
Solar Reflectance Index (SRI) – Background and Spectrometric Determination

**Helen Rose Wilson*— Johannes Hanek*—
Tilman E. Kuhn***

** Fraunhofer-Institut für Solare Energiesysteme, Heidenhofstr. 2,
79110 Freiburg i. Br., Deutschland
helen.rose.wilson@ise.fraunhofer.de*

ABSTRACT.

Solar Reflectance Index (SRI) – Background and Spectrometric Determination
With the aim of reducing the cooling energy demand of buildings and limiting the urban heat island effect, the optical properties of building materials such as roofing and pavers are taken into account in the U.S. American LEED® Green Building Rating Systems. According to the ASTM E1980-11 standard, opaque roofing or paving materials which are installed horizontally or at a low tilt angle can be characterised by the so-called “Solar Reflectance Index – SRI”. It is calculated from the solar reflectance (SR) and the thermal emissivity, and is a measure for the relative heating of such materials when absorbed solar radiation and heat emitted to the atmosphere are considered. The paper illustrates why the SRI value of surface-covering materials is significant for urban climates. It will also present the derivation of the SRI value from measured reflectance spectra, SRI examples for concrete pavers of differing colours and correlations with other quantities which can be derived from the reflectance spectra, such as solar and visual reflectance.

Solar Reflectance Index (SRI-Wert) – Hintergrund und Spektrometrische Bestimmung

Um den Kühlenergiebedarf von Gebäuden zu senken und den „heat island“ Effekt in Städten einzugrenzen werden die optischen Eigenschaften von Baumaterialien wie Dach- und Bodenbedeckungen im Rahmen der amerikanischen LEED®-Vorschriften auch einbezogen. Nach der Norm ASTM E1980-11 werden opake Bedeckungsmaterialien, die horizontal oder mit geringer Neigung verlegt werden, durch einen sogenannten „Solar Reflectance Index – SRI“ charakterisiert. Er wird

aus dem solaren Reflexionsgrad (SR) und dem thermischen Emissionsgrad berechnet und stellt ein Maß für die relative Erwärmung der Materialien bei Berücksichtigung der absorbierten Sonneneinstrahlung und der gegen Himmel abgestrahlten Wärme dar. Im Beitrag werden die Bedeutung des SRI-Wertes von Bedeckungsmaterialien für das Stadtklima, die Herleitung des SRI-Wertes aus gemessenen Reflexionsspektren, SRI-Beispiele für Betonproben unterschiedlicher Farbe und Zusammenhänge mit anderen aus Reflexionsspektren abgeleiteten Werte wie Solar- und Lichtreflexionsgrade vorgestellt.

KEYWORDS: Solar Reflectance Index (SRI), ASTM E1980-11, solar reflectance, thermal emissivity, concrete pavers

1. Background – Urban Heat Islands

Compared to nearby rural areas, the air temperature in urban areas is higher due to:

- Higher effective absorptance of solar radiation because of urban morphology
- Higher density of local (waste) heat generation
- Lower heat losses due to convection
- Less transpiration cooling by vegetation

This effect, commonly known as “urban heat islands”, contributes to problems in warm climates such as the overheating of buildings, higher sickness and mortality rates during heat waves and high energy consumption for cooling.

