

# Thermal Resistance Measurement of Glazing System Edge-Seals and Seal Materials Using a Guarded Heater Plate Apparatus

J.L. Wright, P.Eng.

Student Member ASHRAE

H.F. Sullivan, Ph.D., P.Eng.

Member ASHRAE

## ABSTRACT

*In cold climates the increased edge-glass heat transfer at the perimeter of a sealed glazing unit creates a special problem. This is where condensed water and frost most readily occur. One mechanism contributing to edge-glass heat transfer is edge-seal conduction. Very few data are available regarding the thermal resistance of the various edge-seal configurations that are commercially available. An experimental procedure has been devised whereby the thermal resistance of an edge-seal can be directly measured using a guarded heater plate apparatus. Results are reported for nine edge-seal test samples. In addition, results from similar tests provide measured thermal conductivities for four of the materials used in the construction of the edge-seal test samples and commercially available edge-seals.*

## INTRODUCTION

A typical window assembly consists of two or more sheets of glass separated at their edges with a spacer bar, dessicant, and some type of sealant all held in a frame that may have a complex cross-sectional construction. The large number of available glass types, coatings, pane spacings, fill gases, spacer bars, sealants, and frame materials and configurations preclude the possibility of experimentally obtaining the thermal performance of these window assemblies. Ideally, the real-life performance of a sealed glazing unit in a frame could be calculated. To do this accurately would require a very detailed model, which does not yet exist.

The development of a detailed model requires information regarding center-glass, edge-glass, and frame heat transfer. The mechanisms governing center-glass heat transfer are reasonably well understood and computer programs containing center-glass heat transfer models are readily available. Two of these programs are WINDOW (Rubin et al. 1985) and VISION (Wright and Sullivan 1987; Sullivan and Wright 1988; Baker et al. 1988). Similarly, a window frame heat transfer program called FRAME (Carpenter 1987) is available.

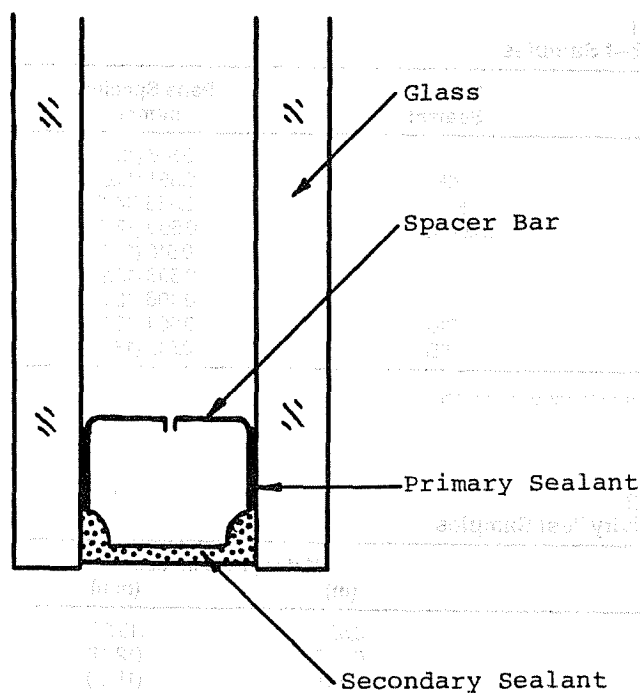
This study provides new experimental data for the

thermal resistance of nine edge-seal test samples consisting of a variety of spacer bar and sealant combinations. Results from thermal conductivity measurements of materials used in the construction of the edge-seal test samples are also tabulated. These experimental data provide a new perspective regarding the relative thermal performance levels to be expected from various edge-seal designs as well as an insight into the way in which edge-seals conduct thermal energy. It is expected that this information will serve an important function in the ongoing effort to improve the models of window thermal performance.

