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Thermal Characteristics and Durability of Sealed Insulating Glass Units Incorporating Muntin Bars Under Ultraviolet Exposure

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ABSTRACT

Recent developments in glazing manufacturing have resulted in the introduction of a variety of glazing systems to meet the consumers demand and, in many cases, with better thermal performance than conventional glazing. Insulating glass (IG) units are now available where air is replaced with argon and other heavy gases (or mixtures of gases), low emissivity coatings on glass or plastic films, and muntin bars in the cavity between the sheets of glass.

Muntin bars are made of various materials such as aluminum (anodized or painted), vinyl, or silicone foam. Although muntin bars are used for aesthetic reasons, they may cause adverse effects on the IG units performance, which may be attributed to the improper preparation of the muntin bars or the use of inferior paints.

Ultraviolet (fogging) tests were performed on a number of argon-filled IG units with and without muntin bars. The test results indicate that most of the IG units with muntin bars fail the UV test when viewed at off-angle. Meanwhile, when viewed at right angle, most of the IG units with muntin bars passed the UV test. Test results also showed that the R-value and condensation resistance of IG units with muntin bars are 4% to 7% lower than those units without muntin bars. The thermal bridging effect of the muntin bars contribute to the lower glass surface temperature in the area adjacent to the muntin bars.

INTRODUCTION

Sealed insulating glass (IG) units have gone through many changes during the past two decades. These changes were intended to improve their thermal performance and enhance the comfort conditions in the indoor environment.

Air in the cavity between sheets of glass is replaced by heavier gases (than air) or gas mixtures, low emissivity coating (of different composition and characteristics) is applied to glass or thin plastic films, and metal spacers are replaced by insulating spacers. The net effect of these features is an increase in the thermal resistance of the IG units and a higher glass temperature on the interior glass surface.

Market demands have generated new types of IG units that incorporate decorative muntin bars inside the cavity of the IG units. The muntin bars are made of vinyl, aluminum, anodized aluminum, or other suitable materials. The bars can be painted or unpainted depending on the consumer's demand.

The introduction of muntin bars was seen by some as a problem when filling the units with argon or other heavy gases. This is particularly true when the design of the units is such that compartmentalization of the cavity occurs when the grill touches or comes very close to the glass surface. The presence of muntin bars in the cavity of IG units also can impact the R-value of the units and affect the interior glass surface temperature. This may be expected because the muntin bars, in most cases, have higher thermal conductance than the air in the cavity. This situation also may be complicated if the grill touches the glass surface. In this situation, an active thermal bridging effect exists that will reduce the unit's R-value.

In cases of large temperature gradients across the air cavity of IG units, those units with muntin bars may exhibit lower glass surface temperatures than units without muntin bars, particularly in the area adjacent to the muntin bar. When air circulates inside the cavity of an IG unit under the influence of the natural convection currents, a localized high air velocity (and, hence, high film heat transfer coefficient) exists between the glass and the surface of the muntin bar. The result is a higher heat transfer rate through the glass, and hence, a lower glass surface temperature. This mainly occurs in the vicinity of the muntin bar elements and may result in a reduction of the condensation resistance of the IG units. It also could be argued

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that the muntin bars cause restriction to the airflow in the cavity, and hence, improve R-value and higher glass surface temperature. In practice, however, the glass surface temperature is lower around the muntin bars, which may indicate that the thermal bridging effect is more dominating. Perhaps further investigation of this issue using a sophisticated computer simulation model would provide better understanding of this behavior.

The IG units undergo an extensive testing program to examine the seal integrity and the durability of the unit. For example, IG units are tested in the weathercycling, high humidity, and ultraviolet exposure program according to CAN/CGSB 12.8 (CGSB 1990) or ASTM E773 (ASTM 1994) standards. These standards do not include specific tests for IG units with muntin bars, and hence, units with muntin bars are installed in buildings without being tested in accordance with recognized standards. It is worth noting that the Canadian standard is being revised to include testing of units with muntin bars.

This paper presents a summary of a testing program to evaluate the degradation of IG units with muntin bars when exposed to ultraviolet radiation during the volatile (fogging) test as specified in the CGSB 12.8 standard. This paper also presents a summary of the results from the testing of glazing units to determine the effect of incorporating the muntin bars into the IG units on their R-value. The R-value testing was performed in the IRC guarded hot box (Bowen 1985; Elmahdy 1993).

