Ventilation of Small Multispan Greenhouse in Relation to the Window Openings Calculated with CFD

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Keywords: greenhouse design, wind direction, size of window, climate

Abstract

Ventilation is the most important aspect for the climatization of greenhouses. Heat, moisture, and CO_2 are removed through ventilation. The effect of the dimensions of the ventilation windows and the orientation to the wind are investigated for a summer condition for a greenhouse design with a crop.

Calculations are done using computational fluid dynamics (CFD). The ventilation rate and the temperature distribution in the greenhouse are compared for the different ventilation openings. The influence of wind direction is determined at 5 m s^{-1} windspeed together with the situation when no wind is present.

The results show a large temperature gradient in the greenhouse. This gradient can be explained from the fact that the heat input is high causing a substantial temperature difference between the greenhouse air and the ambient. Ventilation increased as the window opening increased as expected. Opening only the window on the windward side resulted in almost double the ventilation than opening both the leeward and windward orientated windows. Side ventilation increases the ventilation especially when no wind is present.

INTRODUCTION

Ventilation is the most important instrument to influence the greenhouse climate. The size and shape of the windows in combination with the overall design of the greenhouse determine its ventilation characteristics. The greenhouse construction has to be optimized for its application. For a specific greenhouse design as depicted in Fig. 1 the influence of the size of the windows is investigated using computational fluid dynamics (CFD). The ventilation rate and the temperature distribution in the greenhouse are compared. The objective of the work is to determine the influence of the size of the windows opened on one or two sides of the ridge in relation to the wind direction and speed.

MATERIALS AND METHODS

The theory of computational fluid dynamics is described in numerous textbooks and publications (Boulard et al., 2002; Mistriotis et al., 1997a,b; Versteeg and Malalasekera, 1995), and was for this reason not be described in the present paper. The CFD simulations were carried out with the commercial CFD package Fluent 5.3 (Fluent, 1998). The calculations will not be validated with experimental results but numerous other studies have shown that CFD is a useful tool to determine the ventilation characteristics (Campen and Bot, 2003).

Tracer gas measurements are done to determine the ventilation rate in practice where the decay rate measured. This method can also be applied in a simulation by making the simulation time-dependent (Bartzanas et al., 2004). Making a time-dependent simulation is more time consuming than a steady state simulation. For this reason a constant dosing of tracer gas is applied in this study and the resulting concentration in the greenhouse indicates the ventilation rate.

The ventilation flux ϕ_v in m^3/s is calculated assuming the background concentration of tracer gas to be zero by

$$\phi_v = \frac{\phi_{input}}{\left(\bar{c}_{greenhouse}\right) \cdot \rho_{air}}$$

where ϕ_{input} is the amount of tracer gas released in the greenhouse in kg/s; $\bar{c}_{greenhouse}$ is the average concentration of tracer gas in the greenhouse air in kg/kg; and ρ_{air} is the density of air in kg/m^3. The amount of tracer gas released in the greenhouse is small, 1 mg s^{-1}m^{-3}, so it does not influence the ventilation rate.

The greenhouse design depicted in Fig. 1 is investigated. The span width is 9.6 m. In total 5 spans are included and the length of the greenhouse is 50 m. The height of the window opening is 1.2, 2.1 and 3.4 m. The window roof openings are located on one side of the greenhouse ridge. For the windows with a size of 2.1 m, the situation is also investigated when the windows can be opened on both sides. The ventilation is determined for the summer situation so the windows are fully opened.

The solar radiation is released in the greenhouse directly in the crop. The resistance of the crop for the air is included in the model assuming the crop is a porous medium. The greenhouse is air tight except for the windows. The solar radiation is set at 600 W m^{-2} inside the greenhouse, of which 50% is transferred into sensible heat and the rest is used for the transpiration of the crop. This assumption is based on experimental measurements (Stanghellini, 1987). The heat is transferred to the air by the crop. The climate in the greenhouse is calculated without and with wind of 5 m s^{-1}. The wind direction has an angle of 80° to the gutter for both the lee and wind side since this is the dominant wind direction considering the placement of the greenhouse. The outdoor temperature is 20°C.

