



National Fenestration Rating Council Incorporated

NFRC 300-2010_{E1A0}

Test Method for
Determining the Solar Optical Properties
of Glazing Materials and Systems

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FOREWORD

The National Fenestration Rating Council, Incorporated (NFRC) develops and operates a uniform rating system for energy and energy-related performance of fenestration and fenestration attachment products. The Rating System determines the U-factor, Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT) of a product, which are mandatory ratings for labeling NFRC-certified products, and are mandatory ratings for inclusion on label certificates, and are supplemented by procedures for voluntary ratings of products for Air Leakage (AL) and Condensation Resistance. Together these rating procedures, as set forth in documents published by NFRC, are known as the NFRC Rating System.

The NFRC Rating System employs computer simulation and physical testing by NFRC-accredited laboratories to establish energy and related performance ratings for fenestration and fenestration attachment product types. The NFRC Rating System is reinforced by a certification program under which NFRC-licensed responsible parties claiming NFRC product certification shall label and certify fenestration and fenestration attachment products to indicate those energy and related performance ratings, provided the ratings are authorized for certification by an NFRC-licensed Certification and Inspection Agency (IA).

The requirements of the rating, certification, and labeling programs (Certification Programs) are set forth in the most recent versions of the following as amended, updated, or interpreted from time to time:

- NFRC 700 Product Certification Program (PCP)
- NFRC 705 Component Modeling Approach (CMA) Product Certification Program (CMA-PCP)

and through the Certification Programs and the most recent versions of its companion programs as amended, updated, or interpreted from time to time:

- The laboratory accreditation program (Accreditation Program), as set forth in the NFRC 701 Laboratory Accreditation Program (LAP)
- The IA licensing program (IA Program), as set forth in NFRC 702 Certification Agency Program (CAP)
- The CMA Approved Calculation Entity (ACE) licensing program (ACE Program) as

set forth in the NFRC 708 Calculation Entity Approval Program (CEAP)

NFRC intends to ensure the integrity and uniformity of NFRC ratings, certification, and labeling by ensuring that responsible parties, testing and simulation laboratories, and IAs adhere to strict NFRC requirements.

In order to participate in the Certification Programs, a Manufacturer/Responsible Party shall rate a product whose energy and energy-related performance characteristics are to be certified in accordance with mandatory NFRC rating procedures. At present, a Manufacturer/Responsible Party may elect to rate products for U-factor, SHGC, VT, AL, condensation resistance, or any other procedure adopted by NFRC, and to include those ratings on the NFRC temporary label affixed to its products or on the NFRC Label Certificate. U-factor, SHGC and VT, AL, and condensation resistance rating reports shall be obtained from a laboratory that has been accredited by NFRC in accordance with the requirements of the NFRC 701.

The rating shall then be reviewed by an IA that has been licensed by NFRC in accordance with the requirements of the NFRC 702. NFRC-licensed IAs review label format and content, conduct in-plant inspections for quality assurance in accordance with the requirements of the NFRC 702, and issue a product Certification Authorization Report (CAR) and may approve for issuance an NFRC Label Certificate for site-built or CMA products and attachment products. The IA is also responsible for the investigation of potential violations (prohibited activities) as set forth in the NFRC 707 Compliance and Monitoring Program (CAMP).

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NFRC manages the Rating System and regulates the PCP, LAP, and CAP in accordance with the NFRC 700 (PCP), the NFRC 701 (LAP), the NFRC 702 (CAP), the NFRC 705 (CMA-PCP), and the NFRC 708 (CEAP) procedures, and conducts compliance activities under all these programs as well as the NFRC 707 (CAMP). NFRC continues to develop the Rating System and each of the programs.

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The structure of the NFRC programs and relationships among participants are shown in Figure 1, Figure 2, and Figure 3. For additional information on the roles of the IAs and laboratories and operation of the IA Program and Accreditation Program, see the NFRC 700 (PCP), NFRC 701 (LAP), and NFRC 702 (CAP) respectively.

