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Assessment of Spacer Bar Design and Frame Material on the Thermal Performance of Windows

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ABSTRACT

High-performance glazing systems incorporate low-emissivity coating on glass, heavy gas fill in the glazing cavity and thermally improved spacer bars instead of the conventional metal bars. The improved design and proper selection of material for spacer bars provide means to improve the overall thermal characteristics and condensation resistance of windows, particularly in the edge-of-glass region. Experimental results showed that there is an interaction between the spacer bar and sash/frame material of the window assembly that affects the overall performance of the fenestration products.

In an effort to investigate the interaction between the spacer bar design and frame/sash material on the thermal performance of windows, a series of tests were performed on a number of windows in controlled environment (e.g., laboratory testing). In an earlier study, a summary of the experimental setup and the results of testing small insulating glass (IG) units was presented to report the surface temperature distribution and condensation resistance of a set of IG units in the absence of framing material. Ten spacer bars, including conventional metal spacer, hybrid system, silicon foam and thermally broken bars were included in that set of IG units. The later spacer bars were referred to as warm edge technology (WET) bars. The full documentation of that part of the study was published in Elmahdy 2002.

In this paper, the results of investigating the thermal coupling effects and the interaction between the spacer bar and the window sash/frame material of a number of different spacer bar designs and frame material are summarized. The same spacer bars reported in the earlier study are included in this paper. Framing materials (wood, vinyl, aluminum and glass fiber) were used to study the combined effect of spacer bar design and frame material on the overall window performance.

The test results showed that the use of WET spacer bars demonstrated higher glass surface temperature in the edge-of-glass region, improved the condensation resistance and the overall R-value of the fenestration products relative to windows made with conventional metal spacers. There exist some combinations of certain spacer bar designs and frame material that produce favorable performance. However, it is important not to generalize the reported results due to the many varieties in frame designs and profiles that would have greater impact on the final results. On the other hand, these results provide clear indications of the interaction between spacer bar design and the frame material on the overall thermal performance of windows. As an added benefit, window designers have options to produce windows of wide range of performance factors to meet the demands for different applications and consumer's preferences.

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Key words: insulating glass units, condensation resistance, U-factor, testing, spacer bars, windows

INTRODUCTION:

Following the publication of the results of testing of small IG units (Elmahdy 2002), it was logical to proceed with testing complete window assemblies. These windows were made of IG units that incorporated the spacer bars tested earlier, and frames of different material (the description of the spacer bars is provided later in this paper). The earlier results showed that the use of WET spacer bars demonstrated higher glass surface temperature, particularly in the edge-of-glass region, and hence improved the condensation resistance of the IG units relative to those made with conventional metal spacers (see Figure 1). Common practices suggested that there exist some combinations of certain spacer bar designs and frame material that would produce favorable performance.

Basic heat transfer principles suggest that the heat transfer at the interface between the IG unit and sash/frame element of the window is not a simple one-dimensional phenomenon. At that region, dissimilar materials at different temperatures exchange heat in a complex manner that is usually analyzed by means of computer simulation models such as: THERM (THERM, 2000), FRAME (FRAME 1988), PHYSIBEL 1992) etc. Also, infrared thermography was used to obtain detailed temperature mapping of this region (Elmahdy 2005, Elmahdy 1996, Griffith et al 1996, Griffith et al. 2002 and Wright et al. 2003). Almost all of the aforementioned work investigated the complexity of surface temperature determination at the interface between the IG units and sash/frame members of the window assembly.

The focus of this paper is on determining the impact of use of WET spacer bars and different framing materials on the surface temperature, condensation resistance and overall U-factor (or R-value) of a number of fenestration systems.

TEST SETUP AND APPARATUS:

Tests were performed (for R-value and condensation resistance) in IRC/NRC guarded hotbox and according to a well-established R-value test procedure (Elmahdy 1992 and Elmahdy et al 1988). In addition, the Temperature Index (TI) principles for the investigation of condensation resistance were used as outlined in the CAN\CSA A440 Windows standard (CSA 2001) and Elmahdy 1990. Thermocouples were installed on the surface of the glazing, sash and frame elements on each window to obtain a comprehensive temperature mapping over the window surfaces (see Figure 2).

Tests were conducted with the room side air temperature at 21±1° and natural convection with the film coefficient about 8±1 W/(m^2.K), and the weather side temperature at -18±1°C and film heat transfer coefficient about 25±3 W/(m^2.K).

Ten 1 m by 1 m glazing units were provided by different manufacturers, each was made of double clear air filled IG unit. The glass was made of 3 mm (nominal) glass thick and each incorporated one of the ten spacer bars under investigation.. The ten spacer bars are described as follows, and a schematic diagram showing their details is given in Figure 3:

Description	Designation
Hybrid spacer (PVC and aluminum)	IG1
Two aluminum spacers with foam thermal break	IG2
Metal with mastic desiccant tape	IG3
Glass fibre spacer	IG4
Steel channel in a foam substrate with desiccant	IG5
PVC and galvanized steel	IG6
Conventional metal spacer	IG7
Silicone foam spacer	IG8
Corrugated metal strip in a mastic tape	IG9
Two metal spacers with polyurethane thermal break	IG10

The surface temperature measurements of the IG units indicated that there is a considerable difference of the glass surface temperature (particularly in the edge-of-glass region) between units made with conventional metal spacer and those made with warm edge designs, see Figure 1.

The four window frames were provided by four different manufacturers and were identified as follows:

AL-FR	Aluminum frame	**WO-FR**	Wood frame
VY-FR	Vinyl frame	**FG-FR**	Glass fiber frame

TESTING OF WINDOW ASSEMBLIES AND RESULTS:

Each of the aforementioned IG units was mounted in four different types of window frames (one unit at a time). The overall thickness of the IG units varied according to the spacer bar type. Although the manufacturers were instructed to produce identical units made of 3 mm glass thickness, the spacer bar design and manufacturing tolerances resulted in a slightly different overall unit thickness. The minimum unit thickness was 18.14 mm and the maximum unit thickness was 20.33 mm. A summary of the overall IG thickness of the ten units is as follows:

IG Designation	**IG1**	**IG2**	**IG3**	**IG4**	**IG5**	**IG6**	**IG7**	**IG8**	**IG9**	**IG10**
Overall unit thickness, mm	20.33	19.10	19.07	19.30	19.38	18.36	19.55	18.14	18.72	18.82

Table 1 provides a summary of the surface temperature measurement of the ten IG units when mounted and tested in a **VY-FR**. The glass surface temperature is affected by the material of spacer bar in the edge-of-glass region (about 67 mm from the sight line). This was demonstrated in Table 1 when comparing the glass surface temperature of the ten IG units (mounted in the **VY-FR**). For a highly insulated spacer bar (e.g., silicon foam [IG8] or corrugated (or fluted) metal spacer [IG9]), the glass surface temperature would be higher than that of a highly conductive spacer bar such as a conventional metal spacer (e.g., IG7).

