ESTABLISHMENT OF A SOLAR HEAT GAIN COEFFICIENT TEST METHOD

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EXECUTIVE SUMMARY

A test procedure has been established for the determination of fenestration solar heat gain coefficient (SHGC) using simulated solar irradiance. In this procedure, a calorimeter cell is used to measure the thermal performance of a full scale window sample under the controlled environmental conditions of an indoor simulator facility. The SHGC of the test sample is determined from the ratio of the measurement of solar heat gain entering the metering cell over the available energy provided by the solar simulator.

A sensitivity analysis is presented to assess the effect of environmental conditions encountered during testing at the National Solar Test Facility and comparison is made to performance simulations under CSA daytime winter design conditions. SHGC measurement using this method are presented for nine high-performance windows. A comparison of these test results with values calculated using the *VISION3* and *FRAME* simulation programs shows good agreement.

The project was commissioned by the CANMET Division of Energy, Mines and Resources Canada, to support the development of testing capabilities for the national window rating and labelling Program. The test procedure draws collectively upon past research undertaken by the Solar Calorimetry Laboratory toward the development of a universal solar simulator based test method and references the extensive work conducted in support of ANSI/ASHRAE Standard 93-1986.

SOMMAIRE

On a établi une méthode d'essai pour la détermination du coefficient de gain thermique solaire (CGTS) d'un fenestrage par simulation de l'éclairement énergétique solaire. Dans cette méthode une cellule calorimétrique est utilisée pour mesurer le rendement thermique d'un échantillon de fenêtre grandeur réelle dans les conditions environnmentales contrôlées d'une installation de simulation intérieure. Le CGTS de l'échantillon à l'essai est déterminé à partir du rapport du gain thermique solaire mesuré entrant dans la cellule de mesure à l'énergie disponible fournie par le simulateur solaire.

On présenteune analyse de sensibilité destinée à évaluer les effets des conditions environnementales qui régnaient pendant l'essai effectué au Centre national d'essais d'équipements solaires, et on fait une comparaison avec des simulations de rendement dans les conditions diurnes hivernales de calcul de l'ACNOR. Des résultats de mesures du CGTS effectuées avec cette méthode sont présentés pour neuf fenêtres à haut rendement. Une comparaison de ces résultats d'essai avec des valeurs calculées à l'aide des programmes de simulation *VISION3* et *FRAME* montre une bonne compatibilité.

Le projet a été mis en service par la Division de l'énergie de CANMET, d'Énergie, Mines et Ressources Canada, en vue de soutenir la mise au point d'outils d'essai pour le programme national d'évaluation et d'étiquetage des fenêtres. La méthode d'essai est fondée sur l'ensemble des travaux antérieurs de recherche réalisés par la Laboratoire de calorimétrie solaire en vue de mettre au point une méthode d'essai universelle basée sur l'utilisation d'un simulateur soliare, et elle fait référence aux vastes travaux effectués à titre de soutien de la morne 93-1986 de l'ANSI/ASHRAE.

Establishment of a SHGC Test Method

1 INTRODUCTION

The solar heat gain characteristics of fenestration systems impact daytime building energy performance, occupant comfort, and utility load demands. A measure of the fraction of available solar energy entering a building interior per unit window area is defined as the solar heat gain coefficient (SHGC). Together with a window's thermal transmittance (U-value), the SHGC is used in the ranking of comparative fenestration products and allows for the calculation of Energy Rating (ER) numbers and annual energy performance.

The need to measure and compare advances in window technology has led to the development of experimental and analytical methods for the determination of fenestration SHGC. Several test facilities currently or previously capable of performing fenestration SHGC measurements exist worldwide. Experimentally determined results using these facilities have provided design data for handbook tables, and have been instrumental in the development and validation of predictive analytical methods and computer simulation tools. These facilities have, however, operated in the absence of an industry standard test procedure for SHGC performance.

Consequently, efforts have been focussed on the development of consensus test procedures for the evaluation of window energy performance. Standards and rating organizations in Canada [1] and the United States [2,3] are developing standard test methods and computational procedures to rate fenestration products on comparative energy performance. These efforts are being undertaken to support the national window rating and labelling programs currently being legislated.

This report describes activities performed by the Solar Calorimetry Laboratory (SCL) toward the development of a SHGC test method using simulated solar irradiance.

2 SHGC TEST PROCEDURE

BACKGROUND

Anticipating the requirement for universal testing and rating methods, Energy, Mines and Resources Canada, through the Buildings Group of CANMET, supported the development of a unique test capability based on the use of a solar simulator test facility. Contracting with the Solar Calorimetry Laboratory of Queen's University, a prototype test facility was designed and installed at the Canadian National Solar Test Facility (NSTF) between April 1988 and March 1989. The SCL developed a test procedure for use with this facility that yielded both SHGC and "daytime" U-values for residential fenestration systems [4]. CANMET has continued to support improvements to the facility including an upgrade to the environmental simulator air handling system and the development of a commercial-grade calorimeter cell to replace the original prototype apparatus [5]. During the summer of 1992, the complete facility was calibrated and commissioned for fenestration testing. Concurrent with this activity, efforts were also directed toward the refinement of a SHGC test procedure for rating purposes.

