Determining of Climatic Parameters Using CFD in Different Window Span in Naturally Ventilated Greenhouses

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Abstract: The aim of this study was to compare with the measured inner air temperature and relative humidity values and the simulated values determined with Computational Fluid Dynamics (CFD) in the naturally ventilated gable-roofed single glass greenhouse located North-South direction, having 45° and 90° window spans and under no cultivation.

The measured values were recorded every 2 hours from 8 am to 18 pm using the relative humidity and air temperature sensors placed in 7 different locations. Measurements were made in case of the 45° and 90° window span openness. For CFD simulations, the SolidWorks 2011 software was used. The values of air temperature and relative humidity inside the greenhouse were simulated depending on the outside ambient conditions and structural and physical properties of greenhouse. Then, the measured values were compared with the simulated values and error rate for each sensors were determined.

As a result, it was determined minimum error rates of the measured and simulated air temperature and relative humidity in greenhouses is 4.8% and 4.7%, respectively. The study showed that the CFD can be used as a powerful tool for determining inner climatic factors in naturally ventilated greenhouses.

Keywords: CFD, greenhouse, simulation, air temperature, relative humidity.

1. INTRODUCTION

The main factors which characterize and influence the greenhouse environment are light, humidity, air temperature, carbon dioxide concentration and ventilation rate. Ventilation is the main control method of the greenhouse's high temperatures. Natural ventilation is mostly used nowadays since it requires less energy, equipment and power than other forms of ventilation. The performance of ventilation plays an important role to the production, affecting not only the environmental conditions of the greenhouse, but the qualitative and quantitative properties of the crop product as well [1].

Natural ventilation is considered as one of the most important factors of greenhouse environment, since it directly affects transport of sensible, latent heat and CO_2 concentration to or from the interior air. In the Mediterranean area (high radiative loads) an efficient climatization is crucial in order to decrease the inside air temperature and to remove excess humidity [2].

In spite of, the greenhouse is a very complex bio-system, in which there are several physical, chemical and biological interacting process and phenomena, during the last decade, due to the development of computer simulation tools and the increase in computational processing power, it is possible to develop numerical models for the greenhouse environment such as more accurate models for transport phenomena and energy exchange inside the greenhouse. As a consequence, these studies have led to improvements in the design of greenhouses [3].

Recent progress in computer performance and developments in flow modeling using computational fluid dynamics (CFD) provide a new opportunity to analyze the heterogeneity of the climate and to predict the ventilation rates in greenhouses. The principle of this technique is based on the resolution of transport equations in closed [4, 5] and ventilated [6] greenhouses. The CFD approach may provide a better understanding of the ventilation process for a wide range of greenhouse shapes, vent combination and boundary conditions and can help engineers and greenhouse manufacturers to improve greenhouse control and design.

CFD is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems involving fluids flow. Therefore, it is possible with the use of computers to perform millions of calculations to simulate the interaction of liquids and gases with surfaces defined by the boundary conditions. In recent studies the modeling of air flow, CFD has deepened to test their effectiveness in relationships of climatic factors [7].

Molina-Aiz *et al*. (2004), [8] analyzed to effect of wind speed on the natural ventilation of an Almeria-

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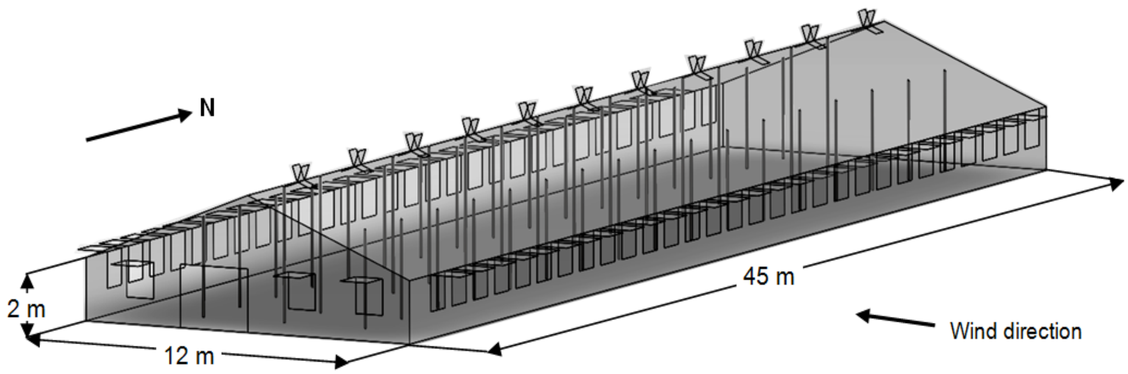

Figure 1: Schematics of greenhouse used in the study.

type greenhouse by means of computational fluid dynamics (CFD), using the commercial program ANSYS/FLOTRAN v6.1 based on the finite elements method.