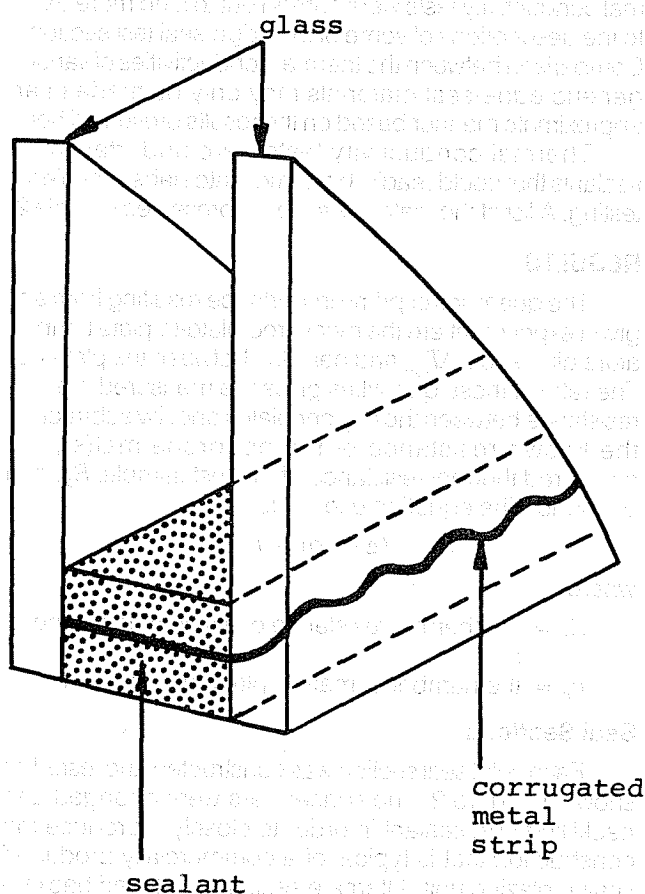
## THERMAL PERFORMANCE

A number of performance parameters are used to specify the thermal characteristics of a window, including the U-value (or R-value) and shading coefficient (SC) (ASHRAE 1985). However, the condensation resistance of a window is an equally significant measure of good window design. This concern is addressed in some window U-value hot-box tests by taking thermocouple temperature measurements at vulnerable locations on the indoor pane. It is clear that one could design a window with a satisfactory overall U-value and SC, but which is susceptible to condensation problems because of high edge-glass heat transfer. It is difficult to obtain specific edge-glass heat transfer information from a window U-value hot-box test because it represents a small component of the total heat transfer. Somewhat more information might be obtained from the direct temperature measurements on the pane(s) and frame, but the complexity of the heat transfer paths makes this approach difficult at best (Wright and Sullivan 1989).

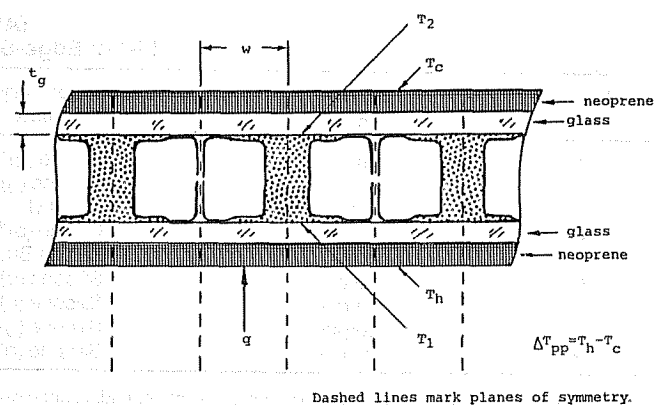
In the present research study, a guarded heater plate apparatus, which has been successfully used for the measurement of center-glass U-values, was used for the direct measurement of heat transfer through a series of test samples constructed from commercially available spacer bars and sealant materials. In addition, a series of thermal conductivity measurements were performed for layers of some of the materials from which the edge-seal test samples were constructed.



