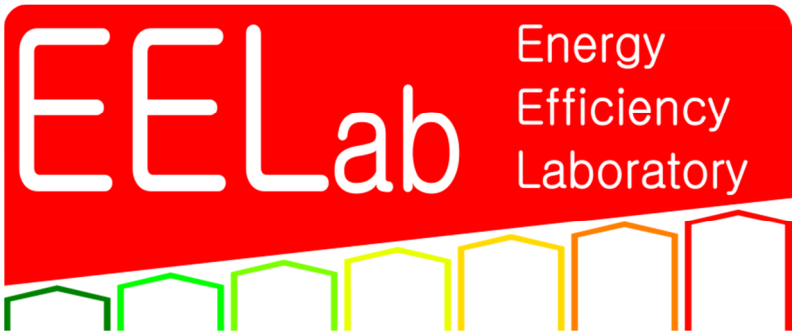
Department of Engineering Enzo Ferrari
University of Modena and Reggio Emilia



Object:	Measurement of solar reflectance, thermal emittance and Solar Reflectance Index – Report
Reference person:	Alberto Muscio – Antonio Libbra
Client:	Advanced Materials GMBH / SRL
Sample designation	AIRLITE SUNLIGHT
Commitment document:	Mail dated 26/06/2014 sent by Antonio Cianci
Notes:	Report rev. 1
Report date:	04/07/2014

Dip. di Ingegneria Enzo Ferrari / EELab
Università di Modena e Reggio Emilia
www.eelab.uimore.it

Via Vignolese 905/B – 41125 Modena – Italy
Partita IVA e codice fiscale 00427620364
tel. +39 059 2056313 – fax +39 059 2056126

1. Object of the work

The activity was aimed at measuring the performance of a paint on wood support, produced by Advanced Materials GMBH/SRL, Via Leonardo Da Vinci 12, 39100 Bolzano/Bozen, Italy.

The analysis was articulated in the following steps:

- Measurement of the Solar Reflectance of the sample surface normally exposed to the atmosphere, performed in compliance with the ASTM Standard E903 by means of a UV-Vis-NIR spectrometer; more specifically, the solar reflectance was evaluated as the average of the spectral reflectivity in the range of interest for solar radiation, weighted by the solar spectrum at the Earth's surface.
- Measurement of the Thermal Emittance of the sample surface normally exposed to the atmosphere, performed in compliance with the ASTM Standard C1371 by means of an IR emissometer.
- Calculation of the Solar Reflectance Index of the sample surface normally exposed to the atmosphere, performed in compliance with the ASTM Standard E1980 from the measured values of Solar Reflectance and Thermal Emittance.

2. Measurement Methods

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 widely used to test products commercialized in the U.S.A.

In order to determine the solar reflectance R of the analyzed surface, defined as the ratio between 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 between 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 of solar irradiance 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.

