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**Original Article**

# Experimental and Numerical Investigation for Mechanical Ventilated Greenhouse

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## Abstract

Using computational fluid dynamics (CFD) in agriculture field especially in designing greenhouses is becoming ever more important to reduce the energy consumption, wherefore a comparison between the experimental and numerical results increasing the credibility of theoretical studies and therefore depending on it. The experimental study located at October 6 University, 6 October city, Giza, Egypt in august. Standard K-ϵ model used for the (CFD) numerical study implemented for comparison between the experimental and numerical measurements. A good qualitative and quantitative agreement was found between the numerical results and the experimental measurements.

**Keywords:** Greenhouse; Mechanical ventilation; CFD.

## 1. Introduction

Operating mechanical ventilation effects on the yield and quality of almost all greenhouse crops. Mechanical ventilation is used to reduce the greenhouse effect inside the greenhouse during the hot days, which leads to attain the optimum crops temperature with minimum power. The numerical solution allows to make changes to the geometrical shape and method of mechanical ventilation by computational fluid dynamics (CFD) to reach the ideal solution for mechanical ventilation which provides better efficiency.

Okushima (1989) is the first user for early version of a CFD model to predict the distributions of climatic factors inside and outside small naturally ventilated greenhouses [1]. Two equation K-ϵ model is used to computed airflow distributions compared with the wind–tunnel results, which made different openings in the roof and side walls [2]. While the experimental results showed little correlation with the computational model, the study demonstrated the possibility of using a CFD model to predict environmental distributions for naturally ventilated greenhouses. Two dimensional K-ϵ model studied to validate the experimental data for multi-span greenhouse in different velocity inlet at 0.9 m/s and 2.5 m/s, validation made with only four air temperatures sensors across the 33 m * 35 m multi-span greenhouse, which means a simple understanding of temperature distribution in the greenhouse. The maximum error between the experimental measurements and numerical data is 3.2% [3].

Campen show that the three-dimensional calculations are preferable over the two-dimensional calculations [4], for computational assessment of ventilation rate with wind direction. Crop is not considered in the model since no crop was grown during the experiments. The calculations resembled experimental data within 15%. The wind speed correlated linearly with ventilation rate for both configurations without the buoyancy effect, which goes with the basic theory on ventilation. The CFD calculations is standard K-ϵ model and indicated that ventilation rate for both configurations is largely dependent on wind direction, which is also observed with the experimental investigation.

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Four different configurations of ventilators are investigated resulting in different ventilation rates and different airflow and temperatures patterns [5]. The presented results indicate that the highest ventilation rates are not always the best criterion for evaluating the performance to the agriculture crops in the greenhouses. The standard K-ϵ model remains the standard used in the modelling of agricultural structures and applications.

CFD with standard K-ϵ model used to study more than one aspect [6], the rate of air change with different ventilation opening in the roof, air speed, humidity and temperature distribution. The temperature measurements inside the greenhouse with three sensors for the greenhouse of 7.5 * 28 length. This area is large to monitor the change in temperature, which is observed in the theoretical study that there is a temperature range almost 15 k and surely could not showed that in experimental measurements, due to the limitation of temperature measuring instruments. It is also recommended not to increase the speed of mechanical ventilation because it may lead to loss of crops.

Previous studies have studied the natural and mechanical ventilation in terms of different air speeds, air change rates, roof and side walls openings, but did not sufficiently studied the temperature distribution in experimental and numerical investigations, which is the direct effect on plants and crops in the greenhouse. In previous works computational fluid dynamics (CFD) is used in mechanical and free ventilation of the greenhouses, found some time gaps in the literature CDF studies due to low computational capability of the CFD programs and the limited computing power available at that time. Especially, they failed to describe in detail the effects of fluctuating turbulent airflow and the temperature distribution on the air exchange of the greenhouses with their CFD model.

The objectives of the present study are to verify three-dimensional standard K-ϵ model CFD numerical simulations of air temperature distributions along the greenhouse axis and to compare experimental temperature measurements in a full–scale, mechanical ventilated, even–span greenhouse. verification tests are during summer day for hot and clear sky.

