Designation: E 971 – 88 (Reapproved 1996)$^{\epsilon 1}$

Standard Practice for Calculation of Photometric Transmittance and Reflectance of Materials to Solar Radiation[1]

This standard is issued under the fixed designation E 971; 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.

ϵ^1 Note—Keywords were added editorially in April 1996.

1. Scope

1.1 This practice describes the calculation of luminous (photometric) transmittance and reflectance of materials from spectral radiant transmittance and reflectance data obtained from Test Method E 903.

1.2 Determination of luminous transmittance by this practice is preferred over measurement of photometric transmittance by methods using the sun as a source and a photometer as detector except for transmitting sheet materials that are inhomogeneous, patterned, or corrugated.

1.3 *This standard does not purport to address all of the safety concerns, 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:*

E 772 Terminology Relating to Solar Energy Conversion[2]

E 891 Tables for Terrestrial Direct Normal Solar Spectral Irradiance for Air Mass 1.5[3]

E 903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres[2]

E 972 Test Method for Solar Photometric Transmittance of Sheet Materials Using Sunlight[2]

E 1175 Test Method for Determining Solar or Photopic Reflectance, Transmittance, and Absorptance of Materials Using a Large Diameter Integrating Sphere[2]

2.2 *CIE Standard:*

Standard Illuminator D65[4]

3. Terminology

3.1 *Definitions*—For definitions of other terms used in this practice, refer to Terminology E 772.

3.1.1 *illuminance*, *n*—luminous irradiance.

3.1.2 *luminous* (photometric), *adj*—referring to a radiometric quantity, indicates the weighted average of the spectral radiometric quantity, with the photopic spectral luminous efficiency function given in Annex A1 being the weighting function (see Appendix X1).

3.1.3 *radiant flux*, $\Phi = dQ/dt$ [Watt(W)], *n*—power emitted, transferred, or received in the form of electromagnetic waves or photons. See radiometric properties and quantities.

3.1.4 *solar irradiance at a point of a surface*, $E_s = d\Phi/dA$, *n*—the quotient of the solar flux incident on an element of a surface containing the point, by the area of that element, measured in watts per square metre.

3.1.5 *solar*, *adj*—*(1) referring to a radiometric term*, indicates that the quantity has the sun as a source or is characteristic of the sun. *(2) referring to an optical property*, indicates the weighted average of the spectral optical property, with the solar spectral irradiance $E_{s\lambda}$ used as the weighting function.

3.1.6 *spectral*, *adj*—*(1) for dimensionless optical properties*, indicates that the property was evaluated at a specific wavelength, λ, within a small wavelength interval, Δλ about λ. Symbol wavelength in parentheses, as L (350 nm, 3500Å), or as a function of wavelength, symbol L (λ). *(2) for a radiometric quantity*, indicates the concentration of the quantity per unit wavelength or frequency, indicated by the subscript lambda, as $L_\lambda = dL/d\lambda$, at a specific wavelength. The wavelength at which the spectral concentration is evaluated may be indicated by the wavelength in parentheses following the symbol, L_λ(350 nm).

4. Summary of Practice

4.1 Spectral transmittance or reflectance data between wavelengths of 380 and 760 nm (3800 to 7600 Å), which have

[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 Subsystems and Systems.

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[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] Available from Commission Internationale de l'Eclairage, Bureau Central de la CIE, 4 Av. du Recteur Poincaré, 75-Paris, France.

been obtained in accordance with Test Method E 903, are multiplied by solar spectral irradiance values provided in Standard Tables E891 and by the photopic spectral luminous efficiency function (see Annex A1). The resulting product is integrated over the spectral range from 380 to 760 nm using a summation procedure to approximate the integral. This summation procedure is then repeated with the product of the solar energy spectral distribution and the photopic spectral luminous efficiency. The ratio of the two integrals is the solar luminous (photometric) transmittance or reflectance of the measured sample.

5. Significance and Use

5.1 Glazed apertures in buildings are commonly utilized for the controlled admission of both light and solar radiant heat energy into the structure. Other devices may also be used to reflect light and solar radiant heat into a building.

5.1.1 Most of the solar radiant energy entering a building in this manner possesses wavelengths that lie between 300 and 2500 nm (3000 to 25 000 Å). Only the portion between 380 and 760 nm is visible radiation, however. In daylighting applications, it is therefore important to distinguish the solar radiant energy transmittance and reflectance of these materials from their luminous (visual or photometric) transmittance and reflectance.

5.2 For comparisons of the energy and illumination performances of building fenestration systems it is important that the calculation or measurement, or both, of solar radiant and luminous transmittance and reflectance of materials used in fenestration systems use the same incident solar spectral irradiance distribution.

5.2.1 Solar luminous transmittance and reflectance are important properties in describing the performance of components of solar illumination systems (for example, windows, clerestories, skylights, shading and reflecting devices) and other fenestrations that permit the passage of daylight as well as solar energy into buildings.

