Transvision: a Light Transmission Measurement System for Greenhouse Covering Materials

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Abstract

For determining the optical performance of greenhouse covering materials other than standard float glass the current Dutch NEN 2675 norm is no longer appropriate. The emergence of a new generation of materials (diffuse, layered) resulted in a new measuring protocol developed by TNO and Wageningen UR. In line with this protocol Wageningen UR has developed an accurate measuring device (Transvision) for measuring the light transmittance for direct and hemispherical incident light. The device is based on spectral analysis of a perpendicular beam passing the material under a variable angle of incidence into an integrating sphere. With the angular transmission data, the hemispherical transmission can be calculated which is the most important benchmark for the performance as a covering material at northern latitudes. The device is specially developed for measuring thick, multi-layer and large materials which cannot be cut for testing, like tempered or structured glass panes. For clear float glass the device meets the specifications of the NEN 2675 and the results are comparable with those of professional spectrometer systems.

INTRODUCTION

Light is the energy source for plant growth. Solar irradiance is sustainable and free and therefore the most favourable source of light. Greenhouse covering materials that protect the crop for adverse influences of outside weather conditions will affect the level and composition of this solar irradiance at its entrance into the greenhouse envelope. A vast amount of industrial and scientific research is carried out in order to optimize the transmission properties of covering materials, especially in their interaction with other requirements of the greenhouse cover, such as strength, thermal insulation and durability.

Until recently the only norm available for measuring the light transmission of greenhouse glass was the Dutch norm NEN 2675 (NEN 2675, 1990). This standard describes a method for measuring the PAR transmission for normal incidence (parallel to the normal of the surface) and is primary intended for product comparison. For the optical performance of greenhouses however, the hemispherical transmission is a more important factor than perpendicular transmission, especially at northern latitudes. Here diffuse light dominates the global radiation, up to 80% in winter. Since the refractive index of standard float glass hardly differs between glass producers, the normal transmission is a representative value for the transmission for other angles of incidence, and thus the transmission for hemispherical incident light. Since the last 5 years however, a large variety of new covering materials with improved thermal insulation, light transmission and diffusing properties has been developed. For these materials, often with coatings, the relation between the normal and hemispherical transmission is not straightforward which makes the NEN 2675 inappropriate.

Another important development in greenhouse horticulture is using covering materials which scatter the direct incoming light and make it diffuse to some extent. This is called the haze of the material. At high irradiation levels, diffuse greenhouse coverings result in better light distribution, lower crop temperature, decreased transpiration, and increased photosynthesis and growth (Hemming et al., 2007). Also diffuse materials prevent high direct radiation which could cause burning of leaves and flowers. For crops with low light demands a compromise between diminished light transmission and a high haze factor of the greenhouse covering is accepted, even up to 50% reduction of the transmission for some crops (Hemming et al., 2007).

To enable a fair comparison between new materials, TNO and Wageningen UR developed a new protocol for measuring the transmission of greenhouse covering materials (Ruigrok, 2008). In line with this protocol Wageningen UR has developed a new device (Transvision) for measuring the angular and hemispherical transmission of transparent (greenhouse covering) materials as well as the haze. This device supports manufacturers in developing new materials and is able to collect optical data for energy and light models.

MATERIALS AND METHODS

Integrating Sphere

An integrating sphere (also known as Ulbricht sphere) is an optical component consisting of a hollow spherical cavity with its interior covered with a diffuse white reflective coating, with small holes for entrance and exit ports. Its relevant property is a uniform scattering or diffusing effect. Light rays incident on any point on the inner surface are, by multiple scattering reflections, distributed equally to all other points. The effects of the original direction of light are minimized. An integrating sphere may be thought of as a diffuser which preserves power but destroys spatial information. It is typically used with some light source and a detector for optical power measurement (Wikipedia, 2012).

It is important that the optical sensor is shielded from direct light from the light source or scattered from the sample. In theory, an integrating sphere should have no disturbances inside the sphere. In practice, the port dimensions should not exceed 5% of the inner sphere surface and components like baffles should be minimized.

The size of the sphere largely determines the accuracy of the measurement. The light intensity will decrease strongly with the diameter which makes measurements especially in the NIR range complicated. As a consequence, thick materials, materials with a large structure and materials with strong light scattering properties require a relatively large sphere.

