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Influence of vents arrangement on greenhouse thermal driven ventilation

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Abstract: A numerical analysis of the natural ventilation in greenhouse was performed at no-wind and low-wind speeds with the use of Computational Fluid Dynamics CFD. Imposed boundary conditions correspond to the average measured experimental values during a ten days period. Numerical predictions of the ventilation efficiency and microclimate distribution of an arch type tunnel greenhouse were obtained for various ventilator configurations. Quantitative and qualitative results concerning airflow and air temperature distribution for two different vents configurations were collected and analysed. Numerical predictions of natural ventilation agreed well with relative published data. Results show the importance of rollup sidewall ventilators for efficient thermally driven ventilation.

Key words: natural ventilation; CFD-CFX1; convection; greenhouse; climate distribution.

1. Introduction:

Excessive temperature is probably the most serious problem faced by greenhouse growers in hot and warm Countries like the Mediterranean area. In fact due to the high thermal loads during the warm period, growers are forced to reduce cultivation period. Attempts have been made to reduce the greenhouse temperature by shading greenhouses (Baille et al. 2001) or evaporative cooling (Kittas et al. 2003).

However the majority of greenhouses in the Mediterranean area are rudimentary equipment and natural ventilation is the primary control tool to manage greenhouse microclimate.

Natural ventilation driving force is the combination of buoyancy and wind effects, and their relative importance depends on the wind speed and the internal to external temperature differential. In these greenhouses, ventilation plays a key role in determining the greenhouse microclimate, affecting specifically the temperature, humidity and composition of the greenhouse air, and influencing crop growth and development.

The most unfavorable conditions for ventilation are when the wind speed is near zero and thermal effects control the exchange of air.

This is particularly crucial during calm summer periods when greenhouse cooling is needed. Until recently, most studies of natural ventilation were based on estimates of a global air exchange rate from tracer gas measurements (Boulard and Baille, 1995) or energy balance methods (Kimball, 1986), which provides no details of internal flow patterns and temperature profiles. These studies assumed a global homogeneity of the greenhouse atmosphere and a uniform air temperature and a uniform air velocity are applied. However, this is not the case, since greenhouse microclimate was characterized by strong heterogeneity. Recent progress in computer performance and developments in flow modeling using computational fluid dynamics (CFD) provide à new opportunity to analyse the heterogeneity of greenhouse microclimate. In the CFD model actual weather conditions and structural specifications can be change easily while maintaining stable boundary conditions. Since the pioneering works of Nara (1979) in assessing the distributed climate in a greenhouse, many studies have been undertaken to achieve a better understanding of the ventilation mechanism in greenhouses, even in vary large structures (Fatnassi et al. 2003; Campen and Bot, 2003; Bartzanas et al.2004).

In many regions with intense greenhouse cultivation, weak wind situations coincide with high temperatures, when high ventilation efficiency is mostly required. Therefore, the investigation of the structural characteristics of greenhouses influencing the ventilation process at low-wind-speeds can offer hints for improvements of the greenhouse design towards more efficient thermally driven ventilation. Aim of the present study was to numerically investigate the influence of four commonly found vent configuration on airflow temperature patterns in a typical Mediterranean greenhouse type at zero and low wind speeds.

