New Developments of Energy-saving Greenhouses with a High Light Transmittance

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Abstract

The scope of this investigation is the development of a new energy-saving greenhouse with a high light transmittance. With GE-Plastics a new Zigzag double-web structure is developed which combines energy saving and a high light transmission. The following factors were taken into account: light transmittance, insulation value, material consumed and material strength. The insulation value of the sheet was calculated according a European Standard method with a computational fluid dynamics (CFD) program.

An extra advantage of these zigzag-sheets is that they can be built in without glazing bars. These double structures of ARM-glass or the Zigzag Lexan can just compensate the light losses caused by an extra layer. Therefore this material combines high light transmittance with good thermal insulation. With the simulation program "Kaspro" we can predict the year round energy consumption of greenhouses with hourly climate data. Different greenhouse constructors have build Venlo type greenhouses and also a wide span greenhouse.

INTRODUCTION

Energy saving is an important issue for the northern countries with colder winter climate conditions. Extra insulation by an extra covering layer however results in a decrease of light transmittance, which is an important property for crop production. When an insulating double sheet construction is made of the common covering materials like glass, sheet or film then light transmittance is too low for horticultural applications.

Several types of double-web plastic sheets with different thickness already exist in practice. Applied materials are polymethylmethacrylate (PMMA) and polycarbonate (PC). These rigid flat sheets have good insulation capacities (depending on the thickness of the air layers in the sheets). However the application of this type of double-web sheets for greenhouses was only minor in the past years due to the fact that these sheets transmit about 10% less light compared to single glass. Moreover the transmittance reduces over time caused by weathering of the material. For example the transmittance for diffuse light of a standard PC double-web sheet with an air layer thickness of 16 mm is measured at 76%. For a standard PMMA double-web sheet this is measured at 85-89 % (Breuer , 2000).

At the moment energy saving is not only important for economical (Sonneveld, 2000(3)&(4)) but also for ecological reasons (Glami, 1980-2010). In the near future the pressure towards the growers to save energy will increase strongly. The Dutch growers association has promised to limit the fossil energy consumption in the year 2010 to 35% of the energy consumed in the reference year 1980 (Glami, 1980-2010). To achieve this goal extensive measures are necessary. Next to the conventional measures as application of energy screens and modifications of the heating installations etc, the growers will have to apply innovations like good insulated greenhouses in the future. In response to these demands A&F has developed the so-called zigzag-sheet together with a producer of PC-plastic sheets, General Electric Plastics in Bergen op Zoom, the Netherlands (Stoffers, 1998, Sonneveld, 2002(1)). The sheet is a transparent double-web sheet made of PC with zigzag-shape geometry. The basic idea was to develop a sheet, which insulates well and at the same time transmits the same quantity of light compared to single glass.

MATERIALS AND METHODS

Material Design

The special structured polymer material was designed by A&F with a ray tracing computer program, which has resulted in the optimal Zigzag geometry of the material.

When a beam of light is incident to a flat transparent sheet, part of this light will be transmitted, according to Fresnell law, and another part will be reflected (Fig. 1a upper). At higher angles of incidence (angle with the normal line) reflection increases. For a flat sheet the reflected part of the light does not enter the greenhouse and therefore is not available for plant growth. For a zigzag-surface the primary reflected part of the light hits again another part of the sheet surface and after transmission then partly enters the greenhouse after all (Fig. 1a below). This is especially effective at high angles of incidence. By this effect the transmittance for diffuse light of a zigzag-shaped single sheet increases about 5% compared to a flat single sheet of PC. A&F developed the idea and the optimal shape, thickness and grid of such a zigzag-sheet. In Fig. 1b a sample of a double zigzag-structure material is seen, which is manufactured with a vacuum form technique.

In Figure 2 the calculated and measured data of direct light transmission is presented for a single PC-sheet and a double-wall sheet. The results for diffuse light were presented earlier (Sonneveld, 2002(1)). The horizontal axis shows the inclination of the zigzag-shape, the vertical axis shows the light transmittance. The diagrams show that without the color additives (less absorption by pigments), a considerable improvement of the light transmittance is realized. The light transmittance shows a strong increase around 45^0 with 5% (single layer) to 10 % (double layer) as can be seen in Figure 2.

It can also be seen in Figure 2 that the local optimum for the inclination of the zigzag-shape is 45-60^0. The local optimum for the inclination of the zigzag-shape of 45-60^0 was also found for diffuse light (Sonneveld, 2002(1)). When regarding other criteria like insulation value, material consumed and material strength (see below) an inclination of 48^0 is ideal. The light transmittance of a double zigzag-sheet with an inclination of 48^0 without colour pigments is 90,8 % for direct light and 80% for diffuse light. The measurements were carried out on the integrating sphere of A&F with a sample size of 50 x 50 cm.

