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THE OPTICAL PROPERTIES OF IN'FLECTOR WINDOW SAMPLES

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Contents

I. List of Tables

I. List of Figures

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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 currently being sought (2). Spectrophotometric instruments are serviced annually by the respective manufacturers. All measurements are made in accordance with recognised international procedures and instruments 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.

This report presents results of measurements made to determine the total near-normal hemispherical spectral reflectance and transmittance of 2 In’flector window foil and edge-sealed glazing unit samples for the wavelength range 280 – 2500 nm. For the In’flector window foil sample the spectral near-normal diffuse transmittance and reflectance were also measured.From these measurements integrated visible and solar optical properties are calculated in accordance with accepted international standard procedures (9).

For the In’flector window foil sample the total near-normal hemispherical spectral transmittance and spectral reflectance were measured for the wavelength range 2.0 – 18.0 micron (µm) using a Bruker IFS66 Fourier transform spectrometer with a gold integrating sphere reflectance /transmittance accessory. Reflectance measurements were made for both sides of each 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 673 and EN 12898 (10, 11).

2. The In’flector Window Samples

The In’flector window samples submitted for measurement are identified in Table 1.

Sample No.	Sample ID	Sample Descriptor
INF-01-A	In’flector foil	Aluminised side
INF-01-B	In’flector foil	Black side
INF-DGU-A	In’flector edge sealed double glazed unit	Laminated pane with aluminised foil side visible (Side A)
INF-DGU-B	In’flector edge sealed double glazed unit	Coated glass pane side with blackened foil side visible (Side B)

Table 1. Identification of the In’flector window samples submitted for measurement.

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 (12). The measurement procedures were performed in accordance with EN 14500 and CIE 130 (13, 14).

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.

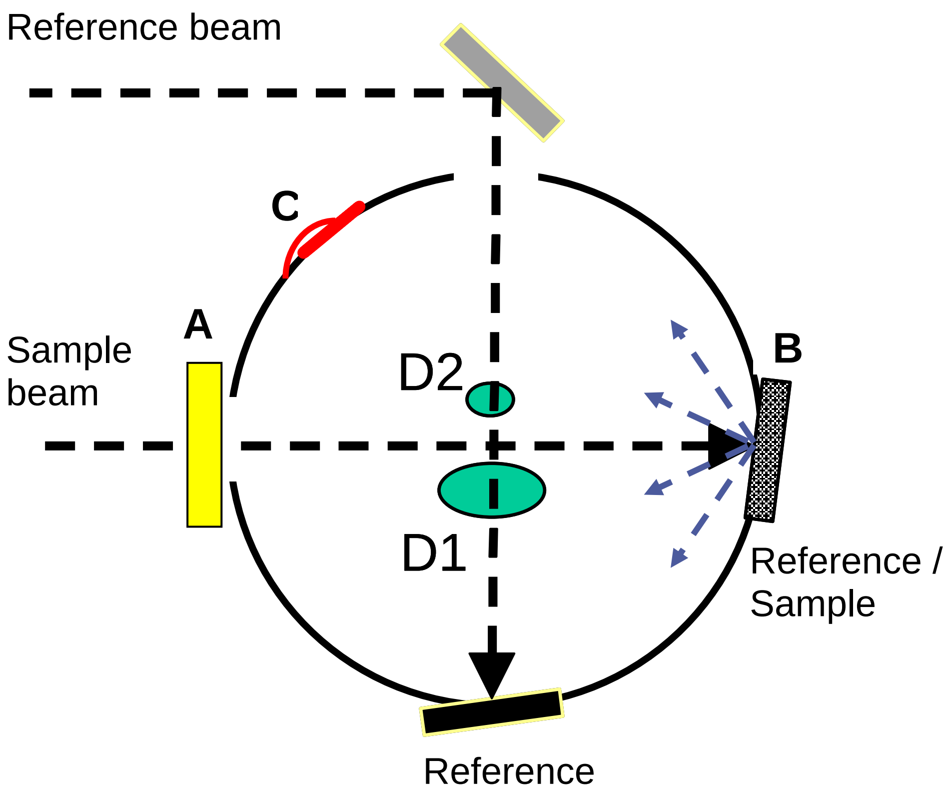

Figure 1. Experimental configuration for the measurement of spectral transmittance and reflectance (UV/Vis/NIR) using the PELA 150 integrating sphere reflectance accessory.
(D1: Photomultiplier detector; D2: PbS detector)

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 (15) and a bare gold mirror calibrated to a traceable NPL gold mirror (16).

