

**SIMULATION AND MEASUREMENT OF WINDOWS WITH METAL FILMS  
USED IN CONJUNCTION WITH TEFLON INNER GLAZINGS**

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Summary

Previous work has shown that highly infrared transparent plastic films are well suited for use as inner glazings when used in conjunction with a low emissivity coating. Thermal resistance measurements of a set of glazing systems incorporating gold or copper coatings plus Teflon intermediate glazings are reported. The same glazing systems were simulated using a computer program called VISION. The agreement between the two sets of results was found to be very good.

Résumé

Des études antérieures ont démontré que des pellicules de plastique transparent hautement infra-rouge utilisées avec un revêtement à faible émissivité sont très appropriées comme lustrage interne. Des mesures de la résistance thermique de différents systèmes de lustrage comprenant des couches d'or ou de cuivre avec des lustrages intermédiaires de Teflon sont présentées. Ces mêmes systèmes ont été simulés sur ordinateur à l'aide du programme VISION. La comparaison entre les résultats numériques et expérimentaux est très bonne.

Kurzfassung

Frühere Arbeiten haben gezeigt, dass infrarot-transparente plastische Filme gut geeignet sind für innere Verglasungen wenn sie mit einem Belag niedriger Ausstrahlung versehen sind. Experimentelle Werte werden gegeben vom thermischen Widerstand einer Reihe von Verglasungen. Diese verglasungssysteme haben Gold or Kupfer Beläge mit zwischenliegenden Teflon Folien. Dieselben Verglasungssysteme wurden rechnerisch modelliert unter Anwendung des "VISION" Computerprogramms. Die Übereinstimmung zwischen den gemessenen und errechneten Resultaten war sehr gut.

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**Introduction**

A computer simulation study reported at the ISES Intersol'85 conference in Montreal (1) illustrated that plastic films that are highly infrared (IR)\* transparent are well suited for use as inner glazings when used in conjunction with a low emissivity (low E) coating. Teflon† film was chosen for the study because of its excellent chemical and ultraviolet (UV) stability, very high solar and visible transmissivity, low weight and off-the-shelf availability as well as its high IR transmissivity.

It was shown that two panes of glass plus one low E coating and one Teflon film have more than 50% greater thermal resistance than the same system without the Teflon film - and more than double that of conventional double glazed. Another observation stemming from that study was that there was little benefit to be gained by using more than two Teflon films adjacent to a low E coating.

The current work extends this research to examine the use of low emissivity, but less selective, metal coatings such as gold or copper in lieu of the low E coating. These glazing systems are better suited to applications where solar gains are not desired but where high thermal resistance is useful, a situation common in large commercial buildings.

Computer simulations have been carried out in order to model a variety of glazing systems with up to two Teflon intermediate panes used in conjunction with either a gold‡ or a copper metal coating on the indoor facing side of the outdoor glazing. The computer simulation was carried out using a two-band thermal analysis program called VISION (2). VISION provides reliable estimates of U-value and shading coefficient (SC). Heat transfer within the glazing/environment array is modelled using a detailed algorithm which is sufficiently general to treat an

\* "infrared" (IR), "thermal" and "long wave" are used interchangeably to describe wavelengths greater than 3  $\mu\text{m}$ .

† Registered trademark of I.E. duPont de Nemour and Co.

‡ The "gold" coating is actually a copper/aluminum alloy that has a gold appearance. Henceforth, the terms "gold" and "copper/aluminum" are used interchangeably to describe this coating.

arbitrary number of glazings. Each glazing can have asymmetric radiative properties and can be partially transparent to thermal radiation. The latter capability is of particular importance since thin Teflon films are significantly transparent to thermal radiation. The models incorporated in VISION have been found to be accurate to within 2% when used to predict measured heat transfer rates across stagnant air layers containing a single Teflon film (3,4). Published U-values of commercial windows can be predicted generally to within 10% (5).

