Technics Topics
Distortion in Sealed Glazing Units

Researcher and consulting engineer **Armand Patenaude** introduces a solution to the problem of distorted images in glass façades.

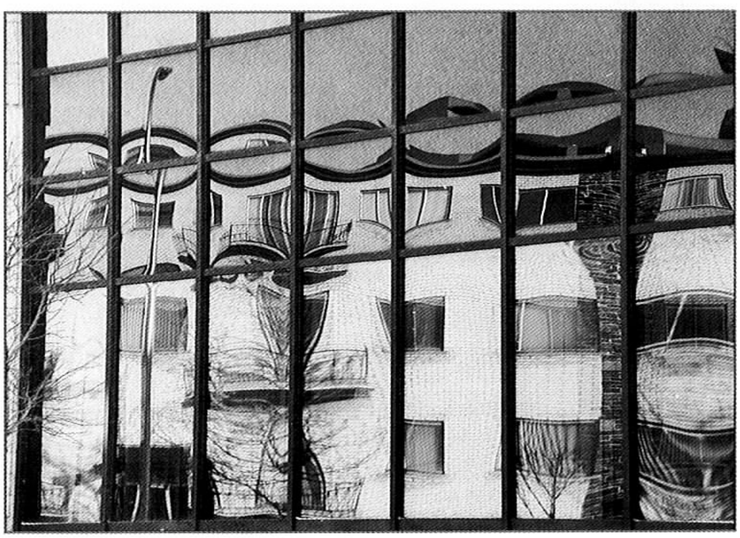
During the days of single glazing, it was possible to design and build a reflective curtain wall or store front that behaved like a nearly perfect mirror. With the widespread demand for sealed insulating glazing units (IGUs), however, visual distortion of reflected images (1, 2) has become more than an annoyance to designers: Dissatisfied owners have sued and demanded corrective measures for glazings that failed to meet their visual expectations. This article offers a solution to the problem of visual distortion, and it suggests acceptable limits for distortion-causing deflection based on a laboratory study.

Nature of the Problem

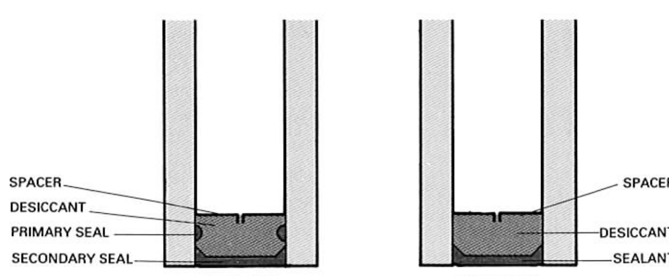
Insulating glass units (IGUs) are made of two or more panes of glass separated by a spacer containing desiccant material (a molecular sieve) installed around the edge, and closed at the perimeter with a single or double seal (3).

Once assembled, sealed units are subject to differences in environmental pressure and temperature. A rise in barometric pressure and a drop in temperature will cause concavity, where the glass bends towards the middle of the gas-filled space between the panes, while a drop in barometric pressure and a rise in temperature will cause convexity, where the glass bows out from the middle of the gas-filled space (4).

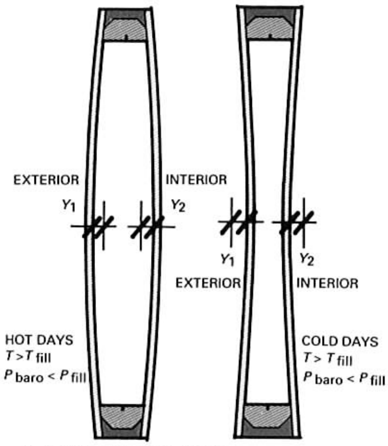
The surface adherence (adsorption) or release of one or more of the gas filler components on the desiccant will produce the same effect. Because mean barometric pres-



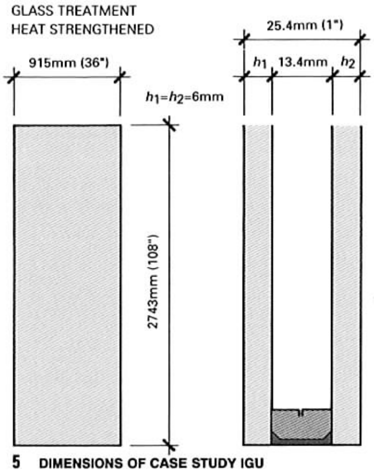
1, 2 *Visual distortions are caused by changes in temperature and barometric pressure, which cause glass lights to bow in or out.*



