SOLAR HEAT GAIN PERFORMANCE EVALUATION OF COMMERCIAL SOLAR-CONTROL GLAZINGS AND SHADING DEVICES

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DISCLAIMER

NOTE

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Abstract

The use of solar-control glazings and shading devices as a means of enhancing window and building energy performance has been increasing. The determination of fenestration system solar-heat-gain (SHG) values for these complex fenestration systems is required to evaluate the energy performance of buildings, to estimate peak electrical loads, and to ensure the comfort of building occupants.

This report describes a study to investigate the potential of a solar-simulator-based test method for use with complex fenestration systems. Commissioned by CANMET and Ontario Hydro, SHG values were measured for generic commercial shading products. The results of this study demonstrate the feasibility of the test method for the evaluation of solar-control glazings and shading devices.

Solar Heat Gain Performance Evaluation of Commercial Solar-Control Glazings and Shading Devices

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Executive Summary

The use of solar-control glazings and shading devices as a means of enhancing window and building energy performance has been increasing. The determination of solar-heat-gain (SHG) values for these complex fenestration systems is required to evaluate the energy performance of buildings, to estimate peak electrical loads, and to ensure the comfort of building occupants.

In the past, the ASHRAE handbook has been used for this purpose, however, recent developments in window technology have resulted in many new products for which data does not exist. In addition, available computer programs used for simulating windows were not designed to evaluate the effects of shade and blind combinations when used in conjunction with glazing assemblies.

Responding to these needs, CANMET sponsored the development of a unique facility and test method for the experimental determination of Solar Heat Gain Coefficient (SHGC). A subsequent study showed a high degree of agreement between measured and computer simulated results for simple glazing configurations and illustrated the potential of the test method to rapidly and accurately determine SHGC values. As an extension to that original study, CANMET and Ontario Hydro commissioned this project to measure SHGC values for generic commercial shading products including different types of glazings, blinds and shades.

Samples were evaluated at normal-incidence irradiance conditions and the results produced are suitable for product rating and comparison, equipment sizing, or peak load analysis. In addition, measured SHGC results were compared to values predicted by the *VISION4* computer program, using spectral optical data. For clear or tinted, homogeneous glazing systems, the experimental portion of this study strongly support its use. The results also indicate that computer simulation is suitable for curtainwall and retrofit films if optical property data is available.

In the case of complex fenestration, however, the program's application is restricted due to limitations in its theoretical optical and heat transfer modeling. The development of suitable methods to model the convective and radiative heat transfer properties in unsealed shades and blinds, or their directional-optical dependencies, is an area requiring considerable research.

In addition to normal-incidence test results, product performance at angles of incidence, that are representative of diurnal or seasonal variations in sun-angle, are also needed to accurately predict the energy consumption for heating or air-conditioning applications. As angular variations in shading performance are significant for directional shading devices such as venetian or slat-type blinds, testing was also conducted, at a range of incidence angles, on two complex glazing assemblies.

This demonstrated the capability of the facility to produce angle dependence results, however, the full characterization of these devices requires an extensive mapping of their performance at a range of solar altitude and azimuth angles.

An important aspect of solar-control glazings and add-on shading devices is their visible transmittance. In general, as visible transmittance is increased, solar heat gains will also increase. However, results show that in certain cases, e.g., for the curtainwall samples, visible transmittance is significantly higher than the corresponding values of SHGC.

In the case of interior blinds and shades, it was observed that, even for products with very low values of visible transmittance, high values of SHGC may occur. This has a significant impact on heat gain calculations for commercial buildings and shows that care must be taken when using interior shading devices to reduce air-conditioning loads. This is particularly important if the shade or blind is not highly reflective to sunlight.

Finally, the results of this study demonstrate the feasibility of the solar-simulator-based test method for the evaluation of solar-control glazings and shading devices, and represent a significant step toward establishing universal testing capabilities for window energy-ratings and the validation of computational procedures.

Résumé

Des vitrages solaires et dispositifs pare-soleil sont de plus en plus employés pour améliorer la performance énergétique des bâtiments et des fenêtres. Pour évaluer la « performance énergétique » des bâtiments, estimer les charges électriques de pointe et assurer le confort des occupants, il faut déterminer les valeurs d'apport calorifique dû au rayonnement solaire, ou gain thermique solaire, correspondant à ces fenêtrages complexes.

Dans le passé, on utilisait pour ce faire le manuel de l'ASHRAE; cependant, les récents progrès de la technologie ont amené sur le marché le lancement de nombreux nouveaux produits pour lesquels on ne dispose pas encore de données. De plus, les logiciels utilisés jusqu'ici pour la modélisation des fenêtres n'étaient pas conçus pour évaluer les effets combinés de stores et systèmes pare-soleil utilisés conjointement avec des ensembles de vitrage.

Pour répondre aux besoins en la matière, CANMET a commandité la mise sur pied d'une installation et d'une méthode d'essai originales, destinées à déterminer expérimentalement le coefficient de gain thermique solaire (CGTS). Par la suite, une étude a démontré qu'il existait une concordance étroite entre les mesures relevées et les résultats simulés par ordinateur, pour les vitrages de configuration simple, et révélé le potentiel de la méthode d'essai pour déterminer les valeurs de CGTS de façon rapide et précise. Pour faire suite à cette étude originale, CANMET et Ontario Hydro ont commandité le présent projet ayant pour but de mesurer les valeurs de CGTS de produits commerciaux génériques comprenant différents types de vitrages, de stores et de systèmes pare-soleil.

Des échantillons ont été évalués dans des conditions d'irradiation solaire sous une incidence normale; les résultats obtenus permettent la classification et la comparaison des produits, le dimensionnement des équipements ou l'analyse des charges électriques de pointe. En outre, les mesures de CGTS ont été comparées aux valeurs prédites par le programme d'ordinateur VISION4, à l'aide de données optiques de répartition spectrale. Dans le cas des systèmes à vitrage homogène, clair ou teinté, la portion expérimentale de la présente étude appuie fortement son utilisation. Les résultats montrent aussi que la simulation par ordinateur convient également, dans le cas des murs-rideaux et de pellicules utilisées pour des modifications, si l'on dispose de données sur leurs caractéristiques optiques.

Toutefois, pour ce qui est des fenêtrages complexes, l'application du programme est restreinte en raison de limites dans la modélisation théorique des caractéristiques optiques et du transfert thermique. La mise au point de méthodes appropriées pour modéliser les propriétés de la transmission de la chaleur par convection et par rayonnement dans les stores et dispositifs pare-soleil non scellés, ou l'effet sur ceux-ci de paramètres directionnels et optiques, sont des questions qui exigeraient des recherches approfondies.

Outre les résultats d'essais sous incidence normale, le comportement des produits sous des angles d'incidence représentatifs des variations diurnes ou saisonnières de la hauteur relative du soleil est également nécessaire pour prédire précisément la consommation d'énergie des appareils de chauffage ou de climatisation. Comme les variations angulaires de l'efficacité d'atténuation du rayonnement sont déterminantes pour les dispositifs pare-soleil directionnels, comme les stores vénitiens ou à lames, des essais ont également été faits sous différents angles d'incidence, sur deux ensembles de vitrage complexes.

Ces essais ont démontré la capacité de l'installation à produire des résultats en fonction de l'angle; cependant, la caractérisation générale de ces dispositifs nécessite un relevé complet de leur performance en fonction d'une plage de hauteurs relatives et d'angles d'azimuts du soleil.

Un aspect important des vitrages solaires et des pare-soleil ajoutés est leur transmittance visible. En général, le gain thermique augmente avec la transmittance visible. Toutefois, les résultats montrent que dans certains cas, par exemple avec des échantillons de murs-rideaux, la transmittance visible est largement supérieure aux valeurs correspondantes de CGTS.

Dans le cas des stores et pare-soleil intérieurs, on a remarqué que des valeurs élevées de CGTS apparaissent parfois, malgré des valeurs de transmittance visible très basses. Cet effet a des répercussions importantes sur les calculs de gain thermique dans les immeubles commerciaux, et montre qu'il faut veiller, quand on utilise des dispositifs pare-soleil intérieurs, à réduire les charges de climatisation; cela est particulièrement important si le store ou pare-soleil ne réfléchit pas suffisamment la lumière solaire incidente.

Enfin, les résultats de l'étude démontrent la faisabilité de la méthode d'essai par modélisation du rayonnement pour évaluer des vitrages solaires et des dispositifs pare-soleil; cette méthode constitue une étape capitale dans la mise sur pied de mécanismes d'essai de portée universelle pour la classification énergétique des fenêtres et la validation des procédés de calcul.

Solar Heat Gain Performance Evaluation of Commercial Solar-Control Glazings and Shading Devices

1. INTRODUCTION

The use of solar-control glazings and shading devices as a means of enhancing window and building energy performance is increasing. The determination of fenestration system solar-heat-gain (SHG) values for these complex fenestration systems is required to evaluate building energy performance, to estimate peak electrical loads, and to ensure occupant comfort.

In the past, tables within the ASHRAE Handbook of Fundamentals[1] have been used for this purpose, however, developments in window technology have resulted in the availability of a wide range of new fenestration products. As a result, these tables are not adequate for a significant number of products now used on residential and commercial buildings. In addition, computer programs currently used for simulating windows[2,3] were not designed to evaluate the effects of shade and blind combinations on glazing assemblies. These factors have created a need for an accurate test method for evaluating SHG values for all types of fenestration.

Responding to these needs, CANMET recently sponsored the development of a unique facility and test method for the experimental determination of Solar Heat Gain Coefficient (SHGC)[4,5]. These developments were immediately followed by a study to validate the test method for use with conventional residential window systems[6]. That study showed a high degree of agreement between measured and computer simulated results for simple glazing configurations. It illustrated the potential of the test method to rapidly and accurately determine SHGC values.

An obvious extension of this original validation study was an investigation of the potential of the method for use with complex fenestration systems typically used in commercial buildings. As a result, CANMET and Ontario Hydro commissioned this study to measure SHGC values for generic shading products*. This report summarizes the results of this study.