Figure 1

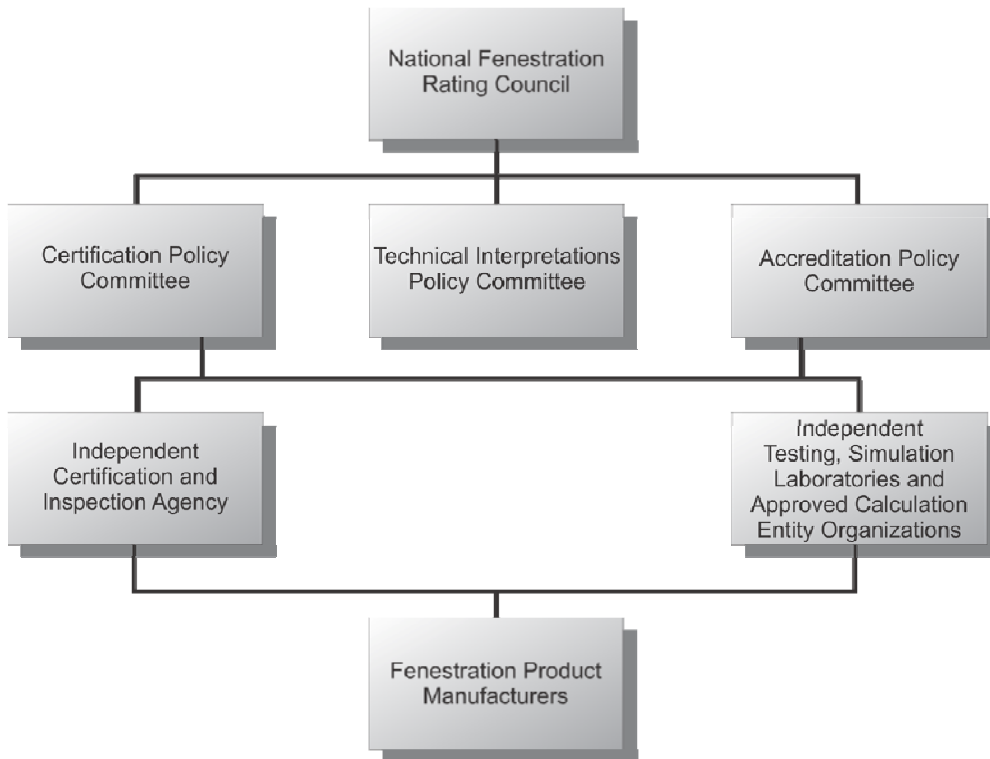


Figure 2

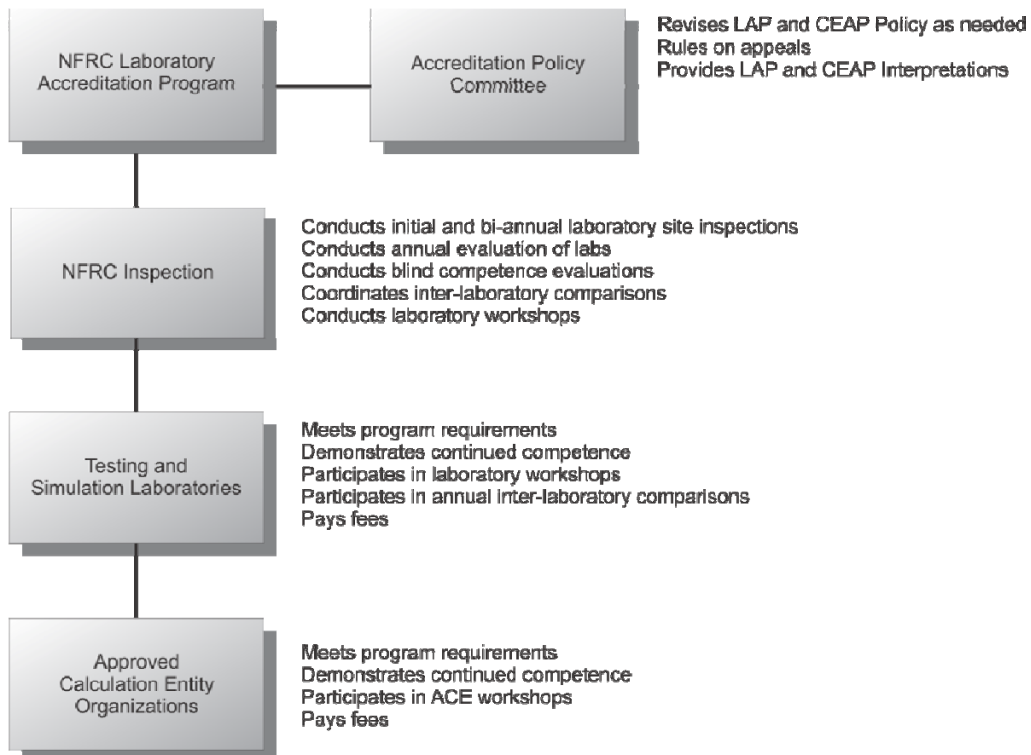
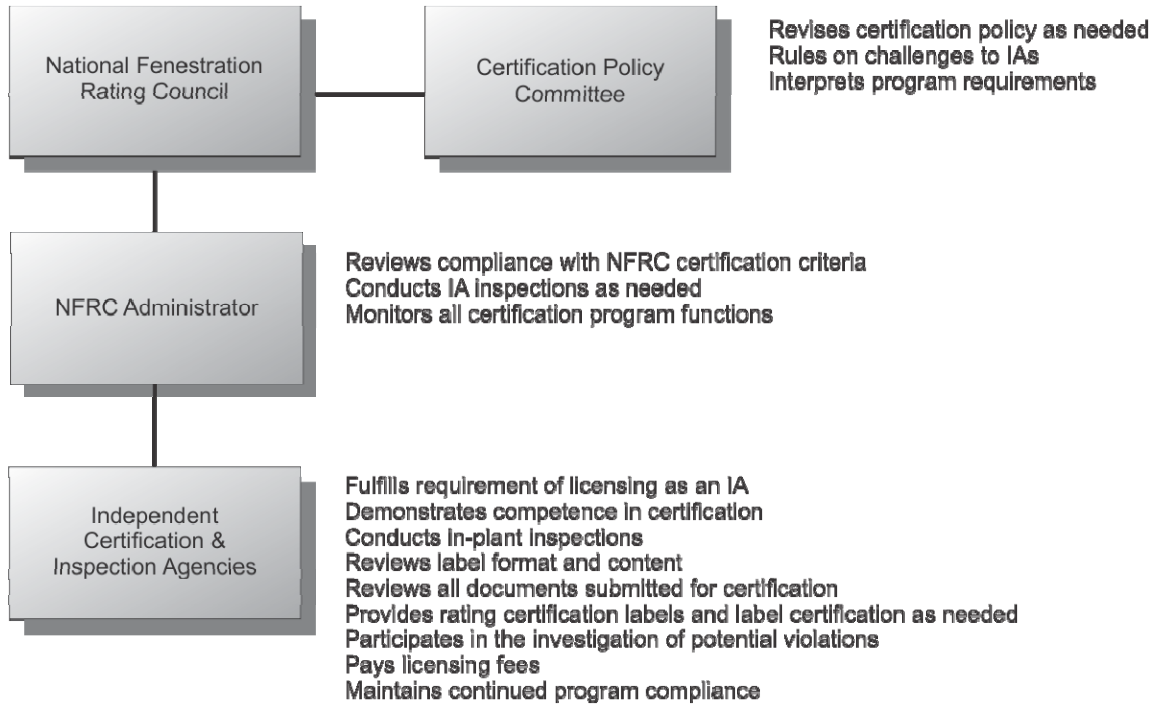


Figure 3



Questions on the use of this procedure should be addressed to:

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NFRC certification is the authorized act of a Manufacturer/Responsible Party in: (a) labeling a fenestration or related attachment product with an NFRC Permanent Label and NFRC Temporary Label, or (b) generating a site built or CMA label certificate, either of which bears one or more energy-related performance ratings reported by NFRC-accredited simulation and testing laboratories and authorized for certification by an NFRC-licensed IA. Each of these participants acts independently to report, authorize certification, and certify the energy-related ratings of fenestration and related attachment products.

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1. PURPOSE

This test method specifies the methodologies for determining the solar optical properties of glazing materials and systems. This test method is issued under the fixed designation NFRC 300; the number following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. Amendments to the documents are reflected in the footer and posted on the NFRC website, www.NFRC.org.

2. SCOPE

This test method includes the experimental procedure for measuring the transmittance and reflectance over the solar spectral range of flat specular glazing materials at normal incidence only. Under certain conditions these same techniques may also be used for nonspecular glazing, but significant errors are possible. This method is generally suitable for measuring the transmittance and reflectance of architectural glazing materials such as glass and plastic layers (coated and uncoated, monolithic or laminated). See section 2.1 for a detailed list of allowed products.

This test method refers to the calculation procedures necessary to determine the net optical properties of glazing systems consisting of combinations of discrete glazing layers. The properties of each layer shall first be tested according to the methods referred to in the previous paragraph and described herein. The calculation of the multilayer system properties is performed at each tabulated wavelength over the solar spectral range.

This test method includes the calculation procedures for spectrally averaged properties of multilayer glazing systems. The properties of the combined multilayer glazing system shall first be calculated according to the method referred to in the previous paragraph and described herein. For current NFRC rating purposes these properties include the reflectance, solar and visible transmittance of the net glazing system.