A validation test program was subsequently conducted in conjunction the Canadian Standards Association (CSA) A440.2 Subcommittee. The intention was to provide a comparison between SHGC results using measurement and simulation methods consistent with the new Canadian energy performance standard for windows [6]. During 1992, measurements were performed at the NSTF according a draft SHGC test procedure. In total, nine commercially available windows were tested and results compared to simulated values.

In November 1992 a final draft SHGC test method was produced as a result of this testing program [7]. The document details a method to evaluate solar heat gain coefficient (SHGC) and represents Part I of the full test method. Part II, which addresses the determination of "daytime" U-value, is still under review and awaits validation with the new test facility.

The existing test method draws collectively upon past SCL research on the development of a solar simulator based test method and references the extensive work conducted in support of ANSI/ASHRAE 93-1986, *Methods of Testing to Determine the Thermal Performance of Solar Collectors* [8].

THEORY

To determine the performance of a window system, the SCL test method measures the net energy transmission through the window based on the use of a specially designed calorimeter cell. The calorimeter cell is a five sided chamber capable of accurately metering heat entering or leaving the cell enclosure. Test specimens are mounted in a mask wall that is affixed to the open side of the cell.

Performance of the fenestration system is determined by considering an energy balance taken over the control volume of the calorimeter cell and test specimen, Figure 1. The net flow through the fenestration system, Q_{net}, is the sum of the heat gain due to the solar input and the conductive heat transfer arising from a difference in temperature between the ambient interior and exterior air.

$$Q_{net} = Q_{solar} - \dot{Q}_{cond} \quad (1)$$

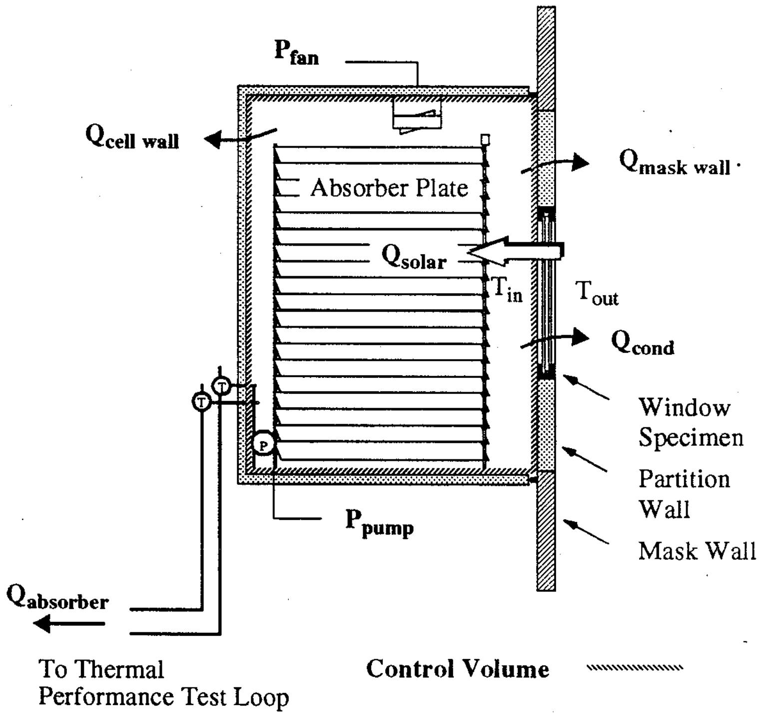


Figure 1. Calorimeter Cell Energy Control Volume

where Q_{solar} represents the fraction of incident solar energy transmitted through the fenestration system including both the directly transmitted and the inward flowing fraction of heat and is given by

$$Q_{solar} = F \cdot G \cdot A_f \tag{2}$$

Q_{cond} is a function of the fenestration thermal transmittance and the temperature difference across the window

$$Q_{cond} = U_f \cdot \Delta T_f \cdot A_f \tag{3}$$

A thermal performance factor of the fenestration system, η, is defined as

$$\eta = \frac{Q_{net}}{A_f \cdot G} \tag{4}$$

Substituting the above equations, the thermal performance factor η can be computed in terms of F and U_f as follows

$$\eta = F - \frac{U_f \cdot \Delta T_f}{G} \tag{5}$$

Performance Analysis

Previous studies on the SCL test method [4] have concentrated on a performance analysis procedure for the simultaneous determination of fenestration SHGC and U-value. Performance efficiency points, η_i, are determined over a range of climatic conditions in which the solar irradiance is varied from G = 200 to 1000 W/m^2 and the temperature difference across the fenestration is fixed at ΔT_f = 40°C. A linear regression of the performance data is used to define the SHGC as the intercept of the regression line with the ΔT_f/G = 0 axis, and the U-value as the slope of the regression line.

A variation of the general SCL test method has been developed for the separate evaluation of the SHGC of fenestration systems. This method differs in that performance data is taken at or near conditions where ΔT_f/G = 0, and η is defined as *F*, the solar heat gain coefficient

$$\eta_{(\Delta T/G = 0)} = F \tag{6}$$

This approach significantly reduces the range of test conditions and time requirements necessary when fenestration SHGC performance is to be determined exclusively.

