# SOLAR & THERMAL 3B
# DETERMINING THE PERFORMANCE OF GLASS & GLAZING

For solar and thermal properties of glass, the measurement of spectral properties is required. This would typically cover the ultraviolet, visible and near infrared regions (UV/vis-NIR) between 380 nm – 2500 nm, as well as regions of the mid and far infrared between 5 µm – 50 µm.

## UV/VIS-NIR MEASUREMENTS

In order to accurately assess the spectral properties of glass and coated glass samples, measurements of the UV/vis-NIR region are carried out using a spectrophotometer, which splits light sources into wavelength components using a moveable diffraction grating. Measurements are made for both transmittance and reflectance.

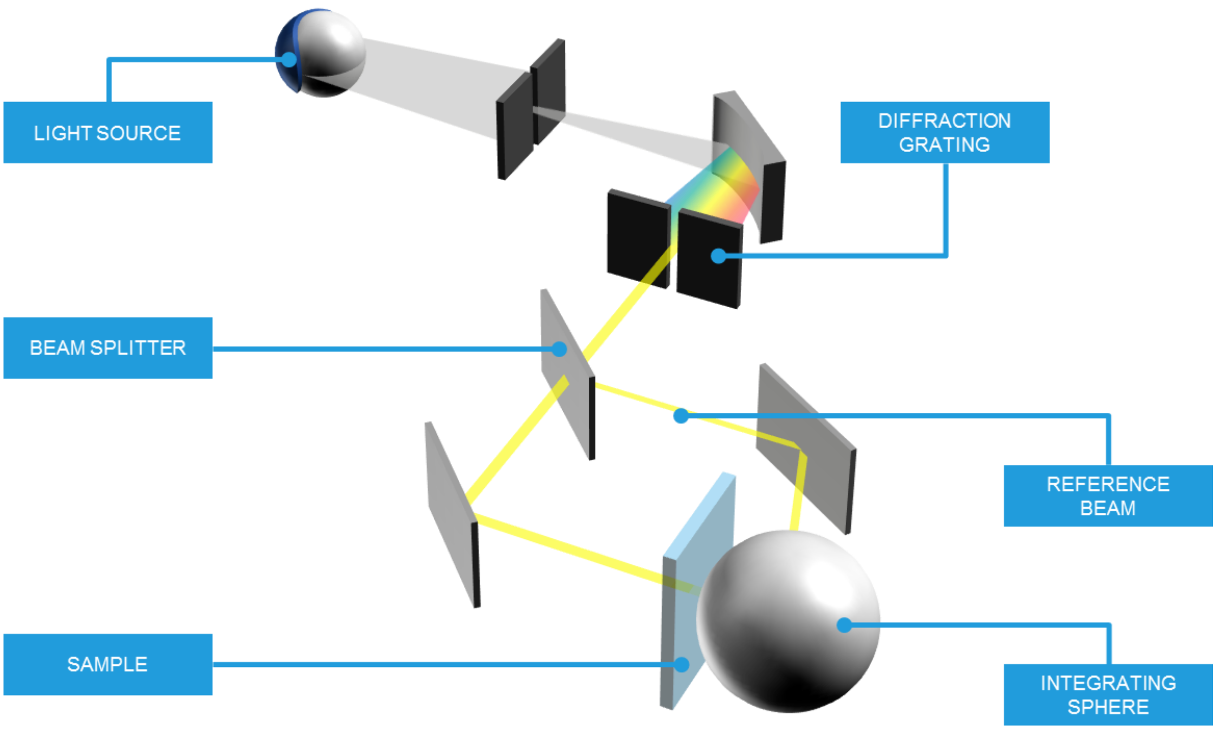


**Figure 1 - Schematic of a Double-Beam Spectrophotometer with an integrating Sphere**

The spectral data obtained is then used with existing data for the spectral distribution of incident solar radiation (Technical Documents **ST-1A**, **ST-1C**, **ST-1D**) in order to determine UV, visible light, and solar energy transmittance and reflectance. Within Europe, this is done in accordance with EN 410 [1]. ISO 9050 [2] provides similar determinations

## TRANSMITTANCE

For solid samples such as glass, the measurement is typically made either with a double beam spectrophotometer, as illustrated above, with a reference beam measurement to baseline for full transmittance, or with a single beam spectrophotometer, baselined against an empty sample port.