Detector

For measuring the spectral light intensity inside the sphere a spectrometer system is used. Professional spectrometer systems often use a monochromator which generally consists of entrance slit, collimator, a dispersive element, such as a grating or prism, focusing optics and detector which receives only a narrow portion of the spectrum. The spectrum is scanned by rotating the grating. With the development of micro-electronics in the field of multi-element optical detectors, low cost scanners, such as device (CCD) cameras have become available and as a result the CCD spectrometer. Together with low absorption silica fibres developed for communication technology, the light intensity in the UV-, VIS- and NIR-range can be measured simultaneously and fast.

Methods

The angle of incidence is defined as the angle between parallel beam of light incident on a surface and the line perpendicular to the surface at the point of incidence called the normal. The direct transmission for x° is defined as the total transmission of light with an angle of incidence x. The device measures direct transmission by splitting up the beam into two beams before it reaches the sample. One beam is used as a reference, the other beam passes through the sample. The reference beam intensity is taken as 100% transmission and the sample transmission is the ratio of the two beam intensities.

The hemispherical transmission is defined as the total transmission for hemispherical incident light and is calculated by numerical integration of the direct transmission values for different angles $T(\phi, \theta)$ according to:

$$T_{HEM} = \frac{\int_{0}^{2pi} \int_{0}^{pi/2} T(\phi,\theta) I(\phi,\theta) \sin(\theta)\cos(\theta) d\theta d\phi}{\int_{0}^{2pi} \int_{0}^{pi/2} I(\phi,\theta) \sin(\theta)\cos(\theta) d\theta d\phi} \quad (1)$$

where ϕ: azimuth angle (horizontal plane); θ: angle of incidence: $I(\phi,\theta)$: distribution function, in this case according to the "standard uniform sky" (I=1), uniform luminance that does not change with altitude and azimuth.

Haze is defined as the fraction of the transmitted light which is scattered more than a certain deviation of the incoming incident angle. Currently there is no standard available for greenhouse covering materials but the ASTM standard for transparent plastics (ASTM D1003-95) is a good indicator for the scattering properties of.

Critical Dimensions

The relationship between beam width, sample size and diameter of the various ports of the integrating sphere affect the accuracy of the measurement and depends strongly on the scattering properties of the material. For this only rules of thumb can be given:

- the sample must be larger than the sample port and much thinner than the diameter of the sample port.
- the beam must be either larger or smaller than the sample port which minimizes light loss due to scattering and refracting of the light through diffuse materials and inter-reflection in specular samples at off-normal incident light. In both cases a fraction of the transmitted light will not enter the integrating sphere which causes an under estimation of the transmission. The basic principle is that the illuminated area with the size of the sample port should enter the sphere one way or another (Fig. 1).

Besides edge effects, the illuminated area of the sample should be large enough to cover patterns or structures in the material. In other words, the measurement result must be independent on which part of the material is illuminated. As a rule of thumb at least 10 repeating structures should be illuminated. To be sure, the measurement must be repeated at least once with the sample in a different position. In case the structures are larger than one tenth of the illuminated area, the measurement must be repeated for different positions of the sample.

RESULTS AND DISCUSSION

On base of the theory above, Wageningen UR developed a device for measuring the angular and hemispherical transmission of greenhouse covering materials and transparent materials in general (Fig. 2). A 2000W fixed xenon light source generates a parallel beam along the optical an mechanical axis of a rotatable arm for angular illumination of the sample. A micro lens array is put in the light path and creates a uniform spot. A divergent lens together with a beam splitter create two separate beams for the reference port and sample port. With shutters which block both ports separately, both ports can be illuminated alternately. Both the intensities of light source (for correction fluctuations in source intensity) and sphere are guided to a CCD spectrometer with optical fibre cables.

The device accurately measures the following optical properties:

- Total transmission for angles of incidence from 0° up to 80° (direct transmission).
- Total transmission for hemispherical incident light (hemispherical transmission).
- Haze (also called diffuse transmission), based on ASTM D1003-95, except that the acceptance angle is 1.5° instead of 2.5° and a spectral output instead of an unweighted mean.

The device is specially developed for measuring thick and multi-layer materials and large materials over which cannot be cut like tempered or structured glass panes. Currently transmission between 250 and 1100 nm can be measured but an extension to 2300 nm is planned in 2011.

