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THERMAL - BREAKAGE POTENTIAL OF SEALED GLAZING UNITS

BY

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POTENTIEL DE BRIS DES VITRAGES ISOLANTS PAR TEMPS FROID

par

J.R. Sasaki

SOMMAIRE

Par temps froid, les vitrages isolants hermétiquement fermés à l'usine subissent des contraintes thermiques qui peuvent causer le bris de la paroi intérieure. Le potentiel de bris dépend de la différence entre la température moyenne et la température à la rive de la paroi intérieure. Il dépend des propriétés de l'élément de vitrage lui-même: résistances thermiques de l'espace d'air et du profilé d'espacement. De plus, le potentiel de bris dépend des caractéristiques thermiques du châssis dans lequel le vitrage est monté, des caractéristiques thermiques de l'installation et de la forme et la position de la source de chaleur. L'article rapporte les résultats d'essais en laboratoire sur les effets de ces divers facteurs sur le potentiel de bris des vitrages isolants par temps froid.

ANALYZED

Thermal-breakage potential of sealed glazing units

by J. R. Sasaki

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SYNOPSIS: In cold weather, sealed double-glazing units experience thermal stresses that can lead to breakage of the inner pane. The potential for thermal breakage is related to the difference between the mean temperature and the edge temperature of the inner pane.

Breakage potential is affected by features of the sealed unit itself, such as the thermal resistance of the glazed air space and of the edge spacer. In addition, the breakage potential is affected by the thermal characteristic of the window member in which the sealed unit is glazed, by the thermal characteristics of the glazing method, and by the configuration of the heating terminal unit.

The effects of the above factors on the cold-weather breakage potential of sealed units were investigated in laboratory tests, and are herein reported.

A pane of glass will experience a tensile stress at the edge whenever the temperature of the edge is lower than the temperature of the central part of the pane. The glass will crack if this edge stress exceeds the value that the glass can withstand. This is generally referred to as "thermal breakage."

Other things being equal, a pane of glass with a large difference between mean temperature and edge temperature is more apt to break than one with a smaller difference. This difference can, therefore, be used as an indicator of "thermal-breakage potential." Glass deflection, edge restraint and edge strength are also factors that affect glass-breakage potential but they will not be considered in this paper.

Large temperature differences can occur in the outer pane of a heat-absorbing type of sealed double-glazing unit when the central part of the pane is subject to intense solar radiation, while the edges are shaded and in contact with a cold frame. Similarly, the inner pane of a double unit experiences high edge stresses when the central region is much warmer than the edges.

This paper deals with the factors affecting edge stresses on the inner pane; these are usually associated with cold weather. Solar breakage of sealed units will be the subject of a later paper.

The thermal resistance at the edge of a sealed unit is always lower than that of the air space. In cold weather, therefore, the edge temperature of the inner pane is always lower than the temperature of the central portion. This difference is often increased when efforts are made to raise inside window surface temperatures to reduce condensation.

The mean-pane temperature is increased when a heater unit is located beneath the window and discharges heated air against the inner pane. A high mean-pane temperature also occurs in sealed units with a reflective metallic coating on one of the glass surfaces facing the air space.

The metallic coating, although intended primarily for reducing solar heat transmission, also reduces long-wave radiation transfer across the air space and raises inner-pane temperatures.

The thermal-breakage potential of sealed units can be reduced by increasing the edge temperature of the inner pane. The factors affecting edge temperature can be deduced from a simple heat balance between the sealed unit, the window frame, and the inside and outside environments, as illustrated in Fig. 1. The edge temperature of the inner pane, should increase if the following conditions exist:

(1) The thermal resistance of the edge spacer in the sealed unit is high. (Resistance is directly proportional to the length of the heat flow path, and inversely proportional to the conductivity and cross-sectional area of the heat flow path.)

(2) The thickness of sealant, s, between the glass and edge spacer is large.

(3) The thermal resistance of the inner-glazing seal is low relative to that of the outer seal.

(4) The outside edge covered by the frame is large relative to the inside edge cover. This situation will be advantageous only if the

thermal resistance of the outer edge cover is relatively high. (An inherent danger in this approach is that a large outer edge cover increases the potential for outer-pane breakage due to solar radiation.)

The thermal resistance of the glazing seals (condition 3) will have a favourable effect on edge temperature only when the inside frame temperature, t_f, adjacent to the sealed unit is high. This temperature will be high when the inside frame member has both a low resistance and a large area exposed to the inside air, and when the outside frame member has a high resistance or contains a high-resistance thermal separator.

This paper describes a study that was designed to show the influence of the foregoing factors, and of glass type, and under-window heating on the thermal-breakage potential of sealed multiple-glazing units. The first part of the study investigated the effects of the design of the units themselves. A group of twenty units comprising both idealized and proprietary units was tested; the units differed in air space thickness, edge spacer resistance, sealant thickness and edge protection.

The second part of the study investigated the effects of frame design, glazing detail and heater configuration on the thermal-breakage potential of two sealed double-glazing units. One of the units was an ordinary clear unit, the other had a low-emissivity metallic coating on the air-space surface of the inner pane.

LABORATORY INVESTIGATION

The studies were conducted in the DBR/NRC cold-room facility[1] with the specimen in a partition separating the cold and warm rooms.

The air temperature in the cold room was controlled at -20°F and a surface conductance value of approximately 4.5 Btu/hr ft²°F was provided over the cold face of the specimen. The air temperature on the warm side was controlled at 72°F. In the investigations with natural-convection air flow, a surface conductance value of approximately 1.2 Btu/hr ft²°F was provided over the warm face of the specimen. The heater configurations providing forced-convection air flow on the warm side are described later.

