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Laboratory Determination of the Thermal Resistance of Glazing Units

by A.H. Elmahdy and R.P. Bowen

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RÉSUMÉ

L'Institut de recherche en construction (IRC) du Conseil national de recherches du Canada (CNRC) a mis au point une installation et une méthode d'essai visant à déterminer les caractéristiques thermiques des fenêtres. Les premiers travaux ont porté sur les types de vitrages suivants:

- double vitrage isolant clair
- double vitrage isolant clair avec couche à faible émissivité
- triple vitrage isolant clair
- triple vitrage isolant avec couche à faible émissivité sur mince pellicule de plastique
- double vitrage non isolant sans espaceur

On a contrôlé tous les vitrages afin de déterminer leur résistance thermique (valeur R surface à surface) dans les conditions d'essai suivantes:

- Température côté intérieur : 21 °C
- Température côté extérieur : -7, -21 et -35 °C; certains vitrages ont aussi été contrôlés à -14, -18 et -28 °C.
- L'écart de pression de part et d'autre de l'échantillon a été maintenu en deçà de 3Pa.
- L'écoulement de l'air du côté froid était perpendiculaire à l'échantillon.

On indique aussi les coefficients de transmission de chaleur (coefficient K) en combinant les coefficients d'échange superficiel, suivant les recommandations de l'ASHRAE, et la valeur R déterminée pour chaque échantillon.

Il n'existe pas actuellement de méthode d'essai normalisée servant à déterminer le coefficient de transmission de chaleur (coefficient K) des vitrages isolants, mais les résultats des essais effectués indiquent la performance relative des échantillons contrôlés.

Les résultats obtenus concernant certains des échantillons sont comparés aux valeurs calculées à l'aide du programme informatique VISION mis au point pour le compte du CNRC et servant à évaluer la performance thermique des vitrages.

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LABORATORY DETERMINATION OF THE THERMAL RESISTANCE OF GLAZING UNITS

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ABSTRACT

A test facility and procedures to determine the thermal characteristics of window products were developed at The Institute for Research in Construction (IRC), National Research Council Canada (NRCC). Initial work was conducted on the following types of glazing units:

- sealed double-glazed, clear glass
- sealed double-glazed with low emissivity coating on clear glass
- sealed triple-glazed, clear glass
- sealed triple-glazed with thin plastic film with low emissivity coating
- unsealed double-glazed without spacer

All units were tested to determine their thermal resistance (surface to surface R-value) at the following test conditions:

- room-side temperature: 21°C
- weather-side temperature: -7, -21, and -35°C, and some units were also tested at -14, -18, and -28°C.
- pressure difference across the test specimen was kept less than 3Pa.
- weather-side airflow was perpendicular to specimen.

Overall heat transmission coefficients (U-value) are also provided by combining the surface heat transfer coefficients, as recommended by ASHRAE, with the R-value determined for each specimen.

Although there is at present no standard test procedure for the determination of the overall coefficient of heat transmission (U-value) of sealed units, these test results indicate the relative performance of the samples tested.

The experimental results of some of the specimens are compared with values predicted using the computer program VISION developed, through NRCC, to evaluate the thermal performance of glazing systems.

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INTRODUCTION

Windows constitute an important part of the building envelope and play a significant role in its overall performance. Recently, there has been considerable interest in developing standard test procedures to evaluate the thermal performance of windows. This includes the determination of the thermal resistance (R-value), as well as condensation, and air leakage characteristics of the window assembly.

ASHRAE Fundamentals (ASHRAE 1985) provides data about the overall coefficient of heat transmission (U-value) of a number of generic fenestration systems based on winter and summer design conditions. In addition, ASHRAE emphasized that these data are to be used only in peak load estimations and should not be used in energy analysis (McCabe et al. 1986). This implies that for accurate hourly energy analysis, variations of the overall coefficient of heat transmission with outdoor temperature, wind speed, etc. should be considered.

Since there was no generally accepted laboratory or field test methods to determine the R-value of glazing units (Goss and McCabe 1985), a test procedure and facility have been developed at IRC/NRCC (Bowen 1985; Bowen and Solvason 1984).

Several types of glazing units have been tested using the IRC procedure. This paper summarizes these test results together with the comparable results obtained from the VISION program (Wright and Sullivan 1987a, 1987b).

THEORY

Details of the IRC test facility and the test procedure to evaluate the R-value are described in Bowen (1985) and Bowen and Solvason (1984). In summary, the method involves measuring power input to the calorimeter box, deducting heat flow through the mask, and, hence, determining heat flow through the test specimen (see Figure 1). The room-side equivalent surface temperature is calculated and is used to determine the specimen's thermal conductance, C-value, which is the inverse of the R-value.