VOLATILE (FOGGING) TEST AND SAMPLES

Both the Canadian (CGSB 1990) and the American (ASTM 1994) standards on the durability of IG units include a test to assess the degradation of organic materials in the IG units when exposed to ultraviolet radiation. There is a major difference in the ultraviolet test procedures in the ASTM and the CGSB standards. These differences currently are under review by the Canada/USA Window Standard Harmonization Committee. In this section, the discussion will be focused on the CGSB test procedure.

The volatile (fogging) test was performed according to the test procedure described in the CAN/CGSB 12.8 standard (CGSB 1990). In this test, the units were exposed for seven days to ultraviolet radiation emitted from a standard sun lamp with a minimum output of 0.4 mW/cm^2 when measured with a sun lamp tester at a distance of 300 mm. The units were mounted in a box equipped with the sun lamp and a cold plate, see Figure 1. The air temperature in the box was maintained at 60℃ ±2℃, while the cold plate was kept at 22℃ ±2℃ throughout the test. A small circulating fan is placed at the bottom of the box so that the maximum temperature gradient across the lower face of the unit is not higher than 12℃.

For each given IG configuration (or set), three units were tested. Two units of each set contain low emissivity coating on one glass pane, while the third unit was made up of clear/clear glass. This latter unit was used as a control unit for that given set. During the test, the cold plate was placed on the surface of the glass pane containing the low emissivity coating (for one unit) and on the clear glass pane of the second coated glass unit. This part of the testing program was intended to study the influence of the presence of the low emissivity coating on the detection of the volatile deposits at the end of the test.

Following the completion of the test, the units were placed, one at a time, in a viewing box, (Figure 2) to examine the presence of deposits. The units were examined in two different ways. First, each unit was viewed as described in the CAN 12.8 standard (i.e., at a distance of 2 m standing directly in front of the unit and at a normal angle, with the mid-height of the unit, where the cold plate was placed, at eye level). Then

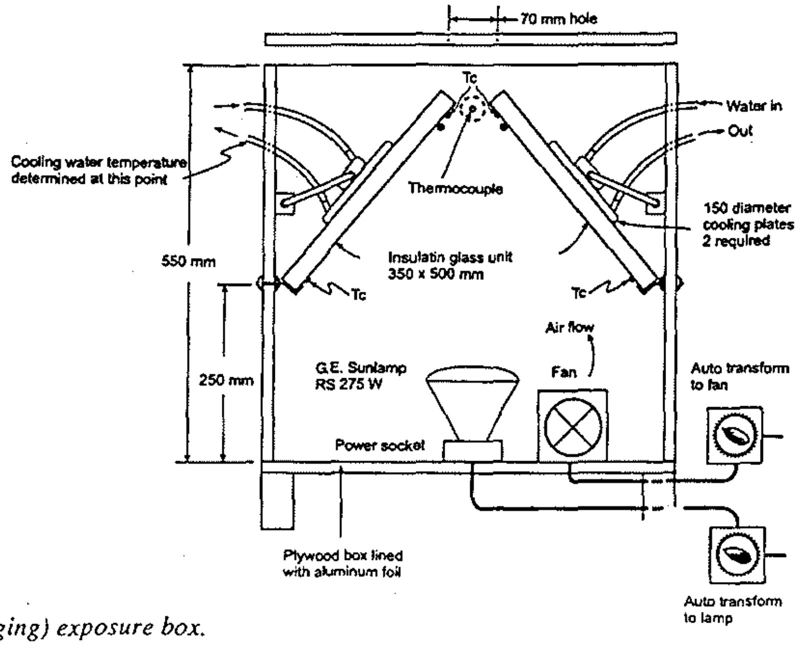

Figure 1 Volatile (fogging) exposure box.

