INFLUENCE OF PRESSURE EQUALISATION ELEMENTS ON THE QUALITY OF INSULATING GLASS UNITS

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Abstract: Continuous increase of expectations concerning improvement in quality of building partitions by means of increasing their thermal insulation properties brings, among others, a need of modification in standards that have been applied to the double glazed windows so far. Triple-glazed and quadruple-glazed IGUs are used more and more often. Such elements have better thermal properties, but they are more prone to deflection and stress resulting from climatic load, i.e. changes in temperature, atmospheric pressure and wind load. Due to the above certain concepts occurred that consist in equalising gas pressure in the gas-filled gaps with the atmospheric pressure. The article contains assessment of such solutions in the context of providing suitable technical parameters of glass panes: thermal insulation and susceptibility to climatic load. It was stated that the pressure-equalizing elements (capillaries) can result in a significant reduction in the quality of the glass partition in the event of the argon purging chamber or damage to the low-E emissions. The lower risk of using required thermal properties occurs when periodically active valves are used, they operate only in case of extreme pressure level differences. Further analysis concerned the idea of pressure equalisation between the gaps of a triple-glazed unit, as that can be done by using an edge spacer of appropriate design. On the basis of comparative analysis of static values it was shown that it is a reasonable solution. Such a unit maintains the properties of a tight unit, while the possibility of gas exchange between the gaps leads to relief of the central glass pane in the unit, thus allowing for decreasing its thickness to 2 mm.

Keywords: quality of building products, insulating glass units, pressure, thermal insulation

1. INTRODUCTION

One of the production engineering objectives is to improve the quality of products as the expectations of the end users grow and the relevant legal requirements are increased (Kaźmierzak, 2013; Sygut, 2013; Ligarski, 2017). In many cases, there is a need to change the long-established quality standard of the product. Sometimes it is necessary to add new element and equip the product with new functional properties. There are many widely known examples of such operations in multiple fields of technology (Sitko and Michalski, 2015; Jakubowski and Crasto, 2016).

Insulating glass units are commonly used elements of window structures and other transparent building partitions. The goal of using such a structure is to improve the thermal insulation of a glass partition, achieved by filling a tight gap with gas (Van Den Berg et al., 2013) of lower thermal transmittance than air (usually with argon) and applying a low-E coating to reduce radiation heat loss from the inside (Fig. 1). However, such a structure presents certain specific properties related to transfer of climatic load. Due to periodical changes of atmospheric pressure and temperature the gas closed in a gap changes its parameters, pressure above all, leading to loading of the component glass panes, that deflect in a characteristic way (Fig. 2, 3) and are subject to stress. The stress may lead to depressurising of the unit at the edges or even to crack of a component glass pane. However, maintaining a tight gap is beneficial with regard to the wind load. If the chamber is not tight, the total external load acts on one component glass pane. In a tight unit the changes of gas pressure inside the gap allow for distribution of external load on both glass panes in the unit, which is beneficial.

Due to the increased interest in energy-saving and passive buildings as well as higher requirements concerning the thermal protection of residential and public buildings (Repelewicz, 2014; Jura, 2016) triple-glazed and quadruple-glazed units are used more and more frequently. Larger number of gas-filled gaps means increased total value of gas-filled gaps thickness, and that, in turn, causes increased values of deflection and stress related to climatic load (Hardtke, 2016).