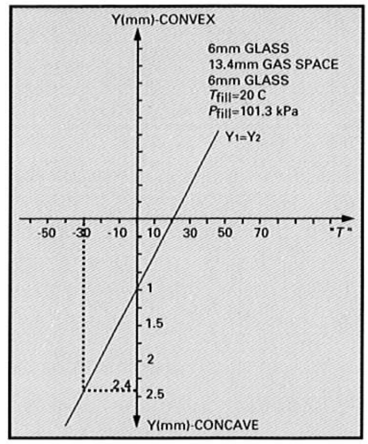
3 *The type of edge seal has little effect on visual distortion in large IGUs.*



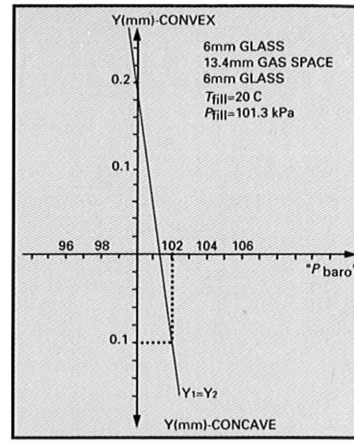
4 DEFLECTION OF Y_1 AND Y_2



5 DIMENSIONS OF CASE STUDY IGU



6 DEFLECTION AS A FUNCTION OF T



7 DEFLECTION AS A FUNCTION OF P_{baro}

sure changes with altitude, differences in elevation between the fabricating shop and the site can produce "built-in" distortions.

Even though the mechanical stress induced by pressure and temperature differentials in large IGUs is relatively small, warping glass panes will cause an unpleasant visual distortion of reflected objects or buildings. Such visual distortions are bothersome to the observer and detract from the aesthetic quality of a building. The distorted images are most apparent during daytime on the outside of curtain walls or large windows. The problem is much less obvious on the inside, because of the softer lighting, shorter viewing distances, and the fact that the glass is often hidden by curtains or blinds.

Control Parameters

As previously mentioned, once the assembly and sealing of insulating units are complete, the initially flat sheets of glass will eventually take on a concave or convex shape. The magnitude of the warp in each glass pane can be controlled within acceptable limits as long as the insulating glass design takes into consideration the following parameters:

- Glazing dimensions
- Thickness of each glass pane
- Thickness of gas space
- Difference between actual barometric pressure (P_{baro}) and gas space pressure at filling (P_{fill})
- Difference between actual temperature of gas space (T) and temperature of gas space at filling (T_{fill})
- The interface between glazing and frame members
- Adsorption or desorption of one or more components of the gas filler.

Case Study

Consider a typical IGU with dimensions of 36″ × 108″ (915 × 2743 mm), 1/4″ (6 mm) thick lights, and a 1/2″ (13.4 mm) wide gas space (5). The influence of temperature and pressure differentials on the center deflection of both glass sheets can be easily calculated* and graphed (6, 7). (Some glass manufacturers will perform such calculations as a service to designers.) The amplitude of deflection of both glass sheets will depend on their respective rigidity. Since the two glass panes are identical and have equal rigidity, the deflection on both sides will be identical and will be unaffected by the glass treatment.

In one particular case where the temperature of the gas-filled space could reach −22 F (−30 C) while the barometric pressure is 102 kPa, the resulting deflection of each glass pane will be approximately 1/10″ (2.5 mm), that is, the sum of the deflections caused by temperature and barometric pressure combined.

For given temperature and pressure conditions, it is also possible to calculate and graph the influence of the gas space thickness (8) on the deflections of the glass panes. Notice that each pane's deflection increases with the thickness of the gas space. Therefore, by increasing nominal gas space thickness from 1/2″ to 1″ (13.4 to 25 mm), the resulting center deflection increases from 1/10″ to almost 3/16″ (2.5 to 4.6 mm).