1.1 Objectives

This study had two main objectives:

i) to establish a listing of performance test results for generic shading products, and to compare measured results with values calculated using analytical methods; and

ii) to continue the refinement of the performance test procedures at the CANMET Window Test Facility, and in particular, to investigate its applicability for complex glazings incorporating solar-control features or add-on shading devices.

* for consistency with handbook[1] values for commercial applications, SHGC results presented in this document are "centre-of-glass" values. When evaluating residential windows[5], it is common practice to include frame effects.

2. METHODOLOGY

It was recognized at the onset of the project that the establishment of an extensive database of SHGC values for commercial solar-control glazings and shading products would be a time consuming and expensive task. This fact was further reinforced by the knowledge that the limited data available in the ASHRAE HOF[1] represents the results of a significant number of researchers' work spanning a period of over 30 years. As a consequence, it was decided to focus the study on a range of representative generic products and to demonstrate the potential of the test method for evaluating complex fenestration systems incorporating solar-control glazings and shading devices. In doing so, it is hoped that manufacturers wishing to market products that can not be evaluated by computer simulation, will have the option of obtaining an experimentally derived result.

When selecting the samples to be tested, products were chosen that were considered beyond the capability of current computer simulation tools, and where generic performance data was not available. Specifically, a variety of glazing and shading systems, including: heat absorbing insulated-glazing-units (IGU's); reflective film and suspended film IGU's; and add-on shading devices (e.g., slat-blinds and shades) were studied.

In all cases, commercially available products were obtained and evaluated in the CANMET Window Test Facility. Testing was conducted according to the documented test method[4,5], using the solar simulator facility at the Canadian National Solar Test Facilty (NSTF). All test specimens were evaluated at normal-incidence irradiance conditions. Normal-incidence results are suitable for product rating and comparison, equipment sizing, or peak load analysis.

During testing, an effort was made to minimize frame effects to ensure that the results would be consistent with the "centre-of-glass" values published in the ASHRAE HOF[1]. The minimal frame and "edge-of-glass" effects experienced during testing were confirmed by analysis of the test-sample mounting-detail with the *FRAME* [5] computer program. Wherever possible, measured SHGC values were also compared to values predicted by the *VISION4* [2] computer program, using spectral optical data.

While normal-incidence test results are suitable for product rating, product performance at angles of incidence, that are representative of diurnal or seasonal variations in sun-angle, are needed to accurately predict energy consumption for heating or air-conditioning applications. Angular variations in shading performance are particularly important for directional shading devices such as venetian or slat-type blinds. Their performance is highly dependant on both solar incidence-angle and the slat orientation. The full characterization of these devices requires an extensive mapping of their performance at a range of solar altitude and azimuth angles representative of the seasonal and geographical range of variation.

To investigate the suitabliity of the test method to derive this type of data, testing at angles other than normal-incidence was undertaken for a limited number of samples. In the case of high sun-altitude-angle tests, planar mirrors were used; a previously untried method.

3. SHGC TESTING

The experimental portion of this study was performed at the CANMET Window Testing Facility at the National Solar Test Facility[6] (NSTF), and included testing of both solar-control glazings and shading devices. In preparation for testing, window samples were mounted in the mask wall of a specially constructed window calorimeter[7], Fig. 1. This calorimeter was then moved into the environmental chamber at the NSTF and testing was conducted under simulated solar irradiance conditions, Fig. 2.

The facility's environmental control system supplied the chamber with humidity controlled air, at a uniform velocity, directed parallel to the floor and perpendicular to the window. The test specimens were irradiated at fixed incidence angles using the facility's single-source arc lamp[8].

3.1 Experimental Test Method

The experimental test method used for this study is approved within the Canadian national standard on window performance evaluation[4,5]. During testing, the net energy transmission through the window was measured with the calorimeter test cell, under controlled air temperature, wind and solar radiation conditions.

Figure 1. Cut-away view of the window calorimeter test cell, (not to scale).

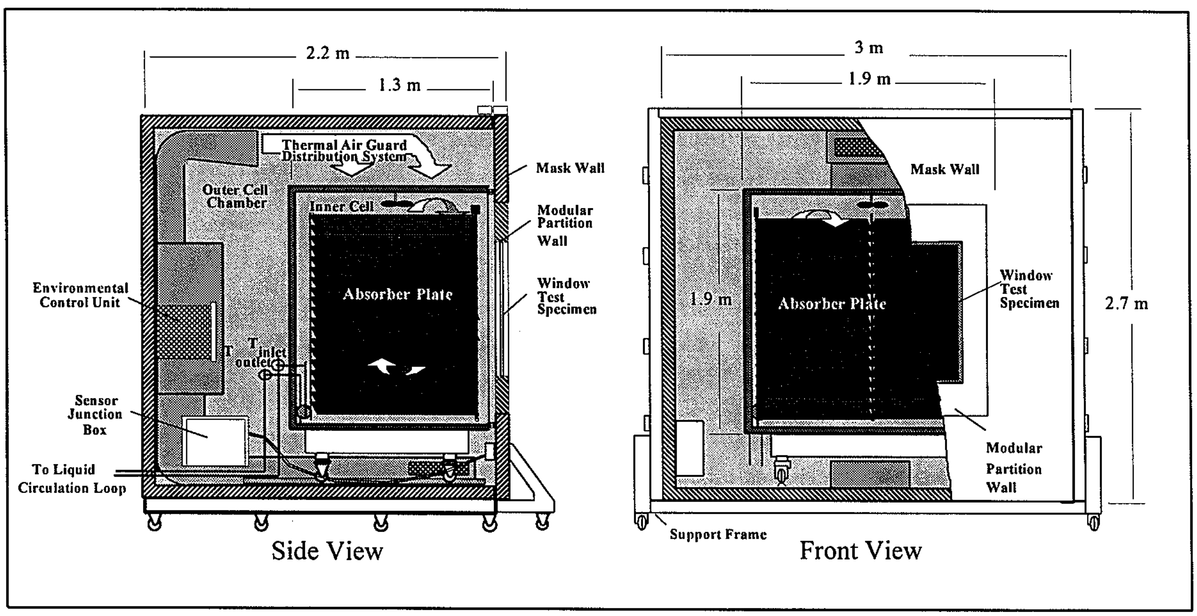
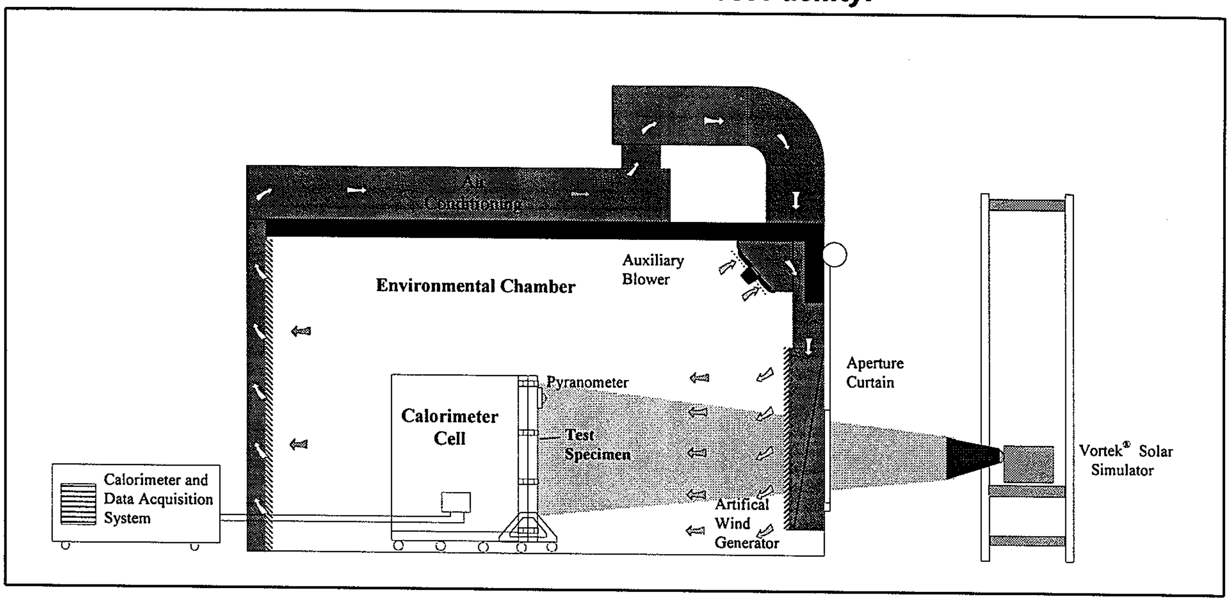


Figure 2. View of the calorimeter cell positioned in the environmental chamber at the National Solar Test Facility.



Tests were conducted under steady-state conditions, i.e., temperatures and simulated solar radiation levels were held constant throughout the test period. Each test was continued until all the measured values, including SHG, were stable. Depending on the specific test sample being evaluated, this normally consisted of a time period of three to four hours.

To determine the value of the solar heat gain coefficient, the temperature difference across the fenestration system was maintained very close to zero (i.e., both the interior calorimeter and environmental chamber temperatures were held at 21°C ±1°C) and the solar irradiance level was held fixed at 783 W/m^2. The wind speed was maintained constant at 3 m/s, corresponding to an exterior film coefficient of 20 W/m^2 K.

All tests were conducted with simulated "beam" solar irradiance (i.e., diffuse sky and ground reflected irradiance were not present).

3.1.1 Testing at Normal Incidence

The window test specimens were irradiated using a single-source, large area solar simulator lamp. The lamp, mounted on an elevator, was situated 11 m from the calorimeter test cell and irradiance entered the environmental chamber through an opening in a moveable aperture curtain. To achieve normal-incidence during testing, the lamp was set at its lowest position allowing the samples to be directly irradiated, (Fig. 2).