The aim of this study is to compare the measured air temperature and relative humidity values with the simulated values using Computational Fluid Dynamics (CFD) in a naturally ventilated, gable-roofed single glass greenhouses located North-South direction, having different window spans such as 45° and 90°. Additionally, effects of the degree of window openness on ventilation was examined.

2. MATERIAL AND METHOD

2.1. Greenhouse Description

The experimental greenhouse are full-scale, naturally ventilated, gable-roofed single glass which is the most common in the province. They are located at West Mediterranean Agricultural Research Institute at the Aksu district of the Antalya province in Turkey (37^{o} 47’ N altitude and 31^{o} 4’ W latitude) on the east of Antalya. The greenhouse are located in the direction of North-South. Measurements were carried out on August 15 and August 17, 2011 in this study. The ridge of the greenhouse is oriented perpendicular to the prevailing wind direction.

The dimension of greenhouse is 12.0 m in width and 45.0 m in length (the surface area of greenhouse is 540 m^2). The greenhouse is covered with a 4 mm thick glass. Height of the side-wall of greenhouse is 1.90 m and the ridge height is 4.00 m. Width of the greenhouse door is 2.50 m and height is 1.90 m. The columns in greenhouse are placed for every 2.50 m of the ridge of the greenhouse. The ventilation of greenhouse is performed from side-wall and roof openings. Side-wall and roof openings are in an alternating manner and their size are 1.20 m x 1.00 m and 0.50 m x 0.50 m, respectively. Total side-wall ventilation area is 57.6 m^2 and total roof ventilation area is 5.50 m^2. While the distances between side-wall openings are 1 m, that of roof openings is 3.50 m. No insect-proof screens were used during the measurements. Since measurements were made on summer time, the greenhouse was covered over with shadow powder to reduce the inner temperature. All measurements are carried out inside greenhouses when no cultivation occurs.

In this study, measurements are made for window openness of 45^{o} and 90^{o} in the greenhouse. Therefore, the greenhouse which has 45^{o} and 90^{o} window openness degree was called as “Case A”, and “Case B”, respectively (Figures **1** and **2**).

2.2. Instrumentation

Internal air temperature and relative humidity values were measured by means of a data logger TESTO 175 H1 equipped with air temperature and humidity probes. While air temperature probe has the range of −20 to 70 ^{o}C with tolerance of ±0.5 ^{o}C, relative humidity probe has the range of 0-100% with tolerance of ±3%. The memory capacity of dual channel data logger is 16000 data. Internal air temperature and relative humidity measurements were taken on August, 15 and 17 2011, from 8 am to 18 pm every 2 hours.

Outside wind speed was measured by means of Kestrel 1000 anemometer equipped with wind speed probe in a range from 0.4-60.0 m/s (1.0-218 km/h). The anemometer measure momentary, maximum and average wind speed. The anemometer used in the outside wind speed measurements is placed 1.4 m height from the ground because this height is exactly middle of the side-wall windows. The outside wind speed also was recorded from 8 am to 18 pm every 2

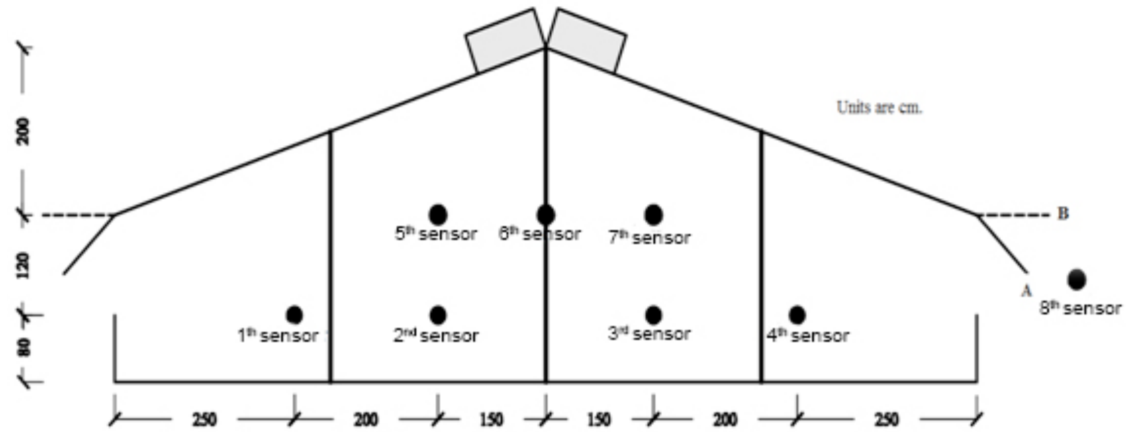

Figure 2: The locations of the air temperature and relative humidity probes for Case A (45°) and B (90°).

