visible from infrared thermography on Figure 7. No touching points were detected on glass sheets.

Figure 7. Outside surface deformation of the temperature field at 33 K difference

6. The results for heat transmission through vacuum glazing
Heat flow meter was used for the thermal transmittance determination of the vacuum glazing. The heat flow meter method specifies the heat transfer coefficient for glazing in its central area. Thus marginal effects caused by the edge of the glazing or by the contact of the hermetically sealed edge with the frame construction are not taken into account. We did not consider possible irregularity of the surface temperatures (deformation of the temperature field) because of support pillars which are spaced in 40 mm in both directions (Figure 8).

Figure 8. Location of heat flow meter and surface temperature sensors PT100
Heat flow meter was placed between the support pillars. Difference in the mean temperatures on the inner and outer glazing during measurement with a steady temperature:
\[ \Delta \theta = (\theta_{si1} - \theta_{se1}) = (20.58 - 2.51) = 18.08 \text{ K} \quad (1) \]

where \( \theta_{si1} \) is the mean temperature on internal surface of the vacuum glazing between the support pillars in °C,
\( \theta_{se1} \) the mean temperature on external surface of the vacuum glazing between the support pillars in °C.

Heat transfer coefficient of the vacuum glazing in the middle between the support pillars is determined as standard heat transfer coefficients on both sides according to:

\[ U_g = \frac{1}{(0.17 + \Delta \theta / q_{sp})} = \frac{1}{0.17 + 18.08 / 9.66} = 0.50 \text{ W.m}^{-2}.\text{K}^{-1} \quad (2) \]

where \( q_{sp} \) is the density of the heat flow through the sample during the measurement in W.m\(^{-2}\).

The value 0.50 W.m\(^{-2}\).K\(^{-1}\) does not include heat flow around the support pillars and heat flow around the sealed edge of the vacuum glazing. It represents an ideal heat flow in the middle of the vacuum glazing without the edge and without the pillars effects as well. It includes a gaseous conduction (heat transfer by residual gas) and a radiation heat transfer between the internal surfaces of the glass sheets.

### 7. The results for the window with vacuum glazing

Thermal performance of wood-aluminium window with the vacuum glazing is verified by a guarded hot-box method.

Heat transfer resistances on the surface in the guarded and cold boxes (under the same condition as the calibration):
- \( R_{si} = 0.17 \text{ m}^2.\text{K.W}^{-1} \) in the guarded box and
- \( R_{se} = 0.06 \text{ m}^2.\text{K.W}^{-1} \) in the cold box and therefore overall is \( R_{st} = 0.23 \text{ m}^2.\text{K.W}^{-1} \).

The density of the heat flow value, \( q_{sp} \), through the window sample during the measurement is calculated based on the formula:

\[ q_{sp} = \frac{\Phi_{in} - \Phi_{sur} - \Phi_{edge}}{A_{sp}} = \frac{25.98 - 3.94 - 3.6}{0.96} = 19.208 \text{ W.m}^{-2} \quad (3) \]

where \( \Phi_{in} \) is the heat input into the metering box corrected for the heat flow through the box walls and the flanking loss, in W;
\( \Phi_{sur} \) is the heat flow rate through the surrounding panel in W;
\( \Phi_{edge} \) is the heat flow rate for the edge zone in W;
\( A_{sp} \) is the projected area of the test specimen in m\(^2\).

The overall thermal transmittance, \( U_m \), expressed in W.m\(^2\).K\(^{-1}\), of the test specimen is calculated using the formula:

\[ U_m = \frac{q_{sp}}{\Delta \theta_n} = \frac{19.208}{22.12 - 1.92} = 0.95 \text{ W.m}^{-2}.\text{K}^{-1} \quad (4) \]

where \( \Delta \theta_n \) is the difference between the environmental temperatures on the each side of the system during the test.

The measured thermal transmittance of the specimen, \( U_m \), is corrected for the effect of \( q \) on the total surface resistance, \( R_{st} \), to reach the standardized thermal transmittance, \( U_{st} \), in W/(m\(^2\).K), using standardized surface heat transfer resistances \( R_{si} = 0.13 \text{ m}^2.\text{K/W} \) and \( R_{se} = 0.04 \text{ m}^2.\text{K/W} \), and so for \( R_{(u),st} = 0.17 \text{ m}^2.\text{K/W} \):
The $U_{st}$ value considers the heat flow through the window, the effect of glazing centre, the edge effect of the glazing, the effect of support pillars and the heat flow through the frame structure.