3.1.2 Angle Dependence Test Method

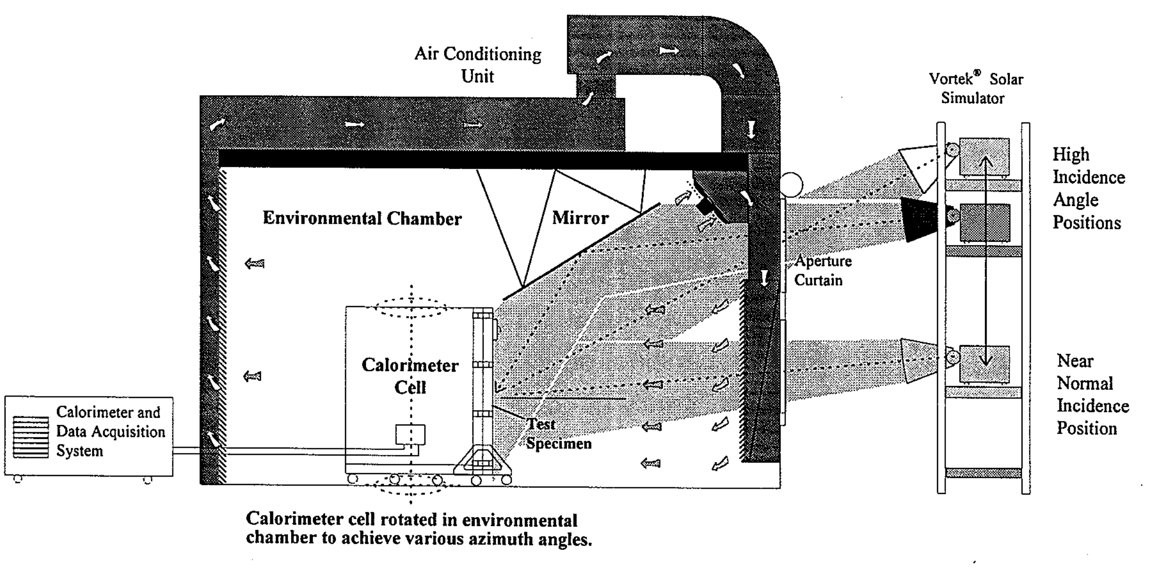
To determine the values of SHGC corresponding to non-normal-incidence angles both the calorimeter cell and the lamp position were adjusted. By raising the lamp on the elevator, test samples could be directly irradiated at altitude angles of up to +30° relative to the horizontal. To simulate altitude angles greater than 30°, a planar mirror assembly was used, Fig. 3.

Variations in azimuth angle were accomplished by rotating of the calorimeter cell about its vertical axis in the environmental chamber. With these adjustments, in lamp position and calorimeter test cell orientation, testing was possible at a range of complex incidence angles.

The testing procedure for each angle dependence test was effectively identical to the normal-incidence tests as described in the published test method[4]. Before each test was conducted, solar irradiance levels were determined by scanning an array of pyranometer sensors across the fenestration aperture. Measured irradiance levels were adjusted to values representative of the average intensity. Beam positioning was facilitated by a small helium-neon laser mounted on the lamp with its beam parallel to the optical axis.

As with the normal-incidence tests, steady-state conditions of solar irradiance, ambient temperature, and wind velocity were maintained during each test. Testing at each incident angle took approximately the same time period as the normal-incidence tests, except new test samples did not need to be fitted to the mask wall between tests.

Figure 3. View of the calorimeter test cell positioned in the environmental chamber showing the possible positions of the simulator lamp.



4. TEST SAMPLES

A variety of commercially available glazing and shading systems (e.g., heat absorbing insulated-glazing-units (IGU's), reflective film and suspended film IGU's) and shading devices (i.e., slat blinds and shades) were evaluated. In addition, a series of architectural translucent sandwich panels were chosen for testing due to their wide usage in commercial buildings and the lack of alternative methods for evaluating their performance. The products evaluated are briefly described below and are summarized in Tables 1 to 3.

Architectural translucent sandwich panels. This glazing system is widely used in commercial buildings (e.g., airports, retail and office buildings, etc.) and is a factory assembled unit consisting of translucent fibre reinforced plastic (FRP) glazings bonded onto both sides of a structural support frame made of aluminum bars or thermally broken FRP bars. The support bars were spaced on 305 x 610 mm centers (12 x 24 in) and the units were 70 mm (2.75 in) thick. The air-filled interior space may be filled with glass fibre insulation of various densities to provide a range of insulating values and glazings with differing solar transmittance values can be specified according to the user's needs. Three samples were selected for testing representing to a range of glazings and spacer combinations.

These glazing systems do not normally provide visual communication to the exterior and, as such, are often used for skylights or natural lighting when security or privacy are desired. The specifications of the panels tested are included in Table 3.

Curtainwall insulated-glazing-units. Curtainwall insulated-glazing-units, consisting of inner and outer glass glazings with two "low-e" coated interior suspended plastic films, were evaluated under this study. These units are intended for commercial building applications and offer high thermal resistance values. Two samples were tested: the first, with two low-e films situated between two clear glazings; and the second, with two low-e films situated between an inner clear glazing and an outer green-tinted glazing.

Insulated-glazing-units (IGU's). A number of insulated-glazing-units, consisting of clear or tinted inner and outer glass glazings, were also tested. On certain samples, low-e or retrofit films were installed on the glass surfaces as indicated. Factory installed low-e coatings are primarily intended to reduce radiative heat transfer between glazings in an effort to increase fenestration thermal resistance. Their use, however, will affect the inward-flowing fraction of any absorbed solar energy[1]. In addition, depending on the transmission characteristics, transmitted solar energy and SHGC may be significantly affected.

Retrofit films offer the potential to improve the shading performance of existing fenestration by reducing their transmission of solar energy. This is accomplished by absorption or reflection of incident solar radiation. Recently, films with spectrally selective optical properties and low-e coating have also become available. Optically selective coatings or glazings transmit only a selected region of the solar spectrum and are primarily used to reduce solar heat gains while maintaining high daylighting levels.

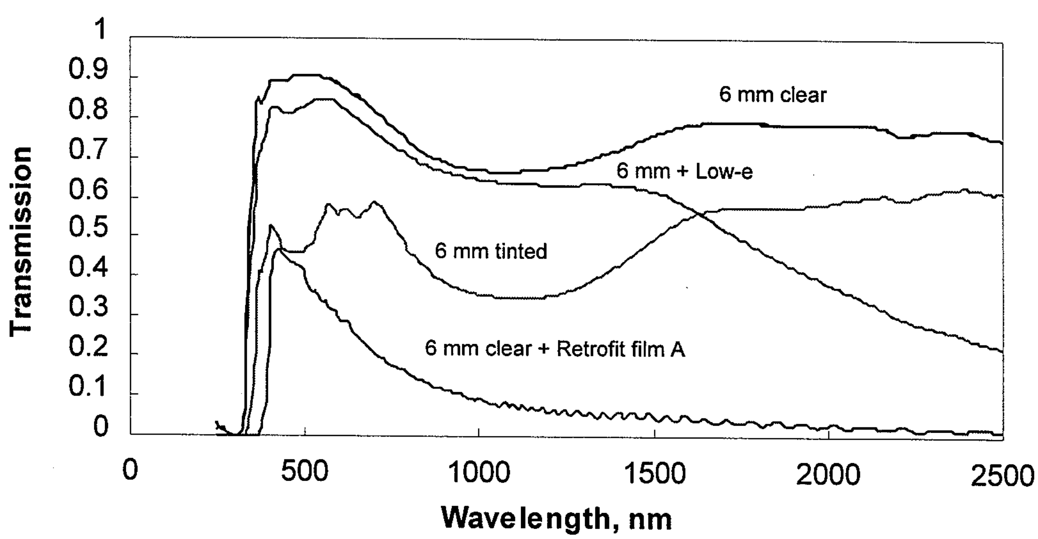
Venetian blinds and shades. Venetian blinds and shades were tested in combination with one of the double glazed IGU's studied. The IGU unit chosen for this evaluation was equipped with a low-e coating on the exterior side of the interior glazing. The low-e unit was selected as there is very little data available on the use of blinds and shades with low-e coated IGUs. Both light and dark coloured venetian blinds and shades were evaluated, in addition to, opaque and translucent light coloured shades. For the purposes of testing, venetian blinds were angled downward at a 45° angle to the horizontal.

A "silver" cloth shade, normally used for light and solar-heat-gain-control in commercial buildings, was also evaluated.

4.1 Optical Properties

The insulated-glazing-units prepared for this study were specially constructed, by a commercial manufacturer, using specified glazing materials. Samples of each glazing were sent for optical characterization to the Institute for Research in Construction, (IRC), at the National Research Council, Canada, (NRC). Typical spectral optical properties are shown in Fig. 4. All Glazing samples were a nominal 6 mm thickness and IGU's were fabricated with conventional aluminum spacers. The curtainwall and sandwich panel test samples were fabricated with proprietary glazing spacers.

Figure 4. Spectral optical properties of glazings used in tested IGU's.



The optical properties of the glazings used in the curtainwall and IGU test samples were calculated based on optical data measured at the IRC laboratory. Values are given in Table 1, as calculated for the AM 1.5 standard solar spectrum with the *Window 4.1* [3] computer program. Solar and visible transmittance (τ_s and τ_v), front and back surface reflectivities (ρ_f and ρ_b) , and front and back surface emissivities (ε_f and ε_b), are tabulated.

Table 1. Optical Properties of Glazings used in Curtainwall and IGU Test Samples

Fenestration & Glazing Description[+]		τ_s	τ_v	ρ_f	ρ_b	ε_f	ε_b
Curtainwall	6 mm green tint glass	0.471	0.768	0.058	0.060	0.84	0.84
	0.076 mm film	0.687	0.896	0.221	0.198	0.114	0.72
	6 mm clear glass	0.761	0.890	0.071	0.070	0.84	0.84
IGU's	5.64 mm clear glass	0.786	0.895	0.077	0.076	0.84	0.84
	5.64 mm clear & pyrolytic (low-e)	0.699	0.838	0.098	0.105	0.197	0.84
	5.64 mm tinted glass	0.479	0.539	0.056	0.058	0.84	0.84
Retro Film	Retro Film "A" on clear glass	0.190	0.334	0.410	0.668	0.34	0.84

[+]Note: Due to technical problems, optical values for Retro Film "B" were not available.

Samples of the shade and blind materials were also sent to the IRC to determine their optical properties. Values of reflectance and transmittance to solar radiation, as calculated from optical data measured by the IRC, are given in Table 2.

Table 2. Optical Properties of shade and Blind materials used in Tests.

