

NFRC 300-2026^[E0A0]

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) has developed and operates a uniform rating system for energy and energy-related performance of fenestration 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, 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 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 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 program (Certification Program) 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).

Through the Certification Program 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 Program, 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 which has been licensed by NFRC in accordance with the requirements of the NFRC 702. NFRC-licensed IAs also 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), or 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).

Ratings for products that are labeled with the NFRC Temporary and Permanent Label, or products that are listed on an NFRC Label Certificate in accordance with NFRC requirements, are considered to be NFRC-certified. NFRC maintains a Certified Products Directory (CPD), listing product lines and individual products selected by the manufacturer/responsible party for which certification authorization has been granted.

NFRC manages the Rating System and regulates the Product Certification Program (PCP), Laboratory Accreditation Program (LAP) and Certification Agency Program (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 program 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

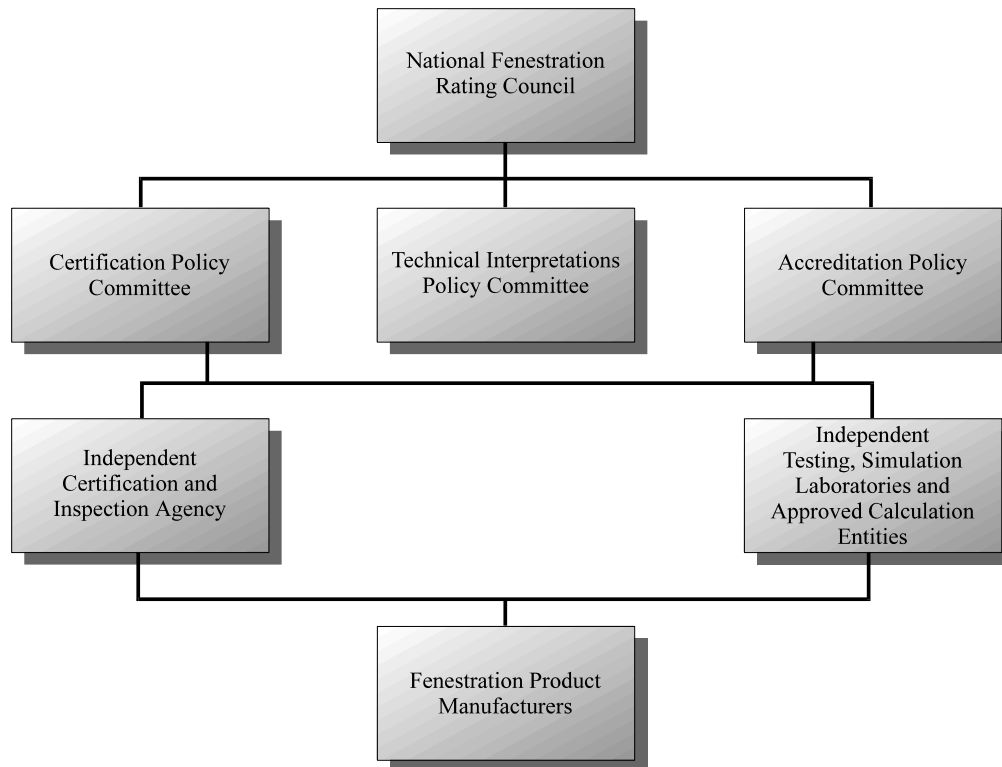


Figure 2

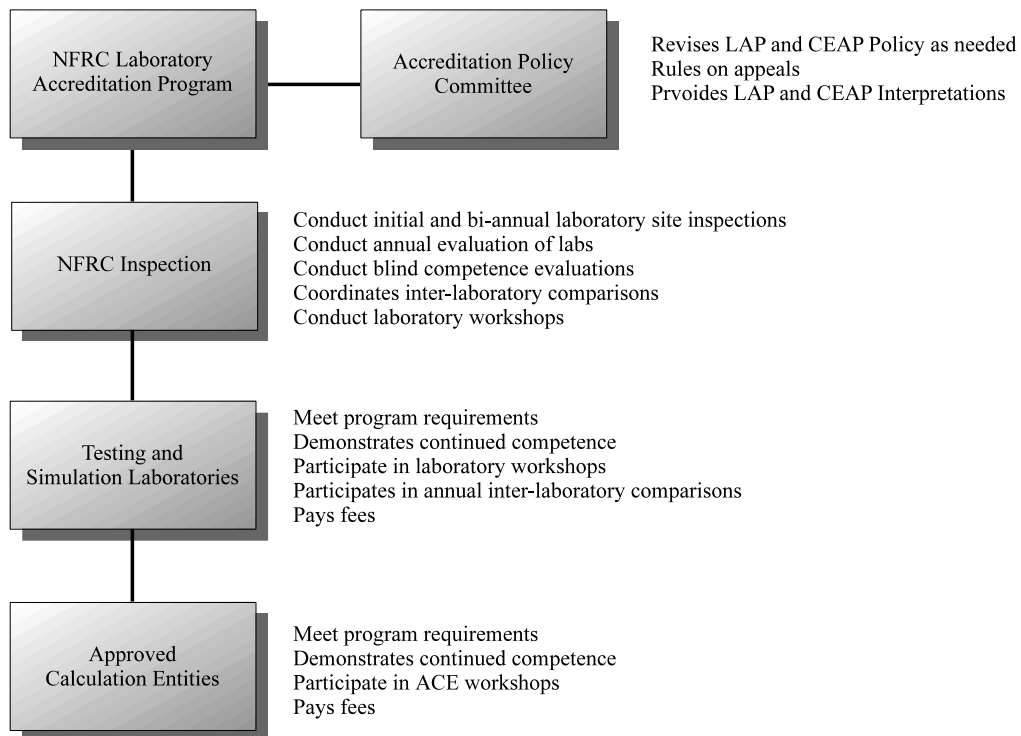
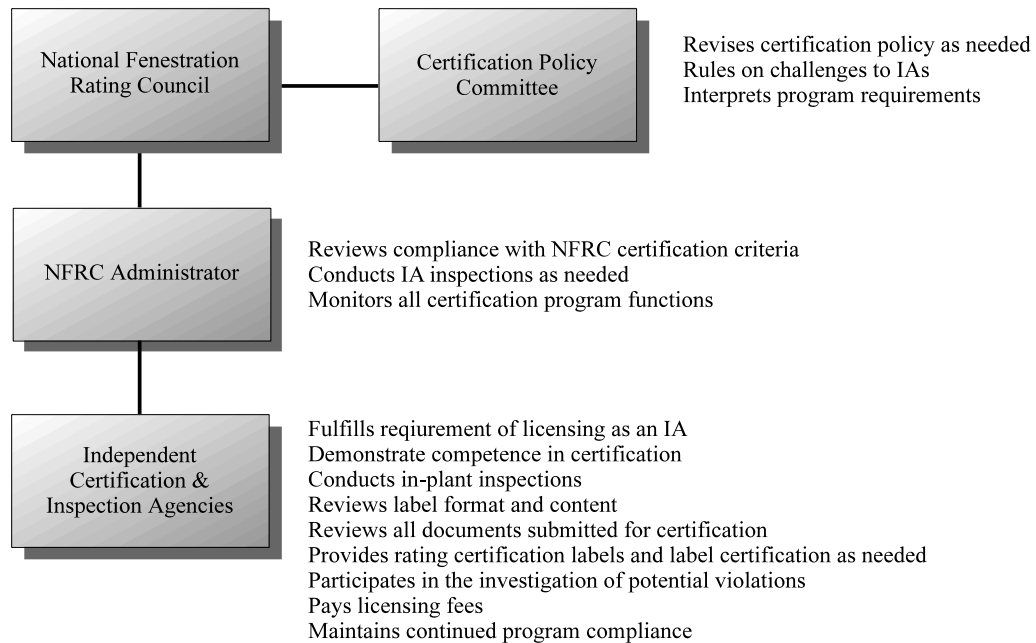


Figure 3



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 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 (diffuse) glazing, but significant errors are possible unless the measurement equipment correctly captures all the scattered light. 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 one of the three currently rated NFRC performance parameters: visible transmittance (VT) of a fenestration assembly at normal

incidence. A second parameter, the solar heat gain coefficient (SHGC¹), uses these spectrally averaged properties as well as 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.

For diffuse samples, separated diffuse and specular information is necessary to allow multi-layer calculations for systems with diffuse (scattering) elements.

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

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

- A. Monolithic homogeneous specular or slightly diffusing materials including glass plates, plastic sheets and flexible plastic film.
- B. Glass or plastic substrates as described in Section 2.1.A with coatings applied by chemical or vacuum deposition processes or with applied films.
- C. 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.
- D. Homogeneous diffusing materials are covered using this test method with special consideration for diffusing samples when noted. Examples of products in this category are fritted glass, etched glass, diffusing interlayers, and diffusing applied films. The product should be homogeneous on a large scale, i.e. it should not matter significantly where on the sample a measurement is carried out. It does not matter if the scattering is generated in the bulk of the material or by surface roughness.

