National Fenestration Rating Council Incorporated

NFRC 300-2004

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

PREPARED BY:
National Fenestration Rating Council
6305 Ivy Lane, Suite 140
Greenbelt, MD 20770-1465
Voice: (301) 589-1776
Fax: (301) 589-3884
Email: info@nfrc.org
Website: www.nfrc.org

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. 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 energy performance of fenestration systems. 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 must use only those glazing materials that are marked as NFRC-approved in the International Glazing Database.

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:

National Fenestration Rating Council
6305 Ivy Lane, Suite 140
Greenbelt, MD 20770-1465
Voice: (301) 589-1776
Fax: (301) 589-3884
Email: info@nfrc.org
Website: www.nfrc.org

Table of Contents

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.

2. SCOPE

This test method covers the determination by measurement and calculation of the optical properties relevant to energy transfer in flat specular glazing materials.

This test method includes the calculation of various properties, which can be derived from the spectral measurements, including spectrally averaged transmittance and reflectance quantities.

This test method includes the calculation procedures necessary to determine the net optical properties of combinations of discrete glazing elements.

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.

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 spectroradiometer or because no calculation procedures have yet been developed to determine the relevant parameters from such spectroradiometric measurements:

A. Strongly diffusing materials.

B. Non-homogeneous patterned or textured materials.

C. Complex glazing or shading systems including but not limited to blinds, drapes, holographic and prismatic panels.

D. Curved glazing including but not limited to domed skylights; and

E. 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.

This method is generally suitable for measuring the transmittance and reflectance of architectural glazing materials such as glass (coated and uncoated), etc. The derived average properties are suitable for determining performance parameters such as thermal transmittance (U-Factor), solar heat gain coefficient (SHGC) and visible transmittance (VT) of a fenestration assembly.

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.

3. REFERENCED DOCUMENTS

ASTM E 903-1996	Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres.
CIE 89/3-1991	CIE Technical Collection 1990/3. Division 6 Report: On the deterioration of exhibited Museum Objects by Optical radiation.
ISO 9845-1:1992 (E)	Solar energy - Reference Solar Spectral Irradiance At The Ground At Different Receiving Conditions.
ISO/CIE 10526: 1991 (E)	CIE Standard Colorimetric Illuminants.
ISO/CIE 10527: 1991 (E)	CIE Standard Colorimetric Observers.

4. TERMINOLOGY

See NFRC Glossary and Terminology of 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

Measure spectral transmittance and reflectance data from at least 0.3 μm to 2.5 μm as described in ASTM E 903.

In the case of glazings incorporating coatings, special requirements apply to sample selection and preparation:

A. For coatings subject to aging and atmospheric attack, the specimen to be measured shall be fresh and in good condition.

B. For coatings subject to heat treatment, such as tempering, two issues shall be addressed:

   i. Assuring the appropriate thermal history of the sample; and

   ii. Assuring that the sample remains flat enough after heat treatment to measure accurately.

   The measurement of the final optical properties is complicated because suitable representative samples cannot be directly cut from large tempered sheets. Either of the following two sampling procedures are permitted to be followed:

   iii. One alternative is to prepare small samples (e.g., 100 mm by 100 mm, 4 in. by 4 in.), which accurately represent the commercial product after heat treatment. This is accomplished by heat treating the small coated samples, while supporting the samples so that they do not sag, in a lab furnace. Temperature is monitored using a thermocouple in contact with the center of the sample. Critical peak temperature is matched to that of the exit of the commercial tempering line.

   iv. The second alternative uses a larger heat-strengthened sample that can be broken down into smaller samples for measurement. This method ensures the proper temperature history by running a large sample through the tempering line with the proper set ups for the normal tempering of that product except that the quench is turned off. The sample is then broken into pieces and one is selected that is small enough to fit in the measurement apparatus and large enough to provide an accurate measurement.

   v. For specular reflectance measurements, no deviation from flatness shall be permitted when visually checking the sample with a straight edge.

   vi. To verify uniformity of the measurements of a heat-treated sample, four separate measurements shall be taken and averaged, by rotating the sample 90 degrees between scans.

7. CALCULATION OF RESULTS

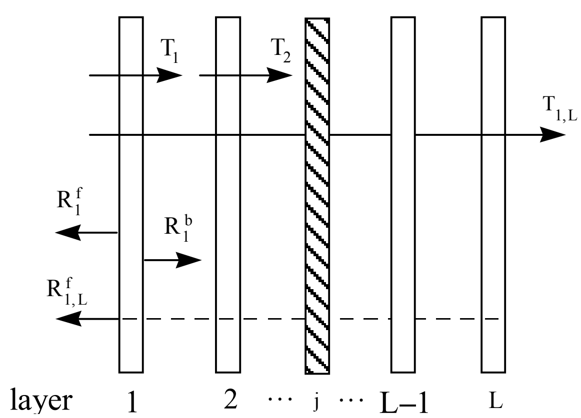
7.1 Order of Calculations

Section 7.2 details how the optical properties of individual glazing layers are permitted to be combined to give the optical properties of a glazing system consisting of several layers. These calculations shall be performed before obtaining spectrally averaged properties for the glazing system as in Section 7.3. Significant errors can result if spectrally averaged properties for glazing layers are used to calculate the properties of glazing systems.

