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Measurement Techniques for Solar Energy Properties of Glazing

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Abstract

Solar energy properties of glazing are derived from reflectance and transmittance spectra obtained with a spectrophotometer. For the reason of simplicity, daylight and solar energy properties of glazing are commonly specified for normal incidence only. Although special precautions have to be taken, (near-) normal measurements are straightforward and can be performed accurately by most laboratories. In the case of directional optical properties things get more complicated and most laboratories are not equipped to do the job. Nevertheless, there is a growing need for data on directional optical properties of glazing, specially, where architects rely on the accuracy of simulation tools to predict the energy balance of buildings in design. The paper gives a brief discussion of the measurement problems and presents a new generation of accessories for spectrophotometers in which these problems are properly dealt with.

1. Introduction

The basic optical properties for the calculation of solar energy properties of glazing are the reflectance and transmittance spectra of the individual panes. These spectra are combined to obtain the reflectance and transmittance spectra for the double or triple glazing units that are used to calculate the glazing factors representing the total solar energy transmittance, visible light transmittance and other specifications.

Glazing performance is commonly specified [1,2] for a (near-) normal angle of incidence, which means with the direction of the incoming radiation perpendicular to the surface of the window. Although this does not represent a realistic condition, for most industrial testing laboratories this is a standard measurement and the only type of measurement they can perform accurately.

Nowadays, this standard measurement is not always sufficient and the need for reliable measurement techniques for directional optical properties is growing. The reason for this is that modern building simulation tools more and more depend on the availability of accurate data describing the performance of glazing under realistic conditions. Unfortunately, these properties are difficult to measure and experimental results from different laboratories seldom agree [3]. This is often the result of lack of experience but also due to the fact that the measurement accessories that are commercial available for this purpose show many shortcomings.

Recently, a three year programme of work called the ADOPT project (Angular Dependent OPTical properties) [4] has been completed. One of its objects was to establish reliable measurement procedures for directional spectral optical properties. As a spin-off of this project, a new generation of spectrophotometer accessories has been developed for directional transmittance and reflectance measurements. These new accessories allow independent and industrial research laboratories to perform state-of-the-art measurements of directional optical properties of coated and uncoated glass samples.

This paper gives a discussion of both the measurement problems as well as appropriate measurement techniques for both (near-) normal and directional optical properties of coated glazing.

2. Measurement problems

The basic instrument for characterisation of coated glass samples is a spectrophotometer, equipped with the appropriate accessories for transmittance and reflectance measurements. Typically, this is a double-beam instrument using slightly diverging rectangular beams of monochromatic radiation to illuminate the sample and separate detectors for the UV/Vis and NIR ranges. One of the problems typically for optical characterisation of coated glass samples is due to back reflectance and multiple reflections inside the sample. The different optical path lengths for these reflected beams result in multiple images on the detector that have not the same shape, size and position. At oblique incidence, these beams are laterally shifted as well as mutually separated by a distance X, as shown in figure 1. Also shown in this figure is a graph of this angular dependent separation, calculated taking for glass the value $n = 1.5$.