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

¹ SHGC is also known as the total solar energy transmittance (TSET), solar factor, or g-value

procedures have yet been developed to determine the relevant parameters from such spectrophotometer measurements:

- A. Geometrically complex glazing or shading systems including but not limited to blinds, drapes, and woven shades
- B. Heterogeneous materials with features on the order of the spectrophotometer beam unless spatially averaged as described herein. (See Section 6.6.2.)
- C. Samples of a large thickness might be impossible to measure using standard instruments, either because multiple reflections are not captured or light is scattering in a way that is not captured by the instrument. Section 6.1 discusses the meaning of “large thickness” in this context.
- D. Curved glazing including but not limited to domed skylights;
- E. Light-redirecting products, including lens-like surfaces, and others that do not scatter light homogeneously.
- F. Products that lack homogeneity on a large scale (e.g. extruded honeycomb structures).

3. REFERENCED DOCUMENTS

ASTM E 903-12	Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres.
ASTM E275-08 (2013)	Standard Practice for Describing and Measuring Performance of Ultraviolet and Visible 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 (https://windows.lbl.gov/publications/window-40-documentation-calculation)
ISO 9050:2003	Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
ISO 15099:2003	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.)

Bi-Directional Scattering Distribution Function (BSDF):

A measure of angle resolved scattering properties of a sample in the unit [sr⁻¹]. Typically described for incident and outgoing angle. The property is similar to Transmittance and Reflectance, with the exception that its definition is with respect to the outgoing solid angle.

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. In measurements, the property of diffuse transmittance and diffuse reflectance is defined by the instrument geometry through the size of the sphere and geometry of the specular exit port in combination with the beam cross-section.

Direct (adj.):

Referring to radiometric quantities, indicates that flux propagates in nearly the same direction, such as the quasi-collimated flux from the sun, whose angular diameter is approximately 0.5°. However, in the context of measured direct properties, as in the difference between a hemispherical and diffuse measurement, the angle is defined by the instrument geometry. Common commercial instruments range between 3-5°.

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 coating has been created by application of a ceramic material to the glass surface, which is subsequently fused at high temperature. The coating can fully, or partially in a pattern, cover the substrate; the coverage is usually quantified by the percentage of the surface area of the glass substrate that is covered by the coating.

Front/back symmetric samples:

A product where the composition of layers (including the consideration of the location and orientation of any coatings, films, surface treatments, or other similar features) is the same front to back as it is back to front. Examples are uncoated monolithic samples and laminate samples with a symmetric interlayer stack between two identical monolithic glazing layers.

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.

Hemispherical (adj.):

Referring to radiometric quantities, indicates flux in all directions on one side of the geometric plan of a sample. Hemispherical collection includes both the diffuse and the specular components. Also known as total or total hemispherical and can be used to describe either transmittance or reflectance.

Integrated 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 and coated internally with a material that has a high Lambertian reflectance. The sphere is fitted with apertures for admitting and detecting flux and usually has 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.

Lambertian (adj.):

An idealized description of light-scattering where the bi-directional scattering distribution function is constant with regard to outgoing angle.

Monolithic:

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

Opaque:

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.

Sphere Aperture:

Opening in an integrating sphere. Examples are sample apertures which allow a sample to be mounted, and a specular exit port which allows a direct beam to escape the sphere.

Thermal Transmittance, U-factor (U):

See “U-factor.”

Transmittance:

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

U-factor (U):

Also called “Overall Thermal Transmittance.” The air-to-air thermal conductance of the glazing system including associated air films.

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.

6.1 Required Equipment

The instrument used for the measurements described herein shall be a double-beam ratio-recording spectrophotometer equipped with a multiple-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.

Special care has to be taken to make sure that no significant light losses are occurring for scattering samples or from multiple reflections from the back of thick samples or scattering samples in general.

Note: A way to quantify the maximum thickness of a transparent sample that can be measured accurately in reflectance is to use a known sample, where the reflectance is measured accurately, and draw it back from the reflectance sample position until the reflectance signal decreases. Using parallel spacers will ensure that the sample stays at a constant angle with respect to the beam.