The spectrally averaged properties listed above are necessary and sufficient for determining two of the three currently rated NFRC performance parameters: the solar heat gain coefficient (SHGC)¹ and visible transmittance (VT) of a fenestration assembly at normal incidence. The third parameter, U-factor, requires the measurement of thermal-infrared emittance which is determined in accordance with NFRC 301. The use of this technical procedure and other 300-series technical procedures is governed by the most recent version of NFRC 302.

This test method may involve hazardous materials, operations and equipment. This test method does not presume to address all of the safety issues associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2.1 Products Covered

¹ SHGC is known in many other countries as the total solar energy transmittance (designated as TSET or g-factor).

The following materials are permitted to be measured using this test method:

- 2.1.1.** Monolithic homogeneous specular or slightly diffusing materials including glass plates, plastic sheets and flexible plastic film.
- 2.1.2.** Glass or plastic substrates as described in Section 2.1.A with coatings applied by chemical or vacuum deposition processes or with applied films.
- 2.1.3.** Laminated glazings consisting of two or more rigid layers combined with one or more adhesive interlayers. The interlayers shall themselves consist of monolithic homogeneous specular or slightly diffusing materials.
- 2.1.4.** Diffusing or light-redirecting sheet materials subject to verification according to NFRC 302. Note: These materials are likely to incur greater errors than specular products. New methods are under investigation, but until such methods have been approved, this procedure may be used subject to verification according to NFRC 302. Diffusing or light-redirecting materials include fritted glass, laminates with diffusing polymer interlayer, acid-etched or sand-blasted glass, patterned glass (extra caution is warranted), honeycomb structures, and applied films with diffusing layers.
- 2.1.5.** Heterogeneous materials are excluded. The effect of non specularity may remain and this effect should be carefully considered as for all nonspecular materials as in Section 2.1.4 above.

2.2 Products and Effects Not Covered

The following materials and systems shall not be measured or calculated using this test method either because they cannot be measured using a Spectrophotometer or because no calculation procedures have yet been developed to determine the relevant parameters from such spectrophotometer measurements:

- 2.2.1 Geometrically complex glazing or shading systems including but not limited to blinds, drapes, and woven shades
- 2.2.2 Heterogeneous materials with features on the order of the spectrophotometer beam unless spatially averaged as described herein.
- 2.2.3 Curved glazing including but not limited to domed skylights;
- 2.2.4 Combinations of glazing elements that include one or more diffusing elements. A single slightly diffusing element, however, can be measured directly as specified in Section 2.1.A.

3. REFERENCED DOCUMENTS

ASTM E 903-1996	Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres.
ASTM E275	Standard Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers
CIE 89/3-1991	CIE Technical Collection 1990/3. Division 6 Report: On the deterioration of exhibited Museum Objects by Optical radiation.
University of California-Lawrence Berkeley National Labs Report 33943	Documentation of Calculation Procedures (http://windows.lbl.gov/software/window)
ISO 9050-03	Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
ISO 15099-03	Thermal Performance of Windows, Doors, and Shading Devices - Detailed Calculations
ISO 9845-1:1992 (E)	Solar energy - Reference Solar Spectral Irradiance At The Ground At Different Receiving Conditions.

ISO/CIE 10526/D65: 08 (E) CIE Standard Colorimetric Illuminants.

ISO/CIE 10527: 07 (E) CIE Standard Colorimetric Observers.

4. TERMINOLOGY

Absorptance (α): The ratio of the absorbed radiant energy to the total incident radiant energy.

Angle of Incidence: The angle between the solar beam and the normal (perpendicular) to the plane on which it is incident. (The plane of incidence may be the aperture plane, the glazing plane, or any other plane of interest.)

Diffuse (adj.): Referring to radiometric quantities, indicates that flux propagates in many directions, as opposed to a direct beam, which refers to quasi-collimated flux from the sun, whose angular diameter is approximately 0.5° . When referring to reflectance, it is the directional hemispherical reflectance less the specular reflectance. Diffuse has been used in the past to refer to hemispherical collection (including the specular component). This use is deprecated in favor of the more precise term hemispherical.

Fenestration: Products that fill openings in a building envelope, such as windows, doors, skylights, curtain walls, etc., designed to permit or limit the passage of air, light, vehicles, or people.

Film: Fenestration attachment products which consist of a flexible adhesive-backed polymer film which may be applied to the interior or exterior surface of an existing glazing system. See Fenestration Attachment in NFRC 600.

