Thermal performance of hybrid vacuum glazing installed in the wood-aluminium frame

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Abstract. The current development in building energy efficiency towards nearly zero energy buildings (nZEB) represents a number of new challenges to design and construction. One of these major challenges is lowering the need for heating by means of highly insulated glazing units, unique glazing technologies, such as vacuum glazing (VG) or hybrid vacuum glazing (HVG). Hybrid vacuum glazing combines vacuum glazing with double glazing technology by adding one low-emissivity glass to the vacuum glazing using a thermally-improved spacer profile to eliminate the thermal bridge at the edge of the vacuum glazing. The gap between the vacuum glazing and the low-emission glass is filled with the inert gas Argon. The thermal performance of a hybrid vacuum glazing was tested using the guarded hot box method developed in accordance with the requirements of ISO 8990. Hybrid vacuum glazing has thermal transmittance about 0.43 W.m-2.K-1.

1. Introduction
Double or triple glazing with a sealed cavity containing air or inert gases and with internal glass surfaces coated with low-emittance (low-e) coatings have been widely used. However, gaseous heat conduction and convection with the glazing cavity restricts further improvement of the thermal performance U-value achievable. Quadruple glazing is rarely used mainly for high weight and high glazing thickness. Multiple glazing with three or more panes along with low-emission layers and gas with very low thermal conductivity (krypton or argon) can achieve thermal transmittance \( U_g \) below 1.0 W.m\(^2\).K\(^{-1}\) [1].

Vacuum glazing units (VG) are thought to be a type of glazing system with superior effective insulation performance. The concept of vacuum glazing was first introduced in 1924 by F. Zoller [2]. In 1995, T. M. Simko [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, 6]. Because of its high vacuity, VG has performed excellent heat insulation, anti-condensation, and sound insulation to the world. From the point of view of VG structure: the edge is soldered, and the middle area is separated by support pillars to become a vacuum chamber. As a result of the above structure, the thermal transmittance coefficient (U value) in the central area of the VG is far less than that its edge, and considering to practice in the reality, the heat transfer around the edge is associated with window frames material. The edge of the VG acts as a thermal bridge. Therefore, the U value in the central area of the glass is only measured for the sake of parameter comparability. U value of VG in the centre area is about from 0.5 to 0.7 W.m\(^{-2}\).K\(^{-1}\).
2. Hybrid vacuum glazing

The combination of VG and other low emissivity glass can further improve the mechanical, thermotechnical and optical properties of the VG [7]. Hybrid vacuum glazing (HVG) combines vacuum glazing with double glazing technology by adding one low-emissivity glass to the vacuum glazing using a thermally-improved spacer profile to eliminate the thermal bridge at the edge of the vacuum glazing.

The HVG as shown in Figure 1 is the combination of a conventional VG and a third glass sheet, separated by a gas filled cavity with an edge spacer bar and sealed with butyl rubber. In Figure 1, the vacuum gap is set facing the warm side.

![Figure 1. Hybrid vacuum glazing (HVG). a-low emissivity layer, b-cover wafer, c-getter, d-solder glass, edge seal of VG, e-vacuum layer, f-support pillar, g-Argon layer, h- thermally improved spacer, i-edge seal of double glazing](image)

At the Faculty of Civil Engineering of the Slovak University of Technology in Bratislava, we assembled a hybrid vacuum glazing using the vacuum glazing of the Asian producer Synergy and the low-emission glass ECLAZ of the product Saint Gobain.

The overall heat transfer through the HVG includes heat flow from the indoor side environment to the warm side glass sheet; radiation between the two glass surfaces bounding the vacuum gap and the argon filled gap; conduction through the pillar array within the vacuum gap and through the edge seal for both the vacuum gap and the air filled gap; heat transfer across the argon gap by convection and conduction; conduction across each glass sheet; and heat flow from the cold side glass pane to the outdoor side environment.

3. Window with hybrid vacuum glazing

Vacuum glazing was used in the office building window for two years from delivery. After two years, the stability of the declared parameters was verified and remained unchanged [8]. After two years, the vacuum glazing was installed in a hybrid vacuum glazing. The hybrid vacuum glazing was then installed in the wood-aluminium frame as is shown in Figures 2 and 3. A 578 x 978 mm hybrid vacuum glazing was installed in a wood-aluminium frame. The window is 800 x 1200 mm.

Thermal performance of hybrid vacuum glazing and window with hybrid vacuum glazing was tested by means hot box method.
4. Testing of thermal performance

The determination of steady-state thermal transmission properties was by means guarded hot box (GHB). This method is primarily intended for laboratory measurements of large, inhomogeneous specimen. GHB is intended to reproduce conventional boundary conditions of a specimen between two air, each at uniform temperature [9]. The specimen is placed between a hot and cold chamber in which environmental temperatures are known. Special inhomogeneous specimens (windows) need additional procedures included in ISO 12567-1 [10]. Measurement device used for a testing window with HVG was according to Figure 4. The metering box simulates the internal side and is constructed as a guarded hot box according to Figure 4. To control climatic steady-state conditions in the metering box, the transmitted energy is absorbed or removed by a heating and cooling system.

