National Fenestration Rating Council Incorporated

NFRC 301-2017[E0A0]

Standard Test Method for
Emittance of ~~Specular Surfaces Using Spectrometric Measurements~~Glazing Products

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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), Ventilation Rating (VR), 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).

Products that are labeled with the NFRC Temporary and Permanent Label, or products that are listed on an NFRC Label Certificate in accordance with NFRC requirements, are considered to be NFRC-certified. NFRC maintains a Certified Products Directory (CPD), listing product lines and individual products selected by the Manufacturer/Responsible Party for which certification authorization has been granted.

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.

NFRC owns all rights in and to each of the NFRC 700, NFRC 701, NFRC 702, NFRC 705, NFRC 707, NFRC 708 and each procedure, which is a component of the Rating System, as well as each of its registration marks, trade names, and other intellectual property.

The structure of the NFRC programs and relationships among participants are shown in Figure 1, Figure 2, and Figure 3. For additional information on the roles of the IAs and laboratories and operation of the IA Program and Accreditation Program, see the NFRC 700 (PCP), NFRC 701 (LAP), and NFRC 702 (CAP) respectively.

Figure 1

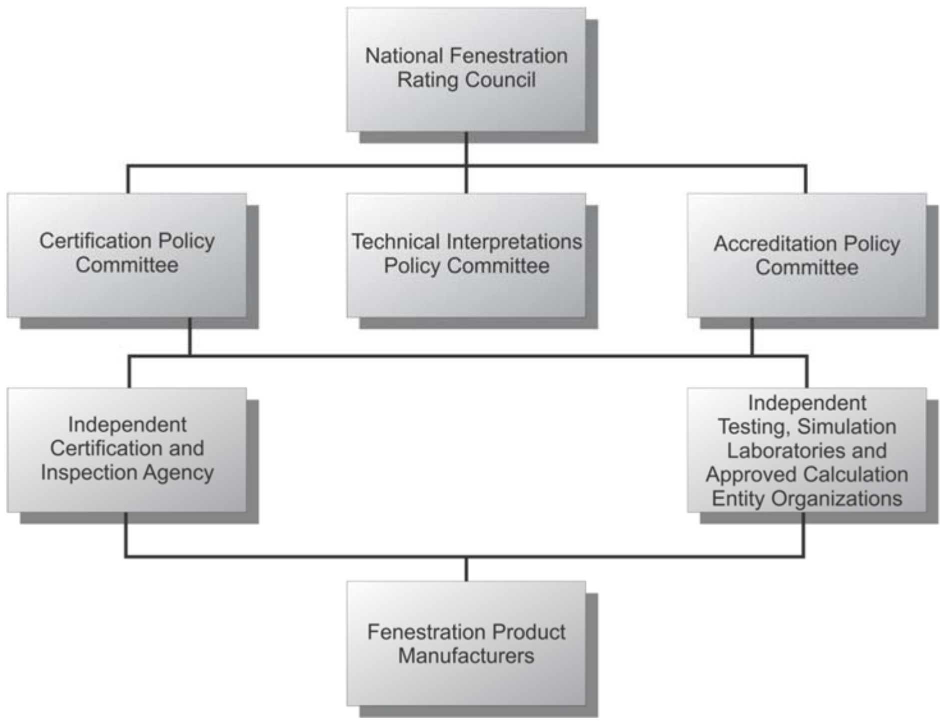


Figure 2

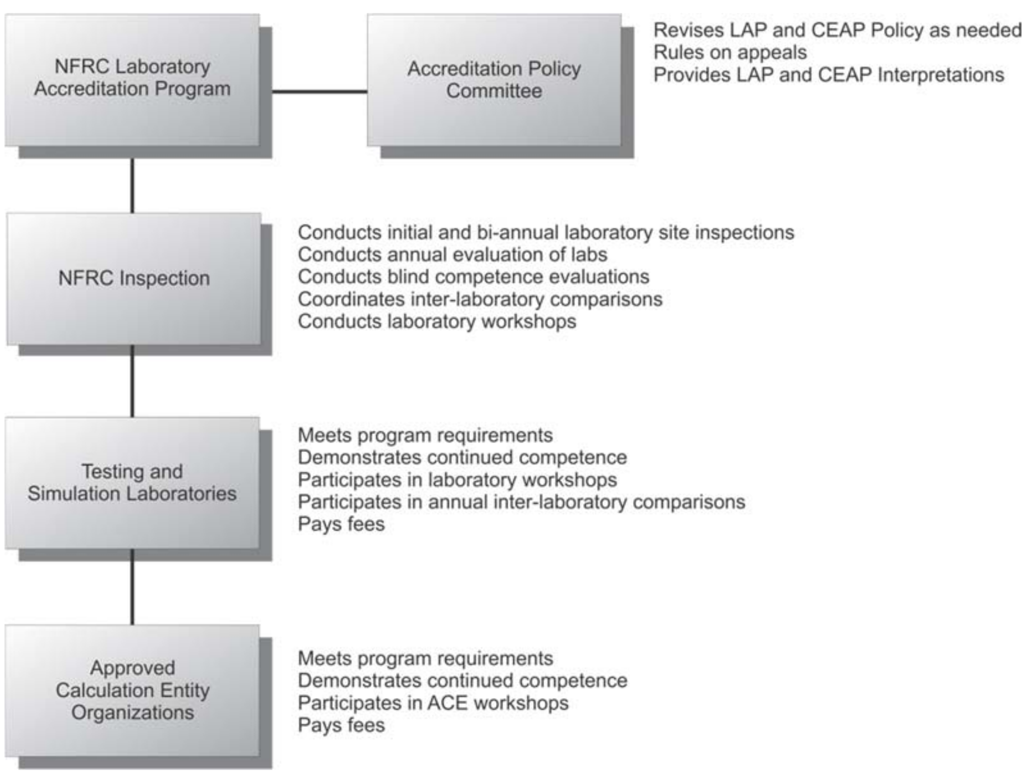
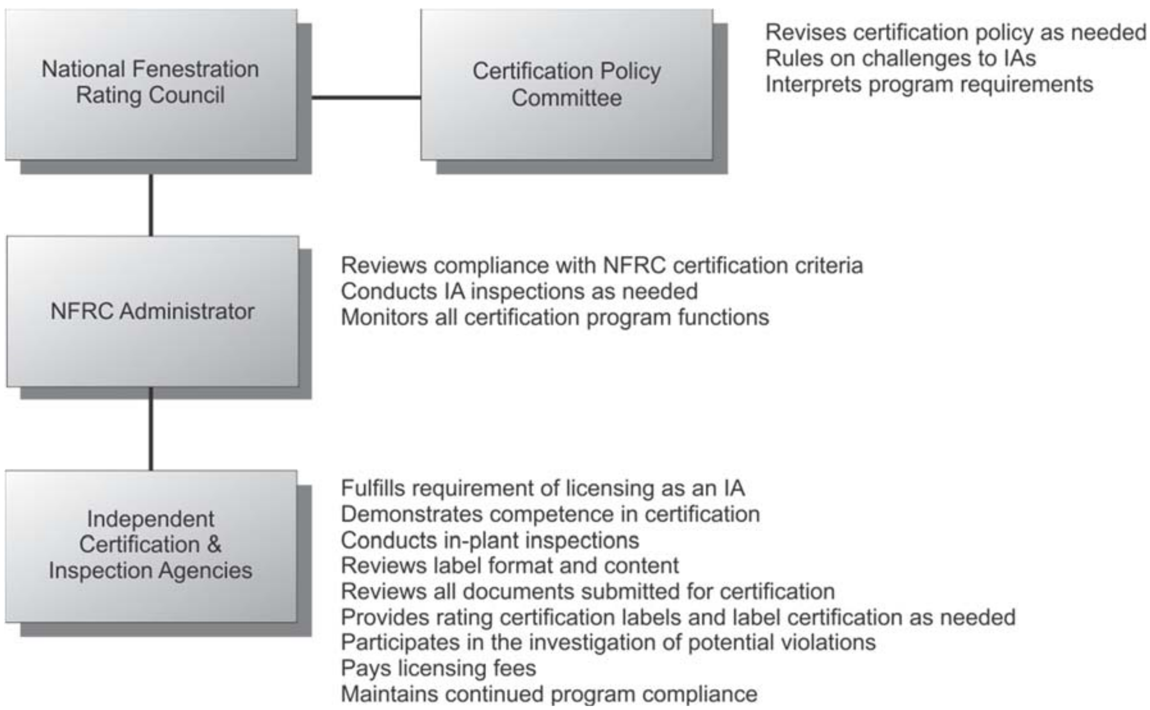


Figure 3



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

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DISCLAIMER

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-related 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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NFRC program participants are required to indemnify NFRC from and against such liability.