7.2 Multipane 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



7.2.1 For single glazing:

Measure the properties T_1, R_1^f and R_1^b (transmittance, front side reflectance and back side reflectance respectively, where the front side is the side facing the exterior) of the layer as a function of wavelength according to Section 6. The front side absorptance of a layer *j* in isolation is $A_j^f = 1 - T_j - R_j^f$ and the back side absorptance is $A_j^b = 1 - T_j - R_j^b$.

7.2.2 For double glazing:

Measure the spectral properties of layer 1 (T_1, R_1^f and R_1^b) and layer 2 (T_2, R_2^f and R_2^b) according to Section 6.

Calculate the properties of the system consisting of layers 1 and 2:

$$T_{12} = \frac{T_1 T_2}{1 - R_1^b R_2^f} \qquad R_{12}^f = R_1^f + \frac{T_1^2 R_2^f}{1 - R_1^b R_2^f} \qquad R_{12}^b = R_2^b + \frac{T_2^2 R_1^b}{1 - R_1^b R_2^f}$$

$$\hat{A}_1^f = A_1^f + \frac{T_1 R_2^f A_1^b}{1 - R_1^b R_2^f} \qquad \hat{A}_2^f = \frac{T_1 A_2^f}{1 - R_1^b R_2^f}$$

Equation 7-1

Where

T_{12}, R_{12}^f *and* R_{12}^b = the transmittance, front side reflectance and back side reflectance of the glazing system consisting of layers 1 and 2

$\hat{A}_1^f$ = the absorptance of layer 1 in the glazing system

$\hat{A}_2^f$ = the absorptance of layer 2 in the glazing system, assuming that radiation is incident on the front (exterior) side

7.2.3 For triple glazing:

Measure the spectral properties of layer 1 (T_1, R_1^f and R_1^b), layer 2 (T_2, R_2^f and R_2^b) and layer 3 (T_3, R_3^f and R_3^b) according to Section 6. Calculate the properties of the system consisting of layers 1 and 2 as in the case of double glazing above.

Calculate the properties of the system consisting of layers 1 through 3 from:

$$T_{13} = \frac{T_{12} T_3}{1 - R_{12}^b R_3^f} \qquad R_{13}^f = R_{12}^f + \frac{T_{12}^2 R_3^f}{1 - R_{12}^b R_3^f} \qquad R_{13}^b = R_3^b + \frac{T_3^2 R_{12}^b}{1 - R_{12}^b R_3^f}$$

$$\hat{A}_1^f = A_1^f + \frac{T_1 R_{23}^f A_1^b}{1 - R_1^b R_{23}^f} \qquad \hat{A}_2^f = \frac{T_1 A_2^f}{1 - R_1^b R_{23}^f} + \frac{T_{12} R_3^f A_2^b}{1 - R_{12}^b R_3^f} \qquad \hat{A}_3^f = \frac{T_{12} A_3^f}{1 - R_{12}^b R_3^f}$$

Equation 7-2

Where

T_{13}, R_{13}^f *and* R_{13}^b = the transmittance, front side reflectance and back side reflectance of the glazing system consisting of layers 1, 2 and 3

$\hat{A}_1^f, \hat{A}_2^f$ *and* $\hat{A}_3^f$ = the absorptances of each layer in the glazing system, assuming that radiation is incident on the front (exterior) side

For more than three glazing layers continue the progression above recursively to obtain the system transmittance and reflectance values. For example, to progress to quadruple glazing, increment index 2→3 and 3→4 in the expressions for triple glazing above.

For any number of layers calculate the absorption in each layer considered as part of the system for radiation incident on the front side of the system from:

$$A_j^f = \frac{T_{1,j-1} A_j^f}{1 - R_{1,j-1}^b R_{j,L}^f} + \frac{T_{1,j} R_{j+1,L}^f A_j^b}{1 - R_{1,j}^b R_{j+1,L}^f} \quad \text{using} \quad \begin{matrix} T_{1,0} = 1, T_{j,j} = T_j \; R_{1,0}^f = 0 \\ R_{L+1,L}^b = 0 \; R_{j,j}^{f/b} = R_j^{f/b} \end{matrix} \qquad \text{Equation 7-3}$$

Calculate spectral average parameters as needed in accordance with the following section.