For accurate measurements of glass sample, which can refract or distort the incident beam, an integrating sphere is typically used. This enables scattered of refracted light to be captured by the detector, giving a more accurate reading for the overall transmittance.

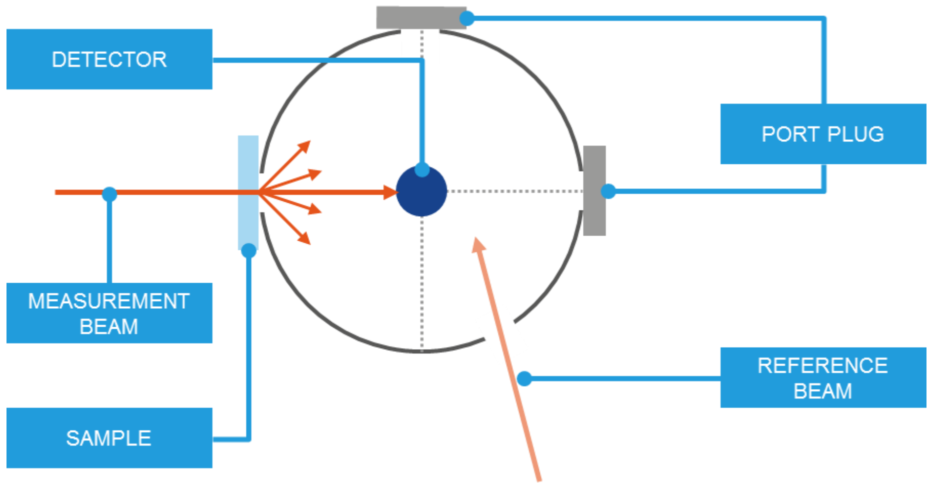


**Figure 2 - Integrating Sphere Schematic (Transmittance)**

## REFLECTANCE

For reflectance measurements, again, an integrating sphere will allow more accurate measurements to account for any refraction of the beam. Measurements are typically made against a baseline generated by using a reference standard of known absolute reflectance in place of the sample.

For coated samples, measurements would need to be made for both the coated and uncoated side. A standard setup for an integrating sphere reflectance measurement is illustrated below.

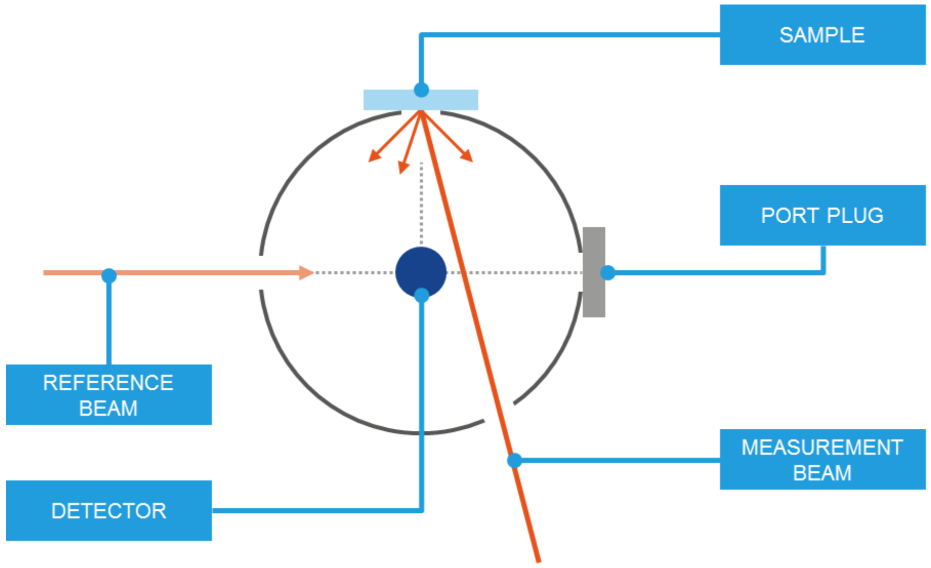


**Figure 3 - Integrating Sphere Schematic (Reflectance)**

# TRANSMITTANCE & REFLECTANCE OF GLASS

Transmittance parameters are considered for visible light, ultraviolet light and solar energy, and reflectance parameters for visible light and solar energy. The determination of these parameters from spectral data is made using the spectral distribution of incident sunlight across the UV, visible and near infrared regions.

