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# HEAT TRANSFER AT THE EDGE OF SEALED INSULATING GLASS UNITS: COMPARISON OF HOT BOX MEASUREMENTS WITH FINITE-DIFFERENCE MODELING

A.H. Elmahdy and Th. Frank

## ABSTRACT

*A number of new insulated spacer bars, which are intended to improve the thermal performance of the edge of sealed insulating glass units (IG), were recently introduced into the market. This technology focuses on an area of the glass that extends about 63 mm above the sight line of the IG perimeter and is usually where a higher condensation risk occurs. The insulated spacer bars help increase the surface temperatures on the room side of the window; therefore, the terminology "warm edge technology" (WET) has been introduced in the literature. In practice, there is a need to define thermal characteristics for the edge-of-glass region of the IG unit in relation to heat loss as well as to condensation potential. Laboratory measurements and/or computer modeling are used to determine the extent of the changes in the thermal characteristics of the units as a result of the use of insulated spacers.*

*This paper presents the results of a first step in evaluating the effect of WET features on the glass temperature in the edge-of-glass region of IG units. The thermal performance of different IG units made with spacer bars (which incorporate WET features) has been investigated by measurements in an environmental test facility and by calculations using a two-dimensional finite-difference heat transfer model. Measured surface temperature distributions and heat fluxes through the edge of glass are compared with the results from computer modeling.*

## INTRODUCTION

The window frame and the edge of the glazing unit with spacer bars show a distinct multidimensional heat flow pattern. The thermal performance of these components is therefore strongly linked together and the boundary conditions are quite complex. The impact of the spacer on the total window heat loss as well as on the surface condensation potential might be important, especially in cases of high-performance glazing units with low- emissivity coatings on the glass and gas-filled (argon and/or krypton).

The thermal analysis of such a complex configuration can be done by calculations using multidimensional finite difference computer modeling techniques (Standaert 1986; Carpenter 1989, 1991). Results of such calculations are only reliable if all material properties, modeling of the unit profile, and the thermal boundaries have been defined correctly. Therefore, there is a need for validating the calculations through laboratory measurements.

In order to investigate the edge effect of different spacer bars, a procedure has been chosen to give the most accurate results possible to evaluate the WET features. For such a procedure, the edge-of-glass region of an insulated glazing unit has to dominate the measured specimen area. Therefore the size of the IG unit was chosen so that it approximately represents the edge-of-glass region. By definition, the edge-of-glass region is the area of the glass where the glass temperature changes until it reaches the constant value of the center of the glass (it is approximately 63 mm from the sight line of the IG unit). Since the IG test units were produced by different manufacturers, uncoated glass and normal air fillings have been used in order to avoid any uncertainty in the thermal performance of the IG unit itself.

The focus of this study is the thermal characteristics of different spacer bars and sealing systems. Questions related to the long-term durability of the sealed units were outside the scope of this study.