In order to provide further comparison between simulated and measured results a set of six glazing system prototypes were constructed. Thermal resistance measurements of these prototypes was carried out using the University of Waterloo Natural Convection Apparatus(6). This apparatus is a guarded heater plate type device that can be used, in a modified form, for the accurate measurement of heat flux across glazing systems. The thermal resistance value that results from this procedure corresponds to the glass-to-glass resistance of a glazing system and includes neither the thermal resistance that exists between a window and its environment nor the experimental difficulty of providing reproducible film coefficients.

### Optical Properties

All of the glazings lites simulated and/or measured consisted either of plain Teflon film or conventional window glass with or without a metal coating. The two metal coatings that were incorporated in this study were copper and a copper/aluminum alloy. The solar optical properties of the glass were characterized using the index of refraction,  $n=1.52$ , and extinction coefficient,  $K=0.024 \text{ mm}^{-1}$ . All of the glass lites were 6 mm thick. Similar data used to describe Teflon were  $n=1.344$  and  $K=0 \text{ mm}^{-1}$ . All Teflon glazings were 0.0254 mm thick.

Table 1 shows the solar and long wave optical properties that were used to model the glazings that were studied. Visible transmittance is also listed in Table 1. The visible transmittance values and solar transmittance and relectance values are for normal incidence. The long wave properties are hemispheric/hemispheric values. The solar and visible property values for both plain and coated glass were provided by the manufacturer.

Table 1. Summary of Optical Properties

Optical Property	Copper	Copper/ Aluminum	Teflon	Glass
Solar Transmittance	0.11	0.041	0.96	0.795
Solar Reflectance (coated side)	0.676	0.759	0.04	0.072
Solar Reflectance (uncoated side)	0.427	0.458	0.04	0.072
Visible Transmittance	0.207	0.079	0.96	0.875
Long Wave Emissivity	0.04	0.132	0.243	0.84
Long Wave Transmittance	0.0	0.0	0.634	0.0

The hemispheric/normal long wave reflectances of the metal coatings on glass were measured using a Gier-Dunkel DB-100 Infrared Reflectometer

and converted to the values shown in Table 1 using electromagnetic theory(7). The solar optical properties of Teflon are based on the manufacturer's literature and on measurement(8). The long wave optical properties of Teflon are also based on measurement(9).

### Measured and Calculated C-Values

Heat transfer testing of the six prototype glazing systems was carried out using the University of Waterloo Natural Convection Apparatus. This equipment is described fully in reference (6). Each glazing system tested was placed between two flat copper plates. Both of the copper plates and all of the glazing systems were square and measured 635 mm by 635 mm. In order to prevent direct contact between the copper and glass surfaces, and to promote good thermal contact, 3.18 mm thick sheets of neoprene were placed between the glazing system and the copper plates.

The individual panes of each glazing system were held at 11.94 mm spacings by spacers made of rigid insulating foam. A cross section of the edge of a double glazed prototype is shown in Figure 1.

