Differences among Light Transmission Tests within the Laboratory, within Short and Long-Duration Studies, on Artificial Testing Stands, and within a Greenhouse Structure with a Plant Crop

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What factors are important to the industry and to the grower?

In the evaluation of a particular glazing for greenhouse use, it may be much more valuable to determine the total amount of energy transmitted during a measured period of time (day, season, year), then to have an instantaneous or short-term value.

For example, this would be calculated by multiplying the hourly average transmission of the glazing/greenhouse system (measured at the plant canopy) by the outside solar radiation measured above the glazing for every hour of the day. The daily sum of these values would represent the total energy available for the plants for that day.

This analysis could stop here or go one step further, by considering the potential of the plant to use this available energy. If the transmission/solar radiation product could be multiplied by the plant photosynthetic efficiency associated with the environmental conditions (radiation intensity, carbon dioxide concentration, etc) during the measurement period, then this procedure would provide comparison of glazing systems based on the potential for plant growth and development, and not solely on the radiation transmission capabilities of the glazing.

This complete procedure requires long-term (lifecycle of the plant) studies, with specific production crops. Of course this is difficult and expensive to do, but it is not impossible and it would offer a much more meaningful measured value for the potential benefit of a glazing over another glazing.

Laboratory Measurements

Measurements performed on the laboratory bench top for radiation transmission of a covering material will provide the maximum transmission for the material. In most cases, this value will be representative of new, clean material, receiving direct radiation that is perpendicular to its surface. This will not reveal the percentage available at the plant canopy within a greenhouse. The average daily transmission of solar energy is affected by the changing angle of incidence, and the losses due to shading by the superstructure, as well as, the other components of the crop production system, located overhead (heating pipes or tubes, energy screen, watering system, etc) (Ting and Giacomelli, 1987b; Giacomelli, et al, 1988).

Measurements within the Greenhouse

Data presented within the discussion by Professor Bill Roberts about greenhouse glazing radiation transmission tests performed within operational greenhouses indicated that other factors such as structural complexity of the greenhouse, solar angle, overhead systems within the greenhouse, etc, were more important than the type of glazing. This was particularly true when considering the percentage of available solar radiation that was transmitted to the plant canopy during the light limiting period of the year. It was especially evident within greenhouses covered with a diffusing glazing like double-layer polyethylene.

This variety of factors and their interrelationships provide great difficulty in accurately determining a representative plant canopy transmission of a greenhouse covering system. Laboratory determinations provide a relative maximum potential transmittance of the covering material alone, but provide little information about the actual covering system transmittance, and certainly nothing of the potential quantity or quality of the daily radiation transmission within a greenhouse. Computer simulation of the physical situation may be helpful for evaluating the potential of new glazing system designs. This procedure is time consuming to initially develop the model, however, once completed; it can efficiently provide a quantifiable relative comparison among various glazing system alternatives.

PAR transmission values measured "in situ", at the plant canopy under diffuse, light limiting radiation conditions, during various times of the year is the most representative means for determining radiation mediated plant production capabilities within a covering and greenhouse superstructure system.

Test Stands

The use of smaller, more manageable solar radiation testing stands is an alternative to laboratory measurements and to large-scale greenhouse testing with crops. Unlike the laboratory tests, the test stands are outdoors, and if measured for a long period of time, can include the effects of season, weather and aging on the transmission of a glazing material. It cannot provide the effect of greenhouse superstructure on the reduction of the plant canopy transmission, as the under-glazing sensor is placed directly beneath the glazing, and the test stand structure offers little local reduction of radiation due to shading.

The test stands can offer a consistency of radiation conditions for multiple test samples, by locating several test stand units within a relatively close proximity.

Reporting of Sample Glazing Tests

Below is a sample report of glazing tests. It includes several important components which should always be included with such tests. These are:

I. Description of the Test Procedure
II. Description of the Test Results
III. Clear Sky Direct Radiation Conditions
- Measured Spectral Irradiance
- Calculated Transmittance
IV. Diffuse Sky Radiation Conditions
- Measured Spectral Irradiance
- Calculated Transmittance
V. Average Overall Radiation Transmission (Table)
VI. Interpretation of Test Results Graphs

Test Procedure

Two LI-COR LI-1800 Portable Spectroradiometer instruments were utilized for the testing. One spectroradiometer was calibrated at the factory within the past six months. Prior to the tests, the second spectroradiometer was calibrated relative to the first unit. The instruments were placed adjacent to each other within a location unobstructed from solar radiation. The instruments were placed on a horizontal surface, which provided a solar angle of incidence of approximately 41o above the horizon for the mid-day tests of February 28 and March 1. The tests lasted about two hours each day. The instruments were programmed to record the average spectral irradiance value (Watt per square meter per nanometer (W m^{-2} nm^{-1})) of 15 scans for each wavelength within the waveband from 300 to 1,100 nanometers (nm) for each of the 4 test samples supplied. A similar record was made without a test sample on the instrument to obtain the natural solar sky spectrum. The samples labeled "A" through "D" were mounted on individual, small frameworks and supported in a horizontal position directly above the sensor of the instrument. Each sample underwent one test under each type of sky condition.