The thermal analysis of the sample mounted in a support wall (mask) placed between a room-side and a weather-side chamber is based on the heat balance in the calorimeter box shown in Figure 1. The heat balance equation is expressed as:

$$Q_s = Q_T - Q_m - Q_e - Q_b \qquad (1)$$

where:

Q_s = heat flow through the sample, W

Q_T = total power supplied to calorimeter, W

Q_m = heat flow through the mask (function of mask surface temperatures, area and conductance), W

Q_e = flanking loss around the edge of the sample, W

Q_b = heat flow through calorimeter box walls (controlled to be close to zero), W

The heat flow from the calorimeter box to the sample, Q_s, consists of convective and radiative components and could be expressed as:

$$Q_s = Q_r + Q_c \tag{2}$$

where:

Q_r = radiant heat exchange between calorimeter surfaces and room-side surface of the sample, W, and

Q_c = convective heat exchange between calorimeter air and room-side surface of the sample, W

In a grey enclosure the radiant exchange between two surfaces can be expressed as:

$$Q_r/A_1 = q_r = F_{1b} \cdot \sigma \cdot (T_b{}^4 - T_1{}^4) \tag{3}$$

where:

A_1 = area of surface 1 (glazing unit), m^2

F_{1b} = overall view factor from surface 1 to surface b (baffle)

σ = Stefan-Boltzman constant (5.6703×10^{-8} $W/(m^2.K^4)$)

T_b = mean temperature of surface b (baffle), K

T_1 mean surface temperature of specimen, K.

q_r = heat flux by radiation, W/m^2

The convective component, Q_c, is approximated by the following expression:

$$Q_c/A_1 = q_c = n \cdot (T_h - T_1)^m \tag{4}$$

where:

q_c = heat flux by convection, W/m^2

T_h = mean temperature of the air in the calorimeter box, K

n&m = constants to be determined from calibration tests.

Equations 3 and 4 are rewritten as:

$$q_r = h_r \cdot (T_b - T_1) \tag{5}$$

$$q_c = h_c \cdot (T_h - T_1) \tag{6}$$

where:

$$h_r = F_{1b} \cdot \sigma \cdot (T^2{}_b + T^2{}_1) \cdot (T_b + T_1) \tag{7}$$

$$h_c = n \cdot (T_h - T_1)^{m-1} \tag{8}$$

h_r&h_c = radiative and convective heat transfer coefficients respectively, $W/(m^2.K)$

If T_h were equal to T_b, the total heat transfer to and through the specimen would be:

$$Q_s/A_1 = q_s = (h_r + h_c) \cdot (T_h - T_1) \tag{9}$$

then,

$$T_1 = T_h - q_s/(h_r + h_c) \tag{10}$$

and,

$$T_2 = T_c + q_s/f_o \tag{11}$$

Where:

q_s = heat flux through the specimen, W/m^2

f_o = weather-side film heat transfer coefficient, $W/(m^2.K)$

T_2 = calculated weather-side surface temperature, K

T_c = mean weather-side air temperature, K.

Equation 11 is based on the assumption that over the range of weather-side temperatures to be used, the special IRC wind machine generates a relatively constant f_o and the radiating temperatures are equivalent to T_c. The specimens thermal conductance, C ($W/(m^2.K)$), and resistance, R ($m^2.K/W$), are determined as follows:

$$C = q_s/(T_1 - T_2) \tag{12}$$

$$R = 1/C \tag{13}$$

For comparison, a design thermal resistance value, R_D, can be obtained by the addition of standard surface film resistances, R_{fi} (room-side) and R_{fo} (weather-side), to the specimen thermal resistance value, R:

$$R_D = R_{fi} + R + R_{fo} \tag{14}$$

Then, the design U-value is:

$$U_D = 1/R_D \tag{15}$$

SAMPLES TESTED

Fourteen units (twelve sealed units and two unsealed units without spacer) were tested using the procedure described in Bowen (1985), Table 1 shows the unit number, size, and other pertinent information of the samples tested.

Figure 2 shows schematic diagrams of the tested units indicating the location of the low emissivity coating for units 4, 5, 6, 9, 10, and 11.

RESULTS

Calibration of the calorimeter box was done to determine the constants n and m in Equation 8 and also to assess the flanking loss, Q_e, over a range of total power input, Q_T, and weather-side temperature, T_c.

The mask wall was built using expanded polystyrene insulation that had a stable thermal conductivity with time and could be sealed to maintain low moisture content. A series of tests has been performed on a full mask wall (no opening) to determine its thermal resistance over a range of mean temperatures to be experienced during tests.

