Double-glazed units with higher stiffness

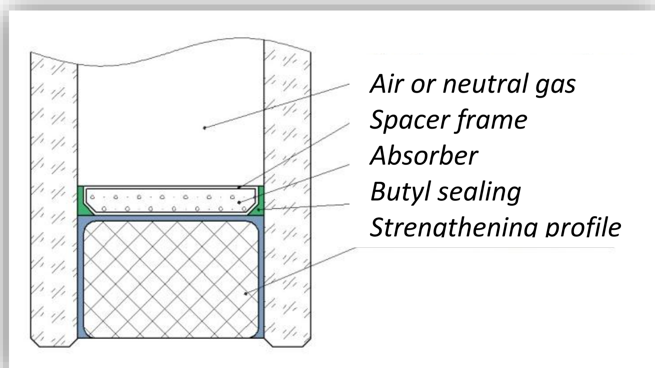
Based on their own engineering design developments and prepared calculations proved by a series of tests and tests protocols from leading organizations in the area of certification of translucent structures, the group of specialists from the company “Designs of Engineering Consulting Group" is offering a universal solution allowing, to a large extent, to architects to remove restrictions for and improve operational characteristics of translucent systems based on large-format glazing.
The proposed solution is based on the double-glazed units with higher stiffness production technology (DGUHS) that uses composite spacers made of pultruded profiles (pultrusion is a method of making fiberglass by pulling a prestressed glass fiber impregnated with resin through a forming unit) and the methods developed for their fixing to various type of facades and dome glazing.

Design features of double-glazed units with higher stiffness

What is a double-glazed unit with higher stiffness? Everyone knows that a double-glazed unit used for facade glazing must withstand temperature and wind loads, in addition to its architectural and heat protection functions. Every time when you design a facade glazing you should think about a formula of double-glass units, in other words – what thickness of glass should be used in your double-glazed units? It is assumed that only the outer glass is affected by wind load (in terms of load-carrying capacity, interior glasses are "parasitic" and serve only to affect thermal and physical characteristics of double-glazed unit), and if it is fixed to all sides of the double-glazed unit, that assumption is true. We are solving this problem by using formulas listed in catalogs and the guidance for calculation of standard mullion-transom systems.

The idea of double-glazed units with higher stiffness is to get those “parasitic” internal glasses to participate in the joint resistance to a wind flow in facade structures or snow load, which is pertaining to dome systems.

In other words, the challenge is to transform an ordinary double-glazed unit from a “sandwich”, in which the glasses may move relatively free along each other in the plane of the unit, into a tubular one when the glasses are firmly glued together through a strengthening spacer which is based on profile composite solutions and special highly adhesive compositions.



Thus, the structural strengthening of the unit stiffness is designed by modification of a typical double-glazed unit by replacing the secondary containment with tightly glued composite profile of rectangular cross section.

The technology of production of double-glazed units with higher stiffness requires certain additional costs, but it allows us to have a significant increase in stiffness which, in turn, enables to reduce the thickness of used glasses or significantly expand the dimensions of glazing fragments.

The materials used for double-glazed units with higher stiffness, as well as the double glazed units as a whole, must meet the following requirements:

- Tightness of double-glazed unit - no penetration of gases, water vapor and water.

- Durability of double-glazed unit – up to 40 conventional years of operation.
- Resistance of double-glazed unit to the heating of up to 80°C with relative humidity of up to 100%.
- Resistance of double-glazed unit to cooling to – up to 50°C.
- Tolerance of double-glazed unit to ultraviolet irradiation at wavelength range of 280 - 400 nm with intensity of 80 W/m^2 and at temperature of up to 50°C.
- Resistance of double-glazed unit to saline solutions of 50°C (3% aqueous solution of NaCl) at solution temperature of 20°C.
- Resistance of double-glazed unit to alkaline solutions (3% aqueous solution of NaHCO3) at solution temperature of 20°C.
- Resistance of double-glazed unit to acidic solutions (3% aqueous solution of H2SO4) at solution temperature of 20°C.
- Ecological purity of double-glazed unit - no toxic substances in the unit.
- Resistance of double-glazed unit to oxygen and ozone.
- Tolerance of double-glazed unit to infrared radiation.
- Resistance of double-glazed unit to macro-and microbiological exposure (insects or fungi).

Additionally, the following spacer requirements should be mentioned:

- Coefficient of spacer frame thermal conductivity ~ 0.4 W/(m ^{0}C).
- High adhesion to glass - no less than $2*10^8 N/m^2$ (200 MPa).
- Modulus elasticity of frame material - at least $1x10^8$ N/m^2 (300 MPa) or no more than 3x109 N/m^2 (3,000 MPa).
- Maximum strength of at least $2*10^7$ N/m^2 (20 MPa).
- Resistance of spacer to silicone seals.
- Adhesion of stiff spacer to silicone seals.

