Dept. of Mechanical and Civil Engineering
University of Modena and Reggio Emilia

Object:	Measurement of Solar Reflectance, Thermal Emittance and Solar Reflectance Index – Report
Client:	RENOLIT ITALIA S.r.l.
Reference persons:	Paolo Tartarini / Alberto Muscio
Work start:	01/08/2008
Work completion:	28/09/2009 (after delivery of weathered samples)
Notes:	Report rev. 4

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1. Object of the work

Regulatory requirements have not yet been emitted by Italian or European administrations about the characterization of radiative properties of building surfaces relevant to their response to the solar cycle. Therefore, measurement methods suggested by the most important organization in the field, the Cool Roof Rating Council (www.coolroofs.org), are used. The procedures defined by the Cool Roof Rating Council are legally recognized by public administrations in the USA (DoE / EPA, State and local governments) and are widely used to test products commercialized in the U.S. market.

In order to determine the solar reflectance R of the analyzed surface, defined as the ratio of reflected part and total incident amount of solar radiation, the spectral reflectivity ρ_λ of the sample is measured at several wavelength values evenly spaced in the range from 300 nm to 2500 nm, which includes more than 99% of solar radiation at the Earth surface (Fig. 2.1). The spectral reflectivity ρ_λ, defined as the ratio of reflected part and total amount of incident radiation at the considered wavelength λ, is measured, in compliance with the ASTM Standard E903 (*Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres*), by means of an UV-Vis-NIR Jasco V-670 spectrometer with 150 mm integrating sphere. The solar reflectance R of the analyzed surface is eventually calculated as the average of the measured spectral reflectivity ρ_λ weighted by the solar spectrum at the Earth surface I_λ [W/(m^{2}nm)] as obtained from the ASTM Standard G173 (*Standard Tables for Reference Solar Spectral Irradiances*) or other equivalent technical rules for air mass 1.5.

$$R = \frac{\int_{300}^{2500} \rho_\lambda(\lambda) \times I_\lambda(\lambda) \times d\lambda}{\int_{300}^{2500} I_\lambda(\lambda) \times d\lambda} \qquad (2.1)$$

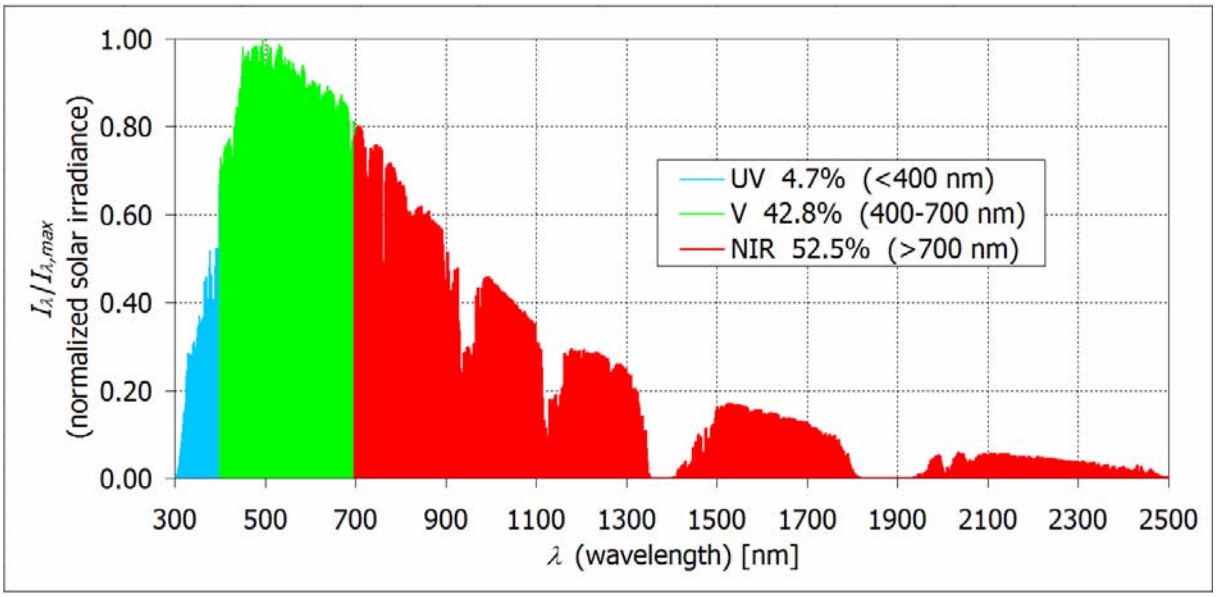

Figura 2.1. Normalized solar radiation spectrum at the Earth's surface
(data from ASTM Standard G173).

