Effect of vent configuration and insect screen on greenhouse microclimate

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ABSTRACT

In this paper the effect of insect screens and vent configuration of a tunnel greenhouse cultivated with a tomato crop on airflow, temperature and humidity patterns was numerically analyzed using a commercial computational fluid dynamics (CFD) code. The numerical model was firstly validated against experimental data, which were carried out in an arch plastic covered greenhouse with continuous side openings. The three components of air velocity and the spatial distribution of air temperature and humidity were measured using a sonic anemometer and fast response sensors respectively. After the good agreement between experimental and numerically obtained results the code was used for parametric studies concerning the effect of different insect screens and vent configuration on the inside climate. Data from the experiments were used to define proper and realistic boundary conditions in the numerical model. A gradual increase of air temperature and humidity and a decrease of air velocity were observed as the porosity of the tested insect screen was reduced. It was found that vent configuration affects the ventilation rate and the climate distribution inside the greenhouse.

1. INTRODUCTION

Natural ventilation of a greenhouse is a complex process, which depends on the greenhouse characteristics (number, location and geometry of windows, area of leaks, etc.) as well as on the external ambient conditions. The role of natural ventilation is predominant in Mediterraneans’ region greenhouses, which are rudimentary equipped and natural ventilation is usually the only climate control system (Baille, 2004). Recently the occurrence of resistance to pesticides in several greenhouses key pests, the necessity to reduce environmental problems associated with the use of pesticides and the consumers’ demands for residue-free products increase the incorporation of insect screens in the ventilation openings. However, insect screens can considerably reduce the ventilation rate, since they act as an extra barrier on the air movement.

Several studies on natural ventilation were based on estimations of a global air exchange rate using tracer gas measurements (Fernandez and Bailey, 1992, Boulard and Draoui 1995, Kittas et al., 1996) and simulations of a homogeneous air temperature from energy balance models (Kindelan, 1980, Wang and Deltour, 1996). Direct estimates of the airflow through the ventilation openings have also been carried out by the measurement of pressure difference in several greenhouses (Kittas et al., 1996). More recently, sonic anemometry was used to measure airflow patterns in greenhouse ventilation openings (Boulard et al., 1997, Wang, 1998).

The resistance of insect screens has been investigated using the approach of Bernoulli with experimentally determined discharge coefficients (Montero et al., 1997, Munoz et al., 1999). Another approach has been based on the flow through porous media using the Forchheimer equation (Miguel, 1998, Bailey et al., 2003).

However none of the above methods allows improving the greenhouse vents’ design. This is because it is very difficult to give fairly identical and stable boundary conditions in field experiment. Moreover the above methods do not allow to clearly map airflow patterns and temperature and humidity profiles within the greenhouse and consequently to quantify greenhouse climate heterogeneity. Recent progress in flow modeling by means of computational fluid dynamics programs (CFD) enable easier studies of the scalars and vector fields present within the greenhouse climate by means of the resolution of the transport equations of the air that governs the ventilation.

Mistriotis et al. (1997) analyzed numerically the ventilation process in empty greenhouse. Boulard et al. (1999), Al-Arif et al. (2001), Campen and Bot (2003) studied various naturally and mechanically ventilated greenhouses. Haxaire (1999) first studied the effects of crop on the airflow inside the greenhouse and determined the drag effects of the plants. This relationship has been used in later CFD studies by researchers who included the dynamic effect of the crop to their simulations (Boulard and Wang, 2002, Bartzanas et al., 2004). The effect of insect screens placed over the ventilation openings were numerically studied by Bartzanas et al. (2002) and Fatnassi et al. (2003). Aim of the present study is after validating a commercial CFD code against experimental measurements to use this code for parametric studies in order to study the influence of insect screens and ventilators configuration on greenhouse microclimate.

2 MATERIALS AND METHODS

2.1 Experimental greenhouse

The experiments were performed in an arch, plastic covered greenhouse, located at the University of Thessaly near Volos. Detailed description of the greenhouse is given by Kittas et al. (2004). During the period of measurements the greenhouse was ventilated by side vents only without screen in the openings. The tomato crop had an average height of about 1.8 m.

