National Fenestration Rating Council Incorporated

NFRC 203-2014[E2A1E2A2]

Procedure for Determining
Visible Transmittance of Tubular Daylighting Devices

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National Fenestration Rating Council®

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 Certificate of Authorization (CA) 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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Figure 1

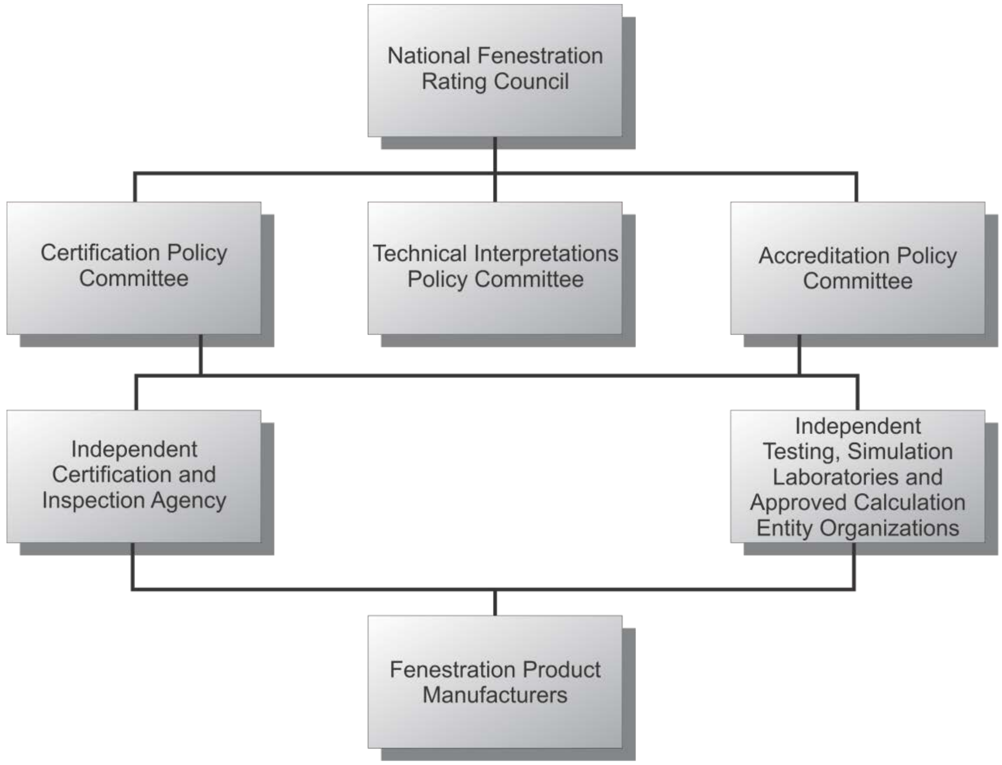


Figure 2

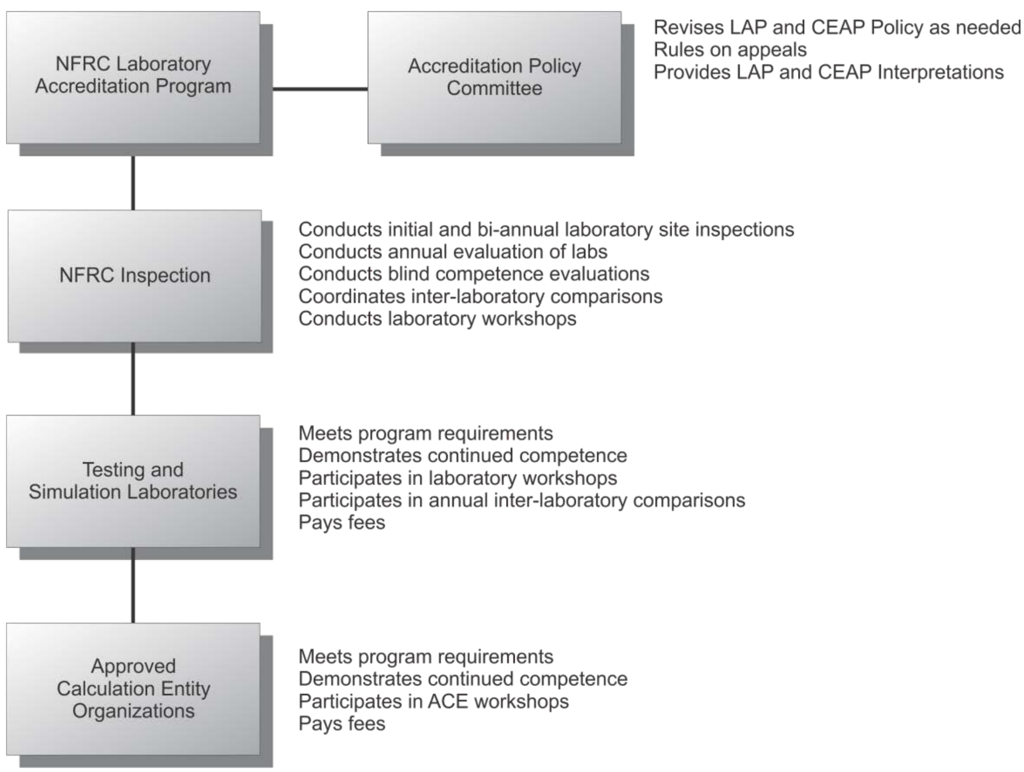
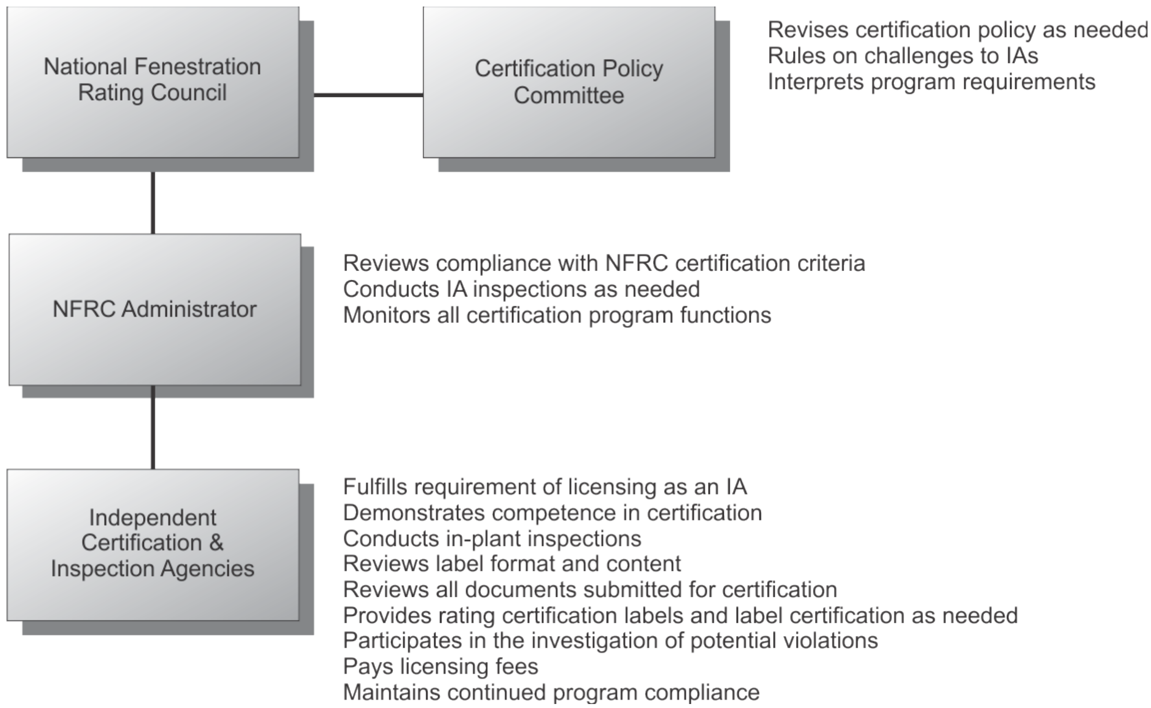


Figure 3



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

To specify a test method for measuringdetermining the visible transmittance (VT) of Tubular Daylighting Devices (TDD/HTDD) at an NFRC pre-determined set of representative annual solar incidence angles in accordance with ASTM E1175 (except where noted), and determining the annual visible transmittance rating (VT_{annual}) according to a prescribed weighted-average method.

2. SCOPE

2.1 Products and Effects Covered

Tubular Daylighting Devices (TDD) and Hybrid Tubular Daylighting Devices (HTDD).

2.2 Products and Effects Not Covered

The following products and effects are not covered:

2.2.1 Large specimens exceeding 24 in. in overall diameter or length of the largest side, for devices that are rectangular or non-circular;

2.2.2 Dynamic TDDs with solar tracking mirrors integrated into the device

2.3 Sample Requirements

Visible transmittance (VT) measurements of the TDDs shall be determined using ASTM E1175.

2.3.1 The sample size shall be in accordance with ANSI/NFRC 100, Table 4-3.

2.3.2 Each unique combination of frame or transparent material characteristics shall be treated as a different product and shall be tested separately using this procedure.