Accuracy

For clear specular materials the total measurement uncertainty of a transmission measurement under normal incidence is ±0.002 which is according to the NEN 2675. For most other materials, as well as the hemispherical transmission measurement, an accuracy of ±0.005 is achieved. This applies to both the spectral values and the (weighted) mean value. For extreme materials like weave structures, elastic and multi-layer materials, the measurement uncertainty will be lower. The measurement uncertainty for haze measurements is ±0.01.

Comparison

In order to validate the output, reference measurements are carried out with a Perkin Elmer Lambda 950 system with the UL270 integrating sphere accessory which is specially designed for measuring light-diffusing materials. The results (Table 1) show an accuracy for specular samples which meets the NEN 2675 and are well within the specified range of ±0.005 for diffuse samples.

CONCLUSIONS

For determining the optical performance of greenhouse covering materials other than standard float glass, the current NEN 2675 norm is no longer appropriate. The emerging of a new generation of materials (diffuse, layered) resulted in a new measuring protocol developed by TNO and Wageningen UR. The measuring device Transvision, developed by Wageningen UR, meets the criteria of this protocol and proved to be an accurate measuring system for new greenhouse covering materials like diffuse glass and multi-layered structures.

Literature Cited

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Tables

Table 1. Comparison of the normal transmission for a specular and diffuse samples, measured on a Perkin Elmer system with UL270 integrating sphere accessory and the device of Wageningen UR.

Sample	Method	PE UL270	Transvision
Standard float glass	NEN 2675	0.902±0.002	0.902±0.002
Prismatic glass 1	TNO-WUR	0.920*)	0.921±0.005
Prismatic glass 2	TNO-WUR	0.969*)	0.966±0.005
Rolled glass 1	TNO-WUR	0.967*)	0.964±0.005
Rolled glass 2	TNO-WUR	0.944*)	0.942±0.005

* Accuracy for non-specular materials is not specified.

Figures

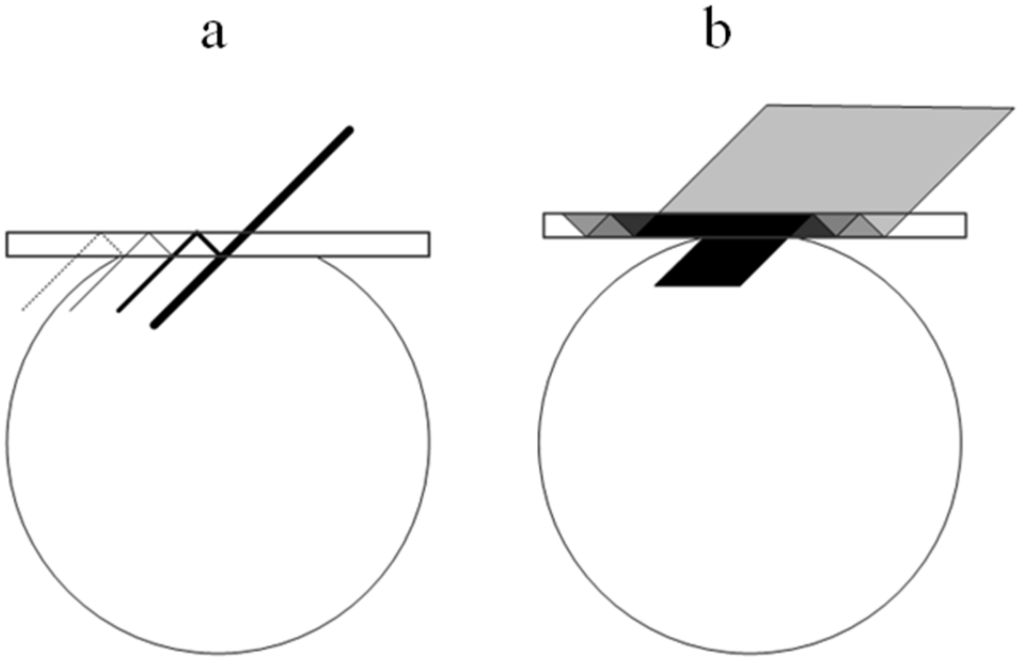

Fig. 1. For measuring direct transmission the beam must be either smaller or larger than the sample port which minimizes light loss due to scattering and refracting of the light through diffuse materials and inter-reflection in specular samples at off-normal incident light. The left figure shows a small beam where a fraction of the transmitted light is lost due to inter-reflection inside the specular sample. In the right figure the lost inter-reflected light on the left of the sample port is compensated by the inter-reflected light on the right.