Surface temperatures were measured with thermocouples attached to the metal and glass surfaces. The reference cold air temperature, t_c, was measured at the mid-height of the specimen and 4-1/2 in. from the cold face of the specimen. With natural-convection air flow on the warm side, the reference warm air temperature, t_w, was measured at the mid-height of the specimen and 6 in. from the warm specimen face. With forced convection on the warm side, t_w, was measured 12 in. from the warm specimen face.

The measured surface temperatures, t, were expressed as a temperature index defined as:

$$I = \left(\frac{t - t_c}{t_w - t_c}\right) \times 100$$

where

t measured surface temperature, °F

t_w reference warm air temperature, °F

t_c reference cold air temperature, °F

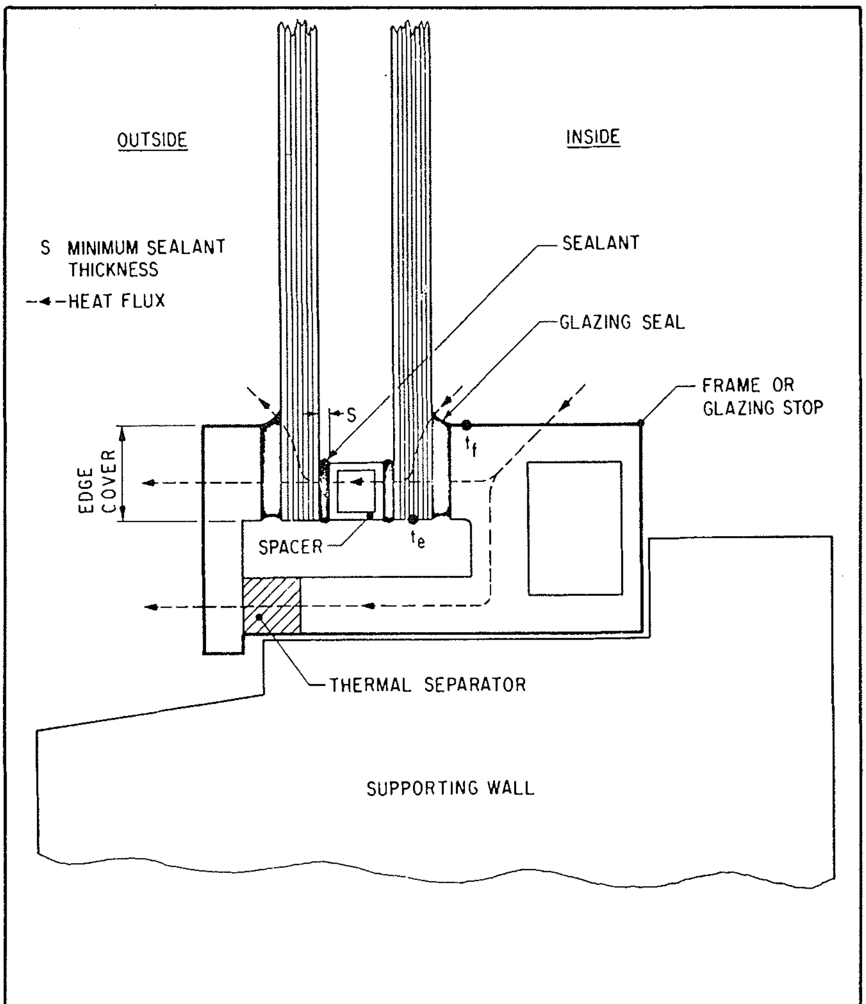


FIGURE I HEAT BALANCE AT EDGE OF SEALED UNIT

EFFECT OF GLAZING-UNIT DESIGN ON EDGE TEMPERATURE

The design features of the units studied are shown in Fig. 2 and described in Table I. The units were approximately 14 in. wide by 20 in. high. Of the twenty units, nineteen were double glazed and one, Unit 20, was triple glazed. All units were sealed with the exception of the idealized units (1, 2, 3 and 11).

Units 1 and 11, which had polystyrene spacers, were intended to show the optimum edge-temperature performance obtainable with sealed double-glazing units. Units 2 and 3 were idealized attempts at using spacer materials with a lower thermal conductance. Units 9, 12, 13 and 20 were developmental units, and the remaining twelve units were proprietary units currently on the market.

The units were tested in the configuration shown in Fig. 3. Surface and edge temperatures were measured along the vertical centre line of the inner pane.

TABLE I

DESCRIPTION AND INSIDE EDGE-TEMPERATURE PERFORMANCE OF SEALED UNITS*

SEALED UNITS		SPACER					CAP	THERMAL PERFORMANCE		
Type	Air space thickness (in.)	Type	Material (k)	Sealant thickness S - (in.)	Primary Sealant	Secondary Sealant	Material (k)	I (mean)	I (edge)	ΔI (mean-edge)
(1) Idealized	1/2	solid	polystrene (0.3)	-	-	-	-	62	52	10
(2) Idealized	1/2	solid	neoprene (1)	-	-	-	-	62	43	19
(3) Idealized	1/2	hollow	aluminum (1400)	0.125	neoprene	-	-	62	39	23
(4)	1/2	rolled (1)	st. steel (115)	0.005	PIB	-	st. steel (115)	62	37	25
(5) cap on	1/2	rolled (1)	st. steel (115)	0.025	PIB	PS	st. steel (115)	62	37	25
cap off								62	39	23
(6)	1/2	soldered	lead (240)	0	-	-	-	62	35	27
(7)	1/2	extruded	lead (240)	<0.002	epoxy	PIB	-	62	35	27
(8) cap on	1/2	rolled (1)	steel (300)	<0.002	PIB	-	st. steel (115)	62	33	29
cap off								62	36	26
(9)	1/2	rolled (1)	aluminum (1400)	0.020	PIB	PS	-	62	39	23
(10)	1/2	rolled (1)	aluminum (1400)	0.005	PIB	PS	aluminum (1400)	62	35	27
(11) Idealized	1/4	solid	polystyrene (0.3)	-	-	-	-	57	51	6
(12)	7/32	extruded	plastic (2)	<0.002	PIB	-	-	57	39	18
(13) cap on	3/8	solid	plastic (2)	<0.002	PIB	-	st. steel (115)	60	37	23
cap off								60	40	20
(14)	5/32	glass edge	glass (6)	-	-	-	-	55	43	12
(15)	1/4	soldered	lead (240)	0	-	-	-	57	37	20
(16)	9/32	rolled (2)	steel (300)	0	PS	-	-	57	36	21
(17)	9/32	rolled (2)	aluminum (1400)	0	PIB	PS	aluminum (1400)	57	36	21
(18)	9/32	rolled (2)	aluminum (1400)	0	PS	-	-	57	38	19
(19) cap on	1/4	extruded	aluminum (1400)	< 0.002	PIB	-	steel (300)	57	37	20
cap off								57	38	19
(20) Triple-glazed cap on	3/16	rolled(1)	steel (300)	<0.002	PIB	-	st. steel (115)	62	37	25
cap off								62	38	24

