Partial Rarefaction as Way to Reduce Distortion Curve of double-glazed unit

Alexander Plotnikov

1 Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: plaa@zmail.ru

Abstract. Use of Insulated Glass Units (IGU) as glazing on building façades causes optical distortions of mirrored images of neighboring buildings in glazed surfaces. Optical distortions are caused by varying distances between glass panes in IGUs as a result of climate factors. This paper examines available engineering solutions that reduce such distortions: use of more rigid outer glasses, encasing the building in a shell of single glass panes, known as the ‘double façade’, and use of vacuum IGUs. A new way is proposed to reduce optical distortions by installing additional pointed or linear supports and creating pre-stress with partial rarefaction inside the IGU. Overpressure that can cause IGU expansion and glass deformation was calculated. In the urban environment of Moscow, reduction of air pressure with simultaneous increase of air pressure inside the IGU during summer heat waves can be as high as 5%, and this figure determines the level of rarefaction.

1. Introduction

Use of IGU double-glazing instead of separate windowpanes has created an ugly architectural problem of distorted surrounding in the glass surfaces of the all-glass façade. Such buildings are unattractive (see Figure 1, 2, 3).

Unfortunately, this is not regarded as a relevant architectural problem today, although it is an important architectural factor, for example, on modern construction projects in historical urban areas [1-5]. Optical distortion on deformed glass surfaces ruins the building’s architectural appearance. Glass must become the architect’s controlled tool used to shape a modern building’s image [6, 7].

Optical distortions are caused by deformation of the outer glass in an IGU (curved glass surface), due to the nature of IGU as an airtight box. It should be noted that distortions are defined not by an deflection (deflection size to flight length), and the radius of curvature of the bent glass, as at a negative and positive deflection.

The more curvature radius, the less distortions. The phenomenon is visible virtually everywhere as convex or concave glass surfaces [8, 9].
Figure 1. (photo by authors)

a) Strong visible optical distortion on the swimming pool façade with small IGU
b) Optical distortion on glass façade – Bank building in Rosenheim, Germany,
c) Optical distortions on glass façade: ‘Russian Standard’ office and warehouse center in Moscow

2. Materials and Methods

The IGU is a 3-dimensional product made of two or three glass sheets that are joined with profile frames on the outline. After assembled the product is made tight around the outline to create closed airtight boxes that trap the air from the room where they are manufactured (Figure 2). Desiccant is added into the frame space to reduce humidity of the air inside.

Figure 2. Single-box IGU design: 1 – glass; 2 – spacer frame; 3 – inner space of spacer, filled with desiccant; 4 – soft sealant; 5 – hard sealant; 6 – air space (distance between panes); 7 – drying holes (perforation)

IGU glasses get deformed by the so-called climate load factor that is created by the pressure difference in and outside of the IGU box [10, 11]. The two pressures are balanced by deformation of glass that is flexible and unable to resist. As glasses deflect, pressure levels out and most of the load disappears. In this way, deflection compensates the load by changing the volume of air in between the glasses. The thermodynamic state establishing connection between the internal pressure, temperature and volume of gas in a double-glazed window is described by the known equation of ideal gas of Mendeleyev-Klapeyrona:

\[
\frac{P_1}{P_2} = \frac{V_1}{V_2}
\]
where $P_1, V_1$ – initial condition of gas in the IGU (when it was manufactured and made airtight); and $P_2, V_2$ – condition of gas inside the IGU at the given moment in time.

Outdoor pressure changes are the result of atmospheric pressure changes and the window’s geodetic elevation. Changes of pressure inside are caused by the temperature of air inside the IGU. The climate factor changes continuously throughout the year cycle, and thus causes changes of glass deformation and its distortion curvature.

There is a number of ways to reduce or completely get rid of optical distortion on a glass façade. The first way is to use more rigid glass on the outside (Figure 3). The greater is the difference in the rigid characteristics of the inner and outer glasses, the less will the outer glass be deformed. The more flexible inner glass makes up for the climate factor. This approach can reduce the curvature of the outer glasses only to a certain extent [5].

