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Determining of some climate parameters using computational fluid dynamic technique in naturally ventilated greenhouses

Doğal havalandırmalı seralarda hesaplamalı akışkanlar dinamiği tekniği kullanılarak bazı iklim parametrelerinin belirlenmesi

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ABSTRACT

Aim of study was to compare the measured inner air temperature and relative humidity values with the simulated values determined with Computational Fluid Dynamics (CFD) technique in the naturally ventilated gable-roofed single glasshouses located East-West direction, having 90° window span and different growing conditions such as plant and without plants. In study, the gable roofed single glasshouses in West Mediterranean Agricultural Research Institute were chosen as material. Study area is located at the latitude of 36º 52' N and longitude of 30º 50' E. In the greenhouses selected as material, measured values were recorded every minute from 8 a.m. to 18 p.m. by using the relative humidity and air temperature meters placed in different locations. However, these values were used as average of 2 hours in calculations to reduce number of data. The Solid Works analysis software was used for CFD simulations of the greenhouses selected as material. The air temperature and relative humidity values 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 compliance levels of these values were determined. In conclusion, the error rates of measured and simulated air temperature and relative humidity values in the greenhouse with plant were found as 4.9% and 0.0%, respectively. Additionally, the same values in the greenhouse without plant were also found as 0.0% and 5.2%, respectively. The study showed that the CFD may be used as a powerful tool for determining inner climatic factors in naturally ventilated greenhouses.

MAKALE BİLGİSİ

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ÖZ

Çalışmanın amacı, Doğu-Batı yönünde yöneylenmiş 90° pencere açıklığına, bitkili ve bitkisiz ortamlar gibi farklı yetiştirme koşullarına sahip doğal havalandırmalı, beşik çatılı seralarda ölçülen iç hava sıcaklığı ve bağıl nem değerleri ile Hesaplamalı Akışkanlar Dinamiği (HAD) tekniği ile simüle edilen değerlerle karşılaştırmaktır. Çalışmada, Batı Akdeniz tarımsal Araştırma Enstitüsü'ndeki beşik çatılı tekil seralar materyal olarak seçilmiştir. Çalışma alanı 36º 52' K enlemi ve 30º 50' D boylamında yer almaktadır. Materyal olarak seçilen seralarda, ölçülen değerler farklı noktalara yerleştirilmiş hava sıcaklığı ve bağıl nem ölçerler kullanılarak 08:00-18:00 arasında dakikalık olarak kaydedilmiştir. Ancak bu değerler veri sayısını azaltmak için hesaplamalarda 2 saatlik ortalamalar şeklinde kullanılmıştır. Solidworks analiz yazılımı materyal olarak seçilen seraların HAD simülasyonları için kullanılmıştır. Sera içindeki hava sıcaklığı ve bağıl nem değerleri dış ortam sınır koşulları ve seranın yapısal ve fiziksel özelliklerine göre simüle edilmiştir. Daha sonra, ölçülen değerler simüle edilen değerlerle karşılaştırılmış ve bu değerlerin uyum düzeyleri belirlenmiştir. Sonuç olarak, bitkili serada ölçülen ve simüle edilen hava sıcaklığı ve bağıl nem değerlerinin hata oranları sırasıyla % 4.9 ve % 0.0 olarak bulunmuştur. Ayrıca, aynı değerler bitkisiz serada sırasıyla % 0.0 ve % 5.2 olarak bulunmuştur. Çalışma göstermiştir ki, HAD doğal havalandırmalı seralarda sera içi iklim faktörlerinin belirlenmesinde güçlü bir araç olarak kullanılabilir.

1. Introduction

For many years, ventilation is needed to assurance an optimum greenhouse simultaneously climate by supporting air exchanges between the air inside and the outside of the supplies greenhouse. It thus protects sound environmental circumstances for plants by impeding extreme air temperature establishes round the plants during periods of strong solar radiation and by holding relative humidity at appropriate levels. There are some greenhouse ventilation types such as natural, which is caused by wind, or mechanical, by using fans. Due to the most energy efficient method and supplies the most uniform circumstances, it is positioned on natural ventilation at this time. (Boulard and Draoui 1995; Papadakis et al. 1996).

Because the greenhouse is a closed environment the moisture is given constantly into the greenhouse from soil and plant. So, the relative humidity of air in greenhouses is higher than the external environment. When the moisture rate of the air increases in the greenhouse the density decreases and heat change increases (Boulard and Baille 1993).