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~~1. Scope .... 1~~

1. SCOPE

This test method determines the normal and hemispherical emittance of a specular surface.

1.1 Specular Samples

~~This~~ The test method for specular samples 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)~~for NFRC calculations 27ºC, as would be needed to determine the thermal performance (i.e., U-factor or Solar Heat Gain Coefficient [SHGC]) 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 to determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

ASTM C 1371-15	Standard Test Method for Determination of Emittance on Material Near Room Temperature Using Portable Emissometers
ASTM E 179-~~96~~ 12~~(2003)~~	Standard Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials
ASTM E 284-~~03a~~13b	Standard Terminology of Appearance
ASTM E 408-13	Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques

ASTM E 932-89 (~~2002~~2013)	Standard Practice for Describing and Measuring Performance of Dispersive Infrared Spectroradiometers
ASTM E 1164-~~02~~ 12e1~~(2003)~~	Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation

3. TERMINOLOGY

Absorptance, α: The ratio of the absorbed radiant energy to the total incident radiant energy.

Angle of Incidence: The angle between the solar beam and the normal (perpendicular) to the plane on which it is incident. (The plane of incidence may be the aperture plane, the glazing plane or any other plane of interest).

Attachment: See Dynamic Attachment or Fenestration Attachment.

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.

Emissivity, ε: The relative ability of a surface to reflect or emit heat by radiation. Emissivity ranges from 0.00 to 1.00. (Blackbody emissivity is 1.0).

Hemispherical Emissivity, ε_h: Emissivity of a surface averaged over all the radial directions of the overspreading hemisphere.

Normal Emissivity, ε_n: Emissivity of a surface into the direction normal to its surface.

Fenestration: Products that fill openings in a building envelope, such as windows, doors, skylights, curtain walls, etc., designed to permit or limit the passage of air, light, vehicles, or people.

Film: Fenestration attachment products which consist of a flexible adhesive-backed polymer film which may be applied to the interior or exterior surface of an existing glazing system. See Fenestration Attachment.

Glass: An inorganic, amorphous substance, usually transparent, composed of silica (sand), soda (sodium carbonate) and lime (calcium carbonate) with small quantities of other materials.

Glazing: The act of installing the glazing system/glazing in-fill. n, The transparent or semi-transparent infill material in a glazing system.

Low-E Coating: Microscopically thin metal, metal oxide or multilayer coating, deposited on a glazing surface to reduce its thermal infrared emittance.

Opaque (adj.): Not allowing visible light to pass through.

Polarization: The condition of electromagnetic waves in which the transverse motion or field of the wave is confined to a plane or ellipse.

Radiation: The transfer of heat in the form of electromagnetic waves or photons from one body to another.

Reflectance: The ratio of the reflected radiant flux to the incident radiant flux.

Solar (adj): (1) Referring to radiometric quantities, indicating that the radiant flux involved has the sun as its source or has the relative spectral distribution of solar flux; (2) referring to an optical property, having as its weighting function a standard solar spectral irradiance distribution.

Solar Heat Gain, SHG: The quantity of incident solar energy passing through a fenestration system. Included are both directly transmitted solar radiation as well as solar energy absorbed by the fenestration system and re-transmitted into the inside space.

Solar Heat Gain Coefficient, SHGC: The ratio of the solar heat gain entering the space through the fenestration product to the incident solar radiation. NFRC rates SHGC at normal incidence.

Spectral (adj): Indicating that the property or quantity was evaluated at a specific wavelength, λ, within a small wavelength interval, $\Delta\lambda$ about λ. Usually indicated by placing the wavelength symbol λ, as a subscript following the symbol for the quantity, as with E_λ, thereby indicating that the flux-related quantity is a concentration of flux at the indicated wavelength, or it may be placed inside parentheses following the symbol for the material property, as with $\alpha(\lambda)$. It is permissible to indicate the wavelength dependence of a flux quantity as follows: $E_\lambda(\lambda)$

Specular (adj.): Indicating that the flux leaves a surface or medium at an angle of reflection or transmission numerically equal to the angle of incidence.