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

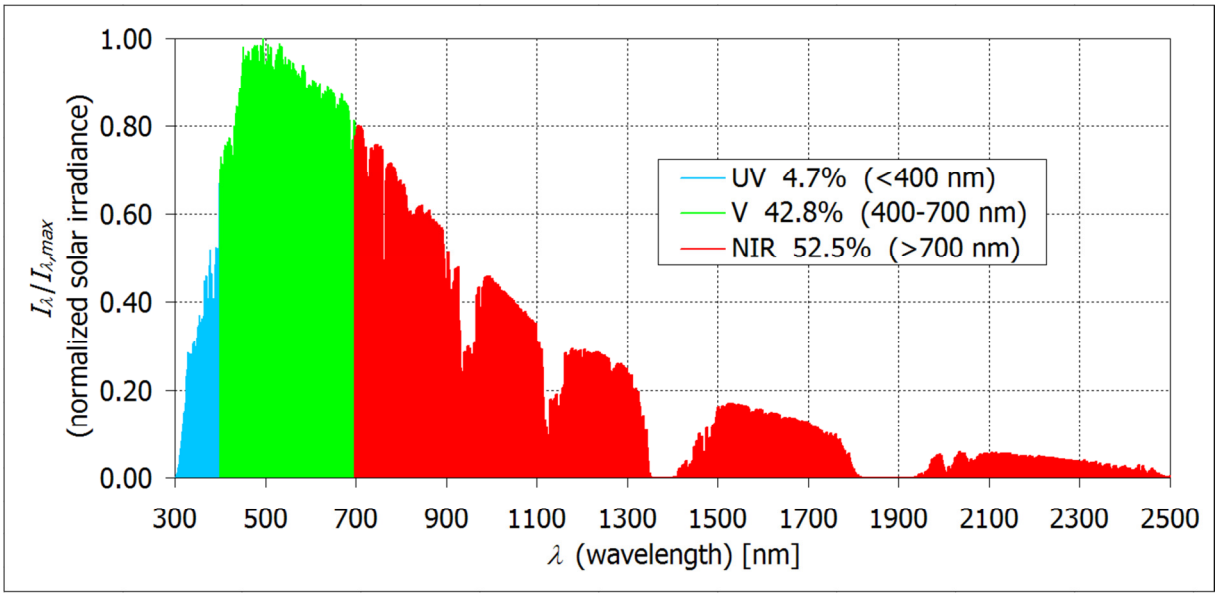


Figura 2.1. Normalized solar radiation spectrum at the Earth's surface (data from ASTM Standard G173).

The thermal emittance E of the analyzed surface, defined as the ratio between 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 surface has known thermal emittance E_d and absolute thermodynamic temperature stabilized at an assigned value T_d [K], higher than 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 $0.03 \le E \le 0.93$.
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. In particular, the actual value E can be directly measured 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). Further details are 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:

$$SRI = 100 \times \frac{T_b - T_s}{T_b - T_w} \tag{2.3}$$

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 percentage terms.

3. Results

The analysis was carried out by testing samples prepared by the Client in the form of flat sheets (Fig. 3.1) and representative of the products identified and briefly described in Tab. 3.1.

Table 3.1.
Sample identification and brief physical description of the analyzed product.

Sample	*Material denomination* *(Brief physical description)*
A	AIRLITE SUNLIGHT (water-based photocatalytic cement-based paint)
Note: information in the table was provided by the Client.	

Figure 3.1. Analyzed sample.

Table 3.2. Measured Solar Reflectance R (T_a = 24°C).

Sample	R_1 [%] (test 1)	R_2 [%] (test 2)	R_3 [%] (test 3)	R_4 [%] (test 4)	R [%] (average)
A	86.2	85.9	86.2	86.0	86
Note: the measurements were made on different surface points of the same sample.					

Table 3.3. Measured Thermal Emittance E (T_a = 24°C).

Sample	E_1 [%] (test 1)	E_2 [%] (test 2)	E_3 [%] (test 3)	E [%] (average)
A	88	88	88	88
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 in-place measurements or thick and/or poorly conductive samples, identified as the 'slide method' and described in the *D&S Technical Note 04-1 – Slide Method for AE Measurements*. Note: the measurements are referred to different tests on the same sample.				

Table 3.4. Solar Reflectance Index *SRI*.

Sample	*SRI* [%] for h_c=5 W/(m^{2}K) (low wind speed)	*SRI* [%] for h_c=12 W/(m^{2}K) (medium wind speed)	*SRI* [%] for h_c=30 W/(m^{2}K) (high wind speed)
A	109	108	108

Table 3.5. Surface Temperature (T_s).

Sample	T_s [°C] for h_c=5 W/(m^{2}K) (low wind speed)	T_s [°C] for h_c=12 W/(m^{2}K) (medium wind speed)	T_s [°C] for h_c=30 W/(m^{2}K) (high wind speed)
A	44.3	41.5	39.2

Table 3.6. Solar Reflectance, Thermal Emittance, *SRI* (medium wind speed), and Surface Temperature (medium wind speed).