hours. Air temperature and relative humidity were measured inside the greenhouse at 7 different points (Figure **2**).

For simulation of the distrubution of air temperature and relative humidity, SolidWorks 2011 package program was used to create in computer environment of greenhouses in the same dimensions by means of Computational Fluid Dynamics (CFD) method.

2.3. CFD Simulation

Equations which on the basis of all CFD calculations define as governing equations. The governing equations are continuity, momentum and energy equations. The governing equations of a fluid flow and heat transfer can be considered as mathematical formulations of the conversation laws that govern all fluid flow, heat transfer and associated phenomena [9].

Computational domain created for the greenhouse using SolidWorks 2011 package program was given Figure **3**. The boundary conditions such as air temperature and relative humidity of external environment, the physical and structural properties belong to greenhouse, the properties of measurement area, etc. were inputted to the program.

The measured air temperature and relative humidity values were compared with simulated values obtained from probes placed in 7 different points. The size of computational domain and mesh generation was determined by carrying out preliminary simulations. Dimensions of this area were defined as 20 m width, 10 m length and 8 m height, respectively (Figure **3**). Totally 244447 meshes were defined for computational domain.

Finally, simulated and measured air temperature and relative humidity values were compared at different

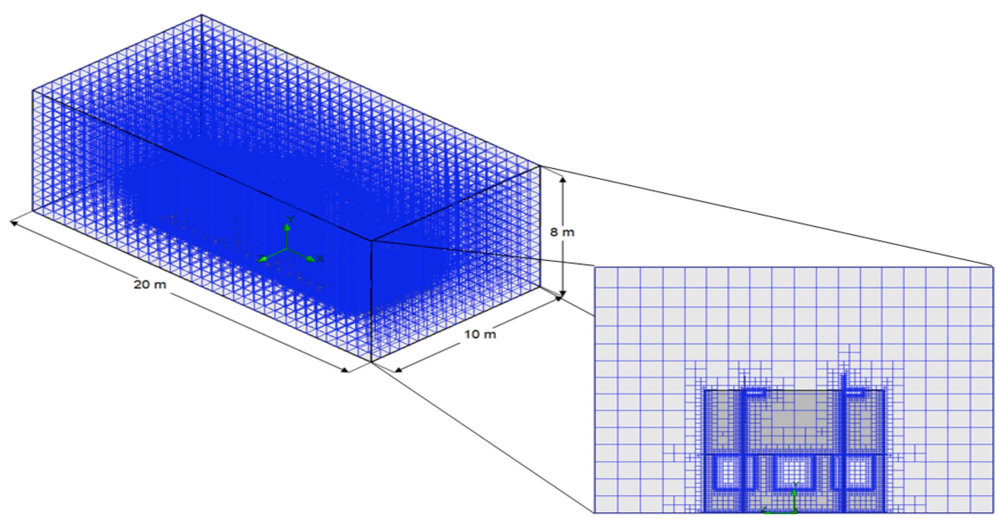

Figure 3: Computational domain and mesh generation of the greenhouse.

window openness and error rates of package program was performed after simulations.

Error rates used to compare simulated and measured values were determined by means of the following equation [10].

$$Error = \left[\left(\frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \right) * 100 \right]$$

Where,

P_i: Predicted values

O_i: Observed values

n: Number of samples

3. RESULTS AND DISCUSSION

3.1. Air Temperature and Relative Humidity Values for Case A

Window opening angle of greenhouse was set to 45^o for Case A. The air temperature and relative humidity probes inside greenhouse were located at 15 m from the entrance of the greenhouse. The air temperature values obtained from simulation for Case A were given below (Figure **4**). In the following figures, measured (observed) values are defined as “MV”, simulated (predict) values are called as “SV”.