Fritted Glass: Glass on which a pattern has been created by application of a ceramic material to the glass surface, which is subsequently fused at high temperature.

Gas-fill: The process of adding a gas between glazing panes. Term typically used to indicate gases other than air, such as argon and krypton.

Glass: An inorganic, amorphous substance, usually transparent, composed of silica (sand), soda (sodium carbonate), and lime (calcium carbonate) with small quantities of other materials.

Glazing: The act of installing the glazing system/glazing in-fill; (n.) The transparent or semi-transparent in-fill material in a glazing system.

Glazing System/Glazing In-fill: A generic term used to describe an in-fill material, such as glass, plastic, or other transparent or translucent material, or assembly of glazing material, spacer, and desiccant, used to enclose openings in a building created by a specific framing system.

Integrating Sphere: An optical device used to either collect flux reflected or transmitted from a sample into a hemispherical solid angle or to provide isotropic irradiation of a sample from a complete hemispherical solid angle. It consists of a cavity that is approximately spherical in shape with apertures for admitting and detecting flux and usually having additional apertures over which the sample and reference specimens are placed.

Interlayer: A layer of material acting as an adhesive between layers of glazing.

Irradiance: A radiometric term for the radiant flux in any or all directions in a hemispherical solid angle that is incident upon, passing through, or leaving a surface.

Monolithic (adj.): Glazing consisting of a single pane of transparent material (glass or plastic).

Opaque (adj.): Not allowing visible light to pass through.

Polarization: The condition of electromagnetic waves in which the transverse motion or field of the wave is confined to a plane or ellipse.

Radiation: The transfer of heat in the form of electromagnetic waves or photons from one body to another.

Rating: Performance values obtained using NFRC-approved procedures used for comparative purposes only (i.e., U-factor, SHGC, VT, etc.).

Rating System: A system that consists of NFRC simulation and test procedures for determining comparative fenestration product energy performance characteristics, as supported by the Certification Program.

Reflectance: The ratio of the reflected radiant flux to the incident radiant flux.

Solar (adj): (1) Referring to radiometric quantities, indicating that the radiant flux involved has the sun as its source or has the relative spectral distribution of solar flux; (2) referring to an optical property, having as its weighting function a standard solar spectral irradiance distribution.

Solar Heat Gain (SHG): The quantity of incident solar energy passing through a fenestration system. Included are both directly transmitted solar radiation as well as solar energy absorbed by the fenestration system and re-transmitted into the inside space.

Solar Heat Gain Coefficient (SHGC): The ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation. NFRC rates SHGC at normal incidence.

Solar Radiation: Electromagnetic radiation covering the spectral range from 300 to 4000 nm, coming from either natural direct beam solar radiation or from an artificial radiation source having a similar spectral distribution.

Spectral (adj): Indicating that the property or quantity was evaluated at a specific wavelength (λ), within a small wavelength interval ($\Delta\lambda$ about λ). Usually indicated by placing the wavelength symbol λ , as a subscript following the symbol for the quantity, as with E_{λ} , thereby indicating that the flux-related quantity is a concentration of flux at the indicated wavelength, or it may be placed inside parentheses following the symbol for the material property, as with $\alpha(\lambda)$. It is permissible to indicate the wavelength dependence of a flux quantity as follows: $E_{\lambda}(\lambda)$.

Specular (adj.): Indicating that the flux leaves a surface or medium at an angle of reflection or transmission numerically equal to the angle of incidence.

Thermal Transmittance, U-factor (U): See “U-factor.”

Transmittance: The ratio of the transmitted radiant flux to the incident radiant flux.

Visible Transmittance (VT): The ratio of visible radiation entering the space through the fenestration product to the incident visible radiation, determined as the spectral transmittance of the total fenestration system, weighted by the photopic response of the eye, and integrated into a single dimensionless value. Weighted by a standard solar spectrum.

Window: An assembled unit consisting of a frame/sash component holding one or more pieces of glazing functioning to admit light and/or air to an enclosure.

5. SIGNIFICANCE AND USE

The thermal performance of glazing materials utilized in building facades plays a major role in the consumption and conservation of energy. Transmittance and reflectance are important materials parameters used to calculate the thermal transmittance (U-Factor), solar heat gain coefficient (SHGC) and visible transmittance (VT) of glazing materials and systems.