3. DEFINITIONS

Definitions and terms are in accordance with terminology in ASTM E972, ASTM E1084, ASTM C168, ASTM E631, ASTM E772 and ASTM E1175 unless otherwise defined in this document.

Diffuse: Property of the transmitting material where emerging rays are transmitted nearly uniformly in all directions.

Illumination: In this document only the portion of solar radiant energy from 380 to 760 nm is of interest.

Large Diameter Integrating Sphere: Also known as LDIS

Photometer: An instrument for measuring luminous intensity, luminous flux or illuminance.

Photopic Response: The spectral response of the average human eye when fully adapted to daylight conditions.

Solar Heat Gain Coefficient (SHGC): The ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and that portion of the absorbed solar radiation, which is then reradiated, conducted, or convected into the space.

Specular: Property of the transmitting material where emerging rays are transmitted in the direction of incidence.

Tubular Daylighting Device (TDD): A non-operable device primarily designed to transmit daylight from a roof surface to an interior ceiling surface via a tubular conduit. The device consists of an exterior glazed weathering surface, a light transmitting tube with a reflective inside surface and an interior sealing device, such as a translucent ceiling panel. See also Hybrid Tubular Daylighting Device.

Hybrid Tubular Daylighting Device (HTDD): A tubular daylighting device (TDD) whose light transmitting tube consists of more than one material and/or has more than one geometry throughout its length. Typically used with suspended ceilings or to illuminate spaces without ceilings.