For diffuse samples as defined by 2.1.4, it is important that the sphere aperture where the sample is mounted is greater than 90 mm in diameter to capture scattered light and to not suffer significant light loss as long as the ratio between beam area and port area is less than 0.05 and the beam is centered. The sphere used to directly measure the total hemispherical value, and possibly also the diffuse component, has to be larger than 250 mm diameter to accommodate such a large aperture, and the ratio between the aperture area and the sphere area should be less than 0.04. The specular component can be calculated from measurements of total hemispherical and diffuse values using a smaller sphere (150 mm diameter minimum) with a smaller aperture, as the error in total and diffuse values cancel out. Alternatively, an integrating sphere with large-area illumination of the sample and a sample aperture of less than a tenth of the illumination of the cross-section could be used to measure normal-hemispherical transmittance of diffuse samples.

These equipment requirements are written to accommodate a majority of samples. However, special equipment might be required to handle samples that are too thick for standard instruments. Guidance to qualify if a sample is too thick for the equipment used is given in Section 6.7.4.

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 2500 nm at 5 nm intervals.

Front/back symmetric samples are an exception and can be submitted with the same reported reflectance spectrum for both the front and the back reflectance. This reported reflectance can either be from a single measurement or the average between the front and back measurements. It is also allowed to report the actual measured front and back data following the general rule above.

6.2.1 Additional measurements for diffuse samples

Spectral data from 300 nm to 2500 nm at 5 nm intervals shall be measured to provide a total of 8 different properties as combination of the 3 property pairs reflectance/transmittance, specular/diffuse, and front/back. Depending on instrument design, it is possible to measure specular, diffuse, and/or total (i.e. specular + diffuse) values, and by using any two of those three measurements it is possible to obtain a third. As noted previously in 6.1, it might be necessary to determine the specular values and the diffuse or total values with two different sizes of integrating spheres. The requirement to measure transmittance from both front and back is to accurately characterize samples with different surface roughness on front/back and samples where the bulk scattering in an absorbing medium is not symmetric between the front and back surface. Front/back symmetric samples are an exception and can be submitted with the same reported spectra for both the front and the back properties. These reported data can either be from a single measurement or the average between the front and back measurements. It is also allowed to report the actual measured front and back data following the general rule above.

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 Instrument Verification

After calibration, for documentation purposes, it is good practice to record a “100% measurement” without any sample in the sample beam path. Repeating this type of measurement at the end of the measurement session is a method to verify that there is no drift or other change in the system. For long measurement sessions, this should be carried out as often as is needed to track the system drift. As an alternative to measuring with no sample in place and expecting 100% values, the instrument verification can be performed with a sample of a stable material with the results compared to expected values.

Note: as the reference material used in the sample reflectance port for the 100% baseline can be removed for reflectance measurements it might be put back in a slightly different position or rotation. If the reference sample is not perfectly homogeneous, it might result in a change in 100% level and the 100% measurement (for instrument verification) should be repeated. Alternatively, this uncertainty can be minimized by scheduling to do all transmittance measurements in a single session before the reflectance measurements.

6.3.1.4 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.

6.3.1.5 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.

6.3.1.6 Additional Transmittance Measurements for Diffuse Samples

Three different values are used to describe scattered light: direct-hemispherical (total), direct-diffuse, and direct-direct (specular). These three values are related through the simple equation

$$\tau^{dir-hem}(\lambda) = \tau^{dir-dif}(\lambda) + \tau^{dir-dir}(\lambda).$$

Due to that relationship it is only necessary to measure two out of the three properties and still obtain a complete description. The recommended method, which is easiest to accomplish with commercial integrating spheres, is to measure the direct-hemispherical and direct-diffuse values and then calculate the direct-direct component for each wavelength by subtraction in accordance with the equation above.

If the larger sphere described in 6.1 is not able to measure the direct-diffuse values (and can only measure direct-hemispherical values), then the direct-direct value is determined using additional measurements with the smaller sphere as described in 6.3.1.6.4.

The baseline calibration described in 6.3.1.1 has to be done with a calibrated diffuse reflectance standard, ideally one of the same materials as the sphere wall. All transmittance quantities measured on samples should have the baseline correction described in 6.3.1.5 applied.

6.3.1.6.1 Measurement of Direct Hemispherical Value

The direct-hemispherical (L) measurement captures all the transmitted light and the set-up is the same as described in 6.3.1.4. An additional correction is described in 6.3.1.6.6 below.