When the Figure **4** is examined, it was determined the air temperature inside the greenhouse similar with outside in the edges of the windows. But it is increasingly towards the ridge in the other parts. Therefore, it was observed inadequate ventilation

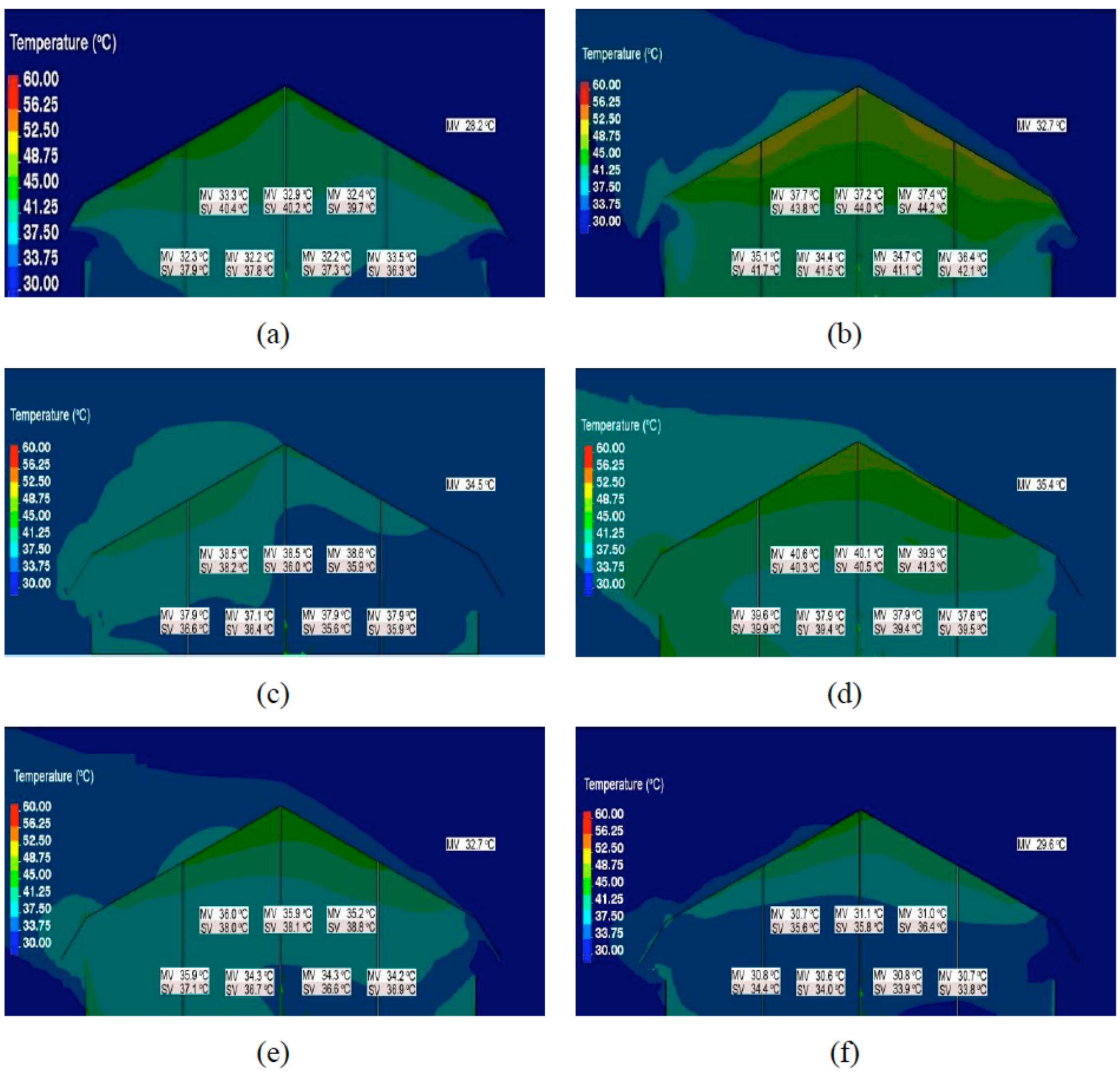

Figure 4: The measured and simulated hourly air temperature values about greenhouse A.
(**a**) 08:00, (**b**) 10:00, (**c**) 12:00, (**d**) 14:00, (**e**) 16:00, (**f**) 18:00.

