THE DETERMINATION OF FENESTRATION SOLAR HEAT GAIN COEFFICIENT USING SIMULATED SOLAR IRRADIANCE

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PREPARED BY:

Solar Calorimetry Laboratory
Department of Mechanical Engineering
Queen's University
144 Albert Street
Kingston, Ontario, Canada
(613) 545-2591; Fax: (613) 545-6549

SCIENTIFIC AUTHORITY:

Joël Allarie
Buildings Group
CANMET Energy Technology Centre
Energy Technology Branch, Energy Sector
Department of Natural Resources Canada
580 Booth Street, 13 Floor
Ottawa, Ontario, Canada, K1A 0E4

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Ottawa, Ontario, Canada, K1A 0E4

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FOREWORD

This document describes a test method for the determination of fenestration solar heat gain coefficient (SHGC) using simulated solar irradiance. This test method has been prepared by the Solar Calorimetry Laboratory, Queen's University, Kingston, Ontario.

The increased emphasis on energy performance and peak load reduction has resulted in a variety of new energy-efficient window products being introduced into the market place. As a result, standards are being developed in Canada and the United States to provide guidelines for the evaluation and rating of complete window (fenestration) thermal performance. In particular, the values of the thermal transmittance or U-value, and the values of the solar heat gain coefficient (SHGC) must be determined.

Traditionally, the determination of fenestration energy performance has been undertaken using tables contained in design handbooks. This has allowed estimates of thermal performance to be made for simple fenestration systems, however recent developments in window technology are providing consumers with a wide range of previously unavailable products. Innovative, high performance fenestration systems now incorporate special coatings, gas-filled glazings units and integral shading devices which minimize thermal losses and control solar gains. As well, advanced glazing systems incorporating electrochromic, photochromic, or thermochromic properties may be commonplace in the future. The accuracy of these traditional methods is unknown when applied to these complex fenestration systems.

Several computer simulation programs are also currently available to calculate the SHG of fenestration components and/or systems under a variety of specified environmental conditions but they have yet to be thoroughly validated against independent experimental measurements. Their ability to deal with complex fenestration systems incorporating shading devices, diffusely transmitting/reflecting layers, or opaque elements has not yet been demonstrated.

Anticipating the requirement for universal, testing and rating methods, Energy, Mines and Resources Canada, through the Buildings Group of CANMET, undertook to support 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.

Based on preliminary investigations conducted at the Technical University of Denmark and at DSET Laboratories Inc. in Arizona, the SCL developed a test procedure that yielded both SHGC and "daytime" U-values for residential fenestration systems. The prototype test apparatus constructed for this initial study was subsequently used to evaluate the test method. Sixteen window samples of differing design were evaluated with this prototype apparatus and the results were compared with simulated values.

These initial tests were promising, however the prototype apparatus, while being suitable for research purposes, was not practical for commercial testing. Consequently, CANMET decided to support the development of an improved commercial grade test facility. During the period that followed, the SCL designed and installed a new test facility at the NSTF. In addition, major modifications to the NSTF environmental simulator facility were completed, improving its flexibility and extending its operating range. During the summer of 1992, the complete facility was calibrated and validation testing was conducted in conjunction the CSA A440.2 Standards

Committee. In all, ten commercially available windows were tested.

The current draft of the test method was produced as a result of this testing program. This 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 references and draws upon the extensive work conducted over the past ten years in support of ANSI/ASHRAE 93-1986 "Methods of Testing to Determine the Thermal Performance of Solar Collectors", which includes requirements for the calorimetric measurement of solar collectors using simulated solar irradiance. Many of the techniques used in this standard are directly applicable to fenestration performance evaluation.

The indoor solar simulator based approach offers a number of advantages. Control of climatic parameters such as solar radiation, temperature, wind and humidity permit highly repeatable test conditions. Other advantages include the flexibility to test windows of varying size and complexity.

Obvious disadvantages associated with this approach are the physical accessibility of full scale solar simulators to some manufacturers, as well as potentially high costs relative to some simplified computational procedures. Questions regarding discrepancies between the indoor simulator spectrum and outdoor spectrum also need to be addressed. In particular, the effects of spectrum variations on glazing transmittance/reflectance values requires quantification.

Worldwide, a large number of advanced solar simulator test facilities exist that may be suitable for use with this test method and consequently it is anticipated that this document may form the basis for a variety of national and international standards.

AVANT-PROPOS

Le présent document décrit une méthode d'essai visant à déterminer le coefficient d'apport par rayonnement solaire (CARS) d'une fenestration au moyen de la simulation de l'éclairement énergétique du soleil. Cette méthode d'essai a été préparée par le Solar Calorimetry Laboratory (SCL) de la Queen's University de Kingston (Ontario).

L'importance accrue accordée au rendement énergétique et à la réduction des charges de crête a conduit à l'apparition sur le marché d'une variété de fenêtres à haut rendement énergétique. Par conséquent, des normes sont élaborées au Canada et aux États-Unis en vue de fournir des lignes directrices pour l'évaluation et la classification du rendement thermique d'un ensemble complet de fenêtres (fenestration). Il faut en particulier déterminer les valeurs du facteur de transmission thermique ou coefficient U et les valeurs du coefficient d'apport par rayonnement solaire (CARS).

Auparavant, la détermination du rendement énergétique de la fenestration était effectuée à l'aide de tables contenues dans des manuels de conception. Il a ainsi été possible de faire des estimations du rendement thermique pour des fenestrations simples, mais les récents perfectionnements réalisés dans la technologie des fenêtres permettent d'offrir aux consommateurs une vaste gamme de produits qui n'existaient pas auparavant. Des fenestrations d'un nouveau type à haut rendement comprennent maintenant des revêtements spéciaux, des vitrages remplis de gaz et des dispositifs d'occultation incorporés qui réduisent les pertes thermiques et régularisent les gains solaires. De même, des vitrages perfectionnés possédant des propriétés électrochromes, photochromes ou thermochromes pourraient bien être courants dans le futur. On ignore l'exactitude de ces méthodes classiques lorsqu'elles sont appliquées aux fenestrations complexes.