CANMET WINDOW TEST FACILITY

A first generation calorimeter cell was commissioned in 1989 for use in the development of the SCL window performance test method. This design was based on a single cell chamber that included highly insulated walls and an electric ceiling guard heater. An estimate of the test cell's conductive loss was computed based on average steady state wall surface temperatures and the wall heat loss coefficient determined by calibration. Primarily designed for research development and proof of concept, the application of this original cell as a research grade apparatus was successful. However, limitations in dynamic response time and the uncertainty associated with the wall heat loss required stringent calibration procedures, making this original cell unsuitable for commercial testing purposes.

Based on the success of this research facility, CANMET funded the development of a commercial test facility to support the national window rating program. The initiative included the development of an improved window calorimeter, upgrades to the environmental air handling system, and modifications to the thermal performance loop and data acquisition system.

A second generation calorimeter cell design was subsequently specified for fabrication. The distinguishing feature of the new design was an air guard system to minimize the uncertainty associated with the metering cell wall heat losses. This derived from the accuracy requirements for measuring high performance fenestrations. Components were designed and constructed at Queen's University and assembled on site at the NSTF. The commissioning and calibration of the calorimeter was performed by the SCL in conjunction with NSTF personnel.

Window Calorimeter

The CANMET Window Calorimeter is shown in Figure 2. The calorimeter consists of an inner metering cell, outer cell and mask wall, together with instrumentation and temperature control equipment.

The outer cell of the calorimeter is a commercially available insulated five sided chamber. A stand-alone mask wall mates with the open side of the outer cell and completes the enclosure. During testing the mask wall is secured to the outer cell by a latching system, sealing the perimeter frameworks. Window test specimens are mounted in the aperture of the mask wall with a series of insulating blocks of known thermal conductance. This system accommodates windows of varying frame sizes up to 1.7 m by 1.7 m, and allows for consistent determination of the mask wall heat losses.

The function of the outer cell is to provide a stable temperature environment for the metering cell. This is achieved through the use of an air guard system which surrounds the metering cell with controlled temperature air. In this manner, adiabatic conditions are maintained across the cell walls. This has the dual effect of minimizing the uncertainty associated with thermally driven wall heat loss and capacitance effects, while reducing the settling time of the apparatus. A temperature controller, driven by a differential signal from a thirty three junction thermopile embedded throughout the metering cell surface laminates, maintains near adiabatic conditions. The controller operates an electric resistance heater installed in line with the blower and cooling coils of the outer cell air circulation system. A minimum wall construction of two inch isocyanurate foam core with fiberglass laminates was specified for the metering cell. Absolute wall temperature sensors are embedded throughout the wall area, in addition to the differential thermopile system used for temperature control.

