National Fenestration Rating Council Incorporated

NFRC 300-2009 (E0A0)

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

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FOREWORD

Architects, builders and consumers have many options when choosing windows, doors, curtain walls, skylights and other fenestration systems for buildings. The advances in glazing systems used in fenestration products include spectrally selective tints and low-emissivity coatings; laminated products and films. In addition, many attachments products are also available, including Venetian blinds, exterior, interior, and integral (between the panes), insect and shade screens, and a variety of other shades and films. While these advances can improve the energy performance of fenestration products, it also increases the difficulty in selecting glazed products for the various building applications.

NFRC 300 has been developed by the National Fenestration Rating Council (NFRC) to meet the need for a fair, uniform and accurate means of determining the optically related energy performance of fenestration systems. Glazing system thermal properties are not covered by NFRC 300. This test method utilizes the most up-to-date technical means for determining the solar optical properties of glazing materials and systems.

The International Glazing Database lists the properties of glazing materials. NFRC approves data in the database that have been determined in accordance with this test method and the NFRC Verification Procedures. In order to obtain NFRC authorized ratings, fenestration manufacturers shall use only those glazing materials that are marked as NFRC-approved in the International Glazing Database, except for product generated using NFRC 303 and 304 procedures. This version replaces all previous versions of NFRC 300. This document is in SI units followed by IP units in parentheses. SI units are primary. IP units are conversions for reference only.

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

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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 or revision, the year of last revision. Amendments to the documents are reflected in the footer and posted on the NFRC website, www.NFRC.org.

2. SCOPE

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

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

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

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

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

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:

2.1.1. Monolithic homogeneous specular or slightly diffusing materials including glass plates, plastic sheets and flexible plastic film.

2.1.2. Glass or plastic substrates as described in Section 2.1.A with coatings applied by chemical or vacuum deposition processes or with applied films.

2.1.3. Laminated glazings consisting of two or more rigid layers combined with one or more adhesive interlayers. The interlayers shall themselves consist of monolithic homogeneous specular or slightly diffusing materials.

2.1.4. Diffusing or light-redirecting sheet materials subject to verification according to NFRC 302. Note: These materials are likely to incur greater errors than specular products. New methods are under investigation, but until such methods have been approved, this procedure may be used subject to verification according to NFRC 302. Diffusing or light-redirecting materials include fritted glass, laminates with diffusing polymer interlayer, acid-etched or sand-blasted glass, patterned glass (extra caution is warranted), honeycomb structures, and applied films with diffusing layers.

2.1.5. heterogeneous materials are excluded. The effect of non specularity may remain and this effect should be carefully considered as for all nonspecular materials as in Section 2.1.4 above.

2.2 Products and Effects Not Covered

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

2.2.1. Geometrically complex glazing or shading systems including but not limited to blinds, drapes, and woven shades

2.2.2. Heterogeneous materials with features on the order of the spectrophotometer beam unless spatially averaged as described herein.

2.2.3. Curved glazing including but not limited to domed skylights;

2.2.4. Combinations of glazing elements that include one or more diffusing elements. A single slightly diffusing element, however, can be measured directly as specified in Section 2.1.A.

3. REFERENCED DOCUMENTS

ASTM E 903-1996	Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres.
ASTM E275	Standard Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers
CIE 89/3-1991	CIE Technical Collection 1990/3. Division 6 Report: On the deterioration of exhibited Museum Objects by Optical radiation.
University of California-Lawrence Berkeley National Labs Report 33943	Documentation of Calculation Procedures (http://windows.lbl.gov/software/window/41/WINDOW%204.0%20Documentation%20of%20Calculation%20Procedures.pdf)
ISO 9050-03	Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
ISO 15099-03	Thermal Performance of Windows, Doors, and Shading Devices - Detailed Calculations
ISO 9845-1:1992 (E)	Solar energy - Reference Solar Spectral Irradiance At The Ground At Different Receiving Conditions.
ISO/CIE 10526/D65: 08 (E)	CIE Standard Colorimetric Illuminants.

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

4. TERMINOLOGY

See NFRC Glossary and Terminology for all definitions.

5. SIGNIFICANCE AND USE

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

6. MEASUREMENT PROCEDURE

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

6.1 Required Equipment

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

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

6.2 Required Measurements

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

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

Table 1- Minimum required measurement intervals.

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

6.3 Operational Guidelines

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

6.3.1 Transmittance Measurement:

6.3.1.1 Calibration of Baseline or 100% Line:

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

6.3.1.2 Calibration of Dark or 0% Line:

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

6.3.1.3 Sample Measurement

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

6.3.1.4 Correction Procedure for Transmittance

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

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

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

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

6.3.2 Reflectance Measurement:

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

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

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

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

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

6.3.2.3 Calibration of Dark or 0% Line:

A zero correction is desirable especially for low reflecting materials. Replace the material covering the reflectance port of the sample beam with a light trap. The sample cover supplied with the instrument may not be adequate, unless totally opaque. Perform a scan with the same instrument parameters as the baseline calibration. This calibration shall be performed at least once per day during measurement periods

6.3.2.4 Correction Procedure for Reflectance

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

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

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

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

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

6.4 Noise Reduction:

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

6.5 Annual Calibration of Linearity and Wavelength

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

6.6 Special Materials

6.6.1 Coated Glazing:

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

6.6.2 Heat Treated Glazing:

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

6.6.2.1 Small sample method

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

6.6.2.2 Broken Sample Method:

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

6.6.3 Low-absorption glass

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

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

7. CALCULATION OF RESULTS

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

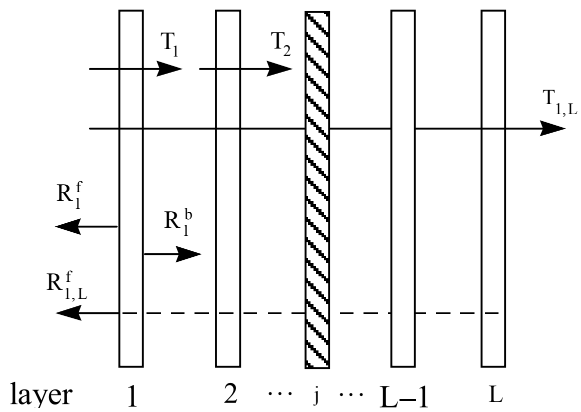
7.1 Multipaned IG Units

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

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

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



7.2 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:

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

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 $\lambda_1, \lambda_2, \ldots \lambda_{N-1}, \lambda_N$. For solar-weighted property value computations, Γx 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:

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

Where

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

7.2.5 Spectral Weighting Functions[4]

At the current time, there are three types of average used by the NFRC: solar, photopic, and damage weighted[5]. Each average has its own particular set of weighting functions and wavelength limits:

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

[5]Sensitivity 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

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}.

Note2: 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 at oblique incidence can be extrapolated from the measured properties at normal incidence using equations in chapter 7.2 of this reference: University of California-Lawrence National Berkeley Laboratory report # 33943 titled *Window 4.0-Documentation of Calculation Procedures*. (See section 3, references).

8. REPORT

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

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