Vapour Removal from the Greenhouse Using Forced Ventilation when Applying a Thermal Screen

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Abstract

The objective of this study is to dimension a system capable of removing water vapour mainly generated by evaporation of the crop when a thermal screen is applied. The humid greenhouse air is replaced by cold dry outside air using an air distribution system. The dry air is injected above the greenhouse floor thereby forcing humid air to pass through the thermal screen. The excess air in the greenhouse will flow away though leaks in the cover. The common procedure to remove moisture from the greenhouse where a thermal screen is applied is by slightly opening the screen. This results in an air exchange of relatively dry air from above the screen and the humid air below the screen. This procedure is difficult to control and causes horizontal temperature differences in the greenhouse. By mechanically controlling the exchange of the greenhouse air and outside air these problems can be resolved. The airflow through the system needed over the year resulting from the evaporation of the crop and the outside conditions is determined using a greenhouse simulation model KASPRO. Based on this result the dimensions of the system are calculated and a control strategy is suggested. The KASPRO calculations also showed that using outside air for vapour removal is more energy-efficient as using the air above the thermal screen. The greenhouse climate resulting from using the conventional method of vapour removal as well as with the forced ventilation is investigated using CFD. The three dimensional CFD calculations show that the climate using the forced ventilation system is much more homogenous and the control is more efficient compared to the conventional method of vapour removal. The system proves to be economical since investment costs are low (expected to be around 3 EURO/m^2 maximum) and it ensures a proper well-controlled climate under the thermal screen resulting in a higher use of the screen through the year. The system is currently being tested in practise at a Dutch commercial tomato grower.

INTRODUCTION

Climate control for horticulture is crucial in order to obtain a high production. Temperature can be well controlled by implementing a heating system and through ventilation. Humidity is also controlled by heating and ventilation. Humidity is difficult to control when the insulation is high. Most greenhouses are insulated by applying a thermal screens that causes less water vapour to condensate on the cover and reduces the air exchange between the greenhouse and the surroundings. Controlling the humidity under the thermal screens is done by slightly opening the screens replacing warm humid air below the screen by cold dry air above the screen. The disadvantages of this measure are that it is not well controllable and it causes horizontal temperature differences. An alternative system has been developed for the humidity control where dry air is blown under the screen by a ventilator. The system is depicted in Figure 1. Three designs of the system, in the figure shown as A1, A2 en B have been studied. In design A the air is either transferred from above the screen (A1) or from outside (A2) by ventilator located in the greenhouse post. Design B has an air duct through which the outside air is distributed in the greenhouse. Design B can be installed easier in exciting greenhouses.

MATERIALS AND METHODS

The capacity of the system is determined using a dynamic simulation model called KASPRO (De Zwart, 1996). This model calculates the greenhouse climate based on the outside conditions, the greenhouse conditions set by the grower, and the technical installation of the greenhouse. The physical heat and mass fluxed are modelled. For the outside conditions a specific year is used that represents an average Dutch year (Breuer and Van de Braak, 1989). The greenhouse conditions are set for a tomato crop since humidity control is crucial for this crop and the area of greenhouse producing tomatoes dominate over other crops for the Netherlands (LEI, 2007). The maximum relative humidity is set to be 85%.

The greenhouse climate is calculated using three dimensional computational fluid dynamics (Versteeg and Malalasekera, 1995) for the case where the screen in slightly opened to remove the humid air and the case where the developed system is used. The commercial CFD software of Fluent (Fluent, 1998) is used. The greenhouse is modelled as a rectangular box of 24 by 40 by 5 meters where the thermal screen is placed 1 meter below the cover. The cover is simplified to reduce the complexity of the mesh and because it does not effect the results for this case. The temperature of the outside air is set to 5°C with a convective heat transfer coefficient of 15 W m^{-2} K^{-1} and the sky temperature is -5°C with an emission coefficient of 0.86 to calculate the radiative heat transfer. The greenhouse floor is set to a specific temperature so that the average temperature in the greenhouse is 20°C. The vapour concentration at the cover is based on the saturated vapour concentration of air with a temperature of 5°C, corresponding to the average temperature of the cover. As a result the cover acts as a negative source of water vapour. The resistance of the crop is taken into account as a porous medium, which is modelled by the addition of a momentum source term. This source term is defined by modelling the crop as in Figure 4. The results are not verified by experiments but it provides an estimation of the influence of the crop. The size of the leaves and the number of leaves correspond to an actual tomato crop. The total volume of crop modelled is one cubic meter. The relation between the pressure difference over the crop and the average velocity through the crop is calculated being $p=1.65\ v^{1.74}$. The transpiration of the crop of 40 g m^{-2} h^{-1} is included as a source of water vapour in the porous medium. The transpiration is based on the period when the thermal screens are used, so during night time (Stanghellini, 1987). The gravitation direction is slightly (1%) tilted to account for the fact that the gutters are at a small angle to run off the rain water. The forced ventilation system is modelled by 30 air inlets distributed evenly over the greenhouse floor. The air flows out the greenhouse through 5 narrow (20 cm) openings stretched over the entire length of the greenhouse. Since these openings are small and the pressure in the greenhouse is higher than outside, no air is entering the greenhouse at these openings.

