Development of a Greenhouse System for Tropical Lowland in Indonesia

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Abstract

Wageningen UR - A&F (former IMAG) developed together with Plant Research International (PRI) and the Dutch industries Rovero Systems B.V. and Plasthill B.V. and the Indonesian company PT East West Seed Indonesia a new greenhouse system for the production of high quality horticultural products in the tropics. In this study plastic-covered greenhouses are designed which are particularly adapted to the regional circumstances of tropical lowland in Indonesia. The greenhouse design has enough resistance against local wind loads, has high natural ventilation, but is at the same time mainly closed for insects by using insect nets. The airflow and the temperatures in the greenhouse are simulated by CFD software during design stage to optimize greenhouse size, shape and the ventilation openings. A new plastic film covering is developed. The new covering consists of a 200 µm polyethylene film with a lifetime of about 3 years in Indonesia. The film contains a UV-block pigment and has highly light diffusing properties. Additionally film prototypes are developed, which selectively reflect near infrared radiation (NIR) with the objective to reach a cooling effect inside the greenhouse. Six identical greenhouse prototypes are produced in The Netherlands and built in the isle of Java in Indonesia in spring 2003. In the greenhouses tomatoes are cultivated and observed. Additionally climate measurements are carried out to evaluate the new designed greenhouses.

INTRODUCTION

In tropical lowland of Indonesia heavy rainfalls, wind and various plant pests and diseases often damage the open field grown vegetables (von Zabeltitz, 1999). The use of pesticides needs to be restricted, while it often leads to unacceptably high levels of residues in the products, heavy pollution of the environment, and high levels of resistance of insects to these pesticides. In Indonesian highland farmers also use simple protected structures for the production of vegetables. In these protected structures they often have problems with the inside temperature and humidity. The bamboo greenhouse construction often used is not durable, plastic films cannot be fixed properly; a lot of maintenance is needed. The greenhouses cannot be made tight for insects; plant pests and diseases affect crop production. An introduction of protected cultivation in tropical lowland of Indonesia can contribute to reach a higher yield and better quality of the crops using less water, fertilisers and pesticides. The agricultural production can be improved, leading to an increasing social welfare of the farmers.

For the greenhouse design with proper indoor climate for crop production the local outdoor climate conditions are boundary conditions. The experience with protected cultivation in Indonesia, the used greenhouse structures, the used materials and the occurring diseases, insects etc. have to be integrated in the design. To do so computational fluid dynamics (CFD) is a powerful tool. CFD modelling for greenhouse design is already reported extensively (e.g. Boulard et al., 1995; Mistriotis et al., 1997; Fatnassi et al., 2002b; Campen en Bot, 2003).

Also the insect nets have to be optimised for local conditions (Ajwang et al., 2002). Mesh size and porosity not only determine which insects are able to enter the greenhouse but also how much the flow resistance of the opening is increased. Smaller mesh sizes stop small insects, like white fly or even thrips from entering the greenhouse. At the same time airflow is limited significantly, so greenhouse air temperature will rise (Sase and Christianson, 1990; Fatnassi et al., 2002a). Wider mesh sizes allow better air exchange, but also allow white fly and aphids to come in. Next to this the covering material can contribute to the proper indoor climate if near infrared radiation (NIR, 800-1100 nm), contributing to the warming-up effect of the greenhouse, can be reflected and photosynthetic active radiation (PAR, 400-700 nm), important for plant photosynthesis, is still transmitted (Brown, 1939; Hoffmann and Waaijenberg, 2002; Verlodt and Verschaeren, 1997).

All these aspects are important for the design of a new greenhouse system for tropical lowland of Indonesia. The main purpose of this project is to find whether the designed greenhouse has enough ventilation capacity, which strongly influences the inside temperatures. The other purpose is to investigate the effect of the NIR-reflecting films on the inside temperature so that plant production is still possible in protected cultivation in tropical lowland achieving a high product quality.