The mean thermal resistance of the mask wall, R_m ($m^2.K/W$), was determined from the test data, and the following expression gives R_m as a function of the mean temperature T_m:

$$R_m = 3.065 - 0.0106 \times T_m \pm 0.011 \tag{16}$$

where:

R_m = mean thermal resistance of the mask wall, $m^2.K/W$

T_m = mean temperature of the mask wall, ^oC
($T_m = (T_{m1} + T_{m2})/2$)

T_{m1}&T_{m2} = mean temperatures of room-side and weather-side of the mask wall, respectively, ^oC

A series of tests were performed to assess the flanking loss, Q_e, over a range of total power input Q_T, and weather-side temperature, T_c (see Table 2). This was done using two calibrated specimens (0.8 m x 1.0 m and 1.0 m x 1.6 m and 17.4 mm thickness) of known thermal resistance traceable to primary standards (ASTM C177).

Table 2 shows that Q_e varies between 0.7 W and 4.3 W (or 0.6 to 2.6 % of Q_T, respectively), over the range of Q_T and T_c shown. It is also worth noting that the weather-side box temperature, as viewed by the specimen, was found to be less than 0.1 K different from T_c.

For testing a glazing unit, Q_s is determined by subtracting Q_m and Q_e from Q_T, as indicated by Equation 1. The appropriate values of Q_e were selected according to the unit size and temperature conditions. It is worth noting that the presence of a metal spacer around the unit edges results in slightly higher values of Q_e than those shown in Table 2 due to changes in the temperature profiles in the vicinity of the unit edges. It is estimated, however, that Q_e is about 3% of Q_s (the overall uncertainty level in determining the C-value is estimated to be $\pm$6%).

The C-value of the tested glazing units were determined at a constant room-side temperature of 21^oC and weather-side temperatures of -7, -14, -18, -21, -28 and -35^oC (not all the units were tested at each of the weather-side temperatures). For each unit tested, the following three values were calculated:

R = surface-to-surface thermal resistance, ($m^2.K/W$)

R_D = design thermal resistance, ($m^2.K/W$)

U_D = overall coefficient of thermal transmission ($1/R_D$), ($W/(m^2.K)$)

The specimen design thermal resistance, R_D, is determined by adding the recommended ASHRAE winter design surface thermal resistances (R_{fi} = .12, and R_{fo} = .03 $m^2.K/W$) to the specimen thermal resistance R. It is also worth noting that the program VISION uses the ASHRAE design surface thermal resistances.

Tables 3, 4 and 5 give summaries of R, R_D, and U_D for glazing units that were tested at weather-side temperature of -7, -14, -21, -28 and -35^oC. Tables 6, 7 and 8 give summaries of R, R_D, and U_D for glazing units that were tested at weather-side temperature of -7, -18, -21 and -35^oC.

COMPARISON OF EXPERIMENTAL RESULTS AND VISION OUTPUT

VISION is a computer program developed for the National Research Council Canada to evaluate and optimize the thermal performance of innovative glazing units (Wright and Sullivan 1987a, 1987b; Barakat 1985). The program is intended for use by designers and manufacturers to assess the thermal performance of glazing units and to examine the variations in performance resulting from changes in parameters. In addition to modeling multi-pane glazing units, VISION is capable of modeling other features, such as: films or glazings that are opaque or partially opaque to long wave radiation; substitute gases and a partial or complete vacuum in the interpane space; convection suppression using slit-type honeycombs; and thin film optical coating. The program is now being upgraded (Wright and Sullivan 1987a).

The program calculates the optical properties of the glazing system, the overall heat transfer coefficient, and the shading coefficient. It also has the option of performing hourly energy analysis of the glazing system.

Since VISION does not account for edge losses of sealed glazing units, it was used to determine the thermal conductance of the core of the glazing unit, U_v, of some specimens.

An attempt was made to separate the heat flow through the core of the sealed glazing unit from the total heat flow through the specimen, Q_s, using the experimental data for units 1 and 2 (double-glazed clear glass units), and 7 and 8 (triple-glazed clear glass units). Using the calculated mean surface temperatures (as calculated from Equations 10 and 11), and assuming one-dimensional heat transfer through the glass panes, then a heat balance on glazing unit 1 and 2 yields:

$$Q_{s1}/\Delta T_1 = C_c \times A_{c1} + C_p \times A_{p1} \quad (17)$$

$$Q_{s2}/\Delta T_2 = C_c \times A_{c2} + C_p \times A_{p2} \quad (18)$$

where:

Q_{si} = heat transfer through unit # i, W

ΔT_i = surface temperature difference of unit # i, K

A_{ci} = core surface area of unit # i, m^2

A_{pi} = perimeter area of unit # i, m^2

C_c&C_p= core and perimeter thermal conductances respectively, $W/(m^2.K)$

Using numerical values from Tables 1 and 9, Equations 17 and 18 were used to determine the thermal conductances of the unit core and perimeter (C_c and C_p). Also, the design coefficient of heat transmission for the core, U_{cD}, and for the perimeter, U_{pD}, were determined using the ASHRAE winter design film heat transfer coefficients, as described earlier for U_D.