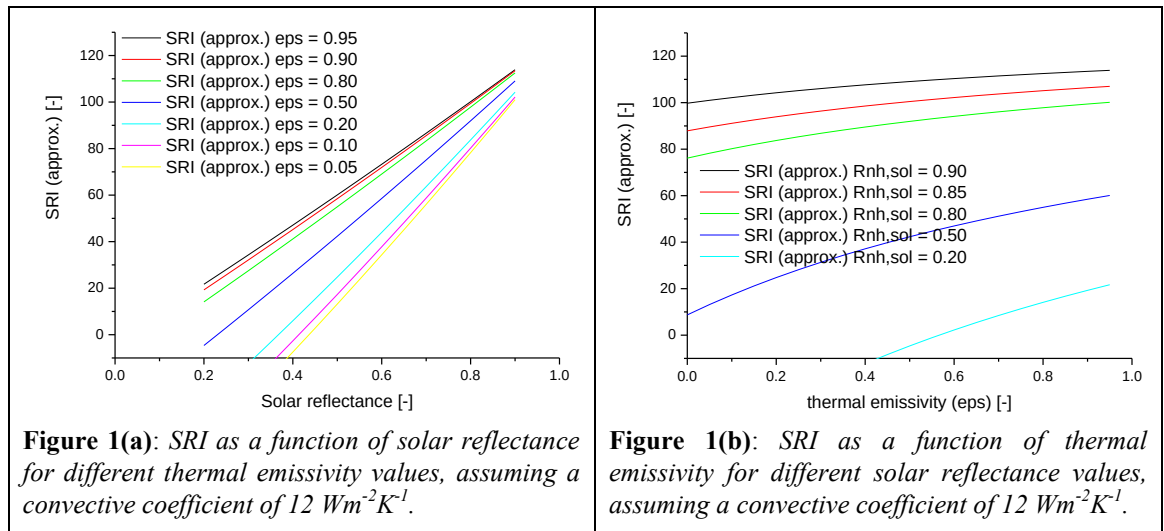
One approach to alleviate the severity of overheating is to reduce the absorptance of solar radiation in urban areas by increasing the solar reflectance of horizontal surfaces such as rooftops and pavements, and to ensure that the thermal emissivity of such surfaces is high. The effects of this approach have been the subject of thorough research since the 1990’s, particularly in North America. Pomerantz et al (2003) experimentally determined that the peak surface temperature of cement concrete paving decreased by about 5 °C for each increase of 0.1 in solar reflectance (SR). A good overview of the topic is provided by the “Cool Pavements Compendium” distributed by the U.S. Environmental Protection Agency and the references therein. A European perspective on the interaction between “Energy and Climate in the Urban Built Environment” is given in the book of that title edited by M. Santamouris (2001).

2. Solar Reflectance Index (SRI)

The solar reflectance index (SRI) was introduced by the ASTM Task Group for the Development and Exploitation of Cool Construction Materials as a single measure of the effectiveness of a horizontal or low-sloped opaque surface in mitigating overheating, and combines the effects of solar reflection and thermal emission. It is currently defined by the standard ASTM E1980-11 as “the relative temperature of a surface (T_s) with respect to the temperature of the standard white

surface (T_w) and the temperature of the standard black surface (T_b) under the standard solar and ambient conditions”. The definitions of the standard white surface (SRI = 100, solar reflectance = 0.80, thermal emissivity = 0.90) and the standard black surface (SRI = 0, solar reflectance = 0.05, thermal emissivity = 0.90) are such that SRI values greater than 100 and less than 0 are possible in principle. ASTM E1980-11 also specifies standard solar irradiation conditions in accordance with ASTM G 173-03 and an ambient air temperature of 310 K, a sky temperature of 300 K and convective coefficients corresponding to low, medium and high wind speeds. Using these parameters, a heat-balance equation is solved iteratively to determine the steady-state temperature of the surface in question. Alternatively, the SRI for surfaces with a solar reflectance between 0.2 and 0.9 can be determined using an approximate equation with an average error of 0.9 and a maximum error of 2, which is also cited in ASTM E1980-11.

Using this approximation and assuming a convective coefficient of $12 \text{ Wm}^{-2}\text{K}^{-1}$, the dependence of the SRI on solar reflectance and thermal emissivity values was calculated and is plotted in Figures 1a and 1b. For thermal emissivity values above 0.85, as are typical for dielectrics such as concrete, the SRI value is seen to be determined essentially by its linear dependence on the solar reflectance value.



3. SRI values and other optical properties of selected concrete pavers

On commission to the Betonverband Straße, Landschaft, Garten e.V (German Concrete Association), Fraunhofer ISE measured the spectral reflectance properties of 16 different concrete pavers, calculated the resulting SRI values and correlated these to other optical properties. Eight of the pavers were chosen to represent

“neutral” colours between black and white, while the other eight represented yellow, red and brown colours. Photographs and brief descriptions of the samples can be found in the Appendix to this paper. The samples were measured in both the solar (wavelengths from 280 to 2500 nm) and the infrared (2500 nm – 17 μ m) spectral ranges.

The reflectance spectra for the neutral coloured samples in Fig. 2(a) are relatively “flat”, with the highest values for the white sample and lowest for the black sample. By contrast, the spectra for the coloured samples in Fig. 2(b) are more complex and there is some “crossing” of spectra between the short and long wavelength ranges. By weighting these spectra with the global (hemispherical) solar spectrum specified in ASTM G 173-03, the solar reflectance values listed in Table 1 were calculated. The legend to the spectra in Fig. 2 indicates the normal emissivity values for the same samples, obtained by weighting the measured IR absorptance spectra with the Planck blackbody spectrum for 300 K. Due to the similarity of the IR spectra in the relevant spectral region, the emissivity values vary only between 0.93 and 0.95. Based on the solar reflectance and normal thermal emissivity values for 350 K, the SRI values were calculated in accordance with ASTM E1980-11 and are presented in Table 1. Table 1 also includes the visible reflectance values for the 16 samples, obtained by weighting the spectra with the photopic spectral response of the human eye, as an indicator of the “lightness” of the samples as perceived by an observer.