Transmittance: the ratio of the transmitted radiant flux to the incident radiant flux.

Transparent (adj.): Permitting light to pass through with clear vision.

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~~ 27ºC~~(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 that are transparent to infrared radiation, such as certain plastics, etc.

5. Apparatus

Spectrometer and specular reflectance accessory(ies) 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 (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° or less to minimize the effects of polarization (ASTM E 179).

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% 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

[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 88).

[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.

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%.

[3] Calibrated primary standards are available from: National Physical Laboratory, Teddington Middlesex TW11, 0LW Great Britain www.npl.co.uk

Table 6-1 -- Absolute Reflectance versus Wavelength of an Aged Evaporated Aluminum Mirror (See Reference 2)

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
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 88). Record the background spectrum at 1 µm intervals;

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

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% 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:

[4] Polystyrene film available from Perkin Elmer. www.perkinelmer.com. Calibration spectra for polystyrene film in Indene solution is provided in ASTM E 932.

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

B. The surface to be measured should be flat across two or three times the measurement area; and

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

8. PROCEDURE

8.1 Measurement Procedure for Smooth Surfaces Using Spectrometers

Follow general procedures as directed by the instrument manufacturer and ASTM E 932 for dispersive instruments or ASTM E408 test method C for FTIR instruments, 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% mixture of 99.9% 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.

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

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:

[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 program written at Lawrence Berkeley Laboratory is available from: http://windows.lbl.gov.

$$E_{b\lambda} = \frac{C_1}{\lambda^5(\varepsilon^{C_2/\lambda T} - 1)}$$ 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($W/m^2 \cdot \mu m$)

For NFRC calculations the temperature T should be 300 K, this temperature is set as default in the standard file used by WINDOW. Calculate the total normal emittance from the spectral reflectance measured according to the procedure of Section 8, using weighted ordinates (Equation 9-2):

$$\varepsilon_n = \frac{\sum_{i=1}^{m}(1 - R_{\lambda i})E_{b\lambda i}\Delta\lambda_i}{\sum_{i=1}^{m} E_{b\lambda i}\Delta\lambda_i}$$ 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 (see Reference 7) provide a conversion from normal to hemispherical emittance. For a coated low-emissivity glazing substitute ε_n from Equation 9-2 into Equation 9-3 to obtain ε_h. For an uncoated glazing such as glass, substitute ε_n into Equation 9-4 to obtain ε_h:

$$\varepsilon_h = 1.3217\varepsilon_n - 1.8766\varepsilon_n^2 + 4.6586\varepsilon_n^3 - 5.8349\varepsilon_n^4 + 2.7406\varepsilon_n^5$$ Equation 9-3

$$\varepsilon_h = 0.1569\varepsilon_n + 3.7669\varepsilon_n^2 - 5.4398\varepsilon_n^3 + 2.4733\varepsilon_n^4$$ Equation 9-4

10. REPORT

Report the following:

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

B. Date of measurement;

C. ~~Spectrometer~~ Instrument 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 for spectral measurements;

F. Blackbody weighting temperature; and

G. Which of Equation 9-3 and Equation 9-4 was 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. REFERENCES

1) Bennett AA, Gray DE, eds. *American Institute of Physics Handbook*. McGraw-Hill: New York, NY; 1957. 6-G1 P. G-65, Radiometry.
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4) Kingslake R, ed. *Applied Optics and Optical Engineering, Volume III: Optical Components*. Academic Press: New York, NY; 1965. Hass G. pp. 309-330.
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7) Rubin M, Arasteh D, Hartmann J. “A correlation between normal and hemispherical emissivity of low-emissivity coatings on glass.” International Communications in Heat and Mass Transfer. 1987; Vol. 14, Iss. 5, pp. 561-565.
8) Umar A, Parmelee GV, Schutrum LF. “Measurement of Angular Emissivity.” ASHRAE Transactions. 1955, Vol. 61, pp. 111-124.

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