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GLASS AND MISTAKES

Abstract: Glass is a complex material and in the last decades it has been extensively used in constructions. It is important to understand its particularities and to design taking into consideration not only material properties, but also application, the way it will be transported and installed, the way it will be used by people and what will happen in case of breakage, and eventually how it will be recycled at the end of its life span.

This chapter will check most common mistakes when designing with glass; without considering it as a complete guide, the examples are useful, and most of them are coming from personal experience of people working in construction industry.

Keywords: glass, mistakes, legislation, energy efficiency, dimensioning

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Introduction

Glass is a complex material and in the last decades it has been extensively used in constructions. It is important to understand its particularities and to design taking into consideration not only material properties, but also application, the way it will be transported and installed, the way it will be used by people and what will happen in case of breakage, and eventually how it will be recycled at the end of its life span.

This chapter will check most common mistakes when designing with glass; without considering it as a complete guide, the examples are useful, and most of them are coming from personal experience of people working in construction industry.

We will group these types of mistakes – that have sometimes led to spectacular breakages – in specific categories:

_Mistakes regarding dimensioning;

_Mistakes regarding comfort and energy efficiency:

_ Mistakes in relation with legislation.

Mistakes regarding dimensioning

In order to avoid difficulties later on during construction phase it's important to know from the design stage how to dimension the glass elements. There are several characteristics which should be taken into consideration.

Architects should be aware that glass dimensions are limited by production capacity, and by processing and transport possibilities. The maximum dimensions for production of raw glass is 3210x6000mm; this is what the contemporary glass plants can provide. The available thickness depends on the speed of movement induced in the line of production: if the tin basin has a slow motion, more melted glass falls into the tank/time unit; if it moves faster, the melted composition will be distributed on a larger surface in the same time unit, hence the thickness will decrease. Regarding thickness range, production of raw glass is 3, 4, 5, 6, 8, 10, 12, 15, 19 and 25mm, but the most common types that are used are 4, 6, 8, 10mm. We cannot use the glass as raw product: we will transform it by cutting, shaping it with beveled edges, tempering, and possibly laminating it. The size of the transformed pieces is limited by the capabilities of the machinery: tempering and laminating can be done usually in size 2400x5100mm, up to 3200x6000mm. On special orders, some larger dimensions can be delivered, up to exceptional 18m long, but the costs might be significant, especially those related to transportation. A glass supplier should be consulted for more details.

Sometimes the weight of glass can be a significant limitation, especially if larger and/or thicker panels are used. Glass density is ρ=2500kg/m^3. Here are some examples:

_a 1 m^2, 4mm thick panel weights 10kg;

_a 1 m^2, 10mm thick panel weights 25kg;

_a double insulated glazing, 4000x2000mm, composition 10-16-88.2 weights 520kg;

_a fish tank 2000x1000x1000mm, composition 10.10.2 (just glass) weights 400kg and, if filled with water (without additional metal structure!) weights 2400kg.

So, designers, architects and engineers should take into consideration the weight of the glass since the design phase, when dimensioning the other structural elements. I remember one situation, when a specialised company created a fish tank on special order of 5000x2000x1000mm wide. Everybody was very much concerned about dimensioning the glass and the joints only to realise, in the moment of filling it with water, that weight exceeded 10tonnes and the building structure was not design to accommodate this extraordinary load. In the end the owner paid for the fish thank and ordered, paid and installed a second one, much smaller in size (and weight!).

Sometimes it's the size of the glass panel itself that causes troubles, especially during transport to the site and installation. Trucks, cranes etc. are usually needed and the possibility of access to construction site must be also checked.

Specialized design company must be used in order to calculate class composition according to EN 16612 standard. Most often, additional to dimensions, they are taking into considerations:

_permanent loads (e.g.: the own weight of the glass element, the weight of other constructive elements permanently fixed to the glass, as well as permanent payloads);

_variable or temporary loads (i.e.: wind load with pressure or suction, the snow load, the hydrostatic pressure in case of aquariums/ swimming pools, etc.);

_accidental actions (i.e: impact with heavy solid bodies, stones, hail, etc.).