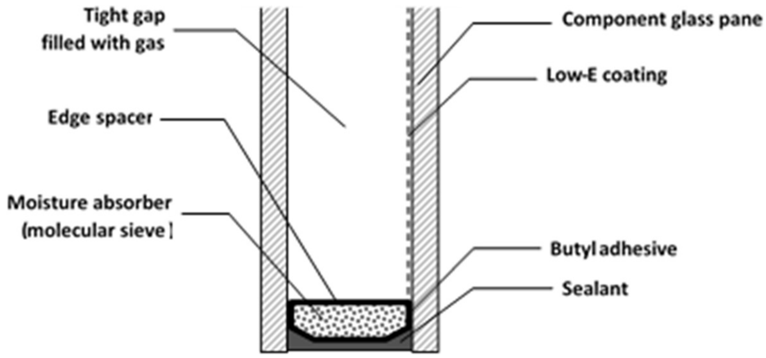

Fig. 1. Scheme of double-glazed IGU structure

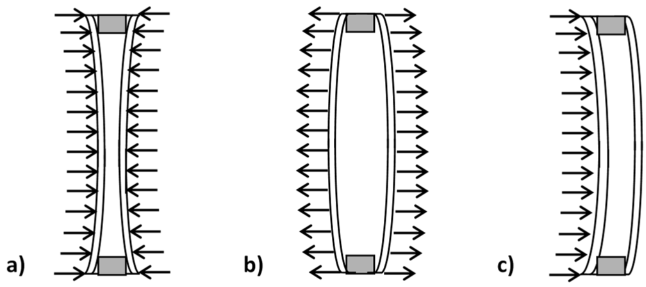

Fig. 2. Typical deflections of insulating glass units: a) increase of atmospheric pressure or decrease of gas temperature in the gaps, b) decrease of external pressure or increase of gas temperature in the gaps, c) wind pressure

a) b)

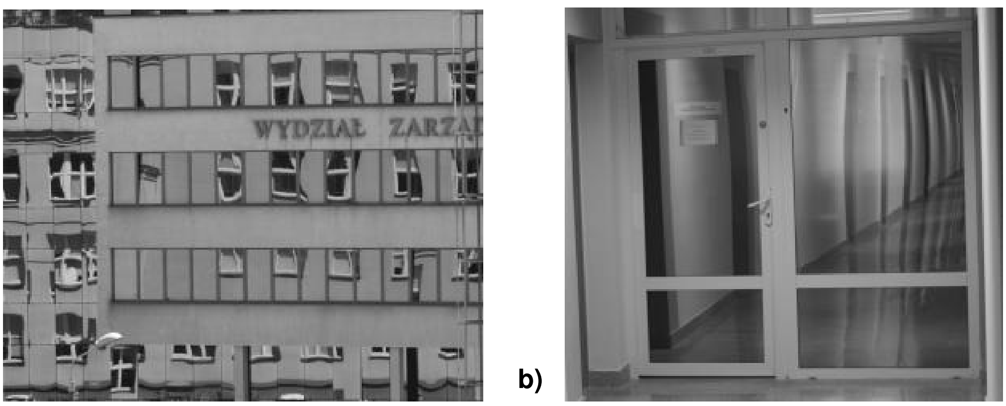

Fig. 3. Deformation of image reflected by glass panes: a) glass facade, c) glass partition wall

In recent years, attempts have been made to apply pressure equalizing elements (devices) in the compartments of insulating glass units in order to minimize the effects of the described loads.

The analysis described herein aims at assessment of reasons to use those elements with respect to maintaining appropriate quality of technical parameters of insulating glass units, that is their thermal insulation properties and susceptibility to climatic load.
The calculations of the thermal transmittance factor were carried out in accordance with the methodology presented in (PN-EN 673:2011), static values were determined on the basis of own calculation model described in (Respondek, 2016), allowing for estimation of operational pressure in the insulating glass units with any number of gas-filled gaps as well as on the basis of general formulas in the theory of plates and shells (Timoshenko and Woinowsky-Krieger, 1962).

2. CLIMATIC CONDITIONS FOR USE OF INSULATING GLASS UNITS

Equalising of gas pressure in gaps of insulating glass units with atmospheric pressure may take place one time or in a continuous manner.
Single pressure equalising is justified if the average climatic conditions (atmospheric pressure, temperature) varies significantly in final destination of IGUs from the conditions in the production location. The loads on insulating glass units result, above all, from the gas laws:

$$\frac{p_e \cdot v_e}{T_e} = \frac{p_0 \cdot v_0}{T_0} = \text{const} \tag{1}$$

where:
p_o, T_o, v_o - initial parameters of gas in the gas-filled gap obtained during production process: pressure (kPa), temperature (K), gap volume (m^3);
p_e, T_e, v_e - operational parameters of gas in the gap -respectively.

