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COMPUTATIONAL FLUID DYNAMIC MODELING TO IMPROVE THE DESIGN OF THE SPANISH PARRAL STYLE GREENHOUSE

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Computational Fluid Dynamic Modeling to Improve the Design of the Spanish Parral Style Greenhouse.

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Abstract. *The Parral type of greenhouse is very common in Southern Spain and other areas of the Mediterranean Sea. It is a simple, low cost greenhouse structure. Ventilation is by small ridge openings that are covered with rolling flaps or operable vents. Some also had limited sidewall openings. These conditions results in major heat stress to the plants.*

Computational Fluid Dynamic (CFD) models of the greenhouses were developed. The models were two-dimensional, steady state using various viscosity models. The results for the airflow through the vent openings and the actual vent opening areas were used to calculate air exchange rates for wind speeds of 2, 3, 4, and 5 m/s. These results compare favorable to tracer gas measurements that were reported in earlier manuscripts. The model will be used to evaluate several design and management changes for this type of greenhouse.

Keywords. *Ventilation, Computational Fluid Dynamics, Greenhouse*

Introduction

The parral greenhouse is becoming increasingly important, mainly because of its widespread use. In Spain, it comprises 84% of the total greenhouse area, and in the providence of Almeria, the most important in Spain for protected horticulture, there are approximately 25.000 ha of parral greenhouses (Sanjuan, 2000). It is the dominant greenhouse structure in Spanish southeast as well as in the Canary Islands, and its use is increasing in other Mediterranean areas such as North Africa (Morocco). Its use is also expanding into Mexico and South America where the climate is similar to the Mediterranean.

The parral greenhouse, Fig.1, can be defined as a simple, low cost, structure for protection of the crops. The greenhouse has evolved from the original use of posts to support vines (Pérez Parra, 1998). Basically, the greenhouse consists of a supporting structure of vertical wooden, concrete or metal posts spaced at intervals which vary from 1 to 2 m around the perimeter and 2 to 3 meters inside the greenhouse. The lower end of the posts set in the soil and their upper ends are connected by a flexible wire grid. The plastic film covering material is supported by this wire grid and is held in place by a second wire grid placed over the film. The roof pitched roof varies from flat to a typical inclination of 11-13º to the horizontal plane. Holes are made in the plastic film along the valleys to allow the rain water to pass through the cover and be collected using plastic or galvanized steel gutters.

Figure 1. Parral greenhouse with openable flap.

Since the cost of mechanical ventilation is too high to be acceptable for the area, natural ventilation is the cheapest, most practical and commonly used method to ensure a near optimal greenhouse climate during both warm and cool periods (Papadakis et al., 1996; Boulard & Draoui, 1995; Montero et al., 1996).

Natural ventilation of the parral greenhouse relies on sidewall or sidewall and roof openings. The roof openings are closed with either rolling covers (23% of parral multispan greenhouses) or flap covers (14% of parral houses). The others have only side ventilation. The sidewall openings are created by manually lowering the plastic wall covering. Rolling covers are operated manually and consist of a pipe on which the plastic film is rolled or unrolled to open and close the cover. Flap covers have plastic on a rigid frame and are opened and closed manually. Normally, they have smaller opening areas than the rolling cover type.

The main internal climate problem of these greenhouse types in the Mediterranean region is the excess of daytime sensible heat which causes high temperatures to occur from early spring until the end of the autumn. These high temperatures have very negative effects on the yield and the quality of most of the greenhouse crops grown in the area. In most of the cases, the principal reason causing these excessive temperatures is the lack of ventilation.

The insufficient ventilation also affects the inside air composition, because CO_2 levels can drop down drastically (Hand, 1984; Lorenzo et al., 1990; Lorenzo, 1994), reducing growth and productivity of the crop (Hand, 1984), and high relative humidities may occur, increasing the risk of fungal diseases (Mistriotis et al., 1997) and decreasing nutrient uptake of the plant (Lorenzo, 1994; Mistriotis et al., 1997) because of a reduction in transpiration (Stanghellini and van Meurs, 1992; Holder and Cockshull, 1990). High humidities also cause a higher condensation on the inner surface of the plastic cover which eventually drips onto the crop, increasing even more the risk of fungal and bacterial diseases. This condensation on the cover also reduces light transmission (Jaffrin and Makhlonf, 1990) which leads to additional yield losses.