5.3 This practice is useful for determining the luminous transmittance and reflectance of glazing materials and diffusely or quasi-diffusely reflecting materials used in daylighting systems. For the results of this practice to be meaningful, inhomogeneities or corrugations in the sample must not be large. Test Method E 1175 (or Test Method E 972) is available for sheet materials that do not satisfy this criterion.

6. Procedure

6.1 *Measurements*—Measure spectral transmittance data $\tau(\lambda_i)$ or spectral reflectance data $\rho(\lambda_i)$ from 380 nm to 760 nm as described in Test Method E 903.

6.2 *Calculations*—Calculate the photometric transmittance τ_v or reflectance ρ_v using Eq 1 as follows:

$$\rho_v \text{ or } \tau_v = \left(\sum_{i=1}^{N} [\rho(\lambda_i) \text{ or } \tau(\lambda_i)] \cdot E_{\lambda i} V_{\lambda i} \Delta\lambda_i / \sum_{i=1}^{N} E_{\lambda i} V_{\lambda i}\right) \quad (1)$$

where:

$E_{\lambda i}$ = terrestrial direct normal solar spectral irradiance for air mass 1.5 provided in Tables E891,
V_{λ} = photopic spectral luminous efficiency function given in Annex A1, and
N = number of wavelengths for which E_{λ} is known between 380 nm and 760 nm.

6.2.1 For the purposes of this practice, the difference $\Delta\lambda_i$ between adjacent wavelengths (λ_i and λ_{i+1}) shall be less than 15 nm for any *i*, *N* shall be greater than 25, and the first and last wavelength (λ_1 and λ_N) shall be within 30 nm of 380 and 760 nm, respectively.

6.2.2 The standard spectral irradiance distribution E_{λ} used in this calculation shall be the direct normal irradiance for air mass 1.5 provided in Standard Tables E891.

NOTE 1—The spectral distribution of CIE standard illuminant D-65 is similar to the spectral irradiance distribution provided in Tables E891. Calculations of solar photometric transmittance and reflectance of a variety of different samples using the D-65 spectral irradiance values for $E\lambda$ above have shown a maximum difference of 0.004 in absolute transmittance of reflectance from those calculated using the spectral irradiance specified in this practice. For chromaticity calculations, refer to standards governing these calculations under the jurisdiction of ASTM Committee E-12.[3]

7. Report

7.1 The report shall include the following:

7.1.1 Photometric transmittance or reflectance, or both, to the nearest 0.01 (1 %).

7.1.2 A copy of the test report resulting from execution of the procedures described in Test Method E 903.

8. Keywords

8.1 clerestories; fenestration; glazing materials; photometric reflectance; photometric transmittance; skylights; solar radiation; windows

ANNEX

(Mandatory Information)

A1. INFORMATION ON THE CIE PHOTOPIC SPECTRAL LUMINOUS EFFICIENCY Vλ AND THE LUMINOUS EFFICACY CONSTANT Km

A1.1 Values for the spectral luminous efficiency function V_λ for photopic vision, as adopted by the International Commission on Illumination in 1924 and by the International Committee for Weights and Measures in 1933 (column for standard values) and intermediate interpolated values (other columns) are given in Table A1.1.

NOTE A1.1—The International Committee for Weights and Measures, meeting at the International Bureau of Weights and Measures near Paris, France, on Sept. 20–22, 1977, approved the value of 683 lm/W for the spectral luminous efficacy constant K_m. This constant is for monochromatic radiation at a wavelength 555 nm (5550 Å) (where V_λ has its maximum value of 1.0002) in standard air for photopic vision.

TABLE A1.1 Values for the Spectral Luminous Efficiency Function V (λ)[A]