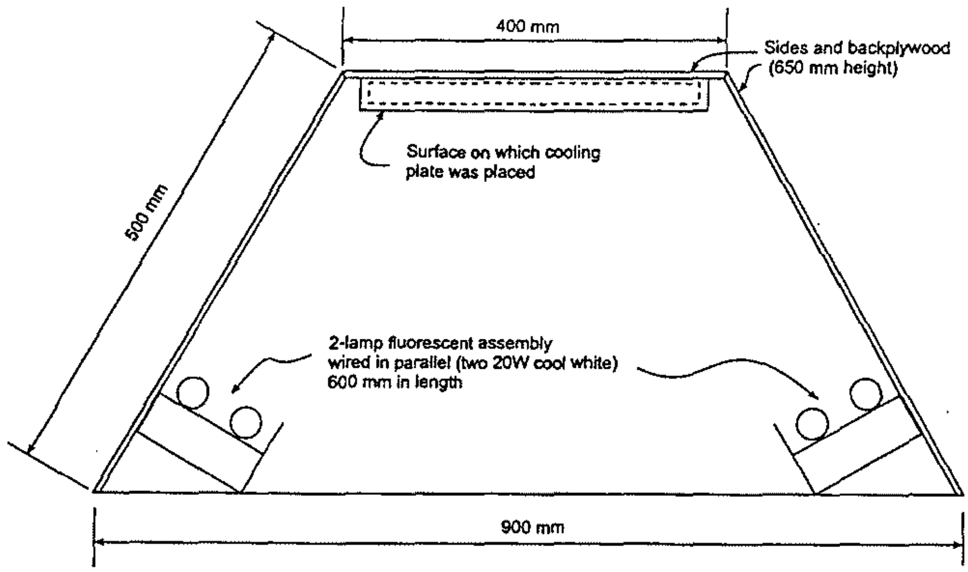

Figure 2 Viewing box for volatile fogging exposure test.

each unit was viewed at a small angle (at about 10 degrees) off the normal angle while maintaining a distance of 2 m from the unit. The purpose of the latter viewing procedure was to examine the angle dependence of the perception of the volatile deposits.

The pass/fail assessment of IG units depends on the presence or absence of chemical deposits on the glass surface during the examination of the units in the viewing box. An IG unit fails this test when the operator observes any oily deposits or traces of fogging on the surface of the glass when viewed at a right angle.

IG units of different construction and muntin bar material were tested for the volatile (fogging) test. All the units were double-glazed 508 mm × 359 mm (20 in. × 14 in.), and were selected to cover as many different designs and materials as commonly used in the market place. A total of 18 sets were tested (for the volatile test) and reported in this paper. The muntin bars were aluminum (anodized or coated with white, bronze, or brown paint), vinyl, or silicone foam. The spacer bars were made of metal, corrugated metal strip, or silicone foam.

R-VALUE AND CONDENSATION RESISTANCE TESTS AND SAMPLES

The IG units for R-value and condensation resistance tests were 1 m × 1 m, double-glazed with low emissivity coating on one surface of the glass. A total of six units were tested: an air-filled unit without muntin bars (control unit), an argon-filled unit without muntin bars (control unit), two units with aluminum muntin bars (3 × 3 grill), and two units with vinyl muntin bars (3 × 3 grill). Two of the units with muntin bars (one each from the aluminum and vinyl groups) were filled with argon gas, and the other two were air filled. The argon gas concentration was determined by means of a gas chromatograph (Elmahdy and Yusuf 1995).

The R-value is determined according to the IRC test method (Bowen 1985; Elmahdy 1993), which forms the basis for the ASTM method (ASTM 1991a, 1991b) for the determination of the thermal characteristics of fenestration systems using the guarded hotbox method.

The condensation resistance was determined according to the procedure in the Canadian Windows Standard, CAN/CSA A440 (CSA 1990; Elmahdy 1990). In this method, the temperature index of the glazing unit, I_g, was determined at different locations on the surface of the IG units and was compared with those of a control IG unit without muntin bars. The room-side temperature was maintained at 21 °C ±0.1 °C and the weather-side temperature at −18 °C ±0.1 °C.

Volatile (Fogging) Test Results

Tables 1 and 2 provide a summary of the volatile (fogging) test results conducted on 54 IG units. These tables show the type of sealant used in making each set, as well as the material and finish of each muntin bar. Also indicated is the positioning of the cold plate during the test.

The tables also indicate the comparison of viewing the units at normal angles (according to the CGSB standard) and of viewing the units at off normal angles (at about 10 degrees).

R-value and Condensation Resistance Test Results

The argon concentration in the three gas-filled units were found to be as follows: 83.6% ±0.3% for the unit without muntin bars, 92.1% ±0.3% for the unit with vinyl grill, and 86.0% ±0.3% for the unit with aluminum grill. These values were the average of two tests performed on each unit.