Ventilation is change of the internal air of greenhouse with the external air to decrease air temperature and relative humidity values inside the glasshouse. Natural ventilation is the cheapest method for ventilation of greenhouses because it does not require any energy requirement in application (Ozturk 2008).

Effective greenhouse ventilation is very important not only northern damp winter climates but also Mediterranean hot summer climates. Under cool conditions, reducing extreme relative humidity levels is essential to preserve crop mineral consuming and fungal diseases. Nevertheless, under hot conditions, it is essential to control air temperature and relative humidity in the greenhouse. Hence, the plant photosynthesis and transpiration activity is sustained, and the physiological quality of crops increases (Mistriotis et al. 1997b).

The plants are adapted to 17-27 °C average in greenhouse conditions. Considering the greenhouse effect, daily average temperature should be of 12-22 °C and the soil temperature is required minimum of 15 °C. It should not be allowed over than 35-40 °C of the air temperature in greenhouse. The relative humidity should be between 70-90% in greenhouses (Zabeltitz 1992; Baytorun 1995; Baudoin and Zabeltitz 2002).

Nowadays, due to the fact that computer performance have improved, it is easier flow modeling by using computational fluid dynamics (CFD). It also ensures a new occasions to analyze the situation of the air conditions and estimate the ventilation proportion inside the greenhouses. The principle of this technique is based on the resolution of transport equations in closed (Nara 1979; Lamrani et al. 2001) and ventilated (Mistriotis et al. 1997a) greenhouses. For a wide variety of greenhouse types, ventilation combination and boundary conditions, a better comprehension of ventilation process can be ensured by Compututional Fluid Dynamics method and may guide engineers and greenhouse manufacturers to develop greenhouse manage and design.

Mistriotis et al. (1997a) used CFD under low wind speed and windless conditions for a scientific analysis of the natural ventilation process in greenhouses, Kacira et al. (1998) determined natural ventilation rates in different roof and side-wall ventilation openings and in different wind speed conditions in the multi span greenhouse using CFD, Haxaire et al. (2000) determined the distribution of air temperature and relative humidity resulting from air streams through the continuous roof ventilated multi span greenhouse. Campen and Bot (2003) for ventilation of the parral type greenhouses, Kacira et al. (2004) for determining the effect of air velocities on air change rates and air flow pattern in the divided gothic-roofed greenhouse that is side-wall and natural ventilated used also CFD. Ould Khaoua et al. (2006) determined the effect of wind speed and roof openings in the divided glass greenhouse on air temperature patterns. Teitel et al. (2008) used CFD to determine the air temperature distribution and air flow patterns in a natural ventilated multi span greenhouse. All researchers reported that there is a good agreement with the values of air velocity and air temperature distribution determined by simulation and experimental results.

In this study, air temperature and relative humidity values measured inside the greenhouse were aimed to compare with the simulated values by using Computational Fluid Dynamics (CFD) in a naturally ventilated, gable-roofed single glasshouses located East-West direction, having 90° window span and different growing conditions (with and without plant). At the end of the study, the accuracy degree of software used in the study was determined by using error rates between the measured and simulated values. Additionally, it was examined how the different growing conditions affect the ventilation.

2. Materials and Methods

2.1. Greenhouses used in study

Study was carried out on August 23th and August 24th, 2011 at West Mediterranean Agricultural Research Institute at the Aksu village of Antalya city. Study area is located in the 36º 52' North latitude and 30º 50' Eastern longitude. In study, naturally ventilated gable-roofed single glass greenhouses having size of 9.6 m in width and 40.0 m in length were used. The greenhouses used as material are located East-West direction. Its window openness degrees are 90°, side-wall heights are 2.2 m and the ridge heights are 4.2 m (Figure 1). The greenhouses are ventilated by side-wall and roof openings. The side-wall ventilation openings sizes are 1.5x1.0 m^2 and the roof ventilation openings sizes are 0.5x0.7 m^2 in an alternating manner. In study, two different greenhouses that their physical properties are the same, but only growing environment, with and without plants, are different. The greenhouse which plants were grown was called as number 1 greenhouse and the other greenhouse that has no plant was called as number 2 greenhouse.