2.2 Measurement

Measurements of the three components of air velocity, air temperature and humidity were carried out at 4 positions in the middle of the greenhouse along its North- South axis at 4 m, 8 m, 12 m and 16 m, from North side and at 5 positions in the middle of the greenhouse along its East- West width at 1 m, 2 m, 4 m, 6 m and 7 m from the East side. The height of the measurements was 1.1 m above ground, which coincided with the midpoint of side openings.

Rapid fluctuations in air velocity were measured by means of one three–dimensional (3–D) sonic anemometer with a sampling frequency of 5 Hz. The time duration of each measurement record was about 5 min. Dry and wet bulb temperatures were also recorded at the same points using an aspirated psychrometer. A weather station tower was installed outside the greenhouse to measure the local climate such as dry and wet bulb air temperatures, wind speed, wind direction and solar radiation. The above variables were also measured each second and averaged over the length of each record.

Measurements were carried out when exterior climatic conditions were stable mainly between one hour before and after solar noon with a relatively stable wind direction (north to south, between 0° and 45°, i.e. almost parallel to the greenhouse ridge). Table 1 summarizes the mean values of outside climate variables, during this period, which was used for the validation of the numerical model.

2.3 Numerical model

The CFD method allows the explicit calculation of the average velocity vector field of a flow by numerically solving the corresponding transport equations. The three dimensional conservation equations describing the transport phenomena for steady flows in free convection are of the general form:

Table 1: Average values of outside climate parameters during the period of measurements.

Parameter	Mean	St. Deviation
Wind speed	3.5 ms-1	0.2 ms-1
Wind direction	40	5
Air temperature	26 °C	0.3 °C
Air absolute humidity	30%	4%
Roof temperature	38 °C	0.4 °C
Greenhouse ground temperature	36 °C	0.2 °C
Soil temperature	36 °C	0.1 °C
Solar radiation	620 Wm-2	10 Wm-2

$$\frac{\partial(U\Phi)}{\partial x}+\frac{\partial(V\Phi)}{\partial y}+\frac{\partial(W\Phi)}{\partial z}=\Gamma\nabla^2\Phi+S_\Phi \qquad (1)$$

In Eqn (1), Φ represents the concentration of the transport quantity in a dimensionless form, namely the three momentum conservation equations (the Navier-Stokes equations) and the scalars mass and energy conservation equations; U, V and W are the components of velocity vector; Γ is the diffusion coefficient; and S_Φ is the source term.

The commercially available CFD code Fluent® was used for this study. The code uses the finite volumes numerical scheme to solve the equations of conservation for the different transported quantities in the flow (mass, momentum, energy, water vapour concentration). For the geometry, a control volume was selected representing a large domain including the greenhouse. The grid structure was an unstructured, quadrilateral mesh with a higher density in critical portions of the flow subject to strong gradients. Pre-simulations were carried out to confirm grid-independence. The standard *k-ε* model (Launder & Spalding, 1974) assuming isotropic turbulence was adopted in this study to describe turbulent transport. The complete set of equations of the *k-ε* model can be found in Mohammadi and Pironneau (1994).

As the prevailing wind direction was parallel to the greenhouse during the experiments, a 3–D model was first built in order to compare the numerical results with the experimental data. At the inlet of the computational domain a logarithmic inlet velocity profile (atmospheric boundary layer model) was considered. All the other simulations, used for cases studies, were two-dimensional since the selected wind direction for the simulations was perpendicular to the axis of the greenhouse.

The crop was simulated using the equivalent porous medium approach by the addition of a momentum source term, due to the drag effect of the crop, to the standard fluid flow equations (Boulard and Wang, 2002). For the insect screens, the Darcy-Forcheimer parameters were considered depending on the porosity of the screen using the following relations (Miguel, 1998):

$$K = 3.44\times10^{-9}a^{1.6} \qquad (2)$$

$$Y = \frac{4.3\times10^{-2}}{a^{2.13}} \qquad (3)$$

where a is the screen porosity, K is the screen permeability in (m^2) and Y is a non-linear momentum loss coefficient due to the screen.

The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm was applied to solve the flow field. The Simple algorithm uses a relationship between velocity and pressure corrections to enforce mass conservation and to obtain the pressure field.