6. MEASUREMENT PROCEDURE

This section describes how the optical property measurements of glazing or other test specimens are performed.²

6.1 Required Equipment

The instrument used for the measurements described herein shall be a double-beam ratio-recording spectrophotometer equipped with a four-port comparison-type integrating sphere. The integrating sphere shall be at least 150 mm in diameter. The sample shall be "wall mounted" against the sphere port rather than being center mounted or mounted at a distance from the sphere.

Note: The setup described above has become the de-facto commercial standard for this application.

6.2 Required Measurements

A complete set of measurements shall include the spectral transmittance and the reflectance from each side of the sample. Theoretically, the transmittance will be the same in either direction through a flat specular sample, but the reflectance, in general, is not. The data shall be collected at wavelengths from 300 nm to 2,500 nm at the minimum intervals specified in Table 1.

² The data from the measurements are typically stored in the glazing library database file of the WINDOW program.

Table 1- Minimum required measurement intervals.

Wavelength Range (nm)	Interval (nm)
300-380	5
380-780	10
780-2,500	100

6.3 Operational Guidelines

Each spectrophotometer model has different operating instructions and this procedure cannot account for these differences. The instruction manual provided by the instrument manufacturer should be used for instrument setup and for general operating procedure. The following additional points must be considered when making measurements:

6.3.1 Transmittance Measurement:

6.3.1.1 Calibration of Baseline or 100% Line:

The open reference beam serves as the standard for the 100% calibration. Cover the reflectance port of the sample beam (and the reference beam) with a diffusing material similar to that of the sphere wall (usually Spectralon). Perform a scan from 300-2500 nm. The ratio of the intensity of the sample beam to the intensity of the reference beam is recorded automatically in modern instruments. This calibration shall be performed at least once per day during measurement periods.

6.3.1.2 Calibration of Dark or 0% Line:

A zero correction is desirable especially for low transmitting materials. Block the sample beam as completely as possible. Sometimes a manual or automatic internal shutter is provided for this purpose. Perform a scan with the same instrument parameters as the baseline calibration. This calibration shall be performed at least once per day during measurement periods.

6.3.1.3 Sample Measurement

Insert the sample in the beam path normal to the beam with the sample ideally flush against the sample transmittance port of the sphere. Perform a scan with the same instrument parameters as the calibration scans. A different instrument mode is often available to distinguish calibration and sample scans so that the proper correction may be applied automatically by the software of the instrument. If this is not the case then perform the calculation manually as in the next section.

6.3.1.4 Correction Procedure for Transmittance

Make the following correction to obtain the final transmittance τ for each wavelength recorded:

$$\tau = \frac{S - Z}{B - Z}$$

Where S = the sample recording, Z = the zero recording and B = the 100% baseline recording.

Note: The above correction may be applied automatically by the instrument's software.

6.3.2 Reflectance Measurement:

6.3.2.1 Calibration of Baseline or 100% Line for Specular Materials (Relative Method):

As in transmittance mode, cover the reflectance port of the reference beam with a diffuse material such as Spectralon. In other words leave the material in place at all times. In this case, however, cover the reflectance port of the sample beam a calibrated specular mirror. Acceptable sources for this mirror include the National Bureau of Standards and Technology (NIST) or the National Physical Laboratory (NPL) or other institutions providing calibration traceable to NIST or NPL. Ideally this reference mirror would have a reflectance value similar to that of the specimen under test. In practice a single highly reflecting mirror is usually used for the wide range of sample reflectance. Perform a scan from 300-2500 nm. This calibration shall be performed at least once per day during measurement periods.

6.3.2.2 Calibration of Baseline or 100% Line for Specular Materials or Diffuse Materials (Absolute Method)

As in transmittance mode, cover the reflectance ports of both beams with a diffuse material such as Spectralon. Perform at scan from 300-2500 nm at the chosen instrument parameters. This calibration shall be performed at least once per day during measurement periods.

Note: This method has two advantages over the Relative Method of the previous section: 1) there is no need to perform two different baseline scans for transmittance and reflectance and 2) there is no need to correct for the reflectance of the standard mirror. The potential disadvantage for specular materials is a different distribution of light for reference and sample, but recent ILCs show that it is possible to make an accurate measurement either way. For diffuse materials there is no option but to use this Absolute Method.