Research in understanding the performance of the different types of vents with and without screens is needed to improve the natural ventilation of these greenhouses. Tracer gas measurements were made to determine the rate of air exchange for these greenhouse vent cover and screening combinations. Evaluating several different designs using this approach is very expensive and time consuming.

During the past years, CFD has become an important simulation tool to study natural ventilation in different types of greenhouses, mainly Venlo-type, arch-shaped roof greenhouses, open roof greenhouses and sawtooth greenhouses, as reviewed by Reichrath and Davies, 2001. Little attention has been paid to study natural ventilation in parral type greenhouse (Perez-Parra et al., 2002; Perez-Parra et al., 2003) and only one work has used 3D CFD (Campen and Bot, 2002).

The aim of this study is to deepen in the knowledge of natural ventilation processes in the parral type greenhouse through

- developing two-dimensional CFD models
- validating CFD simulations with field tracer gas measurements

Methods

During the past years, Computational Fluid Dynamic (CFD) modelling has become an important simulation tool to study natural ventilation in different types of greenhouses, mainly Venlo-type, arch-shaped roof greenhouses, open roof greenhouses and sawtooth greenhouses, as reviewed by Reichrath and Davies, 2001. Little attention has been paid to study natural ventilation in parral type greenhouse (Perez-Parra et al., 2002; Perez-Parra et al., 2003) and only one work has used 3D CFD (Campen and Bot, 2002).

CFD simulations were made of a five-span, polyethylene, covered, parral greenhouse, with ridges oriented North-South, and situated at the Experimental Station "Las Palmerillas" of Cajamar, Almeria. Earlier, experimental tracer gas measurements to determine air exchange rates were made in this greenhouse. The greenhouse was 32 m long, 23.2 m wide, with a ridge height of 4.4 m, and a roof inclination of 11º with the horizontal plane. The greenhouse was equipped with one continuous roof ventilator per span (five ventilators), located near the ridges on the west side of each span.

Two dimensional simulations were made with two different types of roof vent covers, as shown Figure 2. The first type was flap covers, which were hinged to the ridge of each span. The other is a rolling cover, the longitudinal lower edge of the plastic film vent cover was attached to a pipe which rotated to roll up the plastic film and uncover the opening. The dimensions of the openings in the plane of the roof were 8.36 m by 0.73 m for the flap type, giving a total opening area of 30.5 m2 (3.5% of the ground area covered by the greenhouse). Rolling roof ventilators had dimensions of 14.2 m by 1.3 m when completely opened, which gave a total opening area of 92.3 m2 (10.5% of the ground area covered).

Figure 2. The two types common types of vent openings used in the Parral Greenhouse. Flap vent openings are pictured on the left and rolling vent opening on the right.

Model Description

Computational Fluid Dynamic (CFD Modeling) of the continuity and momentum equations has become an accepted tool for studying the Natural Ventilation of Greenhouses. CFD modeling was used to study the natural ventilation of the Parral Greenhouses. A two dimensional CFD model was developed using FLUENT 5.0 CFD software from Fluent, Inc. Separate models were developed for the rolling cover and flap cover arrangements.

The model was of a cross section through the center of the 5 section greenhouse. The Parral greenhouse was located within a computational domain that was 30 m high and 78 m long. This domain dimensions was determined by increasing the size of the domain and comparing the affect on the model results. The leading edge of the greenhouse was located 20 m downwind of the velocity inlet. Figure 3 shows a typical flow domain and the placement of the greenhouse within the flow domain.