2. Numerical model:

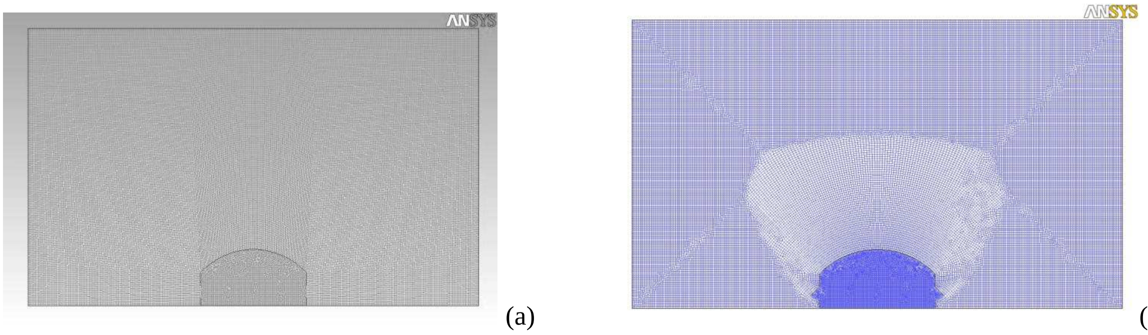
The CFD technique numerically solved the Navier-Stokes equations, the mass and energy conservation equations. The three dimensional conservation equations describing the transport phenomena for steady flows in free convection are of the general form:

$$\frac{\partial(\rho C_\phi \Phi)}{\partial t} + \frac{\partial(\rho u_i C_\phi \Phi)}{\partial \chi_t} = \Gamma_\phi \frac{\partial^2 \phi}{\partial_i^2} + S_\phi \qquad (1)$$

In Eqn (l), 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 governing equations are discretised following the procedure described by Patankar (1980). This consists of integrating the governing equations over a control volume. The commercially available CFD code CFX® was used for this study. CFX® code uses a finite volume numerical scheme to solve the equations of conservation for the different transported quantities in the flow. The code first performs, the coupled resolution of the pressure and velocity fields and then the others parameters, like temperature or water vapour concentration.

Special items like the mechanical or climatic behavior of the rows of tomato crop are determined using a customization, i.e a routine included in a used defined file (UDF) and built for the determination of the parameters exclusively relevant to the vegetation. The domain of interest was generated and then meshed using the integrated preprocessor.

For the simulations a 3-D model was developed. For the geometry, a control volume was selected representing a large domain including the greenhouse. The tested greenhouse was an arch type tunnel greenhouse, which geometrical characteristics were as follows: eaves height of 2.4 m; ridge height of 4.1 m; total width of g m; and total length of 20 m. The grid structure was an unstructured, quadrilateral mesh with a higher density in critical portions of the flow subject to strong gradients (Fig. 1). The final grid size was the result of an empirical compromise between a dense grid, associated with a long computational time, and a less dense one, associated with a marked deterioration of the simulated results.



(a) (b)

Figure l. Detailed greenhouse grid description of the tested configurations (a) and (b)

The standard k-ε model (Launder and Spalding, 1974) assuming isotropic turbulence was adopted in this study to describe turbulent transport. This choice is a good compromise for a realistic description of turbulence and computational efficiency. The standard k-ε model is a semi-empirical model based on model transport equations for the turbulent kinetic energy (k) and its dissipation rate (ε) the wind direction was perpendicular to the ridge. At the inlet of the computational domain a logarithmic inlet velocity profile (atmospheric boundary layer model) was considered. Wall-type boundary condition was imposed along the floor, the roof and the side walls. The boundary conditions were selected from average values of experimental data (Table 1). The classical no-slip boundary conditions are assumed for the walls. The crop was simulated using the equivalent porous medium approach (Boulard and Wang, 2002) by the addition of a momentum source term, due to the drag effect of the crop, to the standard fluid flow equations.

Configuration (a): side openings (roll-up type) the greenhouse is equipped with two continuous rollup type openings located at 0.6m above ground with an opening height of 0.9m.

Configuration (b): side openings (pivoting door type) the greenhouse is equipped with two continuous pivoting door type side openings. The base of the window is at 0.6 m above ground, the height of the window is 0.9 m and the aperture angle is 45^o.