The thermal emittance E of the analyzed surface, defined as the ratio of thermal radiation actually emitted and maximum theoretical emission at the same temperature, is measured by means of an IR emissometer Devices & Services AE1/RD1 compliant with the ASTM Standard C1371 (*Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometer*). The instrument measures the total hemispherical emittance of the sample through the following relationship:

$$\Delta V = k \times \frac{\sigma_0 \times \left(T_d^4 - T_s^4\right)}{\frac{1}{E} + \frac{1}{E_d} - 1} \tag{2.2}$$

In the relationship, the voltage signal ΔV [V] returned by the emissometer is proportional by a calibration constant k to the heat flux exchanged between the surface of the sample and the bottom surface of the emissometer head. The first surface has thermal emittance E unknown and absolute thermodynamic temperature stabilized at a value T_s [K] as close as possible to the ambient one T_a [K], the second one has known thermal emittance E_d and absolute thermodynamic temperature stabilized at an assigned value T_d [K], higher that that of the analyzed surface and the ambient ($T_d > T_s$). In Eq. (2.2), the calibration constant k multiplies the heat flux exchanged by thermal radiation between the two above mentioned surfaces, assumed to be flat, parallel, virtually infinite and facing each other, as well as gray and diffusive.

The emissometer is calibrated before each test by measuring two different samples with known emittance, respectively equal to 0.06 and 0.87. The reference samples are provided by the producer of the emissometer, which ensures the linearity of the instrument and uncertainty ±0.01 in the whole range $0.03 \leq E \leq 0.93$.

If the sample shows a non-negligible resistance to heat transfer, the heat input applied by the emissometer to the measured surface causes a thermal gradient across the thickness of the sample itself. As a result, the temperature at the measured surface rises to a value significantly higher than the ambient one. In this case, the actual value E of the thermal emittance is recovered by using one among the modifications of the standard method described by the producer of the emissometer, for instance increasing the thermal emittance E_m returned by the instrument by an increment ΔE evaluated analytically from the heat transmission properties of the sample (method of the analytical correction).

$$E = E_m + \Delta E \tag{2.3}$$

As an alternative, it is possible to measure directly the actual value E of the thermal emittance by allowing the head of the emissometer to slide above the sample surface, in order to prevent the surface itself from warming up (slide method). Explanation about the modified methods is omitted here for sake of conciseness.

The combined effect of solar reflectance and thermal emittance can be appreciated independently from the building component to be coated or covered by the tested product through calculation of the Solar Reflectance Index (*SRI*), defined in the ASTM Standard E1980 (*Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces*) by the following relationship:

$$SRI = 100 \times \frac{T_b - T_s}{T_b - T_w} \tag{2.4}$$

In the relationship, T_s [K] is the temperature that the analyzed surface would steadily reach when irradiated by a solar flux of 1000 W/m^2 at atmospheric air temperature 310 K, sky temperature 300 K and three different values of the convection heat transfer coefficient h_c, equal to 5 W/(m^{2}K), 12 W/(m^{2}K), and 30 W/(m^{2}K), and respectively corresponding to low (v < 2 m/s), intermediate (2 m/s < v < 6 m/s), and high (6 m/s < v < 10 m/s) wind speed. T_b [K] and T_w [K] are the temperatures that would be reached by two reference surfaces, a white one (R=80%) and a black one (R=5%), both ones having high thermal emittance (E=90%). Therefore, the *SRI* represents the decrement of surface temperature that the analyzed surface would allow with respect to the black one, divided by the analogous decrement allowed by the white surface and given in percent terms.

3. Measurements on new samples from a current production line (sample set A)

The analysis was carried out by testing no. 4 samples of the product under test, RENOLIT alkorPLAN 35276, prepared by the Client in the form of flat sheets with size 50 mm x 50 mm (sample set A, see Fig. 3.1).

Figure 3.1. Sample set A (ALKORPLAN F 35276 WHITE – ALKORBRIGHT): representative sample.

The results are reported as follows:

- in Tab. 3.1, with regard to thermal emittance;
- in Tab. 3.2 and Figs. 3.2.a-b, with regard to solar reflectance;
- in Tab. 3.3, with regard to the Solar Reflectance Index;
- finally, in Tab. 3.4, with regard to the analysis results as a whole.