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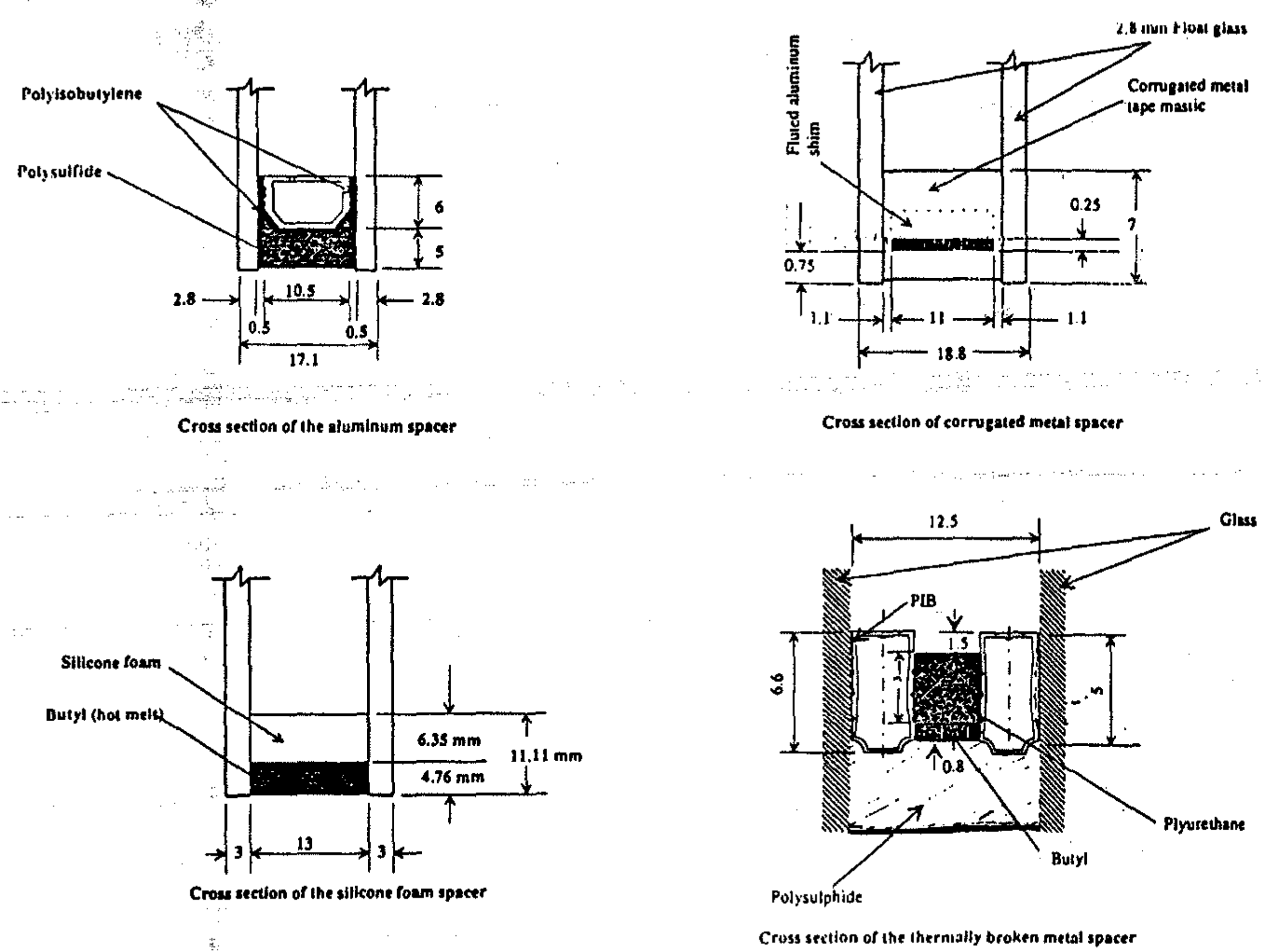


*Figure 1* *Cross Sections of the Spacer Bars Used*

## TESTED IG UNITS

In an attempt to determine the degree of improvement in the thermal performance (in particular the glass surface temperature) of IG units with WET features, special IG test specimens were made. The IG units are 152 mm by 1200 mm in size made of 3 mm (nominal) thick clear glass and a 13 mm (nominal) air gap. Four different sets of specimen were made, each consisting of six identical IG units in every aspect including the spacer bar. The four sets represented the available WET features commonly used in the Canadian market and made available to the testing laboratory. It is possible that other types of spacer bars are available in the market, but were not included in this work for no reason other than their availability and time constraints. It is planned to include as many spacer bar types as possible in future work. The four spacer bar types used in this study are (see Figure 1 for detailed description): spacer #1: normal aluminum, spacer #2: silicon foam, spacer #3: corrugated metal strip, and spacer #4: thermally broken metal.

## TEST METHOD

Each set of IG units (six units) was mounted side by side in the surround panel of the environmental chamber of the window test facility. Figure 2 shows a schematic diagram of the units mounted in the surround panel of the guarded hot box. The main reason behind mounting six identical units side by side was to eliminate any interference between the IG units and the surround panel. In addition, extra units were added to spread the thermocouples on different units to measure the glass surface temperature without significant disturbance to the boundary layer region around the thermocouples. The description of the test facility is reported in Elmahdy and Bowen (1988) and Bowen (1985). The units were sealed with cloth tape at the perimeter and also at the joints between the adjacent units to prevent any air leakage through the test specimen. The glazings were fixed on the top and bottom with a small wood stop (about 28 mm x 84 mm).

The cold-side air temperature was maintained at -18 ±1°C, the warm-side air was kept at 21 ±1°C. These temperature