Table 1. Boundary conditions

Parameter	*Mean*
Wind direction	Perpendicular to the ridge
Temperature	
of the cover, °*C*	32.00
of inside ground, °*C*	45.00
of outside ground, °*C*	30.00
of outside air, °*C*	28.00
Inlet air	
velocity, $m\ s^{-1}$	0; 0.5; 1
density, $kg\ m^{-3}$	1.22
gravitational acceleration, $m\ s^{-2}$	9.81
specific heat, $J\ kg^{-1}\ °C$	1004.00
thermal conductivity, $W\ m^{-2}\ °C^{-1}$	0.0263
Plant canopy	
pressure drop coefficient	0.395
inertial loss factor	0.20
Solar radiation Wm^{-2}	950

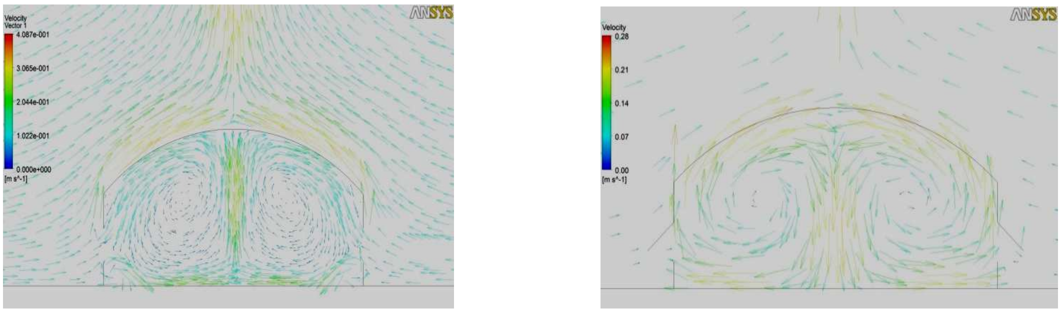
3. Results and discussion:

The ventilation of a greenhouse is the exchange of air between the inside and outside atmosphere in order to dissipate the su4ilus heat to enhance the exchange of carbon dioxide and oxygen and to maintain acceptable humidity levels. A well designed greenhouse with a high air renewal rate uniformly reduces the indoor temperature by ventilation, especially at the canopy level.

Figure 3 presents the computed velocity vectors for the greenhouse equipped with side only openings when the ventilation is purely thermal driven (i.e the outside wind speed was 0 m/s).

Two circulating cells were observed in the cross-section for the both configurations, each occupying nearly half the cross-sectional area. The first one, on the left-hand side, was anti-clockwise, and the second one on the other side was clockwise for the configuration (a) and the opposite for the configuration (b). Both cells met in the central vertical axis of the greenhouse. So, due to the strong mixing, a more or less uniform temperature in the growing area was achieved.

The flow of the warm air is almost vertical due to the buoyancy effect and it reaches greenhouse rood before it exits through the side openings. Similar airflow and temperature patterns were observed by Lamrani et al (2001) using a small scale greenhouse in a wind tunnel.

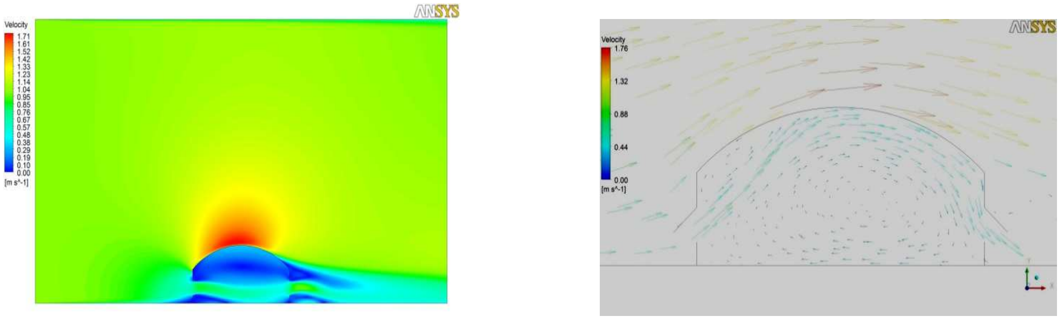


Configuration a Configuration b

Figure 3. Computed velocity vectors for an outside wind speed of 0 m/s

When the outside wind speed increased to 1m/s, figure 4 then greenhouse ventilation is both thermally and wind driven. With side openings (configuration a) airflow was characterized by a strong air current near the ground and a re-circulation loop with slower speed situated near the roof and flowing counter current with respect to outside wind. In the region covered by the crop the air temperature is similar to the outside due to the strong air stream in this region. The mean air temperature difference at his zone and the outside air was 0.5^{o}C figure 6 configuration (a).

