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Greenhouse microclimate and dehumidification effectiveness under different ventilator configurations

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Abstract

In this paper, the efficiency of two different greenhouse ventilation opening configurations on greenhouse microclimate during dehumidification process with simultaneously heating and ventilation was analysed by means of computational fluid dynamics (CFD) using a commercial program based on the finite volume method. The numerical model was firstly validated against experimental data collected in a tunnel greenhouse identical with the one used in simulations. A good qualitative and quantitative agreement was found between the numerical results and the experimental measurements. The results of the simulations performed for an outside wind direction perpendicular to the greenhouse axis show clearly the influence of ventilation opening configurations on the velocity, temperature and humidity distributions inside the greenhouse. With the first ventilation configuration (roll-up type) maximum air velocity inside the greenhouse was reached in the greenhouse near the ground, with the lowest values observed near the greenhouse roof. As a result, temperature and humidity decreased first near the ground and afterwards in the rest of the greenhouse volume during the dehumidification process. The exactly opposite pattern was observed with the second configuration (pivoting door type). The maximum air velocities were observed near the greenhouse roof where air temperature and humidity were decreased first during the dehumidification process. Energetically the first configuration is proven to be better since the ratio of latent to sensible exchanges during the dehumidification process was higher than the first configuration.

Keywords: Natural ventilation; Humidity control; Climate distribution; CFD

1. Introduction

In the Mediterranean area, natural ventilation is the most widely used system to control greenhouse climate since it requires less energy, less equipment operation and maintenance and it is much cheaper that other ventilation systems. During the summer, the main reasons for its use are to lower temperatures and to increase air humidity; while during the winter the ventilation is often used simultaneously with heating to reduce air humidity.

High levels of humidity directly affect the crop yield and quality particularly via the occurrence and severity of fungal diseases [1]. High humidity can result in condensation in plant surfaces, enhances spore germination of certain pathogenic fungi, among them the common greenhouse fungi, *Botrytis cinerea.* The probability of infection with this pathogen, which attacks both vegetable and flower crops, has been shown to diminish as the period of high humidity in the greenhouse decreases [2,3].

Apart from disease problems high humidity levels may lead to leaf necrosis, calcium deficiencies and soft and thin leaves. Crop growth may decrease [4] anatomical changes may occur and plant development can be distributed or delayed [5,6]. High humidity conditions can further hamper pollination in fruit vegetables, as pollen grains tend to remain inside, or stick to the anthers [7,8] and vase life in ornamental plants may be shortened [9,10]. Low vapour pressure deficits tend to reduce the transpiration rate and thus the translocation of elements, particularly calcium [11] which can result in physiological disorders.

Due to its great importance natural ventilation received a lot of attention during the 1990s. However the majority, if not all, of the studies dealing with natural ventilation

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Notation

C_m	model constant of the k–ε model
C_μ	constant fitting parameter
$C_{1\varepsilon}$	model constant of the k–ε model
$C_{2\varepsilon}$	model constant of the k–ε model
C_p	volumetric specific heat of air ($\mathrm{J\,m^{-3}\,K^{-1}}$)
k	turbulent kinetic energy ($\mathrm{m^2\,s^{-2}}$)
G	greenhouse ventilation rate ($\mathrm{m^3\,s^{-1}\,m^{-2)}}$
Q_{sen}	sensible heat exchange ($\mathrm{Wm^{-2}}$)
Q_{lat}	sensible heat exchange ($\mathrm{Wm^{-2}}$)
$\mathrm{RH_i}$	inside air relative humidity (%)
$\mathrm{RH_o}$	outside air relative humidity (%)
S_Φ	source term
T_i	inside air temperature (°C)
T_o	outisde air temperature (°C)
T_d	air dew point temperature (°C)
U, V, W	components of velocity vector
u	air velocity ($\mathrm{m\,s^{-1}}$)
Γ	diffusion coefficient
ε	dissipation rate of turbulent kinetic energy ($\mathrm{m^2\,s^{-3}}$)
λ	latent heat of evaporation ($\mathrm{J\,kg^{-1}}$)
ρ	air density ($\mathrm{kg\,m^{-3}}$)
σ_κ	turbulent Prandtl number for turbulent kinetic energy
x_i	concentration of vapour of the inside air ($\mathrm{kg\,m^{-3}}$)
x_o	concentration of vapour of the outside air ($\mathrm{kg\,m^{-3}}$)

focus on summer conditions based on estimates of a global rate of air exchange using tracer gas technique [12–15] and simulations of a homogeneous air temperature by means of energy balance models [16–19]. Moreover the previous studies only allow prediction of a general ventilation rate. More recently some measurements of the air velocity through the ventilation openings and inside greenhouse have been carried out for a closed greenhouse [20], a two span naturally ventilated greenhouse [21] and a multi-span Venlo-type greenhouse [22].

Even so, there is an important lack of information on the development of the airflow within the greenhouses driven by wind or by buoyancy forces since most of the authors represent the climatic conditions in the greenhouse as uniform temperatures and air velocity without differentiating between the volume occupied by the crop and the area above the plants. Recent advances in computational fluids dynamics (CFD) programs enable easier studies of such scalars and vector fields by solving the corresponding transport equations.

The first simulations by means of CFD for the study of the ventilation in greenhouses were carried out by Okushima [23] who compared this numerical method with the experimental results obtained in a wind-tunnel [24]. Although their results showed little correlation with the experimental data, probably due to the limited power of the available computer resources at that time, they provided important new information on the patterns of flow inside the greenhouses. Since then CFD codes were used for modelling the interaction between the internal climate of greenhouses with external weather conditions, environmental control setting and greenhouse structural specifications. The influence of natural ventilation was studied by Boulard et al. [25] and Lamrani et al. [26] in closed greenhouse whereas its influence in ventilated greenhouses were studied by Mistriotis et al. [27], Boulard and Wang [28], Campen and Bot [29] and Bartzanas et al. [30]. The effect of insect screens placed over the ventilation openings were studied by Bartzanas et al. [31] and Fatnassi et al. [32]. Al-Arif et al [33] studied the air movement in greenhouses equipped with a fan. CFD is an advanced technique for design in engineering; it is increasingly being used in other types of agricultural studies, such as the ventilation of livestock houses [34,35] and in experiments of the aerodynamic resistance of greenhouse structures [36]. Reichrath and Davis [37] have reviewed commercial software packages that address the application of CFD to greenhouses. Nowadays the CFD technique is recognised as a powerful tool to model the climate generated inside the greenhouses and for the development of structural design improvement with regard to ventilation effectiveness.

The aim of the present study is to examine the influence of greenhouse vent configuration on greenhouse microclimate and energy consumption when the natural ventilation system is used simultaneously with the heating system for dehumidification purposes. For this purpose a CFD model was used after its experimental validation. Two commonly found vent configurations (roll-up type and pivoting door type) were tested in a tunnel greenhouse with a mature tomato crop.

2. Materials and methods

2.1. Experimental greenhouse

The measurements were performed in an arch, plastic covered greenhouse, N–S oriented located at the University of Thessaly near Volos, (Latitude 39° 44′, Longitude 22° 79′) on the coastal area of Eastern Greece. The geometrical characteristics of the greenhouse were as follows: eaves height of 2.4 m; ridge height of 4.1 m; total width of 8 m; and total length of 20 m. The greenhouse was covered with a polyethylene sheet and was equipped with two continuous side openings (roll-up type) located 0.6 m from the ground with a maximum opening of 0.9 m. A network of black plastic heating pipes located close to the gutter holding the growing substrate, with one supply and return