MATERIALS AND METHODS

CFD

The CFD program Flovent was applied to optimise the new design of a greenhouse for tropical lowland examining the inside temperature distribution in relation to the size and location of ventilation openings, netting material, light transmission of the covering material and local climate data like: outside wind speed, irradiation and temperatures. Computational fluid dynamics (CFD) is a tool to determine flow field and temperature distributions in and around geometries. A general description of CFD is given by Mistriotis et al. (1997). In a CFD program a system is modelled by discretising space and time (integrated volume method) and by solving the conservation equations of the discretised parts for the relevant quantities considered. The conservation equation reads:

$$\frac{\partial \varphi}{\partial t} + \vec{\nabla} \cdot \varphi \vec{v} = \vec{\nabla} \cdot \left(\Gamma_\varphi \vec{\nabla} \varphi \right) + S_\varphi \tag{1}$$

where $\vec{v}$ is the air flow velocity vector in m s^{-1}, Γ_φ is the diffusion coefficient in m^2 s^{-1} and S_φ is the source term, φ represents the concentration of the quantity considered (total mass, momentum, energy or mass of a component). Solving these equations provides transport between the parts of the model, thus the flow field and temperature and concentration distribution can be determined. Separate models describing the fluctuating part of the flow account for turbulence. The k-ε model is widely used as a turbulence model (Launder and Spalding, 1974).

Various greenhouse constructions are investigated in this study (Fig. 1) with different lengths and different ventilation openings. The mean outside temperature is assumed to be 30°C. The mean irradiation is assumed to be 600 W m^{-2} (reference film) or 300 W m^{-2} (ideal NIR-reflecting film); in the greenhouse 50% of the irradiation is assumed to be released in the air as sensible heat and 50% is assumed to be released by the crop as latent heat. The wind velocity is assumed to be 0 m s^{-1} or 3 m s^{-1}. The buoyancy effect is dominant when the wind speed is below 2 m s^{-1}, which is in agreement with theory on ventilation (Bot, 1983). The airflow resistance of a 2 m high crop is also included in the model. Two different insect screens are investigated. Based on the CFD calculations the optimum greenhouse design for ventilation and insect screens is chosen for this project.

Air Flow through Insect Screens

The influence of the insect screening material on the ventilation is taken into account in the CFD model by a porous medium. Miguel (1998) did a study on transport of air through insect screens and found the following relation between the pressure difference $\frac{\partial p}{\partial x}$ over the screen and the resulting air velocity v:

$$\frac{\partial p}{\partial x} = \frac{\mu}{K} v + \rho \frac{Y}{K^{1/2}} v^2 \tag{2}$$

where μ is the dynamic viscosity in Pa s; K is the permeability of the screen in m^2; ρ is the density of air in kg m^{-3}; and Y is the inertial factor. The porosity of two nets was measured (Econet FL and Econet SF) following the method described by Van den Bongart and Stoffers (1992). The results are used in the CFD model.

Strength of the Construction of the Greenhouse Design

For the chosen greenhouse design the optimum constructional strength has to be calculated; the optimum dimensions of construction materials have to be found. To be sure that the greenhouse is strong enough to resist local wind loads the strength of the greenhouse is calculated following the Code of Practice for greenhouses with flexible claddings (Waaijenberg, 1997). It appeared that the average wind load in Indonesia is comparable to the wind load in The Netherlands. Next to the self-weight of the greenhouse a crop load of 150 N m^{-2} on the horizontal bar is included in the calculations (no loads caused by suspended heating pipes and snow on the roof). The greenhouse design reference period is ten years.

Transmission of the Covering Material

Several film prototypes were developed by the plastic film producer containing different concentrations of NIR-reflecting pigments. The spectral transmission for perpendicular light on these films was measured using a Perkin Elmer spectrophotometer in the range of 300-2500 nm with a resolution of 1 nm. The integral value for PAR (400-700 nm) and NIR (800-1100 nm) was calculated separately. The transmission for diffuse light was measured using an integrating Ulbricht sphere.

RESULTS

The Greenhouse Design

The first CFD-calculations are on a commercial greenhouse design (Fig. 1A). Insect nets cover the open gables and sidewalls of the greenhouse and the ridge ventilation openings. The greenhouse is covered with a conventional plastic films. The effect of the insect screens on the ventilation is investigated in the different greenhouse designs.

The results of the simulations of the average natural ventilation in the different designs are summarized in Table 1 in renewals per hour (h^{-1}). Design A and B cannot be recommended if the wind is leeward, in this case the ventilation rate is only 70-80%.

Fig. 2 shows the temperature distribution at a wind speed of 0.5 m s^{-1} with Econet SF insect screens for the commercial greenhouse design (A) and the commercial design with no top ventilation (C) in the vertical plane of the greenhouse. The design with top ventilation shows higher temperatures in the central part of the greenhouse compared to the design without top ventilation. Fig. 2 shows that the top ventilation disturbs the airflow. The buoyancy force and the force due to the wind are similar. This results in an accumulation of warm air in the greenhouse. More results are presented in Table 2. The effect of the size and location of the ventilation openings can be concluded. Mean air temperatures inside the greenhouses are higher in the situation without wind compared to the situation with normal wind.