The loads on glass panes may also be related with the local atmospheric pressure, which drops as the height above the sea level increases, in accordance with approximate dependence (Feldmayer, 1996)

$$\Delta p_a = -0{,}012 \cdot \Delta h_m \tag{2}$$

where:
Δp_a - increase of atmospheric pressure (kPa);
Δh_m - increase of height above sea level (m).

The loads may also result from changes of temperature. The calculations made by the author have shown that an increase of temperature by 1 K induces a load analogical to a drop of atmospheric pressure by 0.341 kPa.
The pressure equalization after transport to the operation location allows for quick release of the load acting on the glass panes and establishing new initial conditions of gas pressure and temperature (p_0, T_0) - understood as a state without any load acting component glass panes, adequate to the local conditions, influencing favourably further use of glass panes.
Attention should be given to the possibility of partial self-adaptation of gas initial parameters to the local operational conditions. The connections on the edges of component glass panes are not completely tight in the long-term perspective. Sealants used in IGUs production are permeable to argon and water vapour, that concerns especially silicone sealants commonly used in structural facade glazing. Silicone sealants are much more permeable to such gases than polysulphides or polyurethanes (Wirpsza, 2010).

3. CONTINUOUS AND PERIODICAL PRESSURE EQUALIZATION

There are two methods of equalising pressure during the operation of IGUs: either continuously with capillary tubes or periodically by means of valves (Sack and Rose, 2014; Rose, 2017; Vetrotech Saint-Gobain AG, 2016). These elements may be installed in the edge spacer.

The capillaries are thin tubes that provide continuous but very slow gas exchange. The pace of such exchange depends on momentary difference of pressure between the chamber and the environment, on internal diameter and length of a capillary tube (the length of a capillary tube may be increased by incorporating it into the sealing material) as well as on the structure of the insulating glass unit. Pressure equalisation by the capillary tubes is a process that has a certain inertia over time, the loads on component glass panes are not completely eliminated, however their amplitude is significantly smaller than in the case of tight gas-filled gaps. It may be assumed that momentary values of the initial parameters (p_0, T_0) oscillate, in a long-term perspective, near certain values resulting from the climatic conditions in the installation location.

Valve are a spot elements operating on basis of two-way pressure relief valve. The valves open when the difference of pressure between the gap and the environment increases to the values "programmed" as hazardous. During the time the valve is open the gas initial parameters (p_0, T_0) settle at safe level, thus preventing excessive deflection and stress in the component glass panes.

The main disadvantage of pressure equalisation in the gas-filled gaps is the loss of argon in the gaps of an insulating glass unit. Argon is replaced with air, that causes decrease of glass pane insulation properties. With regard to longer service life, it is doubtful if the IGUs should be filled with argon at the production site. Another unfavourable factor may be introduction of excessive quantities of water vapour to the gas-filled gaps during the use of an IGU. There is a risk of water vapour condensation on internal surface of a glass pane leading to low-E coating corrosion. Possible influence of those unfavourable factors on the thermal transmittance/U value of IGUs is presented in Table 1. The assumptions for calculations were following: gas-filled gaps thickness 16 mm and vertical arrangement of glass panes. Values in brackets designate percentage of increase of the U value related to an IGU filled with argon and having correctly functioning low-E layers.