![Figure 3. Using more rigid glass on the outside](image)

The second way is to encase the building in a single-glass shell that protects the façade of airtight IGUs. Single glasses are indifferent to the climate factor, and therefore interior deformations of the IGU are not visible on the façade (Figure 4). This is known as the ‘double façade’. It radically resolves the problem of optical distortion, but also brings numerous new troubles and is a major cost driver. This is how façades look in warm climates where single-pane glazing is good enough.

![Figure 4. Double façade](image)

The third way is to use a vacuum IGU. This completely solves the problem of IGU distortion curvature, as this is practically a solid the design consisting of two glasses and an airless layer less than 1 mm thick in which support in the form of glass elements are established (Figure 5) However, vacuum IGU manufacturing is a highly complex and expensive technology, and such windows have not become widely used at this time.
In article the new way of a solution - creation of partial rarefaction inside the IGU is offered, compensating greatest possible expansion responding to negative climate factors in any season (see P.V. Stratiy, A.A. Plotnikov. “IGU Manufacturing Method”, utility patent No. 2530857. Patent FGBOU VPO MGSU. Registered: 19.08.2014).

To absorb the resulting loads, extra supports must be installed between the panes. Distances between the supports depend on the minimum permissible deformation from the esthetic point of view considering the greatest climate loads in the specific area. This is how the principle of the design is close to that of the vacuum IGU, but here rarefaction is a mere 5-10 kPa, whereas true vacuum technology needs to create a pressure drop of 10-3 kPa and more. Pre-stressed IGU is the simplest and most reliable way to deal with the problem. Its disadvantage is that extra pointed or linear supports need to be installed in the space between the panes (Figure 6).

Added extra supports can reduce deformation only if the IGU is compressed. If it is expanded, the supports become inactive and the panes are free to deflect. In order to prevent such deflection, compression (rarefaction) should be at least equal to the greatest climate load. Distances between supports get out of a condition of the minimum deflections, admissible of esthetic reasons, at maximum climatic load in this concrete area.

3. Measuring the Climate Load
To calculate the necessary extent of rarefaction, we need to know the greatest adverse climate load in the specific construction climate area. Calculations below assume the climate conditions in the city of Moscow.

We can isolate three critical factors contributing to the climate load:
- changing outdoor air temperature;
- changing atmospheric pressure in general;
- changing atmospheric pressure depending on altitude.
We find the climate load as:

\[ P_0 = \pm 0.0045 \cdot \Delta T \pm P_a - 0.0016 \cdot \Delta h \text{ (kPa)} \]  

(2)
where

\[ P_0 \] – pressure in the air chamber of IGU, kPa;
\[ \Delta T = T_i - T_{pr} \] – difference of temperatures inside the IGU air chamber immediately after manufacturing and at this time, °C;
\[ \Delta P_{\text{met}} = P_t - P_{pr} \] – difference of atmospheric pressures during manufacturing and at this time, kPa;
\[ \Delta h = h_i - h \] – ASL elevation difference between the place of IGU operation and the place of its manufacturing, m.

Inputs considered the following. Air temperature inside the IGU assumed low thermal inertia of the IGU. IGU is installed in an unheated building; IGU installed in a building on the 10th level (30 m above ground), terrain elevation drop is 140 m; total ASL elevation drop is \( \Delta h = 170 \) m. Calculation inputs are given in Table 1, results are in Table 2.

