Standard Test Methods for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials[1]

This standard is issued under the fixed designation E424; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These test methods cover the measurement of solar energy transmittance and reflectance (terrestrial) of materials in sheet form. Method A, using a spectrophotometer, is applicable for both transmittance and reflectance and is the referee method. Method B is applicable only for measurement of transmittance using a pyranometer in an enclosure and the sun as the energy source. Specimens for Method A are limited in size by the geometry of the spectrophotometer while Method B requires a specimen 0.61 m^2 (2 ft^2). For the materials studied by the drafting task group, both test methods give essentially equivalent results.

1.2 *This standard does not purport to address all of the safety problems, if any, 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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E259 Practice for Preparation of Pressed Powder White Reflectance Factor Transfer Standards for Hemispherical and Bi-Directional Geometries

E275 Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers

E308 Practice for Computing the Colors of Objects by Using the CIE System

3. Definitions

3.1 *solar absorptance*—the ratio of absorbed to incident radiant solar energy (equal to unity minus the reflectance and transmittance).

3.2 *solar admittance*—solar heat transfer taking into account reradiated and convected energy.

3.3 *solar energy*—for these methods the direct radiation from the sun at sea level over the solar spectrum as defined in 3.2, its intensity being expressed in watts per unit area.

3.4 *solar reflectance*—the percent of solar radiation (watts/unit area) reflected by a material.

3.5 *solar spectrum*—for the purposes of these methods the solar spectrum at sea level extending from 350 to 2500 nm.

3.6 *solar transmittance*—the percent of solar radiation (watts/unit area) transmitted by a material.

4. Summary of Methods

4.1 *Method A*—Measurements of spectral transmittance, or reflectance *versus* a magnesium oxide standard, are made using an integrating sphere spectrophotometer over the spectral range from 350 to 2500 nm. The illumination and viewing mode shall be normal-diffuse or diffuse-normal. The solar energy transmitted or reflected is obtained by integrating over a standard solar energy distribution curve using weighted or selected ordinates for the appropriate solar-energy distribution. The distribution at sea level, air mass 2, is used.

4.2 *Method B*—Using the sun as the source and a pyranometer as a detector the specimen is made the cover of an enclosure with the plane of the specimen perpendicular to the incident radiation; transmittance is measured as the ratio of the energy transmitted to the incident energy. (The apparatus of Method B has been used for the measurement of solar-energy reflectance but there is insufficient experience with this technique for standardization at present.)

[1] These test methods are under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.05 on Solar Heating and Cooling Systems and Materials.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

5. Significance and Use

5.1 Solar-energy transmittance and reflectance are important factors in the heat admission through fenestration, most commonly through glass or plastics. (See Appendix X3.) These methods provide a means of measuring these factors under fixed conditions of incidence and viewing. While the data may be of assistance to designers in the selection and specification of glazing materials, the solar-energy transmittance and reflectance are not sufficient to define the rate of heat transfer without information on other important factors. The methods have been found practical for both transparent and translucent materials as well as for those with transmittances reduced by highly reflective coatings. Method B is particularly suitable for the measurement of transmittance of inhomogeneous, patterned, or corrugated materials since the transmittance is averaged over a large area.

6. Method A—Spectrophotometric Method

6.1 *Apparatus:*

6.1.1 *Spectrophotometer*—An integrating sphere spectrophotometer, by means of which the spectral characteristics of the test specimen or material may be determined throughout the solar spectrum. For some materials the spectrum region from 350 to 1800 nm may be sufficient. The design shall be such that the specimen may be placed in direct contact with the sphere aperture for both transmission and reflection, so that the incident radiation is within 6° of perpendicularity to the plane of the specimen.[3]

6.1.2 *Standards:*

6.1.2.1 For transmitting specimens, incident radiation shall be used as the standard relative to which the transmitted light is evaluated. Paired reflecting standards are used, prepared in duplicate as described below.

6.1.2.2 For reflecting specimens, use smoked magnesium oxide (MgO) as a standard as the closest practicable approximation of the completely reflecting, completely diffusing surface for the region from 300 to 2100 nm. The preferred standard is a layer (at least 2.0 mm in thickness) freshly prepared from collected smoke of burning magnesium (Recommend Practice E259). Pressed barium sulfate ($BaSO_4$) or MgO are not recommended because of poor reflecting properties beyond 1000 nm.

6.1.3 *Specimen Backing for Reflectance Measurement*—Transparent and translucent specimens shall be backed by a light trap or a diffusing black material which is known to absorb the near infrared. The backing shall reflect no more than 1 % at all wavelengths from 350 to 2500 nm as determined using the spectrophotometer.

6.2 *Test Specimens:*

6.2.1 Opaque specimens shall have at least one plane surface; transparent and translucent specimens shall have two surfaces that are essentially plane and parallel.

