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THE OPTICAL PROPERTIES OF DE LEEUW LTD REFLEX-ROL (UK) SAMPLE AR762

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1. Introduction

The Solar Energy Materials Research Laboratory of Sonnergy Ltd undertakes ultraviolet, visible and infrared spectral optical properties measurements of materials for a wide range of industrial clients. The Laboratory is approved by the Ministry of Defence to perform measurements in compliance with Defence Standard DS0023/1 `NATO Infra Red Reflective (IRR) Green Colour for Painting Military Equipment' (1). The laboratory operates in accordance with ISO 17025 for which compliance is being sought (2). Spectrophotometric instruments are serviced annually by the respective manufacturers. All measurements are made in accordance with recognised international procedures and instruments are calibrated using traceable reference standards. The Laboratory participates regularly in proficiency tests and inter-laboratory comparisons for the measurement of optical properties (3, 4, 5, 7). Sonnergy serves as the Chair of the European Union Cool Roofs Council Technical Committee (6) with responsibility for recommending measurement test procedures for product certification, is a full member of the International Commission on Glass Technical Committee 10 “Optical properties of glass and coated glass products” (7) and provides the European representative for the peer review of optical properties spectral data for inclusion in the International Glazing Database (IGDB) (8) administered and maintained by the Lawrence Berkeley Laboratory, USA.

In this report measurements are presented of the total and diffuse near-normal hemispherical spectral reflectance and transmittance of the AR762 sample supplied by De Leeuw Ltd Reflex-Rol (UK) for the wavelength range 280 – 2500 nm. From these measurements integrated ultraviolet, visible and solar optical properties are calculated in accordance with accepted international standard procedures (9).

The total near-normal hemispherical spectral transmittance and spectral reflectance was measured for the wavelength range 2.0 – 18.0 μm using a Bruker IFS 66 Fourier transform spectrometer with a gold integrating sphere reflectance/transmittance accessory. Reflectance measurements were made for both sides of the sample. From these measurements the spectral absorptance was determined. The integrated emissivity was then calculated by weighting the spectral absorptance data with a 283K blackbody spectral distribution using the recommended procedure of EN 12898 (10, 11).

The European Standards EN 14501 and EN 13363-1 (12 ,13, 14) are used to calculate values of the total solar energy transmittance, g_{total}, shading coefficient and shading factor, F_c, for complex glazing employing a fully closed internal blind in combination with the default glazings of each respective standard.

From the measured spectral optical properties data, an ASCII text file has been prepared which conforms to the format as required for the British Blinds and Shutters Association (BBSA) SHADE shading device optical properties database (15, 16).

2. De Leeuw Reflex-Rol (UK) Blind Sample

The De Leeuw Reflex-Rol (UK) sample submitted for measurement is identified in Table 1.

Sample No.	Sample Name	Sample Colour
AR762	Reflex Rol (UK) AR762	Dark Blue

Table 1. Identification of the De Leeuw Reflex-Rol (UK) blind sample.

3. Experimental procedures

3.1. Measurement of Spectral Transmittance and Reflectance

Measurements of near-normal hemispherical spectral transmittance, $\tau(\lambda)$, and spectral reflectance, $\rho(\lambda)$, were made using a Perkin Elmer Lambda 900 spectrophotometer using the PELA 150 integrating sphere accessory. Measurements were made over the spectral range 280 – 2500 nm (UV/Vis/NIR) to enable calculation of the integrated ultraviolet, visible and solar optical properties.

Total near-normal hemispherical spectral reflectance measurements were made with the sample mounted on the rear sample port of the 0.15 m diameter PELA 150 integrating sphere. The basic experimental configuration is shown in Fig. 1. Calibration was made using 2 Labsphere Spectralon white reflectance standards (17). The measurement procedures were performed in accordance with EN 14500 and CIE 130 (18, 19).

For measurement of the total near-normal hemispherical spectral transmittance, $\tau_{n\text{-}h}(\lambda)$, the blind sample is located at the sample entrance port of the integrating sphere (Position A) and the rear sample mounting port (Position B) is covered with a white reflectance standard.

