NSG GROUP

Technical Bulletin

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THERMAL STRESS

Summary

Window glass is heated and cooled by visible and invisible (infra red) radiation from the sun and other heat sources; by natural and forced convection from wind, air from HVAC vents, etc.; and by conduction from contact with framing and other materials. The small differential expansions and contractions of the hot and cold areas create stresses which, if they are excessive, can cause breakage of ordinary annealed glass.

STRESS

The expansion of ordinary window glass with heat is small but can be of considerable consequence. For example, a piece of glass 50″ x 100″, when heated from 0 to 100°F, will only increase in size to 50.025″ x 100.049″. See: ATS #129 for thermal expansion coefficient, and Pilkington North America, Inc. "Good Glazing Techniques" brochure for proper glazing clearances, etc., to accommodate this expansion.

When the glazed edge of a window light is shielded from sunlight by the frame, this covered edge will generally be cooler than the central area which is exposed. The expansion of the central warm area will be resisted by the cool edge. Typically, the hotter exposed area is much larger than the cooler edge area and so the edges are stretched into a state of tensile stress of about 50 psi (pounds per square inch) for every degree ºF difference between the center and the edge. On a calm day, sunlit heat-absorbing window glass can easily reach 40°F above the ambient air temperature. The covered glass edge temperature will be somewhere between that of the ambient air and the exposed glass. The frame detail determines how much heat reaches the edges; e.g., a deep concrete frame insulates the edges, while structural silicone glazing allows edge heating almost equal to that at the exposed area. In the example above with 40 °F temperature difference a stress of 40°F x 50 psi / °F or 2000 psi will be developed if the edge is fully insulated from direct solar heating.

Pilkington North America, Inc.

811 Madison Avenue, Toledo, Ohio 43604-5684

Telephone 800 221 0444 Fax 419 247 451

Typical, high stress fracture, originating at the right hand side. In this case insulation behind an annealed, heat absorbing glass and the shadow from an overhang caused excessive stress on a clean cut edge.

EDGE STRENGTH

When the tensile stress in a glass edge exceeds 2,000 to 3,000 psi, the probability of breakage becomes significant. The actual edge strength depends on the cut edge quality. The edges must be 'clean cut' (with minimum serration, hackle, etc.), fabricated (into insulating glass units, etc.) without damage from sealant nozzles, tools, hard surfaces, etc., and then handled and installed without being damaged to minimize breakage probability.

Fully polishing the edges of annealed glass will lessen the probability of transport and installation damage. A fully polished edge has a higher resistance to thermal stress breakage.

SHADOWS

Shadows from vertical mullions and horizontal frame overhangs cause temperature differences in heat-absorbing glass. If a vertical mullion is less than 20" deep, then its shadow can be considered "mobile" as it sweeps across the glass because it does not remain stationary long enough to develop major temperature differences. Vertical mullions 20" to 30" deep develop "static" shadows which create higher glass stress. Overhangs greater than 3" deep develop static shadows. Mobile shadows typically develop 11% more stress than the "no shadow" situation. Static shadows develop about 35% more stress than the "no shadow" condition.

Unusual shadow patterns, e.g. "V" or "L" shaped shadows, cause higher stresses than the simple cold edge case detailed above. It has been shown theoretically (Boley, 1964), and measured in practice, that the resulting stresses are not more than 30% greater than that for the basic condition of a hot central area with cold edges.

HEAT TRAPS

Heat Trap conditions caused by insulating blinds, drop ceilings below the level of the top of the glass, heat-absorbing labels or decorations on the glass, etc., can cause larger temperature differences than are allowable for annealed glass and may cause breakage.

Spandrel glazing represents the extreme heat trap condition where insulation, and restricted air flow on the room side, prevents the solar heat which has passed through the glass from entering the building. The only way for this heat, which is absorbed on the outer facing surface of the spandrel pan insulation, to leave the spandrel is by raising the glass temperature sufficiently for external convection and radiation from the outer glass surface to balance the heat input. Obviously such a condition can develop major temperature differences in the glass. Heat-strengthened or tempered glass is typically used in spandrels to prevent breakage from thermal stress, except in unusual conditions where the heat gain is ventilated to the exterior or there are no shadows or edge cover to develop large temperature differences. Heat strengthening the inner light of an IG spandrel may not be sufficient to prevent breakage in relatively high solar transmission units with low-e coatings and ceramic frit on #4 surface. Fully tempered glass may be needed for the room-side light.

