Greenhouse Design for the Future with a Cladding Material Combining High Insulation Capacity with High Light Transmittance

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Abstract

For the world exhibition Floriade 2002 in The Netherlands a greenhouse design is developed by IMAG together with General Electric Plastics, Bergen op Zoom with polycarbonate double-web sheets with a zigzag-shaped surface. Intensive research was completed to develop the special zigzag shape of the plastic sheets resulting in an enhanced light transmittance and energy saving of approximately 20% over the whole year. The optimal dimensions for the sheets with respect to light transmittance, strength and insulation is a pattern of 50 mm for the zigzag shape, a thickness of 25 mm and the inclination of the pattern is 50°. The transmittance for diffuse light of the entire greenhouse with the double-web sheets is 78.8%.

INTRODUCTION

At the international exhibition Floriade in 2002 in Haarlemmermeer (NL) a greenhouse block for the future was built. One part of this is a greenhouse with double-web plastic sheets in zigzag shape (Derikx et al., 2000). This greenhouse will be described in this paper. The name is the 'Florida' greenhouse because of the expected climate in this house: much light and high temperature caused by the combination of high light transmittance and good insulation.

Several types of double-web plastic sheets in different thicknesses already exist in practice made of the materials polymethylmethacrylate (PMMA) or polycarbonate (PC). These flat sheets have good insulation capacities (depending on the thickness of the sheets). However, the application of this type of double-web sheets for greenhouses was only minor in The Netherlands in the past years due to the fact that these sheets transmit about 10% less light compared to single glass and the transmittance also decreases due to weathering of the material. For example the diffuse transmittance of a standard PC double-web sheet with thickness of 10 mm is 68.1% and of a standard PMMA double-web sheet 75.5% (Breuer and Sonneveld, 2000).

At the moment energy saving is not only important for economic reasons but also for ecological reasons. In the near future the pressure towards the growers to save energy will increase strongly. The Dutch growers have promised to limit the fossil energy consumption in the year 2010 to 65% of the energy consumed in the reference year 1980 (GLAMI Convenant). To achieve this goal extensive measures are necessary. Next to the use of energy screens and modifications of the heating installations etc., the growers have to use good insulated production greenhouses in the future.

In response to these demands IMAG, (together with General Electric Plastics in Bergen op Zoom, The Netherlands), has developed the so-called zigzag-sheet. 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. This project was financed by the Ministry of Agriculture, Nature and Fisheries (LNV), NOVEM and Productschap Tuinbouw.

LIGHT TRANSMITTANCE

When a light beam is incident to a flat transparent sheet, a part of this light will be transmitted, according to Fresnell law, and another part will be reflected (Fig. 1 top). In the case of a flat sheet the reflected part of the light does not enter the greenhouse and therefore is not available for plant growth. In the case of a zigzag-surface the part of the light that is reflected by the sheet hits again another part of the sheet surface and partly enters the greenhouse in that way after all (Fig. 1 bottom). 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. IMAG developed the idea and the optimal shape, thickness and grid of such a zigzag-sheet. Calculations and measurements of single and double sheets with different pigment additives and with and without coatings were performed. The light transmittance of a single PC-sheet and a double-wall sheet with zigzag cross-section are calculated and measured. Leaving out the colour additives (pigments), leads to an improvement of the light transmittance by 4% (for single layer) up to 6% (double layer). These pigments are not necessary for plant growth and are added only to the PC material for cosmetic reasons. The optimal inclination of the zigzag-shape is 45-60° when looking at the light transmittance When regarding other criteria like insulation value, material consumed and material strength (see below) an inclination of 50° is ideal. The transmittance for diffuse light of a double zigzag-sheet with an inclination of 50° without colour pigments is 78.8%. The measurements were carried out with the big integrating sphere at IMAG with sample sizes of 500 x 500 mm.

For comparison: standard single glass has a diffuse light transmittance of 82% (Breuer and Sonneveld, 2000). The transmittance of a double zigzag-sheet (50°) is 89% for direct light. This value is 89-91% for single glass and 68-72% for a standard PC double-web sheet (measurements IMAG, 2000).