For comparison: standard single glass has a light transmittance of 89.5%(direct) and 82%(diffuse) (Breuer, 2000). The direct light transmittance is 85-89% for PMMA double-web sheet and 76% for a standard PC double-web sheet (Breuer, 2000). The basic material of the double zigzag sheets is polycarbonate. This material has good impact resistance and fire extinguishing properties. The light transmittance as function of the angle of incidence is seen in Fig. 3a. For high angles of incidence the transmittance will be increased for angles perpendicular to the zigzag structure, while for angles parallel to the zigzag structure the transmittance will be decreased. With the right orientation extra light enters into the greenhouse. For a Venlo type greenhouse the daily light transmittance with the double zigzag covering can be compared to that of the standard glass (Fig. 3b). As can be expected there is an effect of the orientation of the greenhouse: The gutter north-south oriented will increase the transmission during winter, the gutter oriented east-west will increase the transmission in summer. An overview of the global extra radiation as function of time in a Venlo type zigzag greenhouse was presented before (Sonneveld, 2002(1)). Generally the zigzag covering can increase the light transmission with minimal 2% due to high transmission at low solar positions.

Yield, Energy and Climate Simulations

Another factor affecting optimal sheet geometry is the insulation value. To allocate this insulation value for the different sheet geometries A&F has performed computational fluid dynamics (CFD) calculations according to the European Standard (prEN-ISO

10077-2, 1999). The optimal shape regarding the light transmittance, the insulation and the material strength is a sheet with a grid length of 50 mm and a thickness of 25 mm. The insulation value (U-value) for this sheet is 3.4 $Wm^{-2}K^{-1}$. For comparison: single glass has a U-value of about 6 $Wm^{-2}K^{-1}$.

What is the result for the expected energy saving of a greenhouse with a roof of (double) zigzag-sheets? In the winter months, so when the heating is maximal, the momentary energy saving is calculated at 45%. The typical year round energy consumption is calculated with the simulation program Kaspro for the cultures: sweet pepper, tomato, pot-plant and chrysanthemum using climate data for the Netherlands. In Fig. 4 the results are presented for the four different cultures. For this new covering material we calculated a year round energy saving of 20-25 % (depending of the cultures) compared with single glass covering.

This is lower than the momentary energy saving based on the U-value. With the better insulating covering, dehumidification by condensation is lower so extra ventilation is required for dehumidification resulting in some energy losses. Dehumidification devices could also be enhanced in terms of energy efficiency/heat recovery, leading again to a higher, total efficiency. In the zigzag greenhouse the peak load is 45% lower compared to a common greenhouse covered with single glass without thermal screen. The yearly costs for heating will consequently decrease significantly (Sonneveld, 2000). In the next period practical greenhouses will be monitored to measure the actual yield, climate and energy savings.

Greenhouse Designs

For the Floriade exhibition in 2002 A&F in Wageningen and General Electric Plastics in Bergen op Zoom, the Netherlands developed a so-called Florida greenhouse, which combines a traditional steel structure with a special shaped zigzag-covering of double-web PC-sheets. The main structure of the (prototype) greenhouse will be comparable to a traditional greenhouse: beams, trellis girders, stability bracings will be made of standard steel profiles. The span of the trellis girders is 9.60 m with two roofs of 4.80 m. The mutual distance of the trellis girders is 4.80 m. The ZigZag sheets are mounted water tight on steel gutters. Only the structure above gutter level is new and especially suitable for the zigzag-sheets. Here beams in triangle shape made of steel profiles are used as a structure. These beams are fixed to the trellis girders and have therefore a mutual distance of 4.80 m. Steel purlins carry the zigzag-sheets, which are fixed to the structure without glazing bars. The zigzag-sheets are therefore self-supporting from gutter to purlin over a length of 1.76 m. The continuous roof ventilation window has sides of 0.80 m and will be prefabricated. The mechanism to open the window will be fixed to the extra beam. The ventilation windows opened by lifting it up vertically. The walls of the Florida greenhouse will be covered mainly with standard double-web PC-sheets. The total area of the greenhouse is 844 m^2. For the up-scaling of the ZigZag material again a vacuum form technique was used (Fig. 5a). A point of extra investigation was to develop a method to connect the lower and upper sheets together with a fixed distance. A solution was found by the formation of extra triangles in the under sheets (Fig. 5a). The upper sheets are glued onto the under sheets via these extra triangles. The complete greenhouse of the future was presented in 2002 (Sonneveld, 2002(1)&(2)). At the Floriade exhibition 2002 a well insulated greenhouse with a light transmittance comparable to a Venlo-type greenhouse covered with single glass was presented.