Sample A -- roof material
Sample B -- internal cover material
Sample C -- proposed roof material
Sample D -- sample provided from Florida

The test procedure was completed on February 28th, a day with overcast sky conditions (i.e., a predominance of diffuse solar radiation), and on March 1st, a day with clear bright sky conditions (predominance of direct solar radiation).

Description of the Test Results

I. Clear Sky Direct Radiation Conditions

A. Spectral Irradiance

Three graphs show the average intensity of the radiation for each wavelength from 300 nm to 1,100 nm under clear sky conditions. (Graph #1) The "sky spectrum" is the result of the natural sky condition, without any test films. (Graph #2) "A" and "B" are the average intensity of the radiation for each wavelength as measured beneath test films "A" and "B"
(Graph #3) "C" and "D" are the average intensity of the radiation for each wavelength as measured beneath test films "C" and "D".

B. Transmittance

Two additional graphs show the average percentage of radiation transmission for each wavelength from 300 nm to 1,100 nm under clear sky conditions. These were determined from the spectral irradiance graphs (#1,2,3 above), by calculating the ratio of the intensity beneath each of the films (A or B or C or D of Graphs #2 & 3) to the intensity of the sky spectrum (Graph #1).
(Graph #4) Average transmittance of films "A" and "B".
(Graph #5) Average transmittance of films "C" and "D".

II. Diffuse Sky Radiation Conditions

A. Spectral Irradiance

Three graphs show the average intensity of the radiation for each wavelength from 300 nm to 1,100 nm under diffuse (cloudy) sky conditions. (Graph #6) The "sky spectrum" is the result of the natural sky condition, without any test films. (Graph #7) "A" and "B" are the average intensity of the radiation for each wavelength as measured beneath test films "A" and "B". (Graph #8) "C" and "D" are the average intensity of the radiation for each wavelength as measured beneath test films "C" and "D".

B. Transmittance

Two additional graphs show the average percentage of radiation transmission for each wavelength from 300 nm to 1,100 nm under cloudy sky conditions. These were determined from the spectral

irradiance graphs (6,7,8 above), by calculating the ratio of the intensity beneath each of the films (A or B or C or D of Graphs #7 & 8) to the intensity of the sky spectrum (Graph #6).
(Graph #9) Average transmittance of films "A" and "B".
(Graph #10) Average transmittance of films "C" and "D".

III. Average Overall Radiation Transmission

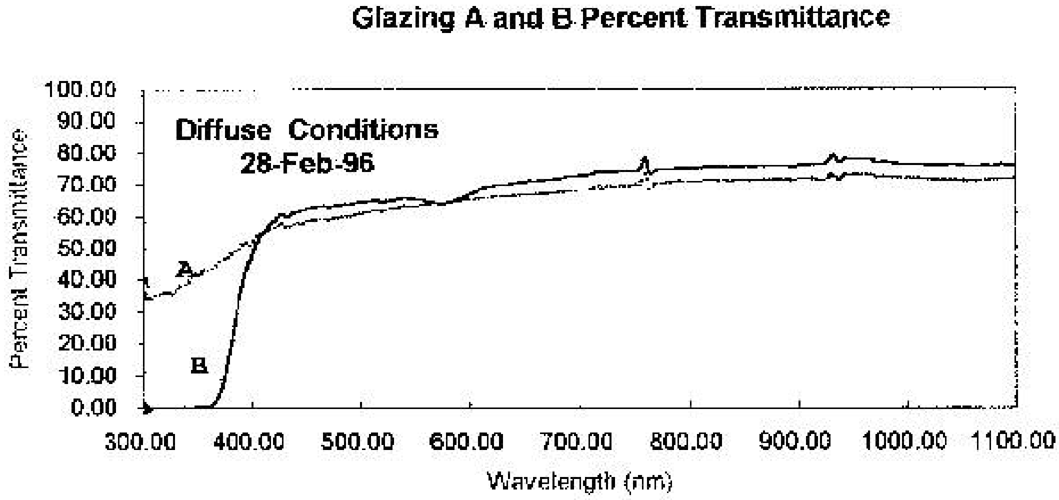
Table 1 contains the average overall radiation transmission for the waveband from 400 to 700 nm (PAR) for each of the four test samples under diffuse and clear sky conditions. Table 2 contains the average overall radiation transmission for the waveband from 300 to 1,100 nm for each of the four test samples under diffuse and clear sky conditions. Table 3 identifies the average percent transmission for each 10 nm waveband from 300 to 500 nm for each of the four test samples under diffuse and clear sky conditions.