## 1. Experimental Setup

The experiments are performed with no crops greenhouse located at October 6 University, Giza, Egypt (longitude 29.98o, latitude 30.95o). The greenhouse of inclined roof type even span greenhouse which is made of rectangular iron pipes and Polycarbonate sheets covering material. The greenhouse with an effective floor 3.6x2.4 m with central height and height of the walls are 2.4 and 1.8 m, respectively. A fan of 350 mm sweep diameter and 1360 rpm with a rated air volume flow rate of 3200 m3/h is provided on the south wall of the greenhouse for the forced convection experiments. Operated the greenhouse system from 8 am, the results presented in this paper are at 12 PM for the experimental data is recorded.

In both cases for measuring temperature used 46 digital temperature sensor (DS18B20) with temperatures range from -55°C to +125°C and ±0.5°C Accuracy from -10°C to +85°C, DHT22 relative humidity sensor with accuracy of 2-5% on the full scale range of 0-100% of relative humidity.

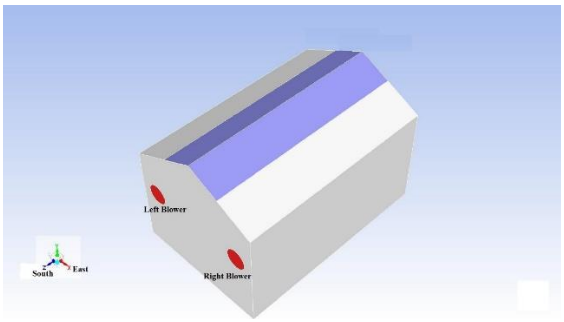


Figure 1 Layout of the greenhouse.

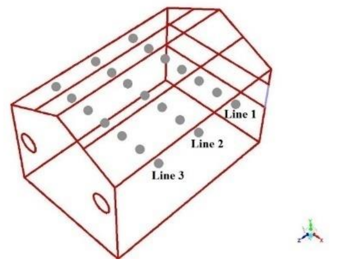
The ventilation opening is located in the northern wall facing the blowers at a height of 0.9 m, length 0.55 m and full width of the greenhouse is 2.4 m.

The distribution of the horizontal and vertical sensors created to measure the temperature shown in figure 2, horizontal lines is located on height 1.6 m when the vertical lines centered at the middle at 1.2 m, both of vertical and horizontal lines distributed in the first quarter, middle and third quarter sections inside the greenhouse.

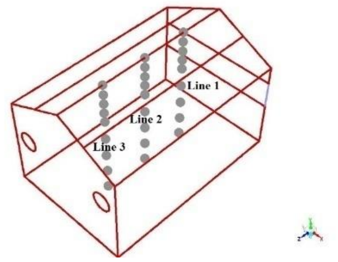
Greenhouse walls temperature measured by 7 (DS18B20) temperature sensor one for each wall and two for the even span roof. In each horizontal line locate 5 temperature sensors the distance between each other 0.4 m and for the vertical line 7 temperature sensors distributed in two parts, 4 sensors are used for the bottom part the distance between each of the 0.4 m and the top part consists of 3 sensors with 0.2 m intervals between them. Used also two temperature sensor to measure outside and inside temperature. Used two relative humidity sensors to measure inside and outside the greenhouse.

Weather temperature for October 6 City during the experimental study was 33°C and 23°C the high and low temperature respectively. [7]

Outside air climate variables are recorded at a nearby, on top the greenhouse. The recorded date at the time of the experiment is 43°C for the outside temperature with 31% and 36% for the internal and external measured relative humidity respectively.



Horizontal Measurements Lines



Vertical Measurements Lines

Figure 1 Horizontal and Vertical Measurements Lines.

## 2.Mathematical modelling

The three-dimensional model of greenhouse structure is established in this study. The cooling pads shape in the ventilation opening and the internal support structure have a small effect on the internal greenhouse temperature, so they are ignored in simplification processing. The ventilation opening placed on the northern wall to reach the maximum cooling effect using the minimum ventilation. The temperature environments for simulation calculation are in hot summer with no wind. Forced ventilation is performed by fan for greenhouses cooling. Entire greenhouse model is divided into 2 million elements. The grid test results show good grid quality. Iterative calculation is conducted using two CPU 3.07 GHz quad-core work station in simulation.

