Distortion in Glass Products

There are many reasons that distortion occurs in monolithic and insulating glass products. Distortion in monolithic glass can be caused by glazing pressure around the periphery of the glass, windloads, and the heat treatment process. The heat treatment process is used for glasses that are heat-strengthened or tempered to meet high windloads, safety glazing applications, or to reduce the opportunity for thermal breakage.

For insulating glass, distortion can be caused by changes in temperature, changes in elevation from where the insulating glass units were fabricated, changes in barometric pressure, windloads, glazing pressure around the periphery of the glass and the heat treatment process used for heat-strengthened and tempered glasses.

Distortion is very subjective and the degree of distortion can change due to environmental conditions as listed above. An article written in U.S. Glass, Metal and Glazing in August 1993 details the causes of distortion and ways to possibly lessen the degree of distortion. This article is an excellent dialogue on the specifics of distortion and is a good article for anyone who has questions or concerns about distortion in glass products.

Making A Difference In Glass Deflection/Image Distortion

When we deal with sealed insulating glass units, both the glasses are in constant bending movement resulting in multi-directional scattering of the image reflection and pronounced distortion. Such is an undefinable optical behavior that is inherent in IG units.

The unique benefits of today's glass products - high energy savings, beauty, durability, and visual transparency - are making a difference in the types and styles of insulating glass (IG) units used in the exterior walls of today's residential and commercial buildings.

These benefits have prompted many state energy enforcement agencies to ensure that standards now utilize window areas of thermal insulation values that are only attainable with insulating glass units of thermally controlling coated glasses. By 1995, the glass area energy standards for all states will require minimum energy values for residential and commercial buildings that can only be achieved through the use of high performance insulating glass units.

While much has been written about the improved energy performance properties of IG units, there is little published on the distinct optical phenomenon that is inherent in all insulating glass units: Reflective Image Distortion.

All industries involved in construction have experienced image reflectance when using glass. Most owners and architects have learned to consider the “non-linearity of reflective images” as a positive design feature. This article will present background information to explain the causes of Reflective Image Distortion.

Light Beams: Light is transmitted through space as wavefronts, traveling in all directions from the sun. By the time light reaches the earth, some 9.3 million miles away, the light waves are essentially straight lines and parallel to each other. When light falls onto a smooth glass surface, some rays are transmitted through, some are reflected back, and some are absorbed. If the incident rays are directly perpendicular to the glass surface, they are reflected straight back as shown in Fig. IG18-1.

If the incident rays (2, 3, and 4) fall obliquely upon the glass surface, their reflective rays bounce back at the same angle but to the other side of the normal perpendicular. The angle of incidence (A) always equals the angle of reflectance (A 1).

As the transmitted light rays enter the glass, as shown in Fig. IG18-2, they are abruptly bent (refracted) at an angle (B) of lesser degree than the incident angle. As the refracted rays reflect from the second glass surface, it is again refracted as it leaves the first glass surface at an angle equal to the original incidence angle.

For each light of glass there are two reflected images; a primary image and a secondary image. With a dual pane insulating glass unit, there are two primary, spaced images (surfaces #1 and #3) and two secondary, spaced images (surfaces #2 and #4). The spacing of these four images from each other will increase and become more noticeable as the incident angle decreases, the glass thickness increases, and the air space increases. (These four images can be seen by holding a lighted match near an IG unit and viewing from an angle.)

When light rays strike a curved glass surface, they reflect in different directions obeying the law of the angle of incidence equals the angle of reflection. All objects being reflected from curved glass surfaces are distorted from their actual form. If the glass curvature is concave, the reflected light rays are projected inward toward a central point causing the reflective image to appear to be short and thin (see Fig. IG18-3A).

If the glass curvature is convex, the reflected rays are projected outward causing the reflective image to be stretched out in both directions (B). In insulating glass units experiencing load changes due to elevation, air temperature or barometer, both glass lights will be in reversed curvature, altering significantly the shape of the object being reflected.