The light transmittance of the sheets can be further improved by the application of anti-reflection coatings. When using a four-sided coating for the double zigzag-sheet the light transmittance of single glass can be matched (measurements IMAG, 2000).

For a Venlo-type greenhouse the daily light transmittance with the double zigzag covering can be compared to a greenhouse with standard glass (Fig. 2). 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.

INSULATION VALUE AND ENERGY SAVING

Another factor influencing the optimal sheet geometry is the insulation value. To allocate this insulation value for the different sheet geometry IMAG has executed calculations according the European Standard (prEN-ISO 10077-2, 1999). Figure 3 shows the results for the double zigzag-shape sheets. The inclination of the zigzag-shape was fixed at 50°. The insulation value (U-value) improves with increasing thickness H and decreasing length L. 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 W m^{-2} K^{-1}. For comparison: single glass has a U-value of 6 W m^{-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 maximum, the monetary energy saving is calculated 45%. The typical year round energy consumption is calculated with the simulation program KASPRO for the cultures: sweet pepper, tomato, potplant and chrysanthemum using climate data for The Netherlands. For the whole year the overall energy saving is about 20%. This is lower than the monetary energy saving based on the U-value. Due to the better insulation, extra ventilation (opening the windows) is required for dehumidification resulting in extra energy losses. (Sonneveld, 2000).

MATERIAL CONSUMED AND MATERIAL STRENGTH

TO BE ABLE TO FIX THE OPTIMAL SHAPE OF THE ZIGZAG-SHEET THE MATERIAL CONSUMED AND THE STRENGTH OF THE SHEETS HAD TO BE CONSIDERED. PREFERABLY THE SHEETS MUST BE CAPABLE OF CARRYING THE LOADS WITHOUT EXTRA STRUCTURAL PARTS LIKE GLAZING BARS. MANY CALCULATIONS OF THE MATERIAL STRENGTH WERE CARRIED OUT. IT IS SHOWN THAT THE MATERIAL CONSUMED STRONGLY INCREASES WHEN THE LENGTH L DECREASES AND THE INCLINATION α INCREASES, IN PARTICULAR ABOVE 50°. BY THE WAY, VARYING THE THICKNESS H HAS ONLY A MINOR INFLUENCE ON THE MATERIAL CONSUMED. WHEN AT THE SAME TIME LOOKING AT THE MATERIAL STRENGTH THE DEFLECTION IS THE CRITICAL FACTOR. THE DEFLECTION IS SMALLER WHEN THE INCLINATION α IS HIGH. THE THICKNESS OF THE UPPER AND LOWER SKINS OF THE SHEET HAVE ONLY A SMALL INFLUENCE ON THE STRENGTH.

THE MATERIAL POLYCARBONATE

The chosen material polycarbonate (PC) has some advantages, but also some disadvantages, when comparing it to the material PMMA. PC a base material has very good impact resistance. As a result, it is applied in locations where glass is not allowed due to the danger of glass breakage (for example in public doors). Due to the high impact resistance the outer skin of the double sheets can still be sufficiently hail resistant at small thickness. Moreover, the sides of the sheets can be applied with a click-connection system because PC is more elastic than PMMA. Two sheets will be connected then only by a click-connection; glazing bars are not needed anymore (Fig. 4). This has a positive effect on the total light transmittance of a greenhouse.

Another advantage of PC is the better behaviour during fire. With PMMA some huge, dangerous fires occurred in the past years. The material PC can indeed be ignited, but PC has a self-extinguishing property in contrast to PMMA.

The disadvantages that can be mentioned are: the lower light transmittance due to higher refraction index and higher sensitivity for altering due to UV-radiation. To avoid yellowing of PC, the sheets will be provided with a UV-absorbing or reflecting coating, which will break the weathering pattern. In this way a guaranteed lifetime of PC of at least ten years without yellowing can be given, comparable to PMMA.