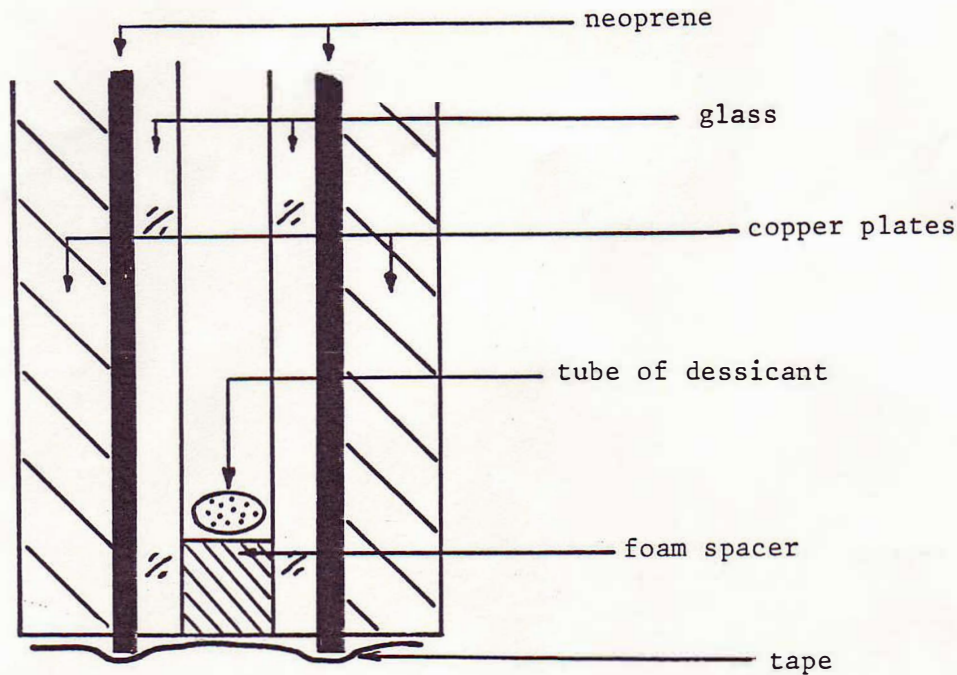


Figure 1. Edge of Double Glazed Prototype Shown Between Test Plates

The copper plates were maintained at different but constant temperatures by fluid that was pumped from two constant temperature circulating baths to manifolds attached to the backs of the copper plates. The temperature difference between the copper plates,  $\Delta T_p$ , was measured using a copper/constantan thermopile - each plate containing six thermocouple junctions.

The warmer of the two copper plates contains three guarded heater plates, each measuring 200 mm by 200 mm. Thermal resistance values reported here were measured at the heater plate located at the centre of the warm copper plate where the heat transfer through the glazing system is assumed to be one dimensional and free of edge effects.

The experimental procedure involved the adjustment of the electrical power supplied to the heater plate until a temperature difference of zero was measured between the heater plate and the larger copper plate in which it is embedded. Once this condition was reached all of the electrical power supplied,  $Q_e$ , is transferred through the glazing system to the cold copper plate. The glass-to-glass thermal conductance of the glazing system,  $C_{meas}$ , was then calculated using equation 1.

$$C_{meas} = [(A_{hp}\Delta T_p/Q_e) - 2R_n]^{-1} \quad W/m^2C \quad (1)$$

where,  $A_{hp}$  = heater plate area = 0.03919 m<sup>2</sup>  
 $R_n$  = thermal resistance of neoprene sheet = 0.017 m<sup>2</sup>C/W

Each prototype system was simulated using a modified version of the VISION program. The program modification involved substituting the thermal resistance of the neoprene sheet,  $R_n$ , for the thermal resistance that would normally be accounted for between the glazing system and its environment. This alteration allows the program to simulate the indoor and outdoor temperature nodes,  $T_1$  and  $T_n$ , as the hot and cold copper plates, respectively. The results of the simulation included the total heat flux through the glazing system,  $q_{tot}$ , plus the temperatures of the glazings adjacent to the hot and cold copper plates,  $T_2$  and  $T_{n-1}$ , respectively. The simulated glass-to-glass conductance,  $C_{VISION}$ , was then calculated according to equation 2.

$$C_{VISION} = q_{tot}/(T_2 - T_{n-1}) \quad W/m^2C \quad (2)$$

It is recognized that the temperatures of the copper plates were slightly different than the temperature settings of the circulating baths. Since the difference in temperature between either copper plate and the corresponding bath was small (always less than 1 C°) the modelling procedure was simplified by setting the simulated plate temperatures equal to the constant temperature bath settings. The simulation error introduced by this procedure was assumed to be negligible.

The measured and simulated C-value results for the prototype glazing systems are shown in Table 2. In addition, all of the glazing systems have been simulated using VISION (in its unmodified form) and the U-values for ASHRAE winter and summer design conditions,  $U_w$  and  $U_s$ , respectively, as well as the shading coefficient are reported in Table 2. The temperature levels,  $T_{hot}$  and  $T_{cold}$ , shown in Table 2 are the constant temperature bath settings.