Table 3 provides a summary of the R-value and condensation resistance of the five IG units. The temperature index, I_g, was determined as follows:

TABLE 1
Volatile (Fogging) Test Results for IG Units with Muntin Bars
(Non-Metallic Spacer Bars)

Sealant/Spacer Type	Muntin Bar Type	Low-e Type	Cold Plate Placement	Results (At Normal)	Results Off Normal
1. Corrugated Metal Strip	Al[a] (anodized)	soft	1. low-e 2. clear 3. control	fog no fog no fog	fog fog fog
2. Corrugated Metal Strip	Al (white paint)	soft	1. low-e 2. clear 3. control	no fog no fog no fog	fog fog fog
3. Corrugated Metal Strip	Al (gold colored)	soft	1. low-e 2. clear 3. control	no fog no fog no fog	fog fog fog
4. Corrugated Metal Strip	Al (anodized)	soft	1. low-e 2. clear 3. control	fog (heavy) no fog no fog	fog fog fog
5. Corrugated Metal Strip	Al (bronzed -C)	soft	1. low-e 2. clear 3. control	fog (heavy) no fog no fog	fog fog fog
6. Silicone Foam Spacer	Silicone Foam	clear	1. clear 2. clear	no fog no fog	no fog no fog

a. Aluminum.

TABLE 2
Volatile (Fogging) Test Results for IG Units with Muntin Bars
(Metallic Spacers)

Sealant/Spacer Type	Muntin Bar Type	Low-e Type	Cold Plate Placement	Results (At Normal)	Results Off Normal
1. Polysulphide	Al (white paint)	hard	1. low-e 2. clear 3. control	no fog no fog no fog	no fog no fog no fog
2. Polysulphide	Al (anodized)	soft	1. low-e 2. clear 3. control	fog no fog no fog	fog fog fog
3. Polysulphide	Al (bronzed -C)	soft	1. low-e 2. clear 3. control	no fog no fog no fog	no fog no fog no fog
4. Polysulphide	Al (polish brass)	hard	1. low-e 2. clear 3. control	fog (heavy) no fog no fog	fog fog fog
5. Polysulphide	Al (white paint)	hard	1. low-e (argon) 2. low-e (air) 3. control (air)	no fog no fog no fog	no fog no fog no fog
6. Polysulphide	Vinyl (white)	hard	1. low-e (argon) 2. low-e (air) 3. control	fog (heavy) fog (heavy) fog (heavy)	fog fog fog
7. Polyurethane	Al (anodized)	soft	1. low-e 2. clear 3. control	no fog no fog no fog	fog fog fog

TABLE 2 (Continued)
Volatile (Fogging) Test Results for IG Units with Muntin Bars
(Metallic Spacers)

8. Polysulphide	Al (anodized)	hard	1. low-e 2. clear 3. control	no fog no fog no fog	no fog no fog no fog
9. Polysulphide	Al (bronzed)	hard	1. low-e 2. clear 3. control	no fog no fog no fog	no fog no fog no fog
10. Polysulphide	Al (brown paint)	hard	1. low-e 2. clear 3. control	fog fog fog	fog fog fog
11. Polysulphide	Vinyl (no perimeter)[a]	hard	1. low-e 2. clear 3. control	no fog no fog no fog	no fog no fog no fog
12. Polysulphide	Vinyl (with perimeter)[a]	hard	1. low-e 2. clear 3. control	fog fog fog	fog fog fog

a. Units #12 were constructed with the grill mounted in a frame around the edges and the entire assembly mounted inside the sealed unit.

TABLE 3
R-Value of 1 m x 1 m Glazing Units

Unit Description	Argon Concentration (%)	R-value $m^2 \cdot K/W$	Percentage Variation from the Reference %
Air filled, no grill (control unit for air filled units)	N/A	0.41	N/A
Air filled, white aluminum grill (3 x 3)[a]	N/A	0.38	−7.3
Argon filled aluminum grill (3 x 3)	86.0	0.43	−2.3
Air filled, white vinyl grill (3 x 3)	N/A	0.38	−7.3
Argon filled, white vinyl grill (3 x 3)	92.1	0.42	−4.5
Argon filled, no grill (control unit for argon filled units)	83.6	0.44	7.3 relative to air filled

a. 3 x 3 grill means that the IG unit is divided into three sections (vertical) and three sections (horizontal) by means of two vertical muntin bars and two horizontal muntin bars, see Figure 3.

$$I_g = \frac{T - T_c}{T_h - T_c} \cdot 100 \quad (1)$$

where

T = glass surface temperature at a given location, °C,

T_h = room-side air temperature, °C,

T_c = weather-side temperature, °C.