![Figure 2. Window with HVG](image)

![Figure 3. Window with HVG - section](image)

![Figure 4. Guarded hot box with a solar simulator. A – Cold box, B – Guard box, C – Metering box, D – Frame with the specimen, E – Solar simulator](image)
The aim of testing thermal performance was to determine the U value of the window with HVG, to determine the influence of the edge of the glazing of the HVG on the temperature drop and to determine the deformation of the internal surface temperature on the supporting distance profiles. The U value of HVG with the influence of support profiles was also determined.

5. Results and discussions

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 an air temperature difference $\Delta \theta = (20 \pm 2) \text{ K}$, which is recommended in [10]. Measuring thermal transmittance of HVG considers support pillars which are spaced in 40 mm in both directions (Figure 5).

\[ U_g = \frac{1}{\frac{1}{0.17 + \Delta \theta} / q} = \frac{1}{0.17 + 18.01 / 8.42} = 0.43 \text{ W.m}^{-2} \text{.K}^{-1} \]  (1)

Where $q$ is the density of the heat flow through sample HVG during the measurement in W.m$^{-2}$.

Thermal transmittance of HVG without influence support pillars was estimated for means surface temperatures on internal side $\theta_i = (20.55 + 20.23)/2 = 20.39 \text{ °C}$, and for external side $\theta_e = (2.40 + 2.36)/2 = 2.38 \text{ °C}$. Difference in the mean surface temperatures measurement with a steady temperature is $\Delta \theta = 20.39 - 2.38 = 18.01 \text{ K}$. Thermal transmittance of HGV with influence support pillars is $43.042.8/01.1817.0$.
support profiles in the HVG will increase thermal transmittance about 0.03 W.m\(^{-2}\).K\(^{-1}\). Thermal transmittance of the window with installed HVG is influenced by frame. The frame construction of the wood-aluminium window is based on the wooden profile IV88. Thermal transmittance of the wood-aluminium window with HVG was 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):

\[ R_{\text{si}} = 0.17 \text{ m}^2.\text{K.W}^{-1} \text{ in the guarded box and} \]

\[ R_{\text{se}} = 0.05 \text{ m}^2.\text{K.W}^{-1} \text{ in the cold box and therefore overall is } R_{\text{st}} = 0.22 \text{ m}^2.\text{K.W}^{-1}. \]

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

\[
q = \frac{\Phi_{\text{in}} - \Phi_{\text{sur}} - \Phi_{\text{edge}}}{A_{\text{sp}}} = \frac{23.30 - 3.52 - 3.6}{0.96} = 16.854 \text{ W. m}^{-2}
\]  

(2)

where \( \Phi_{\text{in}} \) is the heat input into the metering box corrected for the heat flow through the box walls and the flanking loss, in W;

\( \Phi_{\text{sur}} \) is the heat flow rate through the surrounding panel in W;

\( \Phi_{\text{edge}} \) is the heat flow rate for the edge zone in W;

\( A_{\text{sp}} \) 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:

\[
U_m = \frac{q}{\theta_i - \theta_e} = \frac{16.854}{21.99 - 1.93} = 0.823 \text{ W. m}^{-2}.\text{K}^{-1}
\]  

(3)

where \( \theta_i - \theta_e \) is the difference between the environmental temperatures on 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, \( R_{\text{st}} \), to reach the standardized thermal transmittance, \( U_{\text{st}} \), in W/(m\(^2\).K), using standardized surface heat transfer resistances \( R_{\text{si}} = 0.13 \text{ m}^2.\text{K/W} \) and \( R_{\text{se}} = 0.04 \text{ m}^2.\text{K/W} \), and so for \( R_{\text{(s,t)st}} = 0.17 \text{ m}^2.\text{K/W} \):

\[
U_{\text{st}} = \frac{1}{U_m^{-1} - R_{\text{st}} + R_{\text{(s,t)st}}} = \frac{1}{0.823^{-1} - 0.22 + 0.17} = 0.831 \text{ W. m}^{-2}.\text{K}^{-1}
\]  

(4)

The \( U_{\text{st}} \) value considers the total heat flow through the window: It includes the effect of HVG, the edge effect of HVG, the effect of support pillars and the heat flow through the frame structure.

Thermal irregularities of HVG was tested by means surface temperatures distribution from the middle to the edge. The temperature difference between the hot and cold side of HVG was 20 K for 22 °C inside and 2 °C outside. Internal and external surface temperatures were measured by PT100 sensors. They were spaced over HVG area located opposite on the hot and cold side (Figure 6). Support spacers have little effect on the internal surface temperature deformation of the HVG. It ranges from 0.01 to 0.22 K in the central area of the HVG. However, the deformation of the internal surface temperature between the center of the HVG and the edge of the HVG installed in the wood-aluminum window is significant. It is 20.34 - 16.93 = 3.41 K (Figure 7).
6. Conclusions
The hybrid vacuum glazing has excellent thermal insulation properties, better than the vacuum glazing itself. The measured value of HVG is 0.43 W.m⁻².K⁻¹ is also influenced by support spacers. Surprisingly, support spacers have little effect on the internal surface temperature deformation of the HVG. It ranges from 0.01 to 0.22 K in the central area of the HVG. However, the deformation of the internal surface temperature between the center of the HVG and the edge of the HVG installed in the wood-aluminum window is more significant. It is 20.34 - 16.93 = 3.41 K. The influence of the thermally-improved spacer profile (model swisspacer) installed in HVG did not completely eliminate the thermal bridge of the vacuum glazing formed by the sealing technology which uses the Indium strip at the edge of VG.

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