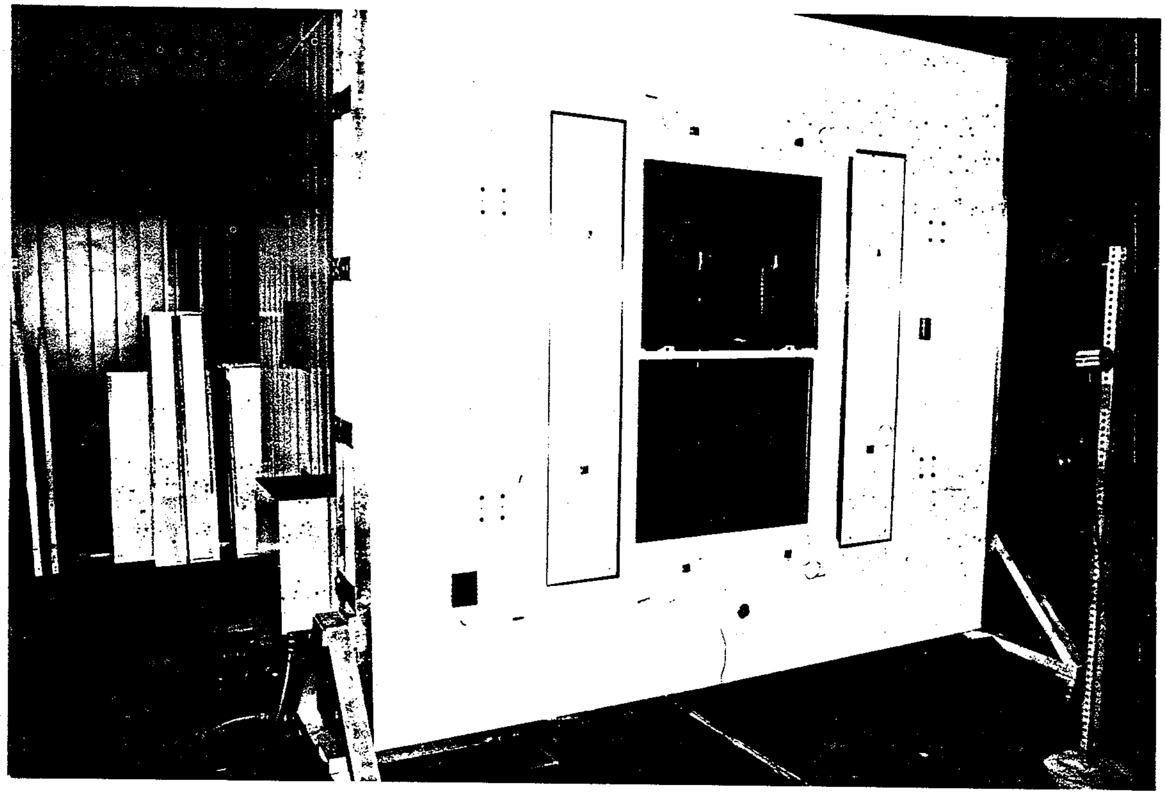


Figure 2. Calorimeter Cell

An absorber plate is used to add or remove heat from the metering cell. The plate heat exchanger is constructed of aluminum finned tubes mounted horizontally in a louvered design. A spectrally selective coating covers the front surface of the fins and acts to absorb a maximum amount of solar radiation while minimizing longwave thermal exchange with the window's inner surface. Natural convective air flow through and behind the finned panel is supplemented by a small fan mounted on the ceiling of the cell. A low power recirculating pump ($\approx$ 20 Watts) is located between the temperature sensors of the fluid loop, increasing temperature uniformity across the surface of the absorber plate.

To evaluate the temperature distribution of the ambient air within the metering cell, nine shielded thermocouples are evenly distributed in a plane parallel and adjacent to the window test specimen. Weather side ambient air temperature is measured by shielded thermocouples mounted adjacent to the exterior of the test specimen. Sixteen surface mounted thermocouples on both the weather and room side are used to determine the temperature difference across the mask wall.

Environmental Chamber and Solar Simulator

SHGC testing is performed with the calorimeter cell placed in the environmental chamber of the NSTF, Figure 3. The facility's environmental control system supplies the chamber with humidity-controlled air, at a uniform velocity (adjustable from 0 to 3.0 m/s) in a direction parallel to the floor and perpendicular to the window. The window test specimens are irradiated at a fixed incident angle using a unique, single-source arc lamp, capable of providing irradiance levels ranging from 150 to 1100 W/m^2. This large area solar simulator lamp, manufactured by Vortek® Industries [9], is based on a liquid cooled, vortex stabilized argon arc lamp. The lamp is combined with an optical reflector system and provides uniform irradiance over the test area with a spectral irradiance distribution that approximates the ASTM AM1.5 solar spectrum [10].

Thermal Performance Test Loop

An energy metering test driver is used in conjunction with the calorimeter cell to measure the heat added or extracted through the absorber plate, while maintaining a constant temperature within the cell. The test driver consists of an insulated reference heater, heat exchanger, flow control and immersion heaters. Fluid flow rate is determined by a calorimetric measurement of the temperature rise of the heat transfer fluid as it passes through the insulated reference heater. Temperature measurements made directly across the absorber plate are used to determine the power added to or extracted from to the cell via the absorber plate. Temperature control within the cell is achieved by maintaining the absorber inlet at a constant temperature level.

Originally designed for the testing of solar collectors, the test driver has been upgraded to suit the needs of the window test facility. Modifications include the installation of a new data acquisition system and improvements to the control and user interface routines of the host software.

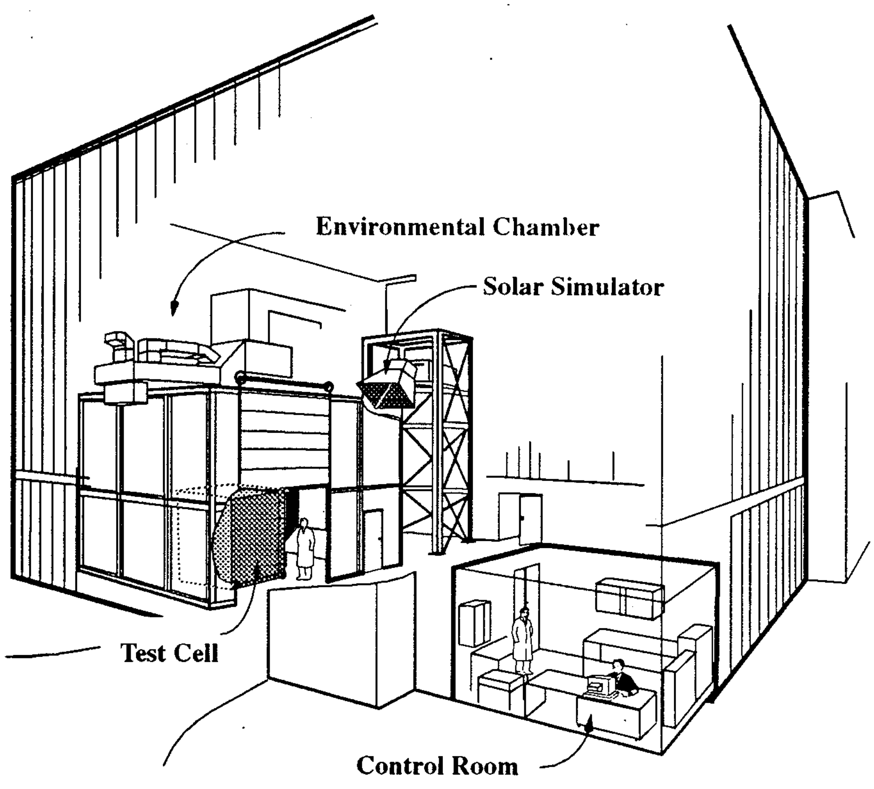


Figure 3. Window Testing at the National Solar Test Facility

SHGC MEASUREMENTS

The thermal performance, η, of the test specimen is directly measured based on an energy balance of the metering cell, Figure 1. The net energy flow through the test specimen is the sum of the energy extracted by the absorber plate, the heat losses through the cell and mask walls, and the electrical power inputs

