National Fenestration Rating Council Incorporated

NFRC 301-2009

Standard Test Method for
Emittance of Specular Surfaces Using Spectrometric Measurements

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FOREWORD

This procedure has been developed by the National Fenestration Rating Council (NFRC) to meet the need for a uniform and accurate means for calculating the solar optical properties of glazing materials. These properties are required for determination of U-Factor, Condensation Resistance and Solar Heat Gain Coefficient (SHGC) of fenestration systems.

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

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Table of Contents

1. SCOPE

This test method determines the normal and hemispherical emittance of a specular surface. This test method describes the spectrometric measurement of the near-normal specular reflectance in the mid-infrared range from 5 µm to at least 25 µm. It includes the calculation procedures required to determine the normal and hemispherical emittance of said object.

This test method includes calibration instructions for the spectrometer and procedures for selecting reflectance-reference standards.

This test method is generally suitable for any flat, specular-reflecting specimen. It is recommended for measuring emittance of architectural glazing materials such as glass (coated and uncoated), etc. This test method is not suitable for determining the emittance of an object, which is transparent in the specified range of infrared radiation.

This test method is suitable for determining the emittance of an object based on blackbody weighing at a specified temperature, typically 23ºC (75ºF), as would be needed to determine the thermal performance (i.e., U-Factor or Solar Heat Gain Coefficient) of a fenestration product.

This test method may involve hazardous materials, operations and equipment. This test method does not presume to address all of the safety problems 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. REFERENCED DOCUMENTS

ASTM E 179-96 (2003)	Standard Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials
ASTM E 284-03a	Standard Terminology of Appearance
ASTM E 932-89 (2002)	Standard Practice for Describing and Measuring Performance of Dispersive Infrared Spectroradiometers
ASTM E 1164-02 (2003)	Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation

3. TERMINOLOGY

See NFRC Glossary and Terminology document for definitions.

4. SIGNIFICANCE AND USE

The thermal performance of glazing materials utilized in building facades plays a major role in the consumption and conservation of energy. Emittance is one of the important attributes used to calculate the thermal performance of glazing materials.

The hemispherical emittance, based on weighing with the radiation of a blackbody at 23ºC (75ºF), is the accepted criterion for assessing the thermal performance of glazing assemblies. Kirchhoff's law states that spectral emittance is equal to spectral absorptance under equilibrium; therefore, spectral absorptance may be considered to be synonymous with spectral emittance. Because the sum of absorptance or emittance, reflectance and transmittance is equal to unity (Law of Energy Conservation), the reflectance of an opaque object may also be considered equivalent to its emittance. (Glass is opaque between 5.0 µm and >50.0 µm). Hence, spectral emittance can be derived from spectral reflectance data.

This test method recognizes that there are other uses of surface emittance, e.g., heat transfer during glass tempering, for which this test method is not applicable.

This test method is not intended for measurement of substrates, which are transparent to infrared radiation, such as certain plastics, etc.

5. APPARATUS

Spectrometer and specular reflectance accessory(s) shall be capable of the measurement of specular reflectance in the range of wavelength range of 5 µm to 25 µm (wave number range of 2000 cm^{-1} to 400 cm^{-1}) at 1 µm intervals at 1 µm intervals (17 cm^{-1} at 25 µm).[1]

Spectrometer must have purge capability to eliminate absorption due to moisture and carbon dioxide in the atmosphere.

The specular reflectance accessory used for the measurement is an all-reflective optical system in which the calibration mirror(s) or samples(s) are located at a 1:1 optical conjugate of the monochromator entrance slits. The angle of incidence with respect to the normal of the sample must be 10 degrees or less to minimize the effects of polarization (ASTM E 179).

[1] This test method requires that measurements be taken up to 25 µm. Measurements covering the range up to 40 µm or even 50 µm, however, should be recorded, if the equipment permits. For samples with significant variation in the extended range, unacceptable error could result (see Section 8).