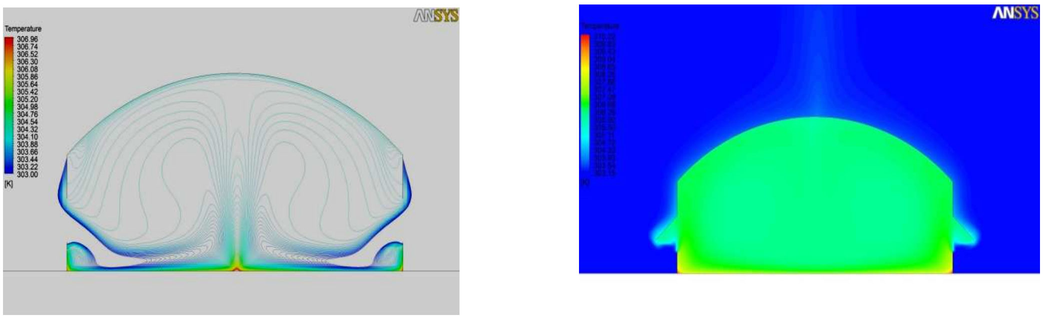
With the second vent configuration airflow pattern shows that the incoming air through the windward side ventilator tends to move up immediately by the influence of inclined ventilator flap and mainly follows the inner surface of the roof. In the space to be occupied with a crop, the reverse flow due to secondary circulation result in the significant decrease of the air velocity. In the region covered by the crop the air temperature was higher than the outside since the main air steam was guided to the roof of the greenhouse. As a result, mean air temperature difference at his zone and the outside air was 2.1^{o}C figure 6 configuration (b).



Configuration (a) Configuration (b)

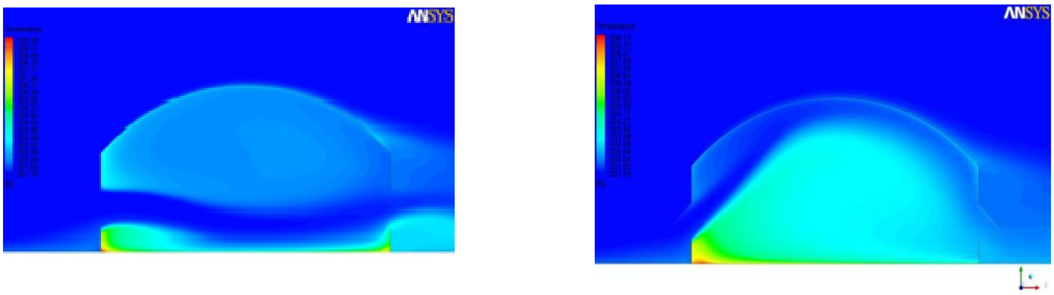
Figure 4. Computed velocity vectors for an outside wind speed of 1 m/s

For the first vent configuration similar with the first vent configuration airflow and temperature pattern was observed. The airflow was thermally driven and the different vent configuration cannot alter the distribution of climate variables within the greenhouse figure 5.