HVAC

Heating, Ventilating and Air Conditioning vents which blow hot or cold air directly against glass will also cause excessive tensile edge stress in annealed glass edges, resulting in possible glass breakage.

UNIQUE CONDITIONS

Unique installations can cause potentially damaging temperature differences to occur. Some examples are given below:

1. Large horizontal sills in front of vertical or sloped heat absorbing glass where snow can accumulate. When the exposed portion of the glass absorbs sunlight a large temperature difference can easily develop between the exposed area and the portion of the glass shaded and cooled by the snow.

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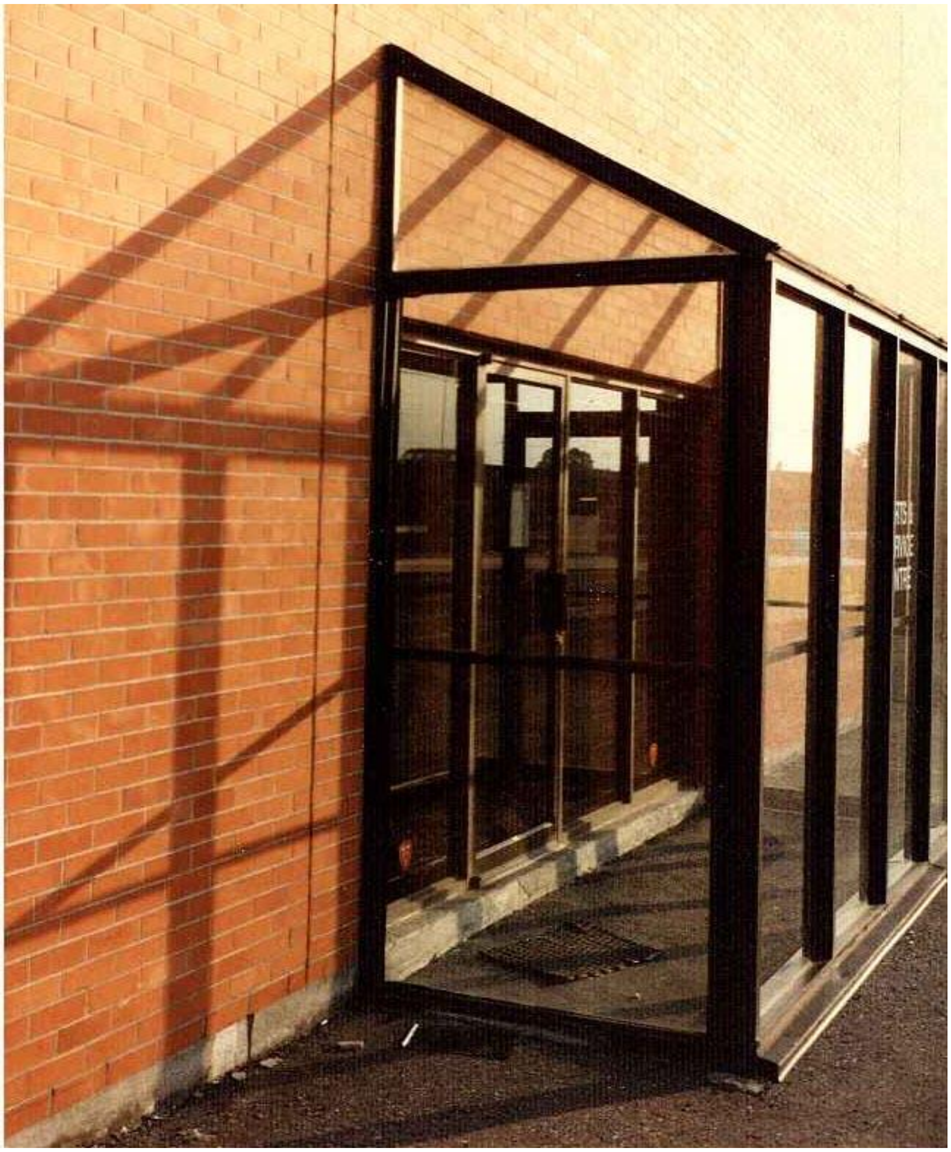
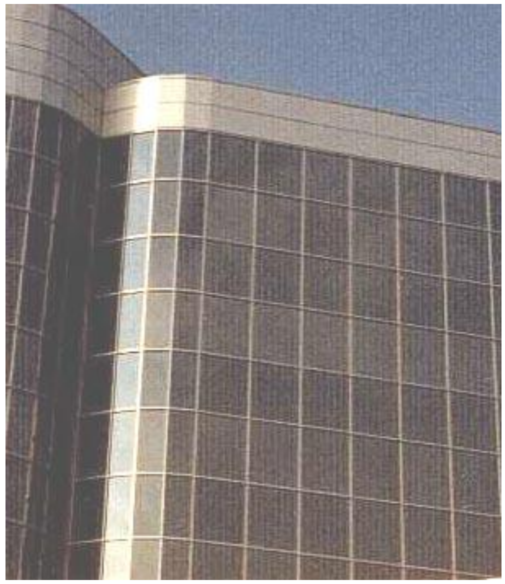
2. When sloped glazing meets a vertical wall a heat trap condition is easily generated at the interior by the rising hot air caused by sunlight, which has passed through the glass, when it is absorbed on the wall surface and then heats the air. Such a space needs to have a ventilation system to prevent the hot air from accumulating.