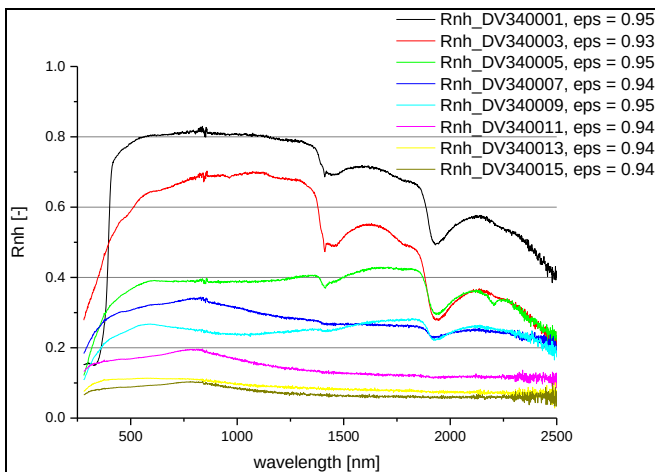


Figure 2(a): Solar reflectance spectra for the eight “neutral” coloured concrete samples; the thermal emissivity (eps) of each sample at 300 K is specified in the legend.

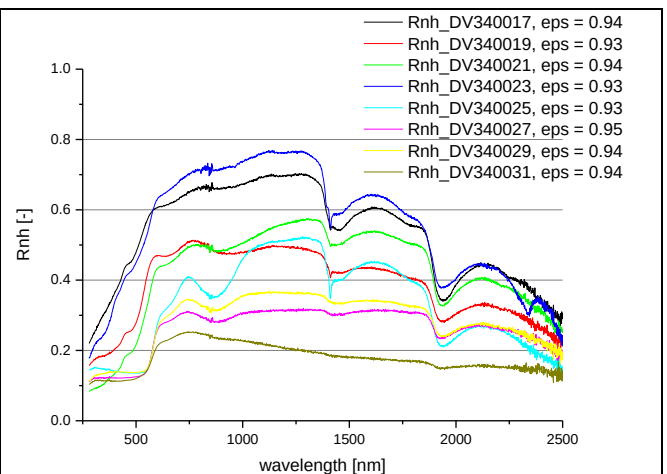


Figure 2(b): Solar reflectance spectra for the eight coloured concrete samples; the thermal emissivity (eps) of each sample at 300 K is specified in the legend.

In agreement with the linear relationships illustrated in Fig. 1, the dependence of the iteratively calculated SRI on the *solar* reflectance is well fit by a linear equation

with a slope of 131.6 and a y intercept of -5.46, resulting in a Pearson R coefficient of 0.9998 for the 16 values. For the eight neutral coloured samples, a linear fit to a plot of the SRI value versus the *visible* reflectance also describes the dependence well, with a Pearson R coefficient of 0.9997. However, when the same dependence is evaluated for the eight coloured samples, the fit is significantly poorer, with an R coefficient of 0.9786. For coloured samples, an observer's subjective impression based on visible reflectance, which only takes the spectral information between 380 nm and 780 nm into account, is an unreliable basis for estimating the SRI value; the contribution to the SRI value from invisible, near-infrared radiation in the solar spectrum is too large.

Whereas the information contained in the solar reflectance spectra is essential for determining the SRI value accurately, the effect of variation in the thermal emissivity value on the SRI value is minimal when samples of a single category of materials, e.g. cement concrete, are compared to each other. However, if the SRI values of different material types, such as cement concrete, polymers and metals are to be compared, the effect of the thermal emissivity on the SRI value can be significant.