Wave-length, nm	Standard Values	Values Interpolated at Intervals of 1 nm								
		1	2	3	4	5	6	7	8	9
380	0.00004	0.000045	0.000049	0.000054	0.000059	0.000064	0.000071	0.000080	0.000090	0.000104
390	0.00012	0.000138	0.000155	0.000173	0.000193	0.000215	0.000241	0.000272	0.000308	0.000350
400	0.0004	0.00045	0.00049	0.00054	0.00059	0.00064	0.00071	0.00080	0.00090	0.00104
410	0.0012	0.00138	0.00156	0.00174	0.00195	0.00218	0.00244	0.00274	0.00310	0.00352
420	0.0040	0.00455	0.00515	0.00581	0.00651	0.00726	0.00806	0.00889	0.00976	0.01066
430	0.0116	0.01257	0.01358	0.01463	0.01571	0.01684	0.01800	0.01920	0.02043	0.02170
440	0.023	0.0243	0.0257	0.0270	0.0284	0.0298	0.0313	0.0329	0.0345	0.0362
450	0.038	0.0399	0.0418	0.0438	0.0459	0.0480	0.0502	0.0525	0.0549	0.0574
460	0.060	0.0627	0.0654	0.0681	0.0709	0.0739	0.0769	0.0802	0.0836	0.0872
470	0.091	0.0950	0.0992	0.1035	0.1080	0.1126	0.1175	0.1225	0.1278	0.1333
480	0.139	0.1448	0.1507	0.1567	0.1629	0.1693	0.1761	0.1833	0.1909	0.1991
490	0.208	0.2173	0.2270	0.2371	0.2476	0.2586	0.2701	0.2823	0.2951	0.3087
500	0.323	0.3382	0.3544	0.3714	0.3890	0.4073	0.4259	0.4450	0.4642	0.4836
510	0.503	0.5229	0.5436	0.5648	0.5865	0.6082	0.6299	0.6511	0.6717	0.6914
520	0.710	0.7277	0.7449	0.7615	0.7776	0.7932	0.8082	0.8225	0.8363	0.8495
530	0.862	0.8739	0.8851	0.8956	0.9056	0.9149	0.9238	0.9320	0.9398	0.9471
540	0.954	0.9604	0.9661	0.9713	0.9760	0.9803	0.9840	0.9873	0.9902	0.9928
550	0.995	0.9969	0.9983	0.9994	1.0000	1.0002	1.0001	0.9995	0.9984	0.9969
560	0.995	0.9926	0.9898	0.9865	0.9828	0.9786	0.9741	0.9691	0.9638	0.9581
570	0.952	0.9455	0.9386	0.9312	0.9235	0.9154	0.9069	0.8981	0.8890	0.8796
580	0.870	0.8600	0.8496	0.8388	0.8277	0.8163	0.8046	0.7928	0.7809	0.7690
590	0.757	0.7449	0.7327	0.7202	0.7076	0.6949	0.6822	0.6694	0.6565	0.6437
600	0.631	0.6182	0.6054	0.5926	0.5797	0.5668	0.5539	0.5410	0.5282	0.5156
610	0.503	0.4905	0.4781	0.4658	0.4535	0.4412	0.4291	0.4170	0.4049	0.3929
620	0.381	0.3690	0.3570	0.3449	0.3329	0.3210	0.3092	0.2977	0.2864	0.2755
630	0.265	0.2548	0.2450	0.2354	0.2261	0.2170	0.2082	0.1996	0.1912	0.1830
640	0.175	0.1672	0.1596	0.1523	0.1452	0.1382	0.1316	0.1251	0.1188	0.1128
650	0.107	0.1014	0.0961	0.0910	0.0862	0.0816	0.0771	0.0729	0.0688	0.0648
660	0.061	0.0574	0.0539	0.0506	0.0475	0.0446	0.0418	0.0391	0.0366	0.0343
670	0.032	0.0299	0.0280	0.0263	0.0247	0.0232	0.0219	0.0206	0.0194	0.0182
680	0.017	0.01585	0.01477	0.01376	0.01281	0.01192	0.01108	0.01030	0.00956	0.00886
690	0.0082	0.00759	0.00705	0.00656	0.00612	0.00572	0.00536	0.00503	0.00471	0.00440
700	0.0041	0.00381	0.00355	0.00332	0.00310	0.00291	0.00273	0.00256	0.00241	0.00225
710	0.0021	0.001954	0.001821	0.001699	0.001587	0.001483	0.001387	0.001297	0.001212	0.001130
720	0.00105	0.000975	0.000907	0.000845	0.000788	0.000736	0.000688	0.000644	0.000601	0.000560
730	0.00052	0.000482	0.000447	0.000415	0.000387	0.000360	0.000335	0.000313	0.000291	0.000270
740	0.00025	0.000231	0.000214	0.000198	0.000185	0.000172	0.000160	0.000149	0.000139	0.000130
750	0.00012	0.000111	0.000103	0.000096	0.000090	0.000084	0.000078	0.000074	0.000069	0.000064
760	0.00006	0.000056	0.000052	0.000048	0.000045	0.000042	0.000039	0.000037	0.000035	0.000032

[A] *IES Lighting Handbook, 1981 Reference Volume*, Illuminating Engineering Society of North America, 345 East 47th Street, New York, NY 10017, Figs. 3–7, pp. 3–5, is the source for this table.

APPENDIX

(Nonmandatory Information)

X1. INFORMATION ON SOLAR ILLUMINANCE

X1.1 If E_λ is the solar spectral irradiance given in $Wm^{-2} \cdot nm^{-1}$, then the solar irradiance E_e will be given as follows:

$$E_e = \int_O^\infty E_\lambda d\lambda \qquad [Wm^{-2}] \tag{X1.1}$$

X1.2 If V_λ is the CIE spectral luminous efficiency function (see Annex A1), then the corresponding solar illuminance E_v will be given as follows:

$$E_v = K_m \int_{380}^{760} V_\lambda E_\lambda d\lambda \, [1m \cdot m^{-2}] \tag{X1.2}$$