6.3.1.6.2 Measurement of Direct-Diffuse Component

The direct-diffuse component of the light is the part that is not considered specular. In most instruments the set-up is almost identical to 6.3.1.4 except for removal of the specular light. Exclusion of the specular component is done by opening the sphere wall where the specular component would end up and make sure that the light exiting the port does not get back inside the sphere to the detector, such as by using a light trap. An additional correction is described in 6.3.1.6.6 below.

NOTE: This measurement will depend on the geometry of the integrating sphere and the intensity distribution of the light onto the sample. The beam size makes it complicated to specify a single angle for which the instrument excludes light as it in reality becomes a distribution of angles that are excluded.

NOTE: Performing a direct-diffuse measurement without any sample is a good way to verify that the light trap has very low reflectance.

6.3.1.6.3 Determination of Direct-Direct Component

As mentioned in 6.3.1.6, measurement of direct-hemispherical and direct-diffuse values, using a single sphere and not moving the sample between the consecutive measurements of direct-hemispherical and direct-diffuse values, is the recommended method, as this is easiest to accomplish with commercial integrating spheres. In this case, the direct-direct values are determined according to the equation in 6.3.1.6 rearranged as shown below.

If the large sphere described in 6.1 is not able to measure the direct-diffuse values, a smaller sphere is used to determine the direct component:

$$\tau^{dir-dir}(\lambda) = \tau^{dir-hem, small}(\lambda) - \tau^{dir-dif, small}(\lambda)$$

Where “small” refers to the smaller sphere as described in 6.1.

If a large sphere according to 6.1 is able to measure the direct-diffuse transmittance, then the direct-direct component is

$$\tau^{dir-dir}(\lambda) = \tau^{dir-hem, large}(\lambda) - \tau^{dir-dif, large}(\lambda)$$

Where “large” refers to the larger sphere as described in 6.1.

Regardless of if the sphere used is large or small, the procedure in section 6.4 should be used to reduce the influence of sphere design on the $\tau^{dir-dir}$ value.

6.3.1.6.4 Determination of Direct-Diffuse Component (when using two spheres)

If the large sphere described in 6.1 is not able to measure the direct-diffuse values, the direct-diffuse values should then be calculated by subtracting the direct component determined using the small sphere (according to 6.3.1.6.3) from the

total hemispherical component measured using the large sphere:

$$\tau^{dir-dif}(\lambda) = \tau^{dir-hem, large}(\lambda) - \tau^{dir-dir}(\lambda)$$

6.3.1.6.5 Correction procedures for diffuse samples

When the 100% line is measured according to 6.3.1.1, it gives the response for a perfectly specular beam, i.e., all the light gets diffused at sphere wall opposite the entrance port. Light scattered by the sample, in theory, need one less wall reflection (on average) to reach the detector. Therefore, it is necessary to multiply the direct-diffuse component with the reflectance of the used reference material according to

$$\tau^{dir-dif\ correct}(\lambda) = \tau^{dir-dif}(\lambda)\rho_{reference}(\lambda)$$

where $\rho_{reference}(\lambda)$ is the tabulated reflectance of the white reference material covering the sample transmittance exit port for the large sphere used to obtain the 100% level in step 6.3.1.1 and mentioned in 6.3.1.6. The equation above is used to correct either the direct-diffuse component measured directly by the large sphere or the calculated direct-diffuse component discussed in 6.3.1.6.4 if two spheres are used.

There is no need to correct a direct-direct component that is determined from the subtraction of direct-diffuse from direct-hemispherical measurements made in a single sphere without moving the sample, because the error is contained in both measurements and cancels out.

If there is a need to report the direct-hemispherical values (and there might not be), these values would also need to have a correction made as the measured values would have an error for the diffuse component as mentioned above. The corrected direct-hemispherical values are therefore determined according to:

$$\tau^{dir-hem\ correct}(\lambda) = \tau^{dir-dif\ correct}(\lambda) + \tau^{dir-dir}(\lambda)$$

Note: This correction method is a simplified version based on a research presented in references (1) and (2).

6.3.2 Reflectance Measurement for Specular Samples

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 with 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 (Absolute Method)

As in transmittance mode, cover the reflectance ports of both beams with a properly cleaned diffuse material such as Spectralon. Perform a 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 Instrument Verification

After calibration, for documentation purposes, it is good practice to record a “100% measurement” with the same material as for 100% calibration covering the sample reflectance port. Repeating this type of measurement at the end of the measurement session is also recommended. For long measurement sessions this should be carried out as often as is needed to track the system drift. As an alternative to measuring with the reference material and expecting reference material values, the instrument verification can be performed with a sample of a stable material with the results compared to expected values.