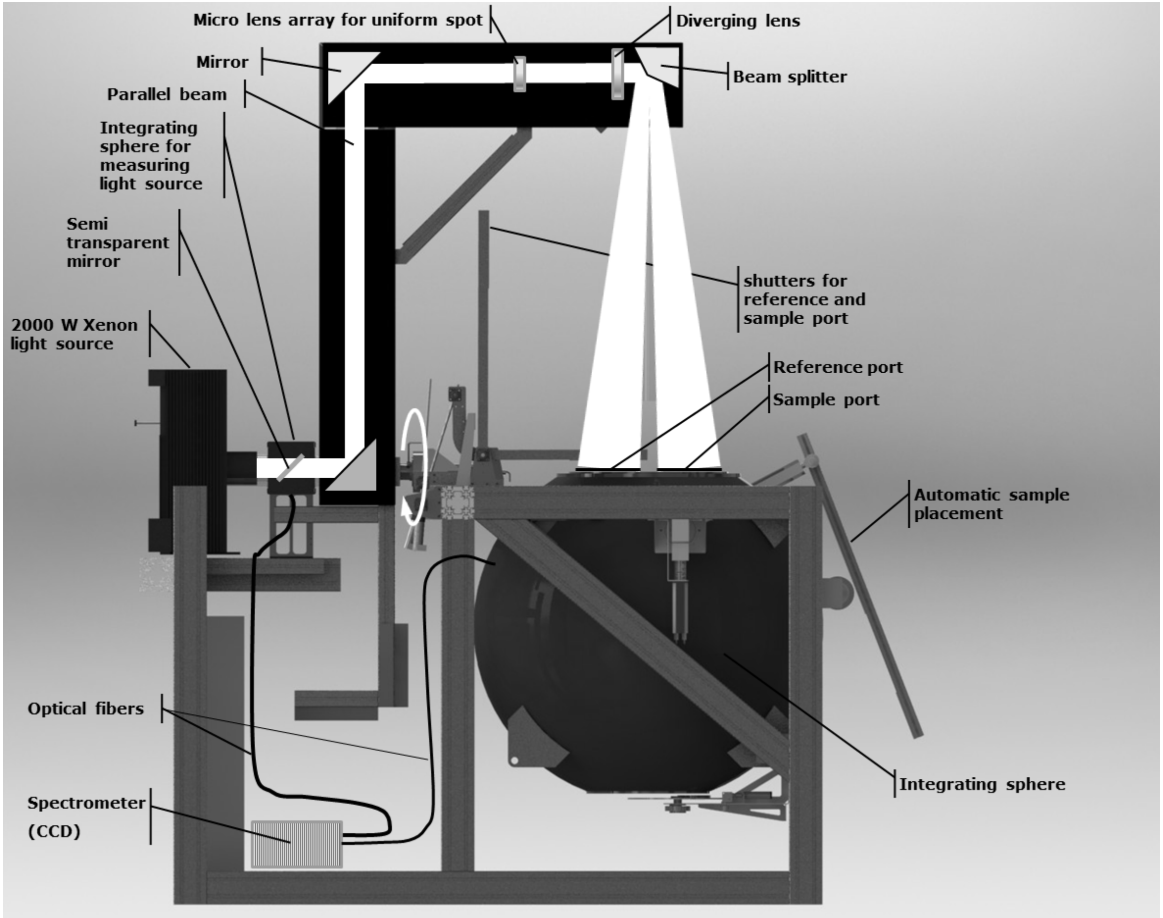

Fig. 2. Schematic overview of the measuring device system. A 2000W fixed xenon light source generates a parallel beam along the optical an mechanical axis of a rotatable arm for angular illumination of the sample. With a micro lens, divergent lens and beam splitter the 170 mm reference and sample ports are illuminated with a uniform spot alternately by means of shutters. Both the intensities of light source (correction for fluctuations in source intensity) and sphere are guided to a CCD spectrometer with fibre cables.