Configuration a Configuration b

Figure 5. Computed temperature contours for an outside wind speed of 0 m/s



Configuration a Configuration b

Figure 6. Computed temperature contours for an outside wind speed of 1 m/s

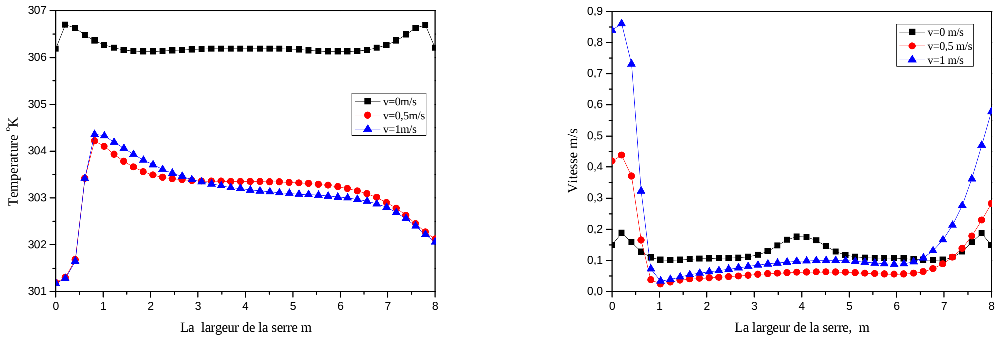


Figure 7. Air velocity and temperature distribution along greenhouse width at a height of 1 m from greenhouse ground for the configuration (b)

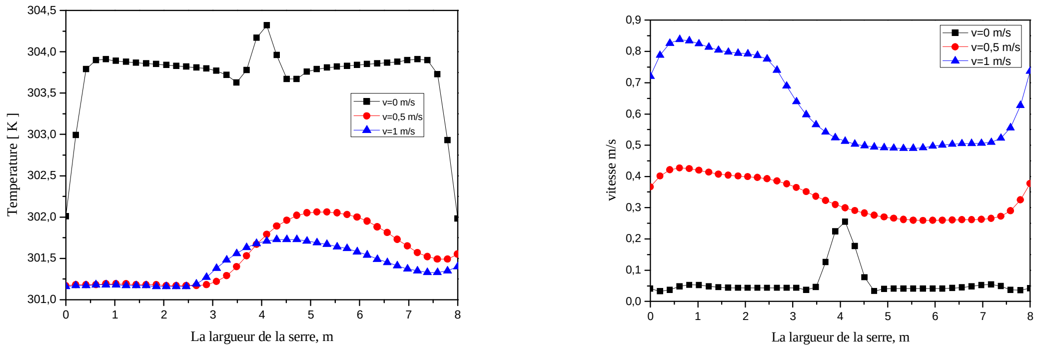


Figure 8. Air velocity and temperature distribution along greenhouse width at a height of 1 m from greenhouse ground for the configuration (a)

Conclusion

In the present work, we attempt to introduce a numerical approach for investigating the ventilation efficiency of greenhouses under low-wind-speed conditions. For this reason, we analysed the ventilation behavior of greenhouse structures when air temperature differences constitute the main driving force of the flow (‘buoyancy effect’).

Most of the greenhouse designers usually neglect to optimise the greenhouse thermally driven ventilation since low-wind-speed conditions are rare in agricultural areas. Nevertheless, low-wind-speeds frequently coincide with high temperatures, when high ventilation efficiency is mostly required. Therefore, more attention should be given to the ventilation efficiency under low-wind-speed conditions.

The present results showed the importance of ventilation combined with' sidewall ventilation for effective greenhouse ventilation. Results also showed that other parameters such as climate heterogeneity should be investigated in order to define the best ventilation configuration. CFD modeling is a powerful tool to help manufacturers to improve greenhouse designs and to adapt equipment to specific situations

Nomenclature

Symbole	Nom, *unité*
C_φ	advection coefficient
S_Φ	source term
T	température, *(°C)*
u_i	component of velocity vector in I direction

Greek Letters

α	Diffusion coefficient
ΔT	temperature difference, *°C*
ρ	air density, *(kg/m3)*
σ	standard deviation
φ	concentration of transported quantity

Exposant, Indices

i	inside
o	outside

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