The local effect of the air distribution is simulated using the model depicted in Figure 1. The gutter height is 5 meters and the ground area measures 8 by 4.5 m. The crop is modelled as a porous media similar to the previous calculations.

RESULTS AND DISCUSSION

The air blown into the greenhouse under the thermal screen can either come from above the screen or from outside the greenhouse. The air above the thermal screen is relatively dry compared to the air below the screen since this volume of air loses vapour by condensation on the cover. The water vapour content of the outside air is less than the greenhouse air since cold air can contain less water vapour. Figure 2 shows the number of hours a certain amount of ventilation is needed to maintain a relative humidity of 85% for both cases. The maximum ventilation needed for the case air above the screen is used, is 10 m3 m^{-2} h^{-1}. Half of this ventilation is needed for the case outside air is used. The temperature of the outside air is lower than of the air above the screen which increases the heating demand. But the fact that the needed ventilation using outside air is less than using air from above the screen, causes this method to be slightly more energy efficient with 11.3 MJ needed yearly to compensate for the heat losses caused by ventilation needed for the vapour removal instead of 11.7 MJ when using air from above the screen. These energy losses are naturally also present when the conventional method for vapour removal is used by slightly opening the screen. The warm greenhouse air is then replaced by the cold relative dry air above the screen the same way as using the system but less controllable. The system is operational in Spring and Autumn when the thermal screens are used and the crop transpiration is high. Figure 3 shows for every week the weekly averaged vapour removal needed per hour.

The greenhouse climate (temperature and relative humidity) three minutes after opening the screen (2.5% of the total surface area) is depicted in Figure 5. The air drops from above the screen at one side of the greenhouse and rises through the narrow openings at the other side of the greenhouse. This air flow causes the temperature gradient in the greenhouse. Due to the temperature drop the relative humidity locally is not decreasing but increasing. The air flow is less dominate when the thermal screen is only opened for 1% but the moisture removal naturally also less in this case.

In case the humidity control is done by forced ventilation the temperature and relative humidity gradient are less than 1 K and 3% as can be seen in Figure 6. The climate is also determined locally where the air is blown into the greenhouse using the model as depicted in Figure 1. The relative cold outside air mixes within 20 cm for the point where it is blown into the greenhouse so no temperature or relative humidity differences are registered near the crop as can be seen in Figure 7. For both the cases where the greenhouse post is used and the air duct is used the direction of the air flow is towards the heating system so the relatively cold air flowing in is directly heated.

CONCLUSIONS

Theoretically the system is capable of removing enough vapour from the greenhouse so the relative humidity stays within limits Using outside air for ventilation a maximum of 5 $m^3 h^{-1}$ per square meter of greenhouse is needed. The climate under the thermal screen is more homogenous when the system is used with temperature differences being less than 1°C. The system can be implemented in exciting greenhouses using an air duct and a ventilator in the side wall. The climate near the crop is not effected by the system. The energy consumption will be less (around 3% of the yearly consumption) since the system allows more control of the climate. By controlling a process more effectively, the limits can be raised and energy can be saved. In the case of thermal screens growers will keep their thermal screens closed for a longer time without the risk of high humidity thereby saving energy. The system will also encourage more grower to implement a thermal screens knowing they can control the climate. Based on this study the system will be tested in practise at a commercial grower. The climate will be monitored in this experiment as well and will be used to validated the dynamic simulation model results and the CFD results.