* NOTES

k = thermal conductivity, Btu-in./hr ft^2 °F
S = minimum sealant thickness, in.
I (mean) = mean temperature index of inner pane,
I (edge) = temperature index at bottom edge of inner pane,
PIB = polyisobutylene sealant
PS = polysulphide sealant.

The surface temperature characteristics of the twenty units are listed in Table I. The term, "edge temperature," used in the following discussion refers to the lowest temperature on the inner pane; this temperature always occurred along the bottom edge.

(a) Edge-temperature performance

The edge-temperature index of the units ranged from a high of 52 to a low of 33. The edge indices of the ideal units (1 and 11) were 52 and 51, respectively, confirming, with these high values, the low thermal conductivity of the polystyrene spacer (k=0.3 Btu-in./hr ft^2 ^{o}F). Both Unit 2, with the solid neoprene spacer (k= 1), and Unit 14, with the welded glass edge (k=6), had an edge index of 43. Units 12 and 13, which had reinforced plastic spacers (k=2), had edge indices that were similar to those of the units with metal spacers (k =115 to 1400). For the majority of the units, therefore, the edge temperature was not greatly dependent on the conductivity of the spacer.

The edge temperatures of the units with 1/2-in.-thick metal spacers appeared to be partly dependent on sealant thickness, but the units with 1/4-in.-thick spacers did not show a similar dependence. The edge indices of the latter units varied from 36 to 38, and were comparable to the indices of the 1/2-in. units that had greater sealant thickness. This anomaly might be due to the reduced convective heat transfer at the bottom of the narrow air space[2].

The protective metal channel covering the edge of some units had a slight effect on edge temperature: the edge index was increased by as much as 3 when the metal surround was removed from a unit.

The edge temperature performance of the triple-glazed unit was similar to that of the double-glazed units. Little thermal resistance appeared to be gained at the edge by the extra glass thickness.

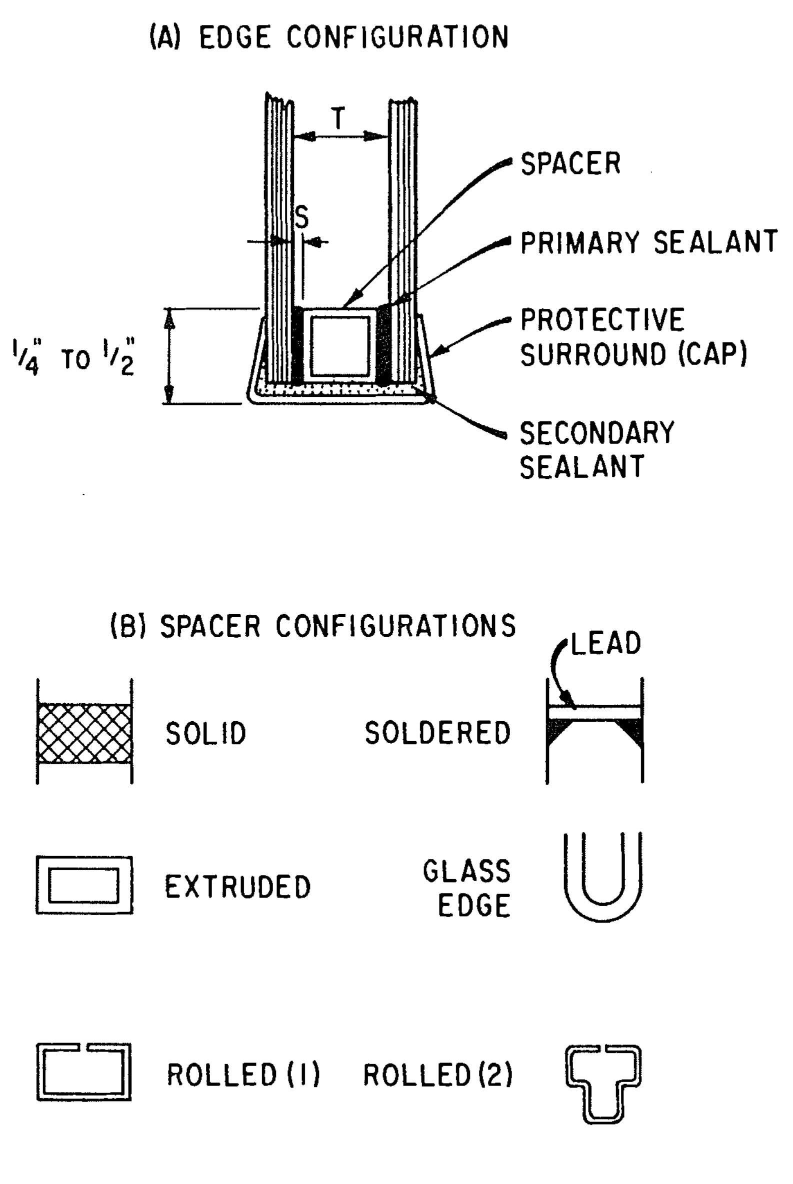


FIGURE 2 DESIGN DETAILS OF SEALED UNITS 1 TO 20

BR 4405-1

(b) Surface-temperature profile and breakage potential

The inside surface-temperature profiles of representative units are shown in Fig. 4. Two proprietary units with 1/2-in. spacers are compared with an idealized unit (1) in Fig. 4a. The profiles of the proprietary units are similar to that of the idealized unit over the centre region but are quite different near the edges.