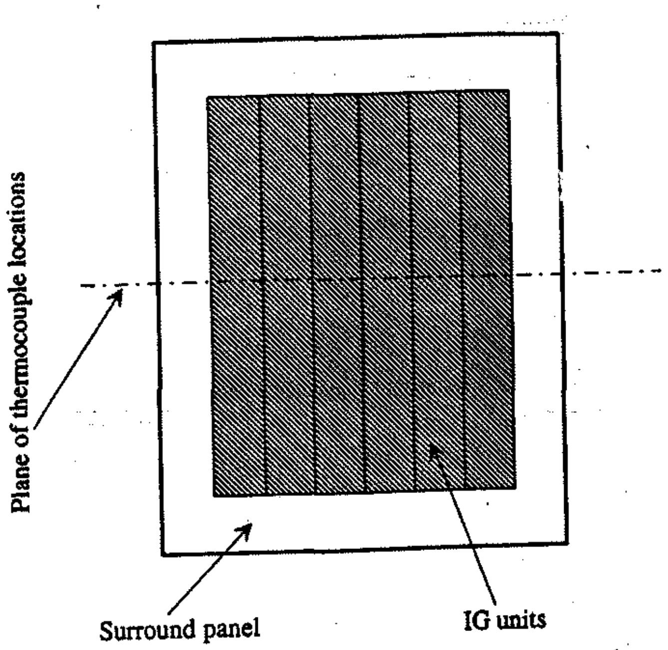


*Figure 2* *Six Identical IG Units Mounted in the Surround Panel*

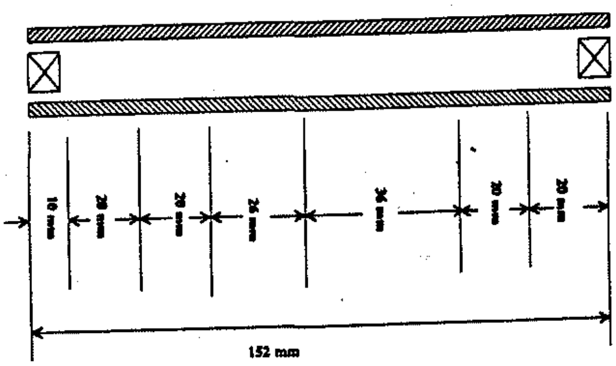


*Figure 3* *Locations of Thermocouples on the Glazing Unit*

conditions are used in ASTM standard E1423-91 (ASTM 1991) and other standard test methods for the assessment of the R-value of windows. The heat transfer in the warm chamber was by natural convection, whereas forced convection was applied in the cold chamber, with a film coefficient of about 25 W/($m^2$K). Thermocouples were attached to the surface of the glass on the warm and cold sides at several locations (see Figure 3) along a section at the middle of the height of the specimens.

## COMPUTER MODELING

The IG units were modeled using a two-dimensional finite-difference heat transfer program (Standaert 1986). The modeling of the units was performed as part of a joint research effort.

The IG unit was subdivided into rectangular blocks within a two-dimensional grid system of 30 by 43 nodes. The smallest size of discretization in the space was 0.5 mm. The

**Table 1**
**Thermal Conductivities Used for the Finite-Difference Calculation**

| Material | Thermal conductivity [W/m·K] |
|---|---|
| Glass | 0.80 |
| Aluminium | 160.0 |
| Wood (pine) | 0.14 |
| Butyl (hot melt) | 0.24 |
| Polysulphide | 0.19 |
| Polyurethane | 0.31 |
| Silicone foam | 0.12 |
| Silica gel (desiccant) | 0.13 |

thermal conductivities used for the different materials are given in Table 1. The boundary conditions for the cold and warm environments have been chosen according to the measured values from the hot box test. The film coefficients have been assumed to be constant and uniform on each side of the specimens.

## RESULTS AND DISCUSSION

### Surface Temperature Measurements and Calculations:

Once steady state is reached, thermocouple readings were recorded at the specified locations, as shown in Figure 3. A comparison between the calculated and measured temperatures is shown in Figures 4 through 7 for the different types of spacer bars. These figures show good agreement between the measured and calculated temperatures on both the warm side and the cold side of the IG unit.

A comparison of the warm-side and cold-side glass temperatures (resulting from computer modeling) of the four different types of spacer bars is shown in Figures 8 and 9, respectively, and Figure 10 shows a compilation of the predicted isothermal lines for the four types of spacer bars.

Among the four types of spacer bars tested, the metal bar had the lowest thermal resistance (Wright and Sullivan, 1989). The exact values of the thermal resistance of the four spacer bars were not determined in this study, but comparable spacer bars were tested at a Canadian university; the results are reported in Wright and Sullivan (1989). It is, however, expected that as the thermal resistance of the spacer bar increases, the glass surface temperature on the warm side tends to increase and the glass surface temperature on the cold side decreases. Both effects are shown in Figures 8 through 10. These changes in the glass temperature are the result of variations in the thermal bridging at the edge-of-glass region and would have an effect on the condensation resistance as well as on the overall thermal resistance, of the IG unit.

