

Air Speed Measurement and Simulation in Fan-Pad Greenhouse with Orchid Crop

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Abstract

In this study, the effects of circulating fan setting conditions, such as number of fans and installation position and angle, on the distributions of air speed and temperature in the agricultural greenhouse, were investigated experimentally and numerically. The environment data of air speed, temperature, humidity and thermal radiation of a demonstrative greenhouse acquired via continuous automated measurement were integrated with micro-climate CFD simulation to reveal the optimal control rule of the air-conditioning instruments. The results show that the uniformities of air speed and temperature were improved substantially; the mean air speed increased from 0.26 m/s in the original setting to 0.62 m/s with a standard deviation of 0.09 m/s, and the temperature variation became lower than 0.3 °C.

Introduction

Greenhouse microclimate is often used in environmental studies of energy consumption and greenhouse planting habitat assessment, especially in Taiwan which has a subtropical climate and humid environment. Poor greenhouse air circulation and temperature transfer process leads to non-uniform temperature near the planting beds and air stagnation region, affecting undesirably the growth of crops. Because the distribution of airflow field, temperature, humidity and other environmental factors are key for the growth and production of crops, assessment of these factors for a greenhouse is particularly important.

The methods for greenhouse environmental assessment include primarily on-site field measurements and numerical prediction. For field measurements, multiple sensors are employed to automatically and continuously measure the spatial extent of the greenhouse environment at specific locations. The measured indoor temperature and flow field are analyzed together with the external factors that affect the environment conditions, to evaluate the variation of environmental factors, such as indoor airflow and temperature, over time.

The numerical simulation prediction method has been widely used in the design and planning for greenhouse micro-environment and the evaluation of environment

temperature, humidity and airflow field. This technology works mainly on the basis of meeting the law of conservation of the Navier-Stoke equations (based on mass, momentum and energy balance). By using numerical methods to solve partial differential equations, designers can get a grip on their greenhouse's air flow, temperature and other environmental physical parameters. Such information can be used to improve the ventilation design and control engineering for optimized efficiency and the reasonableness of space usage. For example, [1-2] used a small greenhouse and miniature greenhouse model to study the climatic environment inside a greenhouse. Wind tunnel tests were also conducted to verify their results. Furthermore, many researchers [3-4] have analyzed the results of simulation concerning the type of structure, size, means of ventilation and various other facilities of a greenhouse, proving that computational fluid dynamics (CFD) predictions agree well with experimental data.

This paper investigates the airflow circulation and its improvement in the greenhouse at National Chiayi University through on-site measurement and numerical simulation, focusing on the influences of installation location, angle and quantity of the inner circulation fan on environmental parameters of the greenhouse. Experimentally, environmental physical parameters including airflow speed, temperature, humidity and thermal radiation were measured automatically and continuously through instruments equipped with multiple sensors deployed in the greenhouse. Meanwhile, the greenhouse micro-environmental climate was analysed numerically using CFD modelling. The results were then used as a basis for the improvement of airflow conditions. After implementing the remedy measures, the airflow speed and temperature uniformity were improved. The average airflow speed became 0.62 m/s with a standard deviation of 0.09 m/s, and the temperature uniformity was within 0.3 °C.

Greenhouse microclimate technology Computational fluid dynamics and numerical methods

Recently, performance of computer has been improved significantly; therefore the CFD techniques are widely used in modern greenhouse environment design, and evaluation of environment temperature, humidity, airflow field for energy-saving control reference. This technique is mainly to meet the law of conservation of the Navier-

Stoke equations, and solve partial differential equations, as shown in Equation (1). The main aspects of the numerical Navier-Stoke nonlinear partial differential equations are discrete algebraic equations, and the whole process will be calculated by the finite volume method and the staggered grids systems.

$$\frac{d(\rho\varphi)}{dt} + \text{div}[(\rho V\varphi - G_\phi \cdot \text{grad}(\varphi))] = S_\phi \quad (1)$$

, where

φ : variables in Equation (1), including u 、 v 、 T 、 C 、 κ 、 ε .