Visible Transmittance, Annual (VT_{annual}):.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, and including weighting factors representing the percentage of time that the sun spends within 18 specific Sky Zones, relative to the time that Solar Altitude angles are between 15º and 75º, and Solar Azimuths are between +/- 75º from true south, for a site located in Middle America which is represented by a 40º North Latitude.

Port: integrating sphere aperture

Solar Altitude Angle (SALT), β: altitude angle of sun above the horizontal, decimal degrees**.**

Solar Azimuth, Φ**:** azimuth angle of sun measured from due south. The solar azimuth, Φ, is positive for afternoon hours and negative for morning hours. Measured in decimal degrees.

Surface Azimuth, Ψ: azimuth angle of a vertical plane through the normal (perpendicular) to a planar surface measured clockwise (looking down on the Earth's surface) from due south (e.g. vertical surfaces that face west have a positive surface azimuth, Ψ; those facing east have a negative surface azimuth.)

Surface Tilt, Σ:, tilt angle of the plane of planar surface from horizontal (e.g., tilt of a horizontal surface equals 0°, and vertical surface equals 90°), decimal degrees.

Surface-Solar Azimuth, γ: angular difference between the solar azimuth, *Φ*, and the surface azimuth, *Ψ*. If the surface-solar azimuth, γ, is greater than 90°or less than –90°, the surface is in the shade. This is a relative solar angle, which is measured in decimal degrees from the plane of the surface. $\gamma = \Phi - \Psi$

Angle of incidence, θ: The angle between the line normal to the irradiated surface and the earth-sun line, *decimal degrees.*

Relative Solar Altitude Angle (RSALT), θ_R: angular difference between the solar altitude angle, *β,* and the surface tilt angle of the aperture plane, Σ, when the earth-sun line is contained in a vertical plane also containing the surface normal of the aperture. This is a relative solar angle, which is measured in decimal degrees. $\theta_R = \beta - \Sigma$ (See Figures 3-2 and 3-3)