Although most IGUs are fabricated with 1/2″ spacers, the combined gas space of units containing suspended films is much greater. With respect to pressure distribution between the glass panes, such units behave as if the film were not there; the flexibility of the film allows the space it separates to pressure-equalize across it.

Improvement in the IGU Design

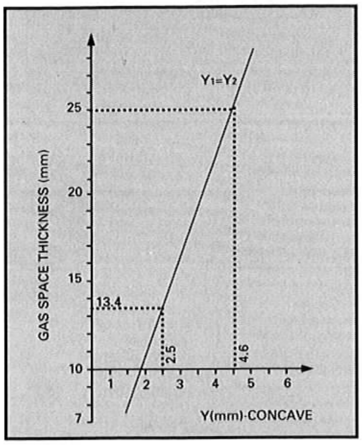
In a shop-sealed insulating unit, the deflection of each glass pane is inversely proportional to its rigidity, which in turn is proportional to the cube of the glass thickness. Consequently, visual distortion can be controlled by increasing the outside pane's thickness, while making the inside pane thinner. Such a modification will also increase the overall strength of the IGU, since most of the exterior loads (wind, snow) will be carried by the thicker glass sheet. Returning to the case study, using a nominal 5/16″ (8 mm) exterior glass sheet and a 3/16″ (4 mm) interior sheet, and keeping the air space at 1/2″ (13.4 mm) will result in a substantial reduction of the outside pane's deflection (9, 10) and an increase in the inside pane's deflection. Although inside reflections are not normally as apparent (and therefore not as troublesome) as exterior reflections, increased deflection of the inside pane may not be acceptable under all circumstances.

For the same temperature and pressure used in the case study (T = −22 F and P_{baro} = 102 kPa), the outside pane deflection is 22 mils (0.56 mm) and the deflection of the inside pane is almost 3/16″ (4.5 mm). The resulting distortion of outside reflections will be approximately five times less than in the standard unit. When compared to a standard unit, this modification will improve the acoustic performance of the unit (see P/A, Aug. 1991, pp. 115–120) and will not affect the thermal resistance.

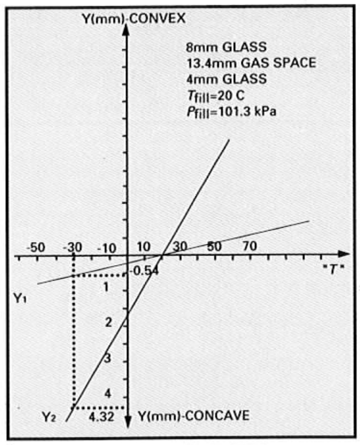
Acceptable Deflection Limits

To maintain the architectural lines of exterior glass walls, the designer should specify an acceptable limit for exterior glass pane deflection. Since this is a visual issue, the human eye is the best detection instrument. There is no accepted procedure or consensus about what is acceptable, and some people (both designers and clients) are more aware of or sensitive to distortions than others.

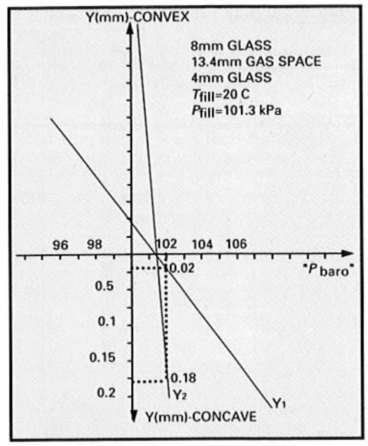
For a given sealed unit, the deflection of a glass sheet is limited by its smallest dimension. The straightness of a reflected straight line, therefore, can be expressed by the ratio of the deflection (Y) to the glass's



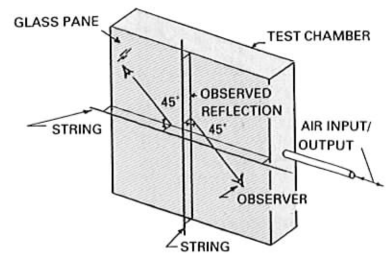
8 DEFLECTION AS A FUNCTION OF GAS SPACE



9 DEFLECTION AS A FUNCTION OF *T*



10 DEFLECTION AS A FUNCTION OF P_{baro}



11 DISTORTION VIEWING TEST SET-UP

smallest dimension (*L*). I suggest that the "*Y/L*" ratio defining the acceptable limits of deflection is on the order of 1/700 to 1/1000. (For small IGUs, the suggested values should be checked to ensure that stresses are kept low.) These figures were obtained from the subjective responses of five individuals, looking at an angle of 45° at a glass surface reflecting the image of two orthogonal strings. The glass was subjected to a uniform load under laboratory conditions (11).

