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Potential for Thermal Breakage of Sealed Double-Glazing Units

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Please note

Sealed double-glazing units with low shading coefficients and low U-values (**CBD 101**) have been in use for some time (Table I). Unfortunately, designers often overlook the fact that sealed units with superior thermal performance experience greater thermally induced stresses than do ordinary sealed double-glazing units. These stresses, by themselves, will not cause good quality glass to break, but when they are added to other stress in the glass they can result in breakage. This Digest discusses the causes of thermally induced stresses and indicates how they can be kept to a minimum.

Table I. Thermal Characteristics of Some Sealed Units (½-In. Air Space)

Sealed Units	Solar Transmittance	Solar Reflectance	Solar Shading Coefficient	U-Value (Winter) (Btu/hr ft²°F)
1. Two clear panes	0.64	0.13	0.81	0.50
2. Outer pane -- heat absorbing Inner pane -- clear	0.37	0.07	0.55	0.50
3. Outer pane -- heat reflecting (high-emissivity coating)	0.13	0.25	0.26	0.50
4. Outer pane -- heat reflecting (low-emissivity coating) Inner pane -- clear	0.16	0.33	0.25	0.31
5. Outer pane -- clear Inner pane -- heat reflecting (low-emissivity coating)	0.16	0.48	0.32	0.31

Many factors affect the thermal stresses occurring in sealed glazing units; outdoor environmental conditions, design of the sealed unit, type of glass used, window and glazing design, type and location of shading devices, configuration of the terminal units of the heating and cooling system. All should be considered at the design stage if breakage problems are to be avoided.

Both panes of a sealed glazing unit experience thermally induced stresses. In the outer pane thermal stress is caused by solar radiation falling on the unit when the outdoor air is cool. Breakage resulting from this stress is termed "solar breakage." Sealed units located on east and west elevations experience their maximum solar-induced stress in the spring and fall; those located on the south elevation experience their maximum in winter.

Thermal cracking of the inner pane is usually associated with very low outdoor air temperature and localized heating on the inside pane. This type of breakage can be termed "cold-weather breakage" to distinguish it from solar breakage. In winter, all sealed units in a building experience some thermal stress on the inner pane and hence have some potential for cold-weather breakage.

The thermal stress in both inner and outer panes of a sealed unit is produced by the same conditions (Figure 1). Tensile stress is produced at the edge of a glass pane when the temperature at the edge is lower than that over the centre. Glass breakage occurs when this stress together with other tensile edge stresses exceed the edge strength of the glass. It should be emphasized that thermal breakage in sealed units is not just a function of thermal stress but is very much dependent on the edge strength of the glass (**CBD 60**) and on edge stresses introduced by factors such as glass deflection, edge restraint, and residual glass stresses.

