



# Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces<sup>1</sup>

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## 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 *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 408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques<sup>2</sup>

E 772 Terminology Relating to Solar Energy Conversion<sup>3</sup>

E 891 Tables for Terrestrial Direct Normal Solar Irradiance for Air Mass 1.5<sup>3</sup>

E 903 Test Method for Solar Absorption, Reflectance, and Transmittance of Materials Using Integrating Spheres<sup>3</sup>

E 1918 Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field<sup>4</sup>

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<sup>2</sup> Annual ASTM Book of Standards, Vol 15.03.

<sup>3</sup> Annual ASTM Book of Standards, Vol 12.02.

<sup>4</sup> Annual ASTM Book of Standards, Vol 04.07.

## 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  $9.5^\circ$  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 ( $\alpha$ )*—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 E 891.

3.1.11 *standard solar and ambient conditions*— for the purpose of this calculation, is defined as a solar flux of  $1000 \text{ W} \cdot \text{m}^{-2}$ , ambient air temperature of 310 Kelvin (K), and sky temperature of 300 K. Three convective coefficient of 5, 12, 30  $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$ , corresponding to low- (0 to  $2 \text{ ms}^{-1}$ ), medium- (2 to  $6 \text{ ms}^{-1}$ ), and high-wind (6 to  $10 \text{ ms}^{-1}$ ) 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 ( $\epsilon$ )*—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  $150^\circ\text{C}$ .

#### 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:

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

where:

$\alpha$  = solar absorptance = 1 - solar reflectance,

$I$  = solar flux,  $\text{W} \cdot \text{m}^{-2}$ ,

$\epsilon$  = thermal emissivity,

$\sigma$  = Stefan Boltzmann constant,  $5.66961 \times 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$ ,

$T_s$  = steady-state surface temperature, K,

$T_{sky}$  = sky temperature, K,

$h_c$  = convective coefficient,  $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$ , 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:

$$T_s = 309.07 + \frac{(1066.07\alpha - 31.98\epsilon)}{(6.78\epsilon + h_c)} \quad (2)$$

$$- \frac{(890.94\alpha^2 + 2153.86\alpha\epsilon)}{(6.78\epsilon + h_c)^2}$$

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:

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

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  $\epsilon$  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  $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$ , 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  $\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$ , 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.<sup>5</sup> 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 ( $\epsilon > 0.8$ ), that is, non-metals. Under these conditions, a  $\pm 1\%$  error in solar reflectance will

result in a maximum error of  $\pm 1.4$  in SRI. Similarly, a  $\pm 1\%$  error in  $\epsilon$  will result in a maximum error of  $\pm 0.6$  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  $\epsilon$ , 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

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<sup>5</sup> 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.

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