For measurement of the near-normal diffuse spectral transmittance, $\tau_{n\text{-}dif}(\lambda)$, the blind sample is located at the sample entrance port of the integrating sphere (Position A) and the rear sample mounting port (Position B) is left open (uncovered) to enable any direct component of the transmitted light to exit the sphere through this port.

For measurement of the total near-normal hemispherical spectral reflectance, $\rho_{n\text{-}h}(\lambda)$, the blind sample is located at the rear sample mounting port (Position B) of the integrating sphere and the sample entrance port (Position A) is left open (uncovered).

For measurement of the near-normal diffuse spectral reflectance, $\rho_{n\text{-}dif}(\lambda)$, the blind sample is located at the rear sample mounting port (Position B) of the integrating sphere and the integrating sphere specular reflectance exit port cover located at Position C is removed to allow the regularly reflected component to exit the integrating sphere.

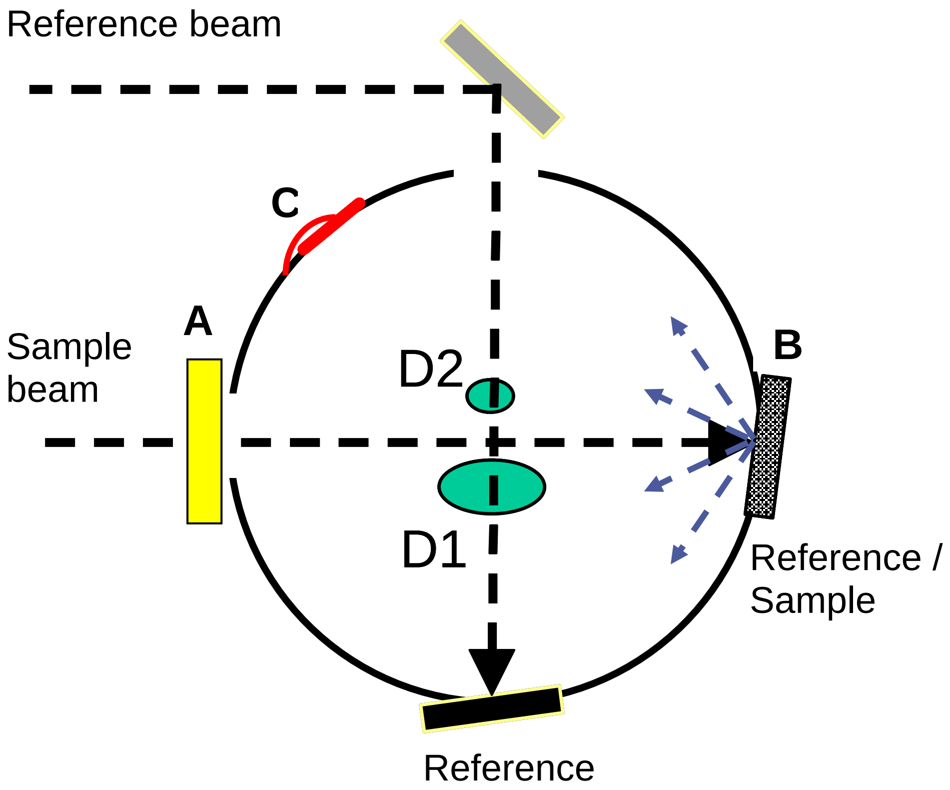

Figure 1. Experimental configuration for the measurement of spectral transmittance and reflectance (UV/Vis/NIR) using the PELA 150 integrating sphere reflectance accessory.
(D1: Photomultiplier detector; D2: PbS detector)

3.2. Measurement of Infrared Spectral Transmittance and Reflectance

Measurements of total near-normal hemispherical spectral transmittance and reflectance in the range 2.0 – 18.0 μm were made using a Bruker IFS 66 Fourier transform spectrometer using a 0.2 m diameter diffuse gold coated integrating sphere reflectance attachment. A globar source and potassium bromide (KBr) beamsplitter combination were employed. The signal level inside the integrating sphere was detected using a wall mounted liquid nitrogen cooled mercury cadmium telluride (MCT) solid state detector with 3 x 3 mm^2 detector area.