Plusieurs programmes de simulation sur ordinateur peuvent aussi être utilisés aujourd'hui pour calculer l'apport par rayonnement solaire des éléments de la fenestration ou des systèmes, ou des deux, dans une variété de conditions environnementales spécifiées, mais il reste encore à en faire une validation en profondeur par comparaison avec des mesures expérimentales indépendantes. Leur possibilité d'application à des fenestrations complexes comprenant des dispositifs d'occultation, des couches de transmission/réflexion par diffusion ou des éléments opaques n'a pas encore été démontrée.

En prévision de la nécessité de méthodes universelles d'essai et de classification, Énergie, Mines et Ressources Canada, par l'intermédiaire du Groupe du bâtiment de CANMET, a décidé d'appuyer la mise en place d'une installation d'essai unique basée sur l'utilisation d'une installation d'essai à simulateur solaire. Dans le cadre d'un contrat passé avec le Solar Calorimetry Laboratory de la Queen's University, un prototype d'installation d'essai a été conçu et installé au Centre national d'essais d'équipements solaires (CNEES) entre avril 1988 et mars 1989.

En se basant sur des études préliminaires effectuées à l'université technique du Danemark et aux DSET Laboratories Inc. en Arizona, le SCL a élaboré une méthode d'essai qui donnait à la fois le CARS et des coefficients U "diurnes" pour des fenestrations de maisons. Le prototype d'appareil d'essai construit pour cette étude initiale a par la suite été utilisé pour évaluer la méthode d'essai. Seize échantillons de fenêtres de différents modèles ont été évalués à l'aide de ce prototype d'appareil et les résultats ont été comparés avec des valeurs obtenues par simulation.

Ces essais initiaux étaient prometteurs, mais le prototype d'appareil, même s'il convenait bien à des fins de recherche, n'était pas pratique pour des essais commerciaux. Par conséquent, CANMET a décidé d'appuyer la mise en place d'une installation d'essai améliorée de qualité commerciale. Pendant la période qui a suivi, le SCL a conçu et installé une nouvelle installation d'essai au CNEES. En outre, d'importantes modifications de l'installation de simulation du milieu du CNEES ont été achevées, ce qui a permis d'accroître sa flexibilité et d'élargir son champ d'application. Au cours de l'été 1992, l'installation complète a été étalonée et des essais de validation ont été effectués conjointement avec le Comité de normalisation CSA A440.2. Au total, dix fenêtres offertes sur le marché ont été mises à l'essai.

Le projet actuel de méthode d'essai a été élaboré à la suite de ce programme d'essai. Le présent document décrit une méthode d'évaluation du coefficient d'apport par rayonnement solaire (CARS) et il représente la partie I de la méthode d'essai complète. La partie II, qui porte sur la détermination du coefficient U "diurne", est encore en révision et elle sera validée avec la nouvelle installation d'essai.

En plus de faire référence à l'énorme travail de soutien effectué au cours des dix dernières années pour la norme ANSI/ASHRAE 93-1986 intitulée "Methods of Testing to Determine the Thermal Performance of Solar Collectors", qui comprend des exigences pour la mesure calorimétrique de capteurs solaires par simulation de l'éclairement énergétique du soleil, la méthode d'essai existante bénéficie de ce travail. Bon nombre des techniques utilisées dans cette norme sont directement applicables à l'évaluation du rendement des fenestrations.

L'approche basée sur le simulateur solaire intérieur offre un certain nombre d'avantages. La régulation des paramètres climatiques tels rayonnement solaire, température, vent et humidité permet de créer des conditions d'essai facilement reproductibles. Les autres avantages sont notamment la flexibilité pour l'essai de fenêtres de tailles et degrés de complexité divers.

Les inconvénients évidents associés à cette approche ont trait à l'accessibilité physique à des simulateurs solaires grandeur réelle pour certains fabricants ainsi qu'aux coûts potentiellement élevés concernant certaines méthodes de calcul simplifiées. Il faut aussi s'intéresser aux questions concernant les écarts entre le spectre du simulateur intérieur et le spectre extérieur. En particulier, il faut quantifier les effets des variations du spectre sur les valeurs des facteurs de transmission/réflexion du vitrage.

À l'échelle mondiale, il existe un grand nombre d'installations d'essai à simulateur solaire perfectionnées qui peuvent appliquer la présente méthode d'essai. Par conséquent, on prévoit que le présent document peut constituer la base d'une variété de normes nationales et internationales.

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Part I: Solar Heat Gain Coefficient

1. PURPOSE

The purpose of this document is to provide a test method for the determination of fenestration system Solar Heat Gain Coefficient (SHGC) using an indoor solar simulator test facility.

2. SCOPE

2.1 This method applies to virtually any fenestration system including windows and doors, translucent systems, and systems incorporating integral or add on shading devices.

2.2 This method can be applied for conducting tests under simulated solar irradiance in an indoor test facility. Experimental apparatus required for this procedure includes a solar irradiance simulator, an environmental control chamber, calorimetric heat exchange loop and calorimeter cell.

2.3 This document describes a method to determine fenestration solar heat gain coefficient (SHGC).

2.4 This method does not apply to:

i) Fenestration systems whose orientation is not in the vertical plane, such as skylights mounted horizontally on any angle other than vertical.