ACKNOWLEDGEMENTS

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Figures

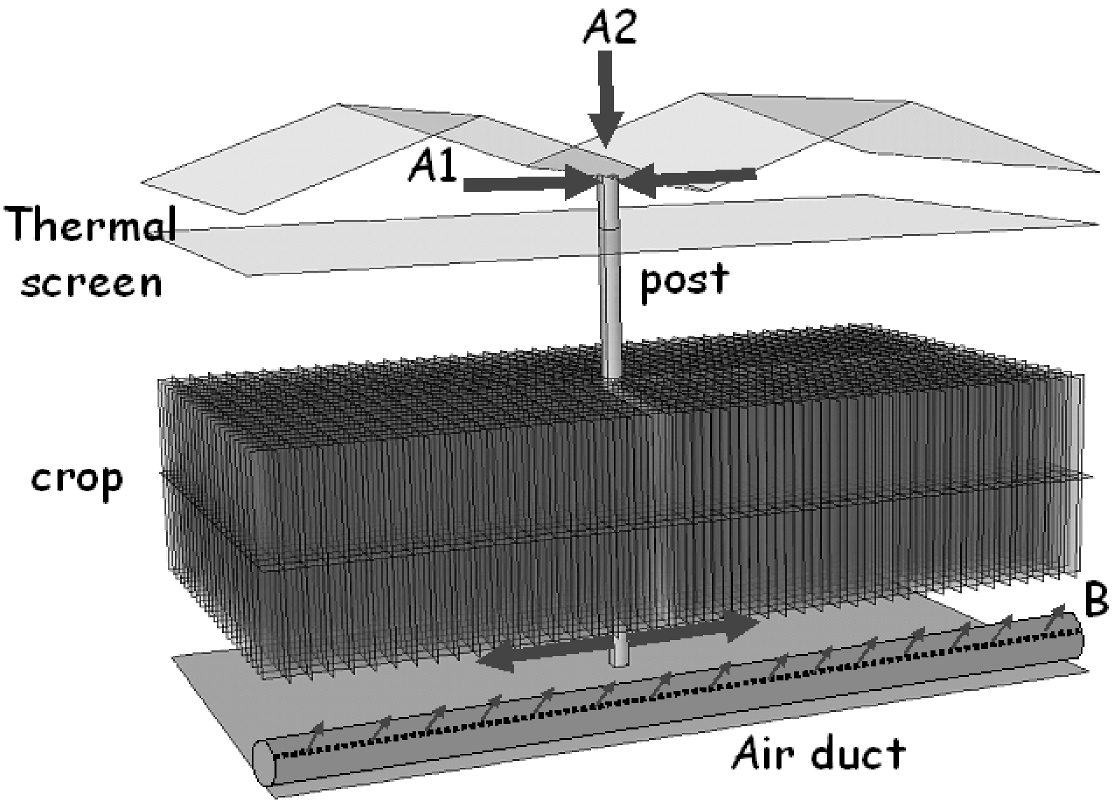

Fig. 1. A schematic representation of the system where A1 and A2 locally ventilated air for above the screen or for outside and system B where the air distributed by a air duct.

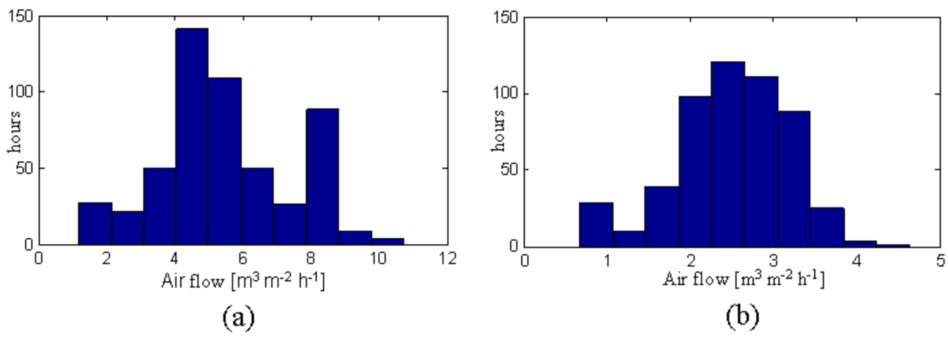

Fig. 2. Histogram of the hours per year a specific amount of ventilation is needed in order to maintain a relative humidity around 85% when ventilation with air above the screen (a) and with outside air (b).

