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Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces[1]

This standard is issued under the fixed designation E1980; 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.

INTRODUCTION

The steady-state surface temperature (T_s) under the sun is strongly correlated to solar reflectivity and thermal emissivity of the surface. For equivalent conditions, the T_s of dark surfaces (with low solar reflectance) is higher than light-colored surfaces (with high solar reflectance); and surfaces with low thermal emissivity have higher T_s's than surfaces with high thermal emissivity. The procedure recommended in this standard will allow a direct comparison of T_s of surfaces under the sun. The procedure defines a Solar Reflectance Index (SRI) that measures the relative T_s of a surface with respect to the standard white (SRI = 100) and standard black (SRI =0) under the standard solar and ambient conditions.

1. Scope

1.1 This practice covers the calculation of the Solar Reflectance Index (SRI) of horizontal and low-sloped opaque surfaces at standard conditions. The method is intended to calculate SRI for surfaces with emissivity greater than 0.1.

1.2

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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:*

E408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques

E772 Terminology Relating to Solar Energy Conversion [2]

E891 Tables for Terrestrial Direct Normal Solar Irradiance for Air Mass 1.5[3]

E903 Test Method for Solar Absorption, Reflectance, and Transmittance of Materials Using Integrating Spheres[3]

E1918 Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37 Tilted Surface

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Building Construction and is the direct responsibility of Subcommittee E06.21 on Serviceability.

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[2] Annual ASTM Book of Standards, Vol 15.03.

[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.

3.1.1 *convective coefficient (h_c)*—the rate of heat transfer from the surface to air induced by the air movement, expressed in watts per square metre per degree Kelvin, $W \cdot m^{-2} \cdot K^{-1}$.

3.1.2 *low-sloped surfaces*—surfaces with a slope smaller than 9.5° from the horizontal.

3.1.3 *reference black surface temperature (T_b)* —is the steady-state temperature of a black surface with solar reflectance of 0.05 and thermal emissivity of 0.9, under the standard solar and ambient conditions.

3.1.4 *reference white surface temperature (T_w)* —is the steady-state temperature of a white surface with solar reflectance of 0.80 and thermal emissivity of 0.9, under the standard solar and ambient conditions.

3.1.5 *sky temperature (T_{sky})*—is the temperature of a black body that would radiate the same power toward the earth as does the sky.

3.1.6 *solar absorptance (α)*—the fraction of solar flux absorbed by a surface. For an opaque surface α = 1 -– a.

3.1.7 *solar flux (I)*—is the direct and diffuse radiant power from the sun received at ground level over the solar spectrum, expressed in watts per square metre, $W \cdot m^{-2}$.

3.1.8 *solar reflectance (a)*—the fraction of solar flux reflected by a surface.

3.1.9 *solar reflectance index (SRI)*—is the relative T_s of a surface with respect to the standard white (SRI = 100) and standard black (SRI = 0) under the standard solar and ambient conditions.

3.1.10 *solar spectrum*—spectral distribution of typical terrestrial sunlight at air mass 1.5 as defined in Tables ~~E 891E 891~~G173.

3.1.11 *standard solar and ambient conditions*— for the purpose of this calculation, is defined as a solar flux of 1000 $W \cdot m^{-2}$, ambient air temperature of 310 Kelvin (K), and sky temperature of 300 K. Three convective coefficient of 5, 12, 30 $W \cdot m^{-2} \cdot K^{-1}$, corresponding to low- (0 to 2 ms^{-1}), medium- (2 to 6 ms^{-1}), and high-wind (6 to 10 ms^{-1}) conditions, respectively.

3.1.12 *steady-state surface temperature (T_s)* —is the temperature of the surface, in K, under the standard solar and ambient conditions.

3.1.13 *thermal emissivity (ε)*—the ratio of radiant flux emitted by a surface at a given temperature to that emitted by a black body radiator at the same temperature. For this calculation, the thermal emissivity is for a temperature below 150°C.

4. Summary of Practice

4.1 For a surface exposed to the sun, when the conduction into the material is zero, the steady-state surface temperature is obtained by:

$$\alpha I = \varepsilon\sigma(T_s^{\,4} - T_{sky}^{\,4}) + h_c(T_s - T_a) \tag{1}$$

where:

α = solar absorptance = 1 -– solar reflectance,
I = solar flux, $W \cdot m^{-2}$,
ε = thermal emissivity,
σ = Stefan Boltzmann constant, 5.66961 x 10^{-8} $W \cdot m^{-2} \cdot K^{-4}$,
T_s = steady-state surface temperature, K,
T_{sky} = sky temperature, K,
h_c = convective coefficient, $W \cdot m^{-2} \cdot K^{-1}$, and
T_a = air temperature, K.

4.2 Given the solar reflectivity and thermal emissivity of a surface, and the convective coefficient, Eq 1 needs to be solved iteratively for surface temperature. Alternatively, one can use the following equation to obtain the surface temperature:

$$T_s = 309.07 + \frac{(1066.07\alpha - 31.98\varepsilon)}{(6.78\varepsilon + h_c)} - \frac{(890.94\alpha^2 + 2153.86\alpha\varepsilon)}{(6.78\varepsilon + h_c)^2} \tag{2}$$

Surface temperature estimated by Eq 2 is accurate within 1 K.

4.3 In this practice, Solar Reflectance Index is defined as:

$$SRI = 100\,\frac{T_b - T_s}{T_b - T_w} \tag{3}$$

where: T_b and T_w are the steady-state temperature of black and white surfaces.

Under the standard solar and ambient conditions, Eq 3 is regressed to:

$$SRI = 123.97 - 141.35\chi + 9.655\chi^2 \tag{4}$$

where:

$$\chi = \frac{(\alpha - 0.029\varepsilon)(8.797 + h_c)}{9.5205\varepsilon + h_c} \tag{5}$$

For α greater than 0.1, and excluding collector surfaces (surface with high solar absorptance and low thermal emittance, that is, α greater than 0.8 and ε less than 0.2), Eq 4 estimates SRI with an average error of 0.9 and maximum error of 2.