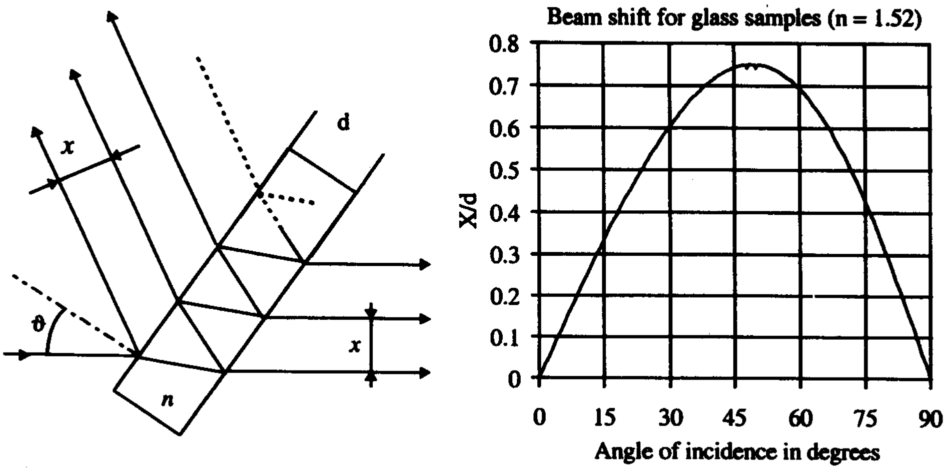

Figure 1 *Secondary beams, occurring as a result of multiple reflections.*

The maximum beam separation is approximately 75% of the sample thickness and occurs at an angle of incidence of about 50 degrees. In commercially available directional transmittance accessories for spectrophotometers, the problem of the lateral beam shift is dealt with by using a second sample that partly compensates for this effect [5]. However, with this method the secondary beams occur on both sides of the optical axis making the problem worse. Although, due to reflection losses, the beams far away from the optical axis have much less energy than the beams close to the optical axis, in practise it will be necessary to include at least the first 3 or 4 beams. This is not possible with the standard detectors generally applied in commercial spectrophotometers. The solution to these problems is to use an integrating sphere with a large entrance port as detector. Not only the secondary beams are collected properly with an integrating sphere, but also beams which are slightly deflected by the surface topology of the sample (for instance in the case of drawn flat glass).

In some cases polarisation plays a role. Spectrophotometers use monochromatic radiation, which is strongly polarised. This polarisation varies with the wavelength as shown in figure 2.

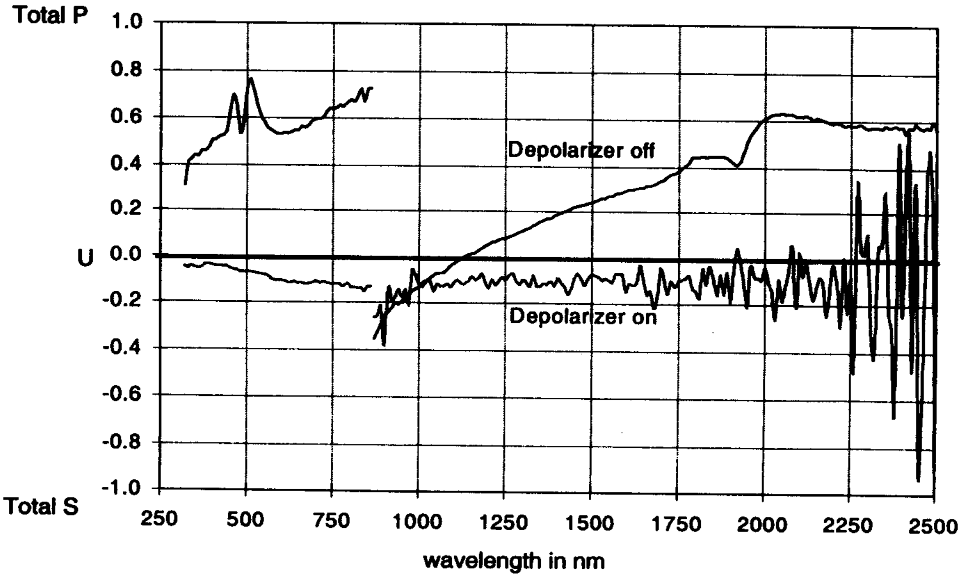

Figure 2 *Degree of polarisation of the beam of a Perkin Elmer Lambda 900 UV/Vis/NIR spectrophotometer, with and without depolariser.*

The optical properties of glazing depend on polarisation. As a result, the measurement results may in generally not agree with the optical behaviour of the glazing under natural daylight, except for the case of normal incidence, where the spectral reflectance and transmittance is the same for all polarisation states.

For measurements at oblique incidence, we have to use a polariser which enables us to perform separate measurements with P and S polarised radiation. The results can then be averaged to obtain the result for random or unpolarised radiation. In the case of S-polarisation, depolarising the beam before it enters the polariser can significantly approve the noise level. Without the depolariser, the amount of s-polarised radiation in the beam is low at most wavelengths (see figure 2). The depolariser evenly re-distributes the energy over both polarisation states, thereby increasing the s component. Obviously, the P component decreases in this case so it is recommended to use the depolariser only when the polariser is set to produce S-polarised radiation.