8. The edge and support pillars effects

An edge effect is defined by linear thermal transmittance ($\Psi$ - value) in European standards [10]. It describes the additional heat conduction due to the interaction between the frame, glazing and spacer located around the edge of the glazing. The linear transmittance, $\Psi_g$, is mainly affected by the conductivity of the spacer material. The thermal transmittance of the glazing, $U_g$, is applicable for the central area of the glazing and it does not include the effect of the glass spacers at the edge of the glazing. On the other hand, the thermal transmittance of the frame, $U_f$, is applicable in case of the absence of the glazing.

The thermal transmittance of a single window $U_w$ is calculated based on formula (6):

$$U_w = \frac{A_g U_g + A_f U_f + l_g \Psi_g}{A_g + A_f}$$

where

- $U_g$ is the thermal transmittance the centre of the glazing;
- $U_f$ is the thermal transmittance of the frame;
- $\Psi_g$ is the linear thermal transmittance due to the combined thermal effects of glazing, spacer and frame;
- $l_g$ is the total visible perimeter of the glazing.

For vacuum glazing, edge effect is caused by the sealing of the solder glass. Moreover, support pillars have effect on the vacuum glazing heat flow. We can assume equation (7) instead of equation (6) for the combined effect of edge sealing and support pillars:

$$U_w = \frac{A_f \cdot U_f + A_g \left(U_g + \Delta U_g\right)}{A_f + A_g}$$

where $\Delta U_g$ is increase of heat flow due to the combined edge and pillars effects in W.m$^{-2}$.K$^{-1}$.

For measured values $U_w = 1.00$ W.m$^{-2}$.K$^{-1}$, $U_g = 0.50$ W.m$^{-2}$.K$^{-1}$ and $U_f = 1.286$ W.m$^{-2}$.K$^{-1}$ and for the visible area of glazing $A_g = 0.947 \times 0.545 = 0.516$ m$^2$ and for $A_f = 0.96 - 0.516 = 0.444$ m$^2$ we have:

$$\Delta U_g = \frac{U_w \left(A_g + A_f\right) - A_f \cdot U_f - A_g \cdot U_g}{A_f + A_g} = 0.254 \text{ W.m}^{-2}.\text{K}^{-1}$$

The value $0.254 + 0.50$ in W.m$^{-2}$.K$^{-1}$ is the heat flow through the glazing considering the support pillars and the edge of the vacuum glazing. This value is relatively high, and so interest was to test a deformation of the temperature fields around the support pillars and the edge of the vacuum glazing.

9. Conclusion

This document explores heat transfer through vacuum glazing which was installed in wood-aluminium frame with the known $U_f$ value. This value was estimated by measurement in a certified body. Heat flow through this type of glazing is influenced by several different processes, including: the heat transfer between the external glass surfaces and the environment; the residual gas conduction and the
radiation heat transfer between the internal surfaces of the glass sheets; the thermal conduction through the mechanical support pillars; and the lateral heat flow along the glass sheets in the vicinity of the edge sealing.

Two methods are described for measurement of the overall heat flow through the vacuum glazing. In the first method, measurements of total heat flow are made through a large area of window with vacuum glazing by hot box method with well defined boundary conditions. The $U_{st}$ value considers the heat flow through the window, with the effect of vacuum glazing, the edge of the glazing, the vacuum glazing support pillars and the window frame structure. In the second method, the local heat flow was measured through the glazing due to radiation and residual gas conduction in a small, pillar-free region with a specially designed heat flow apparatus. The $U_{g}$ value corresponds with the heat flow in the middle of the glazing without affecting of the support pillars. The deformation of the temperature field due to support pillars is surprisingly small and its range is from 0.20 K to 0.51 K with temperature difference on both sides of approximately 33 K. Decrease of internal surface temperature from the middle of glass to edge is about 18.92 °C – 12.37 °C = 6.55 K, and so it is considerable effect.

The effect of the edge on the glazing is not explicitly quantified in the term of heat flow in this paper, but is implicitly included in $U_m$ and $U_{st}$. Value 0.254 W.m$^{-2}$.K$^{-1}$ represents increasing heat flow through the glazing with respect combined effect of support pillars and of edge of vacuum glazing.

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