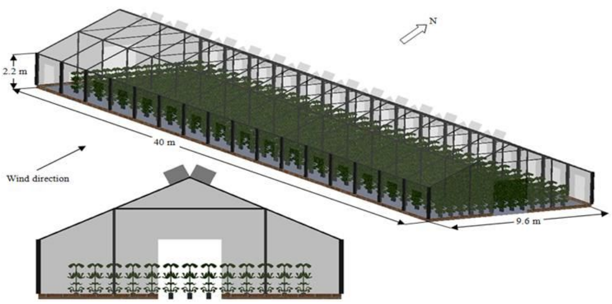

Figure 1. Perspective and cross-section view of greenhouse used as material.

The greenhouses were covered with a 4 mm thick horticultural glass. Widths and heights of greenhouse doors are

2.0 m and 2.2 m, respectively. The columns in greenhouse were placed for each 2.5 m during the ridge of the greenhouse. Total side-wall ventilation area is 45 m^2 and total roof ventilation area is 10.5 m^2 for each greenhouse. Total side-wall window opening area (55.5 m^2) is 14.5% of total ground area. Greenhouses were covered over with shadow powder to reduce the inner air temperature due to measurements are made on summer time.

2.2. Instrumentations used in study

In this study, it was used 8 pieces air temperature meters, 8 pieces relative humidity meters and 1 piece anemometer. The values of air temperature and relative humidity inside the greenhouse were determined by using the air temperature and relative humidity meters that they were placed in 7 different points in the greenhouse and at a point outside the greenhouse.

Internal air temperature and relative humidity values were recorded by means of a data logger TESTO 175 H1 equipped with air temperature and relative humidity probes. These meters can measure the air temperature in a range from −20 to 70 ^oC with tolerance of ±0.5 ^oC and relative humidity of 0-100% with tolerance of ±3%. Resolution of dataloggers is 0.1 ^oC / 0.1 RH%. The memory capacity of data logger is 16000 data. Dataloggers are dual channel and they can measure internal ^oC and RH%. Internal air temperature and relative humidity measurements were taken on 23th and 24th August 2011, from 8 a.m. to 18 p.m. every minutes. However, these values were used as average of 2 hours in calculations to reduce number of data.

Outside wind speed was measured by means of Kestrel 1000 anemometer equipped with wind speed probe. These meters can measure the outside wind speed in a range from 0.4-60.0 m s^{-1} (1.0-218 km h^{-1}). Anemometers could measure momentary, maximum and average wind speed. The anemometer used in the outside wind speed measurements was placed 1.1 m height from the ground because this height is exactly middle of the side-wall. The outside wind speed also was recorded from 8 a.m. to 18 p.m. every ten minutes. However, these values were used as average of 2 hours in calculations to reduce number of data.

The locations of the air temperature and relative humidity meters used in greenhouse were given in Figure 2.

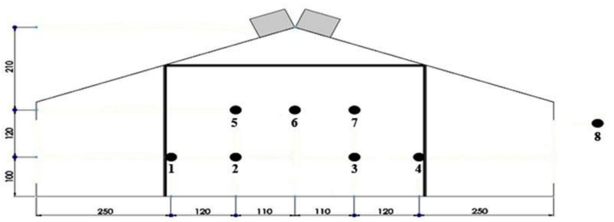

Figure 2. The locations of the air temperature and relative humidity meters in greenhouse.

Then, the greenhouse used as material was drawn in computer media by using SolidWorks software with same properties. After some structural and physical properties of the greenhouse and measured values in the external media conditions had been defined to the software, the values of air temperature and relative humidity were simulated.

2.3. CFD simulations according to measurements

The measured air temperature and relative humidity values were compared with simulated values obtained from sensors placed in different points. Eventually, it was determined how the air temperature and humidity values were changing depending on with and without plants condition in 90° window openness degree and the accuracy degree of software was found by using error rates which determined before.

To make calculations of the software, the boundary conditions must be defined to the software. That means of boundary conditions are some parameters such as air temperature, relative humidity, wind speed, solar radiation. Additionally, it needs to decide the shape of the flow. Software used in study has ability to decide shape of the flow according to input data. Shape of the flow was chosen as turbulent by software. 291 iterations were used in the calculations.

As many as 520537 pieces mesh were used in the analysis. Minimum gap size was determined as 0.03 m by software. Furthermore, accuracy degrees between simulated and measured values were determined by means of the following equation (Eq. 1). The view of the defined mesh of computational domain for simulation was given in Figure 3.

$$Error = \left[\left(\frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \right) x100 \right] \quad \text{(Eq.1)}$$

P_i= Predicted values
O_i= Observed values
n= Number of samples

One of the most important factors affecting the accuracy of results of the analysis is the defined mesh range. The defined small mesh range increases the sensitivity of the accuracy but the calculation and CPU time increases significantly. Whereas defined large mesh range decreases the sensitivity of the accuracy but the calculation and CPU time increases significantly. Therefore, the most appropriate mesh range has been defined according to the CPU capacity by carrying out preliminary simulations.