Note: As the reference material must be removed for reflectance measurements, it might be put back in slightly different position or rotation. If the reference sample is not perfectly homogeneous, it might result in a change in 100% level and the 100% measurement should be repeated.

6.3.2.5 Sample Measurement

This sample should be mounted flush against the sample reflectance port of the sphere, i.e., where the reference is mounted during the baseline measurement. 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.

The sphere is typically designed so that the beam is incident on the sample at an angle near normal (6-12 degrees angle of incidence) rather than at exactly normal angle of incidence.

6.3.2.6 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 for specular samples (and for diffuse samples), 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.

6.3.3 Reflectance Measurements for Diffuse Samples

Similar to transmittance, three different values are used to describe scattered light: direct-hemispherical (total), direct-diffuse, and direct-direct (specular). They are related through the simple equation

$$\rho^{dir-hem} = \rho^{dir-dif} + \rho^{dir-dir}$$

Due to the relationship it is only necessary to measure two out of the three properties and still obtain a complete description. The recommended method, which is easiest to accomplish with commercial integrating spheres, is to measure the direct-hemispherical and direct-diffuse values and then calculate the direct-direct component by subtraction.

6.3.3.1 Baseline measurement for reflectance measurement for diffuse samples

For a baseline measurement, cover the reflectance ports of both beams with a diffuse material such as Spectralon. The material covering the sample reflectance port must be a calibrated diffuse reflectance standard with similar properties as the sphere wall. Perform a scan from 300-2500 nm at the chosen instrument parameters. Also perform the Calibration of Dark or 0% Line as in 6.3.2.3. These baselines shall be performed at least once per day during measurement periods.

All reflectance quantities measured on samples should have the baseline correction described in 6.3.2.6 applied.

6.3.3.2 Measurement of direct-hemispherical value

The direct-hemispherical measurement captures all the reflected light and the set-up is the same as described in 6.3.2.5. An additional correction is described in 6.3.3.6 below.

6.3.3.3 Measurement of direct-diffuse component

The direct-diffuse component of the light is the part that is not considered specular. In most instruments the set-up is almost identical to 6.3.2.5, except for removal of the specular light. Exclusion of the specular component is done by opening the sphere wall where the specular reflected component would impinge and make sure that the light exiting the port does not get back inside the sphere to the detector. An additional correction is described in 6.3.3.6 below.

Note: This measurement will depend on the geometry of the integrating sphere and the intensity distribution of the light onto the sample. The beam size makes it complicated to specify a single angle for which the

instrument excludes light as it in reality becomes a distribution of angles that are excluded.

Note: Performing a direct-diffuse measurement without any sample is a good way to verify that the light trap has very low reflectance.

6.3.3.4 Determination of direct-direct component

As mentioned in 6.3.3, measurement of direct-hemispherical and direct-diffuse values in a single sphere, without moving the sample between the two measurements, is the recommended method, as this is easiest to accomplish with commercial integrating spheres. In this case, the direct-direct values are determined according to the equation in 6.3.3 rearranged as shown below.

If the large sphere described in 6.1 is not able to measure the direct-diffuse values, a smaller sphere is used to determine the direct component:

$$\rho^{dir-dir}(\lambda) = \rho^{dir-hem, small}(\lambda) - \rho^{dir-dif, small}(\lambda)$$

Where “small” refers to the smaller sphere as described in 6.1.

If a large sphere according to 6.1 is able to measure the direct-diffuse transmittance, then the direct-direct component is

$$\rho^{dir-dir}(\lambda) = \rho^{dir-hem, large}(\lambda) - \rho^{dir-dif, large}(\lambda)$$

Where “large” refers to the larger sphere as described in 6.1.

6.3.3.5 Determination of direct-diffuse component (when using two spheres)

If the large sphere described in 6.1 is not able to measure the direct-diffuse values, the direct-diffuse values should then be calculated by subtracting the direct component determined using the small sphere (according to 6.3.3.4) from the total hemispherical component measured using the large sphere:

$$\rho^{dir-dif}(\lambda) = \rho^{dir-hem, large}(\lambda) - \rho^{dir-dir}(\lambda)$$

6.3.3.6 Correction procedures for diffuse samples

When the baseline is measured according to 6.3.3.1, it gives the response for a perfectly diffuse sample, i.e. all the light gets diffused at reflectance sample port. Therefore, it is necessary to multiply the measured direct-diffuse component with the reflectance of the reference material from the baseline scan according to

$$\rho^{dir-dif\ correct}(\lambda) = \rho^{dir-dif}(\lambda)\rho_{reference}(\lambda)$$

Where $\rho_{reference}(\lambda)$ is the tabulated reflectance of the reference used to obtain the 100% baseline level in step 6.3.3.1 for the large sphere.