It is the U_{cD}-value that should be compared with values calculated using the VISION program (U_v), which are provided in Table 9. Also shown in Table 9 is the perimeter loss as a percentage of Q_s (i.e. $(Q_p/Q_s) \times 100$). It is worth noting that as the unit size increases, Q_p/Q_s decreases, and as the overall thermal resistance of the glazing unit increases (e.g., double vs. triple glazing), Q_p/Q_s increases for the same unit size.

Differences between U_{cD} and U_v can be attributed to one or more of the following reasons:

1. Physical dimensions: Among the input parameters for VISION, are the physical dimensions of the glazing unit. Some of these dimensions are difficult to measure (e.g., glass and air space thicknesses). For example, the air space thickness decreases due to reduced pressure in the air space, and VISION does not account for such an effect.

2. Optical properties: The determination of the thermal characteristics of glazing units is sensitive to the optical properties of glass and coating materials. It is essential to use the correct values if the U-value is to be correct. These values are not always available or have significant variations between samples (the VISION program uses default values of some of these properties)

DISCUSSION

The test results show that the thermal resistance of glazing unit R changes with sample size, temperature conditions, and film coating.

As the sample size increases, R increases due to the decreasing effect of the edge losses (ratio of perimeter area to total area decreases): see Tables 3 and 6.

Tables 3 and 6 also indicate that the thermal resistance, R, changes with the weather-side temperature, particularly for units with low- emissivity coating. This reflects the combined effects of changes in radiative and conductive heat transfer components through the air space as a result of variations in the glass surface temperature due to the presence of low emissivity coating.

The magnitude and trend of the changes in the radiative and conductive heat transfer components in the air space depend on the mean temperature, T_m, and the temperature difference, ΔT, across the air space. For example, an earlier study to investigate the thermal characteristics of air spaces (NBS 1954) showed that h_r is proportional to the mean temperature, T_m, raised to the third power (also see Equation 7). In addition, the conductance of the air space increases as T_c decreases as a result of reduced air space thickness due to glass deflection. Thus, as the weather-side temperature, T_c, decreases, the conductive heat transfer increases. Similarly, as T_c decreases, T_m decreases and h_r decreases (hence the radiative component of heat transfer decreases). In case of units with low-emissivity coating, the increase in the conductive heat transfer component is greater than the decrease in the radiative component. The net result is an increase in the total heat transfer through the air space and, hence, a decrease in the R-value with decreasing T_c. This is shown on Table 3 for units 4 and 5, and also on Table 6 for unit 6.

The simple approach used to separate heat transfer through the unit core from the total heat transfer through the glazing unit was useful in comparing experimental results with the predicted values using computer simulation. This approach will be further refined for application in the determination of heat transfer through the various elements of window assemblies.

Comparison of experimental test results of glazing units with predicted values using the computer program VISION showed that accurate simulation or modeling of glazing units can be used to study the thermal characteristics of various glazing units, without having to test each modification in a laboratory setting, which could be an expensive endeavor. However, a sound modeling of glazing units requires the knowledge of accurate information about the optical properties of glass and film coating materials (when applicable).

Heat loss/gain through windows are usually calculated by multiplying U_D and the free-stream temperature difference. Thus, the heat flows in the direction of the lower temperature. In some cases, however, the heat flows in an opposite direction of the free-stream ΔT. This is because the magnitude and direction of heat flow through the glazing unit are dependant on the temperature difference of the boundary layers adjacent to the unit surfaces and not on the free-stream ΔT. And the temperature of the boundary layer on the outside surface of the unit is different from the free-stream air temperature, indicating the influence of opaque surfaces surrounding the glazing unit. Consequently, the heat transfer through the unit is not a function of the free stream temperature difference, $\Delta T_{free-stream}$. Further studies are required to assess the effect of different wall surface configurations and characteristics on the net heat transfer through windows.

CONCLUSION

The test facility and procedure developed by IRC/NRCC to determine the overall heat transmission of insulated glazed units were used to compare the thermal characteristics of various types of glazing units. The test procedure provides a tool to compare R-values as well as U-values of glazing units. Such information is for window designers and manufacturers and it is needed to update current data in design manuals.