With regard to double-glazed units with higher stiffness, we need to pay attention to such a seemingly insignificant requirement as the resistance to heating and cooling. The implicit threat to the DGUHS integrity is a difference between the coefficients of glass and spacer linear expansion.

It is fair to say that similar problems, to a greater or lesser degree, exist in standard double-glazed units that are produced on aluminum and PVC spacer frames, particularly when they are used in structured and semi-structured large format facade systems.

For example, a DGUHS with dimensions of 2,5x1,7m was made in winter time at the workshop where the temperature was +20°C, then it was taken to the place of assembly by an open truck at the outside temperature of -20°C. Thus, the temperature difference was 40°C. Under those conditions, the glass would change its size along the long side by 0.72 mm, the pultruded spacer (consisting of 80% glass fibers – "roving") – by 0.70 mm, the spacer made of ultraviolet (UV) curable acrylic filler – by 18.72 mm, and the epoxy resin spacer – by 4.4 mm. Typical spacer frames made of aluminum and PVC would change their sizes by 4.00 mm and 1.76 mm respectively.

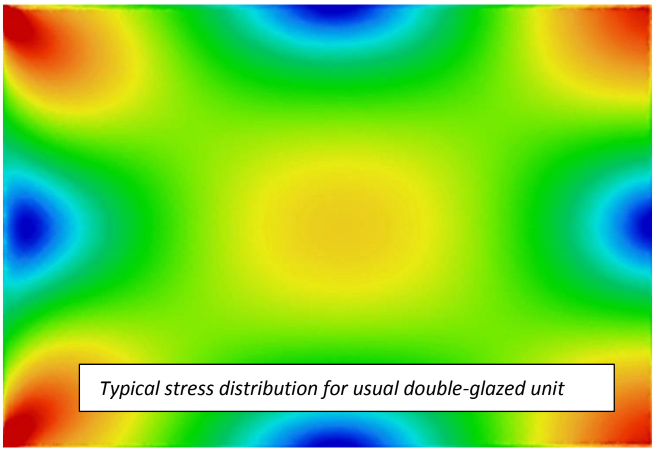
The conclusions suggest themselves - those significant variations in the size of glass and material of spacer frames, when they are used for a long time, lead to sealing leakage and worsening of bearing capacity of glass. The only exception is the strengthening pultruded spacer, the coefficient of linear expansion of which is as close to the glass.

However, the use of materials with high coefficients of thermal expansion is possible in the design of double-glazed unit under specified temperature conditions of production, transportation, installation and operation (e.g. - indoors).

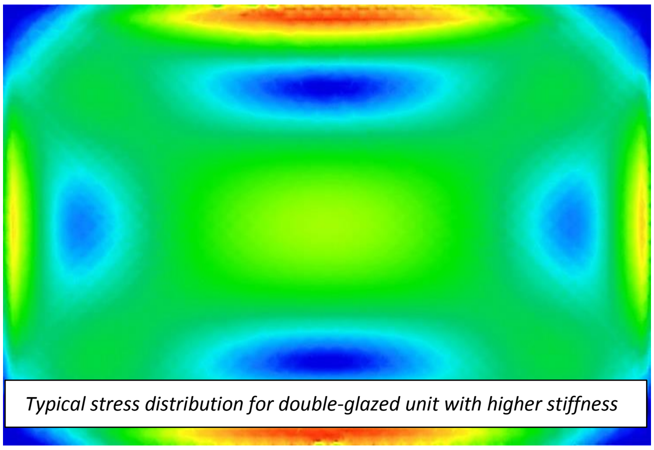
It should also be noted that, despite the added material and labor intensity in the manufacture of DGUHS, their use in large-format facade glazing is economically feasible.

Consider the following example. Suppose that you want to mount a double-glazed unit which withstands the wind load of 60 kg/m^2 and has the dimensions of 2.5x1.7m into a mullion-transom structure. These requirements were met by a typical 10M1-18-8M1double-glazed unit (weight: 191kg.) or by a double-glazed unit made using the technology of glued pultruded profile, which formula is 6M1-18-5M1 (weight: 117kg). It is 1.6 times lighter than the typical unit. In this case, the use of the typical double-glazed unit requires reinforced transoms, while the use of the double-glazed unit does not require such reinforcement.

The nature of the stress distribution in the glasses varies widely: the typical unit has its corner zones more loaded, while marginal zones are more loaded in the DGUHS.