3. DEFINITIONS AND NOMENCLATURE

3.1 Definitions

absorber plate. An absorber plate is a finned tube heat exchange surface which receives incident radiation energy and transforms it into thermal energy. The absorber plate also acts to remove or add heat to the test cell enclosure by convective coupling.

air leakage rate. The air leakage rate is the volume of air flowing per unit of time through the calorimeter cell and window specimen under temperature and pressure conditions specified on both sides of the calorimeter cell, expressed in cubic meters per second.

air mass. The air mass is ratio of the mass of atmosphere in the actual earth-sun path to the mass which would exist at sea level if the sun were directly overhead.

angle of incidence. The angle of incidence of a beam is the angle between the direct beam and the normal to the glazing plane, at the point where the beam meets the glazing.

efficiency, instantaneous thermal. The instantaneous thermal efficiency of a fenestration system is the ratio of the net rate of energy transferred through the fenestration system divided by the total solar radiation incident on the fenestration system, under defined steady state conditions.

fenestration system. The fenestration system is the system through which incident solar radiation energy is transmitted,

irradiance, total. The total irradiance is the quantity of radiant energy incident upon a surface over all wavelengths.

pyranometer. A pyranometer is a radiometer used to measure the total solar radiation incident upon a surface per unit time per unit area. This energy includes the direct radiation, the diffuse radiation and the solar radiation reflected from the foreground.

pyrgeometer. A pyrgeometer is a radiometer used for measuring the incoming atmospheric irradiance at wavelengths greater than approximately 4 μm on a black surface at ambient air temperature. The solar short-wave radiation is excluded from the energy measured.

quasi-steady state. Quasi-steady state describes test conditions when the fluid flow rate and inlet temperature, solar irradiance, and the ambient temperature on both sides of the fenestration system have stabilized to such an extent that these conditions may be considered essentially constant as defined in section 6.3.

solar calorimeter test cell. A solar calorimeter test cell is a heat metering chamber, and includes a mask wall in which the window test specimen is mounted for the purpose of testing. The solar calorimeter test cell houses the absorber plate, through which a metered amount of heat is added or extracted to the test cell.

solar heat gain (SHG). The solar heat gain is the rate of heat transferred from the inner glazing surface, inwards. Included are both directly transmitted solar radiation as well as solar energy absorbed and re-radiated or conducted inwards through the fenestration system.

solar heat gain coefficient (SHGC), F. The SHGC is the ratio of solar heat gain through the fenestration system to solar radiation incident on the system per unit area, for a given angle of incidence and for given environmental conditions (i.e. indoor temperature, outdoor temperature, wind speed and direction, solar radiation).

temperature, outdoor (ambient) air. The outdoor air temperature is the temperature of the air immediately surrounding the outer surface of the fenestration system being tested, and the ambient air temperature within the environmental chamber.

temperature, indoor (enclosure) air. The indoor air temperature is the temperature of the air within the test cell enclosure.

test period, steady-state. The test period is the required time period over which quasi-steady-state conditions must be maintained for each measured efficiency point.

total fenestration area. The total fenestration area is the area of the fenestration system including the frame, and excluding mounting devices (e.g. brackets), as projected on a plane parallel to the glass surface.

3.2 Nomenclature

A = area, m^2
C_p = specific heat, J/(kg ·°C)
E = sum of square of the errors
F = solar heat gain coefficient, dimensionless
G = normal solar irradiance, W/m^2
h = convection heat transfer coefficient, $W/(m^2 \cdot °C)$
C = conductance of the test cell wall, W/(m ·°C)
$\dot{m}$ = mass flow rate, kg/s
P = power, W
Q = time rate of heat transfer, W
$SHGC$ = solar heat gain coefficient, dimensionless
T = temperature,°C
ΔT = temperature difference,°C
U = overall heat transfer coefficient, $W/(m^2 \cdot °C)$
η = thermal performance, dimensionless
ρ = density, kg/m^3
ω = random uncertainty
ε = difference (error)
α = weighting factor
s = standard deviation

Subscripts

abs= absorber
air = air temperature
cond= conductive heat transfer
f = fenestration system
F = SHGC test conditions
i = node i
net = net heat transfer
solar= solar heat transfer
wall= cell and mask wall

4. INSTRUMENTATION

4.1 Solar Radiation Measurement

4.1.1 Radiometers. A pyranometer shall be used to measure the simulated solar radiation in the aperture plane of the fenestration under test. The instrument shall conform with the minimum characteristics as described in Section 6.1.1 of ANSI/ASHRAE 93-1986 [1].

4.2 Temperature Measurements

4.2.1 Methods. Temperature measurements shall be made in accordance with ASHRAE Standard 41.1-74 [2].

If thermocouples (or other point sensors) are used to measure air temperatures, the junctions of the thermocouples shall have bright metallic surfaces, shall be as small as possible to minimize radiation effects, and shall be shielded so that simulated solar radiation emitted from the lamp or reflected from the enclosure surfaces cannot fall upon the sensor. The net affect shall be such that the increase in temperature measurements, as a result of incident irradiance of up to 1000 W/m^2, shall not exceed 0.3°C.

4.2.2 Accuracy and Precision. The accuracy and precision of the instruments including their associated readout devices shall be within the limits as follows:

	Instrument Accuracy *	Instrument Precision **
Temperature	±0.5°C	±0.2°C
Temperature Difference	±0.1°C	±0.1°C

* The ability of the instrument to indicate the true value of the measured quantity.
** Closeness of agreement among repeated measurements of the same physical quantity.

4.2.3 Time Constant. Thermocouples and thermopiles with time constants of less than 1 second and resistance thermometers with time constants of less than 10 seconds shall be used for performing temperature measurements.

4.2.4 Temperature Difference Measurements. The temperature difference measuring devices shall be calibrated for the range of temperatures and temperature differences encountered in the tests.

4.3 Calorimeter Heat Exchanger Flow Measurements. The accuracy of the liquid flow rate measurement shall be equal to or better than ± 1.0% of the measured value in mass units per unit time.