The equation above is used to correct either the direct-diffuse component measured directly by the large sphere or the calculated direct-diffuse component discussed in 6.3.3.5 if two spheres are used.

The specular component of the reflected light interacts with the sphere the same way as the baseline beam, i.e. it gets diffused by the sphere wall. There is no need for a correction assuming that the detector response is the same for light scattered from the white material covering the specular reflectance exit port and the reflectance sample port and that the reflectance of the white material covering the specular exit port and the baseline reference sample is the same. Likewise, there is no need to correct a direct-direct component that is determined from the subtraction of direct-diffuse from direct-hemispherical because the error is contained in both measurements and cancels out.

If there is a need to report the direct-hemispherical values (and there might not be), these values would also need to have a correction made as the measured values would have an error for diffuse samples as mentioned above. The corrected direct-hemispherical values are therefore determined according to:

$$\rho^{dir-hem\ correct}(\lambda) = \rho^{dir-dif\ correct}(\lambda) + \rho^{dir-dir}(\lambda)$$

Note: This correction method is a simplified version based on research presented in references (1), (2), and (3).

6.4 Method for Harmonizing Direct-Direct Values Between Different Sphere Geometries

Direct-direct values can be different between different instruments as the sphere geometry defines the amount of light that is defined as specular. This section provides a practical way to increase the accuracy of the calculated value.

Agreement for transmittance can be achieved by a process where the sample is pulled back from the sphere to simulate a smaller specular exit port.

There are two sequential tests needed to quantify if the sample is considered critical, and in need of special treatment for measurement with a specific sphere. If either of those tests come out negative, the direct-direct component can be obtained as described in 6.3.

However, if there is a difference, there is a different way to measure the value.

This method is considered valuable even though it only works for transmittance measurements, as transmitted haze can be used as a metric for privacy and visibility through a glazing.

6.4.1 Instrument Requirements

The metric used to harmonize between spheres is the ratio between the area of the specular transmittance port and the total sphere area. E.g. Labsphere's 150 mm diameter sphere has a port diameter of 25 mm resulting in an area ratio $AR = 0.0069$.

There is no need to make a correction if the area ratio is in the range from 0.0035 to 0.004, inclusive. Only spheres with larger area ratio can use this method.

Measurements will be taken with the sample flush against the sphere as is normal, but also at a distance from the sphere wall.

6.4.2 Verifying if a Specific Sample is Critical for a Specific Sphere

First we define the direct-direct (or normal-normal) normal transmittance as

$$\tau^{dir-dir}(\lambda, \Delta) = \tau^{dir-hem}(\lambda, \Delta) - \tau^{dir-diff}(\lambda, \Delta)$$

Where λ is the wavelength and Δ is the distance the sample has been pulled back from the sphere wall.

Note: it does not matter if the measured transmittance is with a small or large sphere, as discussed in 6.3.1.6.3.

The first check is to obtain $\tau^{dir-dir}(550\text{nm}, 0\text{mm})$. If this value is smaller than 0.005, no compensation is needed. It is considered to be small enough that a compensation is not significantly improving accuracy.

The second measurement, if needed, is $\tau^{dir-dir}(550\text{nm}, \delta\text{mm})$, where δ is the distance at which the effective area ratio between port and sphere is 0.00375, note that the distance is sphere dependent².

Now we can calculate the gradient

$$\gamma = \frac{\tau^{dir-dir}(550 \text{ nm}, 0 \text{ mm}) - \tau^{dir-dir}(550 \text{ nm}, \delta \text{ mm})}{AR - 0.00375}$$

Where AR and δ are the sphere specific numbers. If γ is smaller than 2 there is no need to do a correction.

6.4.3 Definition of Specular Transmittance for a Critical Sample

If $\tau^{dir-dir}(550\text{nm}, 0\text{mm})$ is greater or equal to 0.005 and γ is greater or equal than 2, the sample is considered critical when measured using that specific integrating sphere, and $\tau^{dir-dir}$ should be obtained by measurement of $\tau^{dir-hem}$ and $\tau^{dir-diff}$ with the sample pulled back δ mm from the sphere port. As discussed in 6.3.1.6.5 both of these measurements are wrong, but in a way that cancels out when they are subtracted from each other.