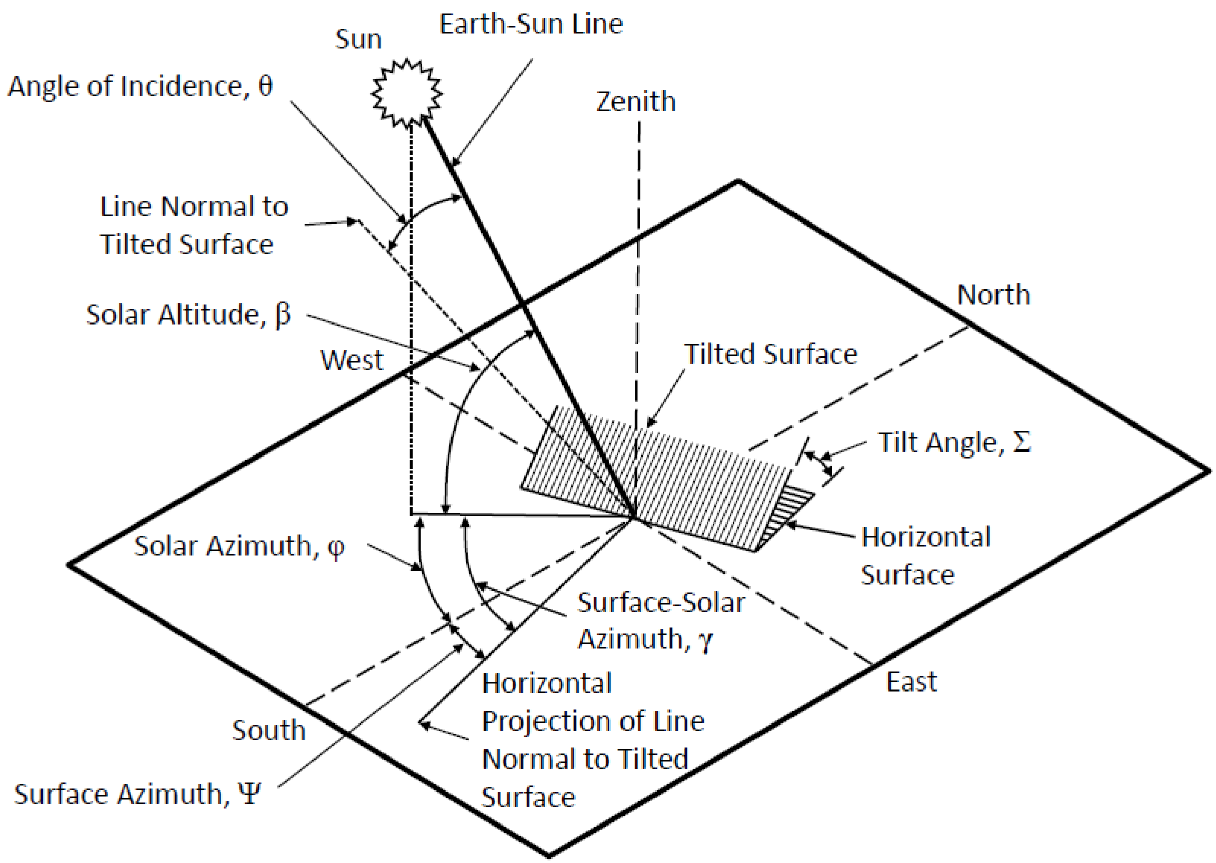

Figure 3-1. Solar Angle Definitions

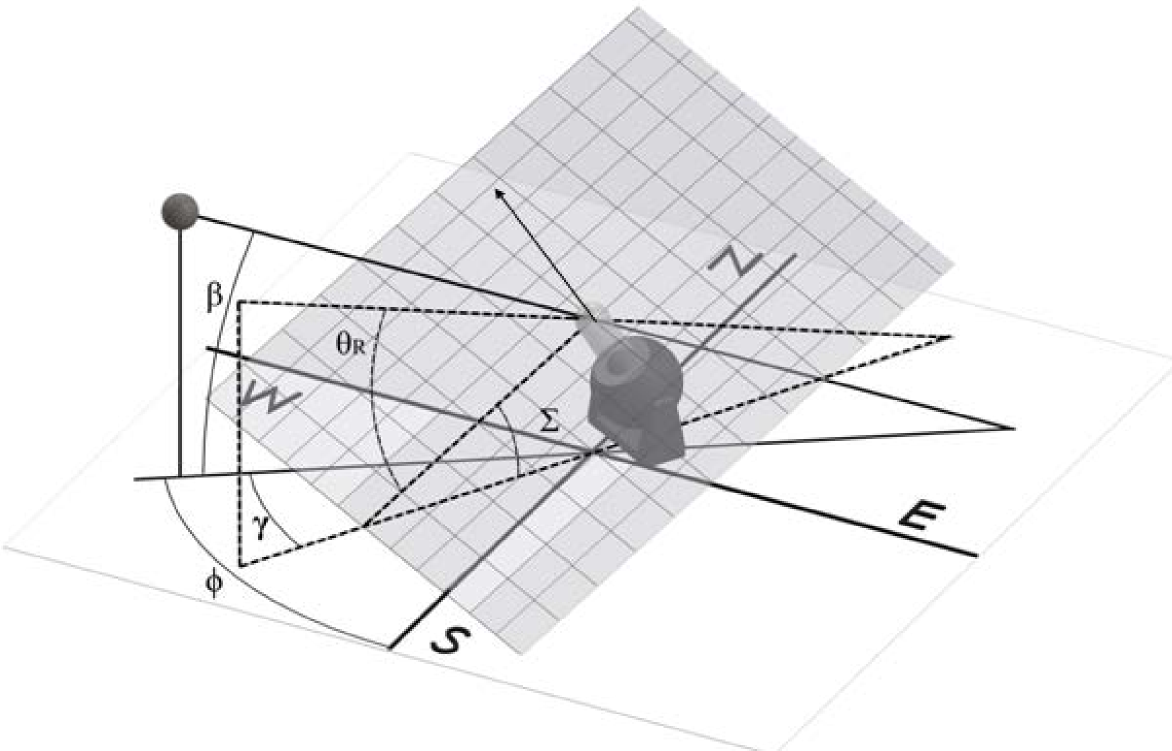

Figure 3-2. Relative Solar Altitude and Surface-solar Azimuth Definitions

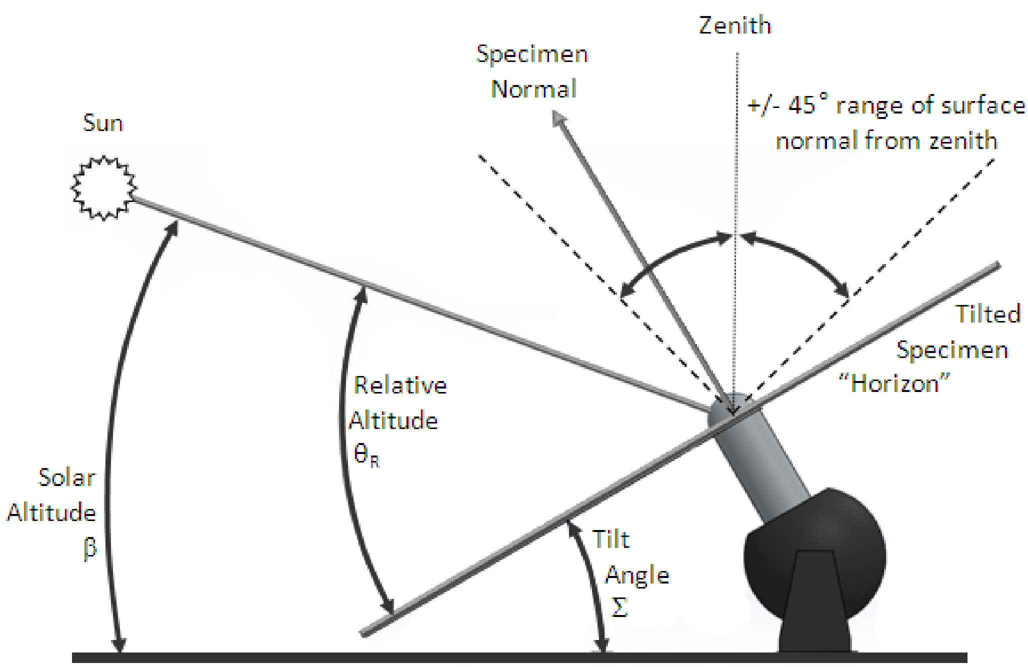

Figure 3-3. 2D Representation of Relevant Angles

Zonal Time, ZT: Zonal Time weighting factors report the percentage of time that the sun spends within each of the 18 specific Sky Zones, relative to the time that Solar Altitude angles are between 15º and 75º, and Solar Azimuths are between +/- 75º from true south, for a site located in Middle America represented by 40º North Latitude. The ZT factors are generated by calculating binned frequency data for the sun's solar position at 30-second intervals for an entire solar year. Each ZT is calculated at the specific solar altitude,β, and surface-solar azimuth,*γ*,, where each angle represents median of the range of angles (e.g., β = 20°, represents range of angles 15° ≤ β < 25°; β = 30° represents range of angles 25° ≤ β < 35°; *γ* = 30° represents range of angles ±15° ≤ *γ* < ±45°, etc.)