Figure 4 and Figure 5 show graphic representations of the glass surface temperature of some selected points from Table 1 (top and bottom sections respectively) of the ten IG units mounted in a vinyl frame **VY-FR**. At 10 mm plane from the top of the sight line, IG8 and IG9 showed the highest glass surface temperature. IG6 showed the lowest surface temperature at that location, and it is very close to IG1, IG2, IG7 and IG10.

Figures 4 and 5 also displayed some interesting results. For example, Figure 4 showed that at 10 mm from the top, the surface temperature is warmer than those at 240 mm from the top. This could be the result of collapse in the region close to the centre-of-glass of the IG units under 39 K temperature difference across the IG units. It also indicates that the IG edge seal is performing properly without any seal breakage. This temperature variation is also due to the convection inside the cavity of the IG units. As the air stream moves downwards, it is cooled as a result of the lateral heat transfer from the warm side to the cold side of the IG units.

In addition, there was consistency in the temperature profiles in all units that showed a rise in the surface temperatures from the bottom sight line and up towards the center-of-glass area. There were also some surprising results where at all points from the bottom IG7 showed relatively better temperature than some “WET” spacers (e.g., IG6, IG8 & IG9). This could be attributed to the smaller thickness of IG 7, IG8, and IG9 relative to IG7 as shown in Table 1, as well as some production deficiencies in the frame profiles that resulted in excessive heat loss in that region.

Figures 6 and 7 provide a summary of the surface temperatures at the bottom and top sections of the ten IG units respectively, when mounted and tested in an **AL-FR**. All data is given in Table 2.

In Figure 7, the temperatures at 10 mm from the sight line of IG5, IG6 and IG7 were very close. This was despite of the fact that spacer bars IG5 and IG6 were marketed as "warm-edge" spacers with improved thermal performance compared to the conventional metal spacer (IG7). This phenomenon was explained earlier when presenting Figures 4 and 5. Also, IG4 showed the highest surface temperature at 10 mm plane, followed by IG3. In addition, Figure 6 showed a consistent trend of close surface temperatures of all IG units away from the edge of glass region and far from the effect of the spacer bar on the glass surface temperature

Figures 8 and 9 shows the corresponding surface temperatures at the bottom and top sections of the units respectively, when mounted and tested in the **WO-FR**. And Figures 10 and 11 show the temperatures at the bottom and top sections of the IG units respectively, when mounted and tested in the **FG-FR** frame. All measurements were shown in Table 3 for the **WO-FR** and in Table 4 for **FG-FR.**

It is clear that the frame material and the spacer bar type have a considerable impact on the glass surface temperatures in the edge-of-glass region. This is illustrated by comparing the glass surface temperatures of the ten IG units at a certain plane (e.g., 10 mm, 20 mm, etc.) in Figures 4 through 11. Each IG unit demonstrated different temperature profile as it was installed in the four different framing materials.

It should be noted that the relative performance of the tested IG units is more important than the absolute values of surface temperature values. There is another factor that may have an impact on the temperature values recorded during the tests: that is the overall IG thickness, as indicated in Tables 1 through 4. The overall thickness of IG units varied between 18.14 and 20.33 mm.

The comparison of the R-value of the window assemblies could also be a useful indicator of the effectiveness of the spacer bar type and the frame material on the overall thermal characteristics of the assemblies. All ten windows were tested for R-value at the test conditions mentioned earlier in this paper. Table 5 provides a summary of the R-value of window units. Each group of four bars represent an IG unit with one specific spacer bar mounted in four different frames.

Figure 12 below shows some interesting features of the IG units' performance when tested in four different framing materials. It is clear that any IG unit, when mounted and tested in a wood frame, shows the highest R-value compared to the R-value of the same IG unit when mounted in the other three types of frames. Although the previous test data indicated that the insulated spacers showed considerable improvements of the glass surface temperatures, the net effect on the R-value is different. Table 5 also shows that the combination of insulated spacers (such as IG8 and IG9) and a wood frame produces a high window overall R-value relative to the other configurations. Also, some spacer bars performed better than others because of their larger thickness and hence slightly larger gap width.

It is important to indicate that the R-value, as a measure of the thermal characteristic of a window, takes into account other facts other than the spacer bar impact on the overall R-value. In other words, it was indicated earlier that the IG units experience some glass deflection during testing, which resulted a reduction of the center of glass temperature. This factor seems to have more negative influence on the R-value than its expected improvement as a result of using high thermally insulated spacer and frame. It is worth noting that the presence of the calorimeter box makes it impossible to determine the glass deflection of the IG unit.

Other interesting observation from Figure 12 is that the frame design and the details of the interior profile have a significant impact on the final R-value of the window assembly. For example, the R-values are affected by the frame profiles, the inclusion of strips of insulation material in the cavities of hollow frames, frame material thicknesses and glass and cavity thickness. These effects are apparent when comparing the overall R-value of aluminum frame and glass fiber windows. Further investigation would be required to address all these factors to generalize the outcome of this work.

CLOSING REMARKS

Commercially available innovative (WET) spacer bars can have a beneficial effect on both the edge-of-glass temperature (condensation reduction) and the overall R-value (capability to reduce heat loss). The results of the IRC research conducted on ten different spacer bar designs provide the construction industry with a comparison of their performance. There is a range in the level of window performance that is required for particular applications or that is affordable by building owners and consumers. Therefore, manufacturers can use the results as a benchmark for choosing suitable combinations of spacer bars and frame materials to meet a range of needs. The results will also help manufacturers to continue their own research and development work on spacer bars, with a view to introducing improvements that will further enhance performance, as even small improvements can be significant.

In general, building designers should specify windows that have a Temperature Index that meets the requirements dictated by climatic conditions and building use, and an overall R-value that meets or exceeds code requirements. The results from this research project provide designers with a better idea of what is involved in achieving these ratings. As well, the research highlights the importance of considering all the factors that combine to affect window performance—the type of spacer bar, frame and glass—for each and every application

Finally, this paper presents information that could be used as guidelines for window design. The data should not be generalized for all windows of similar materials. Window size, frame design, manufacturing tolerances and other factors would affect the final results.