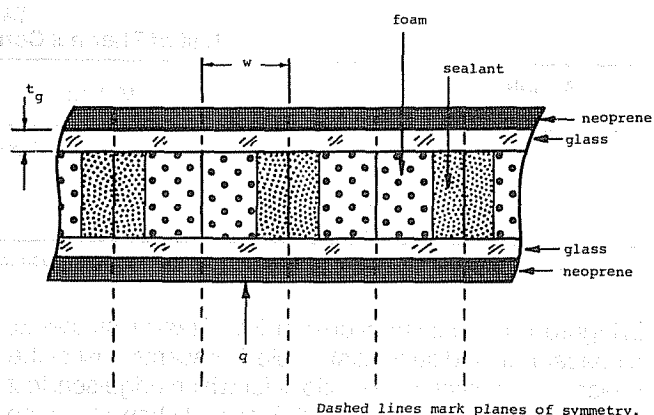
**Figure 1** Typical edge-seal design



**Figure 3** The corrugated strip edge-seal design



**Figure 2** Cross section of edge-seal test sample



**Figure 4** Cross section of edge-seal test sample with foam spacer

## TEST PROCEDURE

Thermal resistance testing was carried out using a guarded heater-plate apparatus. This apparatus consists of two flat copper plates that can be maintained at different but constant temperatures. The test samples were placed between these plates but were separated from the plates by neoprene mats. The heat transfer through each sample (driven by the temperature difference between the plates) was measured over the face of a guarded heater plate (8 x 8 inches [203 x 203 mm]) embedded in the warmer copper plate. The measured heat transfer rate, plate-to-plate temperature difference, and known thermal resistance of the neoprene mats was combined to give a measured thermal resistance of the test sample. A detailed description of the test procedure has been published by Wright and Sullivan (1988).

Each experimental measurement was made under steady-state conditions. The thermostats controlling the constant-temperature circulating baths connected to the copper plates were set at 68°F (20°C) and 32°F (0°C). The resulting temperature difference between the copper plates ( $\Delta T_{pp}$ ) was slightly less than 36°F (20°C) and varied only slightly from one test to the next. The temperature difference experienced across the test samples was felt to be representative of fairly severe winter conditions.

## Seal Sections

A sketch of a typical glazing unit edge-seal is shown

**TABLE 1**  
**List of Edge-Seal Test Samples**

Sample No.	Spacer Bar	Secondary Sealant	Primary Sealant	Pane Spacing in(mm)
1	Aluminum	Silicone (g) +		0.516 (13.1)
2	Aluminum	Silicone (g)	PIB*	0.551 (14.0)
3	Corrugated Strip	Butyl	Butyl	0.555 (14.1)
4	Fiberglass	Silicone (b) +	Silicone (b)	0.500 (12.7)
5	Foam <sup>†</sup>	Hot-Melt Butyl		0.516 (13.1)
6	Foam <sup>†</sup>	Silicone (g)		0.508 (12.9)
7	Fiberglass	Silicone (g)		0.496 (12.6)
8	Fiberglass	Silicone (g)	PIB	0.504 (12.8)
9	Aluminum	Silicone (g)	PIB	0.512 (13.0)

+ The silicone sealant used is designated as either (g) or (b) depending upon whether its color was gray or black

\* PIB is an abbreviation of polyisobutylene.

† This edge-seal consists of approximately 50% foam spacer and 50% sealant

**TABLE 2**  
**List of Thermal Conductivity Test Samples**

Sample No.	Material	Material Thickness	
		(in)	(mm)
10	Foam only between glass sheets ( $t_g = 4.70$ mm)	0.521	(13.23)
11	Silicone (g) + slab	0.477	(12.11)
12	Polysulfide slab	0.441	(11.21)
13	Polyurethane slab	0.473	(12.01)

+ The silicone sealant used is designated as either (g) or (b) depending upon whether its color was gray or black

in Figure 1. The construction consists of two glass sheets, a spacer bar, and sealant(s). Table 1 presents a list of the spacer bar/sealant combinations for which edge-seal test samples were built and tested. Figure 2 shows how the more conventional edge-seal test samples containing aluminum or fiberglass spacer bars were constructed. A two-part silicone was used in most cases because it could readily be gunned into the long, narrow passages of the edge-seal test samples. The designs listed in Table 1 correspond closely to the spacer bar/sealant configuration shown in Figure 1, with the exception of samples 3, 5, and 6. The corrugated strip spacer (sample number 3) is shown in Figure 3. The layout of samples incorporating foam spacers (samples 5 and 6) is shown in Figure 4. This edge-seal consists of single corrugated aluminum strip (with the appearance of a continuous sine wave) embedded in butyl. All of the edge-seals and edge-seal components are commercially available.

The nine seal sections were tested in a horizontal position since it was expected that the heat flux through these samples would take place predominantly by conduction and that the results would be independent of orientation. The hollow seal sections did not contain desiccant. All of the seal sections were the same size and shape (12 × 12 in [305 × 305 mm]). Each unit tested was placed so that the guarded heater plate measured heat flux through the center area of the sample.