RESULTS AND DISCUSSION

In Table 1 the ventilation rate for all the configurations calculated is shown. Increasing the windows opening increases the ventilation rate. The configuration where both windows are opened has a lower ventilation rate as compared to the single side opening when it is opened on the windward side. Opening only one side of the windows causes the air to be forced into the greenhouse, where with a double sided opening part of the air directly flows out of the opposite window again. This can be concluded for the velocity vectors depicted in Fig. 2.

The temperature profile in the greenhouse at a height of 1 m for the windward ventilation is depicted in Fig. 3. The wind direction is from left to right. At the first opening the air is entering the greenhouse causing the relative cold area and the air exits of all the other windows. Temperature differences in the greenhouse are around 10 K. This relative high temperature difference can be explained by:

1. Due to the solar radiation a temperature difference between the greenhouse and the outside air has to be present. If, for example, the ventilation is 30 renewals per hour and the sensible heat released in the greenhouse is 300 W m^{-2} like in the simulations, the temperature difference when the greenhouse has a height of 4.5 m is 6.7 K. This is the mean temperature difference, the extremes are larger. The relation between temperature differences and ventilation rate is also depicted in Fig. 4.
2. Little is known about the temperature difference in greenhouse during periods of high solar radiation. In an article by Fernandez and Bailey (1994) a temperature measurement was done in a small Venlo-type (13 by 33 m). They measured temperature differences of more than 8 K when the solar radiation was around 500 W m^{-2}.
3. The calculation is a steady state situation. In practice the wind (velocity and direction) and the buoyancy are very unstable. Regions of warm air tend to move around causing the average temperature at a certain location to be less extreme.
4. The transpiration of the crop affects the temperature of the air. The crop transpires more when the surrounding air is dry and warm causing a cooling effect (Stanghellini, 1987). In the model the transpiration does not depend on the surrounding air conditions.

The temperature distribution for leeward wind and no wind is depicted in Fig. 5 and 6. The highest temperature can be seen more near the walls of the greenhouse for the leeward ventilation whereas this was more in the centre of the greenhouse for the windward case. The temperature distribution with windows on one side is better than on both sides though the ventilation rate is less. No wind causes large temperature gradients in the greenhouse. Large windows are essential in this case when no screening or cooling is applied. The greenhouse equipped with large windows ventilates better in the no wind condition than the greenhouse where both windows are opened which are smaller.

It can be concluded from these calculations that less surface area of window is needed to ventilate when the windows are only opened on one side of the ridge for leeward, windward and no wind.

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Tables

Table 1. The ventilation rate (h^{-1}) for the different window openings and wind variations.

Wind	1.2 m	2.1 m, single	2.1 m, double	3.4 m
Windward, 5 m s^{-1}	43	74	40	136
Leeward, 5 m s^{-1}	15	30	40	39
No wind	12	16	28	30

Figures

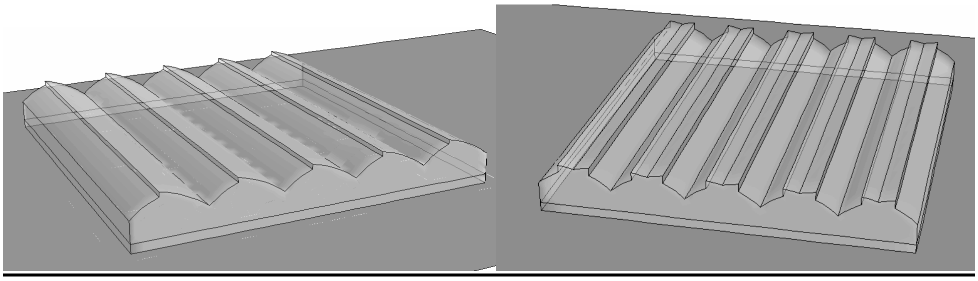

Fig. 1. The CFD model as used for the calculations with window on one side of the ridge with a height of 1.2 m (left); and with windows on both sides of the ridge with a height of 2.1 m (right).