4.4 Instrumentation/Data Recorders. Analog and digital recorders shall conform to the requirements of Section 6.4 of ANSI/ASHRAE 93-1986 [1].

4.5 Liquid Pressure Measurement. The inlet pressure to the absorber plate and the pressure change across the absorber plate shall be measured with a device having an accuracy of ± 3.5 kPa (± 0.5 psi).

4.6 Wind Velocity. The wind velocity shall be measured with an instrument and associated readout device that can determine the average wind velocity to an accuracy of ± 0.5 m/s.

4.7 Humidity Measurement. Humidity measurements shall be made in accordance with ASHRAE Standard 41.6-1982 [3].

4.8 Air Pressure Measurement. The air pressure difference across the interior and exterior air of the test cell and specimen shall be measured with a device having an accuracy of ± 2.5 Pa.

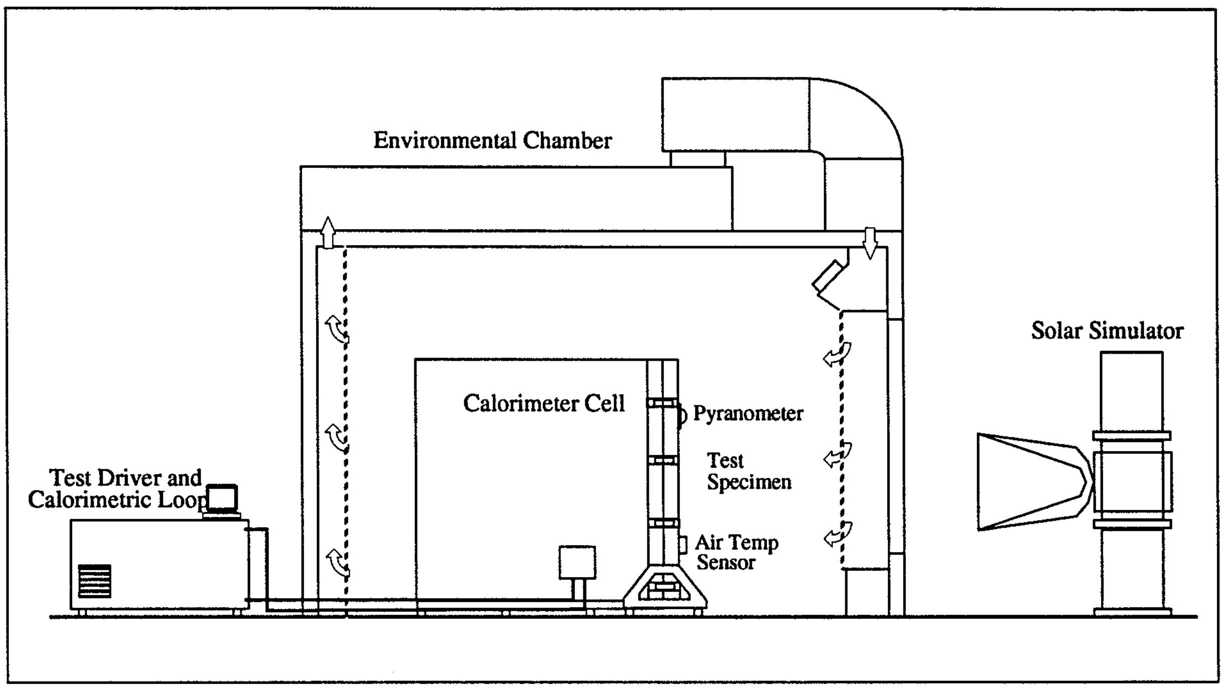
4.9 Air Flow Measurement. The rate of air leakage through the test cell and specimen shall be measured with a device having an accuracy of ± 3%.

4.10 Film Coefficient Measurements. The film coefficient measurement device may be of the type described in reference [4] that incorporates a constant thickness layer of insulation (of known R-value), sandwiched between two clear glazings. Embedded between the core insulation and the inner side of the glazings (i.e. the core sides), are thermocouples able to measure the glass temperature distribution of each glazing.

5. APPARATUS AND TEST MEASUREMENTS

5.1 Test Apparatus Arrangement. The test apparatus consists of a Solar Simulator, Environmental Control Chamber, Calorimeter Cell and Calorimetric Heat Exchange Loop. A arrangement which is representative rather than exact is shown in Figure 1, and described in references [5,6]. During testing, the calorimeter cell and mounted test specimen are placed in the environmental chamber where, under controlled air temperature and simulated wind and solar radia-

Figure 1. Test Apparatus Arrangement



tion conditions, window performance is determined.

5.1.1 Solar Simulator Lamp. The solar simulator lamp employed in the test procedure shall meet those requirements outlined in Section 7.3.1, 7.3.2 and 7.3.3 of ANSI/ASHRAE 93-1986 [1].

5.1.1.1 Spectral Characteristics. The simulator shall provide a spectral distribution that reasonably duplicates that of natural sunlight as defined by the standard air mass AM1.5 solar spectrum. This standard spectrum is given in ASTM Standard E-891 [7]. Measurement of the solar simulator's spectral qualities shall be in the plane of the fenestration system over the wavelength range of 0.3-2.6 μm and is determined in 0.1 μm (or smaller) bandwidths.

Note: Care must be taken in the testing of glazings known to have strongly spectrally selective optical properties. If it is suspected that the total averaged optical properties may differ by more than ± 2% from the value calculated using the standard spectrum, test results should be adjusted to account for these effects. A discussion of the calculation of spectral effects is provided in ASTM standard E-891 [7] and reference [8,9].

5.1.2 Environmental Control Chamber. An indoor solar test facility shall be used to produce fully controlled and repeatable temperature and wind conditions for testing fenestration systems. These simulated environmental conditions shall be fully characterized, and allow for steady-state test conditions.