Table 3.1.
Sample set A: measured thermal emittance E_m
and actual thermal emittance E (T_a = 27°C).

Sample	*Identification code*	E_m [%]	E [%]
A.1	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	87	96
A.2	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	87	96
A.3	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	87	96
A.4	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	87	96
Mean	ALKORPLAN F 35276 WHITE – ALKORBRIGHT samples A.1÷A.4	87	96
Note: This test conformed with all requirements of ASTM C1371 with the exception of using a modification of the standard method proposed by the producer of the emissometer for thick and/or poorly conductive samples, here identified as the 'analytical correction method' and described in the *D&S Technical Note 79-17 – Emissivity measurement for in-place surfaces and for materials with low thermal conductivity*.			

Table 3.2.
Sample set A: measured solar reflectance (T_a= 29.5°C).

Sample	*Identification code*	R [%]
A.1	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	90.2
A.2	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	90.2
A.3	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	90.6
A.4	ALKORPLAN F 35276 WHITE – ALKORBRIGHT	91.1
Mean	ALKORPLAN F 35276 WHITE – ALKORBRIGHT samples A.1÷A.4	90.5

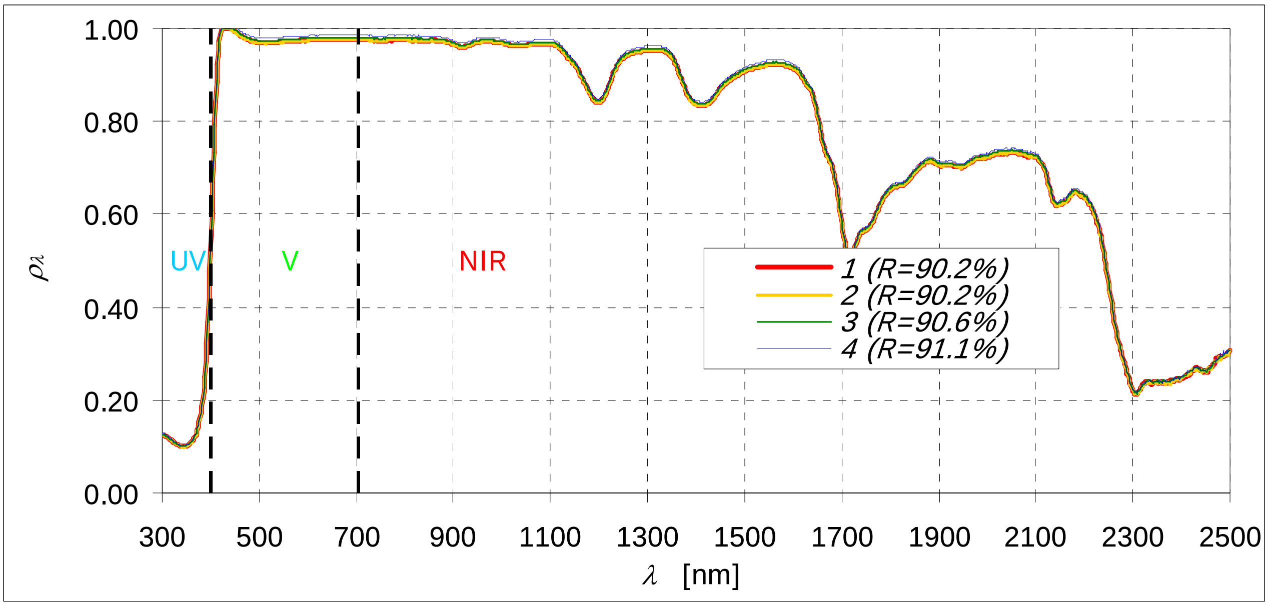

Figure 3.2.a. Sample set A: spectral reflectivity.