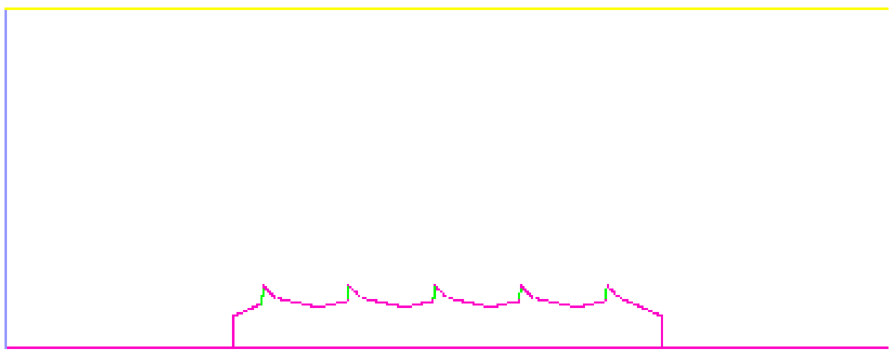

Figure 3. Computational domain of 30m high x 78m long with the 5 span parral greenhouse with vent flaps located 20 m from the velocity inlet on the left.

The upwind boundary condition was a uniform velocity profile. The top boundary condition was defined as symetric. The affect of the top boundary condition as symmetric and a pressure outlet was studied. The use of the symmetric provided better results with a smaller computational zone. The leeward boundary condition was defined as pressure outlet. The other model parameters are presented in Table 1. The model was run for wind speeds of 2, 3, 4 and 5 m/sec and the results compared to tracer gas measurements. The parameters were adjustd to give the best agreement between model results and tracer gas measurements.

Table 1. Input parametes for the CFD model.

Parameter	Value
Solver	Segreagated
Formulation	Implicit
Time Condition	Steady State
Viscous Model	k-epsilon (2 equation) standard with standard wall functions or Renormalized Group (RNG)
Cmu	0.09
C1 Epsilon	1.44
C2 Epsilon	1.92
TKE Prandtl	1

From the model results, the air inflow and outflow through the openings were calcualted. The difference between the air entering and leaving the computational domain and the greenhouse was calculated to verify that continuity equation was maintained in each case.

The CFD model fluxes through the roof openings were adjusted for the net area of the openings to calculate the air exchange in m^3/s. The CFD model results were compared to the tracer gas data.

Results and Conclusions

Figure 4 shows a typical velocity vector map.