Figures 3 through 8 show the glass surface temperature measurements for the glazing units tested for R-value and condensation resistance.

DISCUSSION

Material Degradation Under UV Exposure

The degradation of organic compounds under ultraviolet (UV) exposure has been known for years. It seems, however, appropriate to review some of the basic principles to better understand the reasons of some IG units failing the volatile (fogging) test.

When a molecule absorbs radiation, its energy is raised to an excited state, usually at one particular atom. It may return to its unexcited or ground state by dissipating the energy by radiation or fluorescence, phosphorescence, or heat (Ashton 1970). In such cases, the molecules are not affected, and this is usually what happens with long wave radiation that is turned into heat. If radiation contains sufficient energy, however, it may cause a chemical reaction at the excited atom and this frequently leads to the breaking up of organic materials and the formation of fog and deposits.

Because the UV portion of radiation contains the most energy, it causes the greatest damage to organic materials. Chemical degradation attributed to it can take two paths. With some materials, the energy starts a process the reverse of a polymerization reaction that originally produced the large

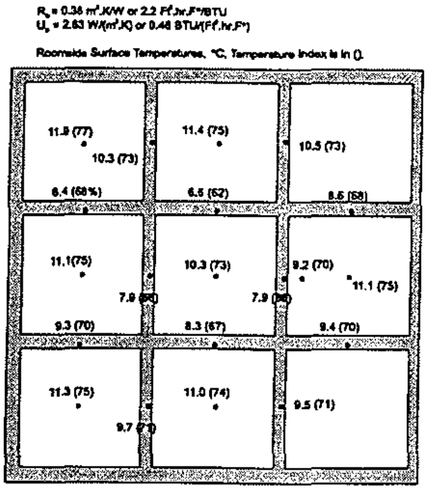

Figure 3 *Surface temperature and the temperature index 1000 mm x 1000 mm IG unit at 21°C/–18°C; 3 x 3 aluminum grill, air filled.*

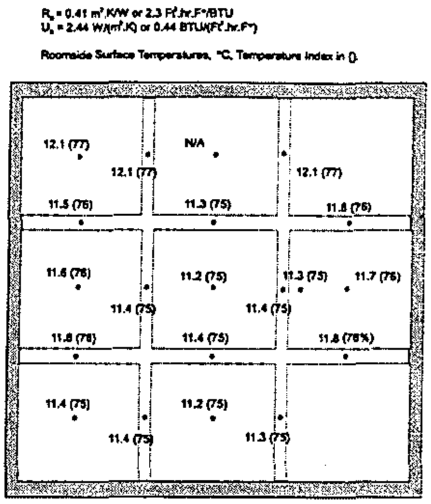

Figure 4 *Surface temperature and the temperature index 1000 mm x 1000 mm IG unit at 21°C/–18°C; no grills, air filled, control unit for air-filled units.*

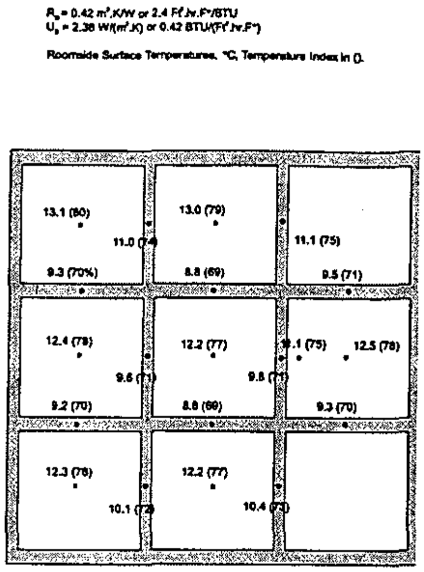

Figure 5 *Surface temperature and the temperature index 1000 mm x 1000 mm IG unit at 21°C/–18°C; 3 x 3 vinyl grill, argon-filled.*