ρ : density of working fluid

V : velocity vector

G_ϕ : diffusion coefficient of variable φ

S_ϕ : source term

The κ - ε RNG turbulence model was employed to improve the accuracy of the model. Solar radiation is also considered with the radiative transfer equation shown as follows, and ignores the effect of scattering :

$$\frac{dI_\lambda(\bar{r}, \bar{l})}{dl} + K_\lambda I_\lambda(\bar{r}, \bar{l}) = K_\lambda I_{b\lambda} \quad (2)$$

, where

I_λ : radiation intensity

K_λ : radiation absorption coefficient

In the solving process, the iterative approach is used to calculate and judged by the convergence criteria.

Greenhouse microclimate measurements

Important parameters for greenhouse environment include temperature, humidity, air speed and solar radiation intensity, etc., so the sensors installed in the greenhouse include the thermometer, hygrometer, anemometer and illuminometer. Figure 1 shows the measurement instruments, which is practically used settings in the greenhouse. According to the environmental conditions inside the greenhouse, we used the weatherproof, high precision thermometer and hygrometer with external radiation masks to prevent the measurements from direct sunlight. In addition, greenhouse airflow is not a fixity ; therefore, the low airflow speed, non-directional probe with 0.05 m/s to 5 m/s measurement range was used .



Fig. 1. Experimental setup of measurement

Greenhouse equipment and research methods

Greenhouse at Taiwan National Chiayi University

The greenhouse at Taiwan National Chiayi University is a formerly greenhouse conservatory in Taiwan, with double layer of plastic film, C-shaped channel support, 10 cm air gap and greenhouse area of 864 m²; currently Greenhouse Phalaenopsis seedlings are planted in. The porous-water wall with blowing fans was used as the cooling system. The installation configurations of environmental equipments and heating system with associated air duct in the greenhouse are shown in Fig. 2 and 3.

To reduce internal temperature difference and keep a uniform temperature, the internal circulating fan is the key point of the greenhouse installation. Although an installation guide for internal circulating fan in greenhouse, described the design basis regulation painting and installment of the engineering guidelines, etc., on-site environmental assessment is still the only way to determine the method of inner circulation ventilation.



Fig. 2. Inner environment of greenhouse

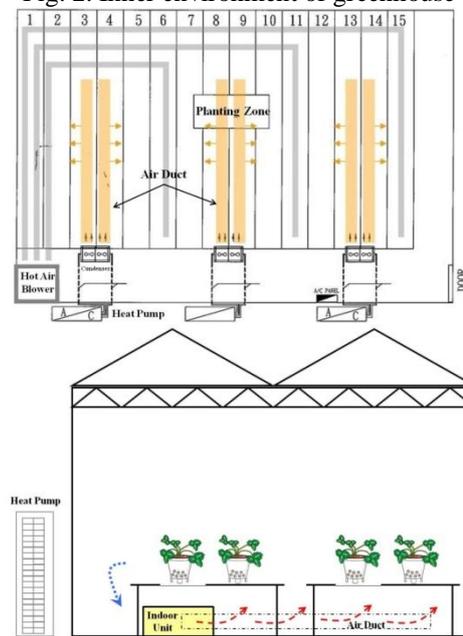


Fig. 3. Heating systems and air duct installation in the greenhouse

Numerical models of the inner circulation airflow field

The greenhouse environment was measured to know the status of greenhouse before the improvement. The inner circulation airflow field is modified by simulations with the demand for internal circulation including the number

of units, fan location and arrangement of angles in the greenhouse. The greenhouse environment was measured again to verify the improvement of the greenhouse airflow. Figure 4 shows the original and modified inner circulation fans. Figure 5 shows the original installation position inside the circulation fan with a modified mounting position and direction. Figure 6 shows the model configuration for CFD simulation. The environmental parameters of the greenhouse at Taiwan National Chiayi University were chosen to investigate airflow and temperature inside the greenhouse model.