IV. Interpretation of Test Results

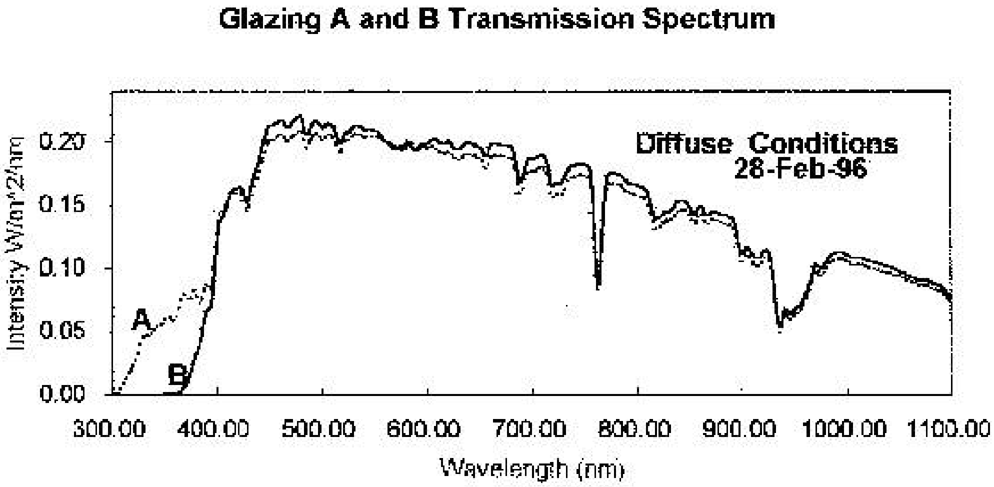
The spectral irradiance is the absolute measure of the intensity of the radiation at each wavelength. These graphs (#1,2,3,6,7,8) are very dependent on the test procedure and sky conditions (clear or cloudy). For example, the time of day, the day of year, the position of the sensor, all contribute to the solar angle of incidence (the angle of the sun relative to the instrument sensor) which can change the absolute value of the intensity measured underneath the films. On the clear day test, the solar intensity without any film was less than 50% of the intensity of a clear summer day with the sun directly overhead. Thus these graphs can be misleading.
Of the four films, only film "B" has unique differences from the others, especially in the 300 - 390 nm waveband. The radiation intensity of Film "B" is much less in this waveband, as compared to the other three films. Film "B" also has slightly improved intensity values at many of the wavelengths from 400 to 1,100 nm. For a practical comparison of films, the transmittance graphs (#4,5,9,10) should be interpreted. These represent the relative amount of radiation that passed through the film compared to the total radiation measured on a horizontal surface during the same time of the test. The transmittance values are determined by the ratio of the intensity measured beneath the film to that measured above the film at each wavelength. In graphs #4 & 5, it is very clear that film "B" transmits much less radiation than films "A", "C" or "D" within the 300 to 400 nm waveband. The actual values of transmission are detailed in Table 3 for the 300 - 500 nm waveband. For wavelengths greater than 400 nm, films "B" & "D" are more similar, whereas films "A" & "C" are more similar in their ability to transmit radiation.
The transmittance for each sample A, B, C or D was similar for both the clear and the cloudy sky conditions.

Tables 1 & 2 provide the average overall transmission for each glazing within the PAR waveband (400 - 700 nm) and the larger spectrum waveband (300 – 1,100 nm), respectively. The "percent transmission" values were determined by the ratio of "under glazing” value to the "sky” values. The values of Table 1 represent an average transmittance of all the wavelengths within the PAR waveband (400 - 700 nm) for diffuse or clear sky conditions. The values of Table 2 represent an average transmittance of all the wavelengths within the broader waveband (300 nm – 1,100 nm) for diffuse or clear sky conditions. Films "B" & "D" have slightly higher average transmittance for both wavebands (Tables 1 & 2).

Note that only 2 graphs are provided as examples.



Glazing A and B Percent Transmittance



Glazing A and B Transmission Spectrum