Table 1: Average Measured and Simulated Air Temperature Values and Error Rates Belong to Sensors

Sensor Point	Average of Measured Values (MV) (°C)	Average of Simulated Values (SV) (°C)	Error (%) $\left(\frac{MV-PV}{MV}\right)*100$
1	35.3	37.9	6.9
2	34.4	37.6	8.5
3	34.6	37.3	7.2
4	35.1	37.4	6.2
5	36.1	39.4	8.4
6	36.0	39.1	7.9
7	35.8	39.4	9.1

especially at noon hours. Average measured and simulated air temperature values belonging to probes and error rates of these values for Case A were given in Table **1**.

When the Table **1** examined, the minimum error rate is with 6.2% in 4th sensor and maximum error rate is with 9.1 % in 7th sensor were obtained.

Simulated relative humidity values for Case A were given in Figure **5**.

When the Figure **5** is examined, it was determined the relative humidity inside the greenhouse more than throughout the window height and it is decreasingly towards the ridge in the other parts. Therefore, it was observed inadequate ventilation especially at noon hours.

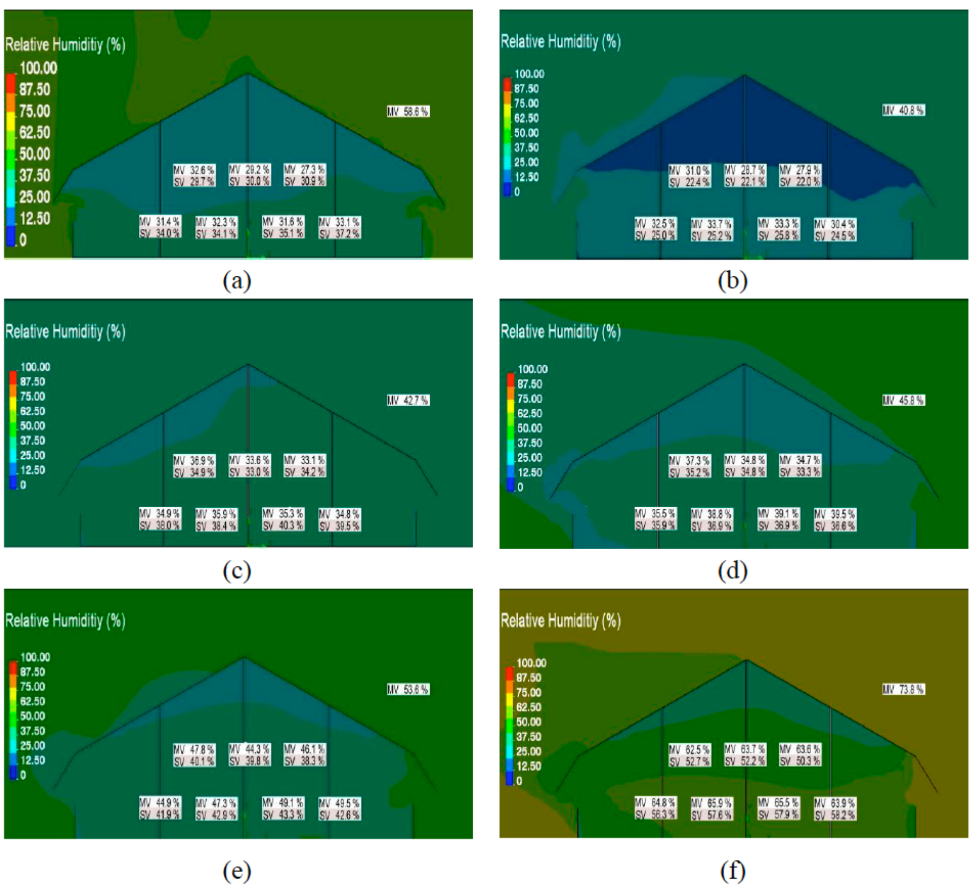

Figure 5: The measured and simulated hourly relative humidity values for Case A.
(**a**) 08:00, (**b**) 10:00, (**c**) 12:00, (**d**) 14:00, (**e**) 16:00, (**f**) 18:00.

Table 2: Average Measured and Simulated Relative Humidity Values and Error Rates Belong to Sensors

Sensor Point	Average of Measured Values (MV) (%)	Average of Simulated Values (SV) (%)	Error (%) $\left(\frac{MV-PV}{MV}\right)*100$
1	40.7	38.5	5.4
2	42.3	39.2	7.3
3	42.3	39.9	5.7
4	41.9	39.8	5.0
5	41.4	35.8	13.5
6	39.1	35.3	9.7
7	38.8	34.8	10.3

Average measured and simulated relative humidity values belonging to probes and error rates of these values for Case A were given in Table **2**.

