



National  
Fenestration  
Rating  
Council

NFRC 301-93:  
Standard Test Method for  
Emittance of Specular Surfaces  
Using Spectrometric Measurements

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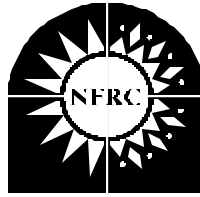


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### *Foreword*

This procedure has been developed by the 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 both U-factor and Solar Heat Gain Coefficient of fenestration systems as well as for daylight transmittance.

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

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**1.0**  
**Scope**

- 1.1** This method determines the normal and hemispherical emittance of a specular surface. This method describes the spectrometric measurement of the near-normal specular reflectance in the mid-infrared range from 5  $\mu\text{m}$  to at least 25  $\mu\text{m}$ . It includes the calculation procedures required to determine the normal and hemispherical emittance of said object.
- 1.2** This method includes calibration instructions for the spectrometer and procedures for selecting reflectance-reference standards.
- 1.3** This method is generally suitable for any flat, specular-reflecting specimen. It is recommended for measuring emittance of architectural or automotive glazing materials such as glass (coated and uncoated), etc. This method is not suitable for determining the emittance of an object which is transparent in the specified range of infrared radiation.
- 1.4** This method is suitable for determining the emittance of an object based on blackbody weighing at a specified temperature (typically 23°C (75°F)), as would be needed to determine the thermal performance (i.e. U-factor, Shading Coefficient, or Solar Heat Gain Coefficient) of a window assembly.
- 1.5** This standard may involve hazardous materials, operations, and equipment. This standard does not presume to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.

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**2.0**  
**Referenced Documents**

**2.1** **ASTM Standards**

- ASTM E 284-91b Standard Terminology of Appearance
- ASTM E 179-91a Standard Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials.
- ASTM E 932-89 Standard Practice for Describing and Measuring Performance of Dispersive Infrared Spectroradiometers

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

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

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3.0 Terminology

- 3.1 The Definitions contained in ASTM E 284-91b are applicable to this standard.
- 3.2 **Blackbody:** a perfect emitter and absorber of thermal radiation. A blackbody emits radiant energy at each wavelength at the maximum rate possible as a consequence of its temperature and absorbs all incident radiant flux.
- 3.3 **Emittance,(e):** a term that describes the ability of an body to emit radiation. It is defined as the ratio

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3.0 Terminology  
(continued)

of the rate of radiant emission of the body, as a consequence of temperature only, to the corresponding emission of a perfect emitter (blackbody) at the same temperature

- 3.4 Hemispherical emittance, ( $e_h$ ):** emittance of a source averaged over all the radial directions of the overspreading hemisphere.
- 3.5 Normal emittance, ( $e_n$ ):** emittance of a source into the direction normal to its surface.
- 3.6 Spectral emittance, ( $e_{n,\lambda}$ ,  $e_{h,\lambda}$ ):** emittance based on the radiant energy per unit wavelength band.
- 3.7 Emissivity, ( $e$ ):** in this method, a term reserved for the emittance for the restricted case of an opaque and homogeneous material.
- 3.8 Specular reflectance, ( $\rho_s$ ):** Reflection in a sharply defined direction equal to the angle of incidence from a smooth interface between homogeneous materials, i.e., obeying the Law of Reflection.

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4.0  
Significance  
and Use

- 4.1** 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 or U-factor of glazing materials.**4.2** The hemispherical emittance, based on weighing with the radiation of a blackbody at 23°C (75°F), 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

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4.0  
Significance  
and Use  
(continued)

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  $\mu\text{m}$  and  $>50.0 \mu\text{m}$ ). Hence, spectral emittance can be derived from spectral reflectance data.

- 4.3** This standard recognizes that there are other uses of surface emittance, e.g. heat transfer during glass tempering, for which this standard is not applicable.
- 4.4** This standard is not intended for measurement of substrates which are transparent to infrared radiation, such as certain plastics, etc.