### Seal Materials

Thermal conductivity data are not readily available for the materials that are customarily used as edge sealants. Since different manufacturers tailor their sealants through the use of various additives and fillers, the properties of a given sealant, even though it is identified by the same name throughout the industry, may vary significantly.

"Butyl" is a particularly good example of a name which is applied to many different sealants. Consequently, the thermal conductivity tests were carried out to lend more detail to the descriptions of some of the edge-seal test sections. Comparison between the thermal conductivities of various generic edge-seal materials may only be made in an approximate manner based on the results presented here.

Thermal conductivity tests were undertaken for sealants that could readily be formed into slabs suitable for testing. A list of the materials tested is presented in Table 2.

### RESULTS

The quantities of prime importance resulting from any given experiment are the measured plate-to-plate temperature difference,  $\Delta T_{pp}$ , and heat flux between the plates,  $q$ . The ratio of these quantities gives the measured thermal resistance between the copper plates and, by subtracting the known resistance of the neoprene mat(s), the measured thermal resistance of the test sample,  $R_{ts}$ , can be found. The equation used was:

$$R_{ts} = (\Delta T_{pp}/q) - n_n R_n \quad (1)$$

where

$R_n$  = the thermal resistance of a single neoprene mat

$n_n$  = the number of mats in place during the test

### Seal Sections

Each solid seal section was constructed and tested as shown in Figure 2. The spacer bars were arranged and backfilled with sealant in order to closely reproduce the construction that is typical of a commercially produced sealed glazing unit. Alternate seals were placed back-to-back to create a condition of symmetry and to allow the measured heat flux,  $q$ , measured over the area of a heater

**TABLE 3**  
**Summary of Results for Edge-Seal Test Units**

	$\Delta T_{pp}$ [C]	$q$ [W/m <sup>2</sup> ]	$t_g$ [mm]	$w$ [mm]	$R_n$ [m <sup>2</sup> C/W]	$R_{seal}$ [m <sup>2</sup> C/W]	$k_{lin}$ [W/mC]
1 Aluminum SS*	18.70	372.2	3.96	12.8	0.017	0.008	1.6
2 Aluminum DS*	18.78	383.9	3.96	12.9	0.017	0.007	1.9
3 Corrug'd Strip	18.90	324.8	2.90	7.43	0.017	0.018	0.41
4 F'glass	19.18	192.2	2.84	16.3	0.017	0.060	0.27
5 Foam/Hot-Melt Butyl	18.98	187.9	4.75	12.3	0.009	0.073	0.17
6 Foam/Silicone	18.69	302.15	3.91	12.7	0.009	0.036	0.36
7 F'glass SS	18.95	272.5	3.91	12.7	0.009	0.043	0.29
8 F'Glass DS	18.96	277.9	3.91	12.7	0.009	0.042	0.30
9 Alum DS	18.41	574.3	3.91	12.6	0.009	0.006	2.1

\* SS and DS are abbreviations of single-seal and dual-seal

**TABLE 4**  
**Summary of Results for Edge-Seal Material Test Units**

	$\Delta T_{pp}$ [C]	$q$ [W/m <sup>2</sup> ]	$t_s$ [mm]	$R_n$ [m <sup>2</sup> C/W]	$k$ [W/mC]
10 Foam*	19.05	151.4	13.23	0.009	0.12
11 Silicone (g)	18.36	431.4	12.11	0.009	0.36
12 Polysulfide	18.82	275.0	11.21	0.009	0.19
13 Polyurethane	19.65	409.1	12.01	0.009	0.31

\* The foam sample included 2 sheets of glass, each 4.70 mm thick, and two neoprene mats were used. Therefore, in this case the thermal conductivity was calculated using Equation 5 in a modified form, namely:

$$k = t_s / ((\Delta T_{pp}/q) - 2R_n - (2t_g/k_g))$$

The foam strips used to make up the foam slab were covered on one side with a very thin metalized plastic film. It was assumed that the presence of these layers did not significantly alter the measurement of foam conductivity.

plate to be an accurate measure of the heat flux through each individual seal. In other words, planes of symmetry between each pair of seals could be considered to be adiabatic.