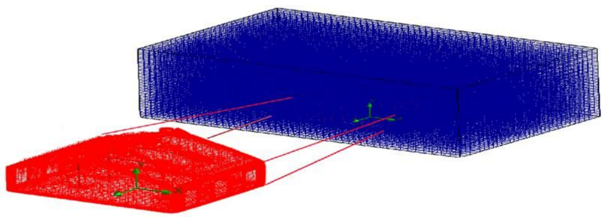

Figure 3. The view of computational domain.

3. Results and Discussion

3.1. The air temperature and relative humidity values for number 1 greenhouse

The number 1 greenhouse is located East-West direction and the window opening angle was set as 90°. The air temperature and relative humidity meters inside greenhouse were located at 22.5 m from entrance of the greenhouse. There were plants in the greenhouse and height of plant is 1.2 m, width is 0.4 m and the row spacing is 1.2 m.

The internal air temperature and relative humidity values belong to number 1 greenhouse were measured. Then, the values of same points were obtained with simulation. The measured air temperature and relative humidity values were compared with simulated values and error rates were obtained using Equation 1.

As a result of the calculations, while the average of air temperature values measured inside greenhouse has been found as 40.4 °C, the average of air temperature values obtained from simulations has also been found as 44.7 °C for all hours in the number 1 greenhouse. Moreover, the average of differences of those values has been found 4.5 °C. Accordingly, the error rate of general average for air temperature was determined as 4.9% [((42.5-40.4)/42.5)x100)] for number 1 greenhouse.

In addition, while the average of relative humidity values measured inside greenhouse has been calculated as 15.9%, the average of relative humidity values obtained from simulations has also been calculated as 15.9% for all hours in the number 1 greenhouse. Moreover, the average of differences of those values has been calculated as 3.0%. Accordingly, the error rate of general average was determined as 0.0% [((15.9-15.9)/15.9)x100)] for number 1 greenhouse.

3.2. The air temperature and relative humidity values for number 2 greenhouse

The number 2 greenhouse is located East-West direction and the window opening degree was set as 90°. The air temperature and relative humidity meters inside greenhouse were located at 22.5 m from entrance in the greenhouse. There were not any plants in the greenhouse. All measurements were recorded under without plant condition.

The internal air temperature and relative humidity values belong to number 2 greenhouse were measured. Then, the values of same points were obtained with simulation. The measured air temperature and relative humidity values were compared with simulated values and error rates were obtained using Equation 1.

As a result of the calculations, while the average of air temperature values measured inside greenhouse has been obtained as 38.9 °C, the average of air temperature values obtained from simulations has also been obtained as 39.3 °C for all hours in the number 2 greenhouse. Moreover, the average of differences of those values has been obtained as 1.7 °C. Accordingly, the error rate of general average was determined as 0.9% [((39.3-38.9)/39.3)x100)] for number 2 greenhouse.

In addition, while the average of relative humidity values measured inside greenhouse has been found as 19.0%, the average of relative humidity values obtained from simulations has also been found as 18.0% for all hours in the number 2 greenhouse. Moreover, the average of differences of those values has been found as 1.7%. Accordingly, the error rate of general average was determined as 5.2% [((19.0-18.0)/19.0)x100)] for number 2 greenhouse.

The most important hours are midday hours for effective natural ventilation inside the greenhouse. The boundary conditions by defining to software, air temperature and relative humidity patterns were obtained for both greenhouses. Air temperature patterns were given in Figure 4 and relative humidity patterns were given in Figure 5 at midday.

As can be seen in the Figure 4, the temperature of inside the greenhouse, in the areas close to the ridge and leeward higher than windward temperature while the windward temperature is almost the same level with the outside for number 1 greenhouse. In number 2 greenhouse, the temperature inside greenhouse is almost same with outside while higher in the ridge.

As is shown in the Figure 5, the relative humidity of inside the greenhouse, leeward and in the areas close to the ridge lower than windward relative humidity while the windward relative humidity is almost the same level with the outside for number 1 greenhouse. The relative humidity inside greenhouse is almost same with outside while lower in the ridge in number 2 greenhouse.