Light, in its transmission, refraction, and reflection behaviors, is rather easy to understand when the glass is flat. The reflective images seen are multiples but exactly like the object reflected. However, when we deal with sealed insulating glass units, both the glasses are in constant bending movement resulting in multi-directional scattering of the image reflection and pronounced distortion. Such is an undefinable optical behavior that is inherent in IG units.

The causes of distortion are the physical behavior of IG units under weather and installation conditions. While these conditions are simple to understand, they are impossible to control. It is amazing to recognize glass's ability to adjust through glass deflection to these extremely high load forces.

We will now consider the influences of environmental conditions on glass deflection. Loads will be given, at times, in wind load equivalent pressures to more easily appreciate the magnitude of the daily forces placed on the IG unit's glasses and edge seal.

Causes of Glass Deflection in Insulating Glass Units: An insulating glass unit is a flexible pressure chamber. It contains the pressure of the elevation, barometer, and air temperature that was in the manufacturing plant at the moment the unit was sealed. Since these weather conditions change daily - or even hourly - no two units have the identical built-in air pressure.

The glasses in a sealed insulating glass unit will deflect if the pressure in the unit's air space is different than that of the surrounding environment. The degree of glass deflection depends upon the difference in these two pressures, the size of the IG unit, its glass and air space thicknesses, and its aspect ratio.

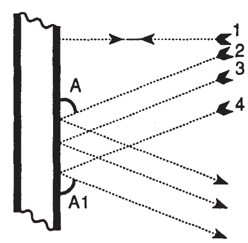

Fig. IG18-1

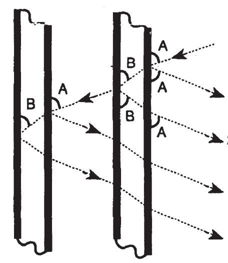

Fig. IG18-2

The unit's edge seal receives the major attention in design because if its singular important job of producing long-term unit field performance. It is recognized that the most positive and attainable action to control high sealant stressing is to permit the deflection of the glass lights.

The various pressures that an IG unit must sustain are generally extremely high and interacting; sometimes additive and sometimes counter-balancing. Let's first consider the forces presented by the environmental conditions of elevation changes, temperature changes and barometric changes.

Elevation: When an IG unit is installed at an elevation above that at which it was made, the lower elevation pressure causes the two glasses to bow outward. As the elevation difference increases, the relatively higher air space pressure becomes more dominant producing greater deflection.

An IG unit made in St. Louis (505' elevation) and glazed in Cincinnati (1,063' elevation) will take a convex shape when experiencing this minus pressure change of 36 PSF (or that produced by a leeward 118 MPH wind). Conversely, an IG unit made in Atlanta and glazed in Philadelphia will have concave bowed glasses due to the drop in elevation of 1,000 feet, or the equivalent of a 168 MPH wind. Seventy percent of our states have elevation differences within a state of over 500 feet. Sixteen states have elevation on differences of over 1,000 feet.

The influence of elevation change on IG unit glass bowing is also influenced by the building floor on which the unit is glazed.

With an IG unit made in the same city in which it is glazed, the second floor units will have negative outdoor elevation pressure equal to a 16 MPH wind, on the fifth floor equal to 37 MPH winds, and on the tenth floor equal to 53 MPH winds. Deflection distortion increases as the height of the building increases.

Temperature Changes: An IG unit's air space temperature, and thereby its internal pressure, is directly influenced by the ambient air temperature and the solar radiation striking the glass. As the air space temperature heats up, the internal pressure increases. As the air space temperature goes down, the internal unit pressure goes down.

These changes vary by hour, day, season of the year, and by geographical location. The heat absorbing property of specific glasses and glass coatings also alter the unit's air space temperature.

Every one degree Fahrenheit (F) change in the air space temperature from that at which the unit was built produces a 3.6 PSF pressure change. While this seems slight, a 20°F change would equal the pressure of a 175 MPH wind. In the southern states where the winter temperatures reach 30°F, the air space temperature would be about 50°F, or 20°F from the 70°F manufacturing temperature. In the northern states where the outdoor temperature reaches 0°F, the internal pressure would be a negative 130 PSF (equals 230 MPH winds) if the glasses did not deflect.