For transmittance measurements the sample was mounted to cover the entry port of the integrating sphere and irradiated with a beam at normal incidence.

For reflectance measurements the sample was mounted on the rear sample port of the integrating sphere and irradiated with a beam at 10^0 angle of incidence. Reflectance measurements were made for both sides of each sample.

The system was calibrated using two diffuse gold reflectance standards (20) and a bare gold mirror calibrated to a traceable NPL gold mirror (21).

4. Calculation Methods

4.1. Visible transmittance and reflectance

The visible transmittance and reflectance of a sample is calculated using the relative spectral power distribution D_λ of illuminant D_{65} (22) multiplied by the spectral sensitivity of the human eye $V(\lambda)$ and the spectral bandwidth $\Delta\lambda$.

Measurements are made of the spectral transmittance, $\tau(\lambda)$, and the visible transmittance, τ_V, is then calculated using a weighted ordinate method (9): according to EN 410 using the relationship:

$$\tau_\upsilon = \frac{\int_{\lambda=380nm}^{780nm} D_\lambda \tau(\lambda) V(\lambda) d\lambda}{\int_{\lambda=380nm}^{780nm} D_\lambda V(\lambda) d\lambda} = \frac{\sum_{\lambda=380nm}^{780nm} D_\lambda \tau(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380nm}^{780nm} D_\lambda V(\lambda) \Delta\lambda}$$

Measurements are made of the spectral reflectance $\rho(\lambda)$, and the visible reflectance, ρ_V is also calculated by weighted ordinates according to EN 410 using the relationship:

$$\rho_\upsilon = \frac{\int_{\lambda=380nm}^{780nm} D_\lambda \rho(\lambda) V(\lambda) d\lambda}{\int_{\lambda=380nm}^{780nm} D_\lambda V(\lambda) d\lambda} = \frac{\sum_{\lambda=380nm}^{780nm} D_\lambda \rho(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380nm}^{780nm} D_\lambda V(\lambda) \Delta\lambda}$$

To evaluate these expressions the values of spectral transmittance and reflectance are taken at 10 nm intervals from 380 - 780 nm and the values are normalised since $\Sigma D_\lambda V(\lambda)\Delta\lambda = 1$. The normalised fractional contributions of each interval to the total sum are tabulated in EN 410 (9).

4.2. Solar transmittance and reflectance.

The solar transmittance, τ_s, is defined (23) as:

$$\tau_s = \frac{\int_{\lambda_1}^{\lambda_2} \tau_\lambda \, G_\lambda \, d\lambda}{\int_{\lambda_1}^{\lambda_2} G_\lambda \, d\lambda}$$

where G_λ is the spectral solar irradiation, τ_λ is the spectral transmittance and λ_1 and λ_2 respectively define the short and long wavelength limits of the solar spectral distribution.

The solar absorptance, α_s, and solar reflectance, ρ_s, are similarly defined:

$$\alpha_s = \frac{\int_{\lambda_1}^{\lambda_2} \alpha_\lambda \, G_\lambda \, d\lambda}{\int_{\lambda_1}^{\lambda_2} G_\lambda \, d\lambda}$$

$$\rho_s = \frac{\int_{\lambda_1}^{\lambda_2} \rho_\lambda \, G_\lambda \, d\lambda}{\int_{\lambda_1}^{\lambda_2} G_\lambda \, d\lambda}$$

where α_λ and ρ_λ are the spectral absorptance and spectral reflectance respectively.

It is normal only to measure ρ_λ and τ_λ and to deduce α_λ from the conservation relationship $\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$.

To evaluate the integrals the recommended procedure of EN 410 (9) is used and a weighted ordinate method is employed. Each of the integrals reduces to the form

$$\tau_s = \sum_{i=1}^{n} \tau_{\lambda i} \, f_i \qquad \rho_s = \sum_{i=1}^{n} \rho_{\lambda i} \, f_i \qquad \alpha_s = \sum_{i=1}^{n} \alpha_{\lambda i} \, f_i$$

where the family f_i are the relative proportions of the total solar energy in each equal wavelength interval and their sum is normalised to unity.