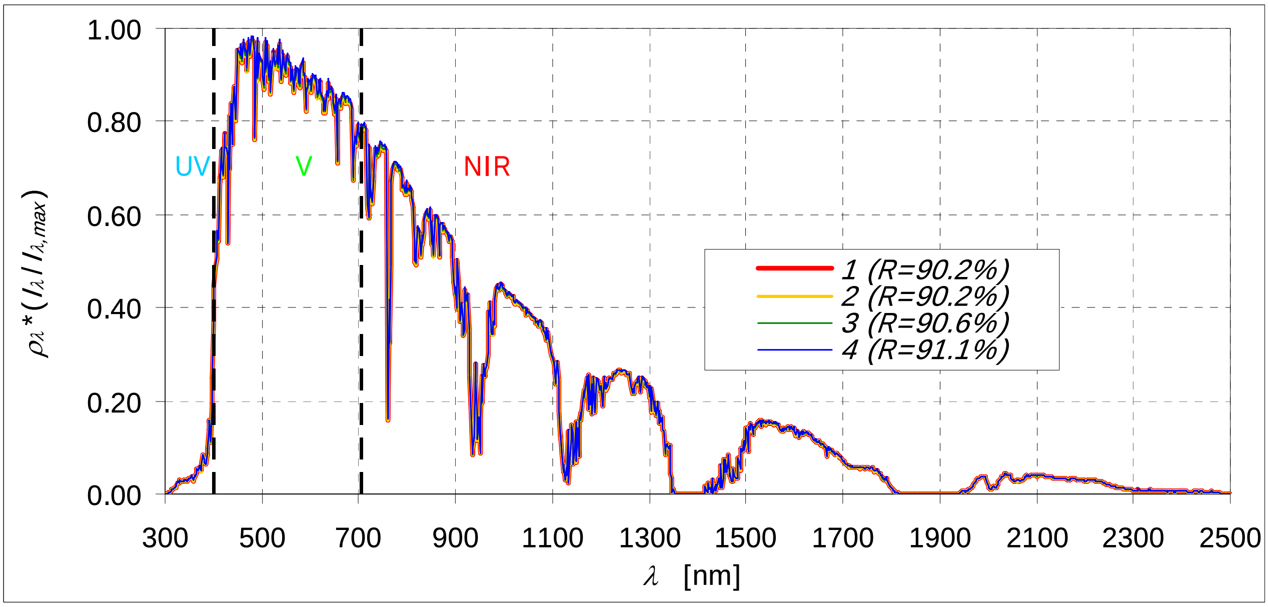

Figure 3.2.b. Sample set A: spectral reflectivity multiplied by the normalized solar irradiance.

Table 3.3.
Sample set A: Solar Reflectance Index (*SRI*).

Sample	*SRI* h_c=5 W/(m^{2}K) (low wind speed)	*SRI* h_c=12 W/(m^{2}K) (intermediate wind speed)	*SRI* h_c=30 W/(m^{2}K) (high wind speed)
A.1	117	115	114
A.2	117	115	114
A.3	118	116	115
A.4	118	117	116
Mean	118	116	115

Table 3.4.
Sample set A: thermal emittance, solar reflectance, and Solar Reflectance Index.

Sample	*E* [%] (thermal emittance)	*R* [%] (solar reflectance)	*SRI* h_c=5 W/(m^{2}K)	*SRI* h_c=12 W/(m^{2}K)	*SRI* h_c=30 W/(m^{2}K)
A.1	96	90.2	117	115	114
A.2	96	90.2	117	115	114
A.3	96	90.6	118	116	115
A.4	96	91.1	118	117	116
Mean	96	90.5	118	116	115

4. Measurements on weathered samples (sample set B)

The analysis was carried out by testing no. 5 samples of the same product, RENOLIT ALKORPLAN F WHITE, prepared by the Client in the form of flat sheets with size 50 mm x 50 mm (sample set B, see Fig. 4.1).

The samples were tested 3 years after production. One sample was obtained from a foil that was kept stored during the whole time, whereas the other four samples were obtained from foils that were weathered 3 years in two different U.S. locations (New River, Arizona, and Miami, Florida) from June 2004 to June 2007.

The weathering process was managed by the Client, with the following weathering conditions:

- New River, Arizona (U.S.A.):
  radiant exposure: 24 473 MJ/m^2, 584 929 Ly, 1032 MJ/m^2 (295÷385 nm)
  type of test: direct 45° south, open backing
- Miami, Florida (U.S.A.), Everglades Site:
  radiant exposure: 18 398 MJ/m^2, 439 725 Ly, 872 MJ/m^2 (295÷385 nm)
  type of test: direct 45° south, open backing

The results are reported as follows:

- in Tab. 4.1, with regard to thermal emittance;
- in Tab. 4.2 and Figs. 3.2.a-b, with regard to solar reflectance;
- in Tab. 4.3, with regard to the Solar Reflectance Index;
- finally, in Tab. 4.4, with regard to the analysis results as a whole.

Figure 4.1. Sample set A (ALKORPLAN F 35276 WHITE – ALKORBRIGHT): representative sample (upper left); sample set B (RENOLIT ALKORPLAN F WHITE): non weathered sample (lower left), samples weathered in Arizona (middle) and samples weathered in Florida (right).