Optical deformations may occur in case the glass is not perfectly flat. When light rays strike a curved glass surface, they reflect in different directions. However, they will still obey the law that the angle of incidence equals the angle of reflection. Therefore, the image of an object will be distorted. The curvature of the glass surface causes it to act as a lens. This can be enhanced by a higher reflection (e.g. reflective coating on the glass) and also by objects in front of the glass, acting as guidance lines. Main causes of not so flat glass units can be:

_Lack of flatness because of tempered glass characteristics. Tempering is done by heating up the glass close to softening point (770°C) and cooling it quickly. This creates specific tension in glass, but also lack of flatness. Standards EN1863-1 and EN12150-1 are explaining the limits allowed. As a conclusion, it is always recommended to use the best technology available in terms of glass tempering, in order to limit as much as possible frame effect, bow effect and also anisotropy.

_Lack of flatness because of barometric and/or temperature and/ or altitude: high atmospheric pressure is forcing glazing units to shrink inwards and this will result in exterior pane being concave and interior pane being convex. Similarly, low atmospheric pressure makes it to swell outwards and this will result in exterior pane being convex and interior pane being concave. It is difficult to avoid this completely but it is possible to limit it, if outside glass is thicker than inside glass. In this case, the outside glass will remain more or less flat and inside glass will take all the bows, but that will be much less visible from outside the building.

Fig. 1. In the reflections on the ground floor one can notice a lack of flatness from the objects reflected acting as guiding lines. At the first floor, due to lack of guidance lines (only sky is reflected), glass seems much more flat. Note: both ground floor and first floor have exactly the same glass structure but apparently they look very different.

Mistakes regarding comfort and energy efficiency

Energy efficiency has been for many years now a major topic in building industry. Because glass is a significant part of the windows or the façade, considerable efforts have been made to improve the glass parameters, mainly thermal transmittance during winter time and solar control during summertime. Ug (known as Thermal transmittance) is the rate of transfer of heat through matter (glass). We call it heat loss coefficient. It is expressed in Watts per squared meter and Kelvin - W/(m^2xK). This means that the higher the U-value the worse the thermal performance of the building envelope. A low U-value usually indicates high levels of insulation. Sometimes, R value is used (known as thermal resistance). The thermal resistance of a structure is the reciprocal of its thermal transmittance: U=1/R.

In case of a window/façade, because of energy efficiency requirements, an insulated glass unit (IGU) should be installed. That's because the glass itself is not an insulating material. If a glass panel, 4-millimeter-thick, is installed in a frame, its Ug value is 5.8 W/m^2K. In order to obtain a reasonable Ug Value, like 1.1 W/m^2K, a total glass thickness of no less than 700mm is needed! Obviously this is totally unpractical, so the solution is to use an insulated glass unit: an assembly of glass, air (gas) and glass, all hermetically sealed on the perimeter, instead of a massive, solid block of glass.

The glass thickness is determined as explained above, but special attention should be paid also to limit heat losses of insulated glass unit, which can happen by conduction, by convection or by radiation. Practically, in order to limit the conduction, the aluminum spacer which is separating the glass panes should be replaced with a plastic/composite material, a "warm-edge spacer" type. To improve convection, it is recommended to use Argon or Krypton (rare gases) between the glass panes, and to keep the gap between 15 and 18mm. If the spacer will be wider (like 24 or 30mm or even more) the extra space will generate extra turbulence (convection) in the gas, which will increase the heat transfer (energy loss). In this case, less is more: if gas will be replaced by vacuum it will be even better (no convection, spacer will be close to zero). During recent years we saw several developments of vacuum glazing, and the results are encouraging. Most probably in the near future (10 years or so) we will have a vacuum glazing that will have better parameters than traditional triple glazing. Cutting heat loss by radiation is obtained by using a low emission (lowE) glass, which will reflect heat back into the building. Also, using a triple glazing (a lowE – clear glass – lowE type) will improve the thermal insulation of a glazing by a factor of 2. If the spacer (gas chamber) will be narrower (6-8-12mm), the gap will not provide enough insulation and the result will be a not so efficient insulation. All these parameters should be taken into account when dimensioning the composition of an IGU, in order to get the best result possible within specific limitations of cost and frame design.