4.3. Ultraviolet Transmittance

The ultraviolet transmittance, τ_{uv} , is calculated as (9)

$$\tau_{uv} = \frac{\sum_{\lambda=280nm}^{380nm} U_\lambda \tau_\lambda \Delta\lambda}{\sum_{\lambda=280nm}^{380nm} U_\lambda \Delta\lambda}$$

where τ_λ is the spectral transmittance, U_λ is the relative distribution of the ultraviolet part of the global solar radiation and $\Delta\lambda$ is the wavelength interval (5 nm).

4.4. Thermal Emittance

The spectral emittance, ε_λ, is derived from the relationship (23)

$$\varepsilon_\lambda = 1 - (\rho_\lambda + \tau_\lambda)$$

For an opaque sample, where $\tau_\lambda = 0$, this relationship reduces to $\varepsilon_\lambda = 1 - \rho_\lambda$
The spectral emittance, ε_λ, derived from spectral reflectance measurements is convoluted with the Planck blackbody spectral distribution, $E_{b\lambda}$, for a temperature of 283 K (4) and normalised to the ideal emitter ($\varepsilon = 1$) to give the total near-normal hemispherical thermal emittance ε_n .

The thermal emittance is thus expressed as

$$\varepsilon_n = \frac{\int_{\lambda_1'}^{\lambda_2'} \varepsilon_\lambda E_{b\lambda}\, d\lambda}{\int_{\lambda_1'}^{\lambda_2'} E_{b\lambda}\, d\lambda}$$

where λ_1' and λ_2' are the respective wavelength limits of the blackbody spectral distribution for the temperature of interest.

To evaluate this expression, the selected ordinate method prescribed in EN 12898 and EN 673 was used (10, 11).

4.5. Total solar energy transmittance, shading coefficient and shading factor

Window and glazing thermal performance is described in relation to thermophysical properties denoting energy gains and losses. For the characterization of the energetical performance of a window the three main areas of interest are the determination of the heat transfer through the window, the solar gain through the window, and the light distribution behind the window. The quantitative properties are the overall heat loss coefficient (U-value), the total solar energy transmittance, which is termed the g value, and the visible light transmittance (τ_v).

The total solar energy transmittance, g, is the measure of the total energy passing through the glazing when exposed to solar radiation. It is the sum of the solar transmittance, τ_s, and the secondary internal heat transfer factor q_i, i.e. $g = \tau_s + q_i$, the latter term arising from absorption of solar radiation in the glazing and subsequent re-radiation at thermal wavelengths to both the outside and the inside of the enclosure. The g-value is also called the Solar Heat Gain Coefficient (SHGC) and the Solar Factor.

The g value may be calculated for single or multiple glazings from the spectral transmittance and reflectance data and from knowledge of the heat resistances and surface heat transfer coefficients. A simplified method for the calculation of the g-value for glazings employing solar protection devices, such as blinds, is described in EN 13363-1 (13, 14). This method is also recommended when performing calculations in accordance with EN 14501 (12).

For the blind used internally, i.e. placed on the room side of the glazing, the total solar energy transmittance of the glazing-blind configuration, g_{total}, is calculated from

$$g_{total} = g\,(1 - g\,\rho_{sb} - \alpha_{sb}\,(\Lambda / \Lambda_2))$$

where

g is the total solar energy transmittance of the glazing without the blind
ρ_{sb} is the solar reflectance of the blind facing the glazing
α_{sb} is the solar absorptance of the blind facing the glazing

Λ represents the effective heat transfer through the configuration defined as

$$\Lambda = 1 / ((1/U) + (1/\Lambda_2))$$

where U is the heat loss coefficient of the glazing without the blind and Λ_2 assumes the value 18 W m^{-2} $^{o}C^{-1}$.