STRUCTURE

At the Floriade exhibition the (prototype) greenhouse has been built. The main structure of this greenhouse is comparable to a traditional greenhouse with beams, trellis girders, stability bracings, etc. The foundation is a combination of prefab concrete parts and cast concrete. The span of the trellis girders is 9.6 m with two roofs of 4.8 m. The mutual distance of the trellis girders is 4.8 m.

Small type steel gutters, which are modern common practice, are used. Only the structure above gutter level is new and especially suitable for the zigzag-sheets. Here extra beams made of steel profiles are used to support the purlins, the ventilation window and the mechanism to open and close the ventilation window (Fig. 5). These extra beams are fixed to the trellis girders and have therefore a mutual distance of 4.8 m. At the level of underside ventilation windows these beams carry horizontal hollow steel profiles. These purlins support 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 width of the double zigzag-sheets is 1.2 m. The continuous roof ventilation window has sides of 0.8 m and is prefabricated. The ventilation window can be opened by lifting it up vertically (Fig. 6). The walls of the Florida greenhouse are covered with standard double-web flat PC-sheets. The total area of the compartment with the zigzag-sheets is about 700 m^2 at the Floriade exhibition.

CONCLUSIONS

IMAG in Wageningen together with General Electric Plastics in Bergen op Zoom, The Netherlands, developed the so-called Florida greenhouse combining a traditional steel structure with a specially shaped zigzag-covering of double-web PC-sheets. It is a greenhouse with high insulation capacity and a high light transmittance. For the special roof concept, national and international patent has been applied for.

The optimal geometry of the sheets is developed using calculations and measurements of models based on the following criteria: light transmittance, insulation value, material consumed and material strength. The sheet geometry with a length L of 50 mm, a thickness H of 25 mm and an inclination α of 50° is considered to be optimal for the mentioned criteria.

Due to the zigzag-shape the single sheet in general causes a diffuse light gain of 5% compared to a flat sheet; in the case of a double-web sheet the gain is 4-10%. The light transmittance of the PC material used has been improved by about 4% by leaving out the ‘cosmetic’ colour pigments, which are commonly used in PC-sheets. The research showed that an anti-reflection coating gives in general an improvement of 2-5%.

One of the advantages of these self-supporting zigzag-sheets is that they can be built without glazing bars. For this reason the double zigzag-sheets show an extra light gain of about 2% compared to a greenhouse commonly covered with standard double-web sheets with glazing bars.

The heat transfer of the designed (double) zigzag-sheet with an anti-reflection coating is 3.4 W m^{-2} K^{-1}. The diffuse light transmittance is 83% (with anti-reflection coatings on all four sides).

With this structure and the designed double zigzag-covering for the roof it is possible to have a greenhouse with a diffuse light transmittance of 79% and an energy saving at the same time of 20% on a yearly basis.

The double-wall sheets for the Floriade exhibition are produced as two separate skins, manufactured by the vacuum forming technique and then adhered with glue. In the future, the sheets will be produced in a continuous process through extrusion (see the prototype sheet in Fig. 4).

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Figures

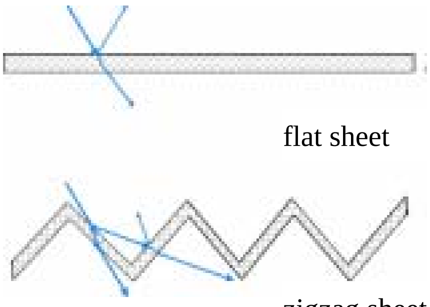


Fig. 1. The principle of the transmittance and reflection of light beams hitting a flat sheet (above) and a zigzag-sheet (below).

