CFD Simulation of Natural Ventilation of a Parral Greenhouse with a Baffle Device below the Greenhouse Vents

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Abstract

An efficient greenhouse cooling with natural ventilation must combine a sufficient number of air exchanges, in order to evacuate the excess sensible heat, with a good air circulation through the canopy. This can be usually achieved with a good combination of roof and not too distant side vents. However, many greenhouses do not have side vents, and air exchange takes place only through the roof vents. If such is the case, it has been observed on CFD simulations that most of the air is exchanged on the upper part of the greenhouse, whilst the air movement in the canopy area is poor, creating large and harmful hot zones. Different design changes can enhance air movement in the canopy area, such as increasing the size of the vents or the slope of the spans. The use of an air flow baffle device below the roof vents has proved to drastically increase air exchange on the canopy area in a single span greenhouse. The present work has used two dimensional CFD simulations to study the effect of 1 m high baffle devices located below the ridge of each one of the spans of a 5 spans parral type greenhouse, for three different roof vent configurations (all windward, alternate vents and double vents). Different wind velocities have been simulated and the results show that the present of the baffles does not affect overall air exchange rate for any of the configurations. However, air flow in the canopy area is enhanced, specially on the first spans, thus reducing temperature differences with the exterior. The air velocity fields suggest that the baffle devices do not have to be used in all the greenhouse spans, as similar results are achieved with baffles in only the first and last span.

INTRODUCTION

Natural ventilation is considered to be the most important tool to modify the greenhouse microclimate, in virtually all kind of greenhouse structures distributed throughout the world. Despite the trend in the most technified greenhouses towards closing the greenhouse, most of the greenhouse areas in the world will still rely on natural ventilation (frequently combined with shading) to cool the greenhouse during warm periods, to dehumidify during cold periods and to supply carbon dioxide with the outside fresh air. Recent works (Gazquez et al., 2006; Baille et al., 2006) have proved for summer Mediterranean conditions that the combination of a good natural ventilation system and a temporal whitening provided same or better results (yield and quality) for a bell type pepper crop, at a lower cost, than other cooling systems such as evaporative cooling or mechanical ventilation.

During the last two decades, more attention has been paid by researchers to a better understanding of natural ventilation processes (buoyancy and/or wind driven) in a wide range of greenhouse structures, from glasshouses to low cost tropical greenhouses (Bot, 1983; Fernández and Bailey, 1992; Boulard and Draoui, 1995; Papadakis et al., 1996; Kittas et al., 1997; Montero et al., 2001; Pérez-Parra et al., 2004). In these works, researchers have used different experimental techniques combined with a theoretical approach to carry on their studies, from mass balances (tracer gas methods) to direct measurements of pressure and velocity in the greenhouse. Recently, most of the efforts on greenhouse natural ventilation research have focused on the simulation of the natural ventilation processes by means of CFD (Computational Fluid Dynamics). Most of the works during the first years, as reviewed by Reichrath and Davies (2001) dealt with the validation and fine-tuning of the computer simulations with experimental measurements, increasing the complexity of the models by adding factors as the presence of insect-screens on the greenhouse vents or including the crop and accounting for its effect on airflow and on the energy and water mass balance. Few of these first studies used CFD simulations as a designing tool to improve natural ventilation systems of the different greenhouse types. However, during the last five years, as reviewed by Norton et al. (2007), CFD has been widely and more accurately used as a powerful designing tool to improve the performance of the natural ventilation systems of the greenhouse.