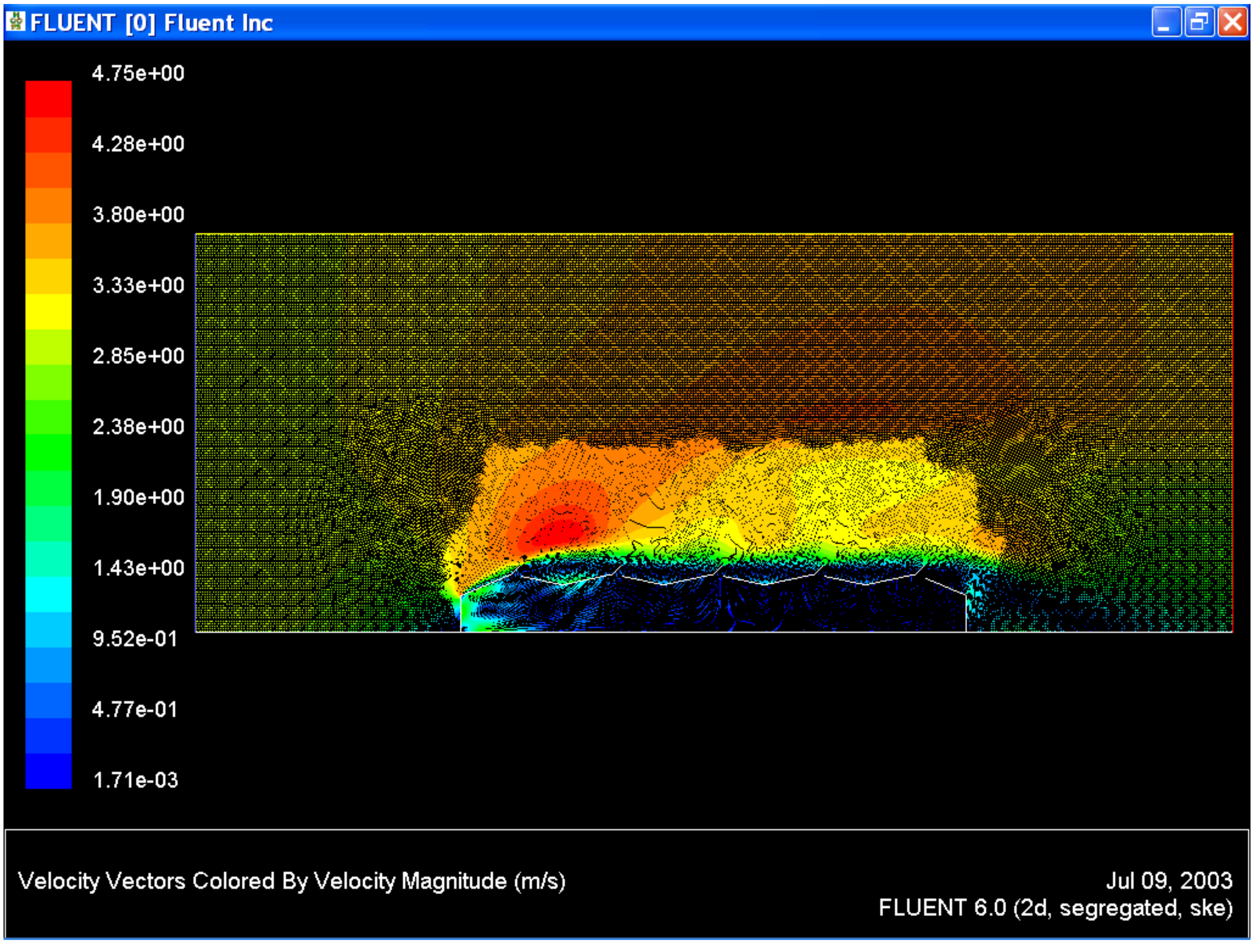

Figure 4. Velocity vector map for 5 bay Parral Greenhouse with flap vents on the leeward roofs and wind velocity of 3 m/s.

Figure 5 shows the CFD model and tracer gas air exchange for the flap opening with both the windward and leeward wind directions. The results for the windward wind direction are presented with both no upwind greenhouses and with an upwind greenhouse (labelled with surroundings.) Figure 6 shows the CFD model and tracer gas air exchange for the rolling flap cover on the leeward side. The effect of increasing the domain size is also shown in this figure. Figure 7 shows CFD model and tracer gas air exchange for the rolling flap cover on the windward side. The results of using the k-epsilon and the RNG viscosity models are also shown in this figure.