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**5.0**  
Apparatus

- 5.1** Spectrometer and specular reflectance accessory(s) designed for the measurement of specular reflectance in the range of 5  $\mu\text{m}$  ( $2000\text{ cm}^{-1}$ ) to  $\geq 25\text{ }\mu\text{m}$  ( $400\text{ cm}^{-1}$ ) at 1  $\mu\text{m}$  intervals ( $17\text{ cm}^{-1}$  at 25  $\mu\text{m}$ ).<sup>1</sup>

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

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<sup>1</sup> This procedure requires that measurements be taken up to 25  $\mu\text{m}$ . Measurements covering the range up to 40  $\mu\text{m}$  or even 50  $\mu\text{m}$ , however, should be recorded, if the equipment permits. For samples with significant variation in the extended range, unacceptable error could result (see Section 8).

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5.0  
Apparatus  
(continued)

**5.3** 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° or less to minimize the effects of polarization (ASTM E 179-91a).

**5.4** 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.

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6.0  
Calibration

**6.1 Reflectance Standards**

**6.1.1** Aluminum, copper, gold, and silver mirrors may all have a reflectance of more than 98.5% at 10µm. Aluminum coatings,<sup>2</sup> 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.

**6.1.2** 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

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<sup>2</sup> 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.

Table 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
0.4	0.9076	1.5	0.9658	24	0.9861
0.45	0.9061	2	0.9699	26	0.9864
0.5	0.9034	3	0.9736	28	0.9867
0.55	0.9032	4	0.9758	30	0.9870
0.6	0.9027	5	0.9772	32	0.9872
0.65	0.8976	6	0.9784	34 *	0.9877
0.7	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
0.8	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
0.9	0.8894	13	0.9826	48 *	0.9890
0.925	0.9030	14	0.9830	50 *	0.9891
0.95	0.9154	16	0.9838	52 *	0.9892
1	0.9324	18	0.9845	54 *	0.9893
1.2	0.9585	20	0.9852	56 *	0.9893

\* extrapolated data

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6.0  
Calibration  
(continued)

must be calibrated from 5 to  $\geq 25$   $\mu\text{m}$  against a primary standard.<sup>3</sup> If no calibration data is available for a specific aluminum mirror the data given in Table 1 may be used. The accuracy of a measurement using calibration data from Table 1 is  $\pm 0.5\%$ .

**6.1.3**

Working reflectance standards should be front surface aluminum mirrors on glass from a reputable manufacturer. The working standards must 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<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, or other non-interfering material.

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<sup>3</sup> 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

The cost of calibration (at the time of this writing, December 1992) from 5 to 55  $\mu\text{m}$  is £580.00 for the first and £420.00 for each subsequent mirror plus the cost of the mirror. The uncertainty of measurements is  $\pm 0.3\%$  absolute value. The cost of NPL uncalibrated mirror is £65.00 for an aluminum mirror, and £200.00 for an aluminum mirror with an aluminum oxide coating which can be cleaned. Calibration is also available for mirrors not supplied by NPL.

At this time NIST does not have the capability to provide or calibrated reference mirror in the thermal infrared. An instrument for measuring absolute reflectivity is under development.

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6.0  
Calibration  
(continued)

**6.2** 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:

**6.2.1** 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).

**6.2.2** 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  $\mu\text{m}$ . Scan from 5 to  $\geq 25\mu\text{m}$  using the same instrument settings that will be used to record the sample spectrum (Section 8). Record the background spectrum at 1  $\mu\text{m}$  intervals.

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

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6.0  
Calibration  
(continued)

- 6.2.4** Compensate sample data for the reflectance of the working standard.
- 6.3** Verification of the following instrumental factors is strongly recommended:
- 6.3.1** Zero setting of the reflectance scale. Setting the baseline to 100% 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.<sup>4</sup>
- 6.3.3** Stray light level should be minimized
- 6.4** 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.

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<sup>4</sup> Polystyrene film available from Perkin Elmer. Part #186-2082 <\$8.00 as of September 1992, for orders call 1-800-762-4002. Calibration spectra for polystyrene film in Indene solution is provided in ASTM E 932-89.

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6.0  
Calibration  
(continued)

**6.5** All measurements should be taken at room temperature ( $21^{\circ} \pm 5^{\circ} \text{C}$  ( $70^{\circ} \pm 9^{\circ} \text{F}$ )).

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7.0  
Specimen Selection

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

**7.1.1** 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.

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

**7.2** For coatings subject to aging and atmospheric attack, the specimen to be measured must be fresh and in good condition.