6.2.2 Comparison of translucent materials is highly dependent on the geometry of the specific instrument being used. It is recommended that the specimen be placed in direct contact with the sphere to minimize and control loss of scattered radiation.

6.2.3 For specularly reflecting specimens the sphere conditions, especially where the reflected beam strikes the sphere wall, shall be known to be highly reflecting (95 % or higher). It is recommended that a freshly coated sphere be used especially when measuring translucent or specularly reflecting specimens.

6.3 *Calibration:*

6.3.1 *Photometric*—The calibration of the photometric scale shall be done as recommended by the manufacturer. It shall be carefully executed at reasonable time intervals to ensure accuracy over the entire range.

6.3.2 *Wavelength*—Periodic calibrations should be made of the wavelength scales. Procedures for wavelength calibration may be found in Recommended Practice E275. A didymium filter has also been used for this purpose. Although the absorption peaks have been defined for specific resolution in the visible spectrum it also has peaks in the near infrared; however, the wavelength of the peaks must be agreed upon, using a specific instrument.

6.4 *Procedure:*

6.4.1 *Transmittance*—Obtain spectral transmittance data relative to air. For measurement of transmittance of translucent specimens, place freshly prepared matched smoked MgO surfaces at the specimen and reference ports at the rear of the sphere (Note 1). The interior of the sphere should be freshly coated with MgO and in good condition.

NOTE 1—Magnesium oxide standards may be considered matched if on interchanging them the percent reflectance is altered by no more than 1 % at any wavelength between 350 and 1800 nm.

6.4.2 *Reflectance*—Obtain spectral directional reflectance data relative to MgO. Include the specular component in the reflectance measurement. Back the test specimen with a black diffuse surface if it is not opaque. Depending on the required accuracy, use the measured values directly or make corrections for instrumental 0 and 100 % lines (see Method E308).

6.5 *Calculation*—Solar energy transmittance or reflectance is calculated by integration. The distribution of solar energy as reported by Parry Moon[4] for sea level and air mass 2 shall be used.

6.5.1 *Weighted Ordinates*—Obtain the total solar energy transmittance, T_{se}, and reflectance, R_{se}, in percent, by integrating the spectral transmittance (reflectance) over the standard solar energy distribution as follows:

$$T_{se} \text{ or } R_{se} = \sum_{\lambda=350\text{nm}}^{\lambda=2100\text{ nm}} T_{\lambda} \left(\text{or } R_{\lambda}\right) \times E_{\lambda} \quad (1)$$

$E\lambda$ for air mass 2, at 50-nm intervals, normalized to 100, is given in Appendix X1.

6.5.1.1 This integration is easily programmed for automatic computation.

[3] For additional apparatus specifications see Recommended Practice E308.

[4] *Journal of the Franklin Institute,* Vol 230, 1940, p. 583, or *Smithsonian Physical Tables*, Table 1, Vol 815, 1954, p. 273.

6.5.2 *Selected Ordinates*—Integration is done by reading the transmittance or reflectance at selected wavelengths and calculating their average. Appendix X2 lists 20 selected ordinates for integration.[5]

6.6 *Report*—The report shall include the following:

6.6.1 Complete identification of the material tested, and whether translucent, clear, or specularly reflecting,

6.6.2 Solar *T* percent or Solar *R* percent, or both, to the nearest 0.1 %,

6.6.3 Specimen thickness,

6.6.4 Identification of the instrument used, and

6.6.5 Integration method.

7. Method B—Pyranometer Method

NOTE 2—The pyranometer is used to measure total global (sun and sky) radiation (previously designated a 180° pyroheliometer; presently the latter word refers to a normal incidence measurement of direct solar radiation). See IGY Instruction Manual, Part VI, *Radiation Instruments*, Pergamon Press, New York, NY.

7.1 *Apparatus:*

7.1.1 *Enclosure*—The apparatus that has been used successfully is a box capable of supporting a 0.61-m^2 (24-$in.^2$) specimen. The box, which would normally be about 0.66-m^2 (26-$in.^2$) outside, should be capable of being faced in any direction, as on a universal mount. The inside of the box should be painted flat black.[3] A typical unit is shown in Fig. 1.

7.1.2 *Sensor:*

7.1.2.1 The sensing element of this instrument is a pyranometer consisting of concentric rings, or wedges of thermopiles, colored alternately black and white. The voltage output of this sensor is proportional to the intensity of the total incident solar irradiation. The spectral sensitivity of this instrument extends from the ultraviolet to infrared wavelengths (280 to 2800 nm), thus encompassing all the solar spectrum. The pyranometer should be located inside the box so that the sensing thermopile is approximately 50 mm (2 in.) from the center of the bottom plane of the sample.