Blinds & Shades Description		τ	ρ
1 in. mini-blinds	off-white (smoke coloured) set at 45°	0	0.484
	teal coloured set at 45°	0	0.353
shades	white translucent cloth	0.160	0.669
	white opaque vinyl shade	0	0.682
	dark brown opaque vinyl shade	0	0.120
	silver cloth shade	0.236	0.457

Descriptions of the complete fenestration assemblies are given in Table 3.

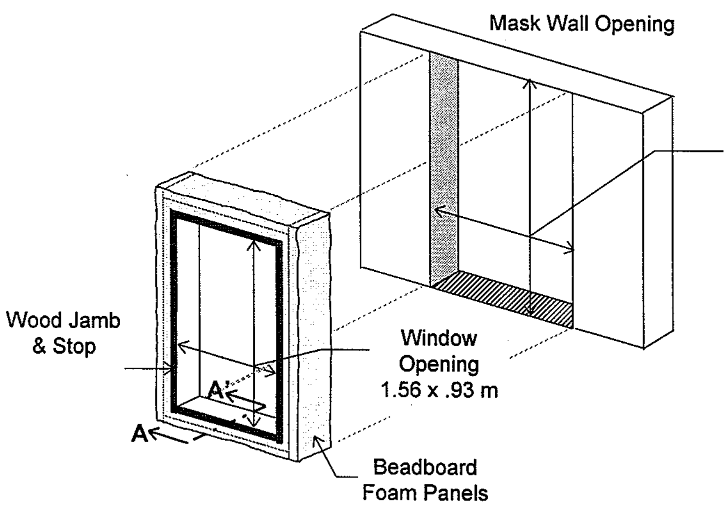
4.2 Test Sample Mounting

Prior to testing, window test samples were mounted in the mask wall of the calorimeter test cell, insulated around their perimeter, and sealed to ensure minimal air leakage into and out of the test cell during testing, Fig. 5.

All normal-incidence tests were made on IGU's and glazing panels without frames. However, a simple support was constructed to hold the glazing units and add-on shading devices during testing. The mounting details for the IGU units and shades are shown schematically in Appendix A. All blinds and shades were attached on the interior of the insulated-glazing-units. Shade assemblies were sealed at their perimeter during testing to limit air flow into and out of the glazing-shade air-space.

The tests performed to evaluate the effects of incidence angle (see section 5.2) were conducted on a commercial double glazed window with a metal-clad, wood frame. For comparison purposes, all test results were reported on "clear opening" to correspond with ASHRAE HOF[1] values for centre-of-glass. Figure 6 shows a photo of one of the fiberglass translucent sandwich panels installed for testing. Figure 7 shows a venetian blind assembly under test.

Figure 5. Mounting detail in calorimeter mask wall for tested IGU's.



MASK WALL DETAIL

Jamb Detail
to fit: 1.550m x 0.920m IGU's

Materials

Beadboard	1.5 in	x 6 in
	1 in	x 6 in
Jamb (wood)	1 in	x 6 in
Stop (wood)	1 in	x 1 in

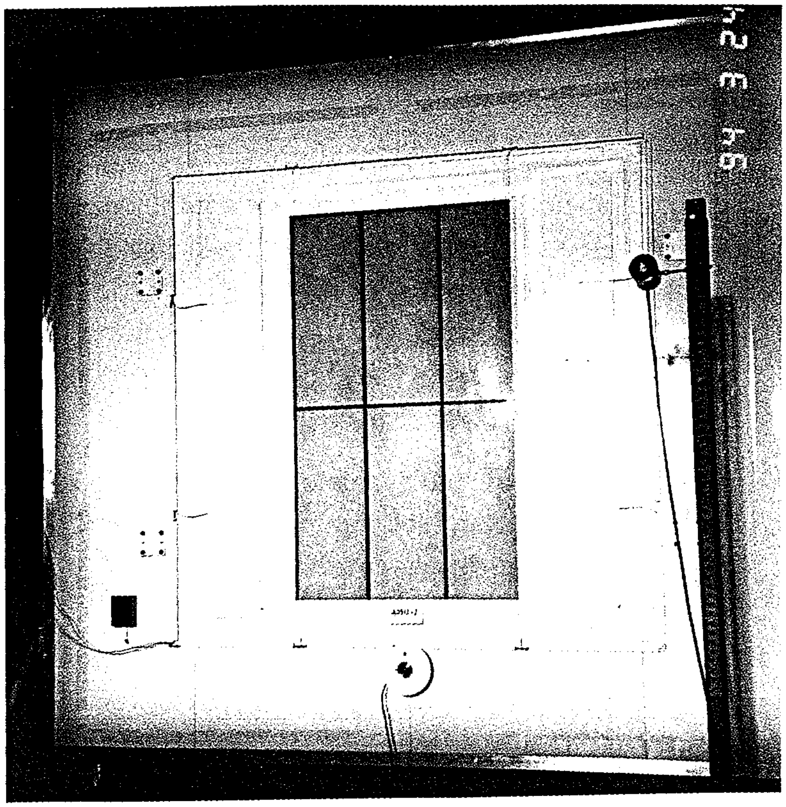


Figure 6. Photo of one of the Fiberglass Translucent Sandwich panels installed for testing.

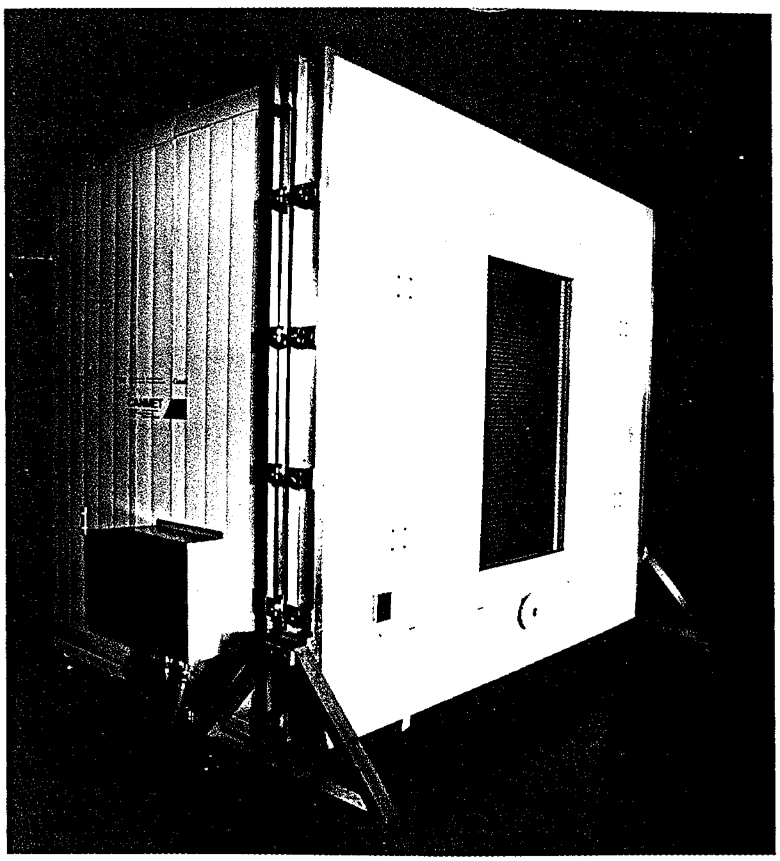
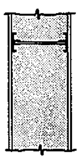
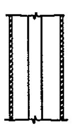
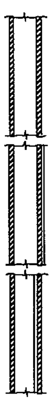
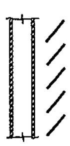
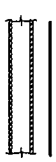


Figure 7. Photo of one of the IGU and Venetian Blind assemblies installed for testing.

Table 3. Description of Test Samples Evaluated

Test Sample	General Description	Sample Specification	τ	ρ	Designation
Fiberglass/Aluminum Translucent Sandwich Panels					
	Architectural sandwich panels with translucent fibre reinforced plastic (FRP) glazings permanently bonded to extruded aluminum spacer bars or FRP spacer bars (thermally broken case). Interior spaces filled with glass fibre (GF) insulation.	.070" crystal FRP/ GF insulation/ .045" crystal FRP with aluminum grid core (i.e., spacer bars)			SP-1
		.070" white FRP/ GF insulation/ .045" white FRP with aluminum grid core (i.e., spacer bars)			SP-2
		.070" crystal FRP/ GF insulation/ .045" crystal FRP with thermally broken grid core (i.e., spacer bars)			SP-3
Curtainwall					
	Architectural curtainwall insulated-glazing-units (IGU's) consisting of inner and outer glass glazings with two low-e coated, interior suspended plastic films. Exterior glazing on $CW_{T+F+F+C}$ was green tinted glass.	- 6 mm outer green tinted glass/ 25mm airspace/ film/ 20mm airspace/ film/ 25mm airspace/ 6 mm inner clear glass			$CW_{T+F+F+C}$
		- 6 mm outer clear glass/ 25mm airspace/ film/ 20mm airspace/ film/ 25mm airspace/ inner clear glass			$CW_{C+F+F+C}$
IGU's					
	Insulated-glazing-units (IGU's) consisting of clear or tinted inner and outer glass glazings. On certain samples "low-e" or retrofit films were installed on the glass surfaces indicated. Surfaces are numbered 1,2,3,4 from the exterior to the interior of the IGU.	- 6 mm clear glass/ 12mm airspace/ 6 mm clear glass			DG
		- 6 mm tinted glass/ 12mm airspace/ 6 mm clear glass			DGT
		- 6 mm clear glass/ 12mm airspace/ 6 mm clear glass with pyrolytic "low-e" on surface #3, (ε=0.2).			$DGLE_3$
		- clear glass/ 12mm airspace/ clear glass with retrofit film "A" installed on surface #4.			$DG+FLMA_4$
	Note: retrofit film A and B are different products.	- tinted glass/ 12mm airspace/ clear glass with retrofit film "A" on #4			$DGT+FLMA_4$
		- clear glass/ 12mm airspace/ clear glass with retrofit film "B" installed on surface #3			$DG+FLMB_3$
Blinds and Shades					
	IGU $DGLE_3$ as described above, plus additional venetian blinds (25mm slat width) and shades as designated.	off-white blind set at 45°	0	0.484	$DGLE+VB_{wht}$
		dark blind set at 45°	0	0.353	$DGLE+VB_{drk}$
		white translucent cloth shade	0.160	0.669	$DGLE+RS_{trns}$
	Corresponding transmittance values, τ, and reflectance values, ρ, for the blinds and shades are tabulated in the adjacent column. Values are calculated for the AM 1.5 solar spectrum[5].	white opaque vinyl shade	0	0.682	$DGLE+RS_{wht}$
		dark opaque vinyl shade	0	0.120	$DGLE+RS_{drk}$
		silver cloth shade	0.236	0.457	$DGLE+RS_{svr}$

5. TEST RESULTS

The results of tests conducted on the samples described in Table 3 are presented below for both the normal-incidence and angle dependence tests. A sample test report is given in Appendix B. Full documentation of the results is kept on file at the Solar Calorimetry Laboratory at Queen's University.