5.1.2.1 Air Flow. Fans or other means shall be used to establish a substantially uniform air flow directed at the test specimen during the pretest conditioning and actual test periods. Air flow shall be directed parallel to the floor and perpendicular to the surface of the mask wall. This simulated wind shall be maintained at a mean speed of 3.0 (± 0.5) m/s and shall be measured before and after each test period in a vertical plane normal to the free stream direction 1 m from the test specimen.

5.1.2.2 Ambient Temperature. Ambient temperature measurements shall be representative of the environmental conditions occurring near the test specimen during testing. The temperature sensor(s) shall be placed adjacent to the surface of the fenestration system and shall be shielded from thermal and simulated solar irradiance as mentioned in Section 4.2.1.

5.1.3 Calorimeter Cell. A specially designed solar calorimeter test cell shall be used to provide for the control and measurement of air temperature and velocity on one face of the specimen under fixed radiation conditions, and for the measurement of heat transfer through the specimen. The usual arrangement is a five-sided chamber and adjoining mask wall. The calorimeter cell may be either guarded and of the type that requires calibration to determine cell wall heat transfer coefficients.

5.1.3.1 Cell Enclosure Temperature. Cell enclosure temperature measurements shall be representative of the conditions inside the calorimeter cell and immediately adjacent to the test specimen. Air and wall surface temperatures shall indicate the degree of uniformity of air and surface temperatures. Use of a small air circulating fan is acceptable to ensure proper mixing of the enclosure air and inner film coefficient value.

5.1.4 Calorimetric Heat Exchanger Loop. The Calorimetric Heat Exchanger Loop employed in the test procedure shall meet with the requirements outlined in Section 7.1 of ANSI/ASHRAE 93-1986 [1]. An absorber plate or equivalent heat exchanger capable of extracting heat in a manner which can be accurately measured is included and resident in the calorimeter cell. Only the use of the absorber plate and liquid cooling method shall be dealt with in this test method. Other means for metering heat flow into and out of the test cell are acceptable provided they can be demonstrated to be of equivalent accuracy as the methods described in [1].

5.2 Measurements

5.2.1 Solar Irradiance. The pyranometer shall be mounted such that its sensor is coplanar with the plane of the fenestration system exposed surface. It shall not cast a shadow onto the fenestration system at any time during the test period, and shall not be mounted so as to receive a percentage of simulator chamber radiation that is disproportionate with that received by the fenestration system.

5.2.2 Long Wave Radiation. The infrared (thermal) irradiance between 3.5μm and 50 μm shall be measured in the plane of the fenestration frame by a pyrgeometer or other equivalent instrument. The infrared irradiance shall be measured during the test period in the plane of the fenestration system and shall not exceed that from a theoretical black body at ambient temperature by more than 20 W/m^2.

5.2.3 Temperature Measurements. Temperature measurements of cell enclosure and ambient air, temperature differences across the cell walls, absorber plate and test specimen shall be made in accordance with Section 4.2.

5.2.3.1 Temperature Difference Measurements Across the Cell Walls. The indoor-outdoor surface temperature difference across the cell walls shall be measured using multiple junction thermopiles. The thermopile wires shall be embedded in the walls in such a way so as to minimize the direct heat transfer path through the cell walls.

5.2.3.2 Air Temperature Distribution Measurements in the Test Cell. If thermocouples are used to measure the temperature distribution of the enclosure air, they shall be evenly spaced through the enclosure and in a plane adjacent to the window specimen.

5.2.3.3 Temperature Difference Measurements across the Absorber Plate. The temperature difference of the transfer fluid between the inlet and outlet of the absorber plate shall be measured in accordance with section 4.2. To minimize temperature measurement error, each probe shall be located as close as possible to the inlet or outlet of the absorber plate and shall be placed adjacent to a mixing device. In addition, the piping or header between the mixing device and the absorber plate shall be insulated in such a manner that the calculated heat loss or gain from the ambient air will not cause a temperature change for any test period of more the ± 0.05°C between each temperature device and the absorber plate.

5.2.4 Air Leakage. Air leakage through the calorimeter cell and/or through the specimen can effect results when testing fenestration systems and shall be minimized and quantified according to Appendix E. Apparatus for measuring flow rate and pressure difference across the cell walls, as described in sections 4.8 and 4.9, shall be used to determine the air infiltration into the cell enclosure for the range of differential pressures encountered during testing. The rate of enthalphy change due to air infiltration shall be calculated, and if greater than ± 1 W, shall be accounted for in the heat balance of the cell enclosure.

5.2.5 Film Coefficient Measurements. The inner and outer film coefficients shall be measured using a calibration transfer standard (as described in section 4.10) which will be able to determine convective film coefficients over the entirety of the fenestration area. The calibration transfer standard surface heat transfer coefficients can be determined by utilization of the air temperature, and air speed and direction measurements specified in ASTM CXX3 [10]. The uniformity of the film coefficients, with the specimen in place, shall be such that the highest and lowest measure of values do not deviate from the average value by more than ± 10%.

5.2.6 Calorimetric Heat Exchanger Flow Measurement. The Calorimetric Heat Exchanger flow measurement shall be made in accordance with Section 7.1 of ANSI/ ASHRAE 93-1986 [1].

5.2.7 Pressure Difference across the Absorber Plate. The fluid pressure drop across the absorber plate at the inlet and outlet devices shall be measured. A corresponding power representing the rate of heat generation within the absorber plate due to losses shall be calculated, and if greater than ± 1 W, shall be accounted for in the heat balance of the cell enclosure.