Table 1. *Optical characteristics of the investigated concrete samples derived from measured reflectance spectra. See text for details of weighting spectra and applicable standards.*

Sample ID	Perceived colour	Visible reflectance [-]	Solar reflectance [-]	Thermal emissivity [-]	SRI [-]
DV340001	white	0.80	0.76	0.95	95
DV340003	quartz white	0.63	0.62	0.93	75
DV340005	light grey	0.38	0.38	0.94	44
DV340007	grey	0.32	0.31	0.94	35
DV340009	grey	0.26	0.25	0.95	28
DV340011	dark grey	0.17	0.17	0.94	17
DV340013	anthracite	0.11	0.10	0.94	9
DV340015	black	0.09	0.09	0.94	7
DV340017	beige	0.56	0.58	0.94	71
DV340019	yellow	0.40	0.42	0.93	48
DV340021	ochre	0.34	0.41	0.94	47
DV340023	beige-red	0.55	0.60	0.92	73
DV340025	red	0.19	0.31	0.92	35
DV340027	red	0.18	0.24	0.95	27
DV340029	red	0.18	0.27	0.94	29
DV340031	brown	0.16	0.19	0.94	20

4. Conclusions and Outlook

The SRI values of 16 commercially available cement concrete samples were determined on the basis of spectral reflectance measurements in the solar and infrared spectral ranges. Neutral coloured samples were found to span a large range of SRI values, from 95 (white) to 7 (black). Although the range determined for samples in the yellow-red-brown colour group was not as large, 71 to 20, it still included several samples with values exceeding 29. This is the threshold value that currently allows paving materials to qualify for a LEED (Leadership in Energy and Environmental Design) credit in certain situations, according to the Heat Island criteria of LEED v3, which was introduced in 2009 and will continue to be acceptable only up to October 2016.

The SRI continues to be used as a criterion for awarding LEED credits to roofing materials in the recently introduced version, LEED v4, where higher threshold values for SRI now apply. However, for non-roofing materials, the rating criterion has been changed to the solar reflectance alone in LEED v4. The effect of aging must also be taken into account, such that now two threshold SR values are specified for paving materials, 0.33 for the initial SR and 0.28 for the “3-year aged” SR value.

As expected for these samples from a single class of material, the *solar* reflectance alone is a reliable indicator at least for the relative order of SRI values, regardless of colour, but the *visible* reflectance is insufficient as an indicator for the SRI or SR values of coloured samples. Conversely, the results indicate that if the reflectance is spectrally selective, high SRI or SR values can be obtained for concrete paving in combination with a variety of visual appearances, including non-neutral colours. This is a topic which could benefit from further research, allowing mitigation of the urban heat island effect to be combined with aesthetically pleasing diversity of appearance.

5. Acknowledgements

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ASTM E1980-11 Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces

ASTM G 173-03 Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37 ° Tilted Surface

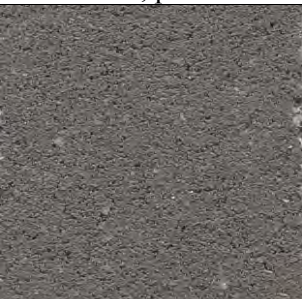
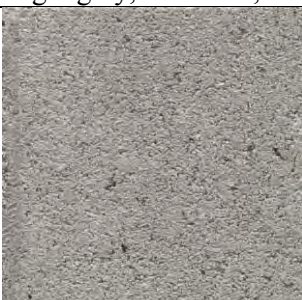
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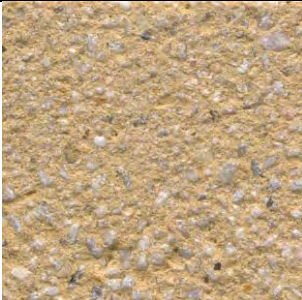
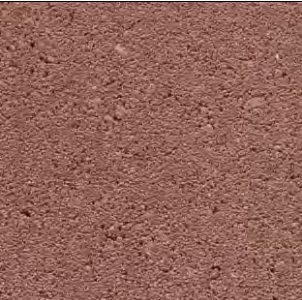
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7. Appendix – Photographs and brief descriptions of investigated samples

	
DV340001: white, smooth, no pores	DV340015: black, untreated, macro-rough
	
DV340003: quartz-white, polished	DV340013: anthracite, polished
	
DV340005: light grey, untreated, macro-fine	DV340011: dark grey, untreated, macro-fine
	
DV340007: grey, untreated, macro-fine	DV340009: grey, untreated, macro-rough

	
DV340017: beige, blasted with steel balls	DV340025: red, polished
	
DV340019: yellow, sand-blasted	DV340027: red, untreated, macro-rough
	
DV340021: ochre, untreated, macro-fine	DV340029: red, untreated, macro-fine
	
DV340023: beige-red, polished	DV340031: brown, untreated, macro-rough