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} (17) multiplied by the spectral sensitivity of the human eye V(λ) and the spectral bandwidth Δλ.

Measurements are made of the spectral transmittance, τ(λ), 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 ρ(λ), 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 (18) 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. Thermal emittance

The spectral emittance, ε_λ, is derived from the relationship (18)

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

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 (11) and normalised to the ideal emitter (ε = 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 673 and EN 12898 was used (10, 11).

5. Calculation of Glazing Performance Parameters

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 (9,10,17). The quantitative properties determined for each double glazed unit are described below:

5.1. Total Solar Energy Transmittance, g

The Total Solar Energy Transmittance, g, or Solar Heat Gain Coefficient (SHGC of the glazing, is the sum of the direct solar transmittance, τ_s, and the secondary fraction, q_i, of the incident solar radiation absorbed in the glazing which subsequently flows inwards through the glazing. The g value is calculated according to the procedures of European Standard EN 410 (9).

5.2. U-value

The U-value, or thermal transmittance, is defined as the (steady state) density of heat transfer rate per temperature difference between the environmental temperatures on each side in the absence of solar radiation, in W $m^{-2}.^{0}C^{-1}$. (10,11).

5.3. Light Transmittance, Tv

The light transmittance is defined as the amount of light transmitted to the indoor environment divided by the intensity of incident daylight radiation.

For double glazing units the visible light transmittance, T_v, is calculated from (9)

$$T_v = \frac{T_{v1} T_{v2}}{1 - R'_{v1} R_{v2}}$$

where

T_{v1} is the visible transmittance of the outer glazing
T_{v2} is the visible transmittance of the inner glazing
R'_{v1} is the visible reflectance of surface 2
R_{v2} is the visible reflectance of surface 3

For the cases calculated in this report the coated side of the outer glazing always forms Surface 2 of the double glazed unit and the coated side of the inner glazing

5.4. Direct Solar Energy Transmittance (DET)

The direct solar energy transmittance DET is calculated in a similar way using the relationship (9)

$$DET = \frac{T_{S1} T_{S2}}{1 - R'_{S1} R_{S2}}$$

where

T_{S1} is the solar transmittance of the outer glazing
T_{S2} is the solar transmittance of the inner glazing
R'_{S1} is the solar reflectance of surface 2
R_{S2} is the solar reflectance of surface 3

5.5. Visible Light Reflectance (Rv)

Two values of the visible reflectance are determined:

The visible reflectance as perceived from outside the building, R_{out_v}
The visible reflectance as perceived from inside the building, R_{in_v}

The light reflectance is calculated from the relationship (9)

$$LR = R_{V1} + \frac{(T_{V1})^2 R_{V2}}{(1 - R_{V1}{}' R_{V2}}$$

where

R_{V1} is the visible reflectance of Glazing 1 in the direction of incident radiation
T_{V1} is the visible transmittance of Glazing 1
R_{V2} is the visible reflectance of Glazing 2 in the direction of incident radiation
$R_{V1}{}'$ is the visible reflectance of Glazing 1 measured in the opposite direction to the incident radiation

5.6. Direct Solar Energy Reflectance (DER)

Two values of the direct solar energy reflectance are determined:

The solar reflectance as perceived from outside the building, R_{out_s}
The solar reflectance as perceived from inside the building, R_{in_s}

The direct solar energy reflectance is calculated from the following relationship (9) :

$$DER = R_{S1} + \frac{(T_{S1})^2 R_{S2}}{(1 - R_{S1}{}' R_{S2}}$$

where

R_{S1} is the solar reflectance of Glazing 1 in the direction of incident radiation
T_{S1} is the solar transmittance of Glazing 1
R_{S2} is the solar reflectance of Glazing 2 in the direction of incident radiation
$R_{S1}{}'$ is the solar reflectance of Glazing 1 measured in the opposite direction to the incident radiation

5.7. Solar Energy Absorption (EA)

The solar energy absorption, EA, in the glazing is given simply by

EA = 1 – (DER + DET)

i.e. 1 minus the sum of the solar energy reflected and the solar energy transmitted by the glazing.