When the Table **2** examined, the minimum error rate is with 5.0% in 4th sensor and maximum error rate is with 13.5 % in 5th sensor were obtained.

3.2. Air Temperature and Relative Humidity Values for Case B

In this study, Case B is located North-South direction and the window opening angle was set 90°. The air temperature and relative humidity meters inside greenhouse were located at 15 m from entrance of the

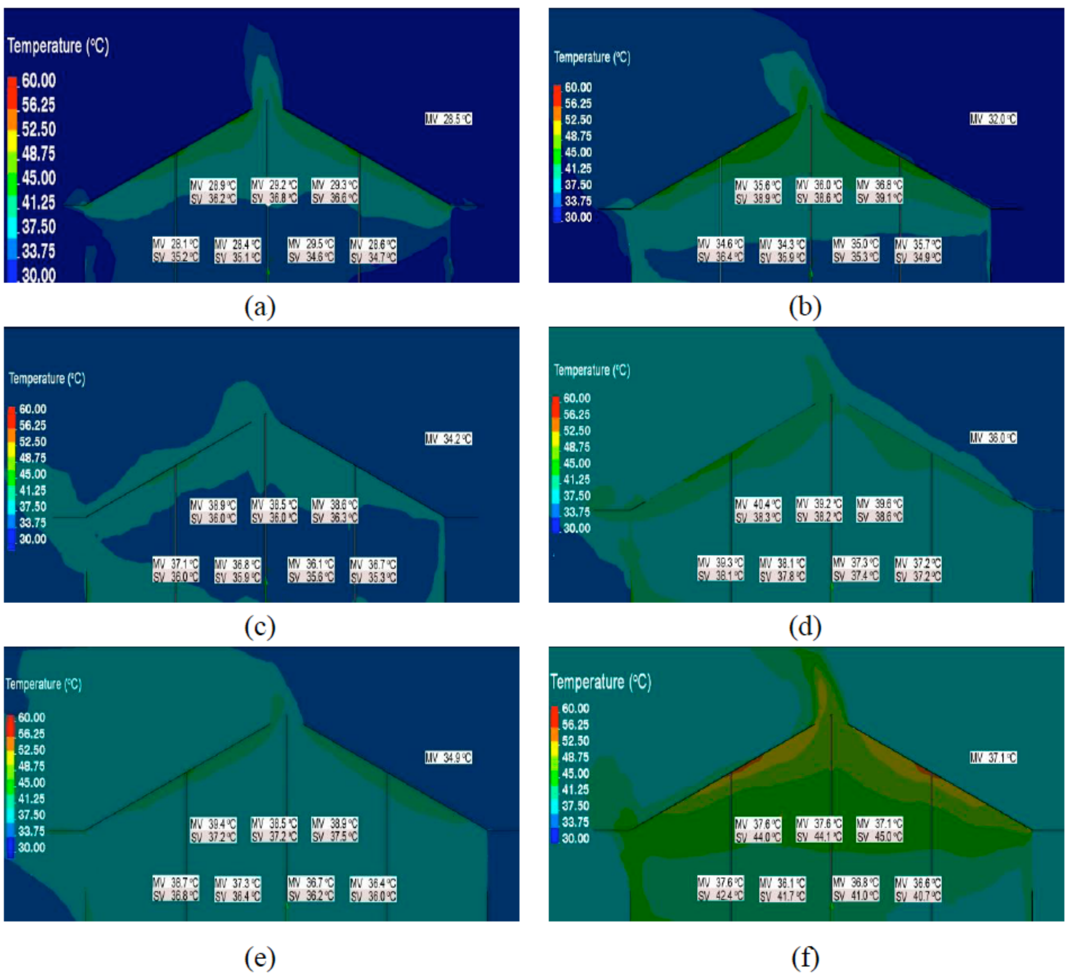

Figure 6: The measured and simulated hourly air temperature values for Case B.
(**a**) 08:00, (**b**) 10:00, (**c**) 12:00, (**d**) 14:00, (**e**) 16:00, (**f**) 18:00.

Table 3: Average Measured and Simulated Air Temperature Values and Error Rates Belong to Sensors

Sensor Point	Average of Measured Values (MV) (°C)	Average of Simulated Values (SV) (°C)	Error (%) $\left(\frac{MV-PV}{MV}\right)*100$
1	35.9	37.5	4.3
2	35.2	37.1	5.1
3	35.2	36.7	4.1
4	35.2	36.5	3.6
5	36.8	38.4	4.2
6	36.5	38.5	5.5
7	36.7	38.9	5.7

greenhouse. The air temperature values obtained from simulation for Case B were given below (Figure **6**).