6. TEST PROCEDURES AND COMPUTATIONS

6.1 General. The Solar Heat Gain Coefficient of the fenestration system can be determined based on the values of the net rate of energy absorption in the calorimeter cell enclosure, incident radiation levels, and ambient and enclosure temperatures. A detailed derivation of the basic thermal performance equations, linear regression analysis and uncertainty analysis procedure is supplied in Appendices A, B and D.

6.2 Set-up. The test specimen shall be mounted in the mask wall of the test cell, and the cell shall be placed inside the chamber with the mask wall facing the solar simulator lamp as described in section 5.1 and depicted in Figure 1.

6.3 Test Conditions. The tests shall be conducted indoors with a solar irradiance simulator under the following test conditions:

6.3.1 Solar Irradiance. The irradiance level during each test shall be constant such that the irradiance shall not vary from the average value by more than ± 5%, and shall be in accordance with those values defined in sections 6.4.1. Incident angles shall be within ± 7° of the normal incident value for direct normal tests.

6.3.2 Ambient Temperature. Ambient temperature in the test chamber shall be constant such that the variations in the temperature from the average value are less than ± 0.5°C, and are in accordance to those values defined in section 6.4.1 and 6.5.1.

6.3.3 Wind Conditions. Air flow shall be established across the test chamber during test periods, and in accordance to those values defined in section 5.1.2.1 and used in determining the film coefficients.

6.3.4 Steady State Conditions. In order to achieve steady-state conditions, the heat transfer fluid shall be circulated through the absorber plate at the appropriate values for inlet temperature and flow rate until they remain constant within ± 0.3°C and ± 1 W/°C, respectively, for 15 minutes prior to each period in which the data will be taken to calculate the efficiency values. A steady state period of at least 1 hour shall be maintained during which 4 data points, each consisting of 15 minute intervals shall be recorded.

6.4 Test Procedure for the Determination of the Solar Heat Gain Coefficient (SHGC)

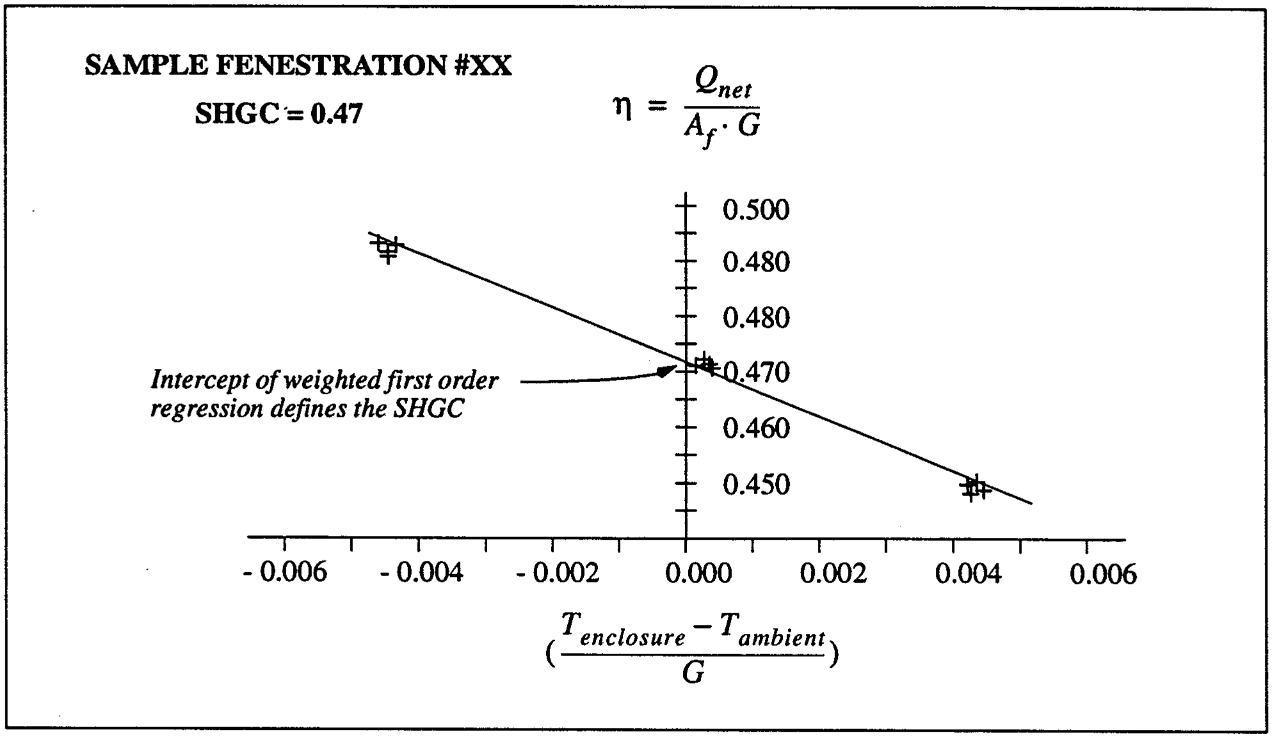
6.4.1 Experimental Determination of the SHGC. Three distinct sets of test conditions shall be used for the determination of the SHGC. Test conditions shall be as follows:

Test Point	G (W/m^2)	T_{indoor}(°C)	$T_{outdoor}$(°C)
#1	783 ± 20	21 ± 1	18 ± 1
#2	783 ± 20	21 ± 1	21 ± 1
#3	783 ± 20	21 ± 1	24 ± 1

6.4.2 Number of Data Points. At least four data points each consisting of 15 minute intervals shall be measured for each of the three test point conditions.

6.4.3 Calculations. Values of the thermal performance factor shall be computed according to Appendix A and plotted as shown in figure 2. A first-order weighted least squares regression equation of the form described in Appendix B shall be fitted to experimental data and the values of the slope and intercept plotted. The value of the SHGC shall be defined by the intercept of the performance curve. An uncertainty analysis shall be performed as described in Appendix C. See figure 2.