As reported by Bartzanas et al. (2004), maximizing ventilation rate values must not be considered as a unique target criterion when evaluating ventilation performance with different design configurations. A good natural ventilation performance must also enhance air movement on the canopy area (lower part of the greenhouse) and create a temperature field as homogeneous as possible, minimizing the presence of hot spots (poor air exchange areas) inside the greenhouse. The role of sidewall vents, in combination with roof vents, in providing a more uniform environment with natural ventilation is fundamental (Bartzanas et al., 2004; Baeza, 2007), although the presence of a well developed crop, specially the orientation of the rows in relation to the side vents, has a very important effect derived from its drag effect (Sase, 2006). In large greenhouses, the absence of sidewall vents is quite common, even in Mediterranean areas (Baeza et al., 2006). Under such circumstances, air exchange takes place only through roof vents. Such is the case of many parral type greenhouses (Baeza et al., 2006), in which air movement in the canopy area is usually very poor ("no crop-small crop" scenario).

Nielsen (2002) studied the effect on the natural ventilation process of a top screen located under a double roof vent in a single span glasshouse. The top screen increased an average of 50% the air exchange in the canopy area and decreased temperature an average of 2.1 ºC in relation to the reference situation without top screen. The aim of the present work is to perform 2D CFD simulations of the performance of the top screen device in an empty multi-span parral type greenhouse model, testing different vents-top screen configurations and evaluating its effect on the overall air exchange and on air movement and temperature field on the canopy area.

MATERIAL AND METHODS

All CFD simulations have been performed in two dimensions by means of a CFD commercial software (Ansys-Fluent v.6.0) which uses the finite volume method to solve numerically the set of equations which describe the ventilation process.

On a first set of simulations, three different vent (flap vents of standard width 0.8 m) configurations were tested (each one with and without 1m high top screens below the ridge of each span): all vents facing windward, alternate vents (windward-leeward) and double vents (Table 1). Then, for the double vents configurations, a simulation was performed including the top screen device below only the first and the last spans (Table 1). All simulations were performed for an empty greenhouse (a situation equivalent to a greenhouse in which small plants have just been transplanted).

The results of the CFD simulations of the natural ventilation performance of the “parral” type greenhouse have been previously validated with experimental results for both situations (with and without energy equation) studied in the present work in a good number of works (Campen and Bot, 2003; Molina-Aiz et al., 2005; Fatnassi et al., 2006; Baeza et al., 2007) in general, with very good agreement.

The different 2D models where created and meshed in Fluent´s pre-processor, Gambit, using the pave scheme for meshing, and increasing the density of cells inside the greenhouse and near the vents (0.2 m) in relation to the rest of the computational domain (0.4 m). The mesh had 151,791 cells. No grid dependence test was performed as the same mesh has proved to provide excellent agreement with experimental results in previous works for the same or very similar greenhouse models (Baeza et al., 2007). To cope with the turbulence created by the wind, the standard k-ε model was used in all the simulations, with and without considering buoyancy effects. First, simulations were performed for wind velocities of 2, 3, 4, 5 and 6 m s^{-1} without energy equation activated. Than simulations were performed for an outside wind of 4 m s^{-1}, activating energy equation (buoyancy effects), with an outside temperature of 303 K, greenhouse soil (sand mulch) temperature of 330 K and plastic film covering temperature 305 K (typical values for an average summer day in Almería around midday measured in an empty “parral” type greenhouse in the Experimental Station of Cajamar). The Boussinesq approach was used to accurately simulate natural convection inside the greenhouse. Continuity equation holding was checked after every simulation, comparing inflow and outflow.