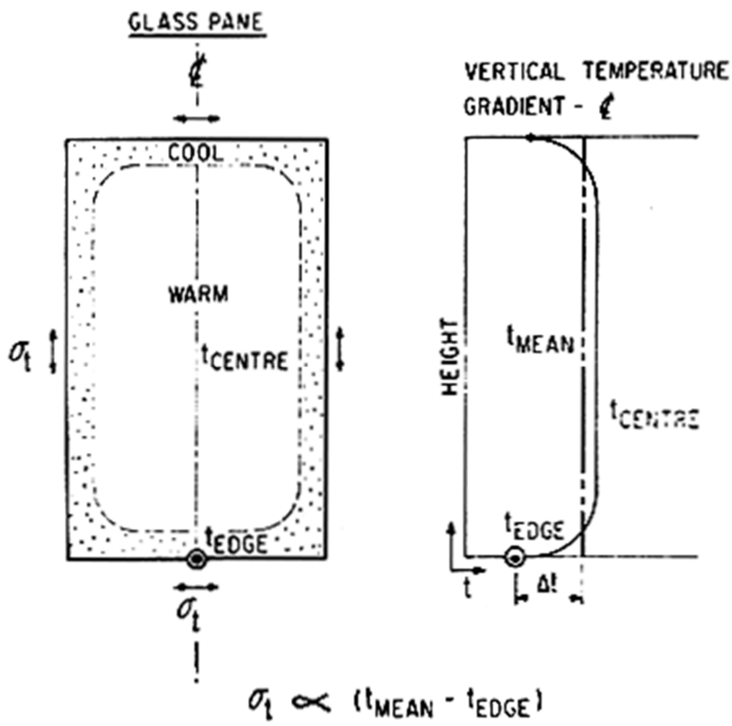

Figure 1. Thermal tensile stress, σ_t

The difference between the mean temperature of the pane and the temperature at the edge is a measure of the potential for thermal breakage. Some sources claim that breakage of normal undamaged glass in the absence of secondary stresses should not occur when this temperature difference is less than about 60 Fahrenheit degrees. If other stresses are present or if poor quality glass is used, however, breakage can occur at a lower value. The potential for breakage of a pane of glass increases when the centre of the pane gains more heat than the edge or loses heat less readily than the edge. This holds for both the inner and the outer pane of a sealed unit.

Solar Breakage Potential of the Outer Pane

In cool weather and in the absence of solar radiation, the outer pane of a sealed unit, both edge and centre, is relatively cool. When this cool pane is suddenly subjected to solar radiation, the temperature of the centre portion of the pane is raised by the absorbed radiation but the edge, being shaded from direct radiation, experiences a much smaller temperature rise. This differential in the rate of heating of the edge and centre of the pane results in a temperature difference and produces thermal stress.

The primary factors affecting the magnitude of the thermal stress in the outer pane are its absorptance, reflectance of the inner pane, and thermal resistance of the air space. The thermal stress will be high, therefore, when the air space resistance is large, as is the case when a low-emissivity metallic coating faces the air space.

Table I lists typical thermal characteristics for several types of sealed units. An analysis of the absorption and reflection characteristics, as shown in **CBD 101**, indicates that a unit with a low-emissivity reflective coating on the inner pane has a higher thermal stress in the outer pane than a clear unit; and that units with a heat-absorbing or heat-reflecting outer pane have an even higher stress. It is very important, therefore, when using these sealed units with low values of shading coefficient to consider carefully all the other factors that might increase the tensile stress at the edge of the unit.

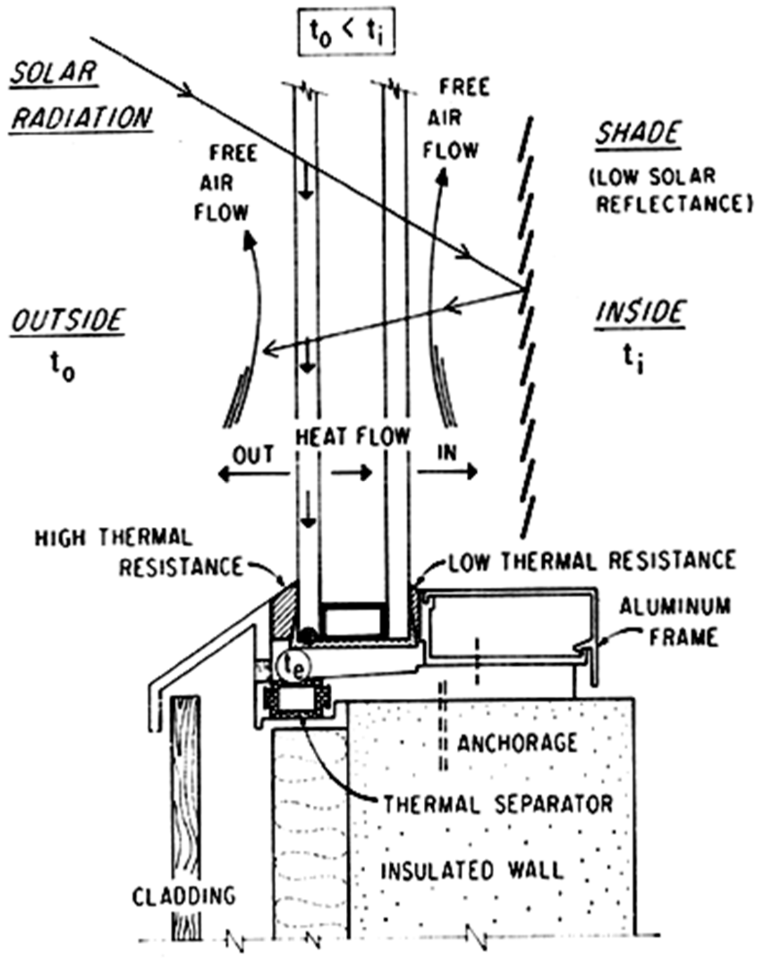

Figure 2. Factors affecting solar breakage potential of the outer pane.