Moreover, the effect of the length of the greenhouses was investigated. In the short greenhouses (12 m) the ventilation rate and inside air temperature are influenced by the relatively large gable ventilation. By increasing the length of the greenhouse the effect on the greenhouse climate can be investigated.

From Table 3 it can be seen that during low wind speeds a long greenhouse (36 m), especially the design (C) is disadvantageous. The mean inside temperature rises from 34°C to more than 36°C. The maximum temperature is 40°C. But also in design (A) the maximum temperature reaches almost 39°C, while the mean temperature is less increased. In the multi-span greenhouse maximum temperatures exceed almost 42°C making plant production almost impossible.

Resulting from all these simulations a new optimal design for the greenhouse was chosen with a continuous open ridge ventilation and ventilation through the gables and sidewalls, all covered with insect nets. The insect net in the top ventilation is located horizontally. In this way the new Procult design (E) combines the good performance of the design without top ventilation (C) during low wind speeds (Table 2) with the advantages of the commercial design (A) when bigger greenhouse areas are built (Table 3). The ventilation rate of the new Procult design does not depend on the wind direction.

The span width of the new Procult greenhouse is 9.6 m, the length 15 m, the column height is 4 m and the distance of the columns in the direction of the gutter is 2.5 m. The greenhouse is provided with a lean-to on all gables and sidewalls to prevent rain entering the greenhouse through the screens. Insect screens with openings of 0.6 x 0.6 mm (comparable to Econet SF) are closing all ventilation openings. Ventilation openings are in all side-walls and front gables from 1 m above ground level (Fig. 3) to gutter level, except the triangle of the front gables above gutter level. This results in a total ventilation area of 40.4% of the greenhouse-covering surface. Each greenhouse entrance is provided with an insect lock on the outside.

The Greenhouse Covering

Next to the reference film (NIR0), two materials with different concentrations of NIR-reflecting pigment (NIR1, NIR2) were developed for this project. All plastic films consist of a 200 µm polyethylene film with a lifetime of about 3 years in Indonesia. The films all contain a UV-block pigment and have highly light diffusing properties. It has to be investigated which kind of polymer is suitable and optimal for tropical conditions. In Table 4 the optical and thermal properties of the newly developed and the reference films are given. NIR2 is reducing the NIR (700-1100 nm) with 25.7%, while the PAR is only reduced by 8.7% compared to the reference film NIR0.

CONCLUSIONS

A new greenhouse system was developed for the production of high quality horticultural products in tropical lowland in Indonesia. The greenhouse design has sufficient stability for local wind loads and has a large opening area for natural ventilation (40.4% of the greenhouse surface area). CFD proved to be a powerful tool for the design, which simulates airflow and temperature distribution. Provisional climate measurements carried out in the new built greenhouses in Indonesia showed that the boundary conditions assumed in CFD were suitable to give a good reflection of the local situation (data not shown here). Since CFD is only a tool to investigate a static situation, it remains necessary to validate the model and to collect dynamic data year around.

The new plastic film covering consisting of a 200 µm polyethylene film with a UV-block pigment and highly light diffusing properties showed that a reduction of NIR (700-1100 nm) up to 25.7% is possible. At the same time PAR is only reduced by 8.7%. Radiation measurements have to show how much of the incoming energy can be reduced by the NIR-reflecting film. For this purpose six identical greenhouse prototypes are built in Indonesia and covered with a reference film and two films containing NIR-reflecting pigments in different concentrations in two repetitions. In the greenhouses tomatoes are cultivated and observed. First data are evaluated at the moment and will be presented in the future.

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Tables

Table 1. Average ventilation rate of various greenhouse designs in renewals per hour with different insect screens at a wind speed of 3 m s^{-1} coming windward and (leeward).

Configuration	No insect screen	Econet FL	Econet SF
A. Commercial design	205 (143)	106 (107)	87 (80)
B. Commercial design with a larger top ventilation	166 (132)	113 (94)	89
C. Commercial design without top ventilation	221 (227)	130 (133)	74 (75)
D. Commercial design as multi-span	170 (148)	102 (82)	61 (59)

Table 2. Influence of the wind speed on mean inside air temperatures and ventilation rate in renewals per hour of various greenhouse designs with Econet SF insect screen per single greenhouse in a row (1-3), wind coming from left.