An important shortcoming of most commercially available accessories for directional measurements is that the setting of the angle of incidence is inaccurate. Especially for angles > 45°, were the angular dependency of optical properties is much greater than at normal incidence, this can lead to significant measurement errors. Most accessories for directional reflectance and transmittance measurements have accuracy in the angular setting in the order of 2° - 5° resulting in errors as large as several percent in the transmittance or reflectance. In order to perform accurate measurements, the accuracy in the angular setting has to be < 0.1° [6]. In order to obtain this accuracy, one has to take into account that positive and negative angles do not necessarily give the same results. This is shown in figure 3. The non-uniform distribution of energy in the spectrophotometer beam is the cause of this effect. This beam consists of rays that, due to beam convergence, interact with the sample under slightly different angles. These rays do not all have the same energy, thereby causing a net difference between measurements at positive and at negative angles of incidence, resulting in a systematic error. The correct result is obtained by taking the average.

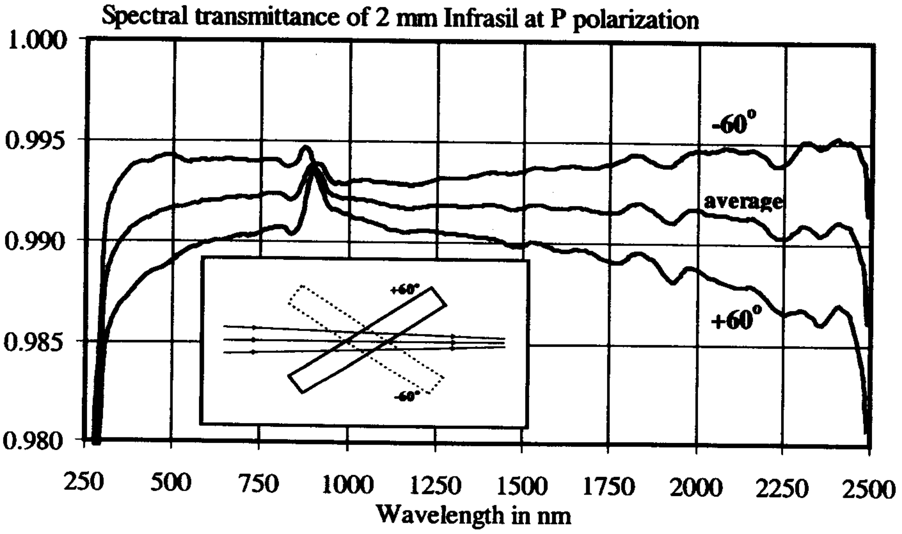

Figure 3 Spectral transmittance measured at "positive" and "negative" angle of incidence.

3. Measurement Techniques

At the TNO Institute of Applied physics, a Perkin Elmer Lambda 900 UV/Vis/NIR spectrophotometer is used for characterising solar energy materials. This spectrophotometer is permanently equipped with an integrating sphere detector unit (PELA 1020), which contains a 60 mm spectralon integrating sphere. This particular sphere has a large entrance port that makes it suitable to capture secondary shifted beams occurring at oblique incidence. After careful alignment, samples with a thickness up to 10 mm can be measured at oblique incidence, with negligible systematic errors related to beam-shift and to the separation of secondary beams.

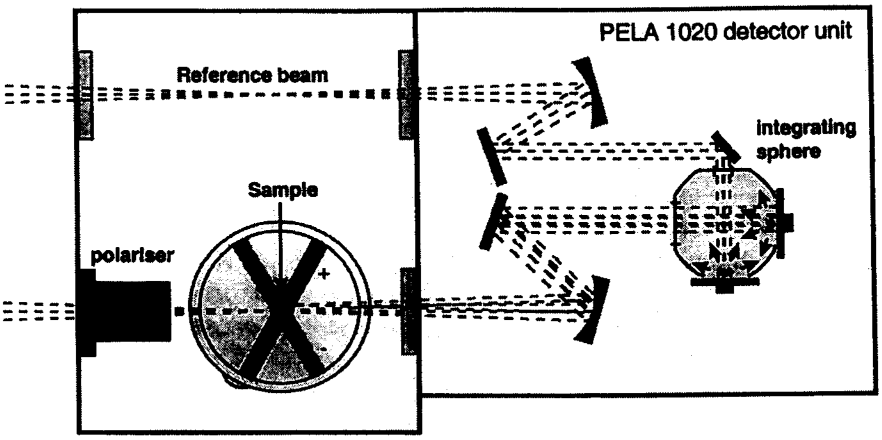

Figure 4 Directional transmittance set-up for the PerkinElmer Lambda 900 spectrophotometer.