3. RESULTS AND DISCUSSION

3.1 Numerical model validation

Figure 1 and 2 shows the experimentally and numerically obtained average transverse horizontal component of the normalised air velocity along the greenhouse length and greenhouse width respectively at a height of 1.1 m above ground in the middle of the greenhouse. The normalized air velocity was obtained by the ra-

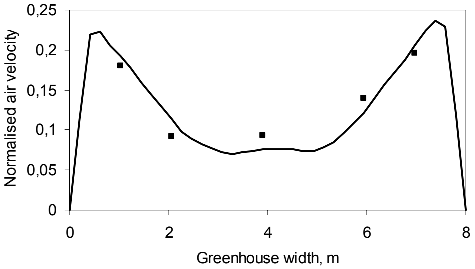

Figure 1: Experimentally (■ ■ ■) and numerically (—) obtained average transverse horizontal component of the air velocity along the greenhouse width at a height of 1.1 above ground normalised by the outside wind speed.

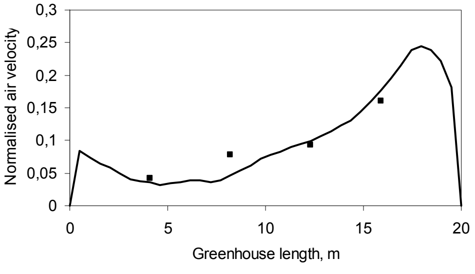

Figure 2: Experimentally (■ ■ ■) and numerically obtained (—) average transverse horizontal component of the air velocity along the greenhouse length at a height of 1.above ground normalised by the outside wind speed.

tio of interior air velocity to the mean external wind speed. For roll-up openings without screen and for a wind direction parallel to the greenhouse axis, both computed and simulated values show that air speed has relative high values near the openings and reduced values near the center of the greenhouse (Fig. 1). Air velocity was lower form the windward to the leeward part of the greenhouse along its axis (Fig. 2).

In general, a good agreement between measured and numerical obtained results was found. The differences between computed values by the CFD model and measured were between 0 to 0.25 ms^{-1} for air velocity, 0.1 to 1.9 °C for air temperature; and 5.9 gkg^{-1} to 7.1 gkg^{-1} for air absolute humidity.

3.2 Influence of insect screen

After the good fit between measured and numerically obtained values, the numerical model was used for parametric studies.

Two commonly used types of insect screens were studied (a) an anti-bemisia insect screen with a porosity of 0.69 and (b) an anti aphid screen with a porosity of 0.56 and

Figure 3 presents the influence of insect screen on the air velocity along the greenhouse width at a height of 1.1 m. The use of an anti-bemisia screen reduces the mean air velocity inside the greenhouse by 30% and the use of an anti-aphid screen by 70% compared to the values of air velocity for a greenhouse without screen. For an outside air velocity of 3.5 m s^{-1} ventilation rate was reduced from 19 m^3s^{-1} for a tunnel greenhouse without screen to 14 m^3s^{-1} by the use of an anti-bemisia screen and to 7 m^3s^{-1} by the use of anti-aphid screen.

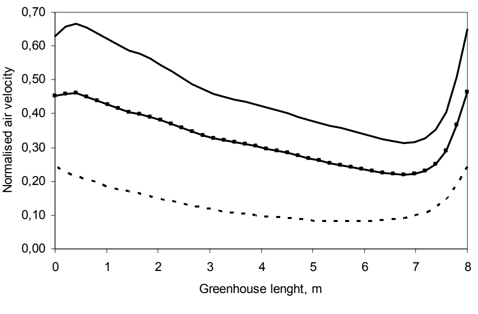

Figure 3: Normalised air velocity along the greenhouse width at a height of 1.1 above ground, for a tunnel greenhouse with side vents without screen (——), with anti-aphid insect screen (— — —) and with anti-bemisia insect screen.

The mean temperature difference between inside and outside air for a greenhouse without screen was 2.1°C, 2.8°C with the use of an anti-bemisia screen and 4.2°C with an anti-aphid screen.