For production on an industrial scale an extrusion profile is developed by GE Plastics. A recent sample produced with extrusion can be seen in figure 5b. The trade name of the product is Lexan® Zig Zag™. The company Alcoa Greenhouse systems developed aluminum extrusion profiles for constructing Venlo type greenhouses with the new extruded ZigZag sheet material. With this new extruded ZigZag sheet material and the Alcoa aluminum profiles, a first Venlo type greenhouse is built at the Lorentz college in Elst (the Netherlands). The span of the roofs is 4,80 m with a span of the trellis girders of 9.60 m. The length is 20 meter. This greenhouse is depicted in Figure 6a and 6b and has one-side ventilation windows, which operate with standard window mechanism.

The third development is the design of an aluminum system for wide span type greenhouses. For this type the company Bosman Kassenbouw developed the properly aluminum profiles. In this case two ZigZag sheets are coupled with an aluminum profile and will result in a span of 14.00 m. In Figure 7a and 7b two pictures are given of this wide span greenhouse with zigzag covering.

CONCLUSIONS

A new high transparent and insulating covering material for greenhouses was developed. It was demonstrated that the zigzag configuration led to a high light transmittance of 90,5% (direct) and 80%(diffuse). This is comparable to single glass and the highest of all known double sheet materials. The basic material of the double zigzag sheets is polycarbonate. This material has good impact resistance and fire extinguishing properties. The good thermal insulation will lead to a yearly energy saving up to 25%. Greenhouse companies developed new profiles for the new zigzag sheets and the first Venlo type and wide span greenhouses are built in the Netherlands. An extra advantage of these zigzag-sheets is that they can be built in without glazing bars.

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Figures

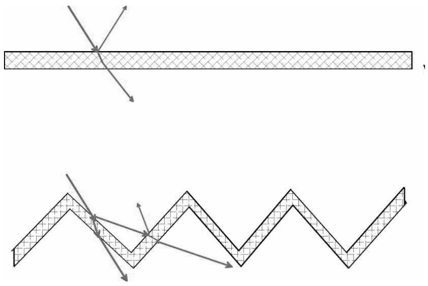


Fig. 1a. The principle of the transmittance and reflection of light beams hitting a flat sheet (above) and a zigzag-sheet (below).

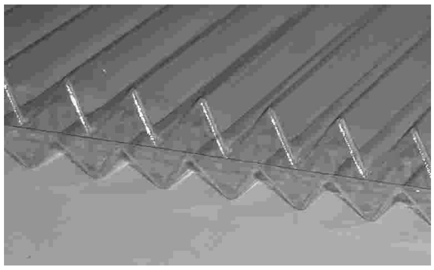


Fig. 1b. Example of the first double layer zigzag-structure manufactured with vacuum form techniques.

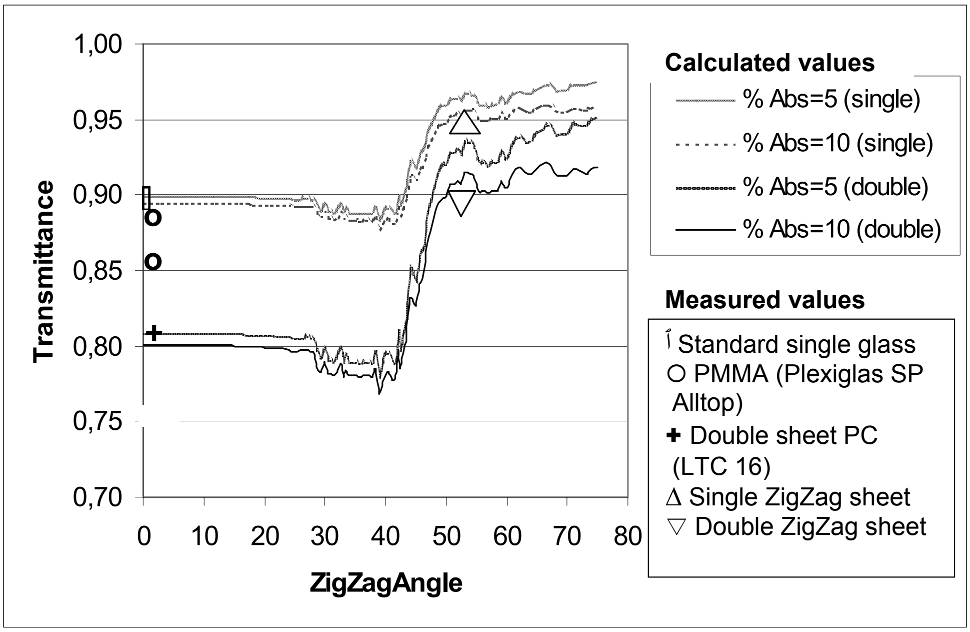
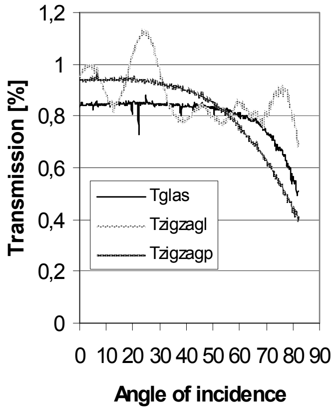


Fig. 2. Overview of the calculated and measured (direct perpendicular) light transmittance of the ZigZag sheet materials (A zero ZigZag angle is a standard sheet material).