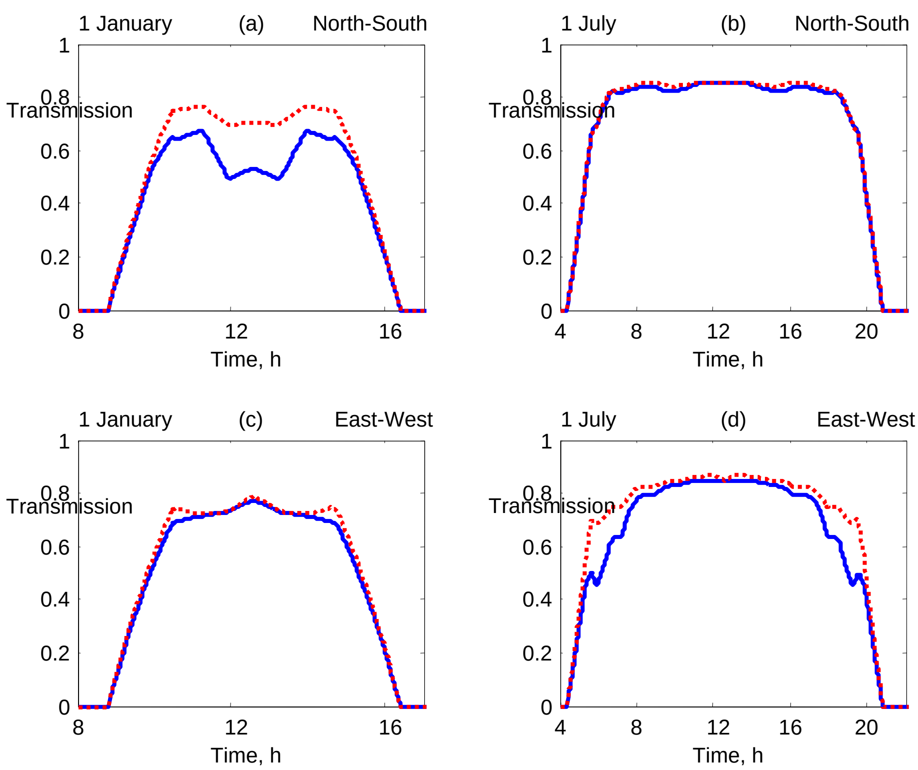
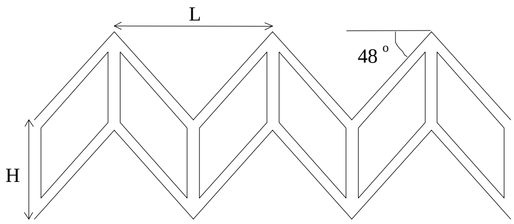
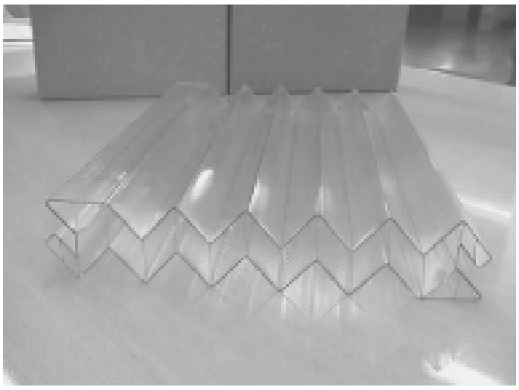


Fig. 2. Daily light transmittance of a double zigzag greenhouse and a standard Venlo greenhouse with single glass covering for two orientations at 1 January and 1 July (........ zigzag greenhouse; ——— standard Venlo greenhouse).



Nr.	L [mm]	H [mm]	U [W/m^2 K]
1	10	10	4,63
2	25	10	4,69
3	50	10	4,91
4	10	25	2,65
5	25	25	2,99
6	50	25	3,38

Fig. 3. Calculated insulation value (U) of zigzag-sheets with different dimensions (thickness H, length L, inclination α =48°).



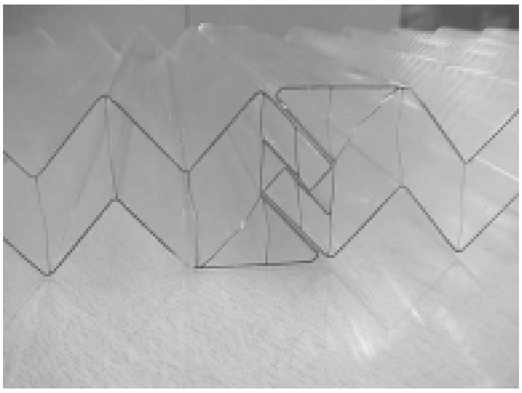


Fig. 4. Cross-section of the zigzag-sheet with click connection on the sides.