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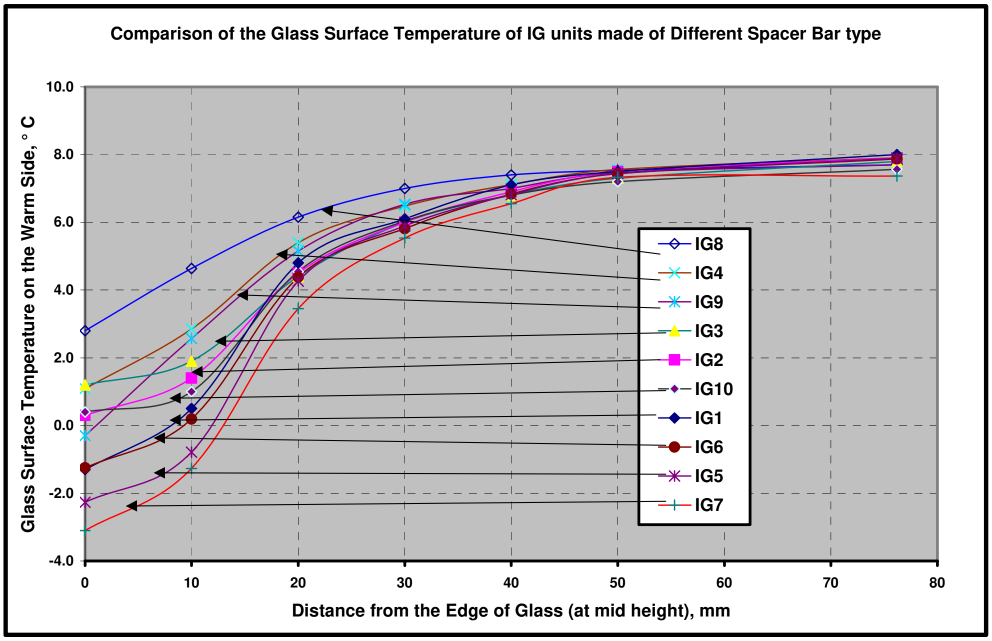

Figure 1 Comparison of the warm side glass surface temperature of ten IG units (Elmahdy 2002)

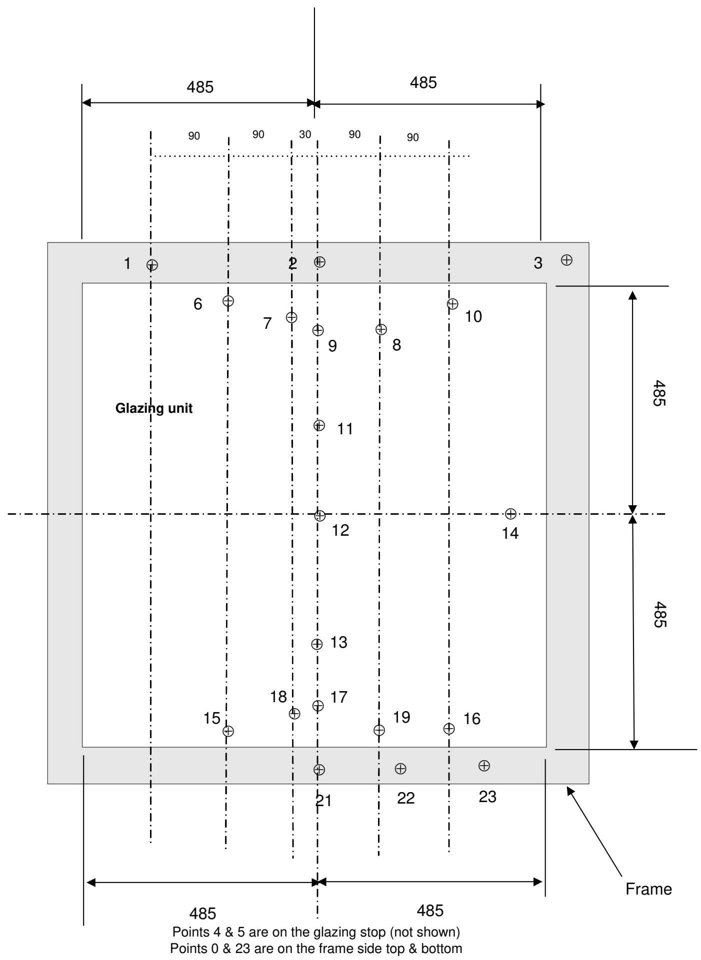

Figure 2 A schematic of the window assembly showing the thermocouple locations (Thermocouples No. 0 to 23)