For transmittance measurements the set-up shown in figure 4 is used. An UV-enhanced Glan-Thompson polariser with an effective wavelength range of 220 nm - 2500 nm is positioned at the entrance port of the sample compartment of the spectrophotometer. In case of the standard measurements (normal incidence) the polariser is removed to obtain a better signal-to-noise ratio. The sample holder is placed on a rotation stage with an angular accuracy < 1/12 degree. At oblique incidence, at least four measurements are necessary, two measurements per angle (positive and negative angles) and per polarisation. This is why directional measurements are more time-consuming than standard measurements.

In the case of standard (near-normal incidence) reflectance measurements, a 6° fixed-angle reflectance accessory is placed into the sample compartment. The set-up used for directional reflectance measurements is shown in figure 5. Again the UV enhanced polariser and the same type of rotation stage as in the directional transmittance measurements is used. An auxiliary mirror is placed at a constant angle of 90 degrees with respect to the sample. In figure 5, the geometry in the case of 'positive' angles of incidence is shown. In the case of 'negative' angles of incidence, the auxiliary mirror and the sample are interchanged.

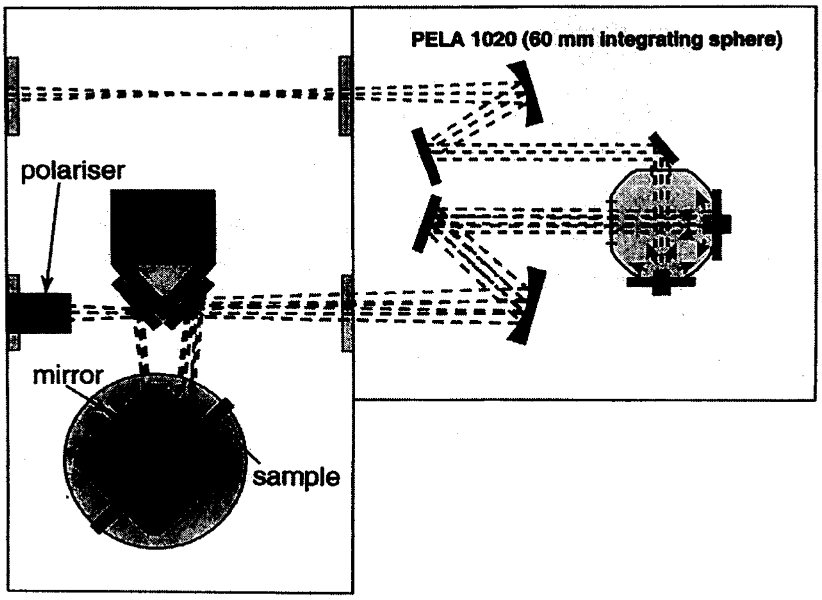

Figure 5 Directional reflectance set-up for the PerkinElmer Lambda 900 spectrophotometer.

The reflectance measurements discussed here require a reference mirror. For the calibration of these reference mirrors, a directional VW accessory has been developed. The measurement principle of this absolute reflectance accessory is based on a combination of two measurements. In the V-mode (see figure 6) the instrument beam is interacting with three mirrors (M1 - M3). In the W-mode the beam additionally interacts twice with the sample. The ratio of the two spectra obtained in the W- and V-mode produces the square of the sample reflectance. The VW method is an absolute one since a calibrated reference is not needed. An advantage of measuring the square of the reflectance is that the total uncertainty in the reflectance is only 50% of the total measurement uncertainty.

In addition to the measurements at (near-) normal incidence (8 degrees), the directional VW accessory is also capable of performing measurements under oblique incidence. In this case, two additional forms of the W -mode are possible, representing "positive" and "negative" angles of incidence. As an example, the two corresponding W-modes for 45° is shown in figure 6.