5.1 Normal-incidence Results

All of the test samples listed in Table 3 were evaluated in the solar simulator facility at normal irradiance conditions. The results of these test are tabulated as SHGC values in Table 4.

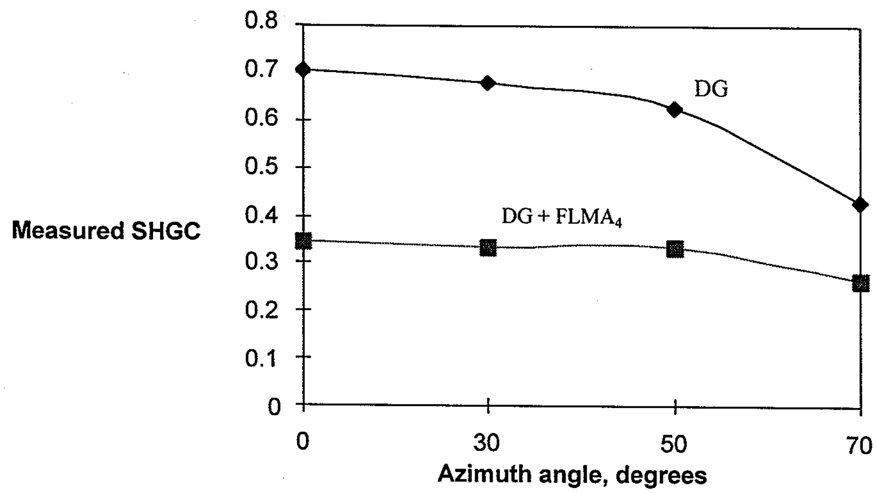
Table 4. Test results obtained at normal incidence.

Test Sample	Designation	Measured SHGC
Fiberglass/Aluminum Translucent Sandwich Panels		
	SP-1	0.34 ± 0.01
	SP-2	0.20 ± 0.01
	SP-3	0.24 ± 0.01
Curtainwall		
	$CW_{T+F+F+C}$	0.32 ± 0.01
	$CW_{C+F+F+C}$	0.48 ± 0.02
IGU's		
	DG	0.70 ± 0.02
	DGT	0.50 ± 0.02
	$DGLE_3$	0.68 ± 0.02
	$DG+FLMA_4$	0.34 ± 0.01
	$DGT+FLMA_4$	0.28 ± 0.01
	$DG+FLMB_3$	0.44 ± 0.01
Blinds and Shades		
	$DGLE+VB_{wht}$	0.54 ± 0.01
	$DGLE+VB_{drk}$	0.59 ± 0.01
	$DGLE+RS_{trns}$	0.31 ± 0.01
	$DGLE+RS_{wht}$	0.28 ± 0.01
	$DGLE+RS_{drk}$	0.52 ± 0.01
	$DGLE+RS_{svr}$	0.46 ± 0.01

5.2 Angle Dependence Results

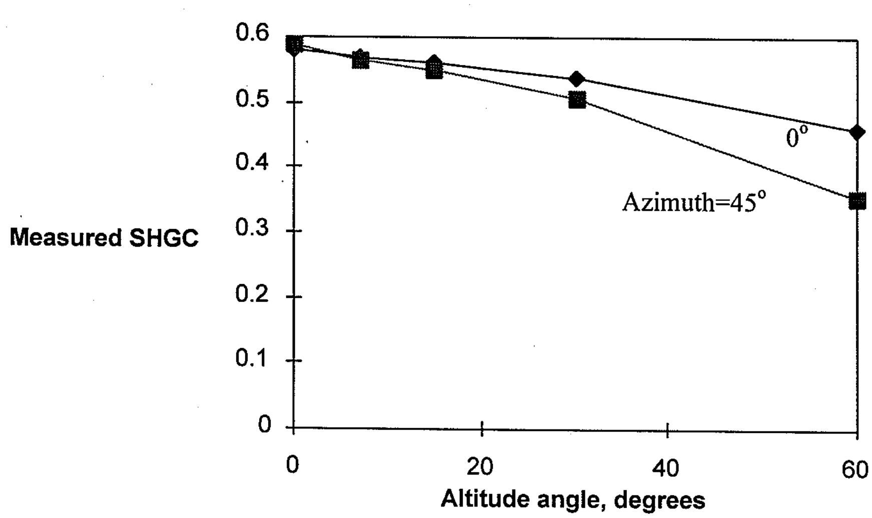
As described in Section 3, in addition to the normal-incidence tests, SHGC data was collected for a limited number of samples at a range of incidence angles. Testing was performed in a similar manner to the normal-incidence tests with the exception of the simulator lamp position. During testing, it was adjusted to achieve specified incidence angles that were representative of desired sun altitude and azimuth conditions. These results are shown in Fig. 8 for the clear DG IGU sample and with, and without, a retrofit film installed on surface #4 (DG + $FLMA_4$).

Figure 8. SHGC versus azimuth angle for double glazed clear glass IGU's with and without a retrofit film.



In addition to the two IGU's described above, a double glazed fenestration with an interior venetian blind was evaluated. Results are plotted as measured SHGC values versus altitude angle, Fig. 9. Two data sets were taken corresponding to azimuth angles of 0 and 45°.

Figure 9. SHGC versus altitude angle for azimuth angles of 0 and 45° for a DG window with venetian blind.



6. ANALYSIS OF RESULTS

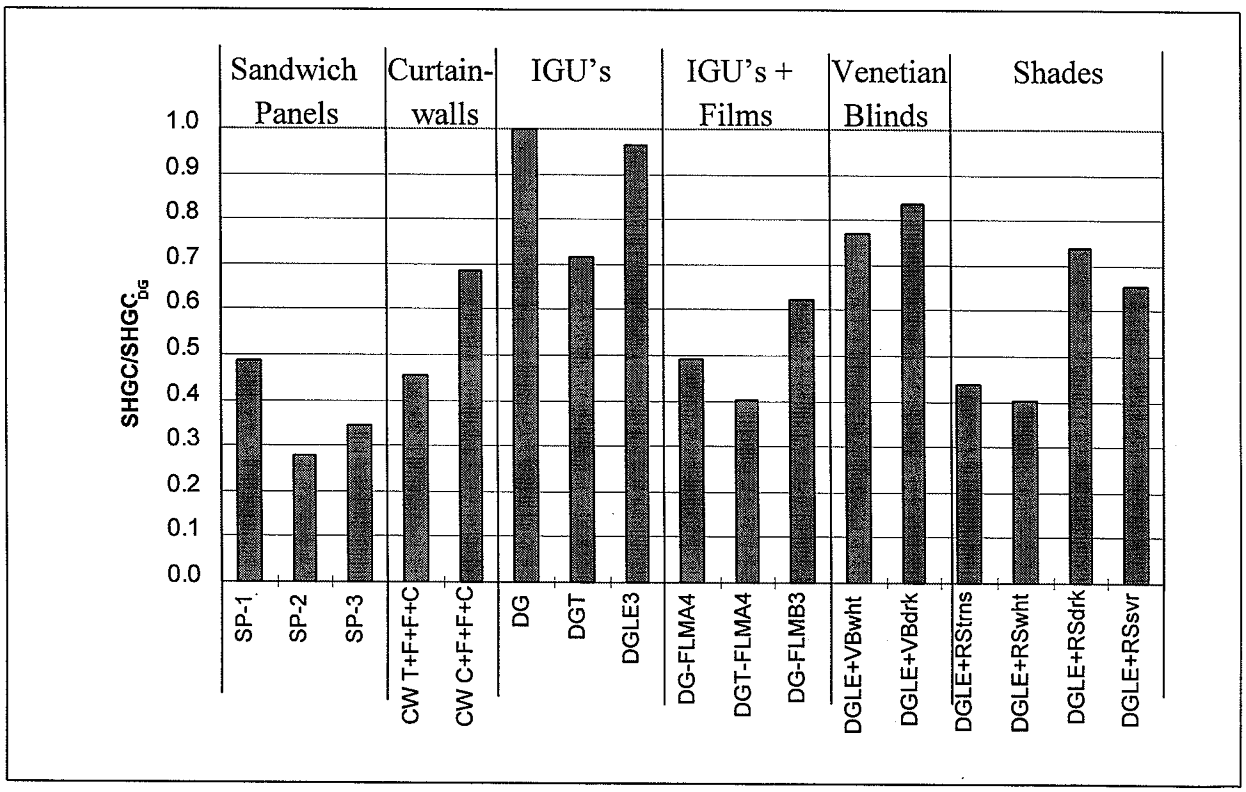
6.1 Normal-incidence Results

Normal-incidence test results are shown in Fig. 10, normalized to the SHGC value for the double glazed (DG) clear IGU, and grouped according to the classes of solar-control glazings.

It is apparent from these results that the SHGC values for the fiberglass sandwich panels (SP-1 to SP-3) were very low, ranging from approximately 0.2 to 0.34. The curtainwall samples also exhibited relatively low SHGC values with the green tinted glass having the lowest value.

The results for the IGUs were higher than the previous cases except when the retrofit films were applied. The value of SHGC obtained with the tinted glass and the retrofit film, was the lowest of the simple IGUs. It would also appear, from the measured results, that the addition of retrofit sun-control films is an effective means of reducing the heat gains of conventional IGUs.