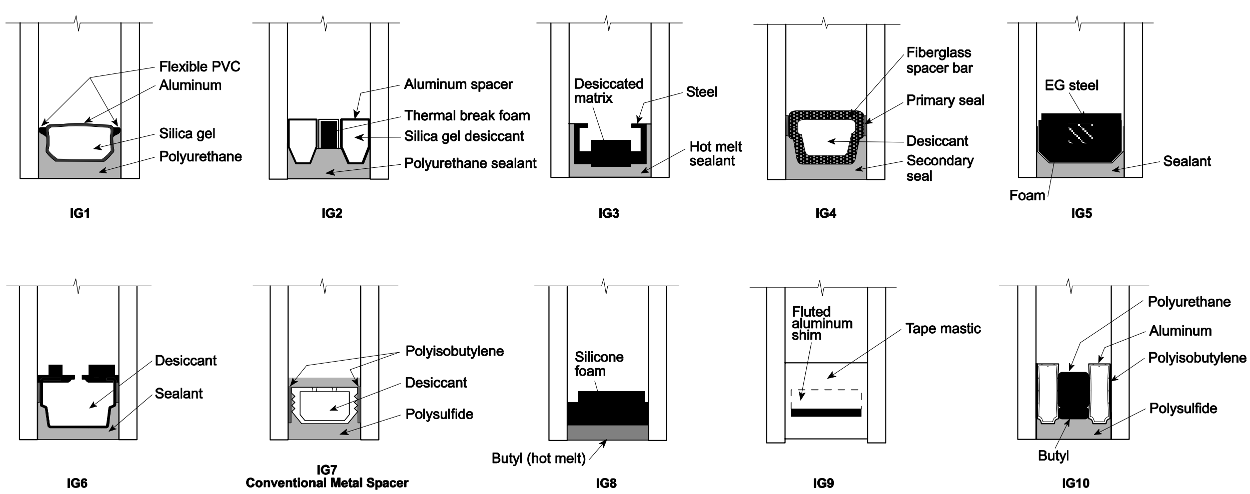

Figure 3 Schematic diagrams of the ten spacer bars tested

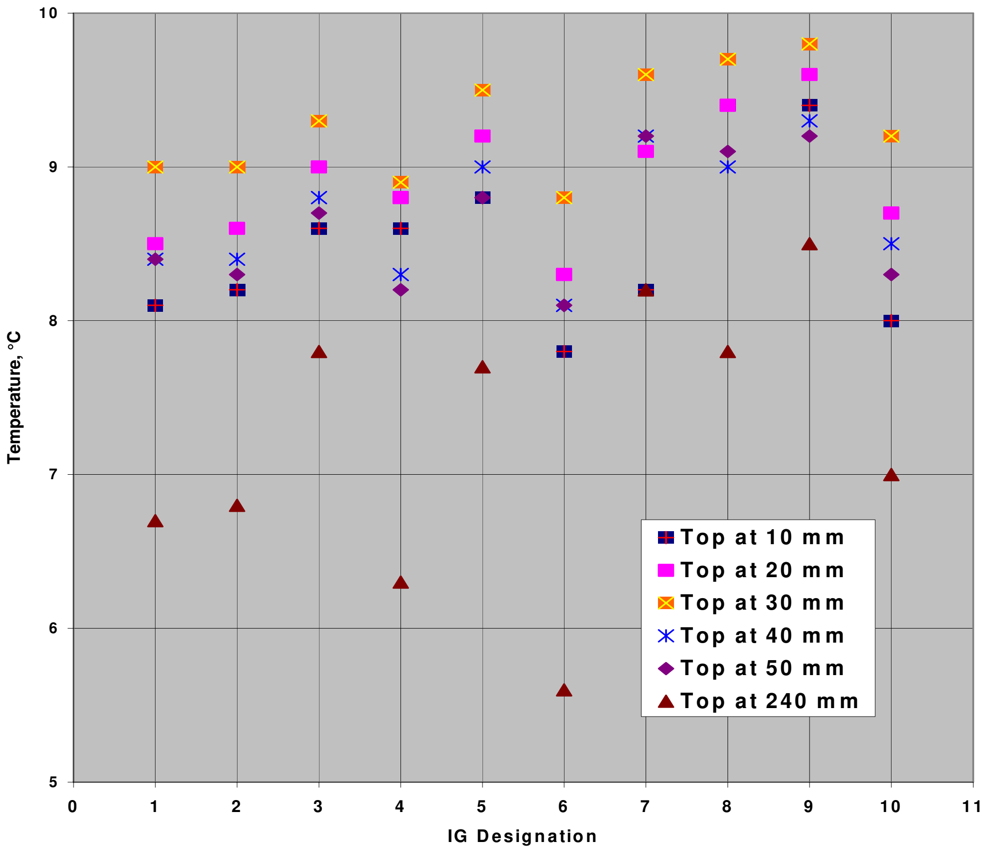

Figure 4 Surface temperatures at the top section on the room side of ten IG units in VY-FR

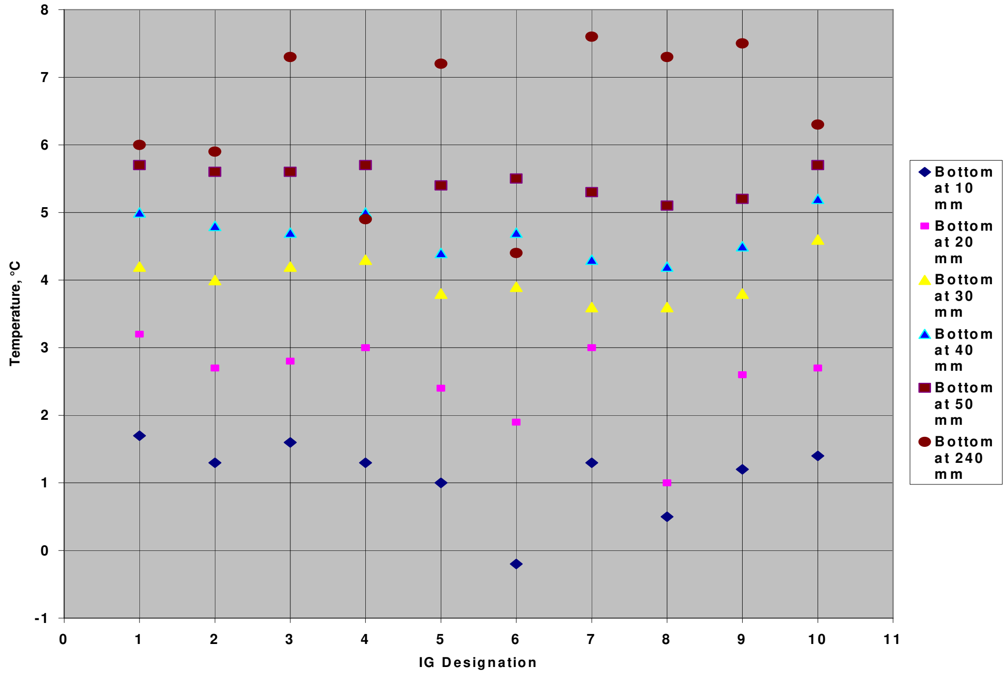

Figure 5 Surface temperatures at the bottom section on the room side of ten IG units in a VY-FR

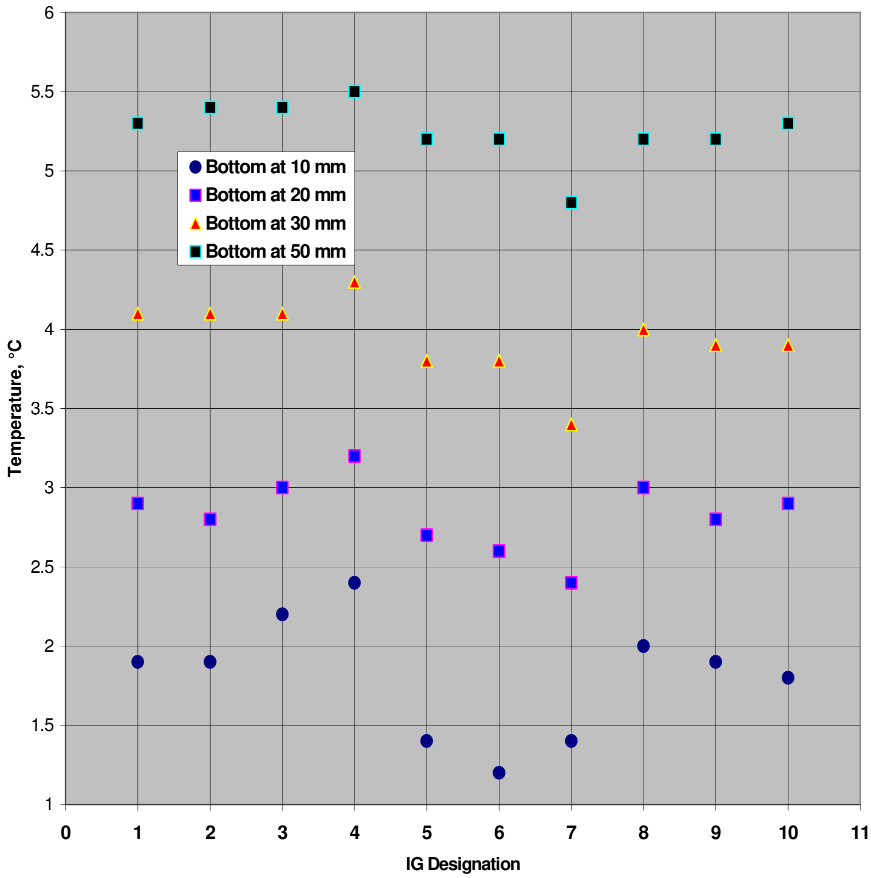

Figure 6 Comparison of the surface temperature at the bottom of ten IG unites in an aluminum AL-FR

Note: The legend frame was placed in an area that does not hide any data. Therefore, it was placed in different places for each plot.