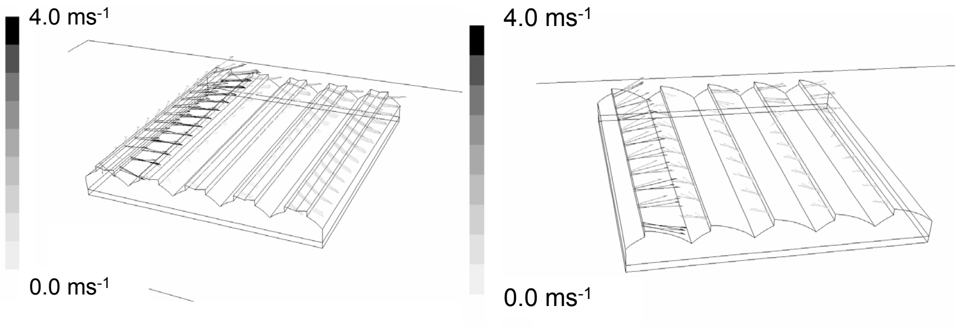

Fig. 2. Velocity vectors in the window for a double sided (left) and a single sided (right) window configuration.

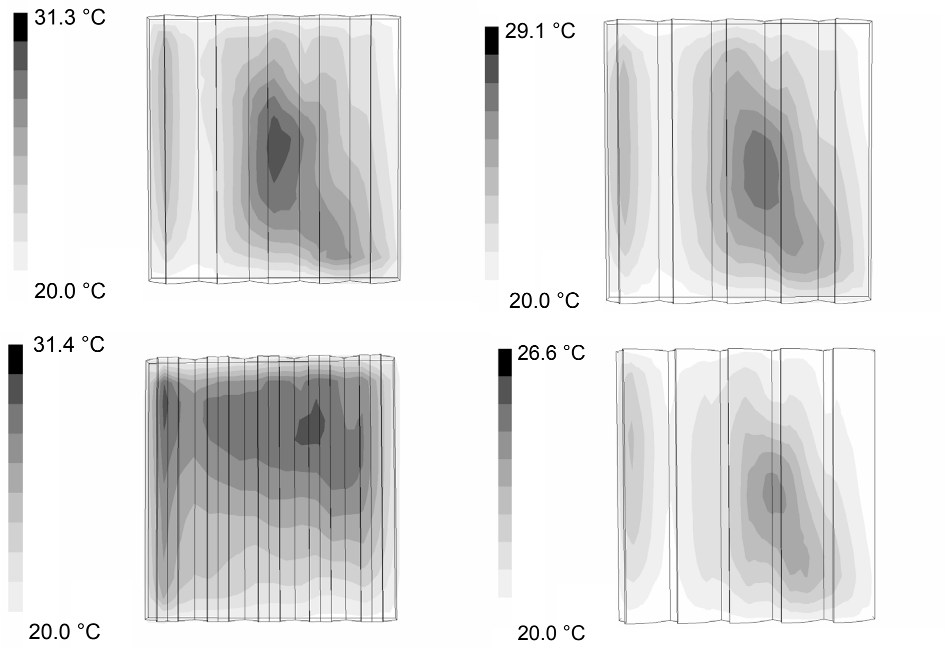

Fig. 3. Temperature profile at a height of 1 m with windward ventilation for 1.2 m (left above), 2.1 m single side opening (right above), 2.1 m both sides open (left below), 3.4 m window opening.

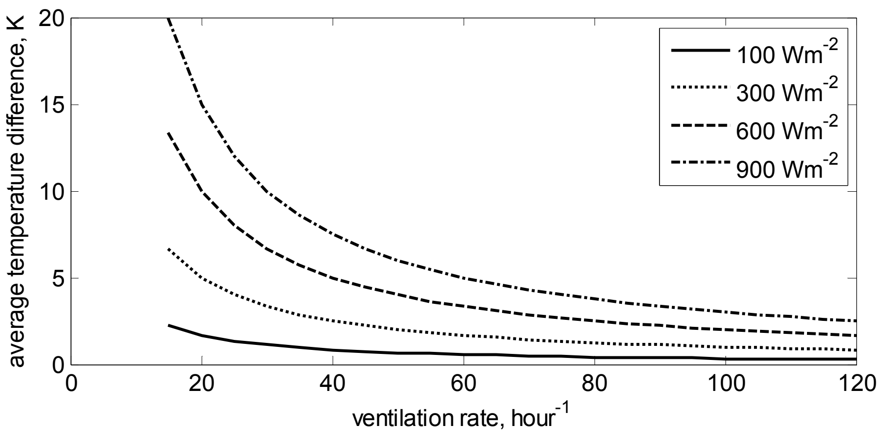

Fig. 4. Temperature difference between greenhouse and surrounding air as a function of the ventilation rate for various inside radiation levels, assuming 50% of the radiation is transferred into sensible heat and the rest into latent heat.