Figure 10. Normal-incidence test results. *



* *Plot of normal-incidence test results. Values shown are measured SHGC values, calculated on "clear-glass" opening and normalized to the SHGC corresponding to the double glazed clear glass sample.*

The addition of shades and blinds to the IGU with low-e coating (DGLE) produced SHGC values that were high for both the light coloured and dark coloured venetian blinds. In the case of the light coloured blind, this is most likely due to the 45° profile angle of the slats (i.e., 45° angle to the horizontal), that resulted in inward scattering of the incident radiation into the "room" calorimeter.

This effect was not evident with the light coloured shades, as they tended to reflect the incident solar radiation back out of the fenestration, resulting in low SHGC values. The higher SHGC value associated with the silver fabric shade was due to its relatively high transmittance value. The SHGC value for the dark opaque shade was very high indicating that a large component of the incident solar irradiance was absorbed and thermally re-radiated into the calorimeter.

It is also worth noting that, even though it had a higher reflectance coating on the slats, the dark venetian blind had a higher SHGC than the dark shade. This is a possible result of inward scattering of the "sunlight" and increased convective heat transfer rates from the blind slats to the calorimeter interior.

6.2 Angle Dependence Tests

When considering the results of the angle dependence tests, it is encouraging to note that the SHGC results versus azimuth angle (effectively the incidence angle for this test set-up) are similar for both the clear DG sample and the DG sample with retrofit film (DG + $FLMA_4$). This supports the use of an angle correction factor, or modifier[9], as a means of accounting for the angle dependence effects. In both cases, the results are consistent with previous predictions, showing that the value of the SHGC drops rapidly beyond incidence angles of 50°.

This conclusion does not hold for the case shown in Fig. 9 for the complex fenestration, (DG + venetian blind). As can be seen from the results, the SHGC is dependent on both the altitude and azimuth angles of the incident solar radiation. This result presents the possibility of applying two or more angle-modifier factors for each of the fenestration's principle axes, as is currently done to characterize the optical characteristics of solar collectors with complex geometries[9]. This is an area for further investigation.

6.3 Comparison with Analytical Methods and Visual Performance

It is worth investigating the potential of existing computer simulation programs to model the performance of these complex glazing assemblies. Using measured optical properties, the curtainwall samples, the insulated-glazing-units, and the blind and shade combinations were simulated with the *VISION4* [2] computer program. The results are shown in Table 5, and plotted in Fig. 11 for measured and simulated SHGC values.

As previously noted, the *VISION4* computer program was not designed to accommodate add-on solar-control devices. However, this comparison does provides an insight into its limits.

Table 5. Comparison of measured and simulated SHGC values, and calculated visible transmittance, for specific test samples.

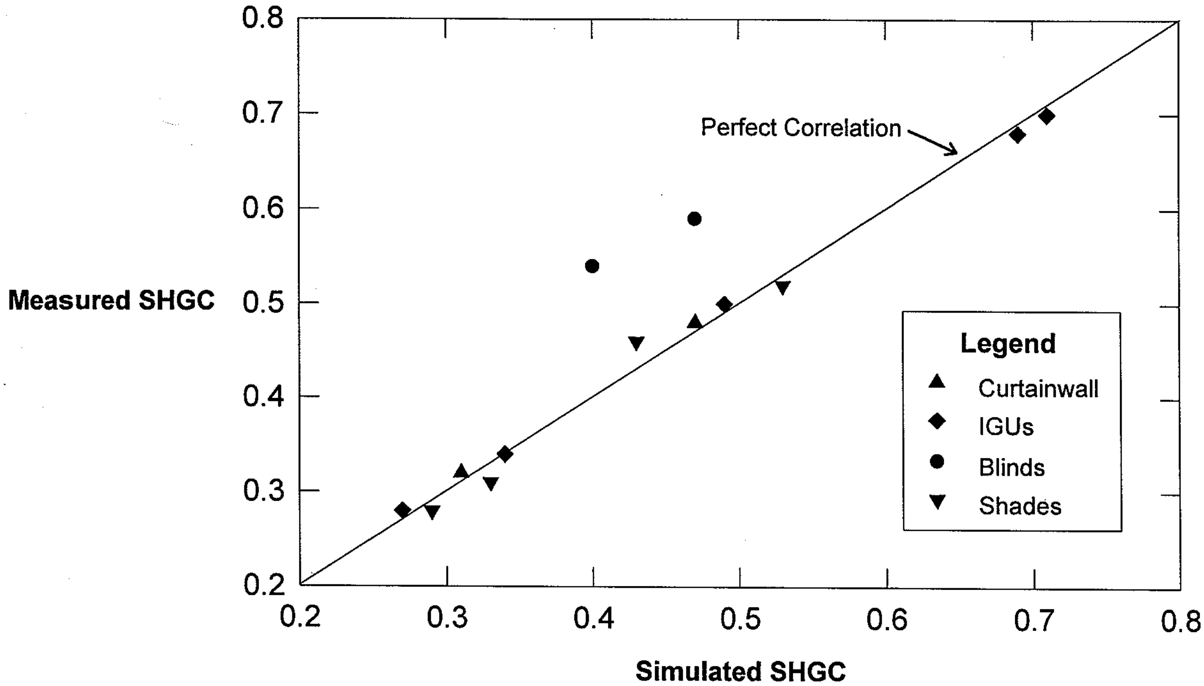
Test Sample	Designation	Calculated, τ_v	Simulated SHGC	Measured SHGC
Curtainwall				
	$CW_{T+F+F+C}$	0.56	0.33	0.32± 0.01
	$CW_{C+F+F+C}$	0.65	0.47	0.48± 0.02
IGU's				
	DG	0.81	0.71	0.70 ± 0.02
	DGT	0.49	0.49	0.50 ± 0.02
	$DGLE_3$	0.76	0.69	0.68 ± 0.02
	$DG+FLMA_4$	0.31	0.34	0.34 ± 0.01
	$DGT+FLMA_4$	0.18	0.27	0.28 ± 0.01
	$DG+FLMB_3$	------	-----	0.44 ± 0.01
Blinds and Shades				
	$DGLE+VB_{wht}$	0	0.40	0.54 ± 0.01
	$DGLE+VB_{drk}$	0	0.47	0.59 ± 0.01
	$DGLE+RS_{trns}$	0.13	0.33	0.31 ± 0.01
	$DGLE+RS_{wht}$	0	0.29	0.28 ± 0.01
	$DGLE+RS_{drk}$	0	0.53	0.52 ± 0.01
	$DGLE+RS_{svr}$	0.19	0.43	0.46 ± 0.01

Note: ----- Data not available.

Simulated SHGC values were evaluated at the test conditions, i.e., indoor "room" and "outdoor" air temperatures were set at 20°C, solar irradiance level set equal to 783 W/m^2, and exterior heat transfer coefficient was set to 20 W/m^2 °C. Tabulated values of SHGC and τ_v were evaluated based on the reference AM 1.5 solar spectrum[5].

The results of this comparison show that, for the curtainwall and the insulated-glazing-units, simulated values correspond closely to measured values. This level of agreement strongly supports the use of computational procedures for this class of glazing system. However, it should be noted that, for the simulations conducted on the glazings with add-on-films, the optical properties were based on spectral measurements made on the combined samples (i.e., the film was applied to the glass sample for spectral analysis). In practice, it is likely that this information will not be available, and only data measured on the individual glass and film layers will be provided. This may impact the accuracy of the simulations.

Figure 11. Comparision of measured and simulated values of SHGC.



In the case of the shades and blinds, it may be observed that the simulation results for the roller shades were close to the measured values. This degree of correspondence is largely due to the configuration used for testing that lends itself to this analysis. Specifically, as the shade layers were sealed at the perimeter and spaced at 12.7 mm, they were modeled as translucent or opaque planar glazing layers. In the case of the light coloured roller shades, the incident solar energy was treated as if it reflected back out of the glazing assembly*, resulting in reduced solar heat gain. In the case of the dark coloured shades, the solar irradiance was treated as if it was absorbed by the shade layer and re-radiated into the calorimeter. As such, the shade was modeled as a opaque glazing with very high solar absorption.

The results of this comparison suggest that this shade configuration, i.e., sealed perimeter, may be modeled by existing programs if care is taken to obtain the spectral optical characteristics of the shade material and the glazing layers. It must be noted, however, that a recent study[11] has shown the measured SHGC, for an unsealed light coloured roller shade, to be 25% greater than the value for the sealed case. In the unsealed case, room air, naturally convecting into the glazing-shade air space, acts to cool the blind and increases the inward-flowing-fraction of the absorbed solar energy. It may also be anticipated that this increase in SHGC, due to an unsealed perimeter, will be more significant as the absorption of the shade is increased, as is the case for dark coloured shades.

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* *Note: In actual fact, the diffusely reflecting shading layer was treated as specularly reflecting, and therefore the model slightly over-predicts the transmission characteristics of the glazing layers to outward reflected solar radiation. As the glazing layers are clear glass these effects should be small.*

A similar situation is evident from the comparison of results for the venetian blinds where the correspondence between measurement and simulation is poor. In this case, natural convection cools the blind slats and increases the transfer of energy, absorbed in the blind, to the calorimeter. With the light coloured blind, this phenomena is augmented by the inward reflection of light from the blind surface. This latter effect would be highly dependent on the blind slat orientation relative to the incoming solar irradiance.

6.3.1 Visible Transmittance

An important aspect of solar-control glazings and add-on shading devices is their visual performance as characterized by the value of the visible transmittance, τ_v. Values are tabulated in Table 1 for specific glazings and are given in Table 5 as calculated with the *VISION4* computer program.

In general, it may be noted that, as visible transmittance is increased, solar heat gains will also increase. This is the case with the IGUs, where the values of τ_v are roughly proportional to the measured SHGC values. This is not a requirement however, as in certain cases, e.g., for the curtainwall samples, visible transmittance is significantly higher than the corresponding values of SHGC. This is a characteristic of glazings and coating with spectrally-selective optical properties.

In the case of interior blinds and shades, it was observed that even for products with very low values of visible transmittance, high values of SHGC may occur. This has a significant impact on heat gain calculations for commercial buildings and shows that care must be taken when using interior shading devices to reduce air-conditioning loads. This is particularly important if the shade or blind is not highly reflective to sunlight.