4. Referenced Standards

4.1 NFRC Standards

ANSI/NFRC 100: *Procedure for Determining Fenestration Product U-factors*

ANSI/NFRC 200: *Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence*

NFRC 201: *Procedure for Interim Standard Test Method for Measuring the Solar Heat Gain Coefficient of Fenestration Systems Using Calorimetry Hot Box Methods.*

4.2 ASTM Standards

ASTM E1175: *Standard Test Method for Determining Solar or Photopic Reflectance, Transmittance, and Absorptance of Materials Using a Large Diameter Integrating Sphere*

Note: For additional test standards related to this NFRC test standard, see those listed in ASTM E1175.

5. Significance and Use

5.1 This proceduretest method details the calibration and testing procedure, and necessary instrumentation, required to measure the visible light transmittance of TDDs.

5.2 Glazed apertures in buildings are generally utilized for the controlled admission of both light and solar radiant heat energy into the structure. The bulk of the solar radiant energy entering a building in this manner possesses wavelengths that lie from 300 to 2500 nm. Only the portion from 380 to 760 nm is visible radiation. In daylighting applications, it is therefore important to distinguish the radiant (solar radiant energy) transmittance of constructions or materials from their luminous (light) transmittance.

5.3 This test method is useful for determining the solar luminous transmittance of TDDs. This test method provides a means of measuring solar luminous transmittance under fixed outdoor conditions of incidence and detection.

5.4 The spectral distributions of both the direct and diffuse solar irradiation, as well as the directional distributions of both at the earth's surface, generally vary with location, season and time of day. Although these variations are typically not significant when testing the visible light transmittance of clear or tinted and uncoated glazing systems at normal incidence, they can influence the measured results if the test specimen has complex spectral or directional optical characteristics. For these reasons, the visible transmittance of these types of products measured at an outdoor laboratory may vary from the results measured at another outdoor laboratory in a different location or under different conditions

5.5 To avoid large variations in solar spectra, early hours in the morning and late hours in the afternoon, when air mass is significantly higher, shall be avoided. Minimum SALT of 20 degrees shall be required (e.g., in Berkeley, CA during Summer months, SALT > 20 degrees is achieved after 8 a.m. in the morning and before 5 p.m. in the afternoon. For the same location in the Winter, acceptable hours would be 11 a.m. to 1 p.m.). The solar altitude during measurements can be verified using the apparatus described in Annex A or can be calculated using local solar time, longitude and latitude. Equations for calculating solar altitude are given in the 2009 ASHRAE Handbook of Fundamental, Chapter 14 (Reference 2).

5.6 The choice of RSALT angle, θ_R as one of the two main reference angles (the other being surface-solar azimuth, γ), instead if more customary angle of incidence**,** θ**,** was made deliberately to simplify measurements and to make them easily repeatable with the potential for automated measurement of multiple angles of incidence in a short period of time (thereby significantly improving test accuracy and repeatability) at various times of the day and year. However, to avoid larger discrepancies between θ_R and θ, measurements shall be done when the normal to the LDIS aperture (also the TDD shaft axis) is angled no more than 45 degrees away from vertical orientation (i.e., looking straight up toward the sky, or zenith).

5.7 The angle of incidence measurement is not required, but if desired it can be determined using the apparatus described in Annex A, or can be calculated using solar altitude, surface-solar azimuth and the tilt of LDIS. Equations for calculating angle of incidence are given in the 2009 ASHRAE Handbook of Fundamental, Chapter 14 (Reference 2).

6. CALIBRATION

6.1 LDIS as referenced in ASTM E1175 shall be calibrated annually.

6.2 Photometric Sensor Calibration: The VT calculation is based on a ratio of measurements made with the same photometric sensors. There is no requirement regarding absolute calibration to calculate VT, however all measurements supporting the VT calculation are expected to be reported in calibrated engineering units of illuminance, typically lux (lm/m^2). The absolute calibration and linearity must be verified by yearly recalibration, using any one of the following three methods:

6.2.1 Return the sensor to the manufacturer for a recalibration, to include a statement of calibration constant and linearity of response, with a calibration certificate being supplied following the recalibration.

6.2.2 Place out of calibration sensors side by side with a current manufacturer calibrated sensor facing direct sun on a clear day and take readings of the raw output signal to be calibrated, compared to the response of the calibrated sensor. In addition to the measurement of uncovered sensors in direct sunlight, a series of measurements made under neutral density filters is used to establish linearity under a range of light intensity. Filters must have less than 2% spectral variation in transmittance over the spectral range from 390 to 750 nm, and known visible transmittances (±1%) ranging from 80% down to 1% in 10 roughly equal steps. Plot the raw measurement output signals under various transmittances versus the corresponding calibrated illuminance values from the sensor with a current calibration. Fit the data points for each sensor to a straight line, and calculate calibration constants for each unknown sensor from the slope of the linear fit. Replace any sensor with greater than 1% variation of a single measurement to the linear fit. The neutral density filters may be replaced by some other means of reducing the solar flux on the sensor by a precise fractional value while providing uniform illumination of all parts of the sensors being measured together.