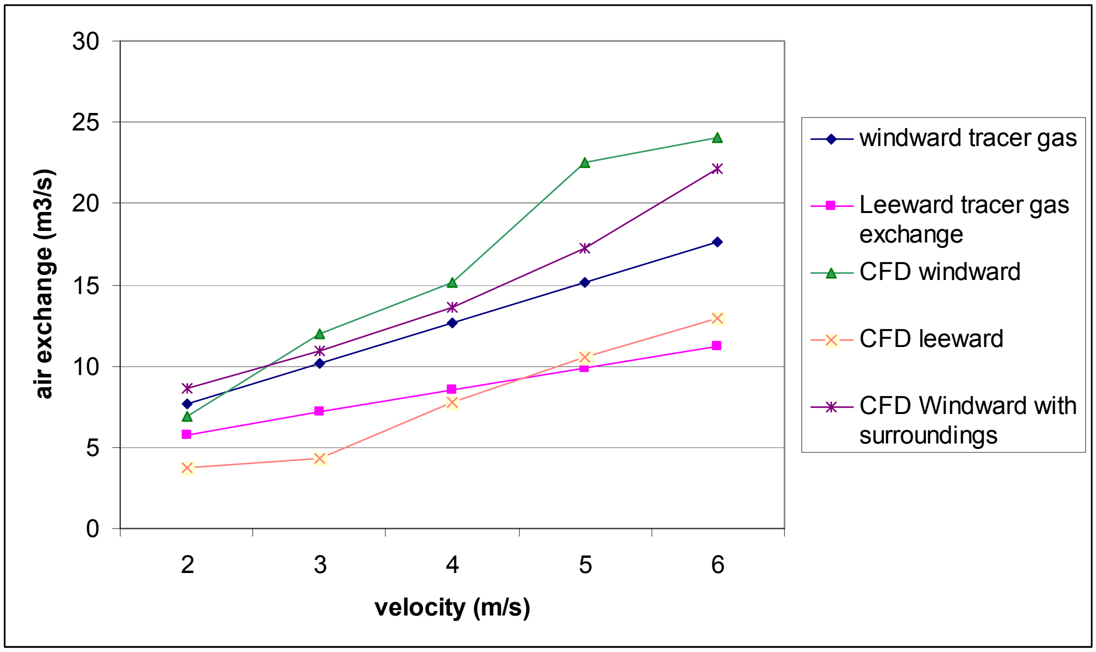

Figure 5. Air exchange rates for Parral flap covered, 5 bay greenhouse at different wind speeds for both windward and leeward opening configurations. Windward configuration with an upwind greenhouse (with surroundings) is also presented.

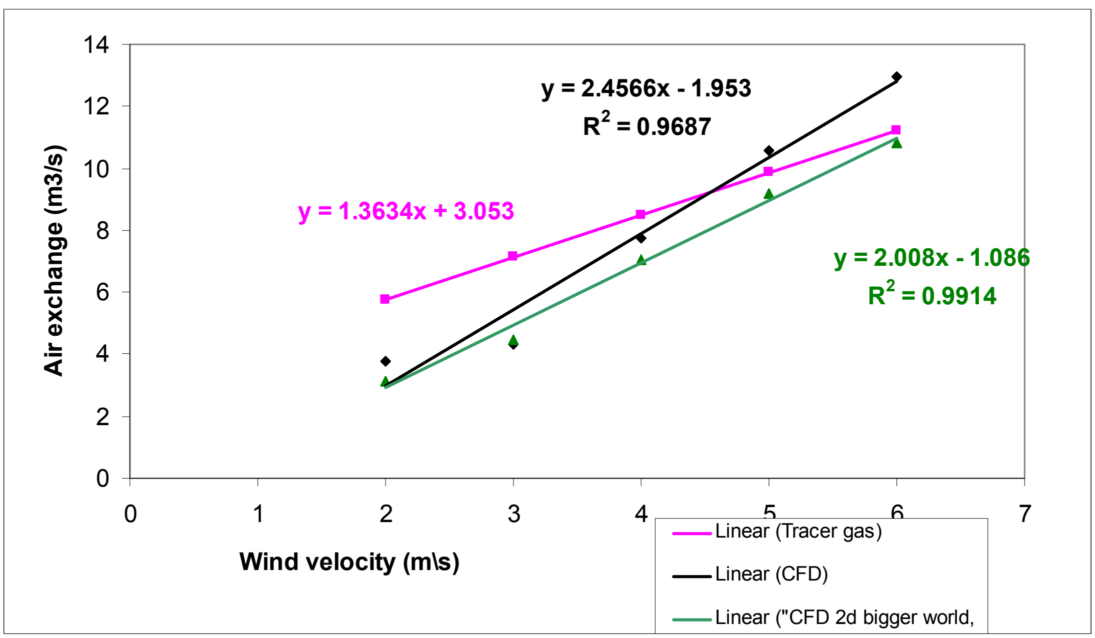

Figure 6. Air exchange for Parral rolling covered, 5 bay greenhouse at different wind speeds for leeward opening configuration. The affect of increasing the computational domain (2d bigger world) is also shown.