The profiles of the idealized 1/4-in. unit, a proprietary 1/4-in. unit, the glass-edge unit and the triple-glazed unit are compared in Fig. 4b. The profiles of units having nominally the same air-space thickness vary widely. This variation is related to the glass and air-space thicknesses.

When a sealed unit is cooled, the glass panes tend to deflect toward each other and reduce the air-space thickness in the centre region. This reduction in air-space thickness causes a local reduction in inside surface temperature.

A greater reduction in temperature occurs with the narrow air space than with the wide one. Since thin glass deflects more readily than thick glass, a narrow sealed unit with thin glass tends to have lower centre temperatures than a similar unit with thick glass.

The breakage potential of the inner pane can be defined as the difference between the mean-pane index and the bottom-edge index. The breakage potential of the ideal 1/2-in. unit was 10; that of the remaining 1/2-in. units varied from 19 to 29.

The breakage potential of the ideal 1/4-in. unit was 6; that of the remaining double units varied from 12

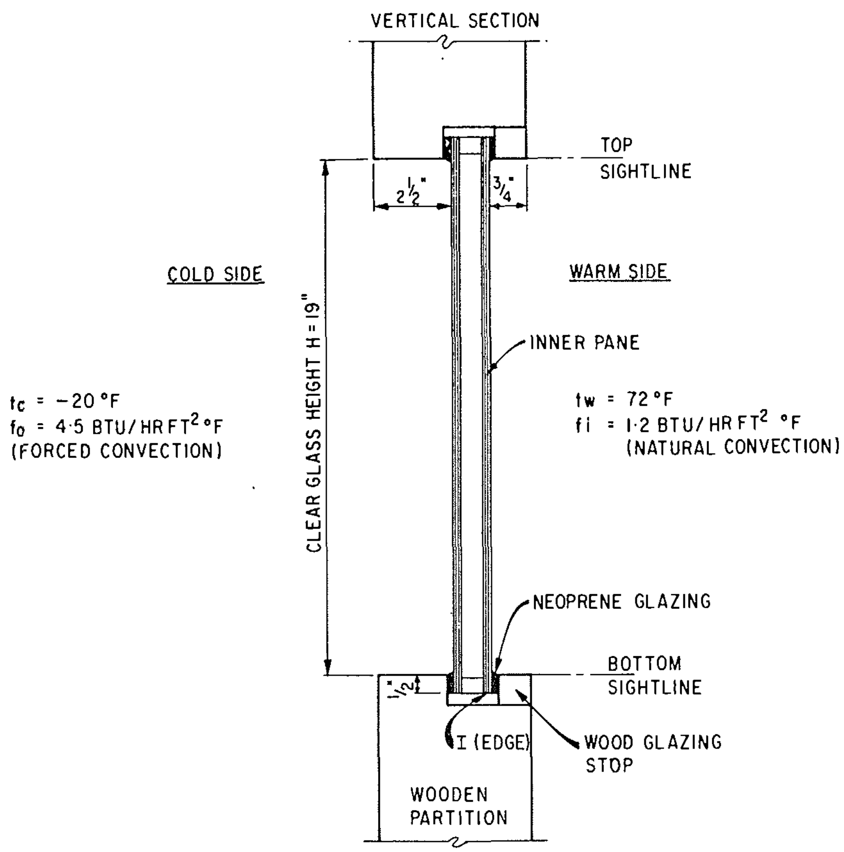


FIGURE 3 INSTALLATION DETAILS BR4605-2

to 23; that of the triple-glazed unit was 25.

The breakage potential of the proprietary 1/4-in. units was generally less than that of comparable 1/2-in. units owing to the lower centre temperatures found in the narrow units.

EFFECT OF GLASS TYPE FRAME DESIGN, GLAZING DETAIL AND HEATER CONFIGURATION ON EDGE TEMPERATURE

Two sealed double-glazed units were investigated with a number of frame and heater configurations. The spacer design of the sealed units was similar to that of Unit 8 as described in the last section. The units were approximately 48-in. high by 39-in. wide and had a nominal air-space thickness of 1/2 in. One unit consisted of two panes of clear glass and was designated the "clear" unit.

The other unit also had two clear panes, but the inner pane had a thin aluminum coating on the surface facing the air space, and was designated the "reflective" unit. The low emissivity of the aluminum coating reduced the thermal conductance of the air space in the reflective unit to approximately 57 per cent of the conductance of the clear unit.

The five frames investigated are shown in Fig. 5. Frames A and B were of similar construction and consisted of inner and outer aluminum members held together by steel screws. Frame C was also aluminum but the thermal separation between warm and cold frame members occurred outside the outer glazing stop. Frame D consisted of an inner aluminum member and an outer glazing stop of wood. Frame E was made of wood.

The configurations listed in Table II were investigated. The heater configurations for the forced convection conditions are shown in Fig. 5.

Surface and edge temperatures were measured along the vertical centre line of the inner or warm pane. The inside frame temperature was measured adjacent to the edge of the sealed unit at the sill.

The glazing materials and glazing methods used in the study are explained in Fig. 6. The "butyl" glazing seal represented seals having a relatively low thermal resistance. A thin (1/16 in.) neoprene face-shim plus sealant had thermal characteristics similar to "butyl" seal. The ribbed "vinyl" seal represented seals having a relatively high thermal resistance. Its behaviour was similar to that of a ribbed or hollow compressible gasket of neoprene.