The measured quantities of prime importance from the solid seal experiments were  $\Delta T_{pp}$  and  $q$ . The ratio of these two values provides the thermal resistance of the neoprene/glass/seal assembly. The thermal resistance of the seals alone,  $R_{seal}$ , can be found by subtracting the resistance of the neoprene mats ( $2R_n$ ) and the sheets of glass ( $2t_g/k_g$ ). This representation of thermal resistance, expressed by Equation 2, is a direct measure of resistance to heat transfer provided by the edge-seal on a "per unit area" basis.

$$R_{seal} = (\Delta T_{pp}/q) - R_n R_n - 2(t_g/k_g) \quad (2)$$

where

$k_g$  = glass conductivity (0.96 W/m°C)

$t_g$  = glass thickness

In order to provide a more useful representation of the results, the thermal measurement quantities were recast into the form of a thermal conductance on a "per unit length of seal" basis,  $k_{lin}$ . This linear conductance is defined by Equation 3:

$$Q = q \cdot A = L \cdot k_{lin} (T_1 - T_2) \quad (3)$$

where

$Q$  = heat loss through seal

$L$  = length of seal

$A$  = area of seal in contact with glass,  $L \cdot w$

$w$  = width of a single seal (see Figure 2)

$T_1 - T_2$  = temperature drop through seal

Equations 2 and 3 can be rearranged to give:

$$k_{lin} = w / ((\Delta T_{pp}/q) - R_n R_n - 2(t_g/k_g)) = w / R_{seal} \quad (4)$$

Table 3 presents a summary of the measured results for the nine edge-seal test sections. In each case the measured values of  $\Delta T_{pp}$ ,  $q$ ,  $t_g$ , and  $w$  are shown along with the resulting values of  $R_{seal}$  and  $k_{lin}$ .

One note of caution is in order. While testing units with very low thermal resistance (e.g., units 1 and 2) the majority of the thermal resistance measured between the copper plates was due to the neoprene mats. The accuracy of the measured thermal resistance of the seal is less than in the experiments where thinner mats were incorporated or where the seals provided more thermal resistance. It is safe to say that the single seal (unit 1) provided more thermal resistance than the double seal (unit 2), but to say it had 19% more thermal resistance would be unfounded. The important observation is that the thermal resistance between the two sets of seals (with and without the conventional aluminum spacer bar) differed by a significant factor. This difference could make the difference between having or not having to deal with condensation running down windows in the winter. The results of other experiments where thinner neoprene mats were used ( $R_n = 0.009 \text{ m}^2 \cdot \text{°C/W}$ ; see Table 2) are much less likely to be in error because of the thermal resistance of the mats.

## Seal Materials

Thermal resistance testing was carried out using four seal material test samples in order to measure the thermal conductivity of the materials listed in Table 2. The thermal resistance testing of the seal materials was similar to the testing of the edge-seal test sections. Each of the conduc-

tivity test samples was the same size and shape as the edge-seal test samples (12 × 12 in [305 × 305 mm]) and was centered directly over the guarded heater plate during testing. The quantities of importance measured during each experiment were the temperature difference,  $\Delta T_{pp}$ , the heat flux,  $q$ , and the thickness of the test material,  $t_s$ . The experiments differed from the edge-seal test procedure in that no neoprene mat was placed between the sample and the cold plate and (with the exception of sample 10) no glass was included in the sample. The measured data were converted to thermal conductivity,  $k$ , using Equation 5.

$$k = t_s / ((\Delta T_{pp} / q) - R_n) \quad (5)$$

The results of the thermal conductivity experiments are shown in Table 4.

## DISCUSSION

The data shown in Table 3 demonstrate that the seals tested possess a wide range of  $k_{lin}$ ; a factor of 12 exists between the lowest and the highest. These seals can readily be grouped according to their thermal performance (on a unit length basis). The more conventional single and double seals (units 1, 2, and 9) provide little thermal resistance while the edge-seals incorporating corrugated metal, fiberglass, or foam spacers provide considerably more thermal resistance. The greatest thermal resistance was measured across the foam edge-seal with hot-melt butyl sealant.