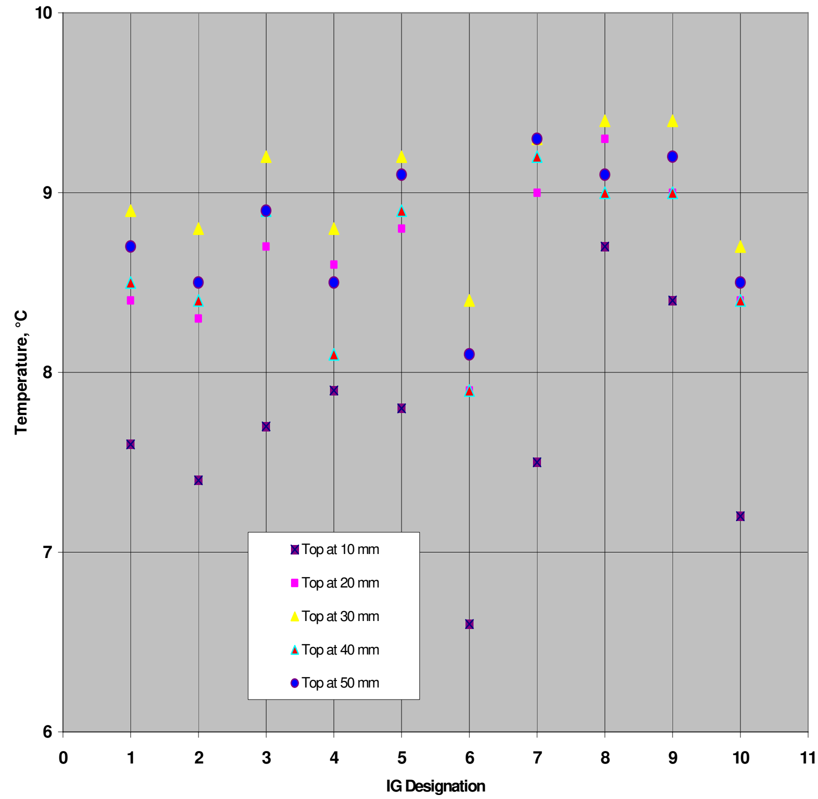

Figure 7 Comparison of the surface temperature at the top of ten IG units in an aluminum AL-FR

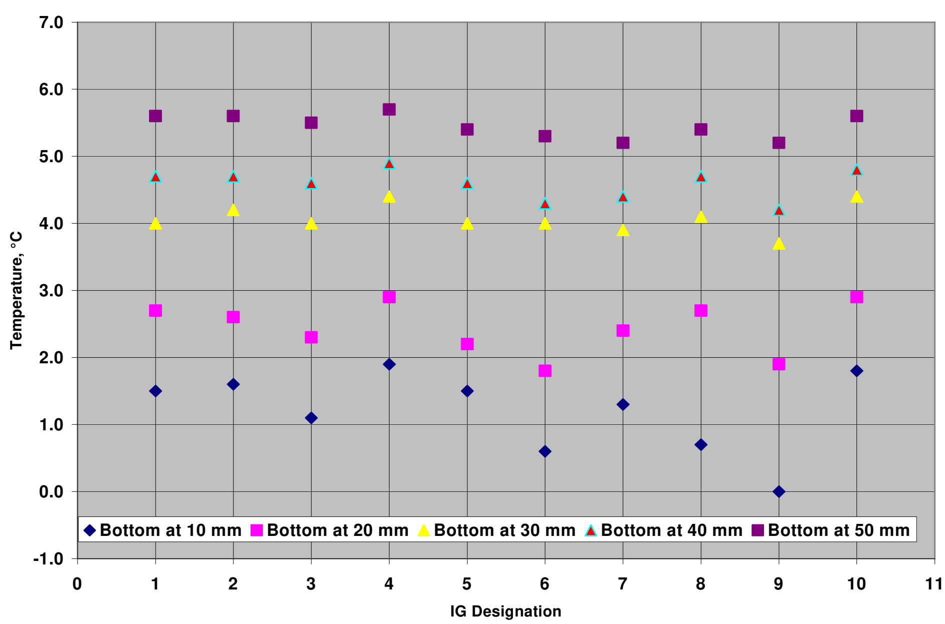

Figure 8 Surface temperatures at the bottom of ten IG units in a wood frame WO-FR