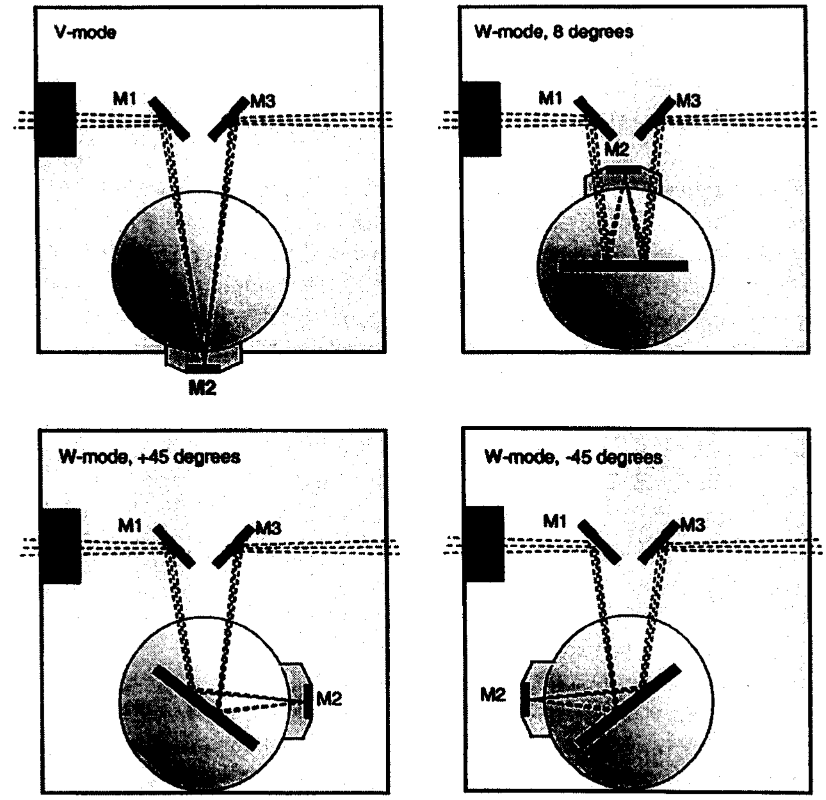

Figure 6 The directional VW reflection accessory shown in the V- and W-modes.

4. Discussion

Commercially available UV/Vis/NIR spectrophotometers are normally not equipped with an integrating sphere as detector. Integrating sphere accessories are mainly intended for measuring diffuse reflectance. Due to the fact that an integrating sphere is relatively insensitive for misalignment and beam-shift, it is also an ideal detector for measuring coated glass samples. However, the design specifications for an ideal detector sphere are essentially different from that of an integrating sphere for diffuse reflectance measurements. In the latter case the sphere must be as large as possible, having small entrance ports and the detector properly screened from seeing any radiation directly coming from the ports or reflection targets. A detector sphere however, can be small to increase its sensitivity (60 mm in diameter is large enough) and preferably has a wide rectangular entrance port to insure that all the secondary beams that give a significant contribution are being collected properly. The best position for the UV/Vis and NIR detectors is directly above, below or next to the entrance port, facing the part of the sphere wall where the beam hits, thereby increasing its throughput. Although the PELA 1020 accessory used in our spectrophotometer is not ideal in this respect, its large entrance port (ø 23 mm) as compared to the beam cross-section (4 mm x 8 mm) and the absence of detector screening which results in a higher throughput makes it a suitable detector sphere.

In the new accessories for directional optical properties discussed in this paper, all major measurement problems, have been successfully dealt with. Having accurate rotation stages for the angular setting is an important improvement. Having the possibility for measuring at "positive" and "negative" angles is a further improvement making it possible to compensate systematic errors, by taking the average of these two types of measurements. This also results in an absolute calibration of the zero position of the angular setting, the lack of which is another shortcoming of most accessories.

5. Conclusion

In measuring the optical properties of coated glass samples with a spectrophotometer, it is absolutely necessary to use an integrating sphere as detector. In case of directional optical properties this raises a problem since not all instruments have the capability of combining an integrating sphere attachment with other accessories.

Most existing accessories for measuring directional optical properties of coated glass samples have shortcomings. A new generation of accessories has been developed which properly deals with all measurement problems, allowing directional optical properties of glazing to be measured accurately. A unique feature of these accessories is the possibility to measure "positive" and "negative" angles of incidence, allowing for compensation of systematic errors and calibration of the angular setting. The directional VW reflection accessory provides the means for calibrating the reference mirrors not only at near-normal incidence, but also at oblique incidence for P- and S-polarisation separately. The new accessories have been designed for the Perkin Elmer Lambda 900 spectrophotometer and are at present commercially available.

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