$$Q_{net} = Q_{abs} + Q_{cw} + Q_{mw} - P_{inputs} \tag{7}$$

where Q_{abs}, the energy extracted by the absorber plate, is the product of the mass flow rate of the circulating fluid as measured by the thermal performance loop and ΔT_{abs}, the temperature rise across the absorber plate

$$Q_{abs} = (\dot{m}C_p) \cdot \Delta T_{abs} \tag{8}$$

Q_{cw}, the heat loss through the inner cell walls, is adjusted by the air-guard control system to be close to or equal to zero. Q_{mw}, the heat loss through the mask wall, is derived from the temperature gradient across the wall, ΔT_{mw}, and the area-weighted thermal conductance of the mask wall, CA_{mw}, which is determined by calibration.

$$Q_{mw} = CA_{mw} \cdot \Delta T_{mw} \tag{9}$$

P_{inputs}, the total electrical power input to the inner cell, includes the power inputs to absorber plate recirculation pump, air circulation fan, and auxiliary immersion heater

$$P_{inputs} = P_{pump} + P_{fan} + P_{heater} \tag{10}$$

The performance factor of the specimen is defined by combining equations (4) and (6)

$$\eta = \frac{Q_{abs} + Q_{mw} - P_{inputs}}{A_f \cdot G} \tag{11}$$

Calibration

A calibration procedure was performed to determine the mask wall thermal conductance coefficient, used in equation 9. The procedure included replacing the mask wall window aperture by a calibration plug of similar construction to that of the existing mask wall. Calibration conditions were set to match test conditions and a steady-state temperature gradient was imposed across the mask wall. A measured amount of heat was extracted from the cell interior via the absorber plate and thermal performance test loop. The heat loss through the mask wall, Q_{mw}, was equated to the net energy input to the cell, and the mask wall conductance coefficient was computed as

$$CA_{mw} = \frac{Q_{net}}{\Delta T_{mw}} \tag{12}$$

where ΔT_{mw} represents the difference in average temperature of the inner and outer surfaces of the mask wall.

The temperature sensors and flowmeter of the thermal performance test loop were calibrated independently. The calculated power added to or extracted from the cell via the absorber plate as the product of these measurements, equation 8, was checked against a reference heat source apparatus.

Analysis of Measurement Uncertainty

When the data sample size is small, it is appropriate to estimate the standard deviation for each data result from the estimated measurement uncertainty of the data point. The measurement uncertainty, δF, is calculated according to the standard propagation of errors technique, described by [11],

$$(\delta F)^2 = \left(\frac{\partial F}{\partial x_1}\delta x_1\right)^2 + \left(\frac{\partial F}{\partial x_2}\delta x_2\right)^2 + \ldots + \left(\frac{\partial F}{\partial x_n}\delta x_n\right)^2 \qquad (13)$$

where x_1, x_2, ..., x_n are the measurement variables taken to define F, and δx_1, δx_2, ..., δx_n are the uncertainties associated with each measurement variable.

An error analysis was performed, according to the above method, to evaluate the magnitude of the random measurement uncertainty of the test procedure. Results show that the SHGC uncertainty is approximately ±4.9%. Further treatment of the uncertainties in the evaluation of window SHGC using this method are provided in reference 12.

EFFECTS OF TEST CONDITIONS

Test conditions for the SCL SHGC method differ from those prescribed for performance simulation under CSA daytime winter design conditions. Parameter values specified for simulation purposes and nominal values encountered during testing are listed below in Table 1.

Table 1: Environmental Conditions for Simulation and Testing

Parameter	Simulation	Testing
Interior air temperature (°C)	21	21
Exterior air temperature (°C)	-18	21
Exterior film coefficient (W/m^2 °C)	30	20
Interior convective and radiative surface coefficient (W/m^2 °C)	$f(T_g, \varepsilon_g, T_i)$	$f(T_g, \varepsilon_g, T_i, T_{cw}, \varepsilon_{cw})$
Solar irradiance (W/m^2)	783	783
Solar spectral distribution	ASTM AM1.5	Vortek Simulator

A sensitivity analysis was performed to assess the effects of these differing conditions on SHGC results. Glazing SHGC results were derived from simulations performed using the *VISION3* computer program [13]. The test parameters considered were *i*) exterior air temperature and film coefficient, and *ii*) solar spectral distribution. To investigate the effect of the latter required replacing the default *VISION3* Glass Library, that includes average optical property data calculated using the ASTM AM1.5 solar spectrum [10], with glazing data weighted using the Vortek solar spectrum. The effects of variations in the interior radiative and convective heat transfer coefficients were excluded from the simulations as this analysis involves complex modelling of the calorimeter cell interior, and is the subject of a separate investigation.

