Effect of Condensation on Light Transmission and Energy Budget of Seven Greenhouse Cover Materials

C. Stanghellini, M. Bruins, V. Mohammadkhani, G.J. Swinkels and P.J. Sonneveld
Wageningen UR Greenhouse Horticulture
Wageningen
The Netherlands

Keywords: antidrop coating, antireflection coating, diffusing materials, film forming, light scattering

Abstract

Model calculations and the few data that are available show that over 100 L water condense yearly on each square meter of a greenhouse cover. It is known that the presence of condensate reduces light transmission. This effect is suppressed to some extent by adding film-forming (anti-drop) additives to plastic film covers and surface structures or coatings on hard cover materials. There is a need, therefore to assess the effect of the surface treatment on the loss of light. On the other hand, condensation releases the energy that was used for evaporation, thereby warming-up the cover and somewhat decreasing the heating requirement of the greenhouse. The amount of condensation energy that is recovered may be expected to depend on the external and internal climate conditions. In this work we analysed the effect of condensation on light transmission and energy budget of a greenhouse, with seven different cover materials. Various internal vs external conditions were created by placing the model greenhouse (about 3×4 m) in a large climate chamber. Each experiment was repeated for two temperature differences between inside and outside (10 and 20°C) and two air movements in the greenhouse (7.5 and 15 cm s^{-1}). Light transmissivity was reduced by 9% on average, with large differences among materials. Anti-drop coatings did suppress this effect, as did a surface structure meant to increase light diffusivity of the material. As far as energy is concerned, the overall heat transfer coefficient (U-value) of the greenhouse increased by an average of 16% (single layers) or 12% (double layer covers) when wet. Obviously there was an effect of the temperature difference on the U-value, which was found to be consistent with the heat transfer theory, whereas little effect was found of the air movement within the house.

INTRODUCTION

Greenhouse covers are often wet inside from condensate, which has consequences for both the light transmission and the heat transfer. Calculations with the KASPRO simulation program (De Zwart, 1996), shows that a typical greenhouse cover is [partly] wet about 50% of the time and that total condensation amounts to some 100 litres water per square meter of the cover per year. Such an amount is confirmed by data from Van der Staaij and Douwes (1996) who collected condensate from a glasshouse for a number of weeks distributed in one year. A uniform water layer adherent to the cover may increase light transmission by a few per cent (Gbiorczic, 2003), whereas scattering and reflection on the surface of droplets will always decrease light (Pieters et al., 1997; Pollet and Pieters, 2000, 2002a, b). The influence of condensate on the light transmission of the cover depends on the shape and size of the water droplets that are formed, which, in turn, depend−among others−on the surface properties of the cover (Von Zabeltitz, 1987; Jaffrin and Morisot, 1994).

Condensation is also an important energy conveyor in the greenhouse, since the energy that was used for crop transpiration (the latent energy of vaporisation) is released when condensation takes place (Morris et al., 1958). The allocation of this energy flow between the internal and external of the greenhouse is also likely to depend on the conditions, such as heat transfer coefficient of the cover and internal and external temperature (Pieters and Deltour, 1998).

The purpose of this work was to analyse the combined effect of properties of the cover and climate conditions on light transmission and energy budget of a greenhouse cover wet with condensate.

MATERIALS AND METHODS

For this purpose a small greenhouse (one span of a Venlo, 3.2 m wide, 4 m long with a ridge height of 1.95 m) was built in a climate room, in such a way that the cover could easily be replaced (Fig. 1). Temperature in the room could be controlled between 10 and 30°C. The room had a built-in ceiling of neon tubes. The temperature inside the greenhouse was controlled by a thermostat which steered two heating elements (2000 W each) hanging about 60 cm above the ground. The energy supply was logged. The vapour source were two evaporators, filled with distillate water, resting on a balance (Mettler Multirange ID5) in the centre of the greenhouse. Both the energy absorbed and the weight of the evaporators were logged as well. Homogeneity of air humidity and temperature was ensured by a fan (whose speed could be regulated), blowing into PVC pipes with evenly distributed holes. The sides and the floor of the greenhouse were thickly insulated, so as to ensure that all energy transfer took place through the cover and condensation was formed only there. Condensate was collected by two gutters and discharged to an additional balance. Condensate remaining on the cover after each condensation cycle was collected and weighed. Additional data that were logged (1 min intervals) were dry and wet bulb temperature (in the greenhouse and in the climate chamber); temperature of the cover through six thermocouples evenly distributed on the two slopes; transmissivity of the cover was determined by comparison of PAR-light measurements (quantum sensors): one above the greenhouse roof and four distributed below it. Figure 2 shows a scheme of the experimental set-up.