Typical stress distribution for usual double-glazed unit



Typical stress distribution for double-glazed unit with higher stiffness

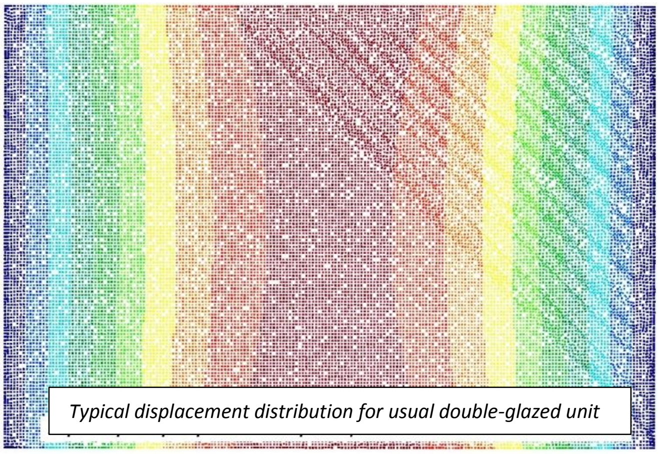
Consider another example. Suppose that you need to install double-glazed units in a row without uprights - using only horizontal transoms (transom facade).

In this case, the double-glazed units with dimensions of 2.5x1.7 m must withstand a wind load of 60 kg/m^2. These requirements were met by a typical double-glazed unit 12M1-18-10M1 which weight is 234kg or by an equivalent 6M1-18-6M1 double-glazed unit with higher stiffness produced using the glued pultruded profile technology (weight: 126kg), which is 1.9 times lighter than the typical unit and 30% cheaper, when using typical tempered glass M1, and much cheaper, when using energy-efficient glasses.

It should also be noted that the use of the double-glazed unit with higher stiffness does not require the use of transoms with higher bearing capacity.

In the above example, the typical double-glazed 12M1-18-10M1, when it is bended, behaves as the triplex 12.10.3 or the equivalent glass with thickness of 14 mm and behaves in the same way as DGUHS 6M1-18-6M1, and here it is easy to notice that the thickness of the equivalent glass for DGUHS can be calculated as a sum of the thicknesses of glasses multiplied by the coefficient K_{eqv} which, in this case, is equal to 1.2. Through a series of numerical calculations of strength, it was found that K_{eqv} may range from 1.1 to 2, depending on the ratio of the sides of the double-glazed unit, the dimensions and physical properties of the strengthening spacer.

The nature of the displacement distribution in the glasses varies widely: the typical unit has the maximum displacements in its marginal zones, and DGUHS - in its central zone.



Typical displacement distribution for usual double-glazed unit

Typical displacement distribution for double-glazed unit with higher stiffness

When a solid pultruded profile with section of 16x16mm and elasticity modulus of $5*10^8$ N/m^2 as a stiff spacer in DGUHS is used, the following formula is applicable to calculate the thickness of the equivalent glass with accuracy of ± 8%:

$$\boldsymbol{\delta eqv} = \frac{(\boldsymbol{\delta 1} + \boldsymbol{\delta 2})}{\sqrt{\frac{\boldsymbol{l}}{\boldsymbol{H}}}}$$

Where, $\boldsymbol{\delta eqv}$ - equivalent thickness of tempered glass (mm),
$\boldsymbol{\delta 1}$ –glass thickness of double-glazed unit on front side (mm),
$\boldsymbol{\delta 2}$ –glass thickness of double-glazed unit on back side (mm),
$\boldsymbol{l}$ – width of double-glazed unit (mm),
$\boldsymbol{H}$ – height of double-glazed unit (мм).

For a standard one-chamber double-glazed unit, the equivalent glass thickness $\boldsymbol{\delta eqv}$ is calculated by the formula similar to the calculation of the equivalent triplex thickness, namely:

$$\boldsymbol{\delta eqv} = \sqrt[3]{(\boldsymbol{\delta 1^3} + \boldsymbol{\delta 2^3})}$$

Where, $\boldsymbol{\delta eqv}$ - equivalent thickness of tempered glass (mm),
$\boldsymbol{\delta 1}$ –glass thickness of double-glazed unit on front side (mm),
$\boldsymbol{\delta 2}$ –glass thickness of double-glazed unit on back side (mm).

After comparing the calculations based on the above formulas, we can surely say that the weight returns to the bearing capacity of DGUHS is 1.5-2 times higher than that in typical double-glazed units, and it provides a significant reduction in costs of facade glazing by reducing the weight characteristics of double-glazed units, supporting structures and building facade system as a whole, as well as a reduction in transportation and installation costs.

In our opinion, the use of double-glazed glass units with higher stiffness is a new step in creation of modern energy-efficient, durable and safe facade systems that combine the implementation of ambitious architectural designs and high operation characteristics.

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