The glazing designations are relevant only to metal frames; they refer to the thermal connection between the sealed unit and the warm side of the frame. The glazing method with a high-resistance seal on the cold side and a low-resistance seal on the warm side would tend to raise the edge temperature of the inner pane and is, therefore, designated the "favourable" method.

The measured inside-frame index, the bottom-edge index, the mean-pane index and the breakage potential of the inner pane are listed in Table II. The inside surface temperature profiles for a select number of configurations are shown in Fig. 7.

Glass Type

The temperature profiles of the clear and reflective units obtained under identical conditions are compared in Fig. 7a.

Due to the higher air-space resistance of the reflective unit, its mean-pane index was higher than that of the clear unit by 10, but the edge indices of the two units were nearly identical. The breakage potential of the reflective unit was, therefore, greater than that of the clear unit by 11 for the same condition of installation.

Glazing Method

The edge temperatures of the clear unit in Frame A were measured with unfavourable, neutral and favourable glazing methods. Comparable results for the reflective unit were obtained in Frame B. For the clear unit, the breakage potential with the favourable glazing method was 17 less than that with the unfavourable method. The breakage potential of the reflective unit with favourable glazing was approximately equal to that of the clear unit with neutral glazing.

Thermal characteristics of frame (reflective unit only)

The favourable glazing scheme caused the glass-edge temperature to approach the inside-frame temperature, and any change that affected the latter had a similar effect on the former.

The frame and glass-edge temperatures in Frame C were lower than those in Frame B even though both frames had the same inside exposure (4 in.). The low temperatures of Frame C may have resulted because heat was lost from the frame to the outer, as well as to the inner, pane.

The frame and glass-edge temperatures in Frame D were relatively high owing to the high thermal resistance of the outer glazing stop. The breakage-potential value (26) obtained with an inside-frame exposure of 2-1/4 in. was comparable to the values obtained in Frames A and B with much greater frame exposures.

Frame E had a high-resistance glazing stop on both sides of the sealed unit. The breakage potential of 40 was similar to that obtained with neutral glazing in an aluminum frame, and was greater than that obtained with favourable glazing in a well designed aluminum frame.

Heater configuration and air-flow condition

The temperature profiles of the reflective unit obtained with natural– and forced–convection air flows in Frames A and C are shown in Fig. 7.

An under-window heater provided the forced-convection air flow. The heater outlet was located 7 in. from the inner pane and 9 in. below the sill of Frame A, and 4 in. from the inner pane and at sill level of Frame C. The air discharge velocity from the heater was approximately 300 ft/min. The temperature index of the discharged air was approximately 110.

The forced convection discharge for Frame A impinged against the inner pane near mid-height. The centre-pane temperatures were consequently raised more than the temperatures near the sill; breakage potential with forced convection, therefore, exceeded that with natural convection by approximately 6.

The under-window heater for Frame C was adjacent to the window sill and provided forced-convection air flow over the sill frame-member as well as over the whole inner pane. The edge and mean-pane temperatures were therefore, increased by the same amount and the breakage potential with forced convection was the same as with natural convection.