Fig. 4. Original (left) and modified (right) inner circulating fans



Fig. 5. Original installation position inside the circulation fan with a modified mounting position and direction

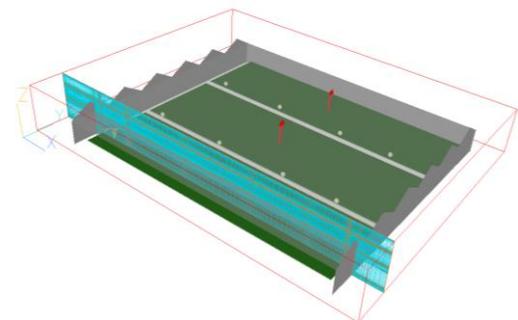


Fig. 6. Physical model for CFD simulation and the distribution of computational grids

The internal circulation fan arrangement distance is appropriate, as the accuracy of the model is validated. Assuming the flow field is incompressible flow, indoor absolute pressure of 1 atm, the flow field near the boundary walls of "generic wall functions", ignoring wall surface roughness model including outdoor environment areas and information, final analysis of its corresponding field distribution as future greenhouse design and methods of measurement of reference. Model grid points distribution, mainly structured as three-dimensional grid, and grid points are about 2.78 million under Cartesian coordinates. The establishment must consider the entire grid convergence, stability and accuracy ; besides, the grid arrangement, the number of grid points and orthogonal distribution are also considered. Calculation procedures will be applied throughout the finite volume method and the use of SIMPLE (Semi Implicit Pressure Linked

Equations) method, and then use numerical method to solve the matrix until 10^{-3} converges.

Environmental temperature, humidity and airflow field measurement

By using greenhouse indoor and outdoor sensors, the environmental parameters of greenhouse including the ambient temperature, humidity, and insolation changes were recorded with continuous automatic way. In this study, solar radiation, temperature, humidity sensors (HOBO) were placed in the center greenhouse, as shown in Figure 7. The measurement point height is 1.5 m above the ground ; the air velocity measurements in mobile way by the hot wire anemometer (Swema 3000) were multi-point measurement at several crop height with 1 m above the ground; the external greenhouse climate was also recorded for reference.

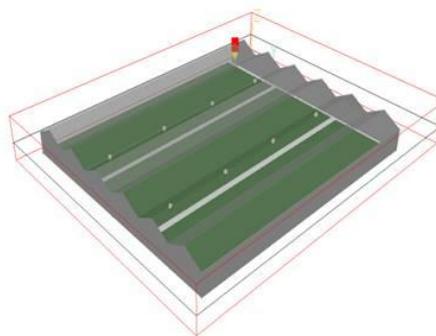


Fig. 7. Greenhouse solar radiation, air temperature and humidity environment measurement locations

Results and discussion

Environmental measurements

Figures 8-10 shows the profiles of solar radiation, indoor and outdoor temperature and humidity changes over time in March 2011. Figure 8 is insolated radiation pprofile over time for both indoor and outdoor. The unit for amount of solar radiation is PAR. The sunny day of March in Chiayi, the sun radiation is reached to its maximum PAR 1846 $\mu\text{mol}/\text{m}^2\text{s}$; furthermore the indoor PAR value can be reached about 251 $\mu\text{mol}/\text{m}^2\text{s}$, and shading rate can be 80 % to 90 %.

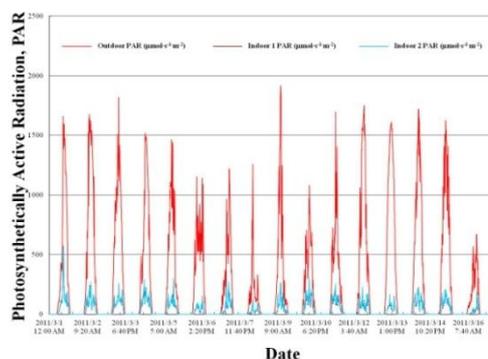


Fig. 8. Solar radiation measurements inside and outside the greenhouse with time

Generally, the suitable temperature for orchid cultivation in greenhouse is 24 °C to 30 °C. It is needed to run the heating system as temperature lower than 24 °C. Also, the attention for circulating ventilation was necessary to be considered. In closed-type greenhouse, it is usual to induce local hot spots and cold spots, so internal circulation fan mounting position is particularly important. Figure 9 shows greenhouse hybrid heating system with time. Figure 10 shows outdoors and indoor humidity, with outdoor humidity range of 50 % to 97 %, indoor humidity range of 40 % to 80%, and high humidity about 80 % at night.