3. Inside corner reflections (where two curtain wall sections meet at a 90 deg angle, measured on the exterior, in plan view) cause increased temperature differences in glass when the heat from the grazing solar reflection of an adjacent glazing is added to the direct solar radiation.



SOLAR ABSORPTION

The temperature reached by the exposed glass depends on its Solar Absorption. This value is available from: brochures; LBNL Window 5 or 6 program; or the glass manufacturer. It can often be calculated from the relation:

Solar Transmission (%) + Solar Reflection (%) + Solar Absorption (%) = 100 (%)

Double glazing changes the amount of heat absorbed by each light depending on the inter-reflections between the two glasses. The effective absorption of the outer glass is typically increased over its nominal single glazed absorption value, while the effective absorption of the inner light is reduced from its single glazed value. These effective absorption values are computed in the 'Optical Data' section of the LBNL Window 6 program.

The use of low emissivity coatings reduces radiant heat flow from the coated side. This increases the resulting glass temperature and stress. Note: the Window 5 or 6 program can be used, with custom ambient conditions (strong sun and no wind), to estimate resulting glass temperatures.

Triple glazed units have a unique condition where the absorbed heat in the middle light of glass faces insulating layers of still air on each side. The center light temperature can then rise significantly, depending on its absorption value. If a low emissivity coating is on the center light that both adds to the absorbed solar radiation and further inhibits the loss of heat from it. In general, a clear glass as the middle light of a sealed triple unit, with a low emissivity coating on either surface #3 or #4, will need to be heated treated to prevent breakage from thermal stress.

CONCLUSION

Where glass temperature differences and the resulting thermal stresses are too great for ordinary (annealed) glass, then heat-strengthened or fully tempered glass can be used to prevent breakage. High stresses caused by deep shadows, heat traps, insulating blinds, etc. can be accommodated by either heat strengthening or fully tempering the glass.

Fully polishing the edges of annealed glass may confer sufficient strength to resist breakage in marginal thermal stress situations.

Both products (heat-strengthened and fully tempered) are generally strong enough to prevent breakage from typical thermal stresses encountered in vision glass in buildings. Heat strengthening is generally preferred, where safety codes permit, because of the reduced risk of the spontaneous breakage which can occasionally be seen with tempered glass. Insulating glass spandrels with ceramic frit on #4 surface may need the added strength of tempered glass for the room-side light.

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