The shading coefficient is derived by comparing the total solar energy transmittance of the glazing with a clear float glass having a total solar energy transmittance of 0.87. This corresponds to float glass of thickness 3-4 mm. The shading coefficient is the total solar energy transmittance, g, divided by 0.87.

The g_{total} and SC values of the glazing/blind configuration are calculated for the blind in combination with default (reference) glazing cases. The two European standards EN 14501 (12) and EN 13363-1 (13) each identify 4 reference glazings.

The 4 reference glazings which represent the default cases defined in EN 14501 (12) together with their respective g and U values are shown in Table 2.

The 4 reference glazings which represent the default cases defined in EN 1363-1 (13) together with their respective g and U values are shown in Table 3.

The Shading Factor, F_c, is defined (17) as the ratio of the total solar energy transmittance of the glazing-blind assembly, g_{total}, to the total solar energy transmittance, g, of the glazing alone, i.e.

$$F_c = \frac{g_{total}}{g}$$

F_c is sometimes also termed z.

Note that for any given blind, the value of F_c is dependent upon the glazing with which the blind is combined, i.e. there is not a unique value of F_c for a given blind product.

Glazing	Thermal transmittance U ($Wm^{-2}\,{}^0C^{-1}$)	Total solar energy transmittance, g
Single clear glass	5.8	0.85
Double clear glass	2.9	0.76
Solar Control 1	1.2	0.59
Solar Control 2	1.1	0.32

Table 2. Values of the glazing thermal transmittance, U, and total solar energy transmittance, g, used to calculate the g_{total} and shading coefficient values for the blind fabrics placed internally (taken from EN 14501 (12)).

Glazing	Thermal transmittance, U ($W\,m^{-2}\,.\,{}^0C^{-1}$)	Total solar energy transmittance, g
Single clear glass	5.7	0.85
Double clear glass	3.0	0.75
Triple clear glass	2.0	0.65
Double clear glass with low E coating	1.6	0.72

Table 3. Values of the glazing thermal transmittance, U, and total solar energy transmittance, g, used to calculate the g_{total} and shading coefficient values for the blind fabrics placed internally (taken from EN-13363-1 (13)).

For the blind used externally, i.e. placed on the outside of the glazing, the total solar energy transmittance of the glazing-blind configuration, g_{total}, is calculated from

$$g_{total} = \tau_{sb}\, g + \alpha_{sb}\, (\Lambda / \Lambda_2) + \tau_{sb}\, (1 - g)\, (\Lambda / \Lambda_1)$$

where

g is the total solar energy transmittance of the glazing without the blind
τ_{sb} is the solar transmittance of the blind
α_{sb} is the solar absorptance of the blind

Λ represents the effective heat transfer through the configuration defined as

$$\Lambda = 1 / ((1/U) + (1/\Lambda_1) + (1/\Lambda_2))$$

where
U is the heat loss coefficient of the glazing without the blind,
$\Lambda_1 = W\,m^{-2}\,{}^oC^{-1}$ and $\Lambda_2 = 18\,W\,m^{-2}\,{}^oC^{-1}$.

5. Results

The two sides of the sample are designated as Face A and Face B. Reflectance measurements ar emade for each face of the sample..

The measured UV/Vis/NIR (300 – 2500 nm) total near-normal hemispherical and near-normal-diffuse spectral transmittance of the De Leeuw Reflex-Rol (UK) sample AR762 are shown in Figure 2.

The UV/Vis/NIR (300 – 2500 nm) total near-normal hemispherical and near-normal diffuse spectral reflectance of the De Leeuw Reflex-Rol (UK) AR762 sample are shown in Figure 3.

From these data, and using the expressions and methods described in Section 4, the respective total and diffuse visible transmittance, visible reflectance, solar transmittance and solar reflectance were calculated. These results together with the ultraviolet transmittance are presented in Table 4. The normal-direct transmittance values were obtained by subtracting the measured diffuse transmittance from the measured total transmittance.

The integrated total near-normal hemispherical, near-normal diffuse and normal-direct solar and visible reflectance and transmittance of the De Leeuw Reflex-Rol (UK) AR762 sample are shown in Table 5.