## VISIBLE LIGHT

In order to provide a single figure value for light transmittance and reflectance, a calculation needs to be carried out, with consideration to the sample transmittance ($\tau_V$) or reflectance ($\rho_V$), the spectral distribution of the light source (D) and the luminous efficiency for photopic vision (V).

Within Europe, calculations are typically carried out in accordance with EN 410 [1], with the light source based on a D65 distribution, and CIE data for photopic efficiency, as shown in Figure 4. The following equation is used for a single glazed configuration;

$$\tau_V = \frac{\sum_{380}^{780} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{380}^{780} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda}$$

For reflectance, the principal is the same, with the following equation being used for a single glazing configuration;

$$\rho_V = \frac{\sum_{380}^{780} D_\lambda \cdot \rho(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{380}^{780} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda}$$

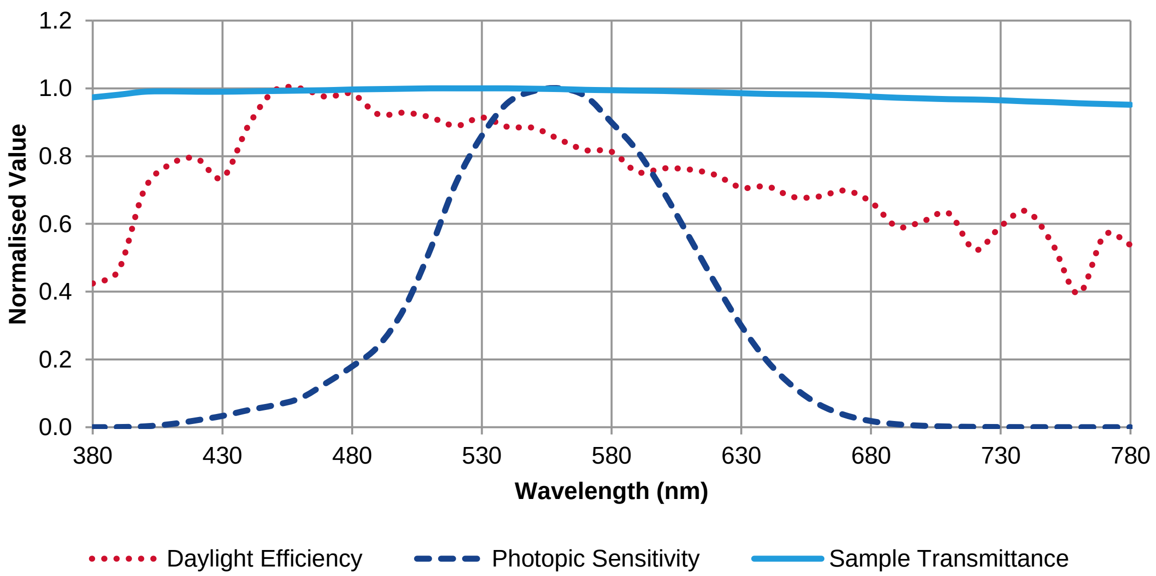


**Figure 4 - Spectrally relevant parameters for the determination of light transmittance**

For double, triple, and more complex configurations, consideration must be given to the spectral transmittance and reflectance values for all panes combined. Full calculation methods are available within EN 410.

## SOLAR ENERGY

In a similar manner to visible light, for a single value of solar energy transmittance, solar energy considers the spectral transmittance ($\tau_e$) and reflectance ($\rho_e$) of a sample, as well as the spectral distribution of solar radiation ($S$). The following equation is used for the determination of solar energy transmittance;

$$\tau_e = \frac{\sum_{300}^{2500} S_\lambda \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{300}^{2500} S_\lambda \cdot \Delta\lambda}$$

For reflectance, the principal is the same, with the following equation being used for a single glazing configuration;

$$\rho_e = \frac{\sum_{300}^{2500} S_\lambda \cdot \rho(\lambda) \cdot \Delta\lambda}{\sum_{300}^{2500} S_\lambda \cdot \Delta\lambda}$$

As well as direct solar energy transmittance, energy that is absorbed by the glass, and re-radiated inwards, the secondary heat transfer factor ($q_i$) is also considered. The solar factor ($g$) is the sum of this energy plus direct solar energy transmittance ($\tau_e$).