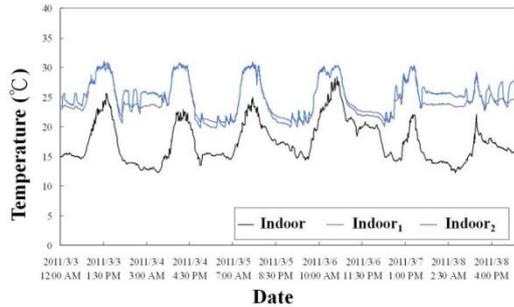


Fig. 9. Indoor-outdoor temperature measuring change vs. time

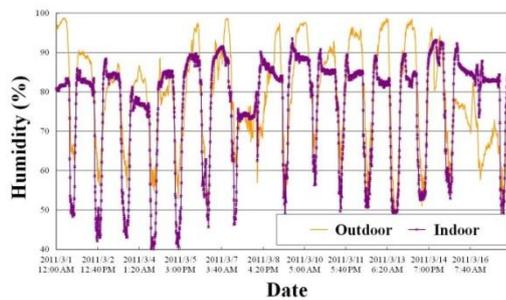


Fig. 10. Greenhouse and outside humidity measurements vs. time

Fig. 11(a) and (b) shows that for the use of multi-point hot wire anemometer measurements near the height of crop leaves airflow conditions within this section. It was found that air speed is only between 0.1 m/s to 0.3 m/s, resulting in local high temperature and uneven temperature distribution, which are less conducive to the growth of crops. Especially for closed-type greenhouse, it is easy to produce localized hot and cold spots when the airflow speed is too low. Therefore, the internal circulation fan mounting position is extraordinarily important.

Figure 12 shows greenhouse temperature distribution by using infrared thermal imager. It can be seen the higher temperatures distribution was focused near the bed plate in the greenhouse. The slow airflow resulted in the chance to increase the temperature unevenness.

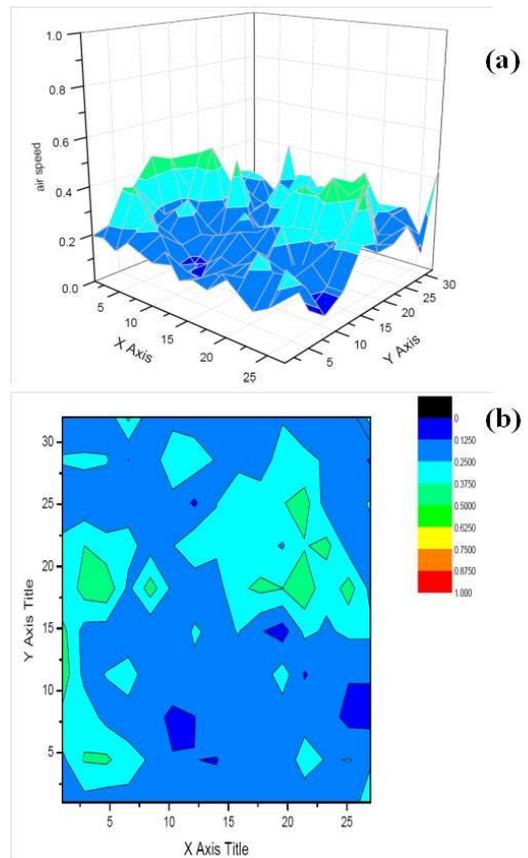


Fig. 11. Airflow speed measurements greenhouse change map.

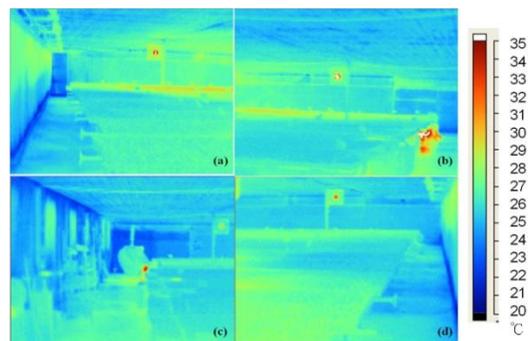


Fig. 12. Temperature distribution measured by infrared thermal imager.

Circulating airflow field simulation and measurement verification

Figure 13 shows the velocity field for 2 m above the ground. Figure 14 is the temperature distribution of cross-sectional position 1 m above the ground, by the fan airflow under the influence of temperature difference between the temperature near the planting area of about 1 °C. Figure 15 shows cross-sectional position 1 m above the ground velocity distribution, the average speed of 0.26 m/s, a speed greater than 0.3 m/s is preferable. Figure 16 is a simulation of the transient temperature distribution in the greenhouse and experimental measurement results beginning from March 8, the simulation starts heating, outdoor temperature and humidity set 15 °C and 80 % relative humidity, indoor temperature was maintained at

about 25 °C, the results can be seen that the temperature predictions are fairly reasonable.