6.3 LDIS System Calibration: The LDIS system shall be calibrated for overall accuracy, using two thin diffusing sheets that were previously measured in a spectrophotometer. Resulting VT for each sheet shall not depart more than 5% from the VT as measured in spectrophotometer.

6.4 If utilized for angle measurements, an accelerometer, or rotary shaft encoder, shall be calibrated once per year against a large scale protractor or a series of precise triangular angle plate references with no more than 1 degree uncertainty. A minimum 2 foot bubble level is to be used to reference one side of the angle standard to the ground plane.

7. APPARATUS AND INSTRUMENTATION

7.1 The required test apparatus is outlined in ASTM E1175.

7.1.1 Photometric Sensor Specifications

Since the test involves the calculation of ratios of measurements made with the photometric sensor, there is no need for its electrical output signal to be converted to illuminance units. However, the following additional specifications for the purchase of a suitable photometric sensor shall be met:

A. Linearity of output signal with respect to incident radiant flux: Maximum deviation of 1% over a dynamic range of 1000 to 1.

B. Stability in output linearity: < ± 2% change over a 1 year period.

C. Response Time: less than 10 ms

D. Temperature Dependence: ± 0.15% per °C maximum

E. Angular response: A cosine corrected photometric sensor shall be used for all measurements (altitude direction). Angular non-uniformity in the azimuthal direction shall be minimized for exterior sensors by selecting photometers with the least azimuthal variation (<2% of average of several sensors for four 90 degree rotations in azimuth)

F. Operating Temperature: -20 to 65 °C

G. Relative Humidity: 0 to 100%

H. Detector: High stability silicon photovoltaic detector

I. Spectral response: As required in ASTM E1175

J. LDIS shall not be smaller than 2m (78 in.) in diameter and opening shall not exceed 0.61m (24 in.).

7.2 The LDIS shall be supplied with a means to precisely adjust the orientation of the sphere aperture and specimen to within ±2 degree of direct rays from the sun. Physical mounting of the specimen to the sphere shall introduce no more than an additional ±3 degree error of angular alignment relative to the mounting plane. The overall error of angular alignment shall not exceed ± 5 degrees.

8. TEST PROCEDURE

The VT measurement shall be performed using ASTM E 1175 as follows:

8.1 TDD shall be installed over the LDIS opening, where the diameter of the shaft shall not be larger than the diameter of the sphere port. See Figure 8-1.

Figure 8-1. Photograph of integrating sphere with TDD installed.

8.2 Test sample size is different for residential and commercial applications. Refer to ANSI/NFRC 100, Table 4-3 for appropriate size. TDD size shall not depart by more than 10% from the standard size.

8.3 Care should be taken so that no light escapes or enters between the test sample and the sphere port. Black foam tape can be adhered to the flush face of the sphere port mounting plane in contact with the test specimen where appropriate, to achieve this requirement. If necessary, an accessory can be constructed to support the TDD at various angles and to ensure a good fit between the sample and the LDIS. Plywood board and bracing brackets can be used for this purpose, as long as they do not interfere with the light transmittance of the TDD.

8.4 VT measurements are to be made under conditions satisfying the CIE clear sky criteria. Measurement of both the diffuse hemispherical illuminance incident on the plane of the specimen aperture, as well as the combined direct and diffuse (global) illuminance on the same plane as the test specimen's aperture, is necessary to make the clear sky determination by calculating the ratio of diffuse to global illuminance. A ratio less than or equal to 0.3 is required at all angles of incidence for which VT is reported. The sky ratio is to be recorded and reported for the initiation and completion of each measurement sweep (lowest and highest surface-solar azimuth). Because two different sensors are used in the ratio, the illuminance measurements must be converted to calibrated engineering units before the ratio can be calculated. The diffuse measurement shall be made by placement of an appropriately sized occulting disc at the distance no less than 20 inches from the photometric sensor. For example, a 2 inch diameter opaque black disc at a distance of 24 inches from the sensor held in place by a slender black wire, has been found suitable in one LDIS installation. Alternatively, a shadow band, such as a 2 inch wide opaque black strip arced at a constant distance from the sensor, can be used to shade the direct component over a range of relative altitude angles without having to readjust the shade. Care should be taken to ensure that the test specimen does not influence exterior illuminance measurements by shading or reflecting light to the exterior sensors, or vice versa. It is best to place the exterior sensors on the plane of the specimen tube entrance, not the top of any domed lens.

8.5 Measurements shall be performed at three surface-solar azimuth angles and six RSALT angles at each surface-solar azimuth, for a total of 18 measurements. The following surface-solar azimuth angles shall be used: 0º, 30º, 60º and the following RSALT angles: 20, 30, 40, 50, 60, and 70 Degrees

8.6 An open reference reading is taken for each of the 18 RSALT and surface-solar azimuth incidence angles with no sample covering the LDIS port. The result is the ratio of output from two photometers meeting the requirements set forth in Section 7 of this document above. The ratio is the signal from a photometer measuring the illuminance incident on the interior sphere wall divided by that of an exterior sensor measuring the illuminance at the plane of the specimen entrance aperture without shading or reflections from nearby portions of the apparatus or specimen. This quantity is also the bracketed denominator in the equation under 8.11.