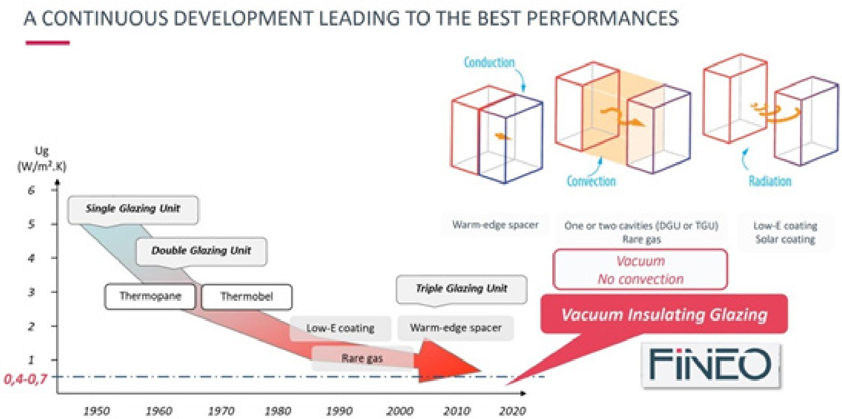

Fig. 2. Improvement of Ug value over the years through specific innovations. © FINEO by AGC

A double insulating unit, comprising of external pane made in clear glass, a 16mm spacer filled with Argon (90% purity, because of technological limitations) and a lowE glass is generating an efficient Ug value of 1,1 or even 1,0 W/m^{2}K. In order to have a better insulating glass, a triple glazing should be used. An ideal composition would comprise low-E outside glass, clear middle glass and low-E inside glass, while spacers should be 16mm wide and Argon filled. The result would be an Ug value of 0,5W/m^{2}K, which is the best value we can obtain in standard, practical solutions.

On top of significant energy savings, using insulating glazing units with low-E glass brings also personal well-being of the people living inside the building: the lower the Ug-value, the higher is the temperature of the glass. That translates in comfort, due to lack of cold wall effect: convection is limited and people can actually use the space near the window, without having chills.

It's not the subject of this paper to cover frames and other materials, but, for sure, a dedicated frame for triple glazing, wide enough and dimensioned considering the correct loads, should be used and later installed accordingly, otherwise all the efforts of having the best glass solution are futile.

During summertime, special attention should be dedicated to solar control solutions. For sure, the best option would be an external shading device, but it's not always possible to have it installed on the building. If this is not possible, then the solar control should be achieved with the help of the glass.

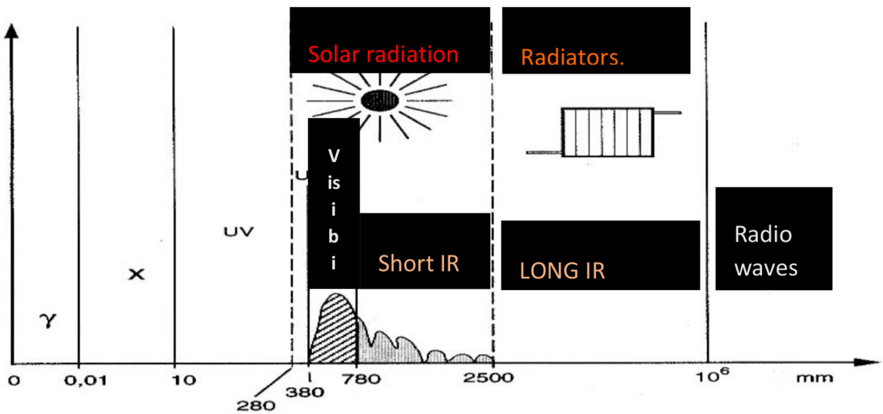

Fig. 3. Energy according to wavelength. Sun radiates energy from 280 to 2500nm (from 280 to 380 it's UV; from 780 to 2500nm is short infrared). Energy produced by burning fuels and energy absorbed by bodies and reradiated has a wavelength above 2700nm (long IR).

The main parameters that characterize the glass unit are:

_Light Transmission (%) is the quantity of light entering a building from the total quantity of light coming from the Sun (wavelength 380 to 780nm). LT of a clear glass is around 85%. A really dark glass has LT around 10%.