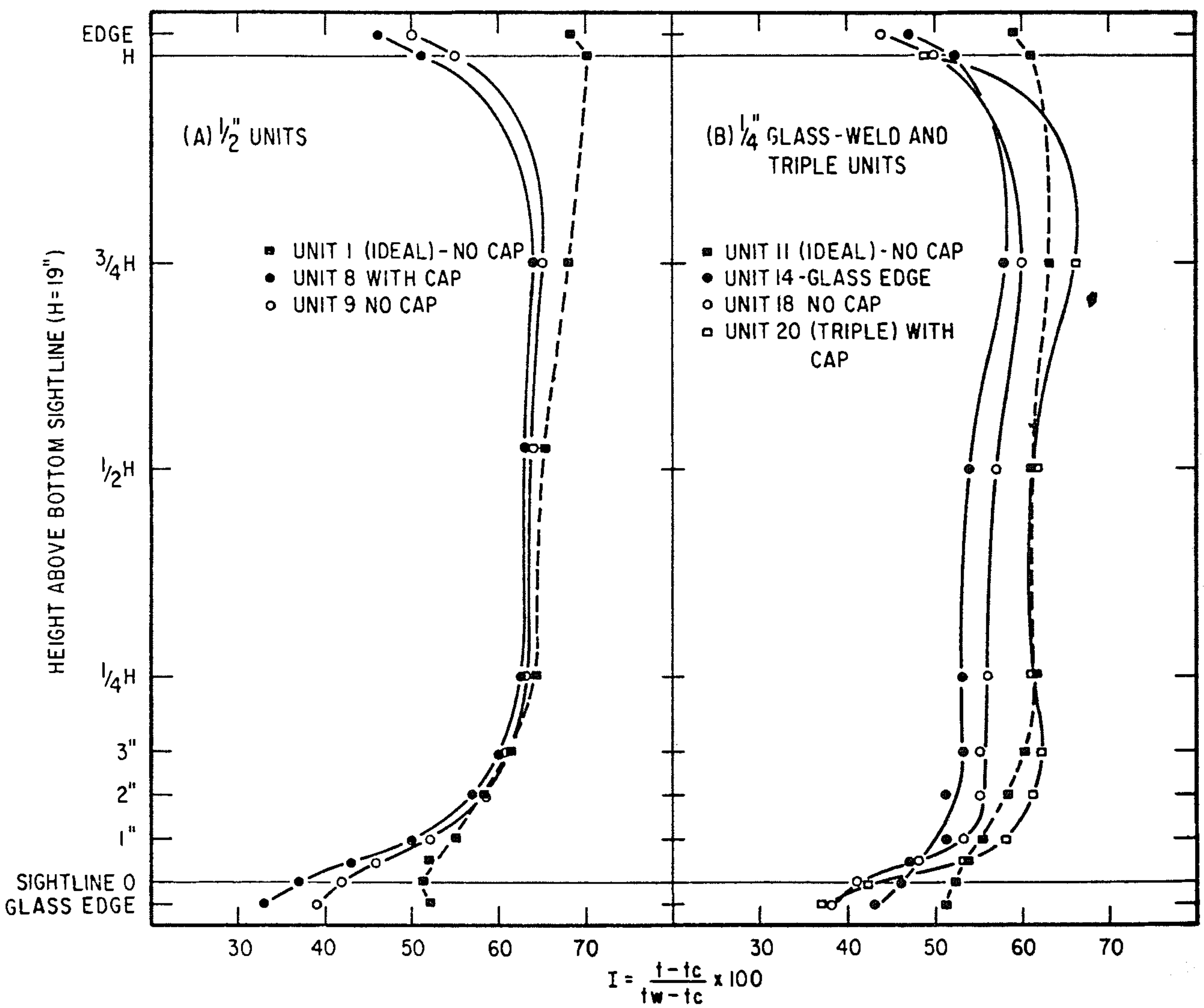


FIGURE 4 TYPICAL INNER-PANE TEMPERATURE PROFILES

BR 4605-8

SUMMARY

Cold-weather breakage of sealed units occurs when the stress resulting from several causes exceeds the edge strength of the inner pane of glass. One major cause of breakage is the difference between the mean-pane temperature and the glass-edge temperature of the inner pane; this difference is designated the breakage potential. Breakage potential decreases as the mean-pane temperature is reduced and the glass-edge temperature is increased.

The current study investigated the effect and relative importance of several factors on breakage potential.

(1) Frame design and glazing method

These factors had the greatest effect on breakage potential. The breakage potential of a sealed unit in a metal frame was affected by the temperature of only the outer frame when the unit was unfavourably glazed, and by the temperature of only the inner frame when favourably glazed; it was not affected by frame temperature with neutral glazing.

The breakage potential with favourable glazing was 13 to 17 less than with unfavourable glazing, and approximately 7 less than with neutral glazing. With favourable glazing in a metal frame, the breakage potential of a sealed unit decreased as the inner frame temperature increased.

The breakage potential of a sealed unit in a wooden frame was equal to that of a unit in a metal frame with neutral glazing.

(2) Glass Type

The breakage potential of a unit with a low-emissivity reflective coating was approximately 10 greater than that of a clear unit. It is, therefore, very important when using reflective sealed units to take advantage of the other factors that can reduce breakage potential.

(3) Heater configuration

Breakage potential was affected by the heater depending on the air discharge configuration and the glazing method. When the under-window heater discharged air uniformly against the sill and centre-pane regions of a sealed unit favourably glazed in a metal frame, the breakage potential was not increased over that with natural convection.

The breakage potential was increased by approximately 6, however, when air was discharged against the centre-pane region but not against the sill frame member.

(4) Air-space thickness

The breakage potential of 1/4 in. units was approximately 5 less than that of the 1/2 in. units owning to the lower centre-pane temperatures of the thinner units.