When the Figure **6** is examined, it was determined the air temperature inside the greenhouse is same with outside in the edges of the windows and it is increasingly towards the ridge in the other parts. Therefore, it was observed more effective ventilation especially at noon hours.

Average measured and simulated air temperature values belong to sensors and error rates of these values for greenhouse B were given in Table **3**.

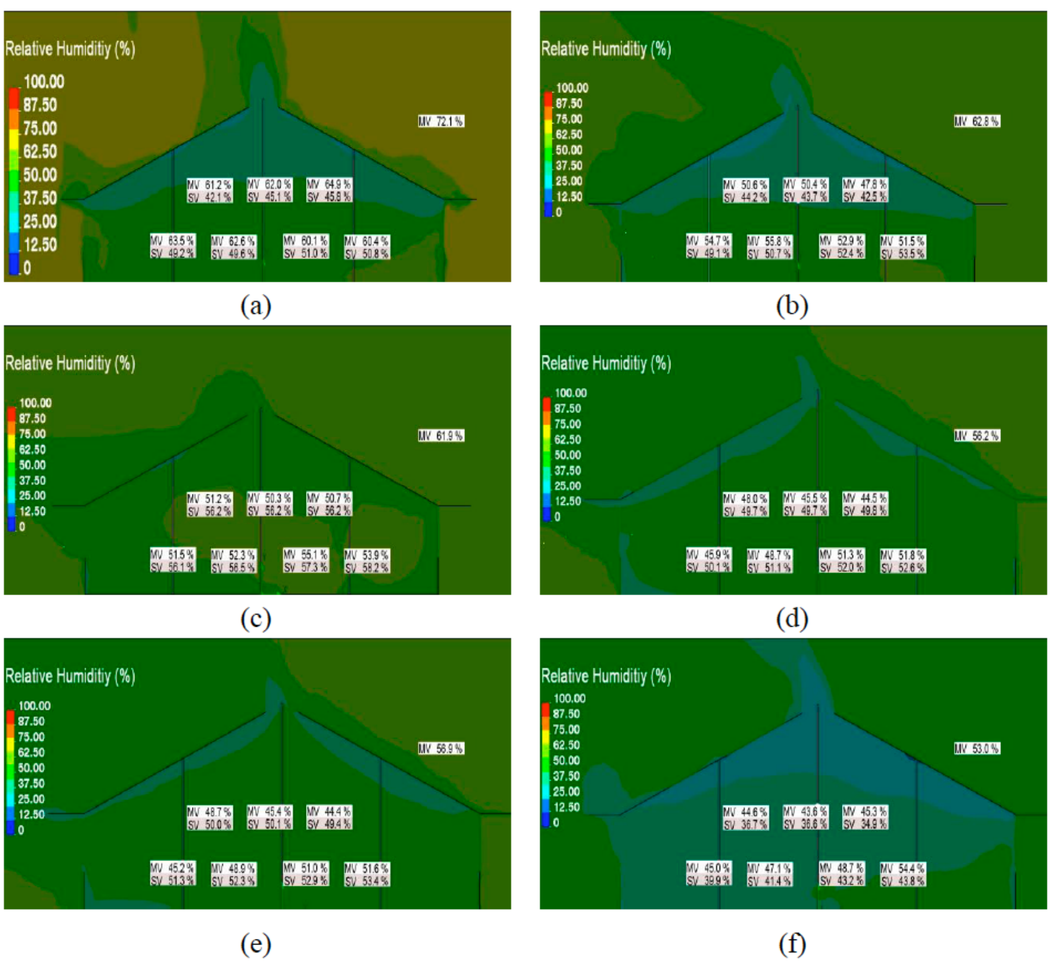

Figure 7: The measured and simulated hourly relative humidity values for Case B.
(**a**) 08:00, (**b**) 10:00, (**c**) 12:00, (**d**) 14:00, (**e**) 16:00, (**f**) 18:00.

Table 4: Average Measured and Simulated Relative Humidity Values and Error Rates Belong to Sensors

Sensor Point	Average of Measured Values (MV) (%)	Average of Simulated Values (SV) (%)	Error (%) $\left(\frac{MV-PV}{MV}\right)*100$
1	51.0	49.3	3.3
2	52.6	50.3	4.4
3	53.2	51.5	3.2
4	53.9	52.1	3.3
5	50.7	46.5	8.3
6	49.5	46.9	5.3
7	49.6	46.4	6.5

When the Table **3** is examined, the minimum error rate is with 3.6% in 4th sensor and maximum error rate is with 5.7% in 7th sensor were obtained.