The measured infrared total near-normal hemispherical spectral transmittance and spectral reflectance of the De Leeuw Reflex-Rol (UK) AR762 sample in the range 2.0 – 18.0 μm are shown in Figure 4.

The emissivity values derived from the infrared measurements of reflectance and transmittance, for each face of the sample are shown in Table 6.

The estimated uncertainty of all ultraviolet, visible and solar values is ± 0.02.

The estimated uncertainty of all emissivity values is ± 0.04.

Total solar energy transmittance, g_{total}, shading coefficient, SC, and shading factor, F_c, values were calculated for the AR762 sample in combination with the reference glazings of the two European standards EN 13363-1 (7) and EN 14501 (17), in all cases with the blind placed on the inside of the respective glazing, using the simplified methods described in EN 13363-1. The results for the complex glazing using the EN 14501 reference glazings are presented in Table 7 and for the EN 13363-1 reference glazings in Table 8 respectively.

			Solar Reflectance	Visible Reflectance	Solar Transmittance	Visible Transmittance	Solar Absorptance	Visible Absorptance	Ultraviolet Transmittance
Sample No.	**Sample Name**	**Sample Colour**	ρ_s	ρ_v	τ_s	τ_v	α_s	α_v	τ_{uv}
AR762_A	Reflex-Rol Aviation Foil	Dark Blue Side A	0.14	0.07	0.22	0.03	0.63	0.90	0.00
AR762_B	Reflex-Rol Aviation Foil	Dark Blue Side B	0.15	0.05	0.22	0.03	0.63	0.91	0.00

Table 4. Integrated total near-normal hemispherical solar, visible and ultraviolet optical properties of the De Leeuw Reflex-Rol (UK) aviation foil AR762 sample
(Solar and visible reflectance values for Side A and Side B).

			Total Near-Normal Hemispherical				Near-Normal Diffuse				Normal-Direct	
			Reflectance		Transmittance		Reflectance		Transmittance		Transmittance	
			Solar	Visible	Solar	Visible	Solar	Visible	Solar	Visible	Solar	Visible
Sample No.	**Sample Name**	**Sample Colour**	ρ_s	ρ_v	τ_s	τ_v	$\rho_{s,d}$	$\rho_{v,d}$	$\tau_{s,d}$	$\tau_{v,d}$	$\tau_{s,n}$	$\tau_{v,n}$
AR762_A	Reflex-Rol Aviation Foil	Dark Blue Side A	0.14	0.07	0.22	0.03	0.01	0.00	0.01	0.00	0.21	0.03

Table 5. Integrated total near-normal hemispherical, near-normal diffuse and normal-direct solar and visible reflectance and transmittance of the De Leeuw Reflex-Rol (UK) AR762 sample.

Sample Reference	Name and Colour	Side	Emissivity ε_n	Infrared Reflectance ρ_{IP}	Infrared Transmittance τ_{IP}
AR762_A	Reflex-Rol Aviation Foil Dark Blue	Face A	0.79	0.22	0.04
AR762_B	Reflex-Rol Aviation Foil Dark Blue	Face B	0.76	0.24	0.04

Table 6. Integrated total near-normal hemispherical emissivity, infrared reflectance and infrared transmittance of the De Leeuw Reflex-Rol (UK) AR762 sample.

Fabric Code	Single Clear Glass (A)			Double Clear Glass (B)			Solar Control 1 (C)			Solar Control 2 (D)		
	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc
Reflex-Rol AR762_A	0.61	0.71	0.72	0.61	0.70	0.80	0.52	0.59	0.88	0.29	0.34	0.92
Reflex-Rol AR762_B	0.61	0.70	0.72	0.61	0.70	0.80	0.52	0.59	0.87	0.29	0.34	0.92

Table 7. Calculated total solar energy transmittance, g_{total}, shading coefficient, (SC), and shading factor, F_c, values of the De Leeuw Reflex-Rol (UK) AR762 sample used as internal shading in combination with the four standard glazings of EN 14501 (12).