Equation 8-1:

$$\mathrm{Ratio} = \frac{\mathrm{E}_{\mathrm{int,open}}}{\mathrm{E}_{\mathrm{ext,open}}}$$

8.7 It is recommended to automate the system with motorized altitude tilt and precise angular measurement of altitude tilt angle, such that it can perform a set of RSALT angle measurements in a continuous "sweep." This allows many measurements before the time lapsed warrants moving LDIS azimuthally. If the plane of the Sun moves more than 2 degrees from the plane of the LDIS during the open measurements for each surface-solar azimuth, reposition the LDIS again before making next open measurement.

8.8 To align the specimen relative to the sun, an RSALT of 90 deg needs to be established initially, followed by known angular increments of RSALT. RSALT of 90 deg and surface-solar azimuth of 0 deg are established by positioning the TDD so that solar radiation beam is parallel to the TDD shaft (i.e., beaming straight down the shaft). This is called the zero position.

8.9 After zero position is established, the first sweep of RSALT angles shall be done for surface-solar azimuth = 0. SALT angles shall either be determined using sensors that can automatically measure the angular position, or using other suitable means of measuring the specimen orientation relative to the sun manually.

8.10 Other surface-solar azimuth angles shall be established by returning LDIS to its zero position and rotating LDIS azimuthally by 30º and 60º, respectively, before repeating the sweep through RSALT angles.

8.11 The visible transmittance of the 18 separate measurements determined in Section 8.5 above shall be calculated using the following equation, one value for each zonal time:

Equation 8-2

$$VT(\boldsymbol{\theta}_R, \boldsymbol{\gamma}) = \frac{\left(\frac{E_{int,sample}}{E_{ext,sample}}\right)}{\left(\frac{E_{int,open}}{E_{ext,open}}\right)} \bullet \frac{A_{port}}{A_{sample}}$$

Where:

$VT(\theta_R,\gamma)$ is a measurement of one of six RSALT angles(θ_R) at one of three surface-solar azimuths(γ) for a total of 18 measurements. (Example: (θ_R = 70º and γ = 0º would be one measurement noted as $VT_{(70,0)}$).

E_{int} is the illuminance on the interior wall of the sphere,

E_{ext} is the illuminance on the plane of the sphere entrance aperture ($E_{ext,open}$) or specimen entrance aperture ($E_{ext,sample}$),

A_{port} is the area of the sphere port, and

A_{sample} is the area of the entrance aperture at the top of the TDD tube

8.12 The total annual visible transmittance, VT_{annual}, shall be calculated using the 18 VT measurements determined in Section 8.11 above and multiplied by the Zonal Time (ZT) factors in Table 8-1 below.

Table 8-1 Zonal Time (ZT) Factors

		Surface-Solar Azimuth Angle, *γ*		
		0°	30°	60°
Relative Solar Altitude Angle (RSALT), θ_R	20°	0	0.106	0.084
	30°	0.074	0.097	0.072
	40°	0.034	0.064	0.068
	50°	0.026	0.053	0.078
	60°	0.023	0.051	0.074
	70°	0.029	0.055	0.012

Equation 8-3:

$$
\begin{aligned}
VT_{annual} = \; & (VT_{20,0}*ZT_{20,0}) + (VT_{30,0}*ZT_{30,0}) + (VT_{40,0}*ZT_{40,0}) + \\
& (VT_{50,0}*ZT_{50,0}) + (VT_{60,0}*ZT_{60,0}) + VT_{70,0}*ZT_{70,0}) + \\
& (VT_{20,30}*ZT_{20,30}) + (VT_{30,30}*ZT_{30,30}) + (VT_{40,30}*ZT_{40,30}) + \\
& (VT_{50,30}*ZT_{50,30}) + (VT_{60,30}*ZT_{60,30}) + (VT_{70,30}*ZT_{70,30}) + \\
& (VT_{20,60}*ZT_{20,60}) + (VT_{30,60}*ZT_{30,60}) + (VT_{40,60}*ZT_{40,60}) + \\
& (VT_{50,60}*ZT_{50,60}) + (VT_{60,60}*ZT_{60,60}) + (VT_{70,60}*ZT_{70,60});
\end{aligned}
$$

Where:

VT_{annual} = Total Annual Visible Transmittance of TDD

$VT(\theta_R,\gamma)$ = Visible transmittance at one RSALT angle and one surface-solar azimuth angle

ZT = Zonal Time Factor

9. TEST REPORT

9.1 Report results per Section 9 of ASTM E1175

9.2 Data resulting from Equations 8-1, 8-2, and 8-3.

9.3 The following statement shall be included, "The sky ratio of 0.3 or less was met per Section 8.4 of NFRC 203."

9.4 Sample retention per NFRC 701.05, Appendix A

10. REFERENCES

1) *CIE "Colorimetry Technical Report." 15:2004 (3rd Edition). International Commission on Illumination (CIE), Vienna, Austria. www.cie.co.at.*

2) *ASHRAE. 2009. Handbook of Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, GA.*

3) *Goudey, H.; Curcija, D.C., Lee, Q.V.; and Hart, R. 2012. "Visible Transmittance Test Procedures for Tubular Daylighting Devices." LBNL Technical Report. March 26, 2012.*

4) *Goudey, H.; Kohler, J.C.; Rubin, M. 2010. "Complex Product Visible Transmittance Research - Tubular Daylighting Devices." LBNL Technical Report. November 4, 2010.*

ANNEX A (NON-MANDATORY INFORMATION)

A.1 Solar Angle Measurement Instrument (Sun Dial)

A.1.1 Overview

The following instrument can be used to measure the solar altitude and azimuth, or the angle of incidence of the sun, depending on where it is installed. If the instrument is installed parallel with the horizon (level) and oriented due south, it can be used to measure the solar altitude and solar azimuth in the same way as a sundial is used to determine the time of day. If the instrument is mounted in the plane of a test specimen, which is oriented to maintain a specific angle of incidence with the sun, it can be used to measure that angle of incidence.