Table 1
Thermal transmittance (U-value) for various structures of IGUs, description in the text

Structure	U value [W/m²K]		
	Filled with argon, Low-E coating	**Filled with air, Low-E coating**	**Filled with air, no Low-E coating**
Double-glazed	1.10	1.37 (25 %)	2.72 (147 %)
Triple-glazed	0.56	0.76 (36 %)	1.76 (214 %)
Quadruple-glazed	0.38	0.52 (37 %)	1.31 (246 %)

Based on the calculations carried out, it was demonstrated that the loss of argon from the gas-filled gaps can result in significant increase of heat loss through glass panes, while in the case of loss through the glass, and in the case of loss of low-emission layers, these losses can be more than doubled. Due to the above it is recommended (Rose, 2017) to increase the amount of drying agent so that its amount was sufficient for the assumed service life of a glass pane, e.g. for 25 years, although it means a higher edge spacer height and increased unit weight. It is also possible to close the capillary tubes before installation of a glass pane – in such case we are dealing with a one-time pressure equalisation.

With regard to the limitations described above, it seems that use of valves makes more sense than the capillary tubes. The valves are closed in the range of pressure levels considered as safe, in consequence the gas exchange between the gap and the environment is lower than in case of capillary tubes.

4. PRESSURE EQUALISATION BETWEEN THE GAS-FILLED GAPS IN AN IGU

Recently, another solution to the analysed problem appeared, it is an edge spacer under commercial name Swisspacer Triple (Swissspacer, 2018). This edge spacer is shaped as horizontally rotated letter B and it is designed to join glass panes in a triple glazed unit in such a way that the central pane is wedged in a notch between the elements of the spacer, while the connection between the spacer and the glass pane is not tight (Fig. 4).

Fig. 4. Edge spacer allowing for gas exchange between the gaps (Swissspacer, 2018)

This way it is possible to equalise pressure in the gas-filled gaps of an IGU, however the gas exchange between the gaps and environment is impossible. Such structure aims at elimination of pressure difference load acting on the central glass pane and, at the same time, allowing for decrease of central glass pane thickness to 2-3 mm.

Table 2 presents static values calculations (resultant load, deflection, stress) for an exemplary IGU with central glass pane 2 mm thick and external glass panes 4 mm thick. Assumed thickness of gas-filled gaps is 16 mm and the total unit dimensions are 80 x 120 cm. Static values in a unit with tight gaps and in a unit with equalised pressure were compared. Following climatic load values were analysed:

- wind pressure of 0.3 kN/m^2,
- increase in temperature in the gaps by 20 K (drop of atmospheric pressure by 6,86 kPa brings similar effects),
- linear drop in temperature: external air temperature -20 ℃, room temperature 20 ℃, intermediate values of temperature in the gaps.

Table 2
Static values for triple-glazed unit 4-2-4 with dimensions 80×120 cm

Load	Glass pane	U value [W/m^{2}K]					
		Tight gaps			Equalised pressure		
		Load, kN/m^2	Deflection, mm	Stress, MPa	Load, kN/m^2	Deflection, mm	Stress, MPa
Wind pressure 0,3 kN/m^2	ex	0.148	**1.20**	**2.78**	0.157	**1.26**	**2.97**
	cen	0.018	1.15	1.33	-	-	-
	in	0.134	1.09	2.53	0.143	1.16	2.72
Temperature increase by 20 K	ex	-0.304	**-2.45**	**5.67**	-0.304	**-2.45**	**5.67**
	cen	0.000	0.00	0.00	-	-	-
	in	0.304	2.45	5.67	-0.304	-2.45	5.67
Linear drop in temperature	ex	0.314	**2.56**	**5.92**	0.306	**2.47**	**5.80**
	cen	-0.019	-1.21	1.40	-	-	-
	in	-0.296	-2.41	5.57	-0.306	-2.47	5.80