_Light Reflection (%) is the quantity of light reflected by the glass from the total quantity of light coming from the Sun. LR of a clear glass is around 10%, while a reflective glass has LR around 50%.

_Solar Factor (%) is the quantity of energy entering a building from the total quantity of energy coming from the Sun. SF of a clear glass is around 80%. A really dark glass or a very reflective one has SF around 5%.

Because solar intensity exceeds 1500 W/m^2 in Romania, choosing a solar control glass is very important, especially in the case of large glass envelopes with orientation towards Sun (south, but also east and west, and also in case of glass roofs). In terms of costs, cooling of a building during summertime with a clear and low-E glass façade exposed to the Sun radiation can be more expensive than heating it during cold winter days, because of the greenhouse effect. This phenomenon was observed since ancient time: clear (or low-E) glass tends to allow visible light and short infrared radiation to pass through its matter almost uninterrupted. However, once the energy has been transmitted through the glass, it is turned into longer infrared radiation waves after it is absorbed by objects; these new waves are blocked by glass and unable to escape back through the windows due to their longer wavelength. Therefore, the heat is trapped inside the room causing the solar gain (overheating). This effect is useful in agriculture and also in cold climates, however, in temperate or warm climates it is causing overheating of the building. In order to keep temperature and cost of cooling under control, a solar control glass must be used. Choosing the right solar control glass is a complex decision: the aspect (color and reflection), the function of the building, the orientation, the ratio between glass surface and opaque surface in a façade, the cost and many other elements must be taken into consideration.

As a very general estimation, the cost of low-E glass is paid back after 1 winter season through energy savings; solar control glass is paid back in 3-5 years through energy savings. If we add the reduced cost of HVAC installation, then we can say that solar control glass is paid back rapidly. Nevertheless, the well-being of dwellers is another benefit of solar control in warm climates:

comfort and general mood are optimised when inside temperatures are not exceeding 25°C.

It is important to remember that finding the best solar factor is something like looking for the Holly Grail: if during summertime we are usually looking for a lower value of SF, during wintertime we prefer a higher SF to get free energy from the Sun. Additionally, by lowering SF, we are lowering LT as well, so a right balance should be chosen. A dynamic solar factor is an ideal situation, but this is possible only in case of external blinds and in case of glass having variable transparency. This is a solution developed in the last years, mainly using electrochromic glass: liquid crystals are able to control both transparency (LT) and energy (SF). There are still several limitations, mainly concerning sizes, low capacity of production and also cost, but in the coming years electrochromic glass will be probably used in most buildings looking for zero consumption (NZEB).

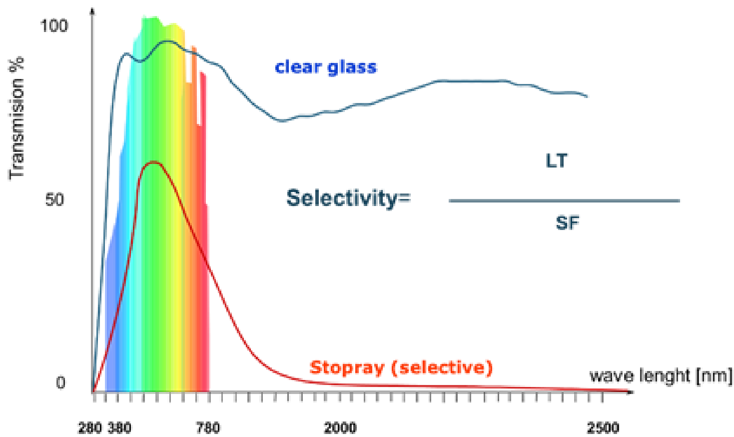

Fig. 4. Clear glass vs selective glass: there is transmission of UV, light and short IR.

In order to understand if a glass is more performant than another, sometimes selectivity is used – a ratio between light transmission and solar factor. The higher the selectivity, the better it is in terms of solar control performance, but architects must choose wisely how much light and how much heat should pass through the glass.

