Designation: E1980 – 11

# 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 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:*[2]

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

## 3. Terminology

3.1 *Definitions:*

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 $\alpha = 1 - a$.

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 G173.

[1] This test method is under the jurisdiction of ASTM Committee D08 on Roofing and Waterproofing and is the direct responsibility of Subcommittee D08.18 on Nonbituminous Organic Roof Coverings.

Current edition approved Jan. 1, 2011. Published January 2011. Originally published in 1998. Last previous edition approved in 2001 as E1980–01, which was withdrawn in January 2010 and reinstated in January 2011. DOI: 10.1520/E1980-11.

[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.

3.1.11 *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:

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

where:

$\alpha$ = solar absorptance = 1 − solar reflectance,
$I$ = solar flux, $W{\cdot}m^{-2}$,
$\varepsilon$ = thermal emissivity,
$\sigma$ = Stefan Boltzmann constant, $5.66961 \times 10^{-8}$ $W{\cdot}m^{-2}{\cdot}K^{-4}$,
$T_s$ = 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:

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

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

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

$$SRI = 100\frac{T_b - T_s}{T_b - T_w} \quad (3)$$

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:

$$SRI = 123.97 - 141.35\chi + 9.655\chi^2 \quad (4)$$

where:

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

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

## 5. Significance and Use

5.1 Solar reflectance and thermal emittance are important factors affecting surface and near-surface ambient air temperature. Surfaces with low solar reflectance, absorb a high fraction of the incoming solar energy. A fraction of this absorbed energy is conducted into ground and buildings, a fraction is convected to air (leading to higher air temperatures), and a fraction is radiated to the sky. For equivalent conditions, the lower the emissivity of a surface the higher its steady-state temperature. Surfaces with low emissivity cannot effectively radiate to the sky and, therefore, get hot. Determination of solar reflectance and thermal emittance, and subsequent calculation of the relative temperature of the surfaces with respect to black and white reference temperature (defined as Solar Reflectance Index, SRI), may help designers and consumers to choose the proper materials to make their buildings and communities energy efficient. The method described here gives the SRI of surfaces based on measured solar reflectances and thermal emissivities of the surfaces.

## 6. Procedure

6.1 Given the solar reflectance and thermal emissivity of a test surface, calculate the SRI for three convective coefficients of 5, 12, 30 $W{\cdot}m^{-2}{\cdot}K^{-1}$, corresponding to low-, medium-, and high-wind conditions, respectively. The following alternate approaches can be used to calculate SRI:

6.1.1 *Approach I*—Calculate the steady-state surface temperatures for the test surface and black and white reference surfaces. Either Eq 1 (with iterative approach) or Eq 2 can be used. Calculate the SRI from Eq 3.

6.1.2 *Approach II*— Calculate SRI from Eq 4.

## 7. Report

7.1 The report shall include the following:

7.1.1 The solar reflectance and the thermal emittance of the test surface.

7.1.2 The calculated SRI for three convective coefficients of 5, 12, 30 $W{\cdot}m^{-2}{\cdot}K^{-1}$, corresponding to low-, medium-, and high-wind conditions, respectively.

## 8. Precision and Bias

8.1 The SRI of a test surface varies with two material properties, solar reflectance and thermal emissivity, and four environmental conditions, solar flux, convection coefficient, air temperature, and sky temperature. A detailed sensitivity analysis for the variation of SRI with respect to the above environmental conditions has been reported.[3] The following is a summary of the results and may be used as a guideline for practitioners.

8.1.1 SRI is an excellent predictor of solar reflectance for materials with high emissivity ($\varepsilon > 0.8$), that is, non-metals. Under these conditions, a ±1 % error in solar reflectance will result in a maximum error of ±1.4 in SRI. Similarly, a ±1 % error in $\varepsilon$ will result in a maximum error of ±0.6 in SRI.

8.1.2 For non-metallic surfaces, SRI is insensitive to choice of convective coefficient.

8.1.3 For metallic surfaces that are characterized with low $\varepsilon$, the SRI calculated by the above procedure varies significantly with the choice of convection coefficient. Hence, the SRI should be reported for three convective coefficients corresponding to low-, medium-, and high-wind conditions.

8.1.4 SRI is insensitive to choice of sky temperature, ambient temperature, and solar flux.

## 9. Keywords

9.1 solar flux; solar reflectance; solar reflectance index; thermal emittance

[3] Akbari, H., R. Levinson, and P. Berdahl, "ASTM Standards for Measuring Solar Reflectance and Infrared Emittance of Construction Materials and Comparing their Steady-State Surface Temperatures," *Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings*, Vol. 1, p. 1, Pacific Grove, CA, August 1996.

## BIBLIOGRAPHY[2]

**(1)** ASTM E408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques

**(2)** ASTM E772 Terminology Relating to Solar Energy Conversion

**(3)** ASTM E903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres

**(4)** ASTM E1918 Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field