For double-beam spectrometers a reflectance accessory identical to the one placed in the sample beam can be placed in the reference beam to reduce the increased noise due to the different path length.

6. CALIBRATION

6.1 Calibration Reflectance Standards

Aluminum, copper, gold and silver mirrors may all have a reflectance of more than 98.5 percent at 10 µm. Aluminum coatings,[2] however, are the least susceptible to both mechanical and chemical degradation. Therefore, aluminum is the material of choice for both transfer and working standards of high reflectance.

The recommended secondary (or transfer) reflectance standard is an undamaged, front-surface aluminum mirror on glass in good condition (free of surface scratches and other contamination). The transfer standard shall be calibrated from 5 µm to ≥ 25 µm against a primary standard.[3] If no calibration data is available for a specific aluminum mirror the data given in Table 6-1 may be used. The accuracy of a measurement using calibration data from Table 6-1 is ± 0.5 percent.

Table 6-1 Absolute Reflectance versus Wavelength of an Aged Evaporated Aluminum Mirror (Bennet 1963)

Wavelength [µm]	Absolute Reflectance	Wavelength [µm]	Absolute Reflectance	Wavelength [µm]	Absolute Reflectance
0.40	0.9076	1.5	0.9658	24	0.9861
0.45	0.9061	2	0.9699	26	0.9864
0.50	0.9034	3	0.9736	28	0.9867
0.55	0.9032	4	0.9758	30	0.9870
0.60	0.9027	5	0.9772	32	0.9872
0.65	0.8976	6	0.9784	34	0.9877
0.70	0.8886	7	0.9794	36 *	0.9879
0.75	0.8761	8	0.9801	38 *	0.9881
0.775	0.8678	9	0.9807	40 *	0.9883
0.80	0.8596	10	0.9812	42 *	0.9885
0.825	0.8556	11	0.9816	44 *	0.9887
0.875	0.8596	12	0.9821	46 *	0.9888
0.90	0.8894	13	0.9826	48 *	0.9890

[2] Gold has a flatter and higher reflectance in the infrared (99%) compared to aluminum, but it needs to be handled with extreme care, which makes it an impractical choice.
[3] Calibrated primary standards are available from: Dr. F.J.J. Clarke, National Physical Laboratory Teddington Middlesex TW11, 0LW Great Britain 011-44-81-943-6574.

Wavelength [µm]	Absolute Reflectance	Wavelength [µm]	Absolute Reflectance	Wavelength [µm]	Absolute Reflectance
0.925	0.9030	14	0.9830	50 *	0.9891
0.95	0.9154	16	0.9838	52 *	0.9892
1.00	0.9324	18	0.9845	54 *	0.9893
1.20	0.9585	20	0.9852	56 *	0.9893

* extrapolated data

Working reflectance standards should be front surface aluminum mirrors on glass from a reputable manufacturer. The working standards shall be calibrated against the transfer standard at least once per month or whenever a change in the condition of the working standard is suspected. The working standard may have a protective overcoat of SiO, SiO_2, Al_2O_3 or other non-interfering material.

6.2 Baseline

Set the baseline for the reflectance scale of the spectrometer by following the instructions provided by the instrument manufacturer. These instructions may only cover the case of transmission and will vary among instrument types. The following guidelines should cover most situations:

A. The reflectance accessory or accessories with the reflectance standards in place must be aligned for maximum sample beam signal (and reference beam if possible). In the case of double-beam instruments a reference standard should be chosen whose reflectance is of the same order as the reflectance of the samples to be measured (e.g., aluminum reference mirror for low-E coatings or a glass reference for low-reflectance coatings like glass).

B. Place working reflectance standards on one or both reflectance accessories. For a double-beam instrument with single-wavelength baseline adjustment, set the readout to 100% at 10 µm. Scan from 5 to ≥ 25µm using the same instrument settings that will be used to record the sample spectrum (Section 8). Record the background spectrum at 1 µm intervals.