3.3 Influence of ventilator configuration

In order to numerically examine the influence of vents configuration on greenhouse microclimate the following cases were examined: (a) *side openings only*; the greenhouse is equipped with two continuous roll-up type openings located 0.6 m aboveground with a maximum opening height of 0.9 m. This configuration leads to a total opening area of 36 m^2, (b) *roof openings only*; the greenhouse is equipped with a pivoting type roof opening. This configuration leads to an opening area of 18 m^2 and (c) *combined roof and side openings*; This configuration combines the roll- up side openings of configuration (a) and the roof opening of configuration (b) leading to a total opening area of 54 m^2.

Using side openings only the air velocity inside the greenhouse was characterized by a strong air current near the greenhouse ground and low air velocities near the roof. The combination of roof and side openings increases air velocity inside the greenhouse due to the entrance of air through the roof opening (Fig. 4). Finally almost still air conditions prevail at the centre of the greenhouse.

Temperature and humidity distribution inside the greenhouse follows the air velocity profile and in regions with small air velocities the air was warmer and more humid compared with the air in regions with high air velocities. Figure 5 presents the computed temperature contours for a greenhouse with roof and side openings. Due

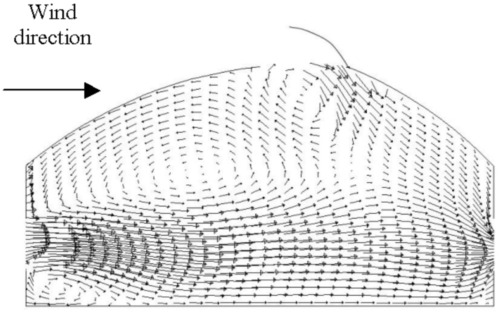

Figure 4: Computed air velocity vectors in a tunnel greenhouse with roof and side openings.

Table 2: Mean and standard deviation values of air velocity (u), and air temperature difference between inside and outside (ΔT) for a greenhouse with side openings only (a), with roof openings only (b) and with both side and roof openings (c).

Case	$\bar{u}$, m^3s^{-1}	σ_u, m^3s^{-1}	$\overline{\Delta T}$, °C	$\sigma_{\Delta T}$, °C
(a)	0.8	0.5	2.4	0.21
(b)	0.2	0.15	3.8	0.12
(c)	1.1	0.58	0.9	0.25

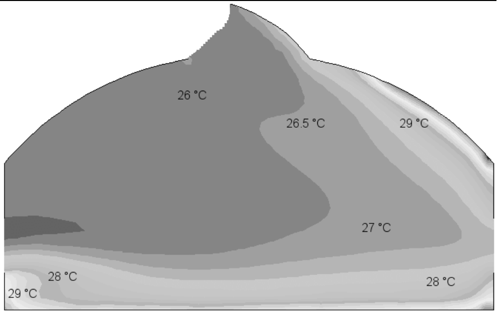

Figure 5: Computed temperature contours of a tunnel greenhouse with roof and side openings.

to the higher air velocities achieved by this configuration inside air temperature was close to outside except for regions near greenhouse floor where air temperature was 3-4 °C higher than outside air temperature. Similar patterns were observed for air humidity (results not shown).

For each vent configuration type, the efficiency of the vent was considered by the mean value of air velocity inside the greenhouse, and the mean air temperature difference between the inside and outside environment. The standard deviation of the above mentioned parameters was used as a criterion for their homogeneity. Table 2 summarises the above results

It is clear that configuration (c), with both roof and side openings was the most efficient since achieved the highest air velocity and the lowest air temperature difference. Similar results were observed for configuration (a). On the contrary from the ventilation efficiency point of view, configuration (b) with roof opening only gave the worst results and presents the lowest ventilation efficiency by elementary surface of opening.

Considering the homogeneity of climate distribution for each vent configuration (b) with roof opening only gave the best results and configuration (a) the worst

5. CONCLUSION

The influence of vent configuration and insect screen on greenhouse microclimate was numerically examined. The numerical code was verified against experimental data with good agreement. The results presented in this work demonstrate the major influence of insect screens on internal greenhouse climate and the necessity to increase the opening area while using insect screens. For the tested vent configurations, the roof and side openings configuration was the most efficient in reducing the inside air temperature while the better climate homogeneity was achieved with roof openings only.

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