Test results have shown that the R-value of glazed units varies with the imposed test conditions. It is, therefore, important to ensure that comparison of the characteristics of glazing units is done at the same conditions.

Finally, the use of computer programs to model glazing units is very useful in studying the thermal characteristics of glazing units. However, particular attention should be given to the accuracy of input data, because of the sensitivity of the results to the physical and optical properties of the glazing units.

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TABLE 1
Description of Samples Tested

No.	Width mm	Height mm	Glass Thickness mm
Double Glazed, Clear Glass			
1	1000	1600	3
2	800	1000	3
3	1000	1000	6
Double Glazed, Low-Emissivity Coating			
4	1000	1600	3
5	800	1000	3
6	1000	1000	6
Triple Glazed, Clear Glass			
7	1000	1600	3
8	800	1000	3
Triple Glazed, Low-Emissivity Coating on Thin Film (Two Air Spaces)			
9	1000	1600	4
10	800	1000	3
11	1000	1000	6
Quadruple Glazed, Two Thin Films, Clear Glass (Three Air Spaces)			
12	1000	1000	3
Unsealed, Double Glazed, No Spacer			
13	1000	1600	3
14	800	1000	3

Notes:
(1) All units are factory sealed except units 13 and 14 (unsealed).
(2) All units have air space of nominal thickness of 13 mm except unit 12, which has three air spaces of 10, 19, and 10 mm nominal thickness.

TABLE 2
Summary of Test Data to Assess Flanking Loss Q_e

Parameter	Weather-Side Temperature, Tc oC									
	1 m x 1.6 m					0.8 m x 1. m				
	-7	-14	-21	-28	-35	-7	-14	-21	-28	-35
Q_T, W	124.9	155.2	183.4	212.1	239.9	91	112.2	132.9	153.3	173.2
T_h, ^oC	22	22.1	22	21.9	22	22	21.9	21.9	21.9	21.9
Q_m, W	39.9	49.1	57.1	66.7	75.1	47.3	58.1	68.6	78.9	88.9
Q_s, W	84.3	104.6	123.9	143.3	162.6	41.6	51.3	60.9	70.6	80
Q_e, W	0.7	1.5	2.4	2.1	2.2	2.1	2.8	3.4	3.8	4.3
Q_e/Q_T %	0.6	1	1.3	1	0.9	2.3	2.5	2.6	2.5	2.5

Notes:

Q_T is measured $\pm$0.01 %
T_c & T_h are measured $\pm$0.1 ^oC
R_m is calculated $\pm$0.011 m^2.K/W
Q_s is calculated $\pm$0.3 W
Q_m is calculated $\pm$0.3 W

TABLE 3
Summary of the Surface-to-Surface Thermal Resistance R for Units #1,2,4,5,7,8,13 and 14

Unit #	R m^2.K/W				
	Weather-side Temperature, Tc oC				
	-7	-14	-21	-28	-35
	Sealed Double Glazed, Clear Glass				
1	.16	.16	.17	.17	.17
2	.15	.15	.16	.15	.16
	Sealed, Double Glazed, Low Emissivity Coating				
4	.33	.32	.30	.29	.28
5	.27	.27	.27	.26	.25
	Sealed Triple Glazed, Clear Glass				
7	.30	.30	.31	.32	.32
8	.28	.28	.29	.29	.29
	Unsealed, Double Glazed, No Spacer				
13	.17	.18	.19	.19	.19
14	.17	.18	.18	.19	.18

TABLE 4
Summary of Design Thermal Resistance RD
for Units #1,2,4,5,7,8,13 and 14

Unit #	R_D $m^2.K/W$				
	Weather-side Temperature, Tc oC				
	-7	-14	-21	-28	-35
	Sealed Double Glazed, Clear Glass				
1	.31	.31	.32	.32	.32
2	.30	.30	.31	.30	.31
	Sealed, Double Glazed, Low Emissivity Coating				
4	.48	.47	.45	.44	.43
5	.42	.42	.42	.42	.40
	Sealed Triple Glazed, Clear Glass				
7	.45	.45	.46	.47	.47
8	.43	.43	.44	.44	.44
	Unsealed, Double Glazed, No Spacer				
13	.32	.33	.34	.34	.34
14	.32	.33	.33	.34	.33

TABLE 5
Summary of Overall Coefficient of Thermal Transmission UD
for Units # 1,2,4,5,7,8,13 and 14