Simulated relative humidity values for Case B were given in Figure **7**.

When the Figure **7** is examined, the relative humidity inside the greenhouse was showed that a more homogeneous distribution and close to external relative humidity was determined. Therefore, it was observed more effective ventilation especially at noon hours.

Average measured and simulated relative humidity values belong to sensors and error rates of these values for Case B were given in Table **4**.

When the Table **4** is examined, the minimum error rate is with 3.2% in 3rd sensor and maximum error rate is with 8.3 % in 5th sensor were obtained.

Ould Khaoua *et al*. (2006), [11] determined that opening configuration combined with wind speeds strongly affect inside ventilation and microclimate parameters. They obtained that air velocity at crop cover level varied according to vent arrangements and compartment positions from 0.1 to 0.5 ms^{-1}, whereas temperature differences varied from 2 to 6 ^{o}C.

Roy and Boulard (2005), [12] the temperature differences is 5 ^{o}K higher for 0° incidence wind in the center of the tunnel when compared with the 90° incidence distribution were obtained. They also obtained that temperature differences between 45° and 90° incidences are lesser than 1 K in the center of the tunnel and relative humidity differences for a 1 m high line, relative humidity is quite 20% higher for 0° incidence when compared with the 90° incidence distribution and less than 5% difference between 45° and 90° incidences.

5. CONCLUSIONS

For Case A, the average of air temperature values measured outside is 32.2^{o}C, the average of the hourly air temperature values obtained from seven sensors located at different points inside of greenhouse is 35.3^{o}C for all hours. However, the average air temperature values obtained from simulations is 38.3^{o}C. Accordingly, the error rate between the average of measured air temperature values and the average of simulated air temperature values is 7.8% $\left[\left(\frac{38.3-35.3}{38.3}\right)*100\right]$ was determined.

The average of relative humidity values measured outside of greenhouse is 52.6%, the average of the hourly relative humidity values obtained from seven sensors located at different points inside of greenhouse is 41.0% for all hours for Case A. However, the average relative humidity values obtained from simulations is 37.6%. Accordingly, the error rate between the average of measured relative humidity values and the average of simulated relative humidity values is 8.3% $\left[\left(\frac{41.0-37.6}{41.0}\right)*100\right]$ for Case A was determined.

For Case B, the average of air temperature values measured outside is 33.8^{o}C, the average of the hourly air temperature values obtained from seven sensors located at different points inside of greenhouse is 35.9^{o}C for all hours. However, the average air temperature values obtained from simulations is 37.7^{o}C. Accordingly, the error rate between the average of measured air temperature values and the average of simulated air temperature values is 4.6% $\left[\left(\frac{37.7-35.9}{37.7}\right)*100\right]$ was determined.

The average of relative humidity values measured outside of greenhouse is 60.5%, the average of the hourly relative humidity values obtained from seven sensors located at different points inside of greenhouse is 51.5% for all hours for Case B. However, the average relative humidity values obtained from simulations is 49.1%. Accordingly, the error rate between the average of measured relative humidity values and the average of simulated relative humidity values is 4.8% $\left[\left(\frac{51.5-49.1}{51.5}\right)*100\right]$ for Case B was determined.

The results between the greenhouses A and B, which are located in the same directions and haven't any plant, are evaluated according to the air temperature and relative humidity each others in case of different windows openness degree (45^o and 90^o) were found as follows.

While the error rate between the average of measured air temperature values and the average of simulated air temperature values is 7.8% for Case A (45^o), this value is 4.8% for Case B (90^o). However, while the average of measured hourly air temperature values for Case A is 35.3^oC, this value was determined as 35.9^oC for Case B (90^o). The air temperature difference is 0.6^oC, between the 2 greenhouses having the same structural and physical properties depending on the condition to windows openness degree (45^o and 90^o).

While the error rate between the average of measured relative humidity values and the average of simulated relative humidity values is 8.3% for Case A (45^o), this value is 4.7% for Case B (90^o). However, while the average of measured hourly relative humidity values for Case A is 41.0%, this value is 51.5% for Case B (90^o). The relative humidity difference is 10.5%, between the for Case A and Case B having the same structural and physical properties depending on the condition to two different windows openness degree such as 45^o and 90^o.

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