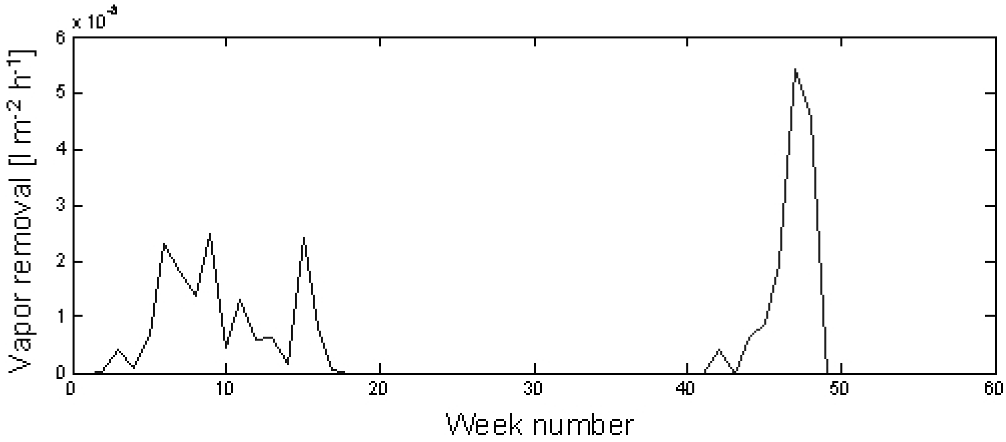

Fig. 3. The amount of vapor removal by the system as a function of the week of the year.

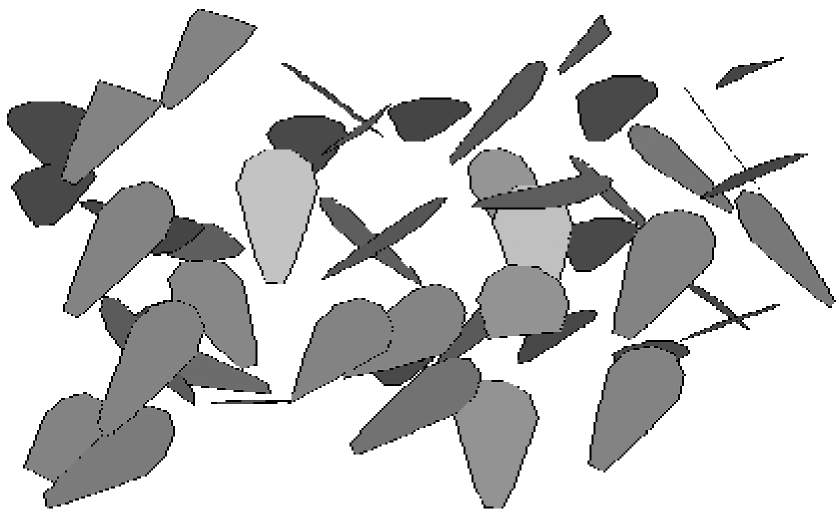

Fig. 4. CFD crop model.

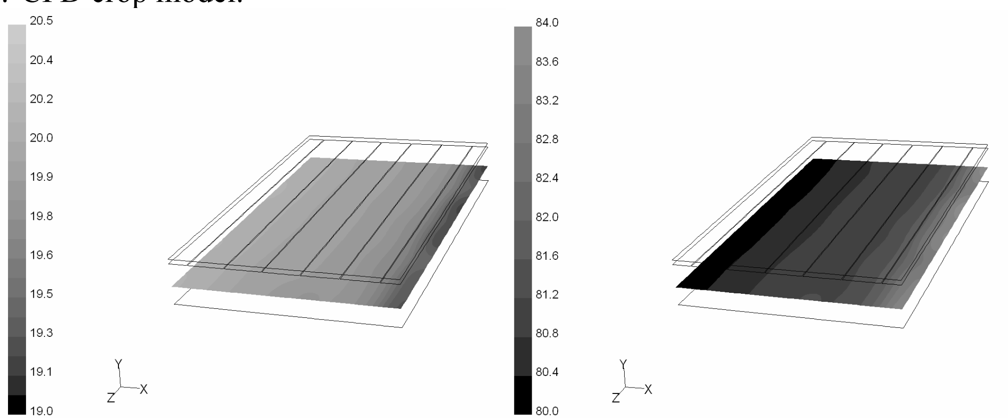

Fig. 5. Temperature (left) and relative humidity distribution at a height of 2 meter after 3 minutes when the openings in between the thermal screen is 10 cm.