7.3 Computation of Spectral Averages

7.3.1 General Method for Computing Spectral Averages

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

$$P_x = \frac{\int_a^b \Phi_x(\lambda) P(\lambda) \Gamma_x(\lambda) d\lambda}{\int_a^b \Phi_x(\lambda) \Gamma_x(\lambda) d\lambda} \qquad \text{Equation 7-4}$$

Where

P = the property to be averaged

Φ_x = a weighting function representing the relative intensity of source radiation for average type '*x*'

Γ_x = a weighting function representing the detector response for average type '*x*'

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

In practice, P, Φ_x and Γ_x are often measured or tabulated at discrete wavelengths, so that the expression above must be evaluated numerically over a set of *N* discrete wavelengths $\lambda_1, \lambda_2, \ldots \lambda_{N-1}, \lambda_N$. However, P, Φ_x and Γ_x are permitted to be measured or tabulated at different wavelengths, so P, Φ_x and Γ_x shall be interpolated onto a common wavelength set before evaluating the integrals numerically.

7.3.2 Method of Interpolation

Use linear interpolation to obtain values between measured or tabulated points in the source, detector or sample data.

In addition to the method of interpolation, the treatment of the end-points of data sets can affect the calculation. Do not extrapolate beyond the limits of any spectra. If data is required outside the limits, use a null value (zero).

7.3.3 Common Wavelength Set

This is the set of wavelengths that the source, detector and data are mapped onto before performing the numerical integration. Use the common wavelength set specified for each type of average.

7.3.4 Numerical Integration

Use the trapezoidal (trapezium) method to numerically approximate the integrals of Equation 7-4. This rule assumes that the quantity to be integrated varies approximately linearly between the values obtained on the common wavelength set:

$$\int_a^b f(\lambda)d\lambda \approx \sum_{i=1}^{N-1} \frac{f(\lambda_i) + f(\lambda_{i+1})}{2} \Delta\lambda_i$$ Equation 7-5

Where

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

7.4 Computation of Solar Spectral Averages

7.4.1 Source Spectrum

Use the tabulated solar spectral irradiance distribution from Table 1, Column 2 of Standard ISO 9845-1:1992(E), as the source spectrum E_λ.

7.4.2 Detector Spectrum

Use a '100%' detector function, i.e., the detector function is 1.0 at all wavelengths.

7.4.3 Common Wavelength Set

Use the wavelengths between 0.3 μm and 2.5 μm to which the source spectrum is tabulated as the common wavelength set, adding the end points 0.3 μm and 2.5 μm. The source spectrum shall be extrapolated or interpolated onto the end-points 0.3 μm and 2.5 μm since these wavelengths are not included in the tabulated wavelength set. Interpolate the measured data onto the common wavelength set.

7.4.4 Numerical Integration

The detector function is permitted to be omitted from the calculations. Calculate the solar spectral average of a property *P* as follows:

$$P_{sol} = \frac{\int_{0.3}^{2.5} P(\lambda) E_{\lambda}.d\lambda}{\int_{0.3}^{2.5} E_{\lambda}.d\lambda} \approx \frac{\sum_{i=1}^{N-1} \frac{E_{\lambda_i} P(\lambda_i) + E_{\lambda_{i+1}} P(\lambda_{i+1})}{2} \Delta\lambda_i}{\sum_{i=1}^{N-1} \frac{E_{\lambda_i} + E_{\lambda_{i+1}}}{2} \Delta\lambda_i}$$

Equation 7-6

Where

$\lambda_1 \ldots \lambda_N$	=	the wavelengths of the common wavelength set, $\Delta\lambda_i = \lambda_{i+1} - \lambda_i$
E_{λ_i}	=	the tabulated or interpolated value of the source spectrum at wavelength, λ_i
$P(\lambda_i)$	=	the measured or interpolated value of the property at wavelength, λ_i

7.5 Computation of Visible (Photopic) Spectral Averages

7.5.1 Source Spectrum

Use the CIE D65 standard illuminant from Table 1, Column 3 of ISO/CIE 10526 as the source spectrum E_{λ}.

7.5.2 Detector Spectrum

Use the observer from 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 $V_{\lambda.}$

7.5.3 Common Wavelength Set

Use a wavelength set constructed by taking every 0.005 µm point between 0.38 µm and 0.78 µm including the endpoints. Interpolate the data, source and detector spectra onto this wavelength set.