5.8. Shading Coefficient (SC)

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 may be divided into two components: the short wave shading coefficient, which is the solar transmittance divided by 0.87, and the longwave shading coefficient, which is the inward flowing thermal fraction, q_i, divided by 0.87.

6. Results

The In'flector window comprises the In'flector metallised foil laminated to a glass pane and then incorporated into a double glazed unit. The second pane is a low emittance coated solar control glass. Only the foil and the edge sealed unit were received as samples for measurement. The component panes and the laminated pane were not submitted as individual samples. Hence no measurements could be made on the component glass panes to enable the window energy performance properties described in Section 5 above to be calculated. This work can be undertaken at a future date if the glass panes are made available.

The measured UV/Vis/NIR (300 – 2500 nm) total normal hemispherical spectral reflectance and transmittance of the metallised side of the In'flector foil sample, INF-01-A, are shown in Figure 2.

The measured UV/Vis/NIR (300 – 2500 nm) total normal hemispherical spectral reflectance and transmittance of the blackened side of the In'flector foil sample, INF-01-B, are shown in Figure 3.

The measured infrared total near-normal hemispherical spectral transmittance and spectral reflectance in the range 2.0 – 18.0 μm of the In'flector foil sample, INF-01, are shown in Figure 4. The infrared reflectance is measured for both the metallised, -A, and blackened, -B, sides of the foil.

From these data, and using the expressions and methods described in Section 4, the respective total visible transmittance, visible reflectance, solar transmittance and solar reflectance were calculated and these results are presented in Table 2. Integrated diffuse solar and visible properties are compared with the total values in Table 3.

The emissivity (thermal emittance) values derived from the infrared measurements of reflectance and transmittance are shown in Table 2.

The measured UV/Vis/NIR (300 – 2500 nm) total normal hemispherical spectral reflectance and transmittance of the In'flector edge sealed double glazed unit measured with the laminated metallised side of the unit, INF-DGU-A, facing the incident beam, are shown in Figure 5.

The measured UV/Vis/NIR (300 – 2500 nm) total normal hemispherical spectral reflectance and transmittance of the In'flector edge sealed double glazed unit measured with the non-laminated coated glass side of the unit, INF-DGU-B, facing the incident beam, are shown in Figure 6.

From these data, and using the expressions and methods described in Section 4, the respective total visible transmittance, visible reflectance, solar transmittance and solar reflectance were calculated and these results are presented in Table 2.

The estimated uncertainty of all visible and solar values is $\pm$ 0.02.

The estimated uncertainty of all emissivity values is $\pm$ 0.04.

			Solar Transmittance	Visible Transmittance	Total Solar Reflectance	Total Visible Reflectance	Solar Absorptance	Visible Absorp-tance	Infrared Transmittance	Emissivity
Sample No.	**Sample Type**	**Sample Namer**	τ_s	τ_v	$\rho_{s,n-h}$	$\rho_{v,n-h}$	α_s	α_v		ε
INF-01-A	In'flector foil	Aluminised side	0.22	0.22	0.48	0.48	0.30	0.30	0.69	0.88
INF-01-B	In'flector foil	Black side	0.22	0.22	0.08	0.08	0.70	0.70	0.87	0.90
										0.89
INF-DGU-A	In'flector edge sealed double glazed unit	Laminated pane with aluminised foil side visible (Side A)	0.17	0.25	0.44	0.49	0.40	0.26	0.84	0.90
INF-DGU-B	In'flector edge sealed double glazed unit	Coated glass pane side with blackened foil side visible (Side B)	0.18	0.27	0.17	0.09	0.65	0.63	0.84	0.90

Table 2. Integrated total near-normal hemispherical solar, visible and thermal optical properties of the In'flector window samples.