Design Conditions

Because exterior distortions are most noticeable during daytime, the acceptable deflection limit should be established for the average design conditions to which the insulating unit will be subjected in summer and winter. Those design conditions will vary with the building's geographic location, orientation, and interior protection (blinds and shades, which affect the temperature of the gas space), and with the specifications of the sealed unit (thermal resistance, absorptivity, reflectivity, transmissivity, and the factors discussed above). The following weather data should be considered during daytime in summer (June and July) and winter (December and January):

- Average solar irradiation (orientation)
- Average outdoor air temperature
- Average wind speed
- Indoor air temperature
- Interior protection (blinds, shades, drapes, etc.)
- Average barometric pressure

With the exception of barometric pressure, all these factors affect the temperature of the IGU gas space. Weather data are readily available for most locations (in the *ASHRAE Fundamentals Handbook*, for example) and technical data on the glass can usually be obtained from the insulating glass unit manufacturers.

Conclusions

Current standards (CAN12.20-M89 and ASTM E1300–89) allow the designer or the manufacturer to determine the glass thickness required to resist loads from wind and snow. However, to ensure and maintain the acceptability of the exterior appearance of reflective curtain walls or any large glazed area, it is also important to limit the deflection "*Y*" of the glass to an acceptable value for normal use conditions. Our work suggests that the deflection should not exceed *L*/1000.

Deflections and distortions can be reduced by increasing the rigidity of the exterior glass pane relative to the inside pane. This approach also allows an improvement of the acoustical performance of insulating units and, because of the wind-load-sharing, a possible reduction in the total glass thickness required. Specifying an acceptable limit to exterior glass deflection in new designs can benefit all parties involved, allowing architectural features to be viewed as originally intended. **Armand Patenaude, PE** ■

Related Reading

Pressures and Stresses in Sealed Double Glazing Units, K. Solvason, NRCC 14167, National Research Council Canada, Ottawa (613) 993-1585, 1974, 19 pp.

Structural design of glass for buildings, CAN/CGSB-12.20-M89, Canadian General Standards Board, Hull, Quebec (819) 956-0425, 1989, 92 pp.

Standard Practice for Determining the Minimum Thickness of Annealed Glass Required to Resist a Specified Load, E 1300–89, ASTM, Philadelphia (215) 299-5585, 11 pp.

"Weather Data." Chapter 24, ASHRAE *Handbook*, 1989 Fundamentals volume, ASHRAE, Atlanta (404) 636-8400.

* These calculations are based on the fact that the mass of gas contained within IGUs is constant and that a change in barometric pressure surrounding the IGUs will cause the glass sheets to deflect until a new equilibrium state of both sheets is reached. The calculations disregard the influence of the glass-to-spacer interface and adsorption of gas filler by the desiccant.

4 *Deflections caused by temperature and barometric pressure changes are identical in IGUs with identical lights.*

5 *The following case studies all assume these dimensions.*

6, 7 *If the IGU is sealed at 20 C, a gas space temperature of −30 C produces a (concave) deflection of 2.4 mm. If sealed at a barometric pressure of 101.3 kPa, an increase to 102 kPa produces a (concave) deflection of 0.1 mm. These deflections are additive, for a total of 2.5 mm.*

8 *Increasing the gas space thickness from a standard 13.4 mm to 25 mm increases the deflection of each light under the foregoing conditions from 2.5 mm to 4.6 mm.*

9, 10 *"Unbalancing" the IGU by using thicker glass on the outside and thinner glass on the inside reduces exterior deflection (Y_1) and increases interior deflection (Y_2). The thicker exterior glass deflects only 0.54 mm at −30 C, and 0.02 mm at 102 kPa, while the interior glass deflects 4.32 mm and 0.18 mm under these same conditions.*

11 *Laboratory viewing assembly.*