Seven configurations of greenhouse covers were tested: a standard single glass cover; a double glass cover; a diffusing glass tested with the rough structure both outside and inside; a single glass with antireflection (AR) coating; and finally a 16mm polycarbonate cover both un-treated and treated with anti-drop coating. In all cases the effect of the water layer on energy loss through the greenhouse cover was investigated by varying the U-value (heat transfer coefficient) maintaining two temperature differences between inside and outside the greenhouse of respectively 10 or 20°C and two air velocities in the greenhouse (7.5 and 15 cm s^{-1}). We did found out that with double-layers covers and the temperature difference of 10°C there was quite some condensate also on the floor of the greenhouse, so that these covers were tested only with the 20°C temperature difference.

All possible combinations were executed in duplicate. An experimental run took several hours: first we waited until we had at least one hour of constant temperature and light data, then we started the evaporators, followed the condensation process through the light sensors and the wet bulb temperature, and then waited until we had again at least one hour of constant data. The data collected during the “equilibrium *dry* and *wet* periods” were used to determine light transmission and the overall heat transfer coefficient (U value) of the greenhouse, as follows:

$$U = \frac{Q_{heater} + Q_{evaporator}}{\Delta T \cdot A_{greenhouse}} \qquad \mathrm{W\ m^{-2}\ K^{-1}} \qquad (1)$$

where Q indicate the power supply (to the evaporator and the heater); ΔT the temperature difference between in- and outside and $A_{greenhouse}$ is the area of the greenhouse floor. The fraction F of latent energy that was not recovered was calculated comparing data from the two periods through:

$$F = \frac{(Q_{heater} + Q_{evaporator})_{wet} - (Q_{heater})_{dry} \cdot \frac{\Delta T_{wet}}{\Delta T_{dry}}}{Q_{latent}} \qquad (2)$$

where the subscripts *wet* and *dry* refer to the periods of constant data, after and before condensation, respectively and Q_{latent} indicates the power really used for evaporation, which was determined through the weight of the evaporators. Obviously some of the power absorbed by the evaporators went into heating. The correction for the ΔT (the temperature difference between in- and outside) was needed since the temperature in the chamber was fluctuating a little.

RESULTS

Light Transmission

The light transmission of the tested greenhouse covers when wet was, on average, 91% of the transmission when dry. However, there were very large differences among materials, as shown by Figure 3, where the light transmission of a the single glass, when dry is used as benchmark and set to 100%. For instance, the transmission of the dry AR single glass cover is larger than the transmission of single glass, in fact 112% of it and 101% when wet, whereas the transmission of the diffusing glass is about the same as dry single glass, both when dry and wet, and irrespective of the placing of the structure (inside or outside). Polycarbonate has a lower light transmission than single glass, but the effect of the anti-drop additive is obvious.

Energy

The energy-conveyor effect of condensation on the overall heat transfer coefficient (U-value) of the greenhouse is shown by Figure 4, where the calculated U-values of the wet cover (y-axis) is plotted vs the corresponding value when dry (x-axis), for all covers and conditions tested. The process of condensation, by releasing energy at the cover surface, increases the heat transfer coefficient of a single-layer cover by 16% and of a double layer by 12%, the difference in slopes is significant ($P<0.05$).