RESULTS AND DISCUSSION

After convergence of the simulations, values of total ventilation flow (m^3 s^{-1}) were obtained for the different wind velocities (Table 2). This table shows results for the three studied vent configurations with and without baffle device below the roof vents. In general terms, a slight decrease in the ventilation rate is observed as a consequence of the presence of the baffle device for the three configurations. The alternate vent and the double vents configurations provide higher ventilation rate values in relation to the standard configuration (all flap vent facing windward) both without (Baeza et al., 2006) and with the baffle device. However, Nielsen (2002) observed an important increase on the ventilation rate values for both the lower and upper part of the greenhouse when placing the top screen baffle device. The reason for this can be found in the fact that Nielsen performed his tests in a single span greenhouse with a much higher slope than the simulated “parral” greenhouse (with the double vents configuration). The combination of a high span slope and a fully opened double vent on the ridge has been observed to cause a large amount of the air to pass below the vents without entering the greenhouse. The presence of the top screen below the vent must have forced the air to enter the greenhouse through the windward flap vent, driving it to the lower part of the greenhouse until the jet reached the leeward sidewall, which forced the air to leave the greenhouse through the leeward roof vent. A similar effect can be observed in the simulations (Figure 1) for the three studied vent configurations. The air entering through the windward vent of the first span is deviated by the baffle to the lower part of the greenhouse. When reaching the ground, part of the air creates a clockwise circulation in the first half of the first span (an area poorly ventilated in absence of baffle device and/or side vents), and the rest of the air flows through the lower part of the greenhouse, near the ground following the outside wind direction. An important increase in air movement on the lower part of the greenhouse can be observed on the first two spans.

It is important to check whether this important increase in the air movement is maintained all along the greenhouse or it only affects the first two windward spans. Figure 2 shows the air velocity vector magnitudes all along an imaginary line located 1.5 m above the greenhouse floor, for the double vent case with and without baffle devices. A very important increase in the air velocity is observed along almost the whole length of the first span (0-7.6 m) and the last span (30.4-38, with maximum values between 5 and 2 times higher than in the reference greenhouse model, for the first and last span respectively. These spans are the most affected by the baffle devices. Along the second, third and fourth span, a smaller increase in the air velocity is observed. In previous works, it has been observed with windward ventilation, for the same 5 spans “parral” type greenhouse, that the central spans have a much lower participation than the extreme spans. This suggests that the use of the baffle device might not be necessary below these spans. A new model, that includes baffle devices only in the first and last spans, was simulated, to test this hypothesis. Figure 2 also shows the air velocity values for this configuration, and it can be seen that in the first span, values are, as expected, almost coincident with the “all spans with baffle” configuration. However, for the rest of the spans slightly higher values of air velocity are observed, thus confirming that baffle device does not have to be installed in every span, at least in greenhouses with low number of spans.

Figure 3(a) and (b) shows the absolute temperature fields for the double vent configuration with baffle device below the extreme spans (1 and 5) and the standard configuration of double vents without baffle device. In general, a more homogenous temperature field, with lower temperatures is obtained thanks to the baffle device, especially on the first two spans of the greenhouse, an expected consequence of the previously described important increase in air movement experienced on this spans thanks to the baffle device.

CONCLUSIONS

According to the CFD simulations, the complementation of flap vents, especially the double vent configuration, with baffle devices below the ridges, affects little the overall air exchange, but increases greatly air movement and in the canopy area, especially in the extreme spans, homogenising and lowering temperatures in this zone. For this greenhouse size (five spans) it provides better result to install the baffle device only in the extreme spans, instead of below every span. It is necessary to perform simulations for larger greenhouses (more spans) in order to know whether it is necessary or not to include more baffle devices in middle spans.

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Tables

Table 1. Scheme of the studied natural ventilation configurations.