For clarification, detailed drawings of the different spacerbars included in this study were provided to the authors by the IG manufacturers, and no changes were made to

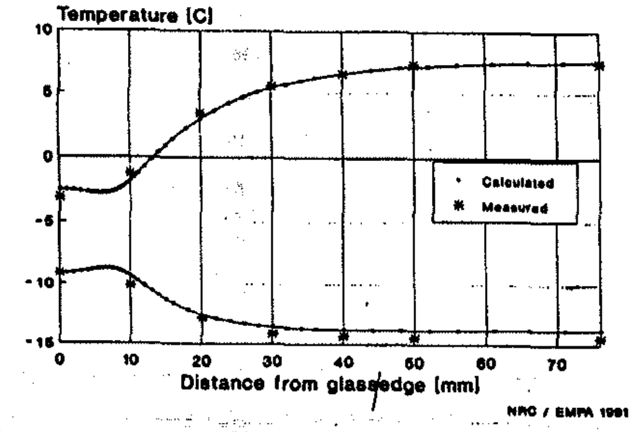


**Figure 4** *Glass Temperature for the Aluminum Spacer (Spacer #1)*

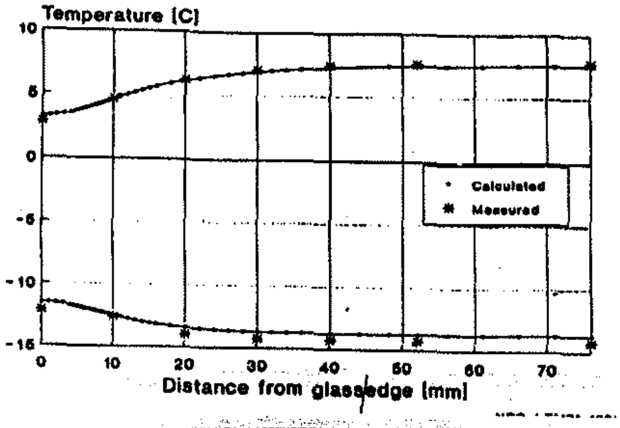


**Figure 5** *Glass Temperature for the Silicone Foam Spacer (Spacer #2)*

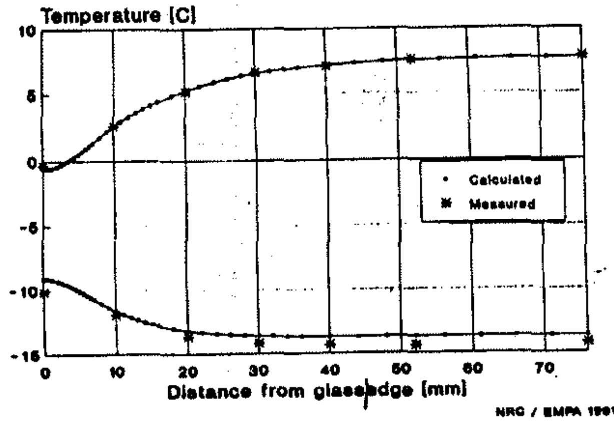


**Figure 6** *Glass Temperature for the Corrugated Metal Spacer (Spacer #3)*

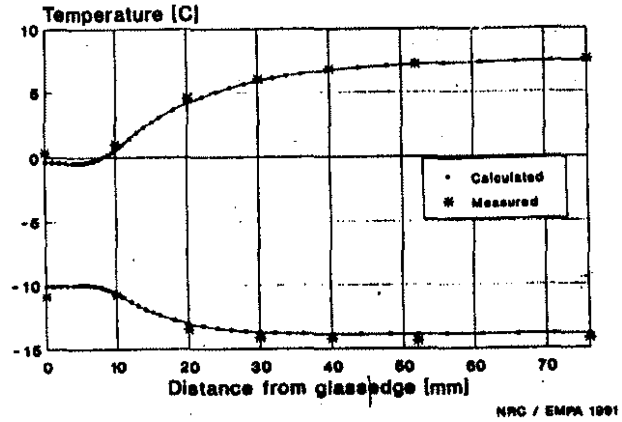


**Figure 7** *Glass Temperature for the Thermally Broken Metal Spacer (Spacer #4)*

reflect workmanship practices or other deviations from the ideal situations. For example, the primary seal is uniformly distributed on the side of the spacer bar without any discontinuity. In the case of the corrugated metal strip spacer, the drawing showed that the metal strip does not touch the glass. Some window manufacturers indicated that in some cases, the metal strip comes in contact with the glass, which results in serious thermal bridging across the sealed unit. Modeling of all the spacer bars included in this study assumed that the configurations shown in Figure 1 represent the tested units. Therefore, readers should be aware of these differences in order not to generalize the results reported in this paper.