6.5 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.

² For the 150 mm Labsphere integrating sphere, δ is 54.1 mm. This is obtained by solving $0.00375 = (25/2)^2 / (4 * ((150 + \delta)/2)^2)$. Replace 25 and 150 for other spheres as needed.

It might be hard to maintain the same quality of signal when using a larger sphere as required for scattering sample. If the signal above 2300 nm is too noisy it can be acceptable to smooth it or do a flat extrapolation to obtain physical values in this wavelength range.

6.6 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

6.7 Special Materials

6.7.1 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.

6.7.2 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.

6.7.2.1 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.

6.7.2.2 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.

6.7.3 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.

6.7.4 Thick Samples

Sample thickness influences the light path from the source to the detector. The thickness of specular samples influences the displacement of back surface reflectance, which at some thickness will cause part of the reflected beam to miss the detector. The thickness of diffuse samples increases the distance from the sample center to where light exits the sample, this can cause a part of the light not to enter the entrance port to the integrating sphere. To further complicate matters, light loss from a diffuse sample is influenced by if the scattering is at the front or back surface, or in the bulk of the sample.

Due to the complex interaction between sample and instrument, it is impossible to define an exact thickness limit. Most specular instruments handle samples up to 15 mm and the large integrating spheres discussed for measuring diffuse samples in this document are expected to handle samples of similar thickness.

Note: It is possible to use a thinner sample and offset it to simulate a thicker sample. This can give some insight to if the sample is too thick or not.

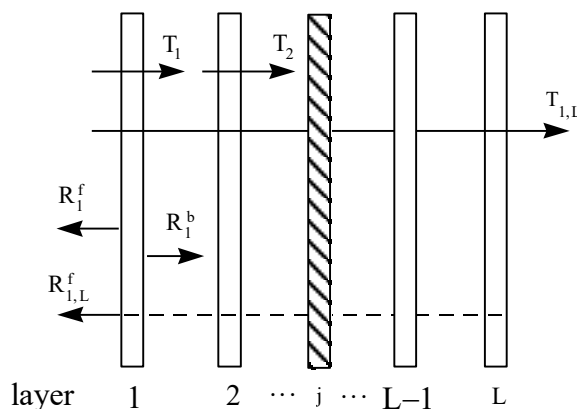
7. CALCULATION OF RESULTS

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.

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



7.1.1 Calculation of Multi-pane IG Units with One or More Diffusing Elements

As for specular samples, IGs with multi-pane systems containing diffuse glass are measured layer by layer and combined through calculation rather than measurement of the whole IG. ISO 15099 describes methods for calculation of multi-pane systems with diffusing elements. If a bi-directional

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

scattering distribution function is available a detailed calculation can be carried out.

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: Ts, Rs	Use the tabulated solar spectral irradiance distribution from Table 1, Column 2 of Standard ISO 9845-1:1992(E), as the source spectrum Eλ.	1.0 (100% absorption)	300-2,500
Photopic: Tp	Use the CIE D65 standard illuminant from Table 1, Column 3 of ISO/CIE 10526 as the source spectrum Eλ.	ISO/CIE 10527 Note #1	380-780
Damage:	Use the tabulated solar spectral irradiance	CIE 89-3	300-700

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

T _{dw}	distribution from Table 1, Column 2 of Standard ISO 9845-1:1992(E), as the source spectrum E _λ .	Note #2	
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[**Note #1:** 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. This is equivalent to the CIE spectral luminous efficiency function V_λ .]

[**Note #2:** CIE action spectrum taken from CIE 89/3 (where λ is in μm):]

$$S_{dm,rel}(\lambda) = e^{(3.6-12.0\lambda)}$$

Equation 7-3

7.3 Angular Dependence of Optical Properties

All properties are determined at normal incidence.

The properties of specular samples 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 Berkeley National Laboratory report # 33943 titled *Window 4.0-Documentation of Calculation Procedures*. (See Section 3, Referenced Documents).

7.3.1 Angular Dependence of Diffuse Products

Using the empirical equations derived for non-monolithic specular products is an initial approximation. To improve accuracy there is a need for an improved equation that takes scattering properties and sample thickness into account as well as surface roughness.

8. REPORT

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

9. REFERENCES

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