6.3.2.3 Calibration of Dark or 0% Line:

A zero correction is desirable especially for low reflecting materials. Replace the material covering the reflectance port of the sample beam with a light trap. The sample cover supplied

with the instrument may not be adequate, unless totally opaque. Perform a scan with the same instrument parameters as the baseline calibration. This calibration shall be performed at least once per day during measurement periods

6.3.2.4 Correction Procedure for Reflectance

Make the following correction to obtain the final reflectance ρ for each wavelength recorded:

$$\rho = \frac{S - Z}{B - Z} \rho^*$$

Where S = the sample recording, Z = the zero recording, B = the 100% or baseline recording, and ρ^* = the known reflectance of the standard mirror. In the case of the absolute method, do not correct for the reflectance of the diffuse cover material and simply use:

$$\rho = \frac{S - Z}{B - Z}$$

Note: the instrument's software may automatically apply the above correction.

6.4 Noise Reduction:

Reducing noise to less than 1% of full transmittance is required and is best achieved by following the instructions of the instrument manufacturer. The specific parameters used are different for each instrument, but they will always involve a tradeoff between noise and scan time or number of scans.

6.5 Annual Calibration of Linearity and Wavelength

Calibrate linearity and wavelength scales of the spectrophotometers as recommended by the manufacturer or in accordance with Practice ASTM E 275

6.6 Special Materials

6.6.1 Coated Glazing:

In the case of coating materials subject to rapid degradation, in particular for silver-based low-e coatings, the specimen to be measured shall be freshly deposited and kept in a dry atmosphere prior to measurement.

6.6.2 Heat Treated Glazing:

For coatings subject to heat treatment, such as tempering, suitable representative samples cannot be directly cut from large tempered sheets. Two issues shall be addressed: 1) Assuring the appropriate thermal history of the sample; and 2) Assuring that the sample remains flat enough after heat treatment to measure accurately. For specular reflectance measurements, no deviation from flatness shall be permitted when visually checking the sample with a straight edge. Four separate measurements shall be taken and averaged, by rotating the sample 90 degrees between scans to assure uniformity.

6.6.2.1 Small sample method

Heat treat small coated samples (100 x100 mm), while supporting the samples so that they do not sag, in a lab furnace. Monitor temperature using an appropriate temperature sensor in the center of the sample. Match critical peak temperature to that of the exit of the commercial tempering line.

6.6.2.2 Broken Sample Method:

Use a larger heat-strengthened sample that can be broken down into smaller samples for measurement. Run a large sample through the tempering line with the proper set ups for the normal tempering of that product except with the quench is turned off. Break the sample into pieces and select one that is small enough to fit in the measurement apparatus and large enough to provide an accurate measurement.

6.6.3 Low-absorption glass

When a glass has a very low absorption level in any part of the solar spectrum, the sum of R+T will be very close to 100%. Noise in the spectrum can then cause R+T to fluctuate above 100%. In this case, the instrument parameters must be set to reduce the noise to less than 1% of full transmittance. This operation shall be noted in the reporting of the data and spectra both before and after smoothing should be shown.

Note: Usually this involves an unavoidable trade-off with scan speed. An alternative is to "smooth" the data or to make multiple scans and average.

7. CALCULATION OF RESULTS

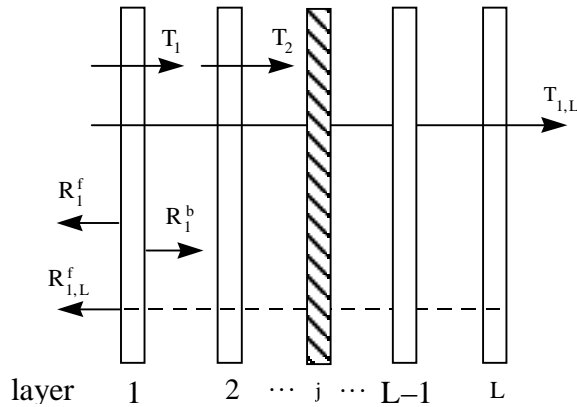
This section describes how the results from the optical property measurements are used to calculate the Visible Transmittance (VT), and Solar Heat Gain Coefficient (SHGC)³.

7.1 Multipaned IG Units

The net properties of a system consisting of layers separated by gas-filled gaps, as in Figure 7-1, can be calculated from the properties of the individual layers. These individual properties may be measured in accordance with Section 6. Neither wavelength, angle of incidence nor polarization appear explicitly in these equations. The most common usage of these equations is to calculate glazing system properties wavelength-by-wavelength at normal incidence, but they are equally valid if angle-dependent or polarization-dependent properties are available.

³ These results are calculated by WINDOW using the methodology specified in this document and NFRC 200.