Simulation results are presented in Table 2 for four representative double glazed systems (DG, clear / clear; DGT, tinted / clear; DGHE, clear / hard coat low-e on surface #3; DGSE clear / soft coat low-e on surface #3)[1]. Note that the *Base Case* represents values simulated under standard CSA daytime winter conditions (i.e. T_o = -18 °C, h_o = 30 W/m^2 °C, and AM1.5 spectrum weighted glazing data). Simulations of the NSTF test conditions were conducted with the following conditions:

Test Case 1.	T_o = 21 °C, h_o = 20 W/m^2 °C
Test Case 2.	Glazing data weighted using the Vortek spectrum
Test Case 3.	*Case 1* and *2* parameters combined

Glazing SHGC results in Table 2 indicate that the temperature and exterior film coefficient conditions encountered during testing have little effect on glazing *SHGC* (maximum of 3.3% increase for the DGT

1. Note that surface #3 denotes the outward facing surface of the interior glazing layer.

system). The results for simulations performed using Vortek spectrum weighted glazing data suggest only a slight increase for the clear and tinted systems (less than 2% for DG and DGT), but a significant increase for the low-E coated glazings (5% for the DGHE and 19% for the DGSE). The DGSE system has a high-performance low-E coating considered to be an extreme case for spectrally selective glazings.

Table 2: $SHGC_g$ for Simulated Test Conditions

Glazing System	Glazing Solar Heat Gain Coeffiicient			
	Base Case CSA Daytime Winter	*Test Case 1* T_o=21°C, h_o=20 W/m^2 °C	*Test Case 2* Vortek Spectrum	*Test Case 3* *Case 1 & 2* parameters combined
DG	0.763	0.765	0.776	0.777
DGT	0.486	0.502	0.495	0.510
DGHE	0.704	0.715	0.738	0.743
DGSE	0.496	0.505	0.591	0.599

The variation in SHGC for conventional glazings is only slight because they exhibit optical responses which are considered "flat", i.e. essentially constant across the solar spectrum. There is a spectrum effect, however, when testing with spectrally selective glazings whose optical properties vary significantly with wavelength. If a transition in the glazing's optical response occurs in a region of the solar simulator's spectrum that is dissimilar from the ASTM spectrum, the variation in SHGC may be significant.

If this is the case, care must be taken in the testing of glazings which exhibit strong spectrally selective characteristics. The possibility of implementing a corrective filter to the simulator spectrum at the NSTF to better match the ASTM spectrum is being investigated. In the interim, recommendations have been included in the SHGC test method for a procedure to adjust measurement values to the ASTM AM1.5 spectrum.

For window systems whose glazing optical properties differ by greater than ± 2% from the values calculated using the ASTM standard spectrum, results are to be adjusted in the following manner,

$$F_{Meas\,(AM1.5)} = \frac{F_{Sim\,(AM1.5)}}{F_{Sim\,(Vortek)}} \cdot F_{Meas\,(Vortek)} \tag{14}$$

$F_{Meas\,(Vortek)}$ represents the raw measured value. $F_{Sim\,(AM1.5)}$ and $F_{Sim\,(Vortek)}$ are simulated values calculated using *VISION3* under CSA daytime winter design conditions and the respective spectrum weighting, and $F_{Meas\,(AM1.5)}$ the measured value adjusted for the ASTM spectrum.

3 CSA SHGC COMPARISON STUDY

To validate the new test procedure and facility, a research project was undertaken to measure the solar heat gain coefficient (SHGC) of nine windows. The project was conducted in conjunction with the CSA Subcommittee A440.2 to provide a comparison of SHGC results using measurement and simulation methods consistent with the new Canadian energy performance standard for windows.

WINDOW SAMPLES

In total, nine window samples were selected to represent a broad range of insulating glazing systems that included clear and heat absorbing glass, reflective and spectrally selective coatings. All samples were specified to be double-glazed air-filled sash units fitting a common casement frame in order to minimize design parameters not intended to be part of this study.

Details of the nine glazing systems are listed in Table 3. Frame and sash cross sections are shown in Figure 4.

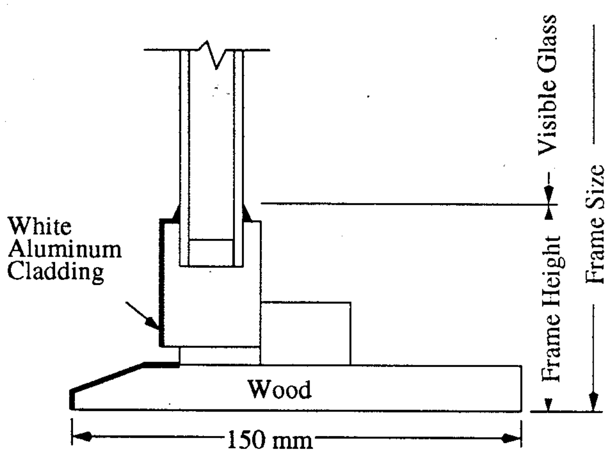
Table 3: Description of Test Glazing Systems

Sash No.	Glazing System
S1	Clear / Clear
S2	Clear / Pyrolytic low-E, ε=0.2, #3
S3	Clear / LoE-178, ε=.08, #3
S4	Clear / LoE Sun-145, ε=0.1, #3
S5	LoE Sun-145, ε=0.1, #2 / Clear
S6	Evergreen Tinted / Clear
S7	Reflective Metal SS-114 #2 / Clear
S8	Clear / Low-E^2-171, ε=.04, #3
S9	Evergreen Tinted / Pyrolytic low-E, ε=0.2, #3

Note: Glazing thickness = 3 mm (nominal)
Surface #3 denotes the outward facing surface of the interior glazing layer.