A photograph of the same IG unit in the winter, spring, summer, and fall would record difference in image distortion. The same IG unit on the same day but receiving direct solar radiation will also show significant differences in appearances. Even a cloud passing in front of the sun causes a measurable deflection change in glass flatness.

Barometric Pressure: The continuing change in the outdoor barometric pressure from the pressure contained in the unit's air space is another cause of glass deflection. A recent check on Philadelphia's barometric pressure showed a change of 0.39" of mercury between two consecutive days. This is a pressure change of 28 PSF or the equivalent of the force of a 105 MPH wind storm. In the United States, it is fairly common to experience a cycle of high to lower pressure systems over a period of three to four days giving pressure variations of 50 PSF. With a decrease in barometric pressure, the IG unit's glass lights will bow outward.

Over most of our country, the barometric pressure is lower in the summer and higher in the winter. With this happening, we have the summer higher air space temperature causing the glasses to bow outward and also the lower barometric pressure adding to the outward deflection of the glass lights.

Wind Loads and Air Conditioning Loads: Other influences of glass deflections are the forces produced by wind loads and the indoor operating forces of the air conditioning and heating operations.

Wind forces - from mild to storming conditions - load the glass area of the building with positive forces on the windward side and suction forces on the other three leeward building sides. When there are climatic conditions also bearing on the building causing an outward deflection of the glasses (high elevation, high temperature, lower barometer), the deflection of the glasses facing the storm are counteracted by these positive wind loads. At the same time, the outward bowed glass of the other three elevations are further deflected outward.

The two to three PSF inner building loads resulting from the operation of the air conditioning and heating equipment also add to the incidence of glass deflection and distortion. With these loads resisting the inward deflection of the IG unit's indoor glass light, the unit's internal pressure transfers the second light inward deflection into additional outdoor glass deflection.

Tempered Glass and Glazing Distortions: Besides the IG unit glass deflections produced by the ever changing environmental loads, image distortions are also caused by the heat treatment of glass and by glass bending that occurs in glazing installations.

Glass is heat treated to produce a strength level - or a break pattern - as required by a building specification. All heat strengthened and tempered glasses processed through roller hearth furnaces contain repeating lines of glass thickness variation (waves) that extend across the glass width dimension as it passes through the oven.

The ceramic rollers that transfer the glass through the furnace produce very slight indentations into the glass surface at the temperature required for successful heat treatment. The radius of curvature of these waves is very small but does produce discernible reflective image distortion.

To minimize the noticeable effect of roller waves, these glasses should be glazed with the roller waves horizontal to the glass's sill edge. An observer traveling alongside the building will not see the repeating pattern of image distortion. If, however, the observer is traveling toward the building, he will see this inherent distortion-producing blemish.