The fraction of latent energy freed by condensation that is lost (that is, that does not lower the heating requirement) was estimated through Eq. (2). It was found that with single layer covers the fraction of latent energy lost increases from 15% at a temperature difference of 10°C to 40% at a temperature difference of 20°C. No significant effect whatsoever was found of air movement (at least in the range we tested).

With respect to the effect of our treatments, the U value with a ΔT of 20°C was, on average, 124% of the corresponding U-value (same cover type, dry/wetness, air movement) at a ΔT of 10°C, which was not significantly different from the 126% that heat transfer theory would predict. Doubling the air movement from 7.5 to 15 cm s^{-1} increased the U-value by only 4%.

DISCUSSION

The light transmission properties of the diffusing glass are the most remarkable, as there was no effect of the presence of condensate. With the surface structure (roughness) facing inside, this could be ascribed the fact that roughness lowers surface tension (Gbiorczyc, 2003), thus favouring film-forming. More puzzling is that there seems to be no effect either when condensation takes place on the smooth, rather than the rough, surface. A possible explanation could be that, as the diffusing surface consists of many ‘small pyramids’, the light scattered by the droplets is captured and reflected by this pyramid structure. If this hypothesis is true it could be that the we hit upon a lucky combination of the angle of the pyramid structure and the advancing and receding angles of the droplets. Nevertheless, this is hardly relevant, since structured glasses are usually placed with the rough surface inside, to prevent dust capture.

This may have a drawback, since we found that the diffusing glass with the structure outside has an 8% lower U-value than with the structure inside, although the difference might be smaller in the real world, where wind speed and energy loss through radiation play a much more relevant role in determining overall heat transfer than in our experimental set-up.

The effect of condensation on the heat transfer coefficient may be surprisingly large. Condensate on a single layered greenhouse cover increases the U-value by 16%, and only slightly less (12%) on double layer greenhouse covers, which suggests that radiation between the two layers is an efficient energy transfer mechanism.

CONCLUSION

Condensate reduced light transmission by 9% on average, with large differences among materials. Anti-drop coatings did suppress the effect of light loss, as did a surface structure meant to increase diffusivity of the material.

As far as energy is concerned, the heat transfer (U-value) of the greenhouse increased by an average of 16% (single layers) or 12% (double layer covers) when wet. There was an effect of the temperature difference on the U-value, which was consistent with the heat transfer theory, whereas little effect was found of the air movement within the greenhouse.

ACKNOWLEDGMENTS

The project was financed by the Dutch Horticultural Board and by the Dutch Ministry of Economy, Agriculture and Innovation, under the program “Kas als Energiebron” (greenhouse as energy source). We are grateful to Leo Oprel and Dennis Medema, the managers of the program, for their positive contribution. We thank BSc Francesco Bianchini for the patient help during the experimental runs.

Literature Cited

De Zwart, H.F. 1996. Analyzing energy-saving options in greenhouse cultivation using a simulation model. PhD Thesis, Agricultural University, Wageningen, The Netherlands, 236p.

Gbiorczyk, K. 2003. New test methods for evaluating the antifog effect of greenhouse films. Gartenbautechnische Informationen, Institut für technik in gartenbau und Landwirtschaft, Universität Hannover, Heft 58:195p.

Jaffrin, A. and Morisot, A. 1994. Role of structure, dirt and condensation on the light transmission of greenhouse covers. Plasticulture. 101:33-44.

Morris, L.G., Trickett, E.S., Vanstone, F.H. and Wells, D.A. 1958. The limitation of maximum temperature in a glasshouse by the use of a water film on the roof. Journal of Agricultural Engineering Research 3(2):121-130.

Pieters, J.G., Deltour, J. and Debruyckere, M. 1997. Light transmission through condensation on glass and polyethylene. Agricultural and Forest Meteorology 85:51-62.

Pieters, J.G. and Deltour, J.M. 1998. Effect of latent heat phenomena on thermal insulation and inside climate of greenhouses. J. Therm. Environ. Build.Sci. 22:9-31.