7.1.2.2 The pyranometer has a viewing area of 180°. An Eppley pyranometer with its 25-mm (1-in.) diameter sensing disk, when placed in the center of the box, views the midpoint of the edges of the test specimen as a cone of 160°; the diagonal of the specimen is viewed as a cone of 166° when the thermopile is 50 mm (2 in.) below the bottom of the specimen.

7.1.2.3 *Read-Out Instrumentation*—A recorder, or a nonrecording meter capable of indicating in the 0.2 to 15-mV range are permissible for use. The output voltage of the pyranometer will be affected by the input impedance of the meter to which it is connected. Thus, the meter used to indicate solar intensity should have a very high input impedance, such as a precision vacuum-tube voltmeter, or a meter which has been calibrated for one particular sensing element, thus compensating for any loading effects on that element.

7.2 *Specimens*—The test specimens should be not less than 0.61 by 0.61 m (24 by 24 in.). If the cross-sectional shape of the specimen is not flat, care must be taken to prevent the possibility of light leaks at the edges such as are caused by the use of oversize specimens.

7.3 *Procedure:*

7.3.1 Conduct the tests on a clear sunny day with no cloud cover interruptions during the individual tests. Conduct testing between the hours of 9 a.m. and 3 p.m. local standard time; this is when the solar radiation is at least 80 % of the value obtained at solar noon for that day. In the Northern hemisphere take readings between November and February only between 10 a.m. and 2 p.m. Expose the test specimen approximately normal to the sun for 15 min prior to testing. Next, align the box normal to the sun's rays and take the average incident solar-energy reading over a period of time (normally several minutes) until a steady trace, or reading is obtained. Then place the test specimen on the box and again record the average solar energy reaching the sensor. When the test specimen has a corrugated or irregular surface move it across the sensing element, and take readings at 10-mm (½-in.) intervals for the width of one corrugation or irregularity, and average the readings. Also measure corrugated specimens with the corrugations in the North-South direction and in the East-West direction.

7.3.2 The solar energy transmittance of the test specimens is the ratio of the energy measured when the test specimen is placed between the sun and the sensor and the energy measured by the sensor with no test specimen in place.

7.4 *Report*—The report shall include the following:

7.4.1 The source and identity of the test specimen,

7.4.2 A complete description of the test specimen, that is, thickness, cross-sectional shape, color, size, translucent or transparent, type of material,

7.4.3 The percent solar energy transmittance to the nearest 1 %,

7.4.4 The place, date, and time of the test,

7.4.5 The intensity of the solar radiation,

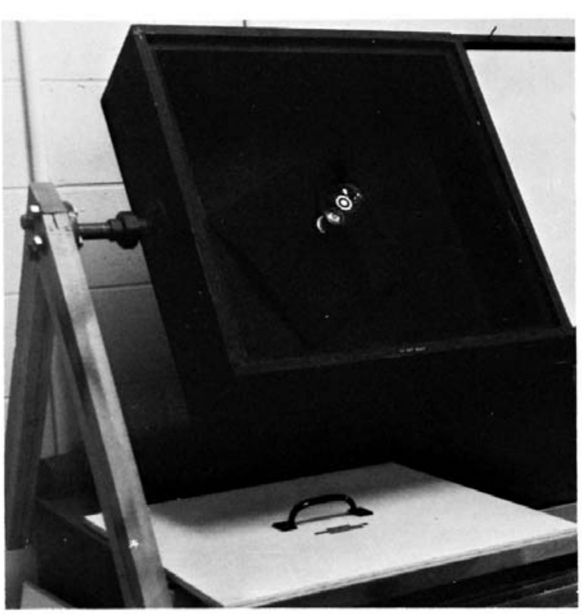

FIG. 1 Typical Unit with Pyranometer Mounted in Black Box

[5] Olson, O. H., "Selected Ordinates for Solar Absorptivity Calculations," *Applied Optics*, Vol 2, No. 1, January 1963.

7.4.6 Type of sensing unit used, and

7.4.7 Ambient air temperature.

8. Keywords

8.1 pyranometer; reflectance; solar energy; spectrophotometer; terrestrial reflectance; transmittance

APPENDIXES

(Nonmandatory Information)

X1. SOLAR ENERGY TRANSMITTANCE OR REFLECTANCE USING WEIGHTED ORDINATES (NORMALIZED TO $\sum$ = 100.00)

$$T_{se}(\%) = \sum_{\lambda=350nm}^{\lambda=2100\ nm} T_\lambda \times E_\lambda$$

Wavelength, nm	Relative Energy	Wavelength, nm	Relative Energy	Wavelength, nm	Relative Energy
350	1.27	950	3.29	1550	1.49
400	3.18	1000	4.25	1600	1.36
450	6.79	1050	3.72	1650	1.17
500	8.20	1100	1.70	1700	0.89
550	8.03	1150	1.46	1750	0.54
600	7.88	1200	2.52	1800	0.01
650	7.92	1250	2.21	1850	0.00
700	7.48	1300	1.78	1900	0.00
750	5.85	1350	0.12	1950	0.12
800	5.79	1400	0.00	2000	0.02
850	5.66	1450	0.16	2050	0.26
900	3.24	1500	1.06	2100	0.58
				Total	100.00