### Table 1 Calculation inputs

| Parameter                | Manufacturing | Operation conditions |
|--------------------------|---------------|----------------------|
|                          |               | Summer               | Winter               |
| Temperature, °C          | +20           | +40                  | -40                  |
| Atm pressure, mercury    | 750           | 720 - 780            | 720 - 780            |
| ASL elevation drop, m    | 120           | 290                  | 290                  |

### Table 2 Calculation results

| Season  | Pressure drop depending on, kPa | Total pressure drop |
|---------|---------------------------------|---------------------|
|         | Atmospheric changes | Air temperature | Elevation |                  |
| Summer  | + 4                           | -0.9               | -0.27     | +2.83             |
|         | - 4                           | -0.9               | -0.27     | -5.17             |
| Winter  | + 4                           | +2.7               | -0.27     | +6.43             |
|         | - 4                           | +2.7               | -0.27     | -1.57             |

Sign “–“ pressure outdoors decreasing, IGU expanding

4. Discussion

Results of calculations show that for conditions of Moscow the size of climatic loading is defined more by change of atmospheric pressure. So if the IGU is made with an average atmospheric pressure (this size for Moscow can be accepted equal 750 mm.r.st.) that maximum expanding and squeezing pressure both in the winter, and will be identical in the summer that in this measurement makes \( \pm 4 \) kPa. If the IGU is made with a low or high atmospheric pressure, then climatic loading can increase twice. The size of climatic loading connected with change of air temperature, in the winter much more, than in the summer. It is clear as air temperature at production of a double-glazed window is always defined by temperature after manufacturing.

However terrestrial climatic loading squeezes a double-glazed window, and summer creates expansion. In our case it is necessary to compensate the expanding loading which can lead to a curve of glasses, and, according to increase of optical distortions. Apparently from calculations, the maximum expanding climatic load works in the summer and is equal to 5.17 kPa. For compensation of this loading it is necessary to create discharge about 5.2% from normal atmospheric for this area. For a resistance this power of this loading it is necessary to establish additional dot or linear support in interglass space. Predesigns showed that distances between support can make 25 - 50 cm depending on thickness and characteristics of glasses, the IGU sizes.
5. Conclusions
1. Optical distortions of glass facades are connected with application of tight IGU. For decrease in distortions there are several options of a solution:
   • use of more rigid external glasses in IGU;
   • creation of an external cover of buildings from an unary glazing;
   • application in designs of facades of vacuum IGU;
2. Designs of preintense IGU due to partial discharge of air in a double-glazed window which allow to avoid deformation of glasses at change of climatic loading both in the summer and in the winter are offered.
3. In the conditions of Moscow the maximum expanding climatic load, at the correct production of double-glazed windows, works in the summer and is equal to 5.2 kPa. For compensation of this loading it is necessary to establish separate dot support or tapes in interglass space and to create the corresponding preliminary discharge.

References
[1] Plotnikov A 2015 Vestnik MGSU 11 pp 7-15
[2] Plotnikov A, Boriskina I and Stratiy P 2011 Zhilishchnoe stroitelstvo 4 Pp 33 – 36
[3] Stratiy P 2011 Zhilishchnoe stroitelstvo 4 pp 33–36
[4] Stratiy P 2013 Magazine of Scientific review 9 pp 185-189
[5] Nazmeeva T V and Vatin N I 2016 Magazine of Civil Engineering 62 (2) 92-101 DOI: 10.5862/MCE.62.9
[6] Derbina S, Boriskina I, Plotnikov A 2011 PGS 11 pp 56-59
[7] Stratiy P and Luchkin E 2016 PGS 4 pp 54-58
[8] Plotnikov A and Stratiy P 2013 Magazine of Scientific review 9 pp 190 - 194
[9] Pukhkal V 2015 Procedia Engineering, 117, pp 616-623, DOI: https://doi.org/10.1016/j.proeng.2015.08.222.
[10] Priadko I N, Mushchanov V P, Bartolo H, Vatin N I and Rudnieva I N 2016 Magazine of Civil Engineering 65 (5) 27-41 DOI: 10.5862/MCE.65.3
[11] Jevric M and Romanovich M 2016 Procedia Engineering, 165, 1478 – 1482, doi: 10.1016/j.proeng.2016.11.882.