Sample	R [%]	E [%]	*SRI* [%]	T_s [°C]
A	86	88	108	41.5

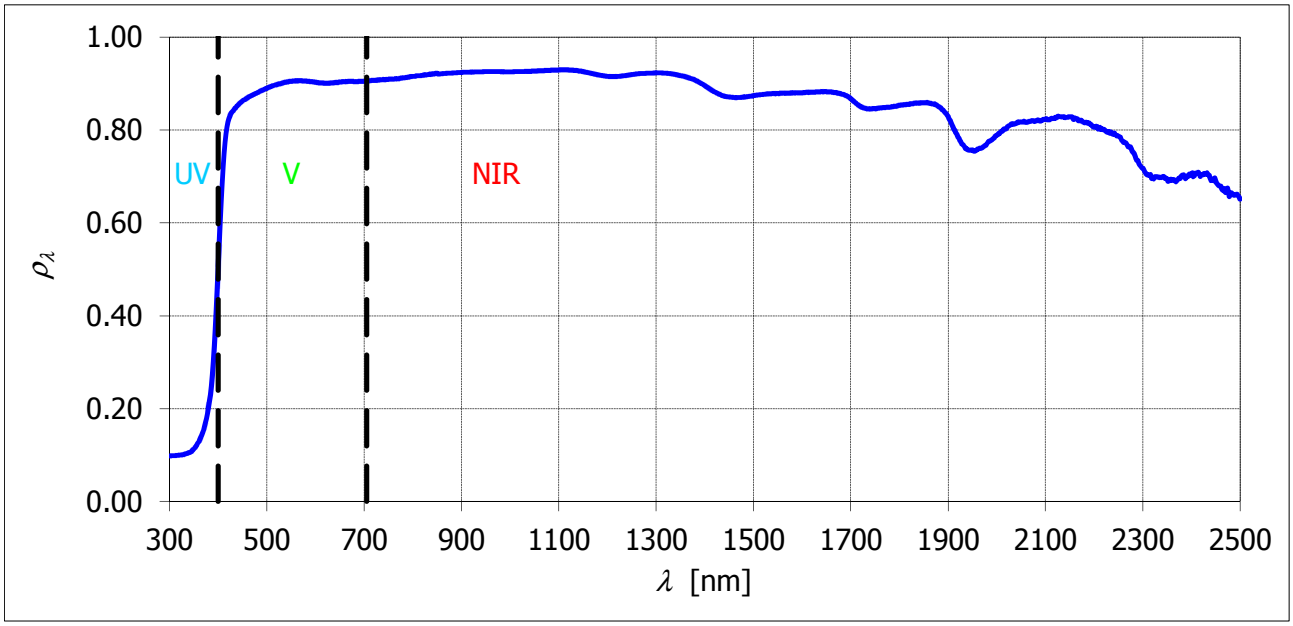


Figure 3.2. Spectral reflectivity.

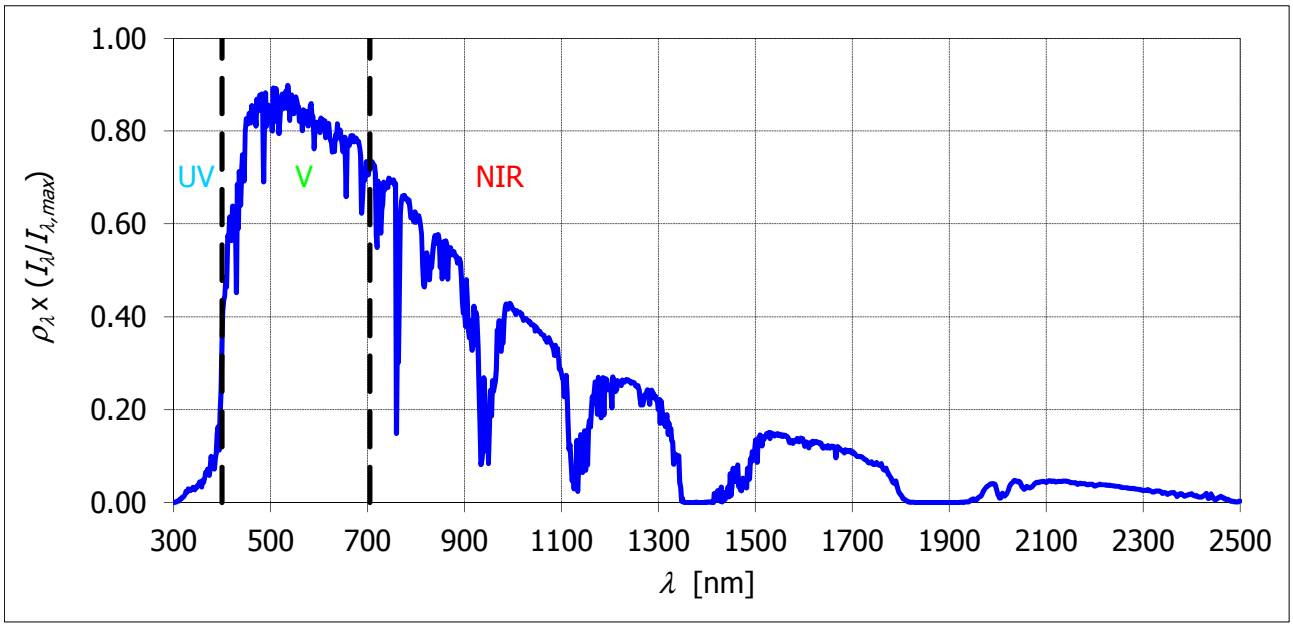


Figure 3.3. Spectral reflectivity multiplied by the normalized solar irradiance.

Symbol Index

Latin symbols

E	thermal emittance [%]
E_d	thermal emittance of the detector [%]
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

ΔV	voltage signal [V]
λ	wavelength [nm]
ρ_λ	spectral reflectivity [%]
σ_0	Stefan-Boltzmann's constant [5.67·10^{-8} W/(m^{2}K^4)]