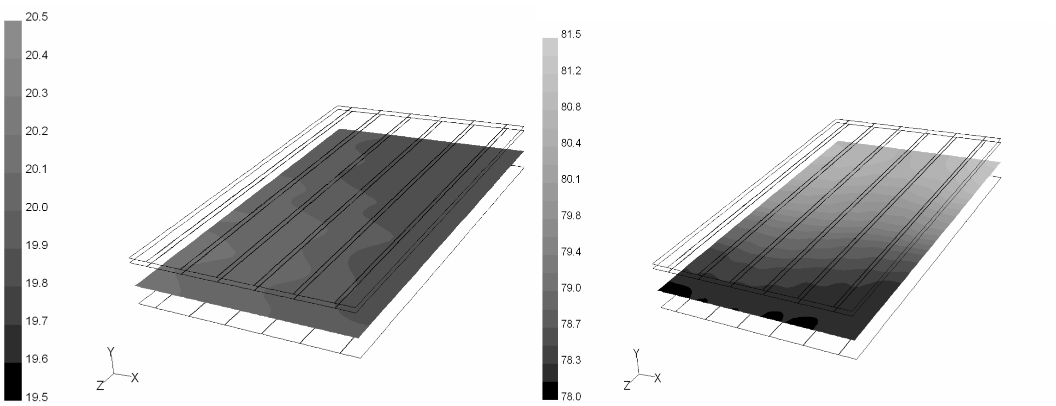

Fig. 6. Temperature (left) and relative humidity distribution at a height of 2 meter when the forced air flow is 1.7 m^3 m^{-2} uur^{-1} with a temperature of 5°C and a relative humidity of 95%.

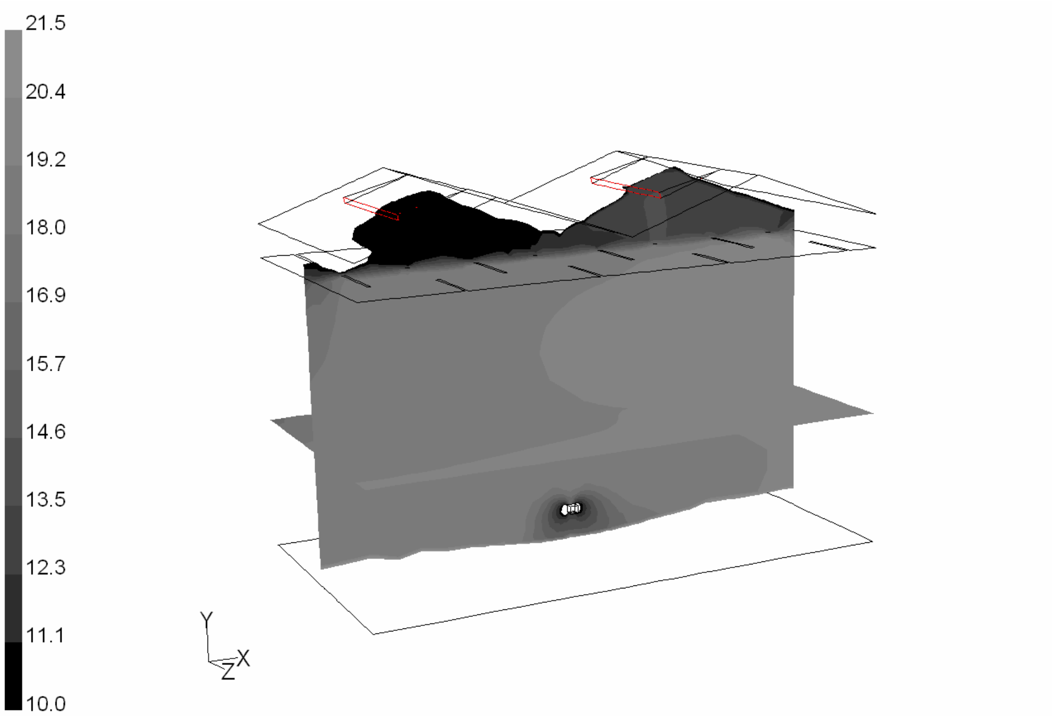

Fig. 7. Temperature (left) and relative humidity distribution at a height of 2 meter when the forced air flow is 1.7 m^3 m^{-2} uur^{-1} with a temperature of 5°C and a relative humidity of 95%.