Pollet, I.V. and Pieters, J.G. 2000. Condensation and radiation transmittance of greenhouse transparent materials. Part 3: results for glass plates and plastic films. J. Agric. Eng. Res. 77(4):419-428.

Pollet, I.V. and Pieters, J.G. 2002a. Visible radiation transmittances of dry and condensate covered glass and plastic greenhouse cladding. Agric. For. Meteorol. 110(4):285-298.

Pollet, I.V. and Pieters, J.G. 2002b. Forward scattering induced by water drops on a transmissive substrate. Appl. Optics. 41:5122-5129.

Van der Staaij, M. and Douwes, S. 1996. Optimalisering van de toepassing van gewasbeschermingsmiddelen in de glastuinbouw. Emissie via condenswater. Proefstation voor Bloemisterij en Glasgroente, Naaldwijk, Rapport 53, ISSN 1385-3015.

Von Zabeltitz, C. 1987. Folien als Gewachshausbedachung. Landtechnik 42:326-327.

Figures

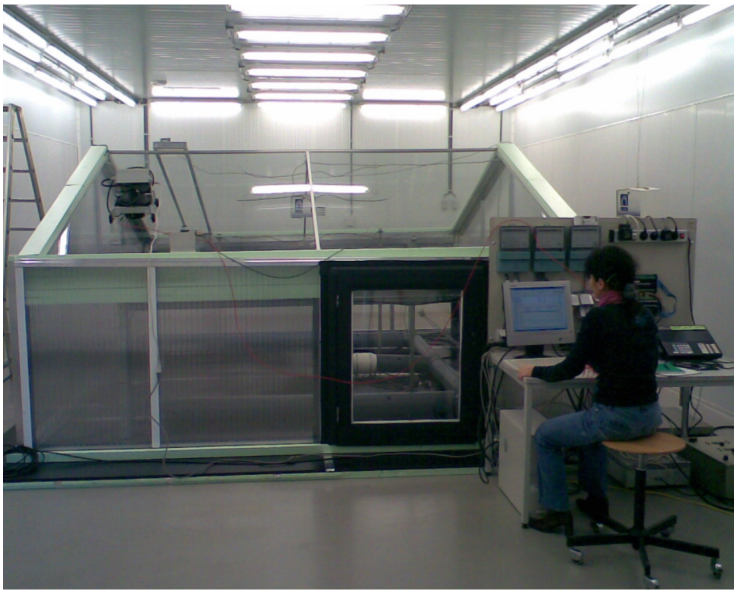

Fig. 1. The experimental set-up: the small greenhouse in the climate room. The loggers of energy, weights etc, can be seen on the panel at left.

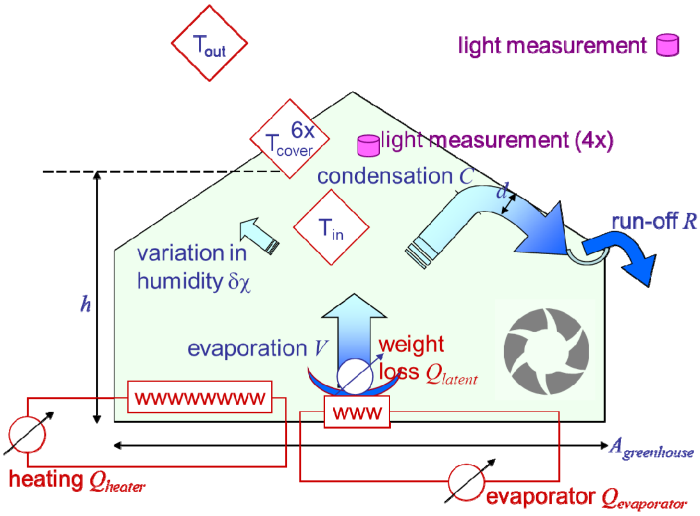

Fig. 2. Schematic overview of the experimental set-up and of the data collection.