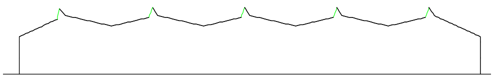
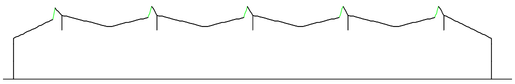
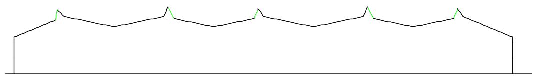
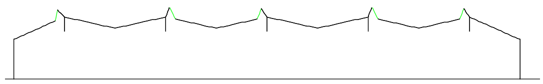
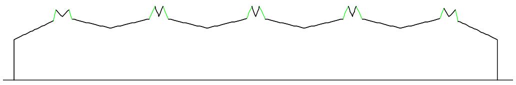
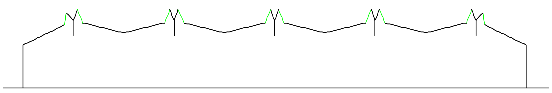
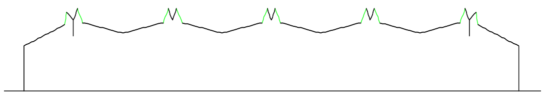
 Model 1(a). Windward vents (no baffle)  Model 1(b). Windward vents (baffle)	 Model 2(a). Alternate vents (no baffle)  Model 2(b). Alternate (baffle)
 Model 3(a). Double vents (no baffle)  Model 3(b). Double vents (baffle)	 Model 3(a) Double vents (baffle in spans 1 and 5)

Table 2. Ventilation flow (m^3 s^{-1}) for three different vent configurations (windward vents, alternate vents and double vents) with and without baffle device in every span, for different wind velocities.

Wind velocity ($m\ s^{-1}$)	Models 1(a) and 1(b) Ventilation flow ($m^3\ s^{-1}$)		Models 2 (a) and (b) Ventilation flow ($m^3\ s^{-1}$)		Models 3(a) and 3(b) Ventilation flow ($m^3\ s^{-1}$)	
	1 (a)	1 (b)	2(a)	2(b)	3(a)	3(b)
2	7,8	6,7	7,9	5,9	11	11,8
3	10,2	8,8	12,6	8,3	15,8	16
4	12,6	10,9	16,5	11	21,5	20,8
5	15,1	13,2	20,7	13,6	26,9	25,6
6	17,6	16	24,7	22,3	32,4	29,9

Figures

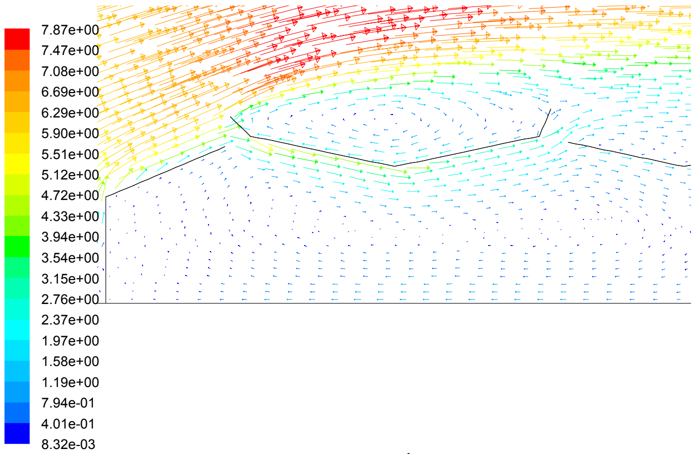


Figure 1(a). Air velocity vector field (m s^{-1}) in the first two windward spans of configuration 2(a).

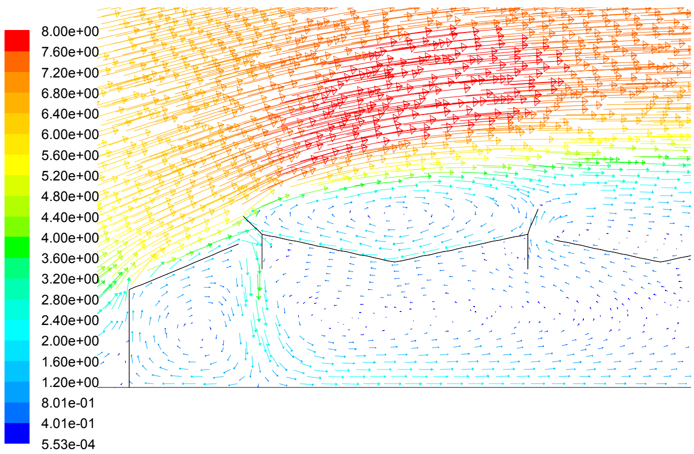


Figure 1(b). Air velocity vector field (m s^{-1}) in the first two windward spans of configuration 2(b).