			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 Type**	**Sample Namer**	ρ_s	ρ_v	τ_s	τ_v	$\rho_{s,d}$	$\rho_{v,d}$	$\tau_{s,d}$	$\tau_{v,d}$	$\tau_{s,n}$	$\tau_{v,n}$
INF-01-A	In'flector foil	Aluminised side	0.48	0.48	0.22	0.22	0.37	0.37	0.01	0.01	0.21	0.21
INF-01-B	In'flector foil	Black side	0.08	0.08	0.22	0.22	0.06	0.06	0.01	0.01	0.21	0.21

Table 3. Integrated total near-normal hemispherical, near-normal diffuse and normal-direct solar and visible reflectance and transmittance of the In'flector foil sample.

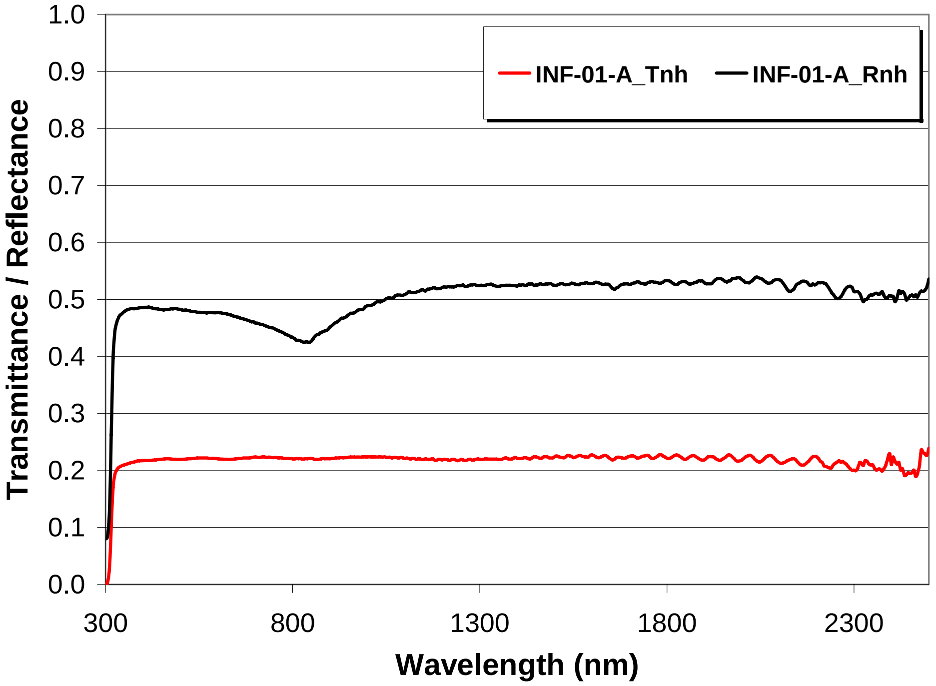

Figure 2. UV/Vis/NIR total near-normal hemispherical spectral transmittance and reflectance of In'flector foil sample INF-01, Aluminium side A.