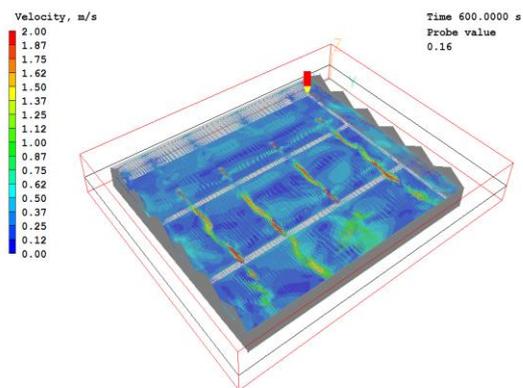


Fig. 13. Simulated velocity field of the cross-section 2 m above the ground

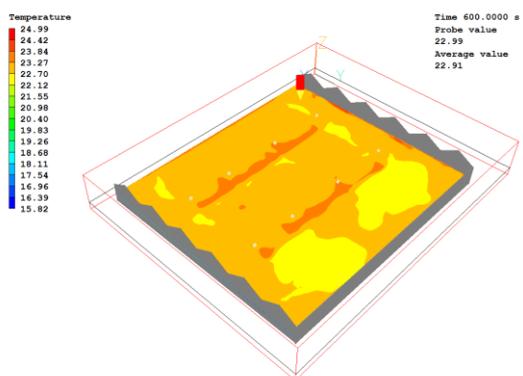


Fig. 14. Simulated temperature distribution of the cross-section 1 m above the ground

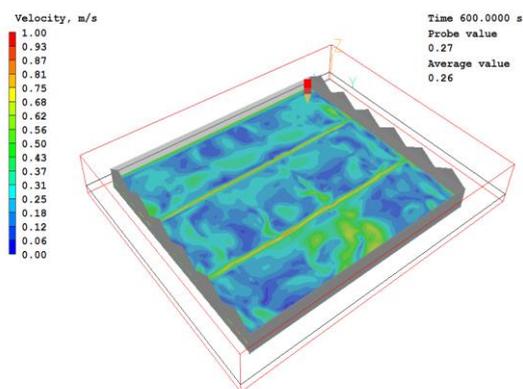


Fig. 15. Simulated velocity distribution of the cross-section 1 m above the ground

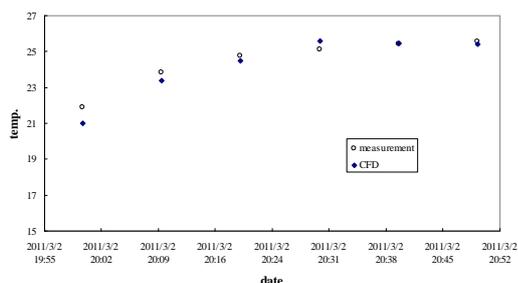


Fig. 16. Greenhouse hybrid heating system and CFD modeling predictions

Circulating airflow field measurement validation and improvement

In order to improve low air velocity and uneven temperature state in greenhouse, we employed simulations to redesign the demand, such as number of units, location and arrangement of angles for internal circulation fan. After implementing the installation, we measured the greenhouse environment again for understanding the improvement of greenhouse airflow distribution to verify the effect of airflow circulation. Figure 17 shows cross-sectional velocity distribution 1 m above the ground before improving, cross-sectional average speed of 0.26 m/s, the standard deviation of 0.086 m/s, speed was less than 0.3 m/s. Many stagnation parts of the region appeared, which is harm for plants environment. Figure 18 shows the velocity distribution for re-installing inner circulating fan. The stagnation parts of the region were improved significantly. Figure 19 shows temperature distribution of 1 m above the ground before improving cross-sectional. The average temperature is 22.91 °C m/s, the standard deviation is 0.27 m/s and higher temperatures will be near the bed. There occurs a vertical temperature difference, which is harmful for plants environment. After Improvement of the internal circulation fan, many stagnant areas were significantly improved. The cross-sectional average temperature is 20.56 °C with a standard deviation of 0.27 m/s, as shown in Figure 19. By conducting simulation and measurements to obtain the flow field distribution, unevenness of humidity at room temperature were effectively improved. In the future, this method would be applied to energy-saving requirement for control the temperature and humidity, resulting in the increase of gas stream quality and reduction of production costs in greenhouse.