Table 4.1.
Sample set B: measured thermal emittance E_m
and actual thermal emittance E (T_a = 27°C).

Sample	*Identification code*	E_m [%]	E [%]
B.1	ALKORPLAN F WHITE – Reference (non weathered)	86	96
B.2	ALKORPLAN F WHITE – Arizona 1	86	96
B.3	ALKORPLAN F WHITE – Arizona 2	86	96
B.4	ALKORPLAN F WHITE – Florida 1	88	98
B.5	ALKORPLAN F WHITE – Florida 2	87	97
Mean	ALKORPLAN F WHITE Samples B.2÷B.5 (weathered)	87	97
Note: This test conformed with all requirements of ASTM C1371 with the exception of using a modification of the standard method proposed by the producer of the emissometer for thick and/or poorly conductive samples, here identified as the 'analytical correction method' and described in the *D&S Technical Note 79-17 – Emissivity measurement for in-place surfaces and for materials with low thermal conductivity*.			

Table 4.2.
Sample set B: measured solar reflectance (T_a = 27°C).

Sample	*Identification code*	R [%]
B.1	ALKORPLAN F WHITE – Reference (non weathered)	80.4
B.2	ALKORPLAN F WHITE – Arizona 1	76.8
B.3	ALKORPLAN F WHITE – Arizona 2	75.0
B.4	ALKORPLAN F WHITE – Florida 1	76.9
B.5	ALKORPLAN F WHITE – Florida 2	74.5
Mean	ALKORPLAN F WHITE – Samples B.2÷B.5 (weathered)	76.2

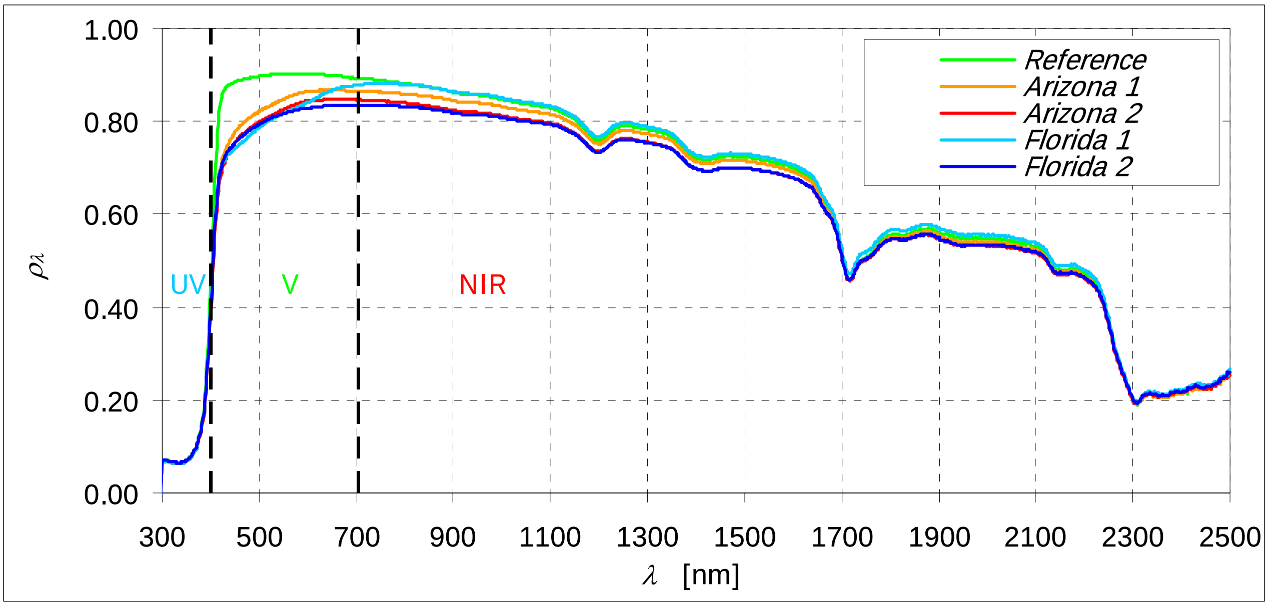

Figure 4.2.a. Sample set B: spectral reflectivity.