Figure 2. Sample Plot for the Determination of SHGC.



7. DATA TO BE RECORDED AND TEST REPORT

7.1 Test Data.

The measurements which are to be made prior to and during the testing sequence to obtain efficiency data points are listed in table 7.1.

Table 7.3: Test Data to be Measured and Recorded

Item	Units
Date of test	
Fenestration type (including shading device if applicable)	
Fenestration construction details (provide assembly drawings where possible):	
Total dimensions and area	m^2
Glazing and dimensions and area	m^2
Glazing and type, materials and optical properties	
Frame dimensions and areas	m^2
Frame type and materials	
Included hardware materials	
Shading device dimensions and area	m^2
Shading device type and materials	
Shading device mounting details	
Barometric Pressure	Pa
Incident Angle	°
Expression defining rate of air Leakage wrt pressure	l/min
Wind velocity 1 m from the fenestration surface	m/s
For each test point:	
Ambient average air temperature	°C
Enclosure average air temperature	°C
G, the incident solar radiation	W/m^2
Temperature difference across the cell walls	°C
Temperature of the inlet to the absorber plate	°C
Temperature of the outlet to the absorber plate	°C
Fluid flow rate through the absorber plate	W/°C
Pressure difference across the test specimen and cell walls	Pa
Pressure difference across the absorber plate	Pa
Electrical power added to the cell enclosure	W
Time at the beginning and end of the test period	

7.2 Test Report

The data and information that are to be included in the test report is listed in Table 7.2.

Table 7.4: Data and Information to be included in Test Report

Item	Units
General Information	
Manufacturer name	
Fenestration model #	
Fenestration construction details (as described in Table 7.1)	
Test Data (for each data point)	
Incident Angle	°
Wind velocity 1m from the fenestration surface	m/s
Ambient average air temperature	°C
Inner Film Coefficient	$W/(m^2 °C)$
Outer Film Coefficient	$W/(m^2 °C)$
Enclosure average air temperature	°C
G, the incident solar radiation	W/m^2
Power added/extracted by the absorber plate	W
Sum of the electrical power inputs to the cell enclosure	W
Heat transfer through the cell walls and surround panel	W
Rate of enthalphy loss through the cell walls and surround panel due to air infiltration (if applicable)	W
Miscellaneous power which may be applicable	W
SHGC Performance	
A plot of the performance factor versus $\Delta T / G$ (as shown in Figure 2)	
SHGC, the intercept of the first order weighted regression through the data points	
The uncertainty associated with the SHGC	

8. REFERENCES

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APPENDIX A - Thermal Performance Equations

A.1 - Theory

A simple energy balance performed on a fenestration system shows that the net heat through the fenestration system can be calculated as the sum of the solar heat gain resulting from exposure to the solar radiation and the net heat flow resulting from a temperature gradient across the fenestration system

$$Q_{net} = Q_{solar} - Q_{cond} \qquad (1)$$

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

$$Q_{solar} = F \cdot G \cdot A_f \qquad (2)$$

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

$$Q_{cond} = U_f \cdot \Delta T_f \cdot A_f \qquad (3)$$

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

$$\eta = \frac{Q_{net}}{A_f \cdot G} \qquad (4)$$

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

$$\eta = F - \frac{U_f \cdot \Delta T_f}{G} \qquad (5)$$

A.2 - Measurements

The thermal performance, η, of the test specimen is directly measured based on an energy balance over the control volume of the inner cell. The net energy flow through the test specimen is the sum of the energy extracted (or added) by the absorber plate, the heat losses through the cell walls, and the electrical power inputs

$$Q_{net} = Q_{abs} + Q_{wall} - P_{inputs} \tag{6}$$

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

$$Q_{abs} = \dot{m} \cdot C_p \cdot \Delta T_{abs} \tag{7}$$

Q_{wall}, the heat loss through the inner cell and mask walls is calculated from the ambient air temperature difference across the wall, the wall area, and the average thermal transmittance of the cell, U_{wall}, determined by the calibration procedure described in Appendix C, i.e.

$$Q_{wall} = UA_{wall} \cdot \Delta T_{wall} \tag{8}$$

A_{wall} represents the combined total of the cell walls and the mask wall surround panel.

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

$$P_{inputs} = P_{pump} + P_{fan} + P_{heater} \tag{9}$$

A.3 - Performance Analysis

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

$$\eta = \frac{Q_{abs} + Q_{wall} - P_{inputs}}{A_f \cdot G} \tag{10}$$

APPENDIX B - Linear Regression Analysis

A classical weighted least squares procedure shall be used to establish the performance curve based on the plot of the performance points. The sum of the square of the errors to be minimized, E, is

$$E = \sum_i \alpha_i^2 \cdot \varepsilon_i^2 \tag{11}$$

where for i=1 to n test points, ε_i represents the difference between measured values of η_i and the corresponding values as predicted from the curve fit equation,

$$\varepsilon_i = [\eta_i - (F - U_F \cdot x_i)] \tag{12}$$

Where for the purposes of determining F, the slope of the line shall be defined by U_F. α_i represents the weighting associated with ε_i and is inversely proportional to σ_i, the uncertainty in η_i as described in Appendix D. α_i is defined by

$$\alpha_i^2 = \frac{1/\sigma_i^2}{\sum_i 1/\sigma_i^2} \tag{13}$$

The values of the slope U_F, and y intercept F, of the regression line can be obtained by setting the partial derivatives of E with respect to U_F and F to zero. Solving this equation for U_F, and F gives

$$F = \frac{\sum_i \alpha_i^2 \cdot x_i^2 \cdot \sum_j \alpha_j^2 \cdot \eta_j^2 - \sum_i \alpha_i^2 \cdot x_i \cdot \sum_j \alpha_j^2 \cdot x_j \cdot \eta_j}{\sum_i \alpha_i^2 \cdot x_i^2 - (\sum_i \alpha^2 \cdot x_i)^2} \tag{14}$$

$$U_F = \frac{\sum_i \alpha_i^2 \cdot x_i \cdot \eta_i - \sum_i \alpha_i^2 \cdot \eta_i \cdot \sum_j \alpha_j^2 \cdot x_j}{\sum_i \alpha_i^2 \cdot x_i^2 - (\sum_i \alpha^2 \cdot x_i)^2} \tag{15}$$

APPENDIX C - Calibration Method

C.1 - Simulated Solar Irradiance.