The overall effect of a spacer bar on the thermalcharacteristics of windows is, to a high degree, dependent on many factors, including the type of frame, sash, and glazing method used. As mentioned above, the sealed units tested were, for the most part, totally exposed to cold (or warm) air without any sash or frame around the edge (except for the wood stop at the top and bottom of the IG units). Therefore, the glass temperatures reported in Figures 4 through 10 do not represent the real situation as applied to windows. In case of a window assembly, the spacer bar is buried in a sash (e.g., wood, vinyl, or metal), which is surrounded by a frame of a similar or different material. This will result in additional resistance to heat flow and different temperature values from those reported in this paper. As an illustration, the four types of IG units were fitted with wood sashes, and the surface temperatures were predicted by modeling (no testing was performed on IG units with wood sashes). Figure 11 shows the calculated isothermal lines of the IG units with wooden sashes. A comparison between the lowest glass surface temperature (with and without a wood sash) for the four spacer bar types is shown in Table 2. The data in Table 2 indicate that the variation in the glass surface temperature due to the presence of different spacer bars diminishes as a result of adding the wood sash. These differences will get smaller when thicker frame profiles are added, as in the case of a real window assembly.

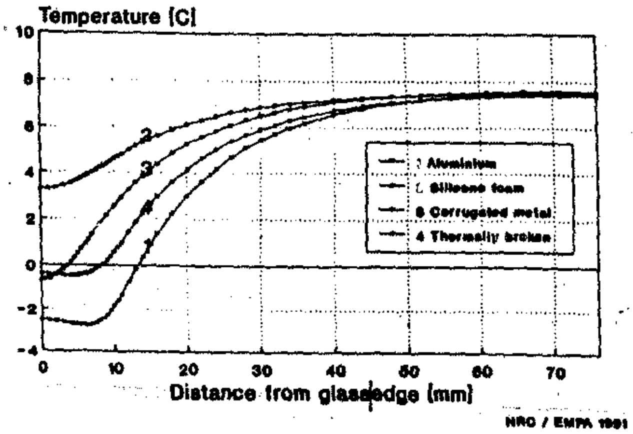


*Figure 8* Comparison of the Warm Side Glass Temperature of the Four Spacers

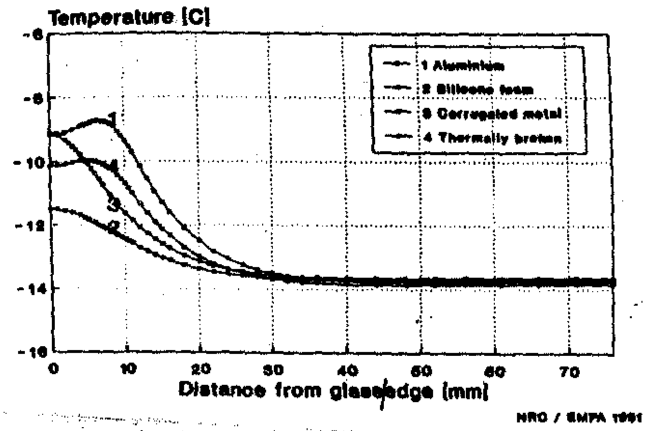


*Figure 9* Comparison of the Cold Side Glass Temperatures of the Four Spacers

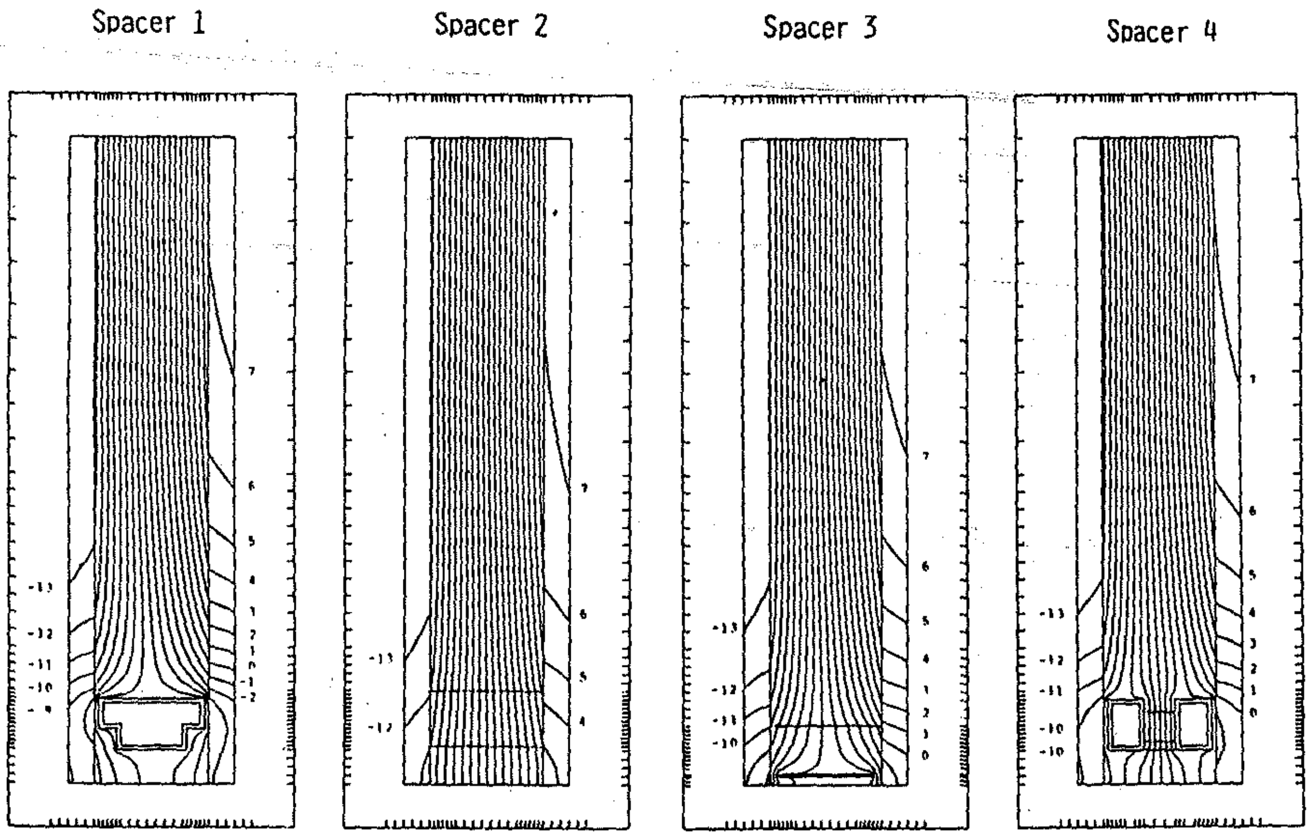


*Figure 10* Calculated Isothermal Lines for the Glass Edge

## Heat Fluxes

This experiment was mainly intended to compare surface temperatures of the edge-of- glass region of the IG units using hot box measurements with results from computer calculations. Since both procedures also provide information on the heat fluxes, a comparison of these results is included in this paper.

The heat flow through the IG unit is derived from the hotbox measurements, and is based on the following heat balance Eq:

$$Q_w = Q_t - Q_m - Q_s - Q_b \qquad (1)$$

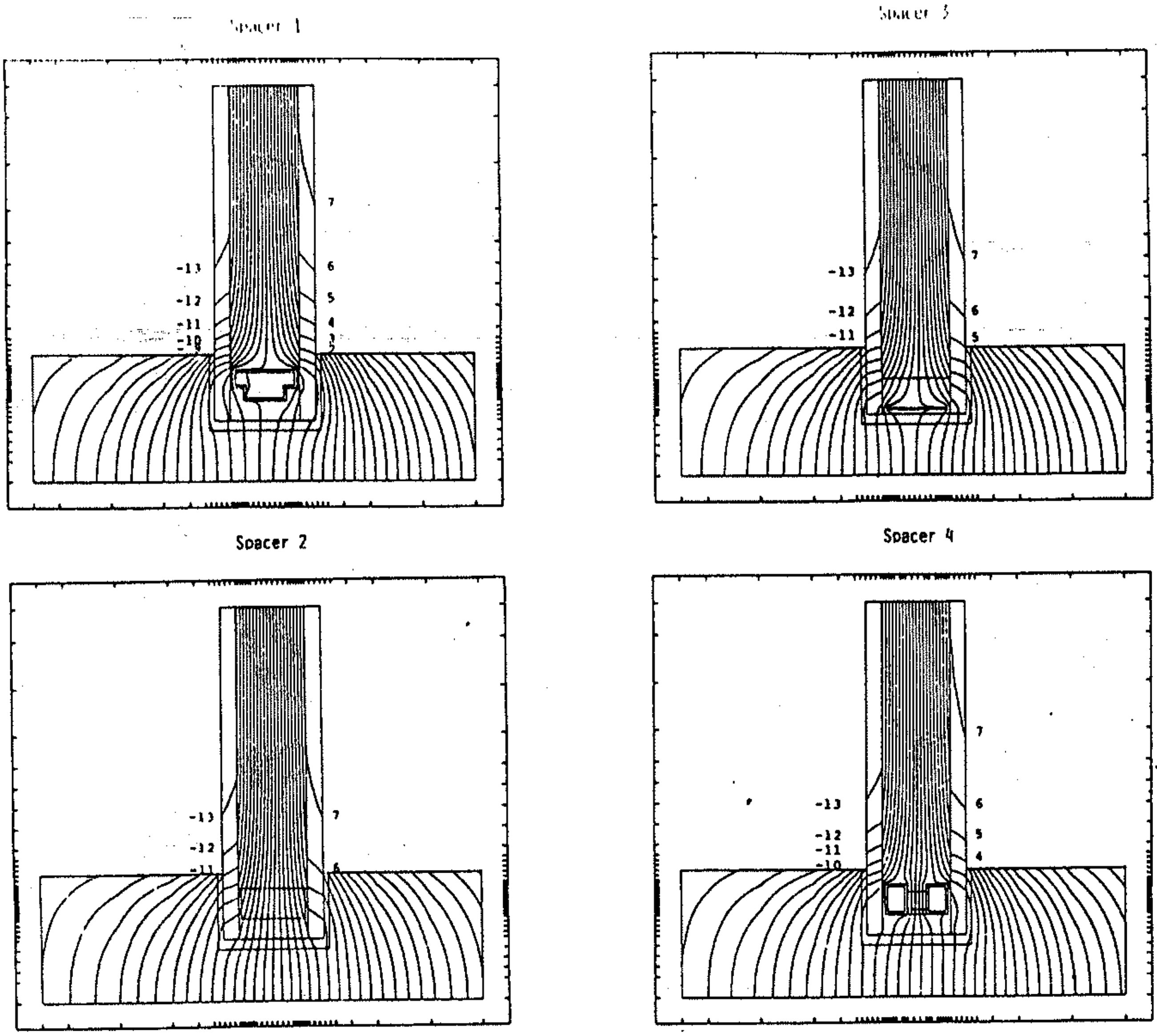


***Figure 11*** *Calculated Isothermal Lines for the Glass Edge with Wood Sash*

where

$Q_w$ = heat flow through IG unit, W;

$Q_t$ = total power supplied to calorimeter, W;

$Q_{sp}$ = heat flow through the surround panel, W;

$Q_e$ = flanking loss around the edge of the IG unit, W;

$Q_b$ = heat flow through calorimeter box walls (controlled to be zero).

The flanking loss, $Q_e$, is determined as the sum of two quantities, $Q_{e1}$ and $Q_{e2}$ (flanking loss without wood stop and flanking loss with wood stop, respectively)

$$Q_e = Q_{e1} + Q_{e2} \quad (2)$$

These two quantities were determined from by finite differences calculation and compared with values determined by hot box measurments (Elmahdy and Bowen 1988) and found to be

$$Q_{e1} = 3.2 \text{ W}$$

and

$$Q_{e2} = 0.8 \text{ W}.$$

A summary of the heat flow quantities, as determined from the hot box measurements, is given in Table 3. These heat transfer values are for the six IG units installed side by side in the surround panel of the hot box. The vertical sides are directly in contact with the surround panel, and the top and bottom edges are clamped in a wood stop, as explained earlier.

**Table 2**
**Calculated Minimal Warm Side Surface Temperatures (See Also Isothermal Lines in Figures 9 and 10 )**

| | Glass edge without sash | Glass edge with wood sash |
|---|---|---|
| Spacer #1 | -2.8°C | 2.1°C |
| Spacer #2 | 3.3°C | 6.1°C |
| Spacer #3 | -0.6°C | 5.1°C |
| Spacer #4 | -0.5°C | 3.6°C |

**Table 3**
**Heat Flow Derived from the Hot Box Measurements**

| | Spacer #1 | Spacer #2 | Spacer #3 | Spacer #4 |
|---|---|---|---|---|
| $Q_t$ [W] | 195.7 | 172.1 | 181.1 | 182.8 |
| $Q_m$ [W] | 39.6 | 39.5 | 39.5 | 39.6 |
| $Q_e$ [W]* | 4.0 | 4.0 | 4.0 | 4.0 |
| $Q_w$ [W] | 152.1 | 128.6 | 137.6 | 139.2 |

* Calculated flanking loss: $Q_e = Q_{e1} + Q_{e2}$
Glass edge without sash: $Q_{e1} = 3.2$ [W]
Glass edge with wood sash: $Q_{e2} = 0.8$ [W]
Total flanking loss: $Q_e = 4.0$ [W]