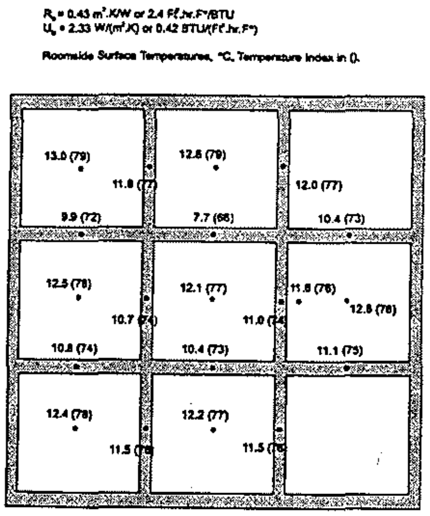

Figure 6 *Surface temperature and the temperature index 1000 mm x 1000 mm IG unit at 21°C/–18°C; 3 x 3 aluminum grill, argon-filled.*

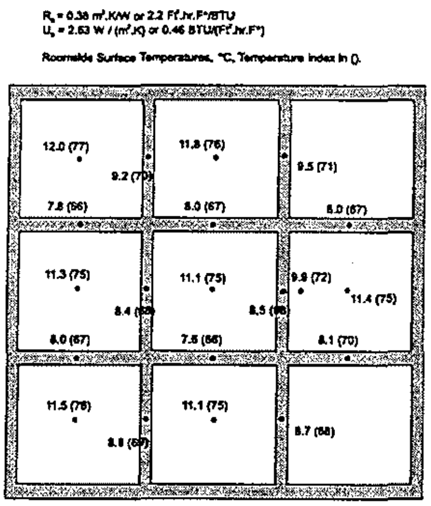

Figure 7 *Surface temperature and the temperature index 1000 mm x 1000 mm IG unit at 21°C/–18°C; 3 x 3 vinyl grill, air filled.*

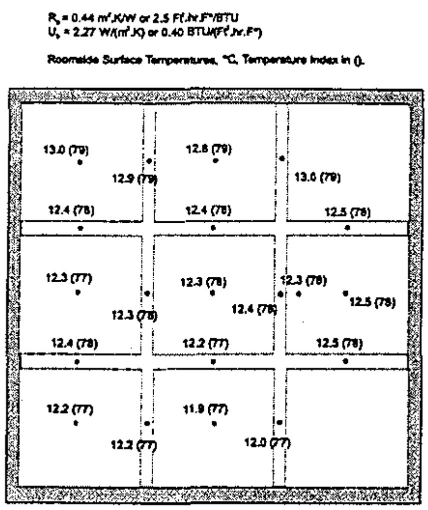

Figure 8 *Surface temperature and the temperature index 1000 mm x 1000 mm IG unit at 21°C/–18°C; no grills, argon-filled, control unit, for argon-filled units.*

molecules. The polymer may be broken in isolated locations—called chain scission—or it may completely revert to small molecules. In the second process, the smaller molecules, produced by chain scission react with other chains. This results in more cross-linking than originally was present so the material becomes harder and more brittle.

Among the most critical elements of an IG unit is the sealant that bonds the glass and the spacer bar together. If the sealants cross-link too much, they either crack or lose adhesion at the interface. More important is the possibility that the sealants may become harder and lose their adhesion to the glass surface. This naturally will lead to a complete failure of the seal, and, hence, moisture intrusion into the IG unit.

The volatile (fogging) test serves to identify the potential for failure due to degradation of the organic materials in the IG unit. As discussed earlier, when some molecules of these compounds become highly excited by the high levels of energy, they will become volatile and then condense on cold surfaces. In this case, oily deposits will form on the glass and this will result in an unpleasant appearance of the glazing unit.

IG units may fail the volatile (fogging) test whether or not muntin bars exist in the cavity. This is because organic materials are used in most common sealants or other components in the IG unit. The incorporation of muntin bars into the IG unit introduces an additional source of volatile material that may cause failure. The process of preparing muntin bars includes cutting. Usually, lubricants and coolants are used during this process that result in the introduction of oil into the IG unit. This happens often, particularly when the muntin bars are not properly washed after cutting.

The introduction of oil into the IG unit also could be the result of handling the glass sheets and other components with contaminated gloves or fingers.

Effect of Viewing Angle and Coating on IG Pass/Fail

Tables 1 and 2 show that when viewing the IG units at normal angles (according to the CGSB 12.8 standard) most of the units pass the volatile (fogging) test. When the cold plate is placed on the low emissivity coated glass pane, volatile materials were observed under the plate (indicating failure). The other two units of the same set did not show any fogging. This means that the presence of the low emissivity coating enhances the appearance of the chemical deposits. This is a result of a relatively rough surface compared to the float glass. If the size of the chemical deposits is smaller than the valleys on the low emissivity coating, then the deposits tend to settle in these valleys and become more visible in the viewing box.