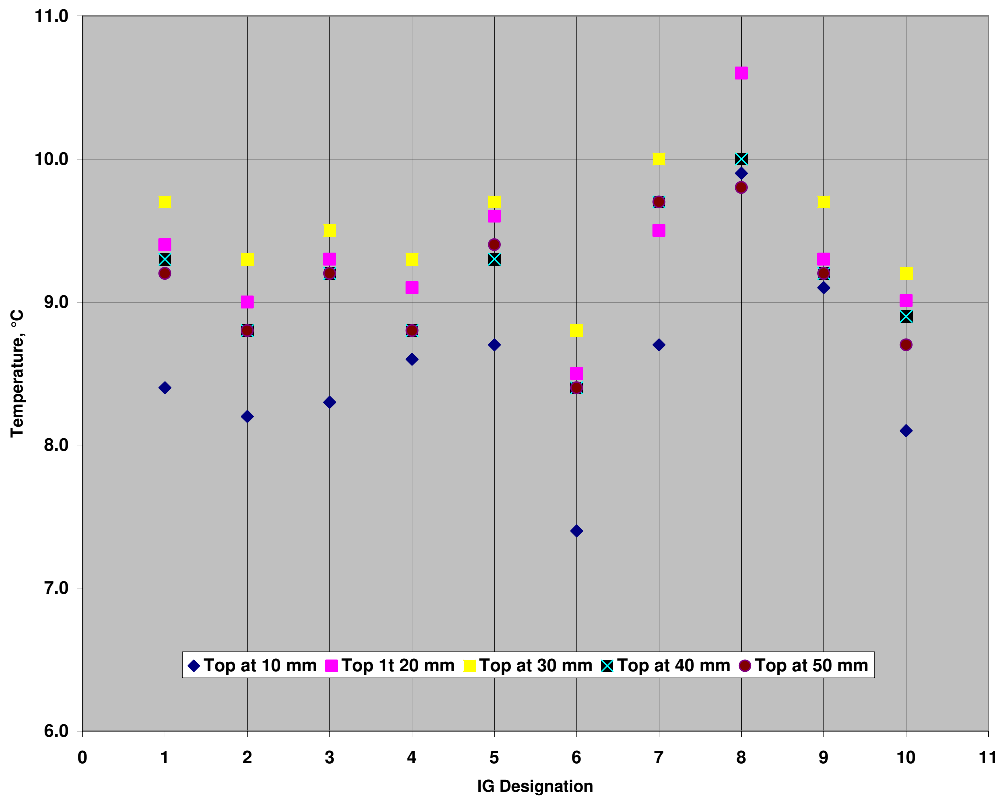

Figure 9 Surface temperature at the top of ten IG unites in a WO-FR frame

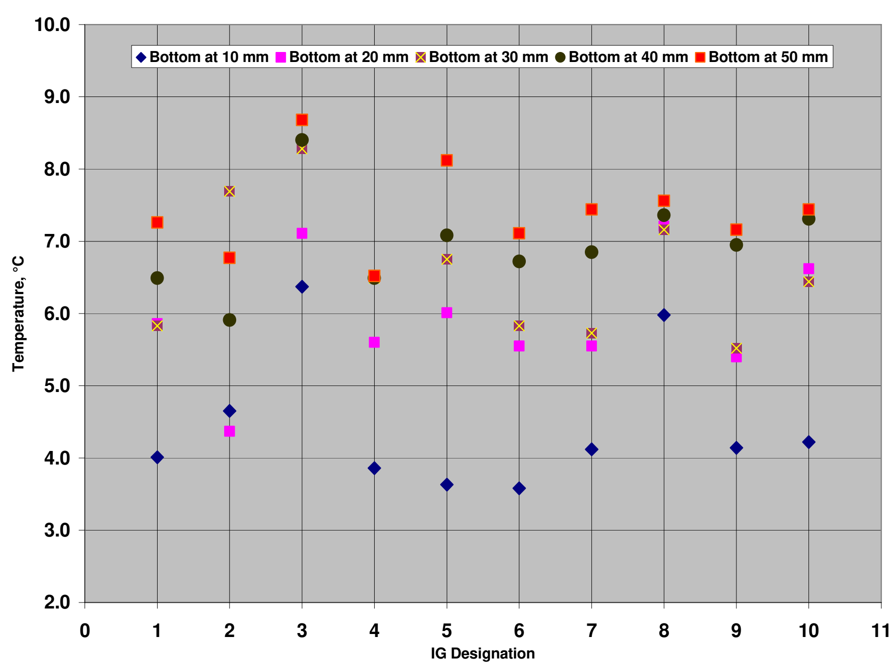

Figure 10 Surface temperatures at the bottom of ten IG units in a glass fiber frame FG-FR

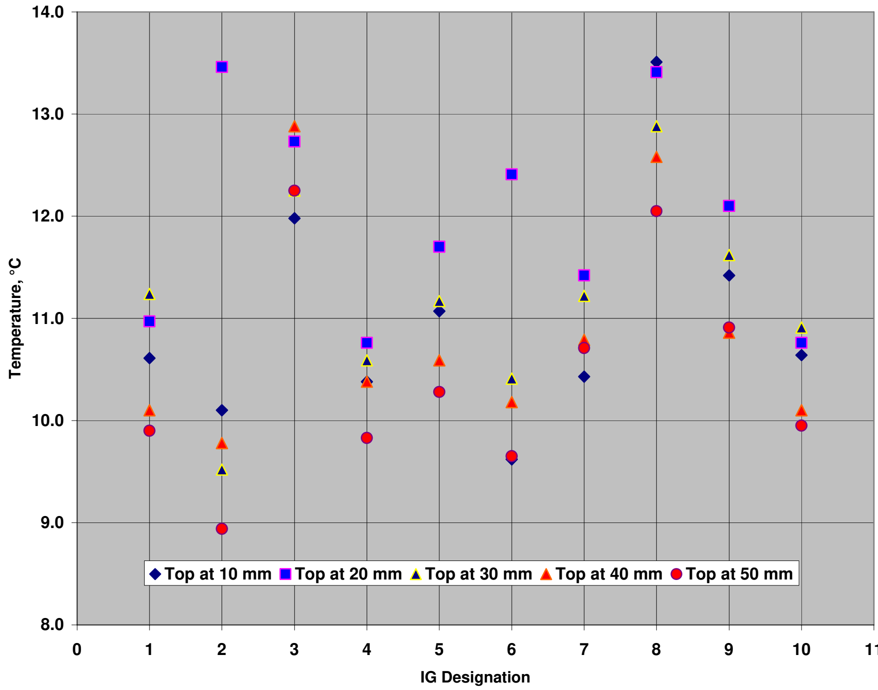

Figure 11 Surface temperature at the top of ten IG unites in a glass fiber frame FG-FR

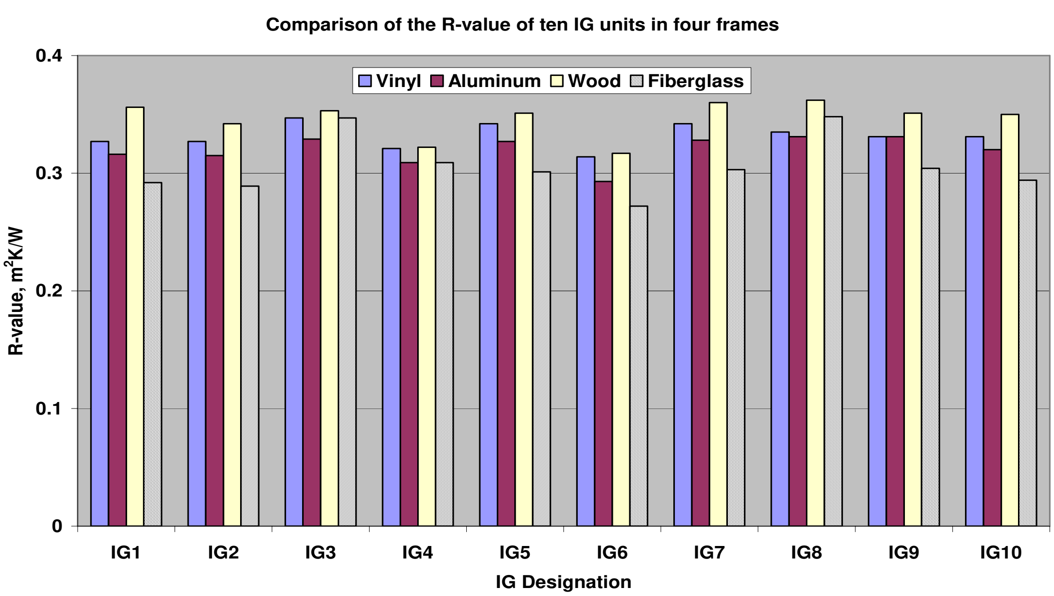

Figure 12 Comparison of the R-value of ten IG units in four frames

Table 1 Summary of the glass and frame surface temperatures on the room side of ten IG units in a vinyl frame VY-FR