7. CONCLUSIONS AND RECOMMENDATIONS

The determination of solar-heat-gain-coefficient values for complex fenestration systems is required to evaluate building energy performance, to estimate peak electrical loads, and to ensure occupant comfort. In the past, simplified techniques have been used to calculate the values of SHGC for fenestration systems. As glazing systems incorporating complex geometries become more common, test methods are required to evaluate these products and to aid in the development of new computational tools.

The results of this study have demonstrated the feasibility of the solar simulator based test method[4] for the evaluation of SHGC values for solar-control glazings and shading devices. A variety of glazing and shading systems, including: heat absorbing insulated-glazing-units (IGUs); reflective film and suspended film IGU's; and add-on shading devices (e.g., slat-blinds and shades) were studied.

Samples were evaluated at normal-incidence irradiance conditions and these results are suitable for product rating and comparison, equipment sizing, or peak load analysis. Results produced, while not exhaustive, should contribute to the body of data on SHGC values*.

Testing was also conducted, at a range of incidence angles, on two complex glazing assemblies to demonstrate the capability of the facility to produce angle dependence results.

Significant findings of this study include the confirmation that:

- retrofit add-on films may be an effective means of reducing the SHGC of simple IGUs;
- interior blinds, while reducing daylighting levels, are not always effective at reducing solar heat gains; and
- the direction of incident solar irradiance is particularly important for shading devices such as venetian or slat-type blinds.

7.1 Analytical Methods

Wherever possible, measured SHGC results were also compared to values predicted by the *VISION4* [2] computer program, using spectral optical data. This analytical tool was developed to perform detailed analysis on clear, homogeneous, specularly reflecting glazing systems. For this class of glazing systems, its use would seem highly desirable and the experimental portion of this study would strongly support this finding. The results of this study also indicate that computer simulation is suitable for curtainwall and retrofit films if optical property data is available.

* *The results of this study were also presented in Reference 11.*

In the case of complex fenestration, however, the program's application is restricted due to limitations in its theoretical optical and heat transfer modeling. The development of suitable methods to model the convective and radiative heat transfer properties in unsealed shades and blinds, or their directional-optical dependencies, is an area requiring considerable research effort.

If accurate computational methods can be developed for complex fenestration systems, they would be a fast and inexpensive means for solar heat gain prediction.

7.2 Recommendations

While normal-incidence test results are suitable for product rating, product performance at angles of incidence, that are representative of diurnal or seasonal variations in sun-angle, are also needed to accurately predict the energy consumption for heating or air-conditioning applications. Angular variations in shading performance are particularly important for directional shading devices such as venetian or slat-type blinds. The full characterization of these devices requires an extensive mapping of their performance, at a range of solar altitude and azimuth angles.

The techniques described in this document should be further refined for the testing of angle dependence and, in the near term, experimental data should be taken to characterize these effects on a representative range of shade and blind systems. In the longer term, a concerted research effort should be undertaken to develop the optical and heat transfer models required to simulate the performance of complex fenestration. As models are developed and refined, the experimental method evaluated in this study will be available to provide validation data.

Lastly, a study is required to evaluate solar heat gain predictions that are based on analytical and indoor experimental results. This would be accomplished by comparison with results measured outdoors under variable atmospheric conditons, and would determine the magnitude of real environmental factors on fenestration performance, including: sun angle and intensity; the percent of diffuse irradiance; ground reflectance; and wind and sky temperature effects.

8. REFERENCES

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(2) Wright, J., *VISION4*, Glazing System Thermal Analysis Program, Advanced Glazing System Laboratory, University of Waterloo, Waterloo, ON, Canada, (1994).

(3) Window 4.1, A PC Program for Analyzing Window Thermal Performance, Windows and Daylighting Group, Lawrence Berkeley Laboratory, University of California, (1988).

(4) CANMET, The Determination of Fenestration Solar Heat Gain Coefficient Using Simulated Solar Irradiance, Report prepared for Natural Resources, Canada. The Solar Calorimetry Laboratory, Queen's University, Kingston, ON, Canada (1993).

(5) CSA Preliminary Standard A440.2-93/A440.3-93, Energy Performance Evaluation of Windows and Sliding Doors, Canadian Standards Association, Toronto (1993).

(6) Harrison, S.J. and van Wonderen, S.J., Determining window Solar Heat Gain Coefficient, ASHRAE Journal, V.36, no. 8, pp. 26-32, (1994).

(7) van Wonderen, S.J., Experimental Determination of Fenestration Solar Heat Gain Coefficient, M. Sc. Thesis, Queen's University at Kingston, (1995).

(8) Camm D.M. et al. , A Large Area Solar Simulator Construction and Performance ,ISES World Solar Forum, (1981).

(9) ASHRAE STANDARD 93-86, Methods of Testing to Determine the Thermal Performance of Solar Collectors, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, (1986).

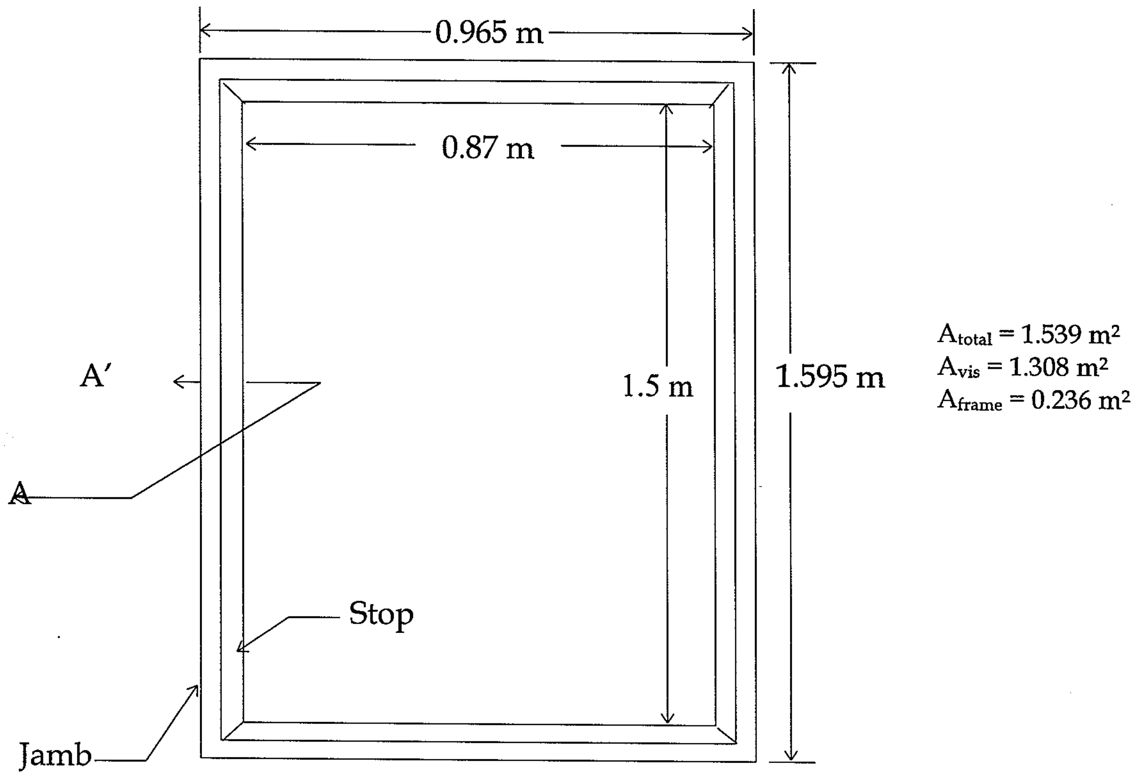
(10) Harrison, S.J. and van Wonderen, S.J., Evaluating Heat Gain for Solar-Control Glazings and Shading Devices, Proceedings of the Window Innovations'95 Conference, Toronto, (1995).

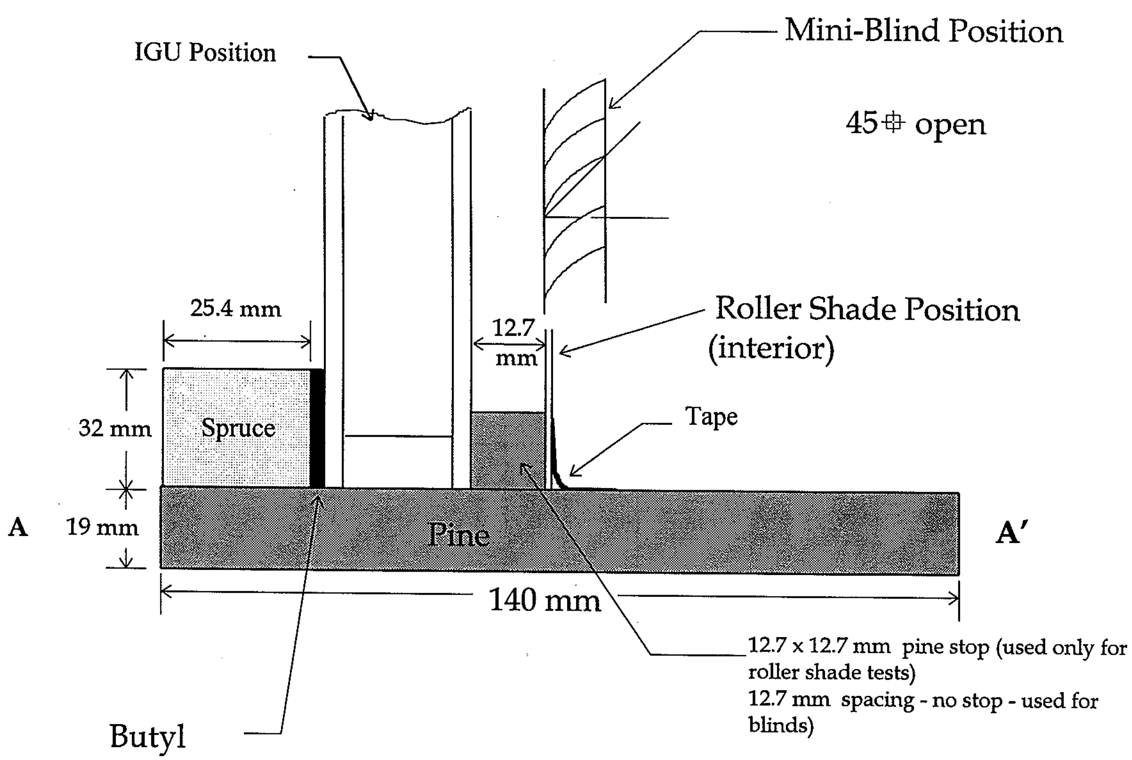
(11) Evaluation of Solar Heat Gain Test Methods, Report prepared for ASHRAE TC 4.5, Fenestration, Research Project 713, S.J. Harrison (Editor), American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, in press (1996).