The viewing angle of the chemical deposits is shown to be a strong factor in the assessment of the volatile test results and the determination of the pass/fail conformance to the standard. As the results in Tables 1 and 2 show, viewing the IG units at off-normal angles indicates more cases of failure than that at normal angles.

It is clear that by looking at the IG unit at a normal angle, the chemical deposits may not be observed as a result of the light reflection/refraction through a thin film at normal incidence. However, by changing the viewing angle by a few degrees (about 10 degrees off the normal), some of the IG units that did not exhibit any deposits at a normal viewing angle showed traces of chemical deposits. In this case, the light reflection/refraction through the thin film deposits enhances the appearance of the deposits to the naked eye. The issue of a viewing angle is being reviewed as a part of the Canada/USA Window Standard Harmonization Committee.

R-value and Condensation Resistance

Six IG units of 1 m × 1 m were tested to determine their R-value, glass surface temperatures, and temperature index(s). Table 3 provides a summary of the R-value test results and Figures 3 through 8 show the glass surface temperature and I_g for all the IG units.

As expected, the gas-filled unit showed about 7% increase in the R-value relative to the air-filled unit. Also, the R-value of IG units with muntin bars are 2.3% to 7.3% lower than those without muntin bars, depending on the nature of the gas in the cavity. The reduction in the R-value is the result of the thermal bridging effect in the area of the glazing unit adjacent to the muntin bar. It also is important to indicate that the variation in the R-value also is affected by the differences in the argon concentration of the units. The differences in the argon concentration are shown in Table 3.

Figures 4 and 8 show that the surface temperature of the gas-filled unit is one to two degrees higher than the air-filled unit (both units are without muntin bars). The increase in the glass surface temperature has impacted on the temperature index, I_g, which is about 2 degrees higher for the gas filled unit than the air-filled unit.

In cases of IG units with muntin bars, the glass surface temperature of the gas-filled units also are higher than those that are air filled. For example, Figures 3 and 6 show the glass surface temperature and temperature index of IG units with an aluminum muntin bar. The variations of the glass surface temperature and temperature index in cases of the gas-filled and air-filled units are similar to those discussed above. In addition, it is clear from those figures and Figures 4 and 8 that the glass temperature (and I_g) at the location of the muntin bar are substantially lower than those at the same location in the unit without a muntin bar.

Similar arguments can be presented in cases of IG units with vinyl muntin bars. The results are shown on Figures 5 and 7. It also is evident from comparing Figures 3, 5, 6, and 7 that the extent of the reduction in glass surface temperatures (and I_g) depends on the material of the muntin bar. Units with vinyl muntin bars showed lower glass surface temperature in the area adjacent to it than units with aluminum bars. This does not mean that the thermal conductivity of vinyl is higher than that of aluminum, but it indicates that the environment around the vinyl muntin bar is more conducive to condensation than the cases of aluminum muntin bars. It is suspected that the gap between the muntin bar and the glass surface is not the same for both cases, or in some cases the glass may have touched the glass surface. The later case could not be proven, since the glass resorts back to its original position after the unit is warmed up to the room temperature.

It is worth indicating that it was impossible to measure the gap between the muntin bar and the glass surface in order to prove the above observation. Perhaps in future work, this issue will be studied on a number of glazing units with muntin bars of different materials and gap widths.

CONCLUSIONS

Test results showed that IG units with muntin bars exhibit a high rate of failure during the volatile (fogging) test than units without muntin bars. The main reason lies in the quality control implemented during the manufacturing process. The oily deposits left on the surface of the muntin bar tend to show as chemical deposits under the cold plate when examined in the viewing box.

The viewing angle has a significant impact on the assessment of the pass/fail criteria of the IG unit. The off right angle viewing of the IG unit shows that many units that passed during viewing at a right angle did not pass the volatile test. The light refraction through the glass and chemical deposits seems to enhance the appearance of chemical deposits.

IG units with muntin bars showed a slight decrease in the R-value relative to those without muntin bars.

The presence of muntin bars inside the IG units have considerable effects on the glass surface temperature and the temperature index of the IG units. The reduction in glass surface temperatures on the warm side adjacent to the muntin bar reduces the condensation resistance in that area because of the reduced gap between the glass surface and the muntin bar.

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