A.1.2 Description of Apparatus

Scribe radial lines and circles on a disk that originate from the center (See Figure A.1). A shadow pole (gnomon) is placed at the center oriented normal to the plane of the disk. The radial lines should be equally spaced, preferably at 5° or 10° intervals. The distance between the circles will depend on the height of the gnomon, and can be determined by the following formula:

Equation A1-1:

$$Rs = \frac{h_g}{\mathrm{Tan}\beta}$$

Where,

R_S = Radius of Circle (length of shadow)
h_g = Height of Gnomon
β = Solar Altitude, degrees

Table A1-1 shows the radius of circles at 5° given a gnomon that is 10 cm tall. If applied to Figure A1-1, the disk would have a diameter of 56 cm. This particular apparatus will be limited to measuring solar altitudes above 20°, or angle of incidences less than 70° unless it is bigger in size, or has the shape of a sphere instead of a disk.

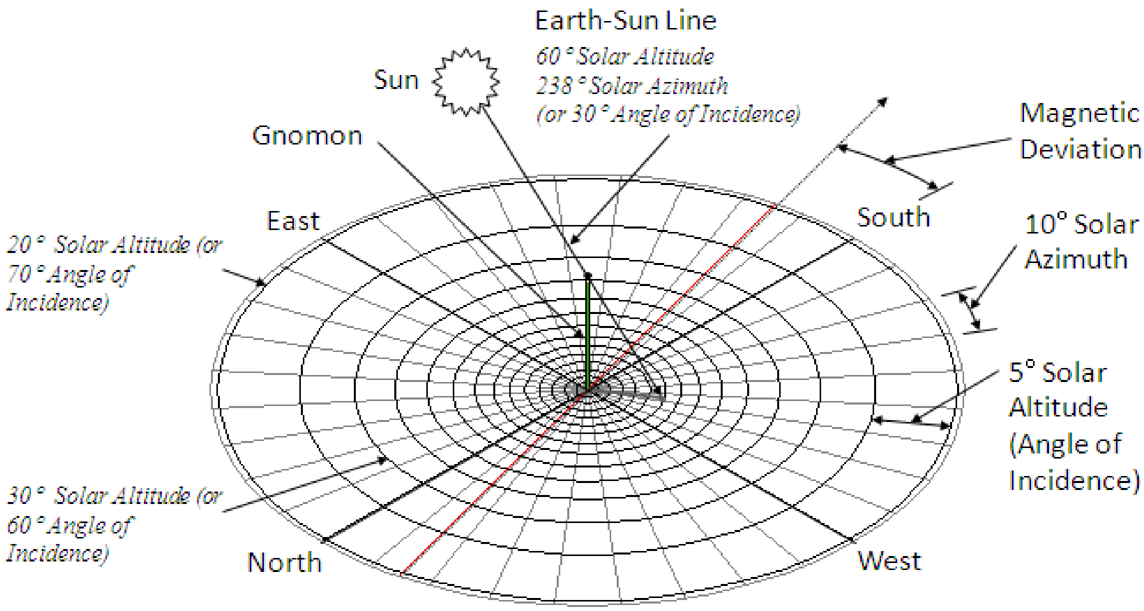

Figure A1-1: Illustration of the Apparatus for Measuring Solar Angles

Table A1-1: Horizontal Projection of Shadow from Gnomon (Gnomon Height, 10 cm)

Solar Altitude *deg. Horz.*	**Angle of Incidence** *deg.*	**Shadow Length** *cm*
90	0	0.00
85	5	0.87
80	10	1.76
75	15	2.68
70	20	3.64
65	25	4.66
60	30	5.77
55	35	7.00
50	40	8.39
45	45	10.00
40	50	11.92
35	55	14.28
30	60	17.32
25	65	21.45
20	70	27.47
15	75	37.32
10	80	56.71
5	85	114.30
0	90	Infinity

A.1.3 Description of Installation and Use

Solar Altitude and Solar Azimuth – This device can be used to measure the solar altitude and solar azimuth of the sun if it is mounted level, and oriented due north. Notice that the cardinal directions on the instrument have been reversed as the shadow represents the projected angle. Therefore, the instrument should be oriented with the "South" label pointing due North, which can be determined by a compass provided that the offset associated with the magnetic declination is included. Magnetic declination for any location in North America can be determined using the web site provided by NOAA's National Geophysical Data Center at http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp.

Angle of Incidence, θ – This device can also be used to measure the angle of incidence of the sun's rays on a test specimen oriented in the same plane as the disk. If the disk is installed on a large-scale integrating sphere or solar calorimeter so that it is in the same plane as the test specimen, it can be used to measure the angle of incidence and surface-solar azimuth.