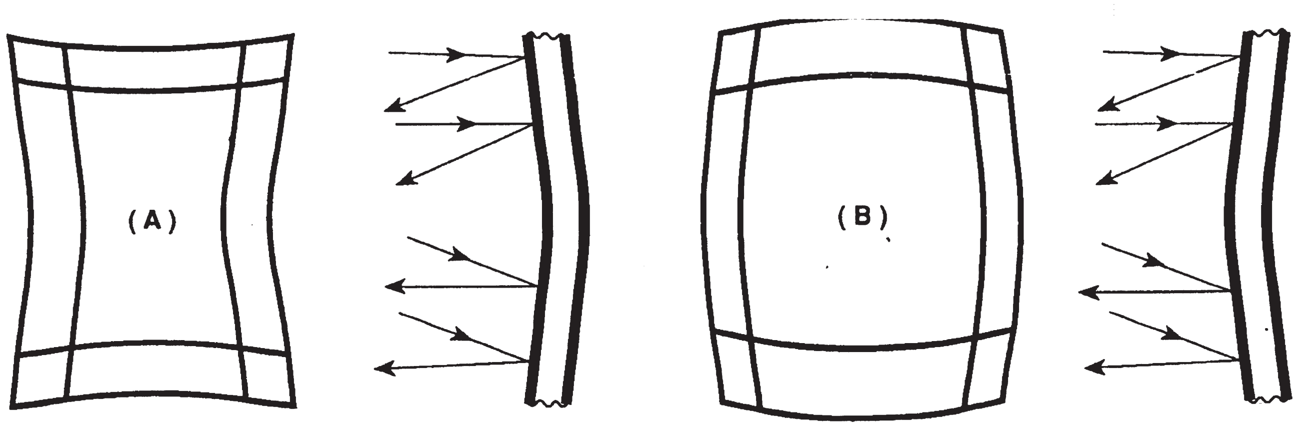

Fig. IG18-3

Glazing frames have their inherent manufacturing tolerances and are sometimes installed without precise plumbness with adjacent glazing frames. The change in the viewer's angle of incidence of light rays will cause a striking difference in the appearance of any reflected object. For image uniformity, the adjacent glasses must be in the exact same planes. Even a slight bow in a glazing frame or a comer area being out of plane will cause the glass to bend and show reflective distortion.

Corner area distortion is caused by joint assembly misalignment, the less compressibility of glazing gaskets at their welded corners and the setting blocks frictional resistance to glass final outward movement during compression glazing.

Lessening The Degree of Glass Distortion: A sealed insulating glass unit will always display reflective object distortion because weather, wind, and glazing will produce ever changing pressure loads that differ from the pressure locked in during its manufacturing. There is no way to eliminate reflective distortion in insulating glass units and only a few IG unit construction modifications will produce noticeable changes.

Venting of the IG unit's air space is a common practice to provide adjustment for major elevation pressure changes. This is achieved by one of two methods. Breather holes - or breather tubes - installed during unit manufacturing into the IG unit's spacer are generally about 1/8" in inside diameter and will rapidly adjust the inside unit pressure as higher elevations are reached. The breather hole of units must be permanently sealed after a relatively short time on the building site to preserve the low moisture content of the air space.

The IG unit manufacturer will advise the elevation above which breather units should be ordered. Very precise instructions are given for field sealing these breather holes which must be exactly followed to preserve the warranty on the IG unit's field performance.

Capillary tube units, which are a more recent development, contain a factory installed 12" long metal tube that has a 0.021" inside diameter. Because of the length of these tubes and their very small inside diameter, they are reported to prevent the influx of moist air to the extent that the desiccant would be affected.

The capillary tubes remain open upon glazing and give a constant balancing of internal and external pressures. Unit size, air space thickness, and pressure differential are all influences to the response time to achieve full pressure equalization.

Rectangular IG units of large aspect ratios and with thicker glasses do reduce glass deflection, but remember that all such steps will not change the pressure differentials created by the changing environment. If glass deflection is so restrained, the remaining very considerable pressure will act on the long term durability of the IG unit's edge seal.

The use of glasses of different thicknesses in an IG unit (with the thinner, more deflecting glass inboard) is a unit construction method used to decrease outdoor viewed distortion. In such cases, a full study of the glass strength capacity of the thinner glass light must be made.

On triple and quadruple glazed units, the interior glass lights should contain a hole to provide for air space equalization. If this is not done, the exterior air space and outdoor glass light will experience very excessive pressures.

Reflective distortion in IG units is not a recently developed phenomenon but one that has been in existence since insulating glass units have been marketed. Clear glass units are deflecting exactly the same today as they did 40 years ago.

Distortion has become more noticeable because of its visibility brought on by colored and coated glasses. With the high light transmission and low reflectance of clear glass, image reflectance is subdued when there is reasonably high indoor illumination. As the IG units' act more like mirrors (low indoor illumination or tinted and coated glass), image reflectance becomes very pronounced.

If reflective distortion is a considerable problem, remember you need only be concerned with the likely location of the observer, the height of the reflecting building, and the height of your building. Generally, only the first, second or third floor of your building will ever be critically reviewed.

Every morning, look at your building and enjoy the reflective distorted images. If such are not occurring, the IG unit has lost its seal. Remember, glass deflection prevents IG unit seal failure.

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