Appendix A: Mounting Details for Fenestration Units and Shading Devices

Frame Detail # 1

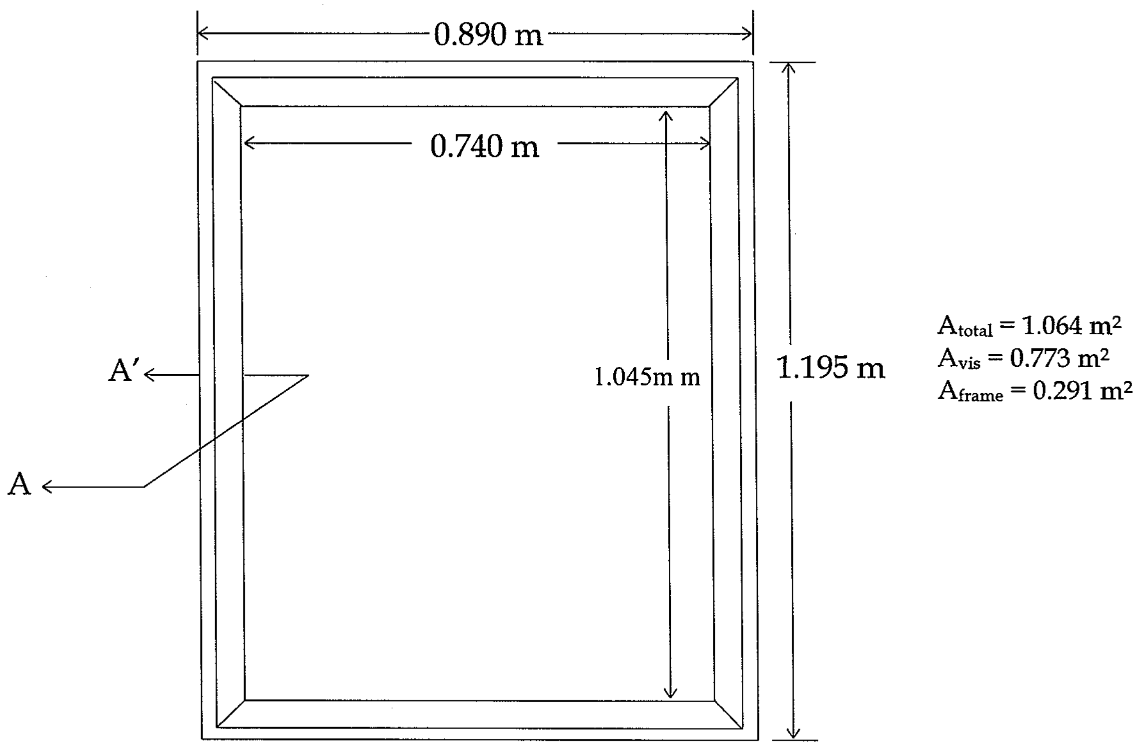
Frame Detail for Normal Incidence Testing

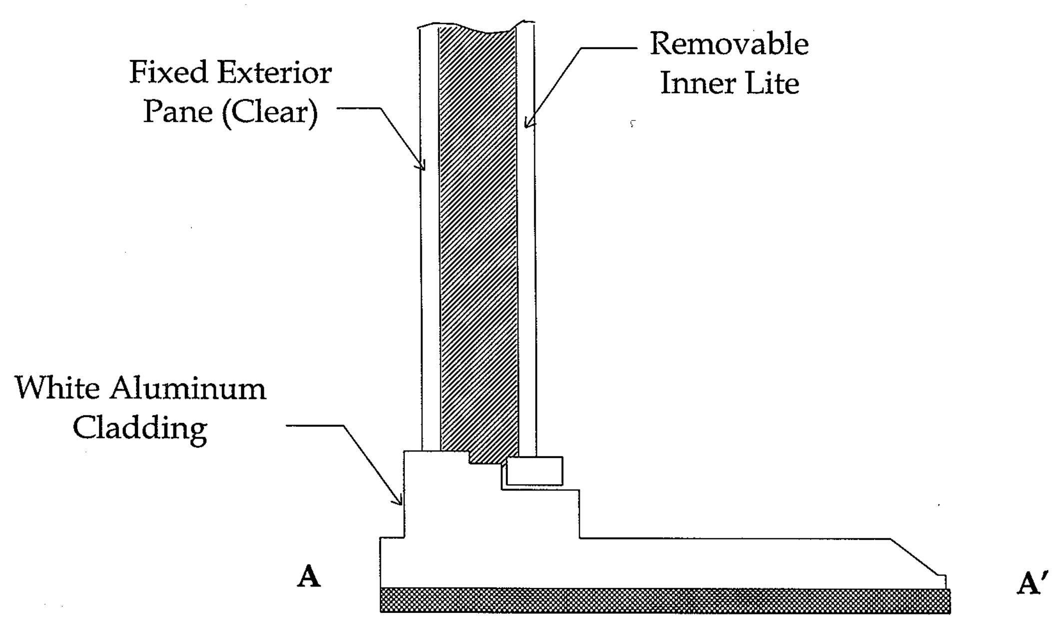




Frame Detail # 2

Frame Detail for Angle Dependence Testing





Appendix B: Sample Test Report

ORTECH Corporation

Solar Heat Gain Coefficient - Test Summary

ORTECH Sample No. 94-E32-A0512-3

Filename: A0512-3
Test Date: 94/3/28

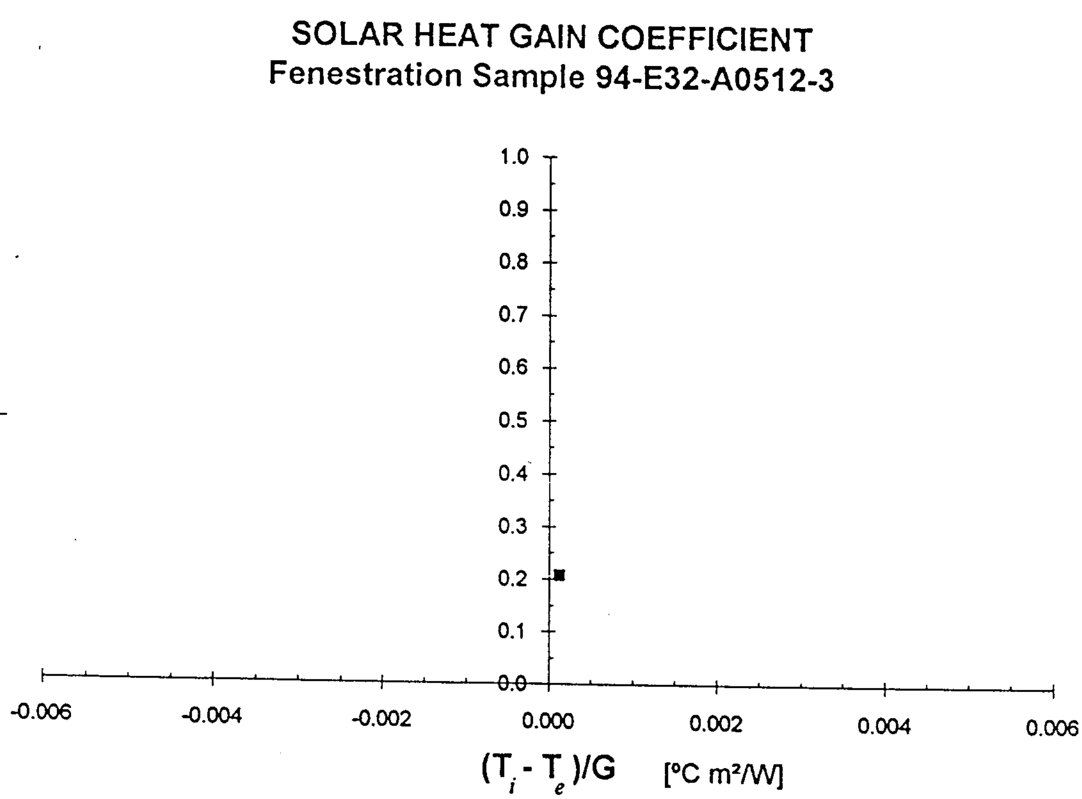
Client Identification: #3. 0.14U, 0.070" crystal exterior, 0.045" crystal interior, thermally broken I-beam aluminum grid.

Sample Description: . . . . . translucent sandwich panel #3.

Environmental Conditions: High wind, near-normal azimuth and altitude.

Fenestration Area (m²) = 1.539

Q abs (W)	*P inputs* (W)	*Q wall* (W)	*Q net* (W)	*T icaa* (°C)	*T ecaa* (°C)	*G corr* (W/m²)	*(Ti-Te)/G* (°C m²/W)	*SHGC*
291	37.8	-5.0	249	21.7	21.6	781	0.0001	0.207
290	37.7	-5.0	247	21.7	21.6	784	0.0001	0.205
292	37.7	-4.9	249	21.7	21.6	785	0.0001	0.206
292	37.5	-5.0	250	21.7	21.6	784	0.0001	0.207
292	37.5	-5.0	249	21.7	21.6	784	0.0001	0.207
292	37.5	-5.0	249	21.7	21.6	783	0.0001	0.207
							Average SHGC =	**0.206**
							Std. Deviation = ±	**0.001**



$$n = \frac{Q_{net}}{A_f * G}$$

Report Date: 94/4/4

National Solar Test Facility