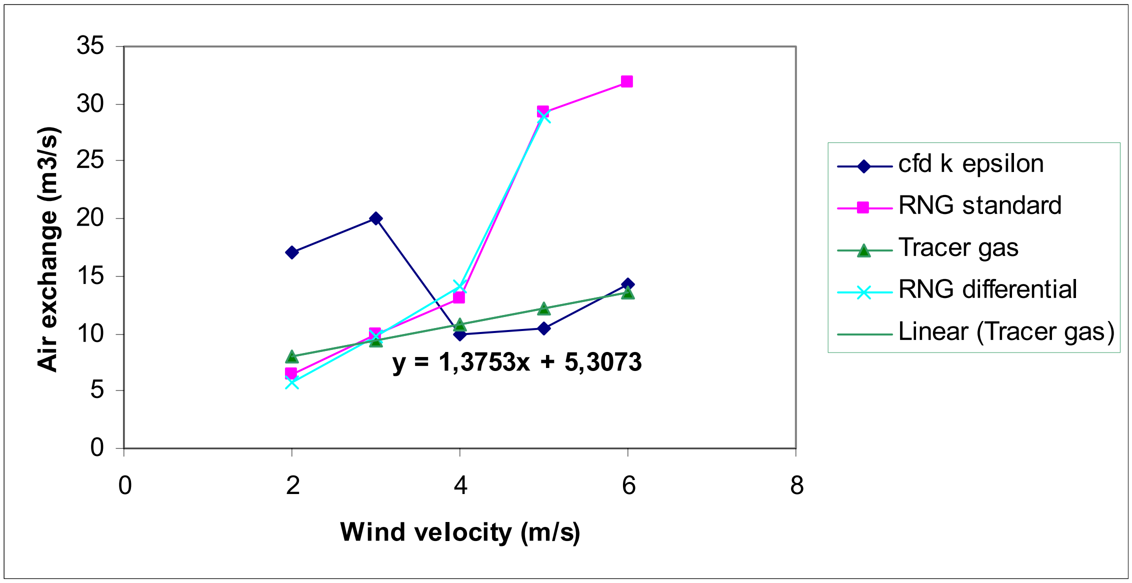

Figure 7. Air exchange for Parral rolling covered, 5 bay greenhouse at different wind speeds for windward opening configuration. The affect of viscosity model for this configuration is also shown.

The agreement between the model results and data varies with wind speed, opening cover and viscosity model. The differences between flux in and out was consistently less than 0.01% for the computational domain and less than 0.1% for the greenhouse when the convergence criteria for continuity, x – velocity and y – velocity were set at 0.001. These values were acceptable to use the results for comparisons to tracer gas data, considering the accuracy of the other factors in the model and the tracer gas data.

For the flap cover model, both the windward and leeward orientations had reasonable agreement between the data and model results. For the windward case, adding a greenhouse structure upwind of the structure being modeled improved the agreement between the data and model results.

For the rolling flap model, the leeward orientation had good agreement between data and model results. This case is used to show the affect of increasing the computational domain on the model results. The increase computational domain resulted in better agreement at higher wind velocities while both gave similar results that under predicted the air exchange at lower wind velocities.

For the rolling flap model, the windward configuration had mixed agreement between a given model and data. In this case, the effect of viscosity model was significant. For wind velocities of 2 and 3 m/s, the RNG model gave much better results than the k-epsilon model. At higher wind speeds, the k-epsilon model gave much better results. This orientation has the air flow up the roof and then encounters the opening. This condition is much more difficult to model.

When the openings are on the windward side of the roof, the air exchange is higher for both the tracer gas results and CFD modeling results. In this arrangement, the wind creates a positive pressure at the first opening(s) which forces air into the greenhouse. The pressure buildup forces air out other openings. In the leeward configuration, there is less pressure drop across the openings to force air into or pull air out of the greenhouses.

At low wind speeds, the tracer gas measurements gave higher rates of air exchange than the CFD modeling results. The CFD model did assumed an air tight wall and roof except for the specified vent openings. The actual greenhouse had leaks in the wall and roof drainage openings which add to the air exchange and allows the gas to diffuse out of the greenhouse, giving a higher air exchange rate. At high wind speeds, the accuracy of the tracer gas method decreases. This can explain some of the differences between CFD model results and tracer gas data.

The results of this works show the importance of obtaining the proper computational domain size and boundary conditions to minimize their affect on the results. The selection of a single viscosity model for all cases can also create significant errors in the model results. Until some ways are developed to assist in determining the best viscosity model, care is needed in assuring that the correct model parameters will provide sound results when modeling new greenhouse structures.

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