SHGC MEASUREMENTS

SHGC measurements were performed at the CANMET Window Test Facility using the Queen's University SHGC Test Method [7], described above. Results for the nine windows tested are presented in Table 4. The average measurement uncertainty is ± 4.9% (± .018) for the nine windows tested.



Frame Size 1200 x 600 mm
Visible Glass 1045 x 445 mm
Frame Height 77.5 mm

Figure 4. Test Frame and Sash Cross Section

As mentioned earlier, for the case of spectrally selective glazings, measured SHGC values depend on the spectral distribution of the solar source. For comparison purposes, measured values were adjusted for all nine glazing systems according to equation 14.

SHGC CALCULATIONS

The window systems were simulated using the *VISION3* [13] and *FRAME* [14] computer programs. Glazing SHGC, F_g, were determined under CSA daytime winter design conditions using *VISION3*. Glazing optical and thermal properties data were taken directly from the *VISION3* Glass Library, and represent average optical property data calculated using the ASTM AM1.5 direct normal solar spectrum [10]. The SHGC of the frame and sash, F_{fr}, was determined according to the formula [6],

$$F_{fr} = 0.0051 \cdot U_{fr} \tag{15}$$

where U_{fr} represents the area-weighted U-value of the frame and sash simulated under CSA nighttime winter conditions using *FRAME*.

Total window SHGC, F_{total}, was calculated as

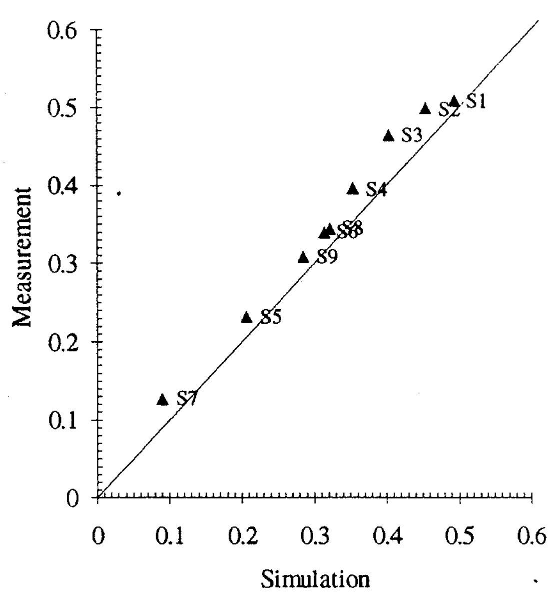
$$F_{total} = \frac{F_g \cdot A_g + F_{fr} \cdot A_{fr}}{A_{total}} \tag{16}$$

RESULTS

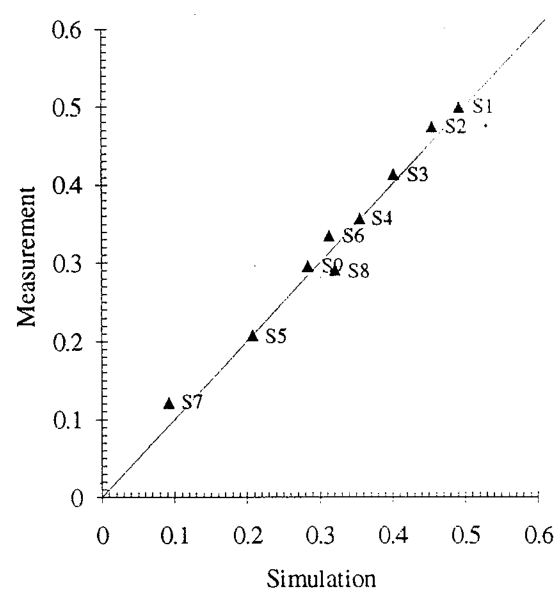
Table 4 and Figure 5 give a summary of window SHGC results determined by measurement and simulation.

Table 4: Summary of Results

Sash No.	Solar Heat Gain Coefficient			
	Measured (Vortek)	Measured (AM1.5 Adjusted)	Simulation	Δ (Meas - Sim)
S1	0.51 ± 0.02	0.50 ± 0.02	0.49	0.01
S2	0.50 ± 0.02	0.48 ± 0.02	0.46	0.02
S3	0.47 ± 0.02	0.41 ± 0.02	0.40	0.01
S4	0.40 ± 0.02	0.36 ± 0.02	0.35	0.01
S5	0.23 ± 0.01	0.21 ± 0.01	0.21	0.00
S6	0.34 ± 0.02	0.34 ± 0.02	0.31	0.03
S7	0.13 ± 0.01	0.12 ± 0.01	0.09	0.03
S8	0.35 ± 0.02	0.29 ± 0.02	0.32	- 0.03
S9	0.31 ± 0.01	0.30 ± 0.01	0.29	0.01



a) Results measured with the Vortek Simulator



b) Measurement results adjusted to ASTM AM1.5

Figure 5. Comparison of Measurement and Simulation SHGC Results

4 CONCLUSIONS

A test method for the determination of SHGC using simulated solar irradiance has been described, together with validation results obtained from laboratory testing at the CANMET Window Test Facility.

The summary of the window SHGC results (shown in Table 4 and Figure 5) indicate that there is good agreement between measured results using this test method and calculated values simulated using the *VISION3* and *FRAME* computer programs. The largest deviation between measurement and simulation results is ± 0.03 and the average measurement uncertainty is ± 4.9% (± .018) for the nine windows tested.