For single glazing, this is calculated by considering the energy absorbance ($\alpha_e$), as well as the internal ($h_i$) and external ($h_e$) heat transfer coefficients. As follows;

$$g = \tau_e + q_i$$

Where;

$$q_i = \alpha_e \cdot \frac{h_i}{h_i + h_e}$$

And;

$$\alpha_e = 1 - \tau_e - \rho_e$$

For double, triple, and more complex configurations, consideration must be given to the spectral transmittance and reflectance values for all panes combined. Full calculation methods are available within EN 410.

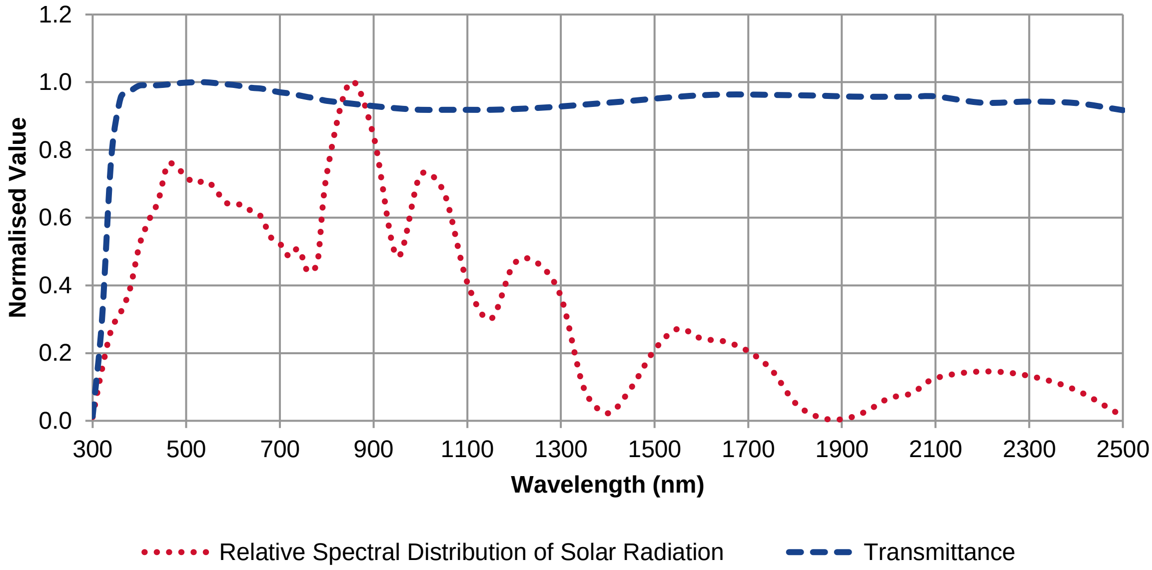


Figure 5 - Spectrally relevant parameters for the determination of energy transmittance

## ULTRAVIOLET LIGHT

Within EN 410 [1], the region between 300 – 380 nm is considered for the assessment of UV transmittance ($\tau_{UV}$), and based on laboratory measurements of transmittance using UV-vis spectrophotometry, and the distribution of the UV portion of global solar radiation ($U$), the UV transmittance can be determined through calculation with the relative spectral distribution of the UV portion of global solar radiation.