The governing equations of fluid flow and heat transfer can be considered as mathematical formulations of the conservation laws that govern all associated phenomena. These conservation laws describe the rate of change of a desired fluid property as a function of external forces and can be written as:

Continuity equation: the mass flows entering a fluid element must balance exactly with those leaving.

$$\partial\rho/\partial t+\nabla\cdot[\rho\vec{V}]=S_m$$

Where $\rho$ is the air density, t is the time, $\vec{v}$ is the velocity vector and $S_m$ is the source term.

Conservation of momentum (Newton's second law): the sum of the external forces acting on the fluid particle is equal to its rate of change of linear momentum.

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla\cdot\left(\rho\vec{V}\vec{V}\right) = -\nabla p + \rho\vec{g} + \vec{F}$$

where $p$ is the static pressure and $\vec{g}$ and $\vec{F}$ are the gravitational body force and external body forces respectively.

Conservation of energy (the first law of thermodynamics): the rate of change of energy of a fluid particle is equal to the heat addition and the work done on the particle.

$$U_j \frac{\partial T}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\alpha\frac{\partial T}{\partial x_j} - \overline{u_j t}\right)$$

The solution method is run to make the control parameter settings of model in the requirement section. The SIMPLE scheme is used in this study in order to make computing convergence faster. Pressure, momentum, turbulent kinetic energy, turbulent dissipation rate, energy and radiation (discrete ordinate) all used second-order upwind for more accurately calculate, and relaxation factor settings are as shown in Table 1.

Table 1 Relaxation factor settings of the solution method.

| Pressure | Density | Body Force | Momentum | Turbulent Kinetic Energy | Turbulent Dissipation Rate | Turbulent Viscosity | Energy | Discrete Ordinate |
|---|---|---|---|---|---|---|---|---|
| 0.4 | 1 | 1 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 |

## 4.Results and discussion

The operation of the greenhouse was started at 9 am on the day of the 25 august to ensure that the optimal representation of the mechanical ventilation inside the greenhouse is maintained at the peak time in the experimental measurements. The location of the greenhouse (latitude and longitude) and the experiment time introduced in the CFD program to show the radiation effect inside the greenhouse.

Horizontal line 1 is shown in figure 3, the average temperature difference between the experimental measurements and numerical calculations was 12% where the maximum temperature difference was 20% at the middle of the horizontal line and the minimum difference was 0.7% at the point located in the west wall. For the vertical line 1 the temperature difference was between 0% and 21.6% with average 12.6%, the highest temperature difference located at height 2m in the triangle zone under the even span roof. This increase is due to the effect of greenhouse effect inside the greenhouse and its appearance on the triangular part in particular. Therefore, there is always a discrepancy between the experimental measurements and the numerical calculations in this part. The temperature difference between the experimental measurements and numerical solution is almost zero at the points located in 0m, 1.2m and 2.4m which means approved difference in other points.In horizontal line 2 can notice that small average temperature difference between the experimental measurements and numerical calculations, the average is 2.26% which the maximum temperature difference is 4.5% and the minimum is 0.85%. For the vertical line 2 can also see the lowest temperature difference between the experimental measurements and numerical calculations, the average temperature difference is 6.5%, which the minimum and the maximum values is 0% and 17.8% respectively. In the third horizontal line, the average temperature difference is 6.5% for minimum temperature difference is 0.45% and the maximum is 12.6%. The average temperature difference in the third vertical line is 9.5% for the highest value of the temperature difference which is 19.7% and the lowest value is 0%.

Will notice the effect of the Sun's movement between East and West in the horizontal lines in figure 3. There is a temperature difference between the East temperatures at point 2.4 m and the west temperatures at point 0m. This temperature difference was 3.25℃ in the experimental measurements and approximately 1.4℃ in the numerical study.