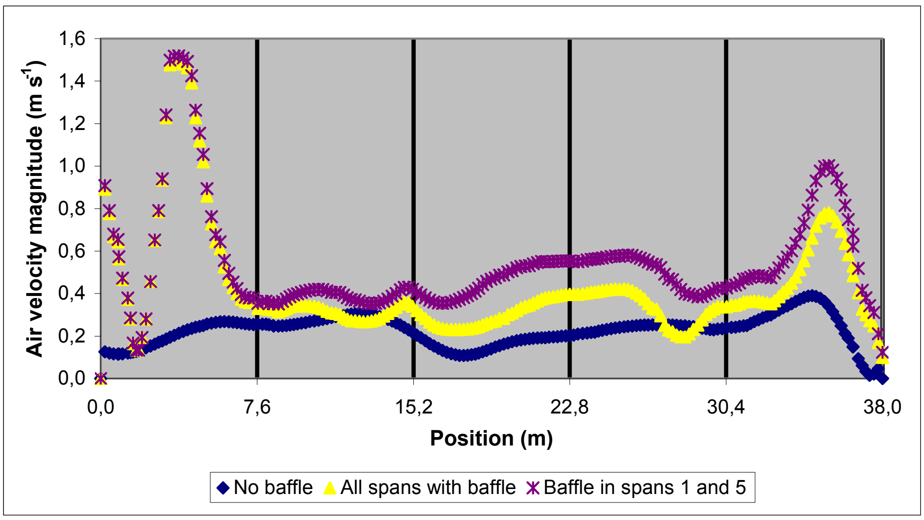
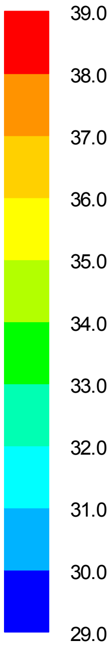


Figure 2. Air velocity values (m s^{-1}) at a heigh of 1.5 over the greenhouse floor, at different distances from the windward side-wall.



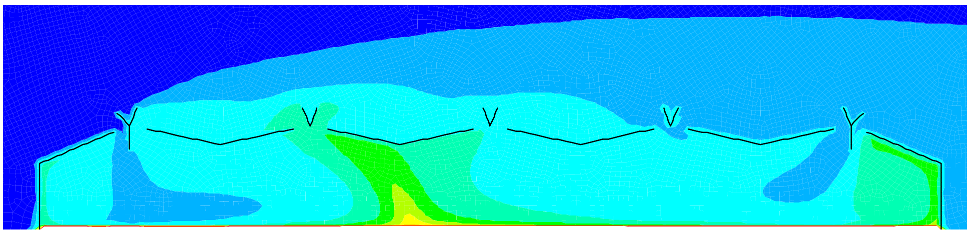


Figure 3(a). Absolute temperature field (ºC) for the greenhouse model with baffle device below the double vents on the extreme spans

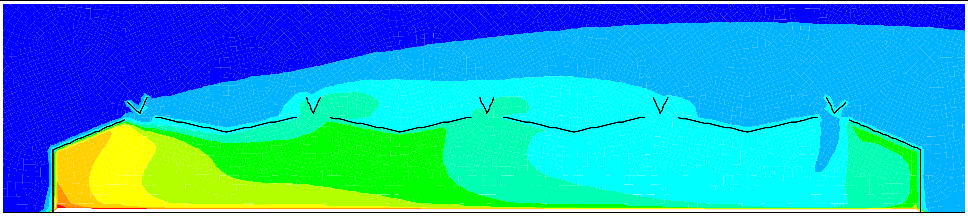


Figure 3(b). Absolute temperature field (ºC) for the greenhouse model without baffle devices