Sound insulation (noise attenuation) is also an important parameter of glass, especially in cities or areas where noise is significant. Excessive noise can affect the well-being of building occupants and cause them to be moodier, with a result in lack of attention and productivity. According to standard EN

ISO 10140-3, sound attenuation is measured in an official notified laboratory (accuracy ± 1dB) always with the same size of the glass (1230x1480mm). The Weighted Sound Reduction Index (Rw) is a number used to rate the effectiveness of a soundproofing system or material. Increasing the Rw by one unit translates into a reduction of approximately 1dB in noise level. Therefore, the higher the Rw number the better a sound insulator will be. C and Ctr are some adjustment factors which are used to account for high, respectively low frequency noise (typically the biggest problem with sound insulation). Ctr is always a negative number, so the Rw+Ctr will always be less than the Rw value. In short, there are few solutions in order to improve sound attenuation of a glazing: more mass (increased glass thickness), asymmetrical glazing in case of insulated units, and especially usage of laminated glass. Most effective is acoustic laminated glass, where the plastic interlayer is specially designed to block sound vibrations. A very effective insulated glass unit can achieve Rw (C; Ctr) of 51 (-1; -4)dB. If we know source of sound and its frequency, we can choose the best glass composition to block the sound propagation as much as possible.

In terms of maintenance, special attention should be dedicated to the possibility of cleaning the glass. Quite often, glass is positioned near solid surfaces (e.g balustrade, ceiling cover, etc.) having very limited space (sometimes centimetres) between inner surface of the glass panel and the other materials. In this case, it is nearly impossible to clean the backside of the glass, and in case the glass remains clear (transparent) the dust, cleaning agent etc. deposit will be very visible. From the design stage, if the glass is not perfectly sealed, for sure it will get dirty over time and it is needed to take into consideration the possibility of cleaning also the back side.

Glass canopies usually installed on top of entrances are also subject of dust deposits, especially if the water stagnates (horizontal installation). In some cases, it is possible for the glass to be permanently damaged because of corrosion of aggressive agents of pollution. The best solution is to install the glass in inclined position, in order to evacuate water and dust, and to have it cleaned regularly.

Sometimes, water condensation may appear on glass surface. There are several possible situations and the solutions should be adapted to each cause.

If condensation appears on the inside surface of the glass it is caused usually by a poorly heated, insufficiently ventilated or very humid interior space. The dew point of a given body of air is the temperature to which it must be cooled to become saturated with water vapor. If the condensation appears on the glass, it is happening because its temperature is bellow the dew point. Condensation on the glass surface facing the room is not a defect; it will improve (decrease) if we will heat the glass, ventilate the room and reduce the air humidity.

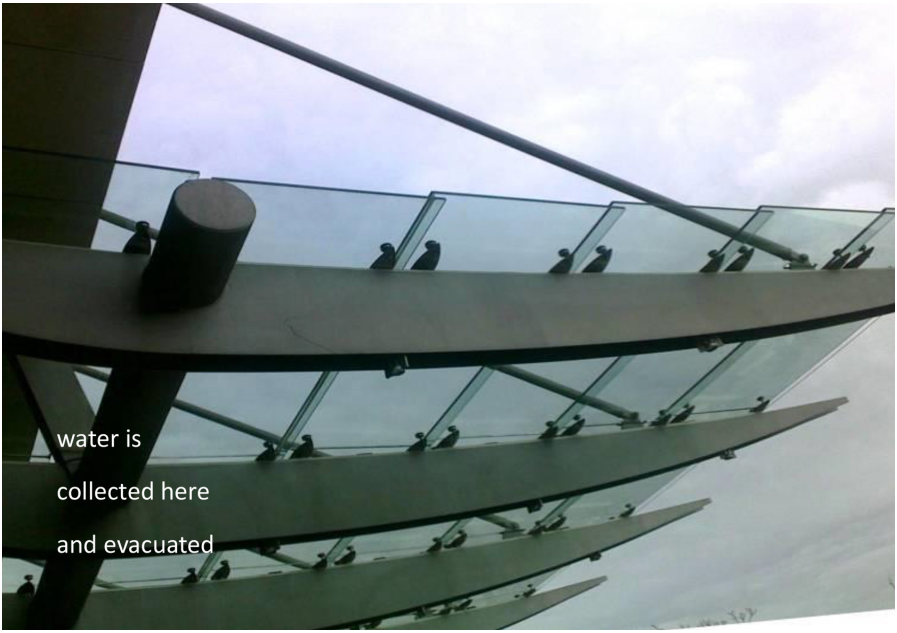

Fig. 5. Glass canopy; water is collected and evacuated.