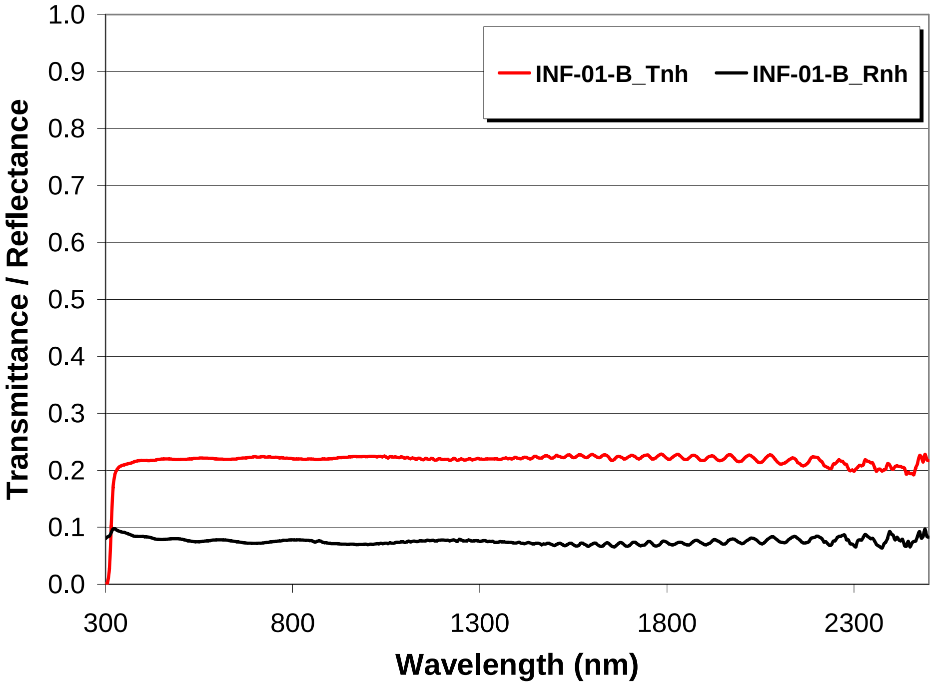

Figure 2. UV/Vis/NIR total near-normal hemispherical spectral transmittance and reflectance of In'flector foil sample INF-01, Black side B.

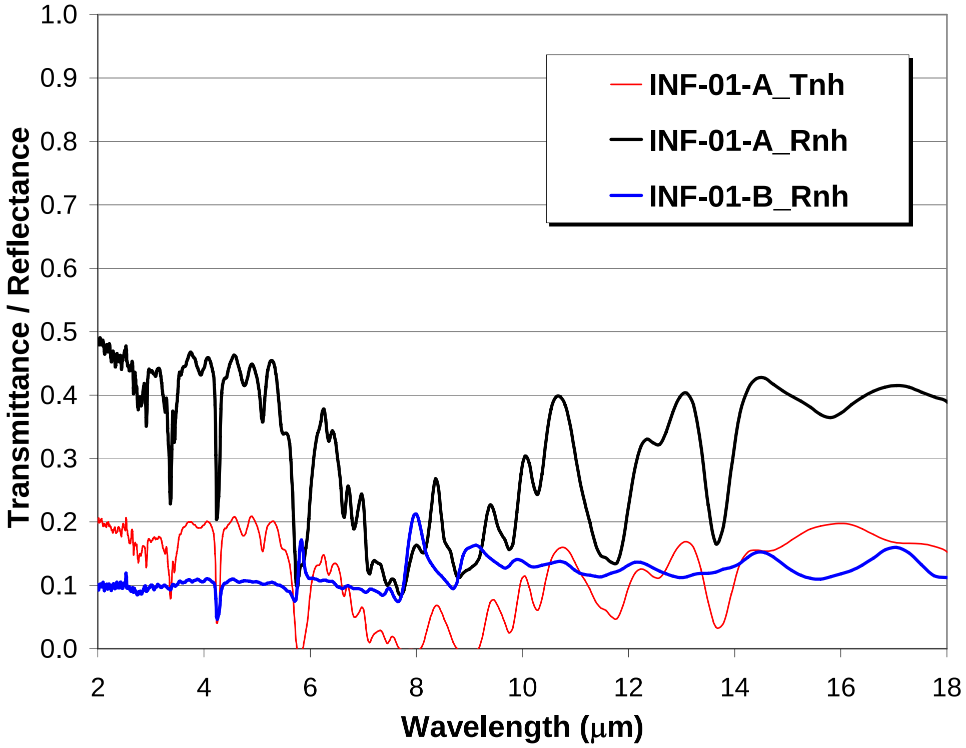

Figure 4. Infrared total near-normal hemispherical spectral transmittance and reflectance of In'flector foil sample INF-01, (Aluminised Side -A; Black side –B).