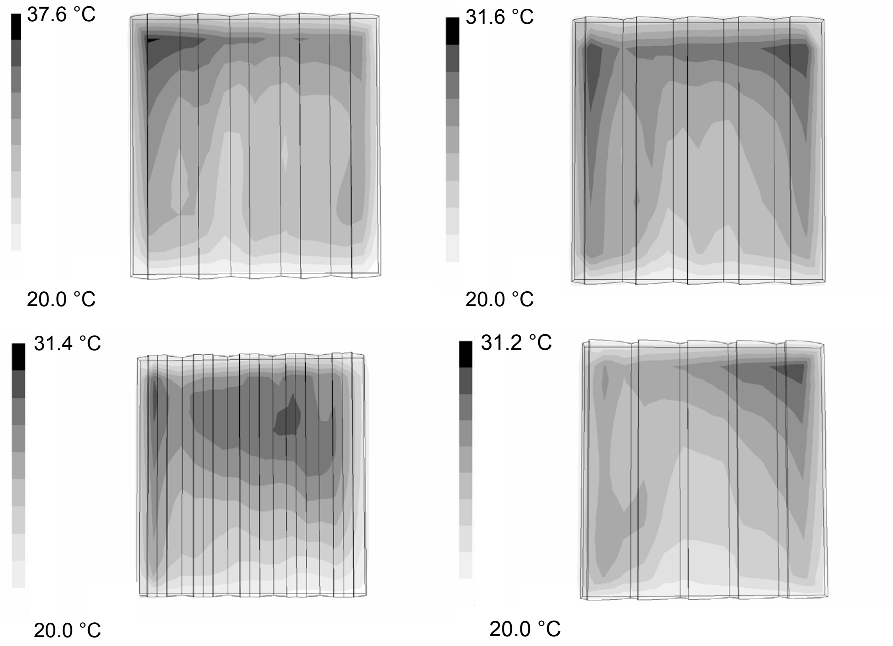

Fig. 5. Temperature profile at a height of 1 m with leeward ventilation for 1.2 m (left above), 2.1 m single side opening (right above), 2.1 m both sides open (left below), 3.4 m window opening.

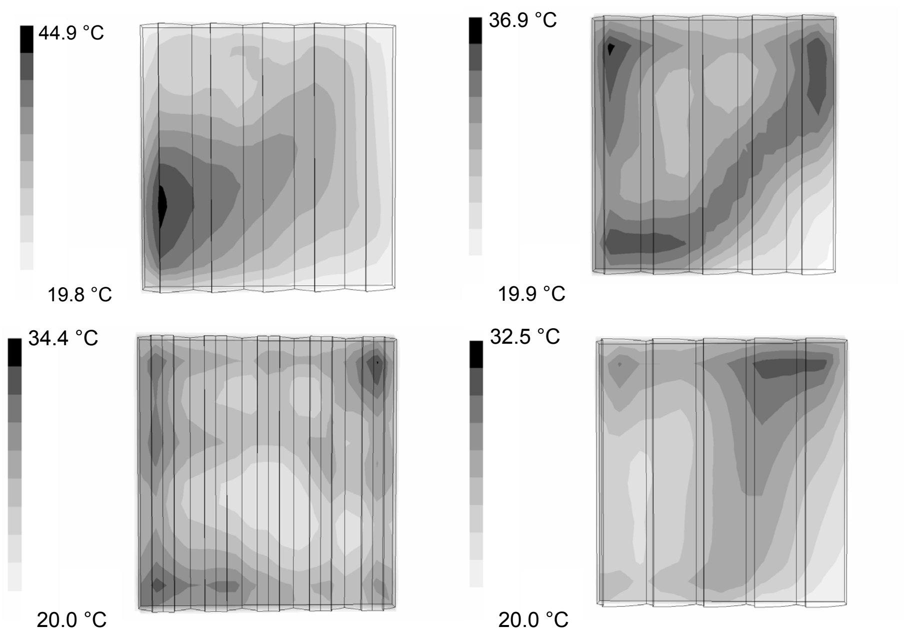

Fig. 6. Temperature profile at a height of 1 m with no wind for 1.2 m (left above), 2.1 m single side opening (right above), 2.1 m both sides open (left below), 3.4 m window opening.