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8.0  
Procedure

**8.1** Follow general procedures as directed by the instrument manufacturer and ASTM E 932-89, with additional, established procedures as required for the particular spectrometer and reflectance attachment being used.

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

**8.3** Handle the specimen carefully and avoid touching the area to be measured. When necessary, clean the specimen. An acceptable cleaning procedure for

8.0  
Procedure  
(Continued)

most specimens is to gently wash with a 50% mixture of 99.9% isopropanol and deionized water, rinse thoroughly with deionized water, and blow off with dry and oil-free N<sub>2</sub>.

- 8.4** Measure the infrared reflectance of the specimen from 5 μm to 25 μm.<sup>5</sup> Resolution should be set to 8 cm<sup>-1</sup> or smaller. Record data at intervals of 1 μm. Use Equation 1 and linear interpolation to convert from wavenumbers to μm.

$$\lambda[\mu\text{m}] = \frac{10,000}{\nu[\text{cm}^{-1}]} \quad [\text{Equation 1}]$$

<sup>5</sup> 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 23°C, about 17% of the blackbody energy is emitted beyond 25 μm while only 5% is emitted beyond 40 μm.

9.0  
Calculation of  
Results<sup>6</sup>

9.1 Planck's law is used to calculate the energy distribution and cumulative energy for this technique. Blackbody spectral emissive power is derived using Equation 2:

$$E_{b\lambda} = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} \quad \text{[Equation 2]}$$

Where:

- C<sub>1</sub> = Planck's first constant (3.743 x 10<sup>8</sup> W μm<sup>4</sup>/m<sup>2</sup>)
- C<sub>2</sub> = Planck's second constant (1.4387 x 10<sup>4</sup> μm K)
- T = Air temperature in degrees Kelvin (°C + 273)
- λ = Wavelength in micrometers
- E<sub>bλ</sub> = Radiation emitted by blackbody at wavelength, λ (W/m<sup>2</sup>/μm)

9.2 Calculate the total normal emittance from the spectral reflectance measured according to the procedure of Section 8 using Weighted Ordinates (Equation 3.):

$$e_n = \frac{\sum_{i=1}^m (1 - R_{\lambda_i}) E_{b\lambda_i} \omega_{\lambda_i}}{\sum_{i=1}^m E_{b\lambda_i} \omega_{\lambda_i}} \quad \text{[Equation 3]}$$

<sup>6</sup> The calculations of this section can be performed with a calculator or with a simple computer program. The WINDOW 4.0 program written at Lawrence Berkeley Laboratory is available from: Ruth Haynes, Lawrence Berkeley Laboratory Bldg.0-3111, Berkeley, CA 94720; ☎ 510-486-4040 or FAX: 510-486-4086

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**9.0**  
**Calculation**  
**of Results**  
(continued)

**9.3** Convert normal to hemispherical emittance. It must 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  $e_n$  from Section 9.2 into Equation 4 to obtain  $e_h$ . For an uncoated glazing such as glass substitute  $e_n$  into Equation 5 to obtain  $e_h$ :

$$e_h = 1.3217e_n - 1.8766e_n^2 + 4.6586e_n^3 - 5.8349e_n^4 + 2.7406e_n^5 \quad \text{[Equation 4]}$$

$$e_h = 0.1569e_n + 3.7669e_n^2 - 5.4398e_n^3 + 2.4733e_n^4 \quad \text{[Equation 5]}$$

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**10.0** Report

**10.1** Report the following:

**10.1.1** Specimen description (see practice ASTM C 1164, Section 11.1.1)

**10.1.2** Date of measurement

**10.1.3** 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)

**10.1.4** Measurement results in the form of tables of reflectance versus wavelength, as well as normal and

hemispherical emittance.

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**10.0**

**Report**

*(continued)*

**10.1.5** Wavelength range

**10.1.6** Blackbody weighting temperature

**10.1.7** Which of Equations 4 and 5 were used to determine emittance

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**11.0**

**Precision and Bias**

**11.1** 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  $\mu\text{m}$  are required.

**11.2** 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.

**11.3** Report hemispherical emittance to three significant figures.

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**12.0**

**Keywords**

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

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**13.0**  
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