Frame Type: Vinyl.		**IG Designation**									
GLAZING	**IG #**	**IG1**	**IG2**	**IG3**	**IG4**	**IG5**	**IG6**	**IG7**	**IG8**	**IG9**	**IG10**
	T/C's No.										
Top @ 10 mm	6	8.1	8.2	8.6	8.6	8.8	7.8	8.2	9.4	9.4	8.0
Top @ 20 mm	10	8.5	8.6	9.0	8.8	9.2	8.3	9.1	9.4	9.6	8.7
Top @ 30 mm	7	9.0	9.0	9.3	8.9	9.5	8.8	9.6	9.7	9.8	9.2
Top @ 40 mm	9	8.4	8.4	8.8	8.3	9.0	8.1	9.2	9.0	9.3	8.5
Top @ 50 mm	8	8.4	8.3	8.7	8.2	8.8	8.1	9.2	9.1	9.2	8.3
Top @ 240 mm	11	6.7	6.8	7.8	6.3	7.7	5.6	8.2	7.8	8.5	7.0
Mid height @ 490 mm	12	5.1	5.2	7.1	3.8	7.1	3.2	7.6	7.2	7.8	5.9
Bot @ 240 mm	13	6.0	5.9	7.3	4.9	7.2	4.4	7.6	7.3	7.5	6.3
Bot @ 50 mm	17	5.7	5.6	5.6	5.7	5.4	5.5	5.3	5.1	5.2	5.7
Bot @ 40 mm	18	5.0	4.8	4.7	5.0	4.4	4.7	4.3	4.2	4.5	5.2
Bot @ 30 mm	16	4.2	4.0	4.2	4.3	3.8	3.9	3.6	3.6	3.8	4.6
Bot @ 20 mm	19	3.2	2.7	2.8	3.0	2.4	1.9	3.0	1.0	2.6	2.7
Bot @ 10 mm	15	1.7	1.3	1.6	1.3	1.0	-0.2	1.3	0.5	1.2	1.4
FRAME											
Header : Corner	4	16.9	16.2	16.9	16.8	16.8	17.1	16.7	17.1	17.3	17.0
Header: Left	5	17.4	17.4	17.5	17.5	17.4	17.5	17.4	17.6	17.6	17.5
Side: Top	3	17.2	17.1	17.3	17.3	17.2	17.3	17.1	17.5	17.4	17.3
Side: Bottom	2	15.7	15.7	15.8	15.7	15.6	15.6	15.7	15.6	15.7	15.7
Sill: Left	1	13.2	13.1	13.3	13.0	13.2	13.0	13.2	12.8	13.2	12.1
Sill: Center	0	13.1	13.2	13.4	12.9	13.3	12.6	13.3	12.7	13.4	13.2
Stop: Left	14	11.0	11.0	11.1	10.8	11.0	10.5	10.9	10.8	11.1	9.8
IG thickness	**mm**	**20.3**	**19.1**	**18.9**	**18.9**	**19.4**	**18.5**	**19.6**	**18.1**	**18.6**	**18.8**

Table 2 Summary of the glass and frame surface temperatures on the room side of ten IG units in an aluminum frame, AL-FR

IG UNIT #	**T/C#**	**IG1**	**IG2**	**IG3**	**IG4**	**IG5**	**IG6**	**IG7**	**IG8**	**IG9**	**IG10**
Top @ 10 mm	6	7.6	7.4	7.7	7.9	7.8	6.6	7.5	8.7	8.4	7.2
Top @ 20 mm	10	8.4	8.3	8.7	8.6	8.8	7.9	9.0	9.3	9.0	8.4
Top @ 30 mm	7	8.9	8.8	9.2	8.8	9.2	8.4	9.3	9.4	9.4	8.7
Top @ 40 mm	9	8.5	8.4	8.9	8.1	8.9	7.9	9.2	9.0	9.0	8.4
Top @ 50 mm	8	8.7	8.5	8.9	8.5	9.1	8.1	9.3	9.1	9.2	8.5
Bottom @ 10 mm	15	1.9	1.9	2.2	2.4	1.4	1.2	1.4	2.0	1.9	1.8
Bottom @ 20 mm	19	2.9	2.8	3.0	3.2	2.7	2.6	2.4	3.0	2.8	2.9
Bottom @ 30 mm	16	4.1	4.1	4.1	4.3	3.8	3.8	3.4	4.0	3.9	3.9
Bottom @ 40 mm	18	4.7	4.6	4.6	4.8	4.4	4.4	4.1	4.6	4.4	4.4
Bottom @ 50 mm	17	5.3	5.4	5.4	5.5	5.2	5.2	4.8	5.2	5.2	5.3
LOCATION ON FRAME											
Header : Left	1	13.1	13.4	13.6	13.5	13.1	13.1	13.2	13.9	13.6	13.5
Header: Center	2	13.4	13.7	13.8	13.7	13.4	13.4	13.4	14.1	13.8	13.7
Header: Right	3	12.9	13.2	13.3	13.2	12.9	12.9	12.8	13.6	13.3	13.1
Side: Top	0	12.4	12.7	12.9	12.8	12.5	12.5	12.5	13.2	12.9	12.8
Side: Bottom	20	10.7	11.0	11.1	11.0	10.8	10.7	10.7	11.3	10.9	11.0
Glazing Stop: Left	4	10.2	10.5	10.6	10.5	10.3	10.2	10.1	10.8	10.5	10.5
Glazing Stop: Right	5	10.1	10.4	10.6	10.5	10.2	10.3	10.1	10.9	10.6	10.5
IG thickness	**mm**	**20.4**	**19.1**	**18.9**	**18.9**	**19.4**	**18.5**	**19.6**	**18.1**	**18.6**	**18.8**

Table 3 Summary of the glass and frame surface temperatures on the room side of ten IG units in a wood frame