The effects of test conditions on SHGC measurements were simulated for four representative double glazed systems. The exterior film coefficient and temperature conditions used during testing were found to have little effect on glazing SHGC. The effect of the simulator spectrum on SHGC results was only slight for conventional clear and tinted glazing systems, but was significant for spectrally selective glazings. This variation arises when testing with spectrally selective glazings whose optical properties may vary significantly in a region of the simulator spectrum that is dissimilar from the ASTM spectrum. An interim procedure to adjust measurement values to the ASTM spectrum has been recommended for strongly spectrally selective glazings until such time that a corrective filter for the simulator is implemented.

The SCL test method represents a first step toward establishing SHGC testing capabilities for the purpose of generating window energy rating numbers. It is intended that this procedure be extended to other fenestrations, including commercial IG units, add-on elements, and interior and exterior shading devices.

5 FUTURE WORK

Based on the results of this study, the following items are considered vital to the continued development and implementation of this test method.

1. An analysis of the equipment modifications necessary to better match the simulator spectral energy output to that of the ASTM AM1.5 spectrum.

2. Validation of the CANMET Window Test Facility for use with the SCL test method for simultaneous daytime U-value and SHGC evaluation.

3. Continuation of the development of the SHGC test method for use with other fenestrations, including commercial IG units, add-on elements, and interior and exterior shading devices.

6 *NOMENCLATURE*

A = area, m^2
C = conductance coefficient, W/(m^2 °C)
C_p = specific heat, J/(kg °C)
ε = emissivity, dimensionless
F = Solar Heat Gain Coefficient, dimensionless
f = function of
G = normal solar irradiance, W/m^2
h = surface heat transfer coefficient, W/(m^2 °C)
m = mass flow rate, kg/s
η = thermal performance factor, dimensionless
P = power, W
Q = energy flux, W
T = temperature, °C
ΔT = temperature difference,°C
U = overall heat transfer coefficient, W/(m^2 °C)

Subscripts:

abs = absorber plate
cond= conducted
cw = cell wall
f = fenestration
fr = frame
g = glass
i = interior
mw = mask wall
Meas= measured
o = exterior
Sim = simulated

7 REFERENCES

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2. NFRC, National Fenestration Rating Council, Silver Spring, MD.

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APPENDIX A - SHGC TEST PROCEDURE

Copies of the report entitled *The Determination of Fenestration Solar Heat Gain Coefficient using Simulated Solar Irradiance* can be obtained through the following:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
580 Booth Street, 7th Floor
Ottawa, Ontario
K1A OE4

or

Document Delivery Service
Library and Documentation Services Division
CANMET
Energy, Mines and Resources Canada
562 Booth Street
Ottawa, Ontario
K1A OG1

Catalogue # M91-7/211-1993E

ISBN 0-662-20316-X

APPENDIX B - PAPERS PRESENTED AT CONFERENCES

Harrison, S.J., Dubrous, F.M., *Uncertainties in the Evaluation of Window SHGC and U-values Measured Using an Indoor Solar Simulator Facility*, presented at the ASHRAE semi-annual meeting, Baltimore (1992).

Harrison, S.J. and Dubrous, F.M., *Measurement of Solar Heat Gain Coefficient Using a Solar Simulator Test Facility*, Proceedings of ISES, Denver, Co., (1991).

Harrison, S.J., *Review of Solar Heat Gain Evaluation Procedures*, report prepared for the Solar Heat Gain Subcommittee, NFRC (1991).

van Wonderen, S.J., Harrison, S.J., *Solar-Optical Properties Measurement Standards*, report prepared for the Solar-Optical Properties Subcommittee, NFRC (1992).

van Wonderen, S.J., Harrison, S.J, *Development of an Improved Window Calorimeter*, presented at 1992 SESCI Conference, Edmonton, Canada, (1992).

APPENDIX C - PARTICIPATION IN RELATED ACTIVITIES

EMR-DOE JOINT CANADA/US RESEARCH PROJECT ON WINDOW PERFORMANCE

A joint research project between Canada and the US was initiated in 1988 to coordinate research activities on window performance in both countries. Since the inception of this project two phases of round-robin testing have taken place, with the participation by various testing laboratory and simulation labs, both in Canada and the United States. The scope of this project includes the development and correlation of calculational, field testing and laboratory test methods. Although the initial emphasis of this project was with respect to the determination of U-Value the scope also includes the characterization of optical properties and SHGC.

The SCL has participated, through this and separate contract agreements, in both Phase I and Phase II of the round-robin testing program. A total of sixteen windows were tested, in support of this project, using the SCL Test Method and prototype calorimeter at the NSTF. Experimentally determined performance data was compared to results determined analytically using computer simulation. Further details of this comparison study, including SHGC results for the sixteen windows tested, are discussed in a technical paper presented at the ISES Solar World Conference in Denver (1991), Appendix B.

STANDARDS ACTIVITIES IN SUPPORT OF THE WINDOW RATING AND LABELLING PROGRAM

Participation in various standards activities in support of the window rating program includes involvement with CSA Subcommittee A440.2 toward the development of a new Canadian energy performance standard, with the NFRC in the development of solar optical properties measurement standards and review of solar heat gain evaluation methods, and with ASHRAE TC4.5.