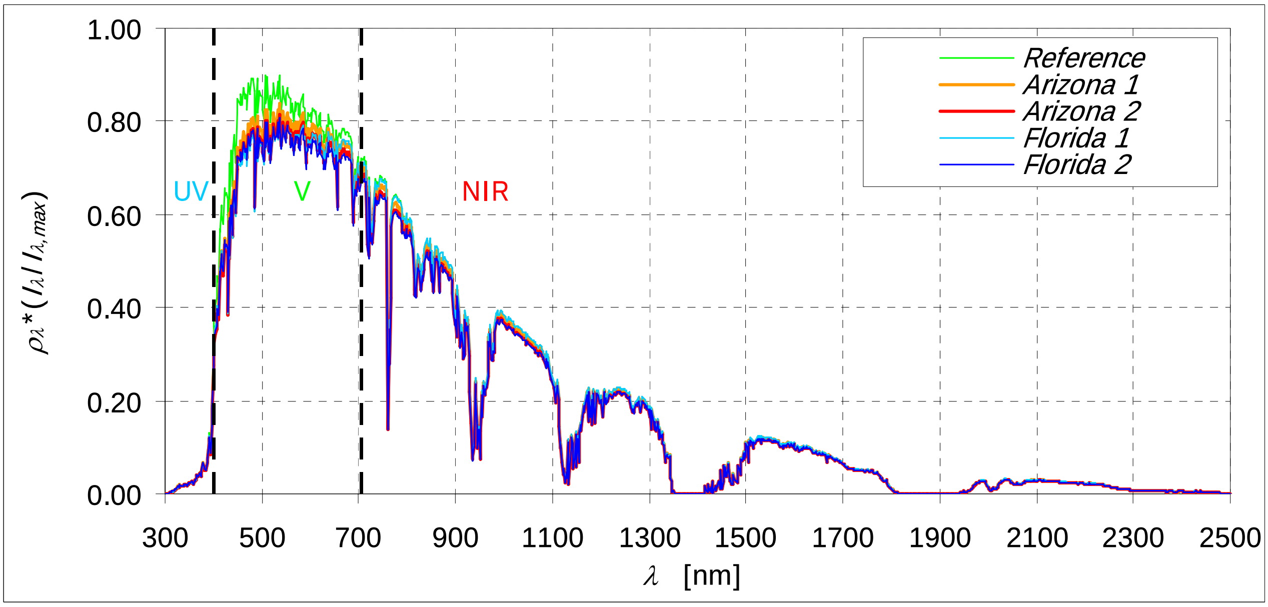

Figure 4.2.b. Sample set B: spectral reflectivity
multiplied by the normalized solar irradiance.

Table 4.3.
Sample set B: Solar Reflectance Index (*SRI*).

Sample	*SRI* h_c=5 W/(m^{2}K) (low wind speed)	*SRI* h_c=12 W/(m^{2}K) (intermediate wind speed)	*SRI* h_c=30 W/(m^{2}K) (high wind speed)
B.1	102	102	101
B.2	97	97	96
B.3	94	94	94
B.4	97	97	97
B.5	93	94	94
Mean	96	96	96

Table 4.4.
Sample set B: thermal emittance, solar reflectance, and Solar Reflectance Index.

Samples	*E* [%] (thermal emittance)	*R* [%] (solar reflectance)	*SRI* h_c=5 W/(m^{2}K)	*SRI* h_c=12 W/(m^{2}K)	*SRI* h_c=30 W/(m^{2}K)
B.1	96	80.4	102	102	101
B.2	96	76.8	97	97	96
B.3	96	75.0	94	94	94
B.4	98	76.9	97	97	97
B.5	97	74.5	93	94	94
Mean	97	76.2	96	96	96

Symbol Index

Latin symbols

E	thermal emittance [%]
E_d	thermal emittance of the detector [%]
E_m	measured thermal emittance [%]
h_c	convection heat transfer coefficient [W/(m^{2}K)]
k	calibration constant
I_λ	spectral solar irradiance [W/(m^{2}nm)]
$I_{\lambda,max}$	maximum value of spectral solar irradiance [W/(m^{2}nm)]
R	solar reflectance [-]
SRI	solar reflectance index [%]
T	temperature [K]
T_a	ambient temperature [K]
T_b	temperature of the reference black surface [K]
T_d	detector temperature [K]
T_s	surface temperature [K]
T_w	temperature of the reference white surface [K]
v	wind speed [m/s]

Greek and mixed symbols

ΔE	adjustment of the thermal emittance [%]
ΔV	voltage signal [V]
λ	wavelength [nm]
ρ_λ	spectral reflectivity [%]
σ_0	Stefan-Boltzmann's constant [$5.67 \cdot 10^{-8}$ W/(m^{2}K^4)]