Configuration	Wind speed 3 m s^{-1}			Wind speed 0.5 m s^{-1}		
	Greenhouse			Greenhouse		
	1	2	3	1	2	3
A. Commercial design	31.5, 115	32.0, 84	32.3, 73	34.6, 38	34.7, 37	34.7, 37
B. Commercial design with a larger top ventilation	31.4, 119	32.0, 85	32.1, 78	34.4, 38	34.3, 39	34.3, 39
C. Commercial design without a top ventilation	31.8, 98	32.6, 67	32.3, 74	33.4, 50	33.5, 49	32.8, 64
D. Commercial design as multi-span	32.8, 61			35.6, 30		
E. New Procult design	31.3, -	31.2, -	31.1, -	33.2, -	33.2, -	33.1, -

Table 3. Influence of the length of the greenhouse on mean air temperatures inside greenhouse with Econet FL insect screen for the different greenhouse designs at a wind speed of 0.5 m s^{-1}.

Configuration	Short greenhouse (12 m)			Long greenhouse (36 m)		
	Greenhouse			Greenhouse		
	1	2	3	1	2	3
A. Commercial design	33.3	33.4	33.3	33.6	35.0	34.7
B. Commercial design with a larger top ventilation	33.1	33.0	33.0	33.5	34.3	33.9
C. Commercial design without a top ventilation	33.8	34.0	33.9	35.3	36.7	36.6
D. Commercial design as multi-span	33.9			35.1		
E. New Procult design	33.2	33.2	33.1	33.7	34.3	34.1

Table 4. PAR transmission (perpendicular, 400-700 nm), PAR transmission for diffuse light (400-700 nm) and NIR transmission (800-1100 nm) of the three different new developed greenhouse covering materials.

PE-film	PAR transmission (perpendicular) 400-700 nm	PAR transmission for diffuse light, 400-700 nm	NIR transmission, 800-1100 nm
NIR0	0.869	0.765	0.891
NIR1	0.804	0.734	0.712
NIR2	0.777	0.681	0.640

Figures

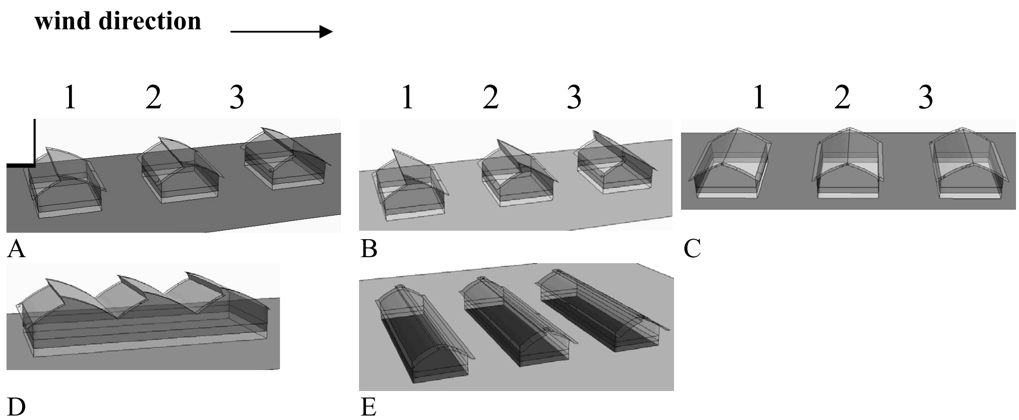
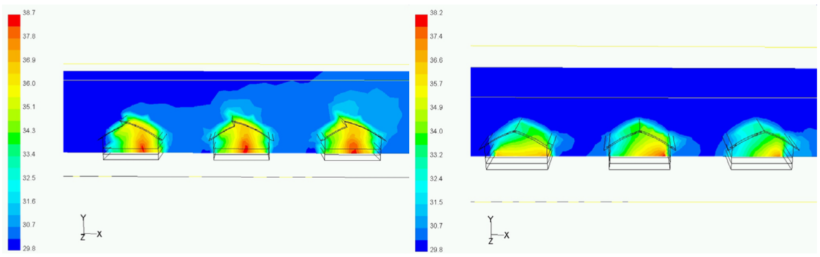


Fig. 1. Different greenhouse shapes are calculated with CFD. A. a commercial design, B. the commercial design with larger top ventilation, C. the commercial design without top ventilation, D. the commercial design as multi-span, E. the new Procult design.



A C

Fig. 2. Temperature distribution at a wind speed of 0.5 m s^{-1} with Econet SF insect screen for the commercial design (A) and the commercial design with no top ventilation (C).

Fig. 3. The new Procult greenhouse design, three greenhouses in a row.