Unit #	U_D $W/(m^2.K)$				
	Weather-side Temperature, Tc oC				
	-7	-14	-21	-28	-35
	Sealed Double Glazed, Clear Glass				
1	3.21	3.19	3.16	3.16	3.15
2	3.31	3.31	3.27	3.30	3.28
	Sealed, Double Glazed, Low-Emissivity Coating				
4	2.07	2.13	2.2	2.29	2.35
5	2.36	2.38	2.40	2.45	2.49
	Sealed Triple Glazed, Clear Glass				
7	2.22	2.21	2.16	2.15	2.14
8	2.34	2.33	2.30	2.29	2.25
	Unsealed, Double Glazed, No Spacer				
13	3.09	3.03	2.99	2.97	2.96
14	3.09	3.02	3.02	2.92	3.02

TABLE 6
Summary of Surface-to-Surface Thermal Resistance R
for Units # 3, 6, 9,10,11 and 12

Unit #	R $m^2.K/W$				
	Weather-Side Temperature, Tc oC				
	-7	-18	-21	-35	
3	.16	.16	.16	.17	(sealed double gl., clear)
6	.30	.29	.29	.27	(sealed double gl., low E)
9	.41	---	.41	.40	(sealed triple low E on thin film)
10	.37	---	.37	.36	(same as #9, different size)
11	.41	.41	.40	.39	(same as #9, different size)
12	.31	.30	.30	.29	(sealed quadruple, two suspended thin films)

TABLE 7
Summary of Design Thermal Resistance RD
for Units #3, 6, 9,10,11 and 12

Unit #	RD $m^2.K/W$			
	Weather-Side Temperature, Tc oC			
	-7	-18	-21	-35
3	.31	.31	.31	.32
6	.45	.44	.44	.42
9	.56	---	.56	.55
10	.52	---	.52	.51
11	.56	.56	.55	.54
12	.46	.45	.45	.44

TABLE 8
Summary of the Overall Coefficients of Thermal Transmission UD for Units # 3,6,9,10,11 &12

Unit #	U_D W/(m^2.K)			
	Weather-Side Temperature, Tc oC			
	-7	-18	-21	-35
3	3.25	3.18	3.19	3.15
6	2.22	2.27	2.29	2.37
9	1.79	---	1.79	1.81
10	1.94	---	1.93	1.98
11	1.78	1.80	1.81	1.84
12	2.18	2.22	2.23	2.28

TABLE 9
Comparison Between Experimental Results and VISION Output for Units # 1, 2, 7 and 8

Parameter	Unit #			
	Sealed Double Glazing		Sealed Triple Glazing	
	#1 1m x 1.6m	#2 .8m x 1m	#7 1m x 1.6m	#8 .8m x 1m
Qs, W	200	101	138.3	71.3
T_1, oC	5.63	5.24	10.35	9.72
T_2, oC	-15.2	-15.1	-17	-16.8
ΔT, ^oC (T_1-T_2)	20.83	20.34	27.35	26.52
C_c, W/(m^2.K)	5.56	5.56	2.72	2.72
C_p, W/(m^2.K)	16.15	16.15	13.24	13.24
R_c, m^2.K/W	0.18	0.18	0.37	0.37
R_1+R_o, m^2.K/W	0.15	0.15	0.15	0.15
R_{CD}, m^2.K/W	0.33	0.33	0.52	0.52
U_{CD}, W/(m^2.K)	3.03	3.03	1.92	1.92
U_v, W/(m^2.K)	2.88	2.88	1.86	1.86
(Q_p/Q_s) x 100	11	16	18	24

Notes:

1. $R_c = 1/C_c$
2. $R_{CD} = R_i + R_o + R_c$
3. $U_{CD} = 1/R_{CD}$

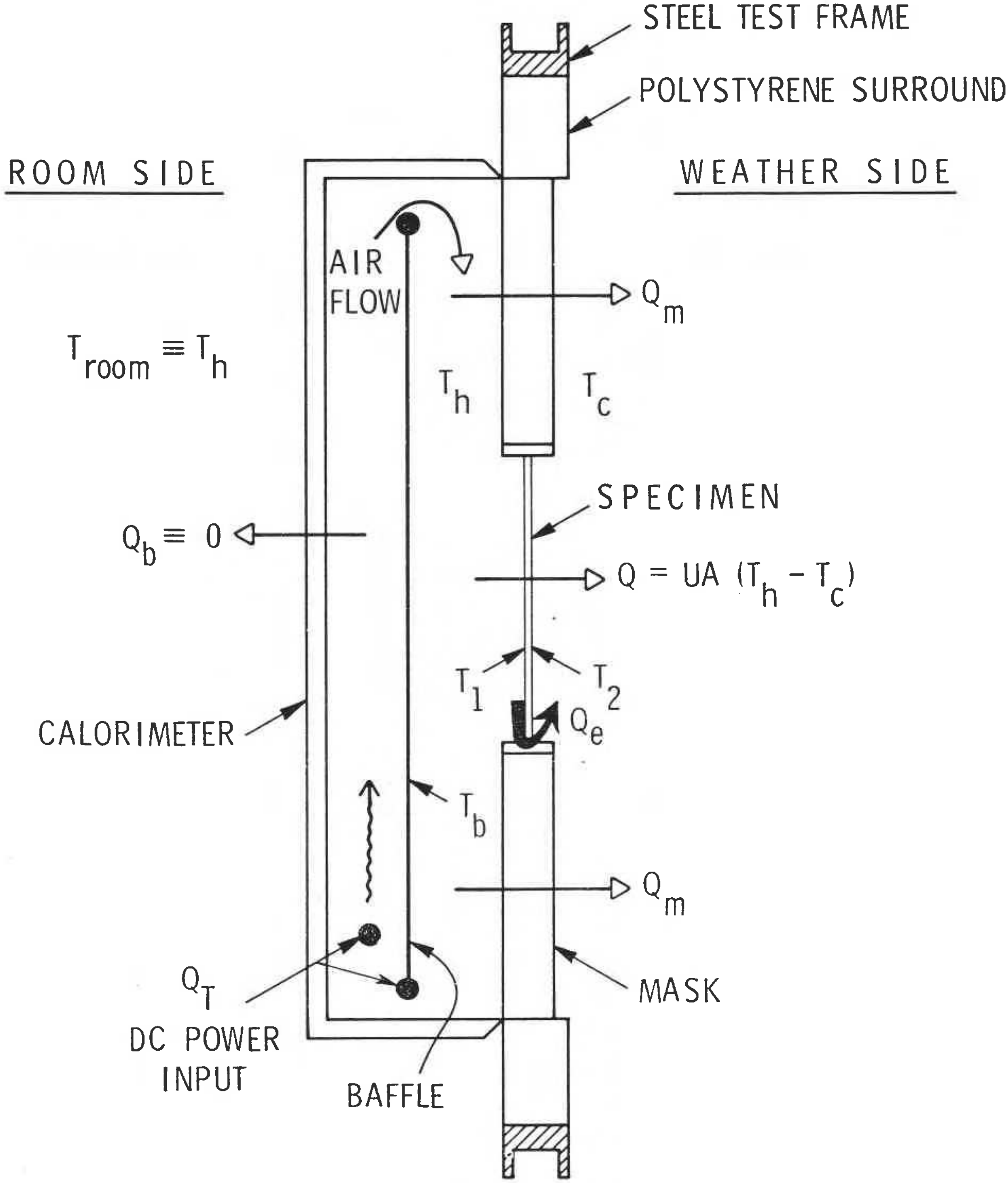

Figure 1 Calorimeter box

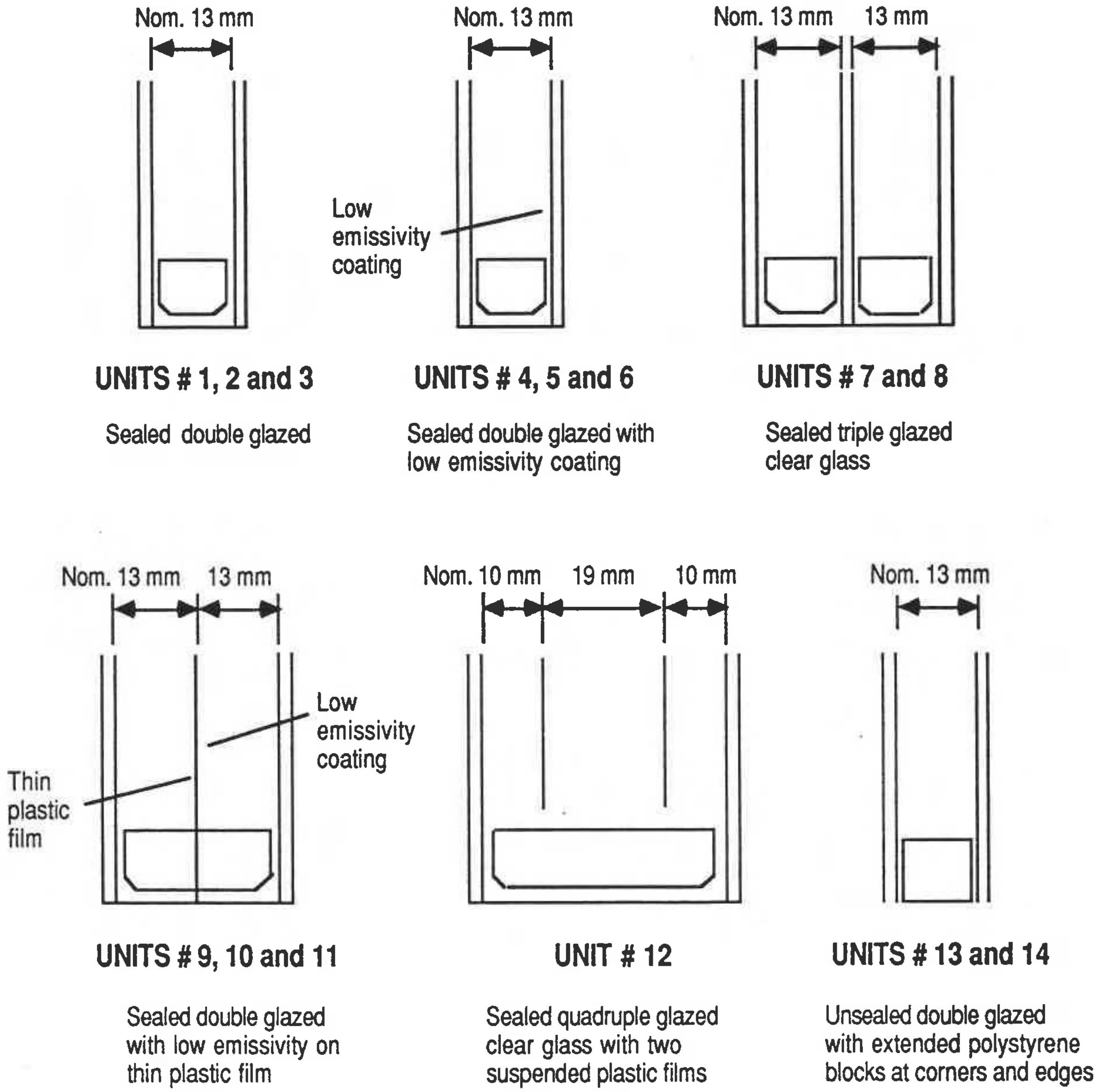

Figure 2 Schematic diagram showing cross section of the tested glazing units

DISCUSSION

D.M. Burch, Mechanical Engineer, National Bureau of Standards, Gaithersburg, MD: In your opinion, can laboratory-measured conductance values for windows be used in mathematical models to predict field performance? Are window U-values measured under laboratory conditions applicable to fluid conditions with solar and night sky temperature affecting thermal performance?

J.B. Findlay, Ottawa, Ontario, Canada: Have you examined U-values for winter under strong solar conditions? I have long objected to the ASHRAE procedure for calculating heat loss under these conditions for use in energy consumption programs.

A.H. Elmahdy: The questions raised by Mr. Burch and Mr. Findlay are interrelated, and I will answer them collectively. The glazing (window without frame) U-value determined in a laboratory setting includes two components: the C-value, that is, the heat transfer characteristic of the glazing unit itself, and the recommended ASHRAE film conductances of the environments separated by the unit. Although the C-value should not change under other environmental conditions, the overall U-value does change because of changes in the boundary conditions.