X2. TWENTY SELECTED ORDINATES FOR EVALUATION OF SOLAR TRANSMITTANCE OR REFLECTANCE AT SEA LEVEL

X3. SOLAR ADMITTANCE PARAMETERS

No.	Wavelength, nm	No.	Wavelength, nm
1	390	11	745
2	444	12	786
3	481	13	831
4	511	14	877
5	543	15	959
6	574	16	1026
7	606	17	1105
8	639	18	1228
9	669	19	1497
10	705	20	1722

X3.1 Solar energy poses a complex problem to architects and engineers concerned with maintaining a comfortable indoor space condition. The problem exists when solar energy is admitted into a space which must be thermally and optically controlled, that is, temperature, humidity, and brightness.

X3.2 The amount of solar-energy admitted into a space can be calculated with the solar-admittance parameters, total solar-energy transmittance (TSET), and total solar-energy reflectance (TSER) of the materials surrounding the space.

X3.3 With homogenous materials the percent of solar energy reflected, *R*, absorbed, *A*, and transmitted, *T*, can be determined by the following equation:

$$100\ \% = R + A + T \quad (X3.1)$$

X3.4 For transparent materials, such as glass and clear plastics, the total solar energy transmittance is significient and environmental control systems must be designed to handle the changing solar load.

X3.5 Space environmental engineers use the total solar-energy transmittance and total solar-energy reflectance parameters of materials to determine the solar energy admitted into a space.

X3.5.1 *For example:* A ¼-in. bronze-tinted glass has the following typical solar energy admittance properties:

TSET = 46 % = *T*
TSER = 6 % = *R*
TSEA = 48 % = *A*

For the following conditions:

Design Day—Sept. 21, 40° North latitude, 4 p.m., West elevation (*ASHRAE Handbook of Fundamentals*, 1967, Table 4, p. 472).[6] (All solar energy rates are per hour, square foot of glazing area.)

Direct normal solar irradiation:	230 Btu
Recommended outdoor wind velocity: (Table 9, Item 3, p. 477)[6]	7.5 mph
[Corresponding outdoor surface coefficient:	4.0 Btu/°F
Recommended indoor air velocity: (Table 9, Item 3, p. 477)[6]	Still
[Corresponding indoor surface coefficient:	1.46 Btu/°F

Total solar energy admitted indoors:

$$\text{Total solar heat gain indoors:} \tag{X3.2}$$

$$= 0.46\ (230) + 1.46/[(1.46+4)\ (0.48 \times 230)]$$

where:

0.46 (230) = transmitted solar energy
= 106 Btu

and:

$$1.46/[(1.46+4.0)\ (0.48 \times 230)] \tag{X3.3}$$

$$(\textit{ASHRAE Handbook}, 1967, \text{p. } 480) \text{ Eq 19}$$

= portion of absorbed solar energy reradiated and convected indoors
= 39 Btu (Note X3.1).

$$\text{Total solar energy admitted indoors} = 136 \text{ Btu } (\text{Note X3.2}) \tag{X3.4}$$

X3.5.2 The 1967 *ASHRAE Handbook of Fundamentals*[6] reviews this procedure on pages 477 through 480.

NOTE X3.1—The amount of absorbed solar energy which is reradiated and convected indoors is a direct function of the air movement over the indoor and outdoor glazing surfaces.

NOTE X3.2—Cooling loads used for design also include conduction resulting from out-in temperature differences; heat capacity of building materials may introduce a delay in peak load timing.

X3.6 The Handbook[6] also illustrates a more commonly used method on pages 470 through 476 with the use of shading coefficients for the glazing under consideration and solar heat gain factors (SHGF) for ⅛-in. clear glass (Tables 2 to 6, pp. 470–474).

X3.6.1 *For example:*

A ¼-in. bronze-tinted glass typical shading coefficient = 0.67.

If, SHGF = 205 Btu (Table 4, Sept. 21, p. 472, West elevation, 4 p.m.),

Solar energy admitted indoors = 0.67 × 205 = 137 Btu.

X3.7 Double glazing computations become more complex and the solar energy admitted indoors requires considerably more calculation as the *R A T* formula does not apply directly. For this type of glazing, the shading coefficient technique is more applicable.

X3.8 Representative shading coefficients are available from glass and plastic manufacturers.

[6] *ASHRAE Handbook of Fundamentals,* American Society of Heating, Refrigerating, and Air Conditioning Engineers, 345 E. 47th St., New York, NY 10017, 1967, pp. 470–480.