Table 2. Comparison of Simulated and Measured C-Values

Metal Coating	T <sub>cold</sub> (C)	# Teflon Films	C <sub>meas</sub> (W/m <sup>2</sup> C)	C <sub>VISION</sub> (W/m <sup>2</sup> C)	U <sub>w</sub> (W/m <sup>2</sup> C)	U <sub>s</sub> (W/m <sup>2</sup> C)	SC
1 gold	-10.0	0	2.72	2.94	1.95	2.91	0.10
2 gold	-10.0	1	1.95	1.89	1.41	1.65	0.09
3 gold	-10.0	2	1.63	1.62	1.24	1.50	0.08
4 copper	-10.0	0	2.32	2.51	1.78	1.80	0.16
5 copper	-10.0	1	1.64	1.56	1.23	1.37	0.15
6 copper	-10.0	2	1.38	1.35	1.08	1.25	0.15
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7 gold	0.0	2	1.67	1.66	1.24	1.50	0.08
8 copper	0.0	0	2.31	2.35	1.78	1.80	0.16
9 copper	0.0	1	1.65	1.56	1.23	1.37	0.15
10 copper	0.0	2	1.40	1.37	1.08	1.25	0.15

Pane spacing = 11.94 mm, T<sub>hot</sub> = 21.0 C, slope = vertical, fill gas = air

The measured and calculated C-value results shown in Table 2 agree very well. The largest discrepancies noted were 8% and were recorded for both of the double glazed systems tested at the higher temperature difference. In general, better agreement was found for glazing systems with more panes. In the cases where the measured C-value changed as a function of the applied temperature difference a similar change in C-value was generally noted in the simulation results.

### Discussion

In reference (1) it has been shown that a triple glazed system that incorporates a low emissivity coating and a highly IR transparent intermediate glazing can provide greater thermal resistance than a similar system with a glass intermediate pane. This combination of low emissivity coating and IR transparent glazing works in such a way that the low emissivity coating is able to attenuate the radiative heat transfer in more than one interpane gap. The more closely the intermediate pane approaches the perfectly transparent condition the greater the thermal resistance becomes.

The design approach discussed above is illustrated in Figures 2 and 3. Figure 2 shows a cross section of the glazing system that is described in row 5 of Table 2. The simulated temperature profile is shown superimposed and the total heat flux and its components are shown below the glazing system. The temperature profile extends beyond the limit of the glazing system to show the temperature change through the neoprene sheets.

Figure 3 shows a glazing system that is identical to the system shown in Figure 2 with the exception that a glass pane has been substituted for the Teflon glazing.

In both Figures 2 and 3 the radiative component of heat flux in the gap adjacent the copper coating is small: 5 and 4 W/m<sup>2</sup>, respectively. When a glass intermediate pane is used the radiative component in the other

# Guarded Heater Plate Test Run

triple glazed, clear glass, 1 fep, cu coating (cold side)  
 Input File: cult.in  
 Output File: cult.out