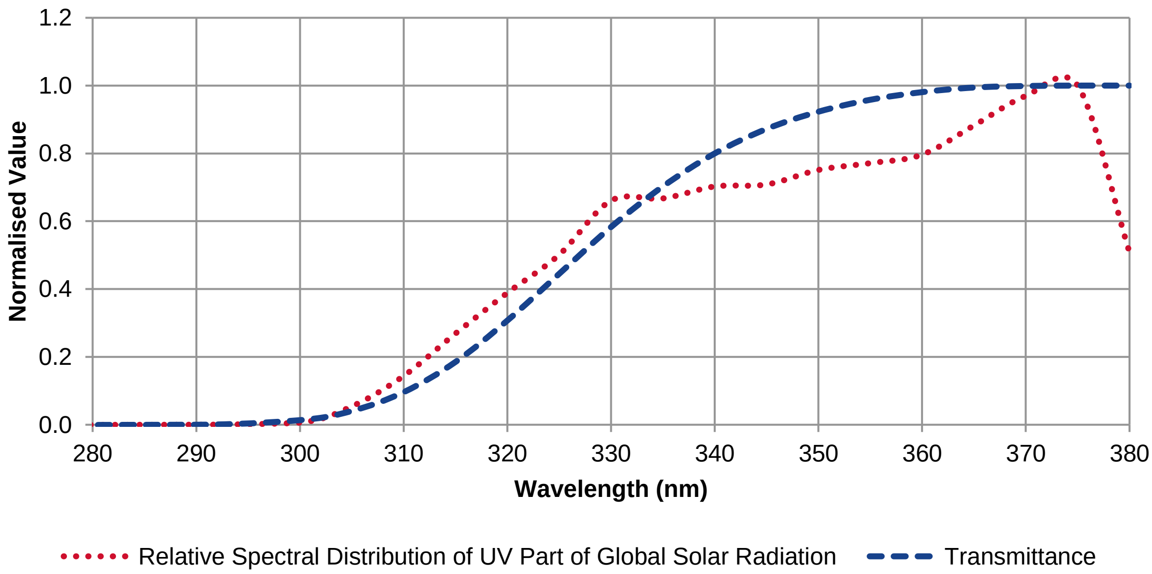


Figure 6 - Spectrally relevant parameters for the determination of UV transmittance

In a similar manner to solar energy, for a single value of UV transmittance or reflectance, UV considers the spectral transmittance (τ) and reflectance (ρ) of a sample, as well as the spectral distribution of UV radiation (U). The following equation is used for the determination of solar energy transmittance;

$$\tau_e = \frac{\sum_{280}^{380} U_\lambda \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{280}^{380} U_\lambda \cdot \Delta\lambda}$$

## MID-IR & FAR IR MEASUREMENTS

For the determination of emissivity, measurement of regions of the mid and far infrared regions of the electromagnetic spectrum, between 5 µm – 50 µm are made. Measurements are typically made using reflectance accessories with a Fourier Transform Infrared Spectrometer (FTIR), against a baseline of a gold mirror, with a pre-determined absolute reflectance.

Using the spectral data, a determination of emissivity can be made in accordance with EN 12898 [3], which involves obtaining the average of 30 points (prescribed by the standard) to determine an average reflectance.