Table 3
Static values for triple-glazed unit 6-2-4 with dimensions 80×120 cm

<table>
<tr><th rowspan="3">Load</th><th rowspan="3">Glass pane</th><th colspan="6">U value [W/m²K]</th></tr>
<tr><th colspan="3">Tight gaps</th><th colspan="3">Equalised pressure</th></tr>
<tr><th>Load, kN/m²</th><th>Deflection, mm</th><th>Stress, MPa</th><th>Load, kN/m²</th><th>Deflection, mm</th><th>Stress, MPa</th></tr>
<tr><td rowspan="3">Wind pressure 0.3 kN/m²</td><td>ex</td><td>0,230</td><td>0,55</td><td>1,92</td><td>0,236</td><td>0,56</td><td>1,99</td></tr>
<tr><td>cen</td><td>0,008</td><td>0,53</td><td>0,61</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>in</td><td>0,062</td><td>0,50</td><td>1,17</td><td>0,064</td><td>0,52</td><td>1,21</td></tr>
<tr><td rowspan="3">Temperature increase by 20 K</td><td>ex</td><td>-0,468</td><td>-1,13</td><td>3,92</td><td>-0,457</td><td>-1,09</td><td>3,85</td></tr>
<tr><td>cen</td><td>0,019</td><td>1,26</td><td>1,46</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>in</td><td>0,449</td><td>3,65</td><td>8,45</td><td>0,457</td><td>3,69</td><td>8,67</td></tr>
<tr><td rowspan="3">Linear drop in temperature</td><td>ex</td><td>0,487</td><td>1,17</td><td>4,07</td><td>0,461</td><td>1,10</td><td>3,89</td></tr>
<tr><td>cen</td><td>-0,039</td><td>-2,52</td><td>2,92</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>in</td><td>-0,448</td><td>-3,65</td><td>8,44</td><td>-0,461</td><td>-3,72</td><td>8,75</td></tr>
</table>

Static values were estimated for each of the component glass panes (ex - external glass pane in contact with outside air, cen – central glass pane, in – internal glass pane on the room side). In case of load and deflection positive value determine direction to the inside (from left to right, as in Fig. 2c). Extreme values of deflection and stress in individual units with specific load were omitted.

Table 3 presents the results of respective calculations for a unit with external glass pane (ex) thickness increased to 6 mm.

On the basis of presented calculations it was demonstrated that the benefits of pressure equalisation between the chambers in operational conditions are visible in case of non-symmetrical loads and in case of various thickness of external glass panes.

In tight units the external glass panes, that are more rigid, bear greater part of the load, but even a small load on central glass panes with thickness reduced to 2 mm results in significant deflection (its value exceeding the glass thickness) and stress.

Pressure equalisation provides relief of the central glass pane without a significant increase of the static values of external glass panes, which is beneficial. Visible stress increase in external glass panes occurs with load of temperature change in a unit 6-2-4, however it is not a significant increase.

Obviously, in real units the equalisation of pressure doesn't happen immediately. An assumption can be made that in case of strong, variable gusts of wind the central glass panes are not completely relieved, thus the units 4-2-4 and the like must be used reasonably in locations exposed to strong wind load.

3. CONCLUSIONS

The increase of requirements concerning thermal protection of buildings creates the necessity to leave the standard double-glazed units commonly used so far. The ideas presented in this article are an attempt to solve a problem of reduction of effects of potentially hazardous climatic load acting on insulating glass units under operational conditions. This problem is particularly important in the case of quadruple-glazed and quintuple-glazed insulating glass units due to the large deflection and stress occurring in such IGUs. It was shown that using elements allowing for equalising gas pressure inside the gas-filled gaps in a unit with the atmospheric pressure can result in lower quality of glazing, that is to worsening of its thermal insulation properties. That applies in particular to the use of capillary tubes, i.e. elements that equalise the pressure in a continuous way. Pressure equalisation, connected with quick argon loss and a risk of damage to the low-E coating are not justified in the context of significant increase of heat loss. It justified, however, to use valves working as a pressure relief valves, that equalise the pressure only in case of extreme loads acting on a partition and putting it under a risk. Performed analysis has also proven that improvement of quality in triple-glazed insulating glass units may be obtained by using edge spacers that provide a possibility to equalise pressure between the gas-filled gaps. Such a structure maintains the advantages of a tight IGU and, at the same time, relieves the load on the central glass pane in a unit, thus allowing for decrease in its thickness even up to 2 mm.

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