Figure 7-1 Glazing system consisting of L plane parallel layers separated by gas-filled gaps



7.2 Computation of Spectral Averages

7.2.1 General Form of the Spectral Average

The weighted spectral average of property P of type 'x' is calculated according to:

$$P_x = \frac{\int_a^b \Phi_x(\lambda) P(\lambda) \Gamma_x(\lambda) d\lambda}{\int_a^b \Phi_x(\lambda) \Gamma_x(\lambda) d\lambda} \quad \text{Equation 7-1}$$

Where

- P = the property to be averaged
- Φ_x = a weighting function representing the relative spectral flux distribution of source radiation for average type 'x'
- Γ_x = a weighting function representing spectral average type 'x' where x = solar, photopic, or damage weighted

The integration is carried out between the wavelengths a and b .

In practice, P , Φ_x and Γ_x are measured or tabulated at discrete wavelengths, so that the expression above must be evaluated numerically over a set of N discrete wavelengths $\lambda_1, \lambda_2, \dots, \lambda_{N-1}, \lambda_N$. For solar-weighted property value computations, Γ_x will be 1.0.

7.2.2 Common Wavelength Set (CWS)

The wavelengths of discrete measurement may not be the same for all measurement apparatus, but the resulting measurements must be reported at a standard set of wavelengths. The Common Wavelength Set (CWS) is the set of wavelengths that the source flux, detector spectral response, and measured spectral data are mapped onto before performing the numerical integration. Because the minimum required wavelengths for measurement of P always include the endpoints a and b , the CWS also includes those wavelengths.

7.2.3 Method of Interpolation

In performing the wavelength mapping process, use linear interpolation as needed to obtain values at the CWS between measured or tabulated points in the source, receiver or sample data.

7.2.4 Numerical Integration

Use the trapezoidal rule to numerically approximate the integrals of equation 7-1:

$$\int_a^b f(\lambda)d\lambda \approx \sum_{i=1}^{N-1} \frac{f(\lambda_i) + f(\lambda_{i+1})}{2} \Delta\lambda_i \quad \text{Equation 7-2}$$

Where

$$\Delta\lambda_i = \lambda_{i+1} - \lambda_i$$

7.2.5 Spectral Weighting Functions⁴

At the current time, there are three types of average used by the NFRC: solar, photopic, and damage weighted⁵. Each average has its own particular set of weighting functions and wavelength limits:

Property	Source E	Receiver	Limits (a-b, nm)
Solar: T _s , R _s	Use the tabulated solar spectral irradiance distribution from Table 1, Column 2 of Standard ISO 9845-1:1992(E), as the source spectrum E _λ .	1.0 (100% absorption)	300-2,500
Photopic: T _p	Use the CIE D65 standard illuminant from Table 1, Column 3 of ISO/CIE 10526 as the source spectrum E _λ .	ISO/CIE 10527 Note #1	380-780
Damage: T _{dw}	Use the tabulated solar spectral irradiance distribution from Table 1, Column 2 of Standard ISO 9845-1:1992(E), as the source spectrum E _λ .	CIE 89-3 Note 2	300-700

[Note: Table 1, Column 3 of Standard ISO/CIE 10527, as the detector spectrum. This column of the table lists the color matching function \bar{y} of the CIE 1931 Standard (2°) observer.

⁴ From a purely technical point of view it is difficult to say that a particular function is absolutely correct or even the single best choice. Conditions vary from place to place, time to time and person to person. When performing annual energy or daylight simulations the ideal approach would be to vary the weighting function with time and place. In a relative rating system such as the NFRC system a single set of functions is chosen with known and accepted limitations. It is apparent that the functions used are not ideal under all conditions. Rather they are chosen based a balance between the latest most highly regarded research and practical considerations such as stability in the NFRC rating system and international harmonization.

⁵Sensitivity of materials with regard to relative color change under the action of solar radiation is a controversial issue. There are many other variables that may contribute to rate of damage or fading, such as temperature, type of material and type of pigment

This is equivalent to the CIE spectral luminous efficiency function V_λ].

[**Note:** CIE action spectrum taken from CIE 89/3 (where λ is in μm):]

$$S_{dm,rel}(\lambda) = e^{(3.6-12.0\lambda)} \quad \text{Equation 7-3}$$

7.3 Angular Dependence of Optical Properties

All properties are determined at normal incidence.

The properties at oblique incidence can be extrapolated from the measured properties at normal incidence using equations in chapter 7.2 of this reference: University of California-Lawrence National Berkeley Laboratory report # 33943 titled *Window 4.0-Documentation of Calculation Procedures*. (See section 3, references).

8. REPORT

See *NFRC 302-Verification Program for Optical Spectral Data* for reporting.

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