Other factors affecting the thermal tensile stress in the outer pane are shown in Figure 2: reflectivity of an inside shading device, thermal resistance between the edge of the glass and the cool parts of the frame or supporting wall, depth of the window reveal with consequent shading of the edge of the window, and airflow over the window. A light coloured curtain or blind increases the edge thermal stress by producing more absorption in the outer pane. A designer should not specify light coloured inside shading devices, therefore, in conjunction with a window that, by itself, has a low shading coefficient. The slight reduction in the over-all shading coefficient of such a window when a light coloured rather than a medium or dark coloured shade is used is generally not commensurate with the increased risk of solar breakage.

Thermal stress in the outer pane can be reduced substantially in an aluminum frame such as that shown in Figure 2 by the use of a glazing material with high thermal resistance on the outside and low thermal resistance on the inside and by having the window frame anchored to the warm part of the wall. This can be easily arranged when the insulation is on the outside of the structural part of the wall, as is recommended in **CBD 50** and **CBD 94**. Such a window design, which isolates the edge of the sealed unit from the outside environment, will also minimize condensation on the inside frame and glass surfaces in cold weather and reduce the breakage potential of the inner pane, as will be explained.

A deep window reveal or an external shading device that shades the edge of the sealed unit will tend to increase edge thermal stress. They should not be employed, therefore, unless the favourable glazing and frame anchoring described above are used to offset the unfavourable effect of edge shading.

Any restriction of airflow over the inner or outer surface of the window will tend to increase the temperature at the centre of the window and hence will increase the thermal stress in the outer pane. Interior and exterior shading devices should be positioned so as to permit reasonably good air circulation between them and the window surface.

Cold-Weather Breakage Potential of the Inner Pane

The primary cause of edge thermal stress in the inner pane is the action of the indoor-outdoor air temperature difference on the sealed unit. The construction of a sealed unit is such that the thermal resistance of the air space is greater than the resistance of the edge spacer. In cold weather, therefore, the mean temperature of the inner pane will be warmer than the edge temperature.

A heat-reflecting sealed unit with a low-emissivity coating on either pane has a greater airspace resistance and a lower U-value than the clear unit, the heat-absorbing unit, or the heat-reflecting unit with a high-emissivity coating. A consequence of greater air space resistance, however, is that this type of unit has a higher thermal stress in the inner pane. The design of the window frame and the configuration of the inside drape and heater terminal unit must, therefore, be given more consideration when using low-emissivity reflective units if cold-weather breakage problems are to be avoided (Figure 3).