The net heat transfer through a glazing unit depends, not only on the C-value, but also on the driving forces of heat transfer. In case of a laboratory setting, these driving forces include effects of T, film coefficients, and radiation from the surrounding surfaces. In the field setting, radiation fields are different from those in the lab. The result would be a different heat transfer across the glazing unit.

The answer to Mr. Burch's first question is simply yes. The U-values determined in the lab can be used in mathematical models to predict the unit's field performance. This, however, requires determining the actual driving forces for heat transfer including the effect of changes in wind direction on the film coefficients, the temperature of the radiation surfaces (e.g., sky), and changes in the spectral emissivity of these surfaces (note: this is the answer to Mr. Burch's second question).

With respect to Mr. Findlay's question, the ASHRAE Handbook --1985 Fundamentals (Chapter 27, Table 13) provides U-values that should be used only for sizing of HVAC equipment and calculation of peak heating/cooling loads. Equation 31 on page 27.16 is used to calculate the total heat transfer through the unit. The term U $(t_o - t_i)$ represents the heat transfer due to the driving force $(t_o - t_i)$, and the other terms in the equation account for the solar radiation components. It is important to note that U-values and the potential for heat transfer used in this equation should be consistent. In other words, if $(t_o - t_i)$ includes solar heat, then U-values should also have the same characteristics built in when combining the film coefficients with the C-value to determine the U-value.