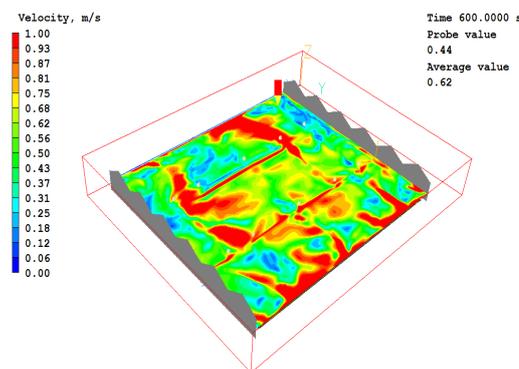


Fig. 17. Simulated velocity distribution of the cross-section 1 m above the ground

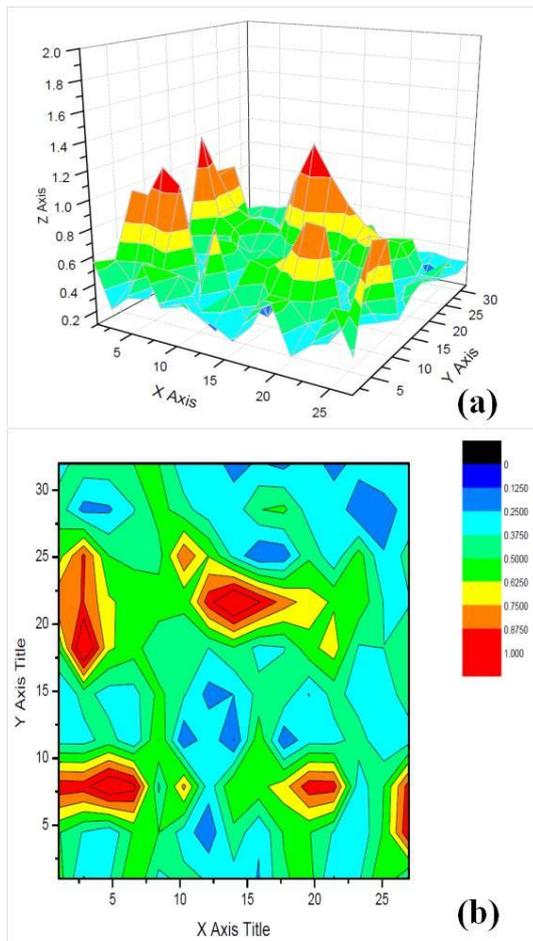


Fig. 18. Measured velocity distribution after reinstalling circulation fans

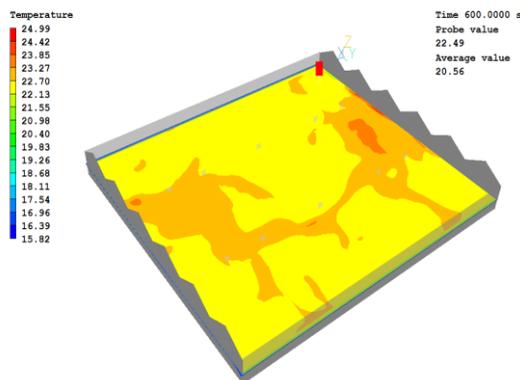


Fig. 19. Simulated temperature distribution of the cross-section 1 m above the ground

Conclusions

This paper investigated the improvement of greenhouse airflow circulation by both on-site measurement and numerical simulation at Taiwan National Chiayi University. We explored the influence of environmental parameters in greenhouse, including the position, angle and number of circulating fans.

The mounting position, angle, and number of circulating fans were studied to improve the performance of the air speed and ventilation in greenhouse. After improvement, the flow rate and temperature uniformity were significantly improved, with the average speed of 0.62 m/s,

the standard deviation of 0.09 m/s and the temperature uniformity less than 0.3 °C.

References

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