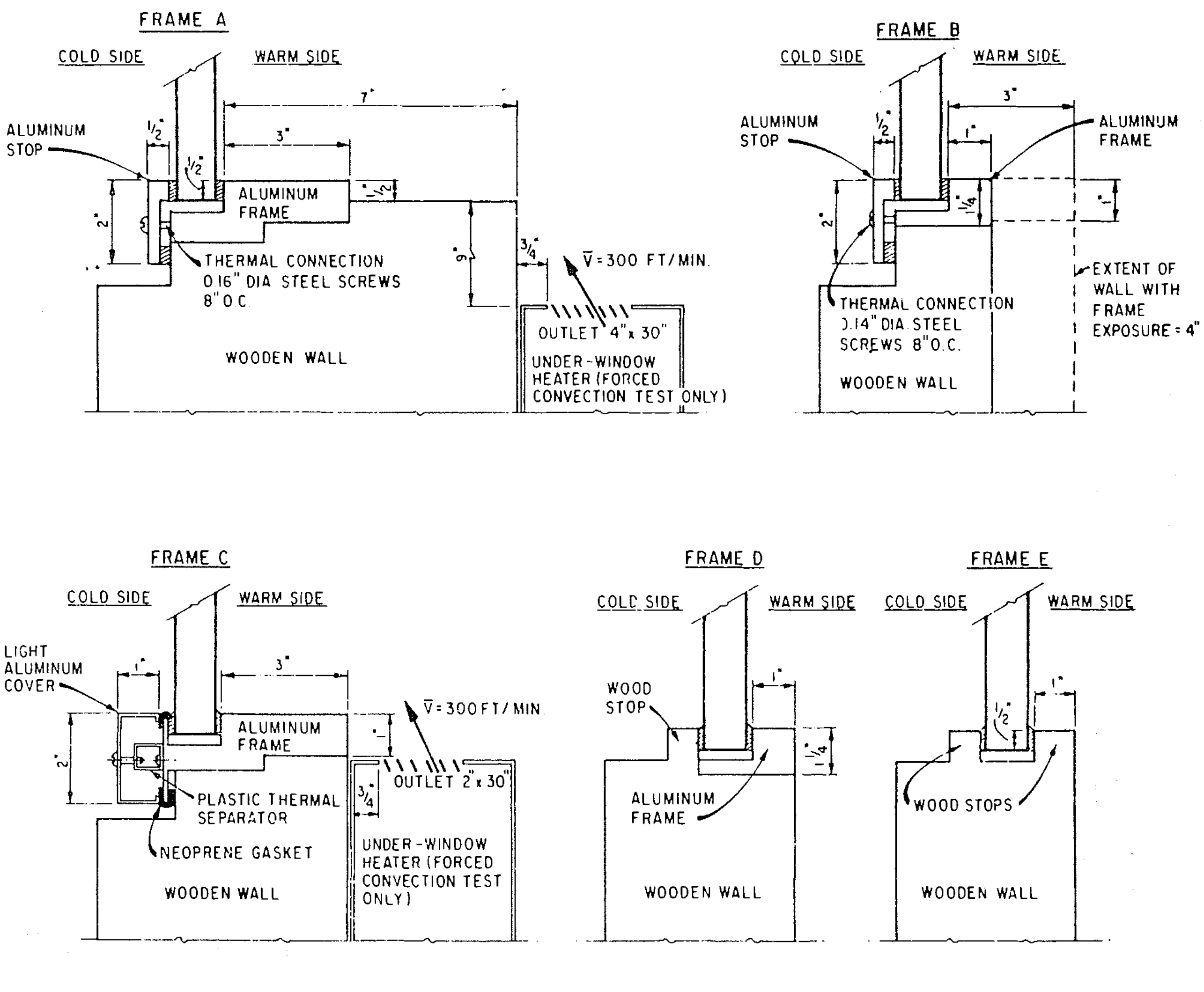


FIGURE 5 WINDOW FRAME DETAILS

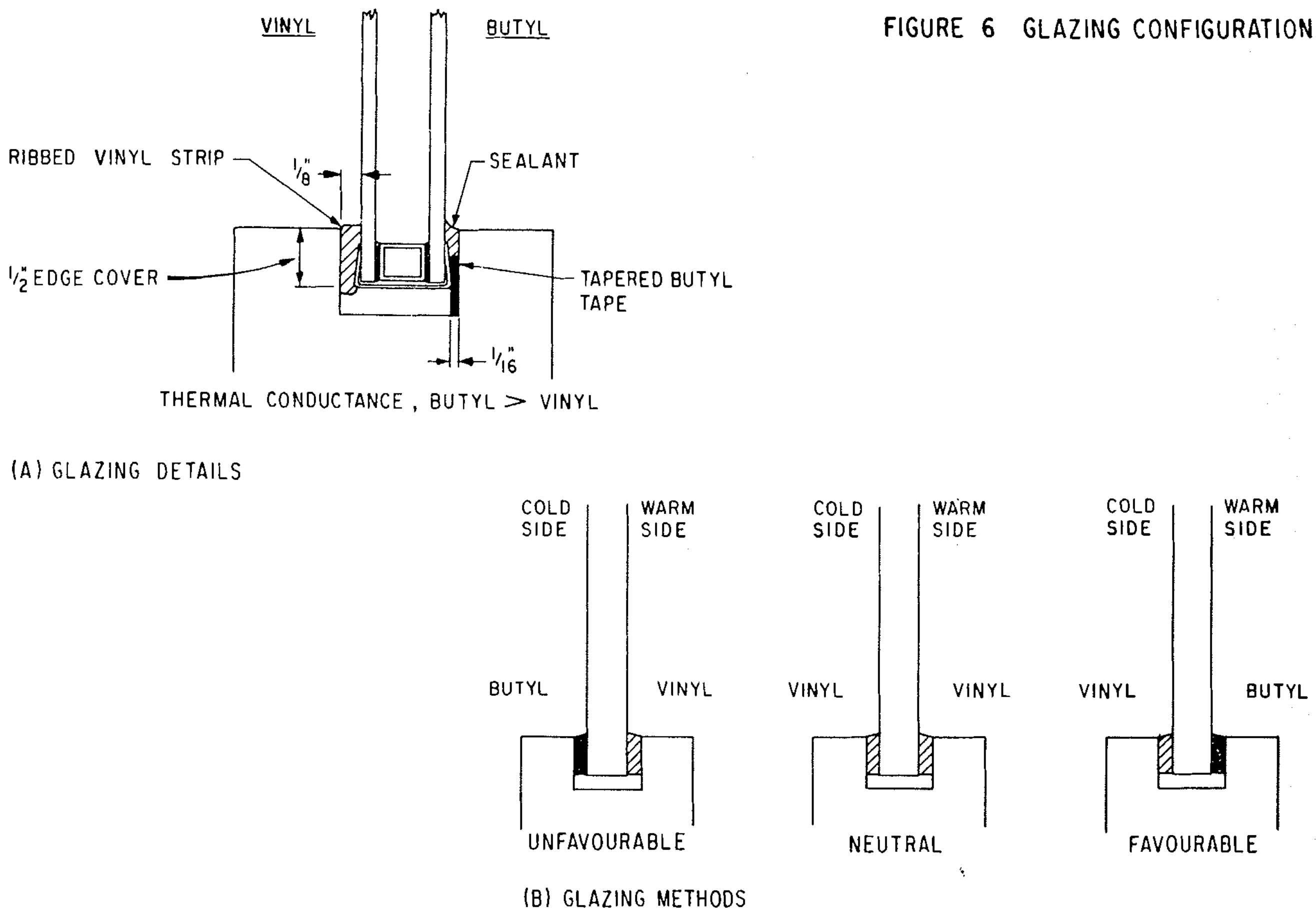
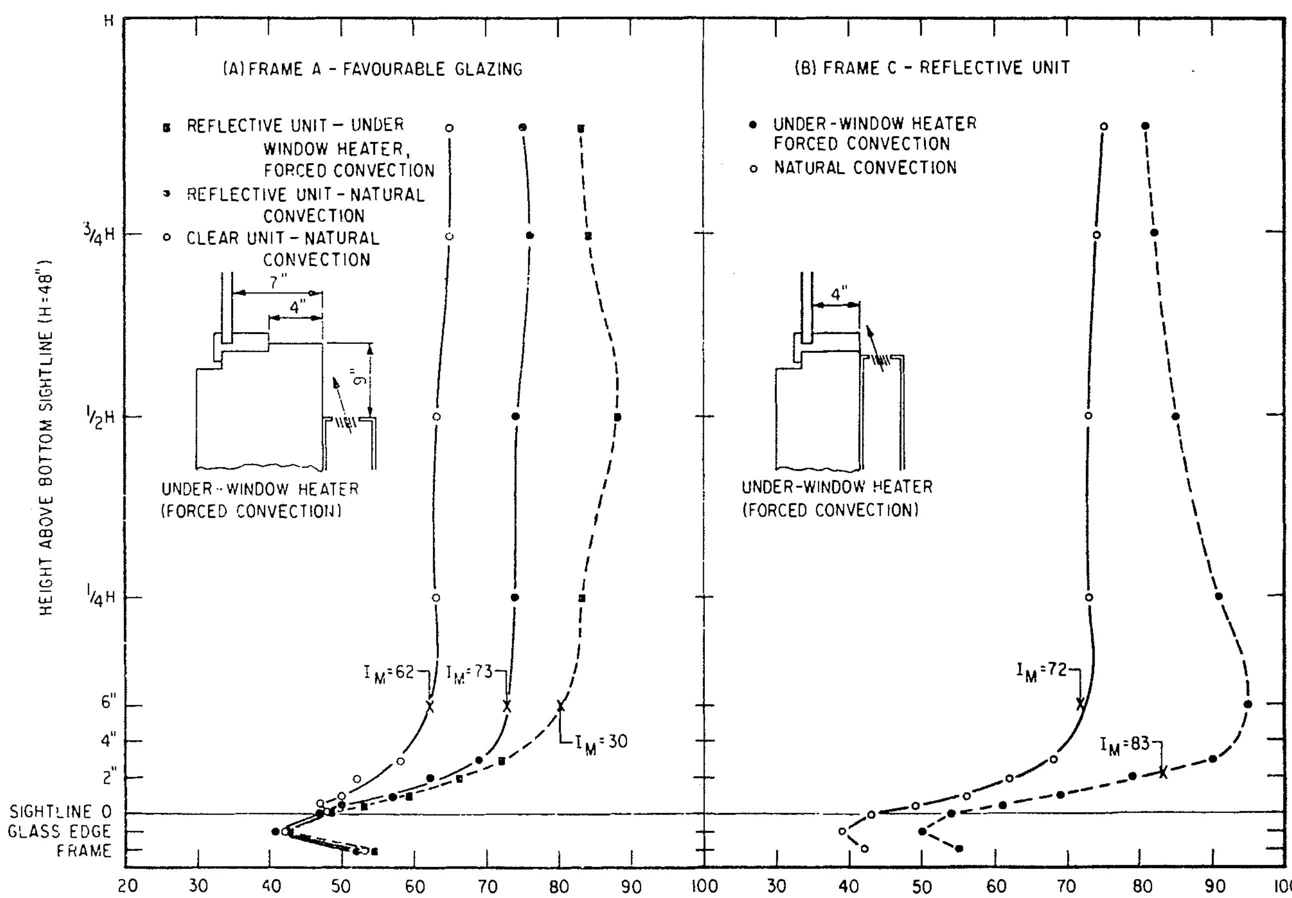