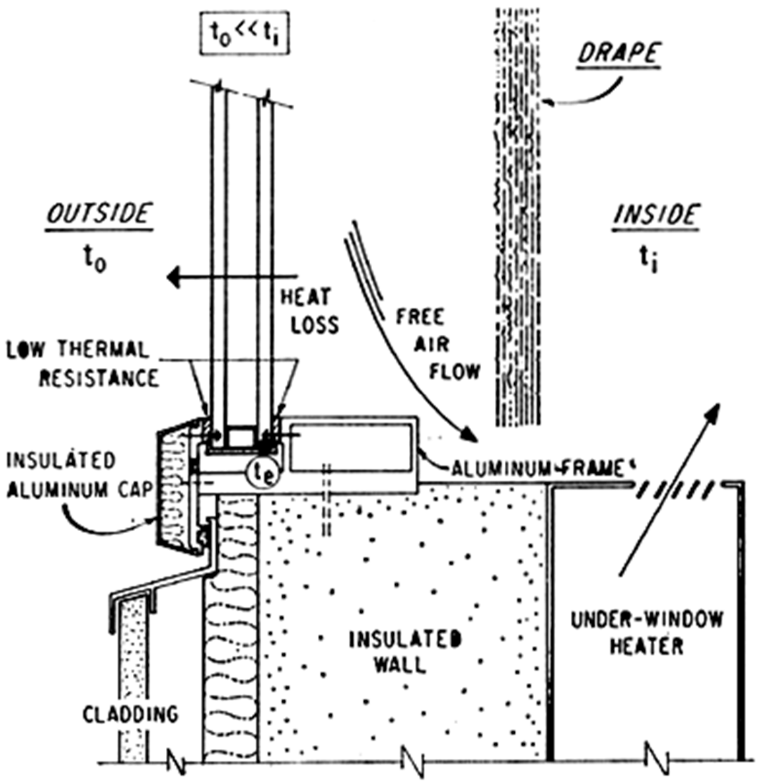

Figure 3. Factors affecting cold-weather breakage potential of inner pane.

Window frame and glazing details that provide a warm environment for the edge of the sealed unit will reduce thermal stress in the inner pane as well as that in the outer. A window detail such as that shown in Figure 2 can therefore be used to reduce thermal stress in the inner pane. Figure 3 illustrates another window design that will reduce this stress. An insulated aluminum cap isolates the main frame member from the cold outdoor environment; glazing material with a low thermal resistance is used inside and outside to provide good thermal contact between the edge of the unit and the main frame member. A large frame area exposed to the inside air and anchorage of the frame to the warm part of the wall ensures a warm frame. When a sealed unit is glazed directly into a precast or masonry wall panel, it must be thermally isolated from the cold part of the wall with insulation or a high-resistance glazing material in order to minimize heat loss from the edges.

Interior curtains should not be located on the room side of an under-window heating unit because trapped hot air will increase thermal stress in the inner pane. They should be hung between the heater and the window, with sufficient clearance, top and bottom, to permit free air exchange between the room and the space behind the curtain. This last condition will help prevent condensation on the inside window surfaces.

The discharge from forced-convection heaters located under the window should be directed away from the window to avoid localized heating of the inner pane that can greatly increase thermal stress. Another heater characteristic that can affect thermal stress is the type of control used with under-window heaters. A modulating control is preferable to a simple on-off control. The latter permits the sealed unit to cool during the off time; then when the heater comes on at full power the centre of the inner pane is heated much more rapidly than the edge, thus creating a high thermal stress.

One last factor that may affect the thermal stress in the inner pane of heat-reflecting units with low U-value is solar radiation. Calculations indicate that solar radiation will produce a higher thermal stress in the inner pane if the low-emissivity coating is on it rather than the outer pane. Limited studies of sealed unit failures on real buildings, however, have not shown any definite relation between solar radiation, inner-pane breakage, and location of the reflective coating.

There still remains a question regarding the proper location of the low-emissivity coating in heat-reflecting units. It is known that solar radiation produces a high-thermal stress in the outer pane when the coating is on the inside of the outer pane. Calculations indicate that an equally high thermal stress should occur in the inner pane if the coating is on the outer surface of the inner pane. This has not been substantiated by field experience to date. As there is no marked advantage for one location over the other, the low-emissivity coating might just as well be located on the outer pane because this gives a lower shading coefficient.

Summary

Both panes of factory-sealed double-glazing units are susceptible to thermal breakage. The outer pane experiences large thermally induced stresses when solar radiation falls on the sealed unit in cool weather. The breakage potential is even greater for units with heat-absorbing or heat-reflecting glass in the outer pane than for units with a clear outer pane. The inner pane experiences a high thermal stress when the outdoor air temperature is very low and the unit is subjected to localized heating. The breakage potential of the inner pane is greater for heat-reflecting units with a low U-value than for clear, heat-absorbing, or high-emissivity heat-reflecting units.

Measured and calculated values of thermal stress for inner and outer panes of sealed glazing units indicate that thermal stress by itself should not cause glass breakage. Extensive breakage failure will only occur if the thermal stress is augmented by other tensile stresses or if weak or damaged glass is used. In the absence of a reliable method of predicting the probability of thermal breakage in sealed units, however, all factors that can possibly reduce the potential for breakage should be accommodated in design. This is especially true for units with heat-absorbing and heat-reflecting glass.