Fill Gas: 1

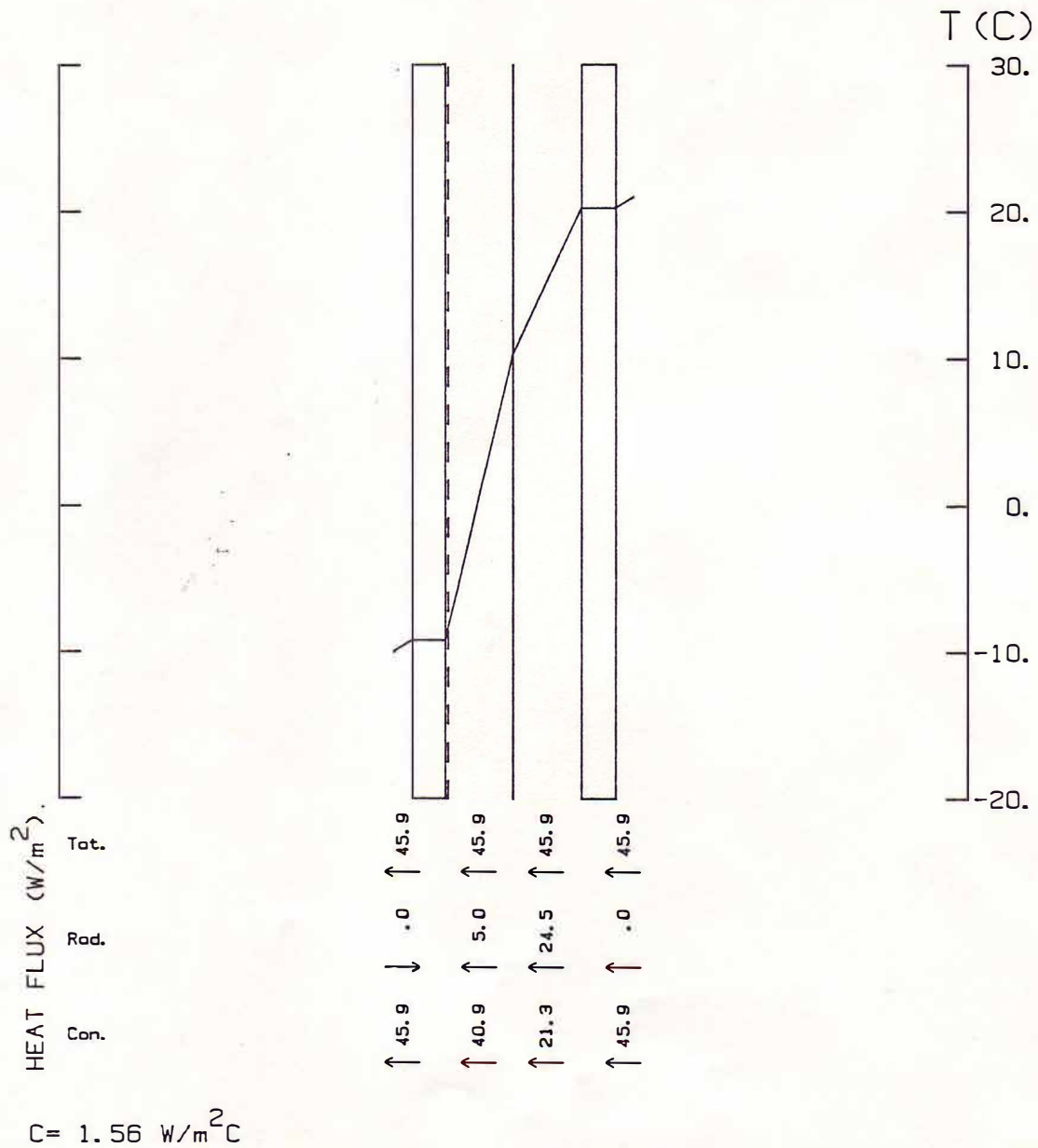


Figure 2. Triple Glazed System with Teflon Intermediate Pane

# Guarded Heater Plate Test Run

triple glazed, clear 6mm, clear 3mm, cu (cold side)  
 Input File: cuig.in  
 Output File: cuig.out

Fill Gas: 1

g  
 ↓  
 Slope: 90. deg.