For number 1 and number 2 greenhouses, the daily average measured and simulated air temperature values were shown as graph in Figure 6 and relative humidity values also were given in Figure 7.

As can be seen in the Figure 6, the daily average measured and simulated air temperature values for number 1 (with plant) and number 2 (without plant) greenhouses were determined as similar but the number 1 greenhouse hotter than number 2 greenhouse. However, a good agreement was observed between the measured and simulated air temperature values for both greenhouses. Particularly, the measured and simulated air temperature values were determined as very similar to each other for mid-day hours ($10:^{\underline{00}}$-$16:^{\underline{00}}$) at which the most important of ventilation efficient to growing plant.

As is shown in the Figure 7, the daily average measured and simulated relative humidity values for number 1 (with plant) and number 2 (without plant) greenhouses were determined as similar. But especially in morning hours, while the maximum measured relative humidity value is 25.0% in number 1 greenhouse that value is 32.5% in number 2 greenhouse. Moreover, in evening hours, while the maximum measured relative humidity value is 18.5% in number 1 greenhouse that value is 25.2% in number 2 greenhouse. However, a good agreement was observed between the measured and simulated relative humidity values for both greenhouses. Particularly, the measured and simulated relative humidity values were determined as very similar to each other for mid-day hours ($10:^{\underline{00}}$-$16:^{\underline{00}}$) at which the most important of ventilation efficient to growing plant.

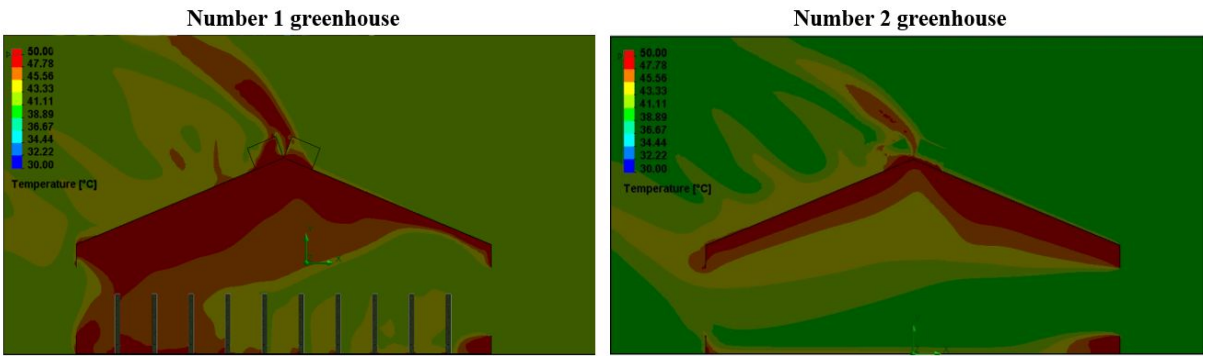

Figure 4. Air temperature patterns at midday for number 1 and number 2 greenhouses.

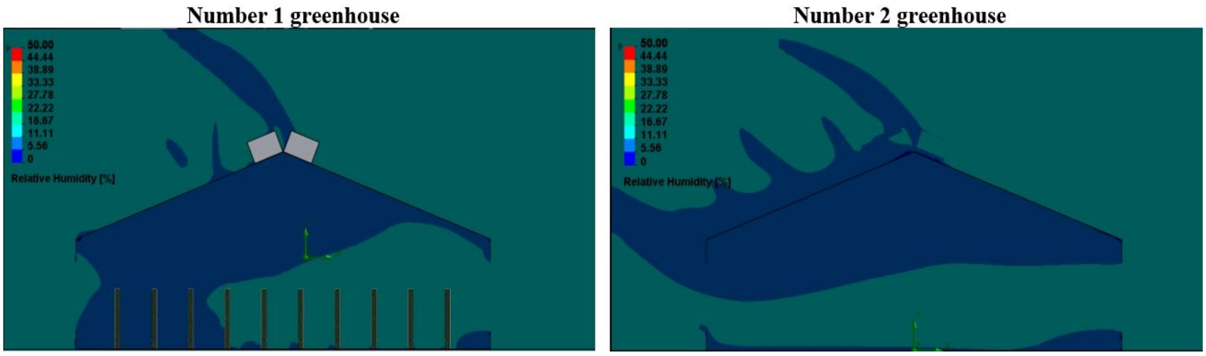

Figure 5. Relative humidity patterns at midday for number 1 and number 2 greenhouses.