C. Some instruments can store the background spectrum electronically for automatic baseline correction.

D. Compensate sample data for the reflectance of the working standard.

6.3 Verification

Verification of the following instrumental factors is strongly recommended:

6.3.1 Zero setting of the reflectance scale

Setting the baseline to 100 percent does not guarantee that the reading with blocked sample beam will be zero. This is especially important with low-reflectance samples. Zero adjustment may not be under the control of the user. Adjustment of the electronics or optical path may be required.

6.3.2 Wavelength scale

There are wavelength calibration standards (e.g., polystyrene sheets or indene solutions) available that are designed to work in transmittance mode.[4]

Stray light level should be minimized.

6.4 Accuracy

Check the accuracy of the measured data by measurement of a series of standards that have been previously calibrated by a standard laboratory or supplied by a dependable source. One known, readily available standard would be clear, uncoated, soda-lime float glass, which has a known spectrally-averaged hemispherical emittance of 0.84.

6.5 Measurement

All measurements shall be taken at room temperature
[21ºC ± 5ºC (70ºF ± 9ºF)]

7. SPECIMEN SELECTION

For highest precision and accuracy, select specimens with the following properties:

A. High material uniformity and freedom from blemishes in the area to be measured. However, blemishes observed under visible illumination might not affect with measurements in the infrared.

B. Surface to be measured should be flat across two or three times the measurement area.

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

[4] Polystyrene film available from Perkin Elmer. Part #186-2082 for orders call 1-800-762-4002. Calibration spectra for polystyrene film in Indene solution is provided in ASTM E 932.

8. PROCEDURE

Follow general procedures as directed by the instrument manufacturer and ASTM E 932, with additional, established procedures as required for the particular spectrometer and reflectance attachment being used.

Prior to each use, calibrate the reflectance scale using a working standard, as described in Section 6.2.

Handle the specimen carefully and avoid touching the area to be measured. When necessary, clean the specimen. An acceptable cleaning procedure for most specimens is to gently wash with a 50 percent mixture of 99.9 percent isopropanol and deionized water, rinse thoroughly with deionized water and blow off with dry and oil-free N_2.

Measure the infrared reflectance of the specimen from 5 µm to 25 µm.[5] Resolution should be set to 8 cm^{-1} or smaller. Record data at intervals of 1 µm. Use Equation 8-1 and linear interpolation to convert from wavenumbers to µm.

$$wavelength[\mu m] = \frac{10,000}{wavenumber\,(cm^{-1})}$$ Equation 8-1

9. CALCULATION OF RESULTS[6]

Planck's law is used to calculate the energy distribution and cumulative energy for this technique. Blackbody spectral emissive power is derived using Equation 9-1:

$$E_{b\lambda} = \frac{C_1}{\lambda^5\left(\varepsilon^{C_2/\lambda T} - 1\right)}$$ Equation 9-1

Where

C_1 = Planck's first constant (3.743×10^8W $\mu m^4/m^2$)
C_2 = Planck's second constant (1.4387×10^4 µm K)
T = air temperature in degrees Kelvin (ºC + 273)
λ = wavelength in micrometers
$E_{b\lambda}$ radiation emitted by blackbody at wavelength, λ($W/m^2 \cdot \mu m$)

[5] For measurements of the infrared reflectance on instruments limited to the range 5 to 25 µm, significant errors could result if the specimen has rapidly varying reflectance beyond 25 µm. Note that at 23ºC (75ºF), about 17 percentage of the blackbody energy is emitted beyond 25 µm while only 5 percent is emitted beyond 40 µm.
[6] The calculations of this section can be performed with a calculator or with a simple computer program. The WINDOW 5.2 program written at Lawrence Berkeley Laboratory is available from: http://windows.lbl.gov, Lawrence Berkeley Laboratory Bldg.0-3111, Berkeley, CA 94720; 510-486-4040 or FAX: 510-486-4086.