**Table 4**
**Heat Flows Derived from Finite Difference Calculations**

| | Spacer #1 | Spacer #2 | Spacer #3 | Spacer #4 |
|---|---|---|---|---|
| $Q_{eg}$ [W] | 129.5 | 112.9 | 118.8 | 122.7 |
| $Q_{egw}$ [W] | 16.9 | 14.9 | 15.6 | 16.1 |
| $Q_w$ [W] | 146.4 | 127.8 | 134.4 | 138.8 |
| $Q_w$ [W] (from Table 3) | 152.1 | 128.6 | 137.6 | 139.2 |
| $\Delta Q_w$ [W] | 5.7 | 0.8 | 3.2 | 0.4 |
| Age Difference, % | 3.8 | 0.6 | 2.4 | 0.3 |

In order to calculate the total heat flow through the tested specimen, the calculations were performed taking into account the heat transfer through the IG unit with and without the wood stop (or sash).

Heat flows derived from finite-difference calculations were as follows:

$$Q_w = Q_{eg} + Q_{egw} \qquad (3)$$

where

$Q_{eg}$ = heat flow through edge of glass area without wood stop

$Q_{egw}$ = heat flow through edge of glass area with wood stop.

A summary of the calculated heat transfer values is shown in Table 4. Also included in Table 4 are the corresponding heat transfer quantities determined from the hot box measurements (as given in Table 3), the difference between calculated and measured values, and a percentage difference (based on the average value) for each spacer bar tested.

As shown in Table 4, the differences between measured and calculated total heat flux through the specimen are less than 4% (calculated as a percentage of the average value). One reason for this good agreement is that uncertainties related to gas filling and low-emissivity coating on the glass were eliminated by testing clear-glass, air-filled units.

## PLAN FOR FUTURE WORK

It is important to indicate that the type of spacer bar does have an impact on the temperature of the glass in the edge-of-glass region as well as the heat loss through that region. The full impact of the spacer bar on a window should be determined by testing or modeling the complete assembly.

As indicated above, the effect of space bar type on the overall thermal resistance (and total heat loss) through windows is strongly dependent on the window design and material. As a result, this work will be extended to determine those effects by testing a number of window assemblies made of different materials (wood, aluminum, fiberglass, and vinyl) with different spacer bars in the IG units. The new study will also cover other spacer bar types, spacer widths, and the location of the spacer relative to the siteline. The results of this project will be published when they become available.

## CLOSING REMARKS

The thermal resistance of the spacer bar material influences the glass temperature in the edge-of-glass region of an IG unit. Based on the limited testing performed and computer modeling, the spacer with the highest thermal resistance shows the warmest glass temperature on the warm side (and the coldest temperature on the cold side) of the glass at a distance 5 to 60 mm from the edge of the IG unit. This study demonstrates that results from finite difference calculations show good agreement with results from hot box measurements.

Computer simulation programs are very helpful tools to provide data for simplified window calculation procedures, as these models consider a large number of parameters. However, these models have to be validated by testing and should be used within the limits of these validations.

The results presented in this paper do not provide a final assessment of a spacer bar type or sealing system. The full impact of thermal characteristics of the spacer bar material on the window thermal resistance and condensation resistance should be determined on a complete window assembly. Other aspects, such as the long-term durability of the whole sealing system, also have to be included in the analysis and validation of these systems.

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## DISCUSSION

**Roger Henry, Project Manager, EMR Canada, Ottawa, Ontario:** Spacers in the wood surround (frame) are set in considerably below the sight line. This could affect heat transfer substantially. What is the reason for this?

**A.H. Elmahdy:** The two pieces of wood shown in the figures were only used to secure the glazing units, rather than sashes or frames. These wood blocks did not impact on the glass temperature measurements because all measurements were made at mid-height of the glazing units. Future testing will include actual frames with 1 m by 1 m glazing units mounted according to common practices.

**William P. Goss, Professor, Mechanical Engineering Department, University of Massachusetts, Amherst:** In your paper, the edge-of-glass region on the sides of the glazing units is less than the 2½ inches (63 mm) used by ASHRAE in the fenestration window U-factor tables of the *Fundamentals Handbook*. Our finite-element modeling, which includes the cavity convective/radiative effects, indicates that 4-inch (102-mm) edge-of-glass regions occur on the top and bottom of windows where the flow in the cavity is turning. Do you plan to study these very important edge-of-glass regions in your future research?

**Elmahdy:** Yes, plans are now in place to test full-size units with thermocouples placed on the top, bottom, sides, edge-of-glass, and center-of-glass regions. The work reported in this paper represented the first step in investigating the impact of spacer bar types on the edge-of-glass surface temperature. We hope to be able to present the results of the next phase in the near future.