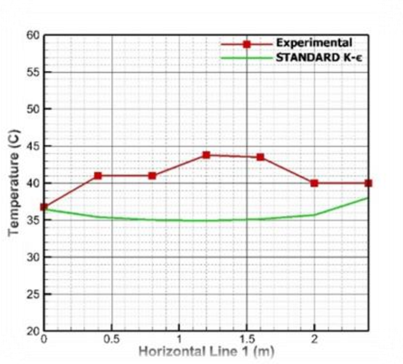
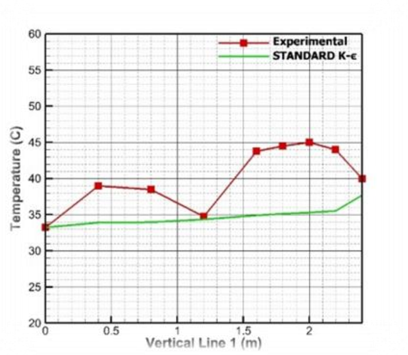
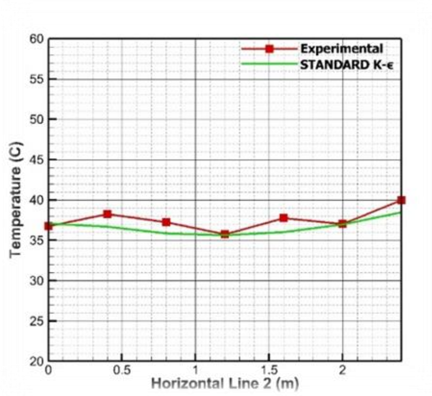
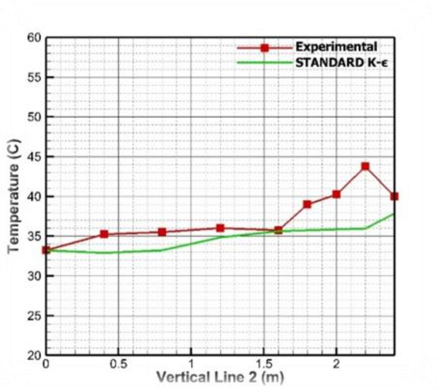
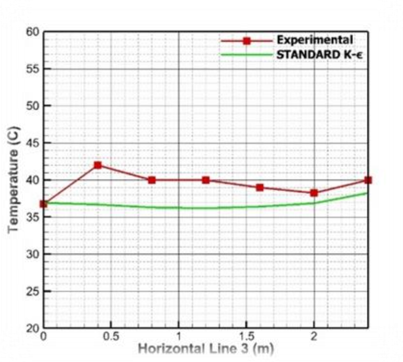
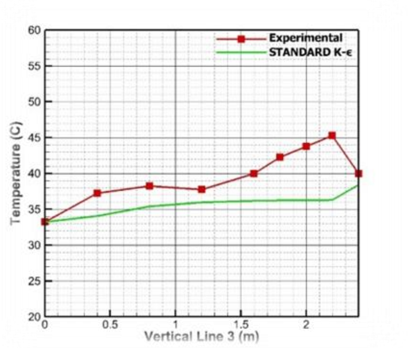
| Horizontal Lines | Vertical Lines |
|---|---|
|  |  |
|  |  |
|  |  |

Figure 2 Experimental and numerical comparison for temperature variation at horizontal and vertical lines.

Also observed on the vertical lines in figure 3 the temperature difference rise from the surface of the earth and the maximum height of the greenhouse and significantly the greenhouse effect, especially from the height of 1.5 m to highest level of greenhouse.

It is necessary to study the distribution of temperature inside the greenhouse accurately with sufficient number of sensors and not rely on a small number of sensors because the results of the small number of sensors cannot explain the places of increasing temperatures and the significantly effect of the ideal growth of plants inside the greenhouse.

## 5.Conclusion

The influence of mechanical ventilation of an even-span greenhouse is numerically investigated using commercial fluid dynamics code. A good qualitative and quantitative agreement is found between the numerical results and the experimental measurements, the numerical calculation resembled experimental data with almost 20% for maximum average difference of all lines. After this good agreement between experimental measurements and numerical calculations.

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