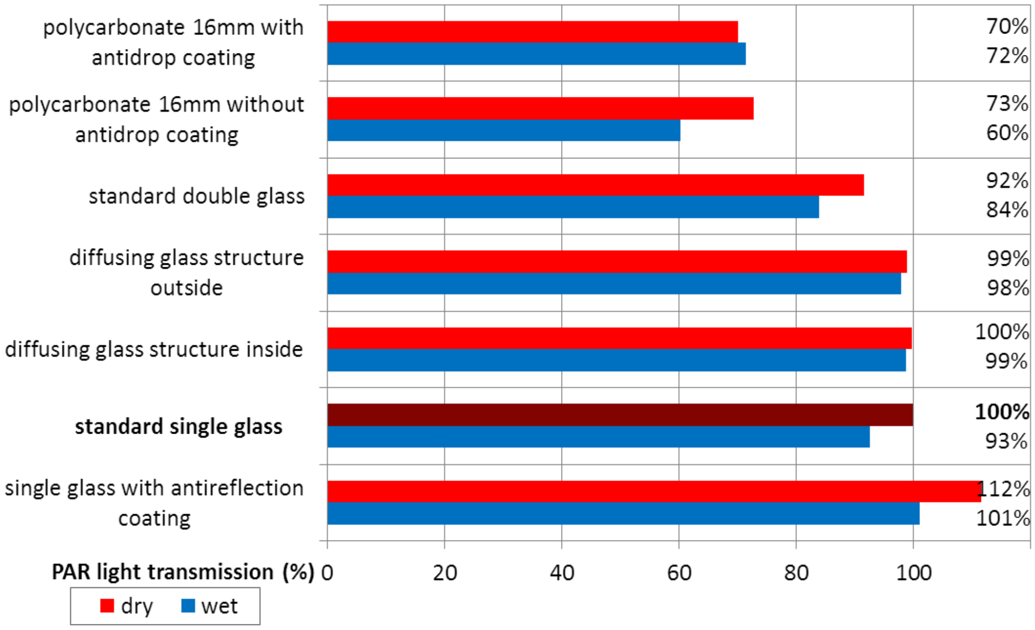

Fig. 3. Light transmission of the analysed greenhouse covers, when dry (red) and wet (blue) with respect to the light transmission of the standard single cover when dry, which is taken as bench mark and set at 100%.

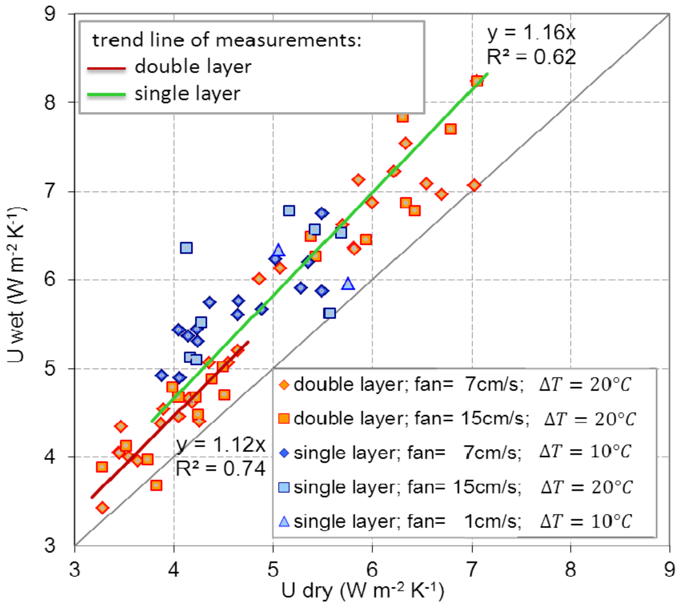

Fig. 4. The heat transfer coefficient (U-value W m^{-2} K^{-1}) of all greenhouse covers, under the conditions indicated, when wet (y-axis) vs dry (x-axis). The short best-fit line (bottom left, R^2=0.75) refers to double layered covers for which condensation could only be realised at ΔT=20°C. The longer best-fit line (R^2=0.62) refers to all measurements with single layer covers.