Fabric Code	Single Clear Glass			Double Clear Glass			Triple Clear Glass			Double Clear low-e		
	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc	Total Solar Energy Trans gtot	Shading Coeff SC	Shading Factor Fc
Reflex-Rol AR762_A	0.62	0.71	0.73	0.60	0.69	0.80	0.55	0.63	0.84	0.61	0.70	0.84
Reflex-Rol AR762_B	0.61	0.71	0.72	0.60	0.69	0.80	0.55	0.63	0.84	0.61	0.70	0.84

Table 8. Calculated total solar energy transmittance, g_{total}, shading coefficient, (SC), and shading factor, F_c, values of the De Leeuw Reflex-Rol (UK) AR762 sample used as internal shading in combination with the four standard glazings of EN 13363-1 (13).

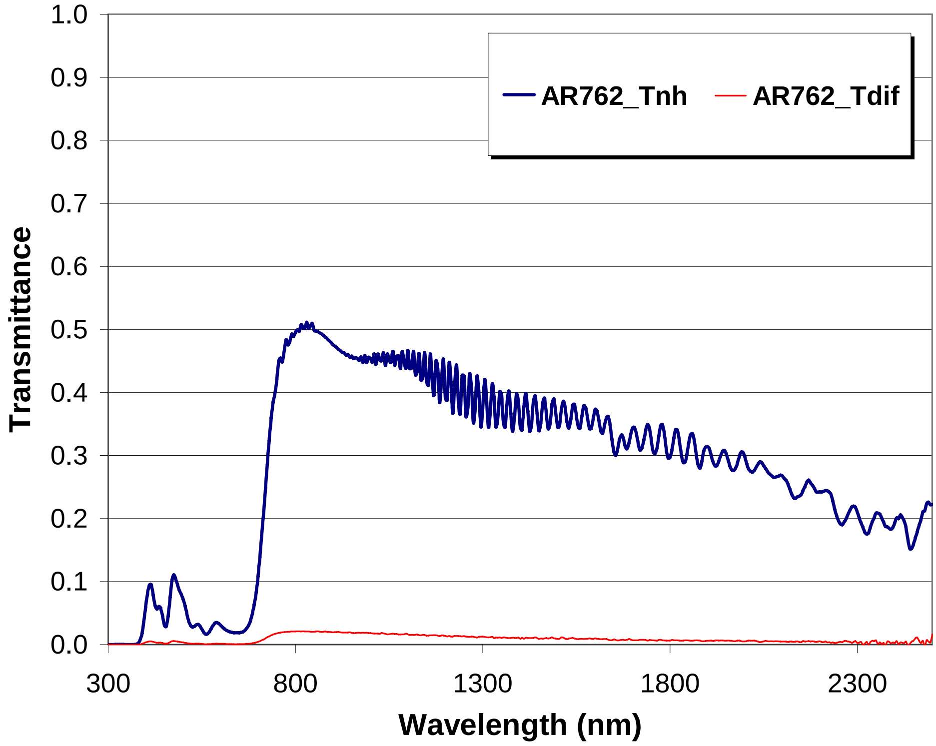

Figure 2. Total near-normal hemispherical and near-normal-diffuse spectral transmittance of De Leeuw Reflex-Rol (UK) sample AR762.