7.5.4 Numerical Integration

Calculate the visible (photopic) spectral average of a property *P* as follows:

$$P_{vis} = \frac{\int_{0.38}^{0.78} E_\lambda P(\lambda) V_\lambda d\lambda}{\int_{0.38}^{0.78} E_\lambda V_\lambda d\lambda} \approx \frac{\sum_{i=1}^{N-1} \frac{E_{\lambda_i} P(\lambda_i) V_{\lambda_i} + E_{\lambda_{i+1}} P(\lambda_{i+1}) V_{\lambda_{i+1}}}{2} \Delta\lambda_i}{\sum_{i=1}^{N-1} \frac{E_{\lambda_i} V_{\lambda_i} + E_{\lambda_{i+1}} V_{\lambda_{i+1}}}{2} \Delta\lambda_i}$$ Equation 7-7

Where

$\lambda_1 \ldots \lambda_N$ = the wavelengths of the common wavelength set, $\Delta\lambda_i = \lambda_{i+1} - \lambda_i$

E_{λ_i} = the tabulated or interpolated value of the source spectrum at wavelength, λ_i

V_{λ_i} = the tabulated or interpolated value of the detector spectrum at wavelength, λ_i

$P(\lambda_i)$ = the measured or interpolated value of the property at wavelength, λ_i

7.6 Damage-Weighted Transmittance

7.6.1 Source Spectrum

Use the tabulated solar spectral irradiance distribution from Table 1, Column 2 of Standard ISO 9845-1:1992(E), as the source spectrum E_λ.

7.6.2 Detector Spectrum

The detector weighting spectrum is given by an analytic function – the CIE action spectrum taken from CIE 89/3 (where λ is in µm):

$$S_{dm,rel}(\lambda) = e^{(3.6-12.0\lambda)}$$ Equation 7-8

The detector spectrum is formed by evaluating the action spectrum function at each wavelength of the common wavelength set.

7.6.3 Common Wavelength Set

Use the wavelengths of the tabulated source spectrum between 0.3 µm and 0.7 µm as the common wavelength set, adding the end points 0.3 µm and 0.7 µm. Interpolate the measured data onto this wavelength set and interpolate the source spectrum onto the end points 0.3 µm and 0.7 µm.

7.6.4 Numerical Integration

Calculate the CIE damage-weighted transmittance as follows:

$$T_{dw} = \frac{\int_{0.3}^{0.7} E_\lambda T(\lambda) S_{dm,rel}(\lambda).d\lambda}{\int_{0.3}^{0.7} E_\lambda S_{dm,rel}(\lambda).d\lambda} \approx \frac{\sum_{i=1}^{N-1} \frac{E_{\lambda_i} T(\lambda_i) S_{dm,rel}(\lambda_i) + E_{\lambda_{i+1}} T(\lambda_{i+1}) S_{dm,rel}(\lambda_{i+1})}{2} \Delta\lambda_i}{\sum_{i=1}^{N-1} \frac{E_{\lambda_i} S_{dm,rel}(\lambda_i) + E_{\lambda_{i+1}} S_{dm,rel}(\lambda_{i+1})}{2} \Delta\lambda_i}$$

Equation 7-9

Where

$\lambda_1 \ldots \lambda_N$	=	the wavelengths of the common wavelength set, $\Delta\lambda_i = \lambda_{i+1} - \lambda_i$
E_{λ_i}	=	the tabulated or interpolated value of the source spectrum at wavelength, λ_i
$S_{dm,rel}(\lambda_i)$	=	the value of the detector function at wavelength, λ_i
$T(\lambda_i)$	=	the measured or interpolated value of the property at wavelength, λ_i

[***Note 1.***: T_{dw} is considered to be the single most appropriate factor relating to relative color change of materials due to solar radiation transmitted through a glazing system. There are many other variables that may contribute to rate of damage or fading, such as temperature, type of material and type of pigment.]

8. REPORT

The report shall include the following:

A. Complete identification of the material tested, specimen size and thickness, surface contour if any, description of optical properties such as diffuse or specularly reflecting, clear or translucent transmitting, etc.

B. Identification of the instrument used. Manufacturer's name and model number including modifications and accessories are sufficient for a commercial instrument. Other instruments shall be described in detail including estimations of their accuracy. Record the instrument parameters (slit width, scan speed, response time, gain, resolution, number of scans, wavelength range and interval) used for the particular measurement. A description of the reflectance accessory shall be kept on record at the place of measurement.

C. Last date of instrument calibration. The calibration and maintenance history of the instrument shall be on record at the place of measurement.

D. Complete identification of any and all standards used for calibrating the measurements. The calibration history of the standard shall be on record at the place of measurement.

E. The dates of measurements.

F. The name of the operator who made the measurements.

G. Solar transmittance, absorptance and reflectance, reported to the nearest 0.001 unit or 0.1 percent.

INDEX