Calculate the total normal emittance from the spectral reflectance measured according to the procedure of Section 8 using weighted ordinates (Equation 9-2):

$$\varepsilon_n = \frac{\sum_{i=1}^{m} \left(1\text{-R}_{\lambda \text{i}}\right) E_{b\lambda i} \Delta\lambda_i}{\sum_{i=1}^{m} E_{b\lambda i} \Delta\lambda_i} \qquad \text{Equation 9-2}$$

Convert normal to hemispherical emittance. It shall be considered that surfaces emit energy in all directions, not just normal to the surface. Rubin et al. provide a conversion from normal to hemispherical emittance. For a coated low-emissivity glazing substitute ε_n from Equation 9-2 into Equation 9-4 to obtain ε_h. For an uncoated glazing such as glass substitute ε_n into Equation 9-4 to obtain ε_h:

$$\varepsilon_{\text{h}} = 1.3217\varepsilon_{\text{n}} - 1.8766\varepsilon_n^2 + 4.6586\varepsilon_n^3 - 5.8349\varepsilon_n^4 + 2.7406\varepsilon_n^5 \qquad \text{Equation 9-3}$$

$$\varepsilon_{\text{h}} = 0.1569\varepsilon_{\text{n}} + 3.7669\varepsilon_n^2 - 5.4398\varepsilon_n^3 + 2.4733\varepsilon_n^4 \qquad \text{Equation 9-4}$$

10. REPORT

Report the following:

A. Specimen description (see practice in Section 12.1.1 of ASTM E 1164).

B. Date of measurement.

C. Spectrometer type, including description of reflectance accessory, type of calibration standards used and instrument parameters (slit width, scan speed, response time, gain, resolution, number of scans).

D. Measurement results in the form of tables of reflectance versus wavelength, as well as normal and hemispherical emittance.

E. Wavelength range.

F. Blackbody weighting temperature.

G. Which of Equation 9-3 and Equation 9-4 were used to determine emittance.

11. PRECISION AND BIAS

Based on demonstrated sample variability, industrial instrument accuracy and repeatability, measured spectral range, radiometric sensitivity and impact of emittance on U-Factor calculation, measurements from 5 to 25 µm are required.

Report accuracy of measured data reflecting error of calibration standard data, accuracy and repeatability of spectrometer and variation of data for measurements of different samples of the same kind.

Report hemispherical emittance to three significant figures.

12. KEYWORDS

Emittance, Emissivity, Reflectance, Infrared, Spectrometer, U-Factor, Shading Coefficient, Solar Heat Gain Coefficient.

13. REFERENCES

[1] American Institute of Physics, AIP Handbook 1957 6-G1 P. G-65, Radiometry.

[2] Bennet, H.E., Silver, M. and Ashley, E.J. "Infrared Reflectance of Aluminum Evaporated in Ultra-High Vacuum," Journal of the Optical Society of America 53 (1963) 1089-1095.

[3] Dunkle, R. V., Trans. ASME, Principles of Engineering Heat Transfer, Giedt, D., editor, D. Van Nostrand, Inc., New York, Vol. 76, (1957), p. 549.

[4] Hass, G., Applied Physical Optics., Eng. III, Optical Components, Academic Press, New York, Vol. 8, (1965), pp. 309-330.

[5] Holman, J.P., "Heat Transfer", 6th Edition, McGraw-Hill (1986).

[6] Kimura, W. D. and Ford, D. H., Appl., Opt., 25(20), (1968), pp. 3740-3750.Umar, A., et.al., ASHRAE Transactions, Measurement of Angular Emissivity, Vol. 61 (1955).

[7] Rubin, M., Arasteh, D. and Hartmann, J. "A Correlation Between Normal and Hemispherical Emissivity for Coated Window Materials," Int. Comm. Heat and Mass Transfer 14 (1987) 561.

[8] Umar, A., et.al., ASHRAE Transactions, Measurement of Angular Emissivity, Vol. 61 (1955).

INDEX