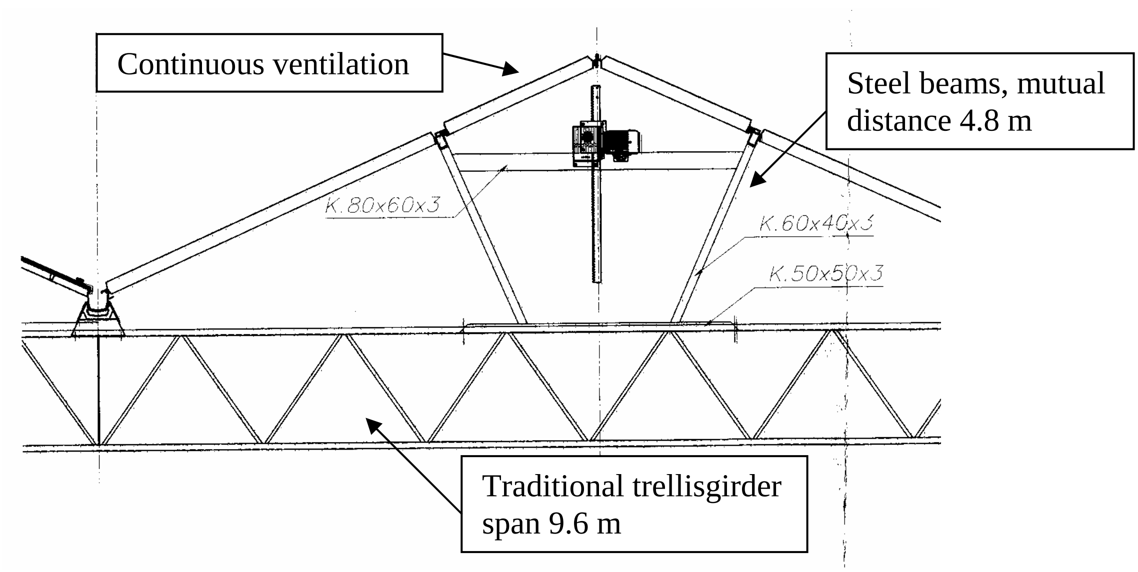


Fig. 5. The roof structure of the Florida greenhouse covered with zigzag-sheets, which are carried by beams in triangle shape and purlins.

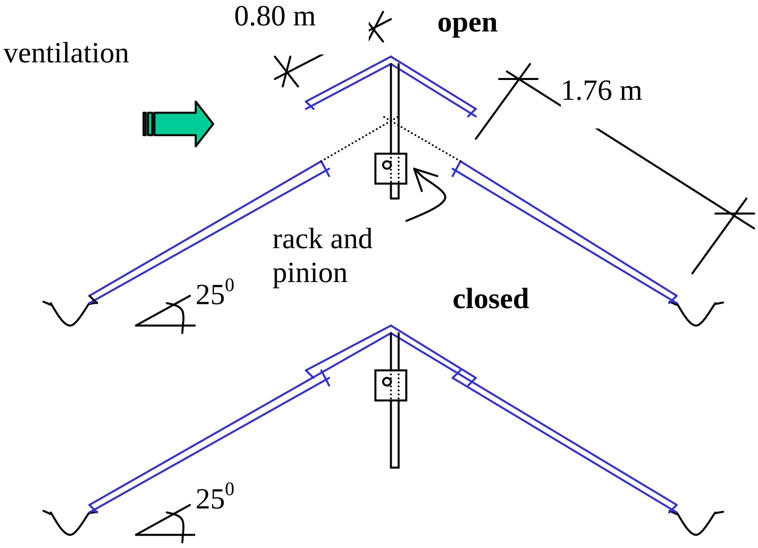


Fig. 6. The ventilation mechanism of the Florida greenhouse.