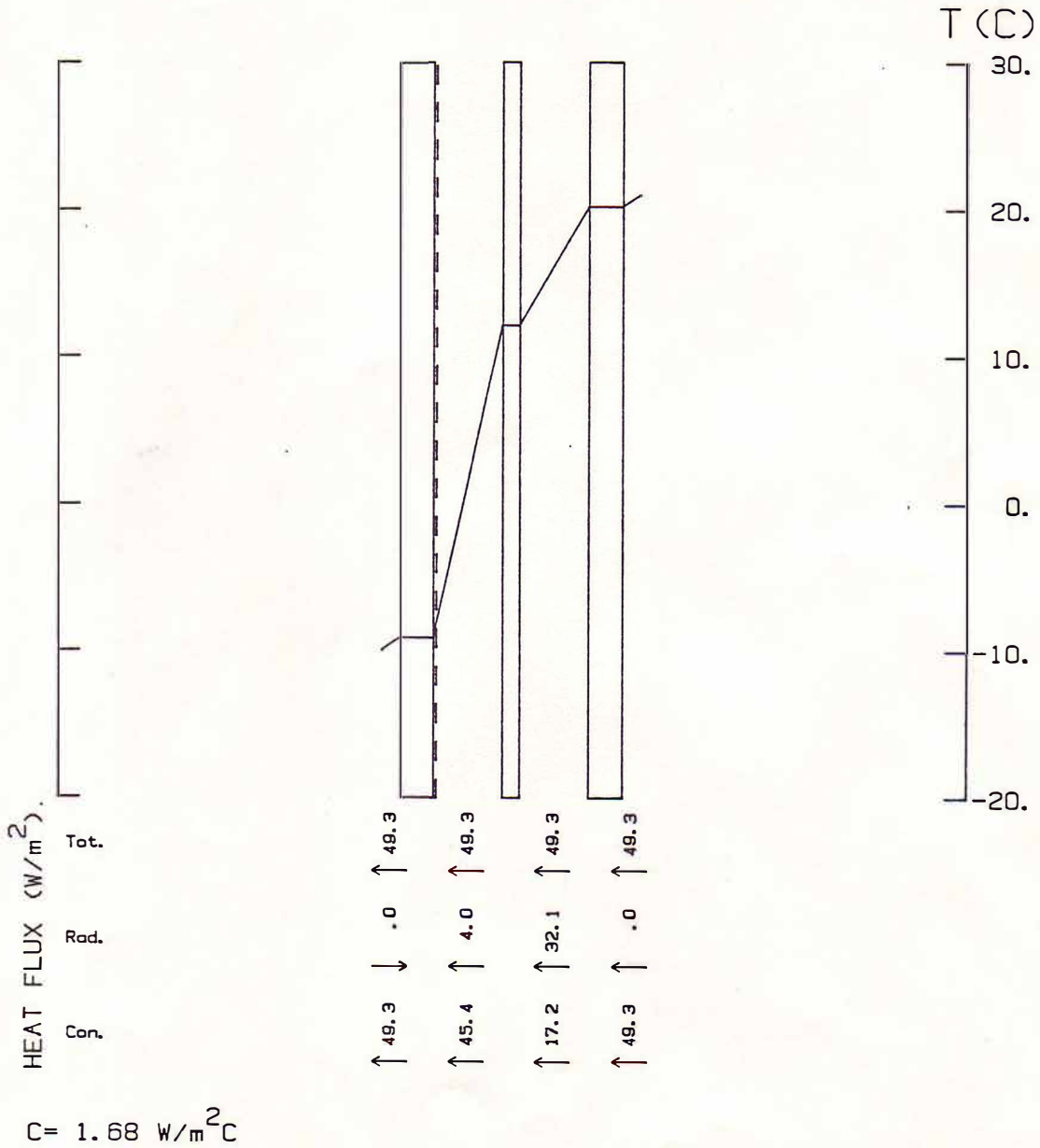


Figure 3. Triple Glazed System with Glass Intermediate Pane



gap is  $32.1 \text{ W/m}^2$ . If Teflon is used instead the net radiative flux drops to  $24.5 \text{ W/m}^2$  because the metal coating is able to "see" the far interpane gap and limit the radiative heat transfer. If a perfectly IR transparent intermediate pane could be used, simulation shows that the radiative component would be reduced to  $5.8 \text{ W/m}^2$  in both gaps. Additional simulation results for this fictitious glazing system are,  $C_{\text{VISION}} = 1.24 \text{ W/m}^2\text{C}$ ,  $U_w = 1.20 \text{ W/m}^2\text{C}$ ,  $U_s = 1.15 \text{ W/m}^2\text{C}$  and  $SC = 0.15$ .

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