Superficial condensation on the outside surface of the glazing is a phenomenon that may happen during night and in the early hours of the morning, when the sky is clear, and in the absence of wind. Thermal losses during clear sky are the main cause of this phenomenon; usually after Sun is rising the condensation is disappearing leaving no visible marks. The phenomenon of condensation on exterior glass surface is a proof of very good thermal insulation and it is not a defect.

In case condensation appears between the glass panes (in the enclosed cavity), it is considered a defect. The gas inside is not dry and probably the sealing is no longer working, causing poor thermal insulation. In this case, the insulated glass unit must be replaced.

Mistakes in relation with legislation

Although this topic is complicated and we cannot cover it fully, there are several important aspects to be mentioned. Glass is a particular material and most concerns are related to safety and security. Because of this, it is important to explain different types of glass and their performance:

_Annealed glass is a simple glass; it has a low resistance on stress and when it breaks, the fragments are a potential risk for persons. Annealed glass is not considered a safety glass, and its usage is limited for application with low risk of impact, failure, etc.

_Laminated glass is a type of safety glass consisting of two or more layers of glass with one or more thin polymer interlayers between them which prevent the glass from breaking into large sharp pieces. Breaking produces a characteristic „spider web" cracking pattern (radial and concentric cracks). The most common uses of laminated glass are in automobile windshields, skylight glazing and balustrades. Because the plastic interlayer is keeping glass fragments together, it is considered safety both against injuries with sharp fragments and against falling through, making it mandatory both for large glass panels in areas with traffic, and for panels which should keep the bodies against falling from height (balustrades, glass from floor to floor, etc.). The plastic interlayer can have a decorative function (colored, transparent or opaque film), or can have advanced properties in blocking the sound (acoustic film).

_The wired glass is obtained during the production process of float glass, by inserting a metal mesh in the melted glass mass. Although wired glass has a specific property (integrity in case of fire), it is not considered a safety glass.

_Heat-Strengthened glass has been heat treated (up to 750°C) in order to improve mechanical properties, and, when broken, a few lines of breakage are visible. Because of that, Heat-Strengthened glass is not a safety glass and is usually used in laminated version.

_Toughened or tempered glass has been heat treated (up to 770°C) and then cooled quickly in a controlled way, in order to significantly improve its mechanical properties up to five times compared with annealed glass. When broken, fragments are small and they are not causing injuries even in case of falling on people. Because of that, tempered glass is a safety glass and can be used in applications with a high risk of breakage and no risk of falling trough. In case there is a risk of falling through, then a laminated glass should be used, maybe with tempered glass in composition.

In Romania, a new regulation was recently adopted, *Indicativ* C 47 – 2022 *Instrucțiuni tehnice pentru configurarea, folosirea și montarea vitrajelor și a altor produse din sticlă în construcții*, which must be used when designing a glass element for a new building. This document can be downloaded from https://www.mdlpa.ro/uploads/articole/attachments/62ce6784b2a66269825548.pdf.

Conclusions

Glass is an old material which has ben constantly reinvented; it has been a fascinating material to humankind since it was first made, almost three thousand years ago. Architects love it because of its unique properties: it is transparent or translucent, it is strong (and brittle), it is available in various beautiful colours and textures, it can be easily cleaned and lately can be produced in absolutly impressive sizes. With the advances in technology, it is possible to make glass that is very light and thin, or stronger than steel. Glass is now being used in the building industry as insulation material, structural component, external glazing material, or a cladding material; it helps us harvest solar energy, it can be used as a projection screen or even as a switchable wall (transparent and opaque at a click); it help us comunicate when used as mediascreen.

If we understand the material and its properties, and by learning from mistakes, we can create amazing objects and buildings. This is why we can say glass is the material for the future.