		IG1	IG2	IG3	IG4	IG5	IG6	IG7	IG8	IG9	IG10
LOCATION ON GLAZING	**T/Cs**										
Top @ 10 mm	6	8.4	8.2	8.3	8.6	8.7	7.4	8.7	9.9	9.1	8.1
Top @ 20 mm	10	9.4	9.0	9.3	9.1	9.6	8.5	9.5	10.6	9.3	9.0
Top @ 30 mm	7	9.7	9.3	9.5	9.3	9.7	8.8	10.0	10.0	9.7	9.2
Top @ 40 mm	9	9.3	8.8	9.2	8.8	9.3	8.4	9.7	10.0	9.2	8.9
Top @ 50 mm	8	9.2	8.8	9.2	8.8	9.4	8.4	9.7	9.8	9.2	8.7
3/4 Height	11	7.3	6.6	7.6	6.0	7.6	5.4	8.1	7.7	7.6	6.9
1/2 Height	12	6.6	5.3	7.0	3.3	6.9	2.3	7.7	7.2	7.1	5.9
1/4 Height	13	7.0	6.0	7.3	4.8	7.3	4.3	7.7	7.3	7.3	6.2
1/2 Height @ 30 mm	14	7.7	7.6	7.7	7.6	7.5	7.4	7.8	7.7	7.9	7.5
Bottom @ 10 mm	15	1.5	1.6	1.1	1.9	1.5	0.6	1.3	0.7	0.0	1.8
Bottom @ 20 mm	19	2.7	2.6	2.3	2.9	2.2	1.8	2.4	2.7	1.9	2.9
Bottom @ 30 mm	16	4.0	4.2	4.0	4.4	4.0	4.0	3.9	4.1	3.7	4.4
Bottom @ 40 mm	18	4.7	4.7	4.6	4.9	4.6	4.3	4.4	4.7	4.2	4.8
Bottom @ 50 mm	17	5.6	5.6	5.5	5.7	5.4	5.3	5.2	5.4	5.2	5.6
LOCATION ON FRAME											
Header : Left	1	16.1	16.1	16.0	16.3	15.9	16.0	16.2	16.7	16.2	16.3
Header: Center	2	17.0	17.0	17.1	17.1	16.9	17.0	17.0	17.4	17.1	17.1
Header: Right	3	16.9	17.0	17.0	17.0	16.9	16.8	16.9	17.4	17.0	17.0
Side: Top	0	17.1	17.2	17.2	17.2	17.2	17.2	17.2	17.5	17.2	17.2
Side: Bottom	20	16.2	16.1	16.0	16.2	16.1	15.9	16.1	16.1	16.0	16.3
Sill: Left	21	14.3	14.2	14.1	14.2	14.2	14.1	14.3	14.3	14.2	14.4
Sill: Center	22	13.9	13.7	13.7	13.5	13.9	13.0	14.0	13.9	13.4	14.0
Sill: Right	23	14.3	14.2	14.1	14.2	14.2	13.6	14.3	14.4	14.3	14.4
Glazing Stop: Left	4	13.3	13.3	13.3	13.3	13.3	13.1	13.3	13.1	12.9	13.6
Glazing Stop: Right	5	13.2	13.2	13.2	13.4	13.2	12.8	13.2	13.4	13.2	13.4
IG thickness,	**mm**	**20.3**	**19.1**	**18.9**	**18.9**	**19.4**	**18.5**	**19.6**	**18.1**	**18.6**	**18.8**

Table 4 Summary of the glass and frame surface temperatures on the room side of ten IG units in a glass fibre frame

LOCATION ON GLAZING	T/Cs	IG1	IG2	IG3	IG4	IG5	IG6	IG7	IG8	IG9	IG10
Top @ 10 mm	6	10.6	10.1	12.0	10.4	11.1	9.6	10.4	13.5	11.4	10.6
Top @ 20 mm	10	11.0	13.5	12.7	10.8	11.7	12.4	11.4	13.4	12.1	10.8
Top @ 30 mm	7	11.2	9.5	12.3	10.6	11.2	10.4	11.2	12.9	11.6	10.9
Top @ 40 mm	9	10.1	9.8	12.9	10.4	10.6	10.2	10.8	12.6	10.9	10.1
Top @ 50 mm	8	9.9	8.9	12.3	9.8	10.3	9.7	10.7	12.1	10.9	10.0
3/4 Height	11	6.6	5.9	9.9	8.1	7.6	6.4	8.0	10.1	8.3	7.0
1/2 Height	12	5.6	4.4	8.3	6.8	7.7	2.1	8.1	9.0	8.5	6.3
1/4 Height	13	6.2	5.5	8.5	7.4	8.6	4.4	8.3	9.2	8.6	7.3
1/2 Height @ 30 mm	14	10.1	9.4	11.1	9.6	10.1	9.7	10.0	11.0	10.3	10.1
Bottom @ 10 mm	15	4.0	4.7	6.4	3.9	3.6	3.6	4.1	6.0	4.1	4.2
Bottom @ 20 mm	19	5.9	4.4	7.1	5.6	6.0	5.6	5.6	7.2	5.4	6.6
Bottom @ 30 mm	16	5.8	7.7	8.3	6.5	6.8	5.8	5.7	7.2	5.5	6.4
Bottom @ 40 mm	18	6.5	5.9	8.4	6.5	7.1	6.7	6.9	7.4	7.0	7.3
Bottom @ 50 mm	17	7.3	6.8	8.7	6.5	8.1	7.1	7.4	7.6	7.2	7.4
LOCATION ON FRAME											
Header : Left	1	10.2	9.4	11.1	9.7	10.1	9.7	10.1	10.9	10.0	10.0
Header: Center	2	13.8	12.7	13.7	11.3	13.7	13.6	13.9	13.7	13.9	13.5
Header: Right	3	15.2	14.4	15.6	14.3	15.5	15.2	15.4	15.7	15.6	15.5
Side: Top	0	9.9	9.5	11.2	9.5	10.3	9.8	10.2	10.7	10.7	10.2
Glazing Stop: Left	4	16.8	16.1	17.2	16.3	17.1	17.0	17.1	17.4	17.2	17.2
Glazing Stop: Right	5	15.1	14.5	15.3	16.7	15.4	15.1	15.4	16.0	15.5	15.4
IG thickness,	**mm**	**20.3**	**19.1**	**19.1**	**19.3**	**19.4**	**18.4**	**19.6**	**18.1**	**18.7**	**18.8**

Table 5 Comparison of the R-value of ten IG units in four frames

	R-value, $m^2.K/W$			
	Vinyl	**Aluminum**	**Wood**	**Fiberglass**
IG1	0.33	0.32	0.36	0.29
IG2	0.33	0.32	0.34	0.29
IG3	0.35	0.33	0.35	0.35
IG4	0.32	0.31	0.32	0.31
IG5	0.34	0.33	0.35	0.30
IG6	0.31	0.29	0.32	0.27
IG7	0.34	0.33	0.36	0.30
IG8	0.34	0.33	0.36	0.35
IG9	0.33	0.33	0.35	0.30
IG10	0.33	0.32	0.35	0.29