The edge-seal thermal resistance results reveal that the single-seal configurations provided more thermal resistance than similar dual-seal configurations in the two cases where direct comparisons could be made. Compare the  $k_{lin}$  results for unit 1 vs. units 2 and 9, which all had aluminum spacer bars and silicone edge sealant, or examine the results for unit 7 vs. unit 8, which both had fiberglass spacer bars and silicone edge sealant. The thermal resistance of edge-seals with aluminum spacer bars seems to be sensitive to the placement of sealant between the spacer and the glass. It might be reasoned that a large portion of the thermal resistance was due to the material in place between the aluminum bar and the glass. Further reasoning indicates that some of the thermal resistance present in the single-seal configuration resulted from a contact resistance between the spacer and the glass and that this resistance was reduced or eliminated by the presence of the primary sealant in the dual-seal design. The results for single- and dual-seal edge-seals with fiberglass spacers (units 7 and 8) support this line of reasoning. In this case, the majority of the thermal resistance exists in the spacer bar and  $k_{lin}$  was insensitive to the presence of primary sealant between the spacer and the glass. In fact, the difference between the  $k_{lin}$  values measured for units 7 and 8 is within the realm of experimental error.

The thermal performance of the edge-seal that incorporates the foam spacer is highly sensitive to the choice of edge sealant that is used. Compare  $k_{lin}$  for units 5 and 6, where the use of silicone sealant instead of hot-melt butyl approximately doubled the linear conductance of the edge-seal. Clearly, the majority of the heat transfer occurs through the sealant rather than the spacer (as opposed to edge-seals with aluminum spacers, where the reverse was

seen to be true). The thermal conductivity figures shown in Table 4 support this assertion in that the conductivity of silicone was found to be three times higher than the conductivity of the foam. It can be reasoned that the thermal resistance of edge-seals incorporating the fiberglass spacer would also be sensitive to the conductivity of the edge sealant but to a lesser extent because the fiberglass edge seal design includes a slightly smaller portion of sealant (about 30% sealant vs. 50% for the foam design). It is likely that if a fiberglass edge-seal with hot-melt butyl sealant had been tested it would have had significantly more thermal resistance than the samples that were tested with silicone edge sealant (units 4, 7, and 8). On the other hand, the use of hot-melt butyl instead of silicone would likely have had little impact on the performance of the units with aluminum spacer bars.

Thermal conductivity data for sealants used in the window industry are extremely difficult to find. This situation is hindered by the large variability in formulations that exists for sealants of the same generic name. The measured thermal conductivity data presented in Table 4 are not only useful to supplement the descriptions of some of the edge-seal test units but also stand as useful information on their own. Although difficulties were encountered in building a hot-melt butyl sample for conductivity testing, the heat transfer results from edge-seal unit 5 (foam/butyl) and conductivity unit 10 (foam only) were used to estimate the conductivity of the butyl to be 0.24 W/mK. This result is well above the speculative value of 0.1 W/mK that was received by word of mouth before this study was undertaken. It is possible that this 0.1 W/mK conductivity value applies to the material from which the butyl sealant is produced (before being combined with fillers and additives such as carbon-black). The conductivities measured for silicone and polyurethane are in good agreement with the 0.3 W/mK value that was generally believed to apply to sealants other than butyl. The conductivity measured for the polysulfide sample is quite good ( $k = 0.19 \text{ W/m} \cdot \text{K}$ ).

## CONCLUSIONS

The guarded heater plate measurements of the solid edge-seal test samples have provided a direct measure of the edge-seal thermal resistance. The seals tested can be grouped into two sets. Seals providing low thermal resistance were the single and double seals with conventional aluminum spacer bars. Seals with high thermal resistance incorporated corrugated metal, fiberglass, or foam spacers. The difference in thermal resistance between these two groups of seals was significant. The presence of a primary sealant in the dual-seal design appears to lower the edge-seal thermal resistance—more for the edge-seals with aluminum spacers and very slightly for the fiberglass spacers. The conductivity of sealant used with the higher thermal resistance spacer bars (fiberglass and foam) has a strong bearing on the thermal resistance of the complete edge-seal.

Even though the difference between the thermal resistances of various edge-seals plays a relatively small role in overall window heat transfer, it is likely that the choice of edge-seal will play an important role in determining the minimum temperature found on the indoor pane and in the outdoor temperature at which condensation will occur. This