Irradiance calibration shall be performed for the energy levels used for testing. The value of irradiance shall be representative of the average value of irradiance over the test plane. During calibration, measurements of irradiance shall be taken on a uniform rectangular grid of maximum spacing of 15 cm, and the average value calculated. Measurements shall also be conducted at the location of the pyranometer, and compared against the calculated average value. A correction factor shall then be determined, for different levels of irradiance.

C.2 - Calorimeter Cell U-Value.

Calibration tests shall be performed for the test conditions used for testing to determine the overall heat transfer coefficient of the calorimeter cell.

Calibration shall be performed using a closed mask wall, (i.e. with the test aperture carefully masked and insulated with material and construction similar to the existing mask wall).

A steady state temperature difference shall be maintained inside and outside the test cell, and U_{wall} shall be calculated from the sum of the heat losses through the total area of the cell and mask walls and the electrical power inputs as follows

$$Q_{wall} = P_{inputs} = U_{wall} \cdot A_{wall} \cdot \Delta T_{wall} \quad (16)$$

During testing the area of the perimeter mask wall surround panel shall be accounted for and the heat loss calculated using U_{wall}.

In the case of a thermally guarded calorimeter cell, only the heat transfer coefficient of the mask wall need be determined.

C.3 - Calorimeter Heat Exchanger. The temperature sensors and flowmeter of the calorimeter heat exchanger system shall be calibrated independently according to sections 4.2 and 4.3.The calculated power added or extracted via the absorber plate as a result of these measurements shall be checked against a reference heat source apparatus similar to that described in [11].

APPENDIX D - Uncertainty Calculation Procedure.

To evaluate the possible sources of error related to the test method and their magnitude, an uncertainty analysis shall be conducted. The random uncertainties of each measurement shall be estimated.

D.1 - Uncertainty on the Performance Points. The uncertainties on the SHGC and U-values shall be computed based on estimates of the standard deviation associated with each performance point, σ_i. Due to the limited sample size, σ_i for each test point can be estimated from the value of the uncertainty, ω_i, as calculated by equation 17, based on the uncertainties associated with the individual measurements [12].

$$\omega_i^2 = \left[\frac{\partial\eta_i}{\partial G}\cdot\omega_G\right]^2 + \left[\frac{\partial\eta_i}{\partial\dot{m}C_p}\cdot\omega_{\dot{m}C_p}\right]^2 + \left[\frac{\partial\eta_i}{\partial\Delta T_{abs}}\cdot\omega_{\Delta T_{abs}}\right]^2 +$$

$$\left[\frac{\partial\eta_i}{\partial\Delta T_{air}}\cdot\omega_{\Delta T_{air}}\right]^2 + \left[\frac{\partial\eta_i}{\partial U_{wall}}\cdot\omega_{U_{wall}}\right]^2 + \left[\frac{\partial\eta_i}{\partial P_{Pump+Fan}}\cdot\omega_{P_{Pump+Fan}}\right]^2 \quad (17)$$

Where ω_G, ω_{mCp}, $\omega_{\Delta Tabs}$, $\omega_{\Delta Tair}$, ω_{Uwall}, $\omega_{Ppump+fan}$ are the random uncertainties in the irradiance level, flow rate, temperature rise across the absorber plate, enclosure and ambient air temperature difference, wall calibration heat loss coefficient and power to the pump and fan respectively. The uncertainties related to the cell and test window areas, and the test-loop fluid specific heat are assumed to be negligible.

D.2 - Uncertainty in the Calculation F. Assuming the errors in F arise from errors in η, the standard deviations in F can be derived from Equation 14 as follows:

$$\sigma(F) = \frac{\left[\sum_i\left[\alpha_i^2\cdot\left(\sum_i\alpha_i^2\cdot x_i^2 - x_i\cdot\sum_i\alpha_i^2\cdot x_i\right)\right]^2\cdot\sigma^2_i\right]^{1/2}}{\sum_i\alpha_i^2\cdot x_i^2 - \left(\sum_i\alpha_i^2\cdot x_i\right)^2} \quad (18)$$

This weighted error represents the uncertainty associated with the SHGC of the fenestration system.

APPENDIX E - Minimizing And Accounting For Air Infiltration

The apparatus and specimen perimeter shall be gasketed or otherwise sealed to limit leakage both to environment and the area around the specimen.

Corrections to the test heat balance for the enthalpy of the infiltration air may or may not be necessary, depending upon the temperature difference of the air and leakage rate.

Using ambient air, a leakage curve is determined by either evacuating or pressurizing the test cell enclosure using a calibrated flow measuring device and by measuring the pressure difference between the test enclosure and ambient. The set-up shall initially consist of a impermeable barrier sealing the mask wall and test specimen. Sufficient data points of pressure and leakage shall be measured for the range of anticipated test conditions and shall act as a baseline air leakage value. The impermeable barrier shall then be removed, and the pressure and leakage test repeated to determine the total air leakage. Curves for the baseline and total air leakage shall be drawn and the difference in slope used to express the actual leakage through the mask wall and test specimen for a given pressure during testing. An example of a representative leakage curve is shown in Figure 3.

Figure 3. Air Leakage Curves.