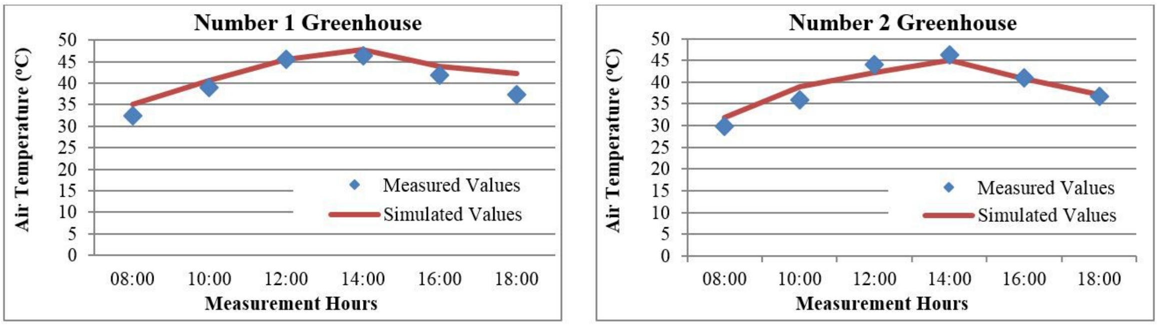

Figure 6. The daily average measured and simulated air temperature values for number 1 and 2 greenhouses.

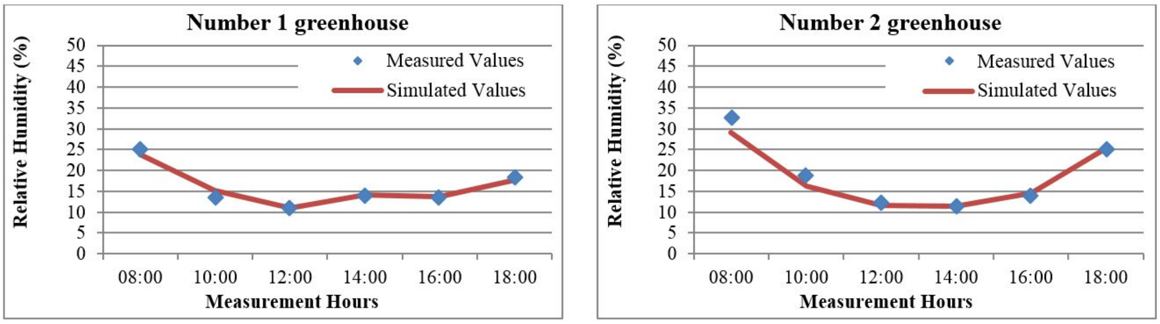

Figure 7. The daily average measured and simulated relative humidity values for number 1 and 2 greenhouses

4. Conclusion

When the number 1 and 2 greenhouses located in the same directions (North-South) and have same window openness degree (90^o) are evaluated according to the air temperature and relative humidity between each other in case of plant and without plant situations;

While the accuracy degree between the average of measured and simulated air temperature values is determined as 95.1% in number 1 greenhouse (with plant), that is 99.1% in number 2 greenhouse (without plant). However, while the average of measured hourly air temperature values in the number 1 greenhouse is determined as 40.4 ^{o}C, this value is 38.9 ^{o}C in the number 2 greenhouse (without plant). The air temperature difference has been found as 1.5 ^{o}C, between the two greenhouses having the same structural and physical properties depending on the condition to be with plant and without plant. The air temperature value in the number 1 greenhouse has been found as 1.5 ^{o}C more than in the number 2 greenhouse (with plant). The reason why those differences may cause from plant. Because plants have prevented both air circulation and temperature distribution.

While the accuracy degree between the average of measured and simulated relative humidity values has been found as 100% in number 1 greenhouse (with plant), this value is 94.8% in number 2 greenhouse (without plant). However, while the average of measured hourly relative humidity values in the number 1 greenhouse has been found as 15.9%, that is 19.0% in the number 2 greenhouse (without plant). The relative humidity difference has been determined as 3.1% between the two greenhouses having the same structural and physical properties depending on the conditions to be with plant and without plant. The relative humidity in the number 2 greenhouse (without plant) has been found as 3.1% more than number 1 greenhouse (with plant).

As a result, there is no difference between measured and simulated temperature values in number 1 greenhouse; it is not found any difference between measured and simulated relative humidity values in number 2 greenhouse also. The study showed that the CFD may be used as a powerful tool for determining inner climatic factors in naturally ventilated greenhouses.

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