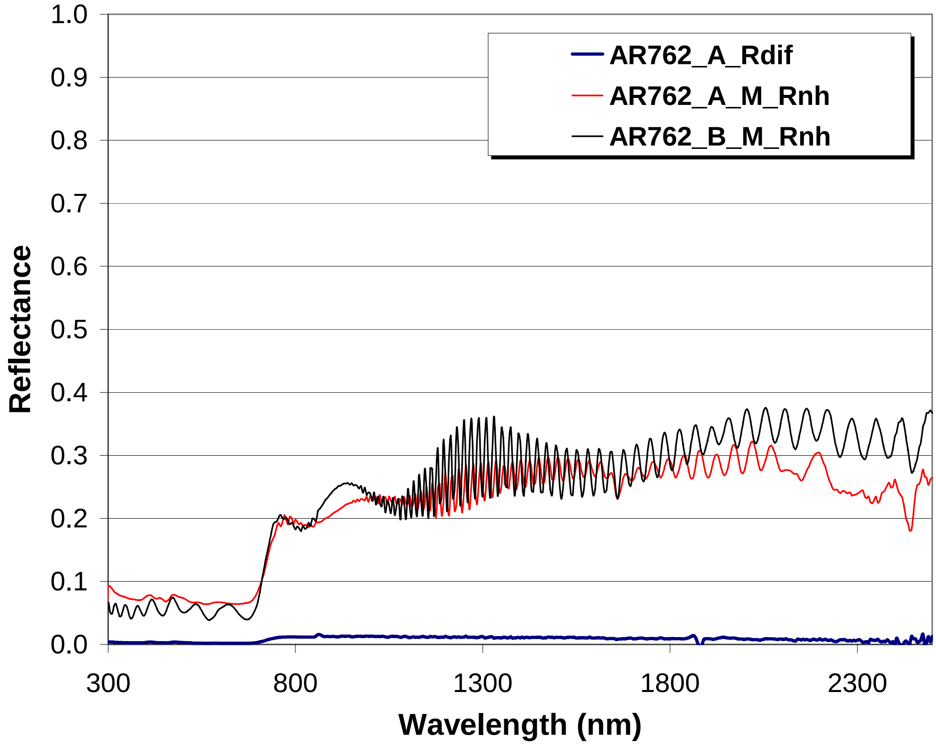

Figure 3. Total near-normal hemispherical and near-normal diffuse spectral reflectance of De Leeuw Reflex-Rol (UK) sample AR762 (Face A and Face B).

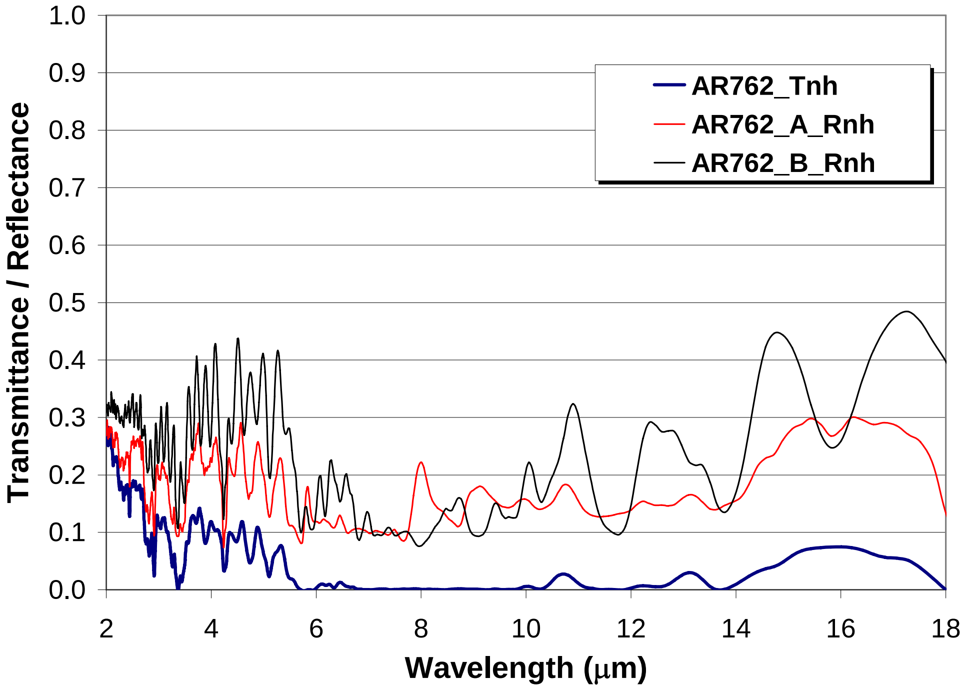

Figure 4. Total near-normal hemispherical infrared spectral transmittance and reflectance of De Leeuw Reflex-Rol (UK) sample AR762 (Face A and Face B).

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