FIGURE 6 GLAZING CONFIGURATION



$$I = \frac{t - t_c}{t_w - t_c} \times 100$$

FIGURE 7 INNER-PANE TEMPERATURE PROFILES

(5) Edge design of glazing units

For those sealed double-glazing units having organic seals, the breakage potential was affected by as much as 4 by the sealant thickness between spacer and glass; the breakage potential was less with greater sealant thickness.

The breakage potential of a unit with a protective metal surround was at most 3 greater than that of the same unit with no surround. It appears that no significant improvement in breakage potential can be effected by changing the edge construction from those currently used, unless perhaps, a radical change is made.

REFERENCES

1. Brown, W. P., K. R. Solvason, and A. G. Wilson, A unique hot-box cold-room facility. ASHRAE Trans., Vol. 67, 1961, pp. 561-577.
2. Christensen, G., W. P. Brown, and A. G. Wilson, Thermal performance of idealized double windows, unvented. ASHRAE Trans., Vol. 70, 1964, pp. 408, 418.

TABLE 11

INSIDE SURFACE TEMPERATURE PERFORMANCE AT SILL
(Indices)

WS EXPOSURE = FRAME SURFACE EXPOSED TO WARM SIDE AIR (In./ft of Frame Width)	NATURAL CONVECTION AIR FLOW (Remote Heating)				FORCED CONVECTION AIR FLOW (Under-Window Heating)			
	I (mean)	I (edge)	I (frame)	ΔI (mean - edge)	I (mean)	I (edge)	I (frame)	ΔI (mean-edge)
FRAME A								
Clear Unit; WS exposure = $3\frac{1}{2}$";								
Unfavourable glazing	62	25	50	37	70	27	54	43
Neutral glazing	62	35	58	27	70	38	61	32
Favourable glazing	62	42	53	20	70	44	56	26
Reflective Unit; WS exposure = $3\frac{1}{2}$";								
Favourable glazing	72	41	52	31	80	42	54	38
FRAME B, Reflective unit								
WS exposure = $2\frac{1}{4}$",								
Unfavourable glazing	72	26	46	46				
Neutral glazing	72	33	48	39				
Favourable glazing	72	39	46	33				
WS exposure = 4",								
Favourable glazing	72	45	53	27				
FRAME C, Reflective unit Favourable glazing, WS exposure = 4"	72	39	42	33	83	50	55	33
FRAME D, Reflective unit Favourable glazing WS exposure = $2\frac{1}{4}$"	72	46	56	26				
FRAME E, Reflective unit Neutral frame	72	32	38	40				