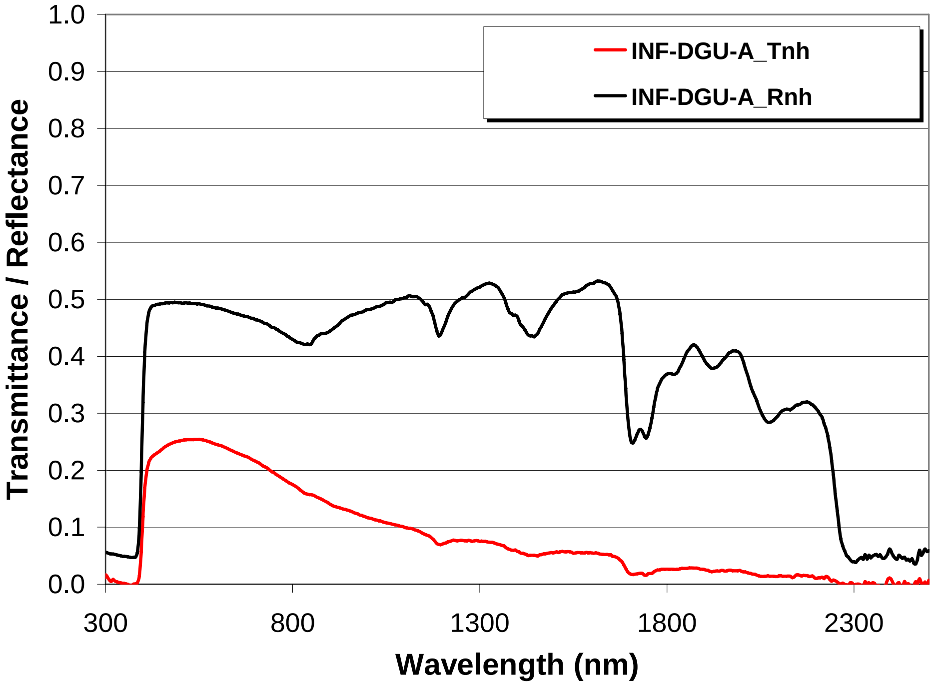

Figure 5. UV/Vis/NIR total near-normal hemispherical spectral transmittance and reflectance of In'flector edge-sealed double glazed unit measured with the aluminised foil side A facing the beam.

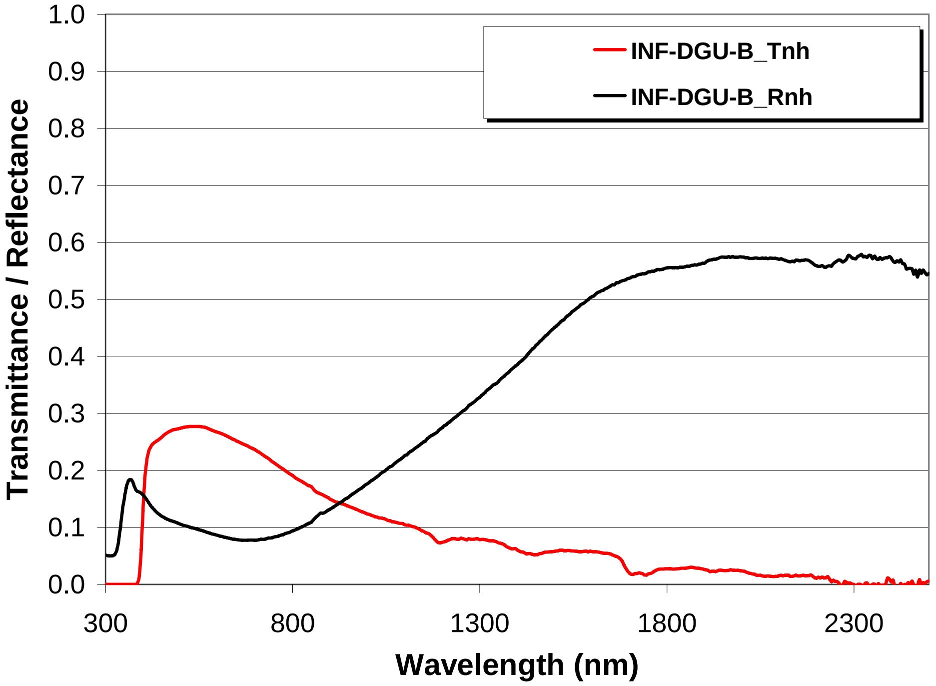

Figure 6. UV/Vis/NIR total near-normal hemispherical spectral transmittance and reflectance of In'flector edge-sealed double glazed unit measured with the non-laminated glass and black foil side B facing the beam.

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