$$R_n = \frac{1}{30} \sum_{i=1}^{i=30} R_n(\lambda_i)$$

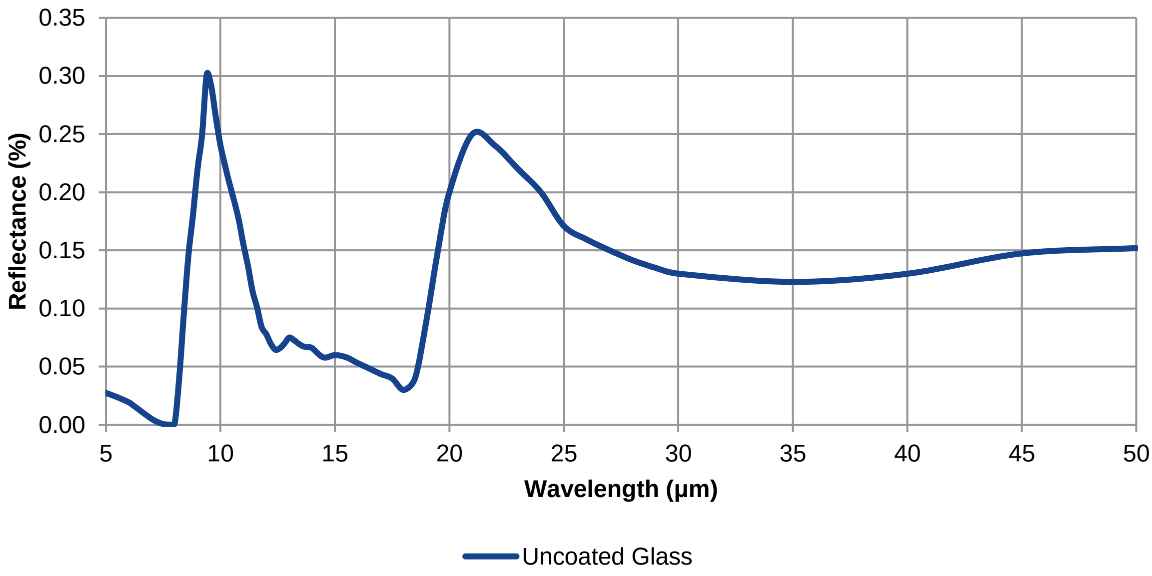


**Figure 7 – Mid-IR, Far-IR Spectrum for Uncoated Glass**

The emissivity is then determined by subtracting the reflectance from 1, which can then be used for the determination of U values in accordance with EN 673 [4].

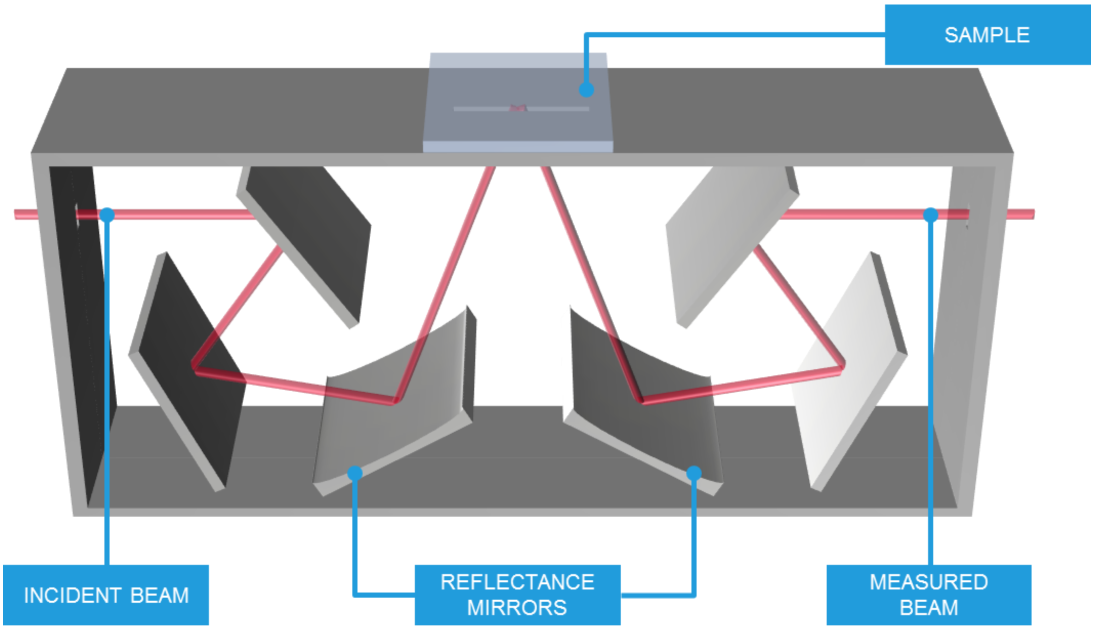


**Figure 8 – Example of an IR Reflectance Setup**

## REFERENCES

[1] European Committee for Standardization, EN 410:2011 - Glass in building. Determination of luminous and solar characteristics of glazing, CEN, 2011.

[2] International Organization for Standardization, ISO 9050:2003 - Glass in building - Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors, ISO, 2003.

[3] European Committee for Standardization, EN 12898:2001 - Glass in building. Determination of the emissivity, CEN, 2001.

[4] European Committee for Standardization, EN 673:2011 - Glass in building. Determination of thermal transmittance (U value). Calculation method, CEN, 2011.