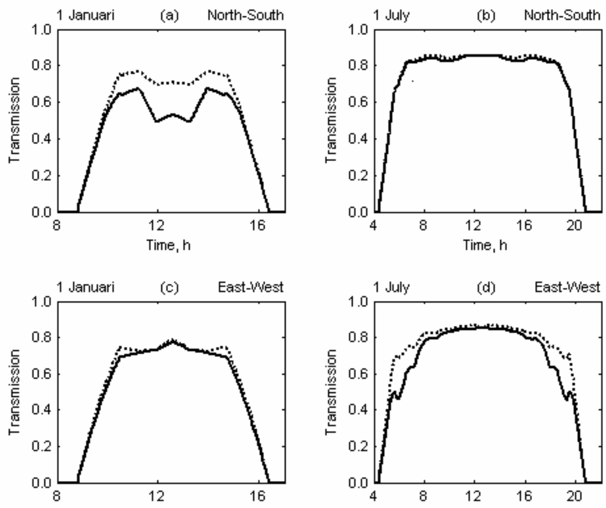


Fig. 3a. Transmission as function of the angle of incidence for incident angles perpendicular (zigzagl) and parallel on the zigzag structure (zigzagp).

Fig. 3b. The transmitted global radiation of a zigzag covering compared with a standard Venlo glass covering.
—— Glass covering
...... ZigZag covering

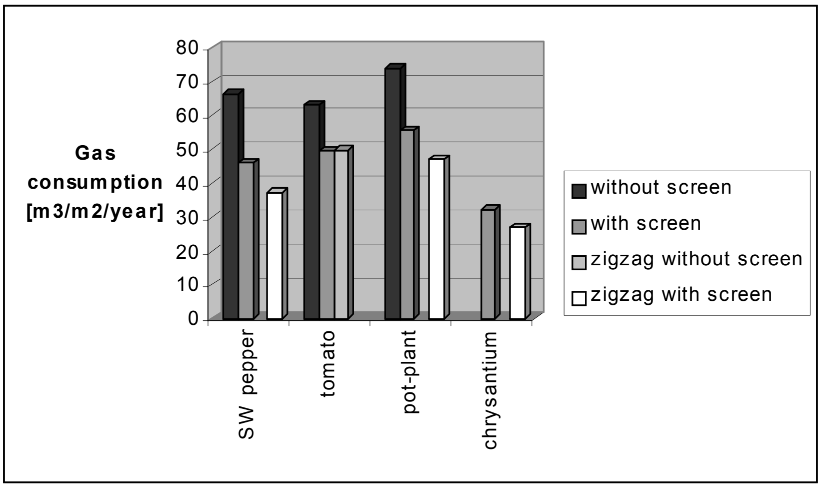


Fig. 4. Calculated results of gas consumption for a year round with the computer simulation program KASPRO. These results are determined with Dutch climate data. The cultures are Sweet pepper, tomato, potplant and chrysanthemum.

Fig. 5a. Vacuum formed ZigZag sheets with spacers in triangle shape between the inner and outer layer.

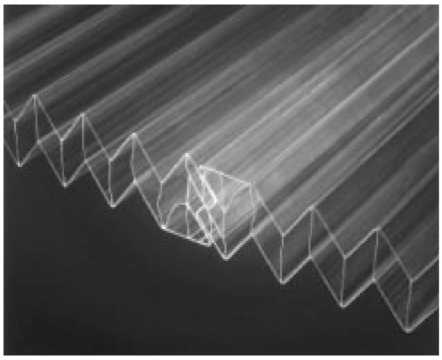


Fig. 5b. Two extruded ZigZag Lexan panels clicked together.

Fig. 6a. First greenhouse with Extruded zigzag sheets: Lexan® Zig Zag™ in Elst (Netherlands).

Fig. 6b. Detail of the roof construction with the extruded ZigZag sheets.

Fig. 7a. First wide span greenhouse with extruded zigzag in Assendelft (Netherlands).

Fig. 7b. Detail of the roof construction of the wide span greenhouse in Assendelft.