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Temperature Simulation of Greenhouse with CFD Methods and Optimal Sensor Placement

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Abstract: The accuracy of information monitoring is significant to increase the effect of Greenhouse Environment Control. In this paper, by taking simulation for the temperature field in the greenhouse as an example, the CFD (Computational Fluid Dynamics) simulation model for measuring the microclimate environment of greenhouse with the principle of thermal environment formation was established, and the temperature distributions under the condition of mechanical ventilation was also simulated.

The results showed that the CFD model and its solution simulated for greenhouse thermal environment could describe the changing process of temperature environment within the greenhouse; the most suitable turbulent simulation model was the standard $k\text{–}\varepsilon$ model. Under the condition of mechanical ventilation, the average deviation between the simulated value and the measured value was 0.6, which was 4.5 percent of the measured value. The distribution of temperature filed had obvious layering structures, and the temperature in the greenhouse model decreased gradually from the periphery to the center. Based on these results, the sensor number and the optimal sensor placement were determined with CFD simulation method.

Keywords: Greenhouse, Temperature, Sensor, Computational fluid dynamics.

1. Introduction

Sensors monitoring is the most direct method for achieving the environmental information of greenhouse and the developed sensor technologies has made it possible. But the excess monitoring sensors would cause a significant increase in cost as well as data redundancy, and interfere with the normal temperature and airflow field. The signal of sensor is important to control system in greenhouse. In fact, environment controlling is a complex process for heat and mass transfer in greenhouse, and achieving the visual information with the fluid mechanics methods has become the hot and difficult problems for environment simulation of greenhouse.

In recent years, with the changing quickly computer technology and developing rapidly simulation for complex fluid, Paying attention to Computational Fluid Dynamics algorithm and its applications has been become more and more popular [1-6]. The CFD method could realize movement prediction, numerical experimentation, movement diagnosis, etc. The CFD method can help designers to select the most rapid and economical approach to conveniently optimizing

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various alternatives, thus significantly reducing the physical work during the experiment. With the complex prototype test and the difficult test for full field information of environmental elements in greenhouse, the CFD method has become an indispensable component of modern regulating principle of greenhouse micro-climate environment. The CFD method was used to simulate the greenhouse environment more than thirty years. The placement of sensor with CFD technology is little in research paper.

In this paper, based on the analysis of formation mechanism of greenhouse microclimate environment, by taking temperature environment as an example, thermal environment model with CFD principle and its numerical solution method and boundary conditions were established. The CFD method for microclimate environment within greenhouse was determined. Finally the results simulated on the condition of mechanical ventilation were applied to study optimal sensor placement.

2. The CFD Simulation Model and its Solution

2.1. Simulation Model

In the greenhouse, the air flow can be regarded as steady-state viscous incompressible turbulent flow. The basic mathematical and physical model for greenhouse temperature environment were composed with the quality equation, momentum equation and energy equation posed [7].

2.2. Model solution

The internal space of greenhouse was chosen as numerical calculation domain. Calculation model and calculation domain are shown in Fig.1.

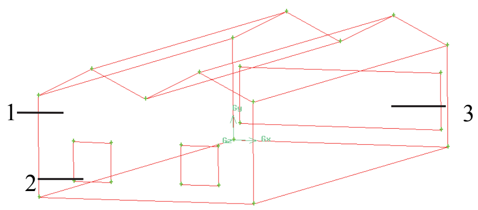


Fig. 1. The calculate region of the greenhouse thermal environment, 1- sun board; 2 - fan; 3 - wet screen.

Use Software GAMBIT was applied for grid generation. The width (x axis) of greenhouse is 8.0 m, height (y axis) of it is 4.5 m, and its length (z axis) is 20.0 m. In the process of Grid Generation, the tetrahedron grid was used, and the size of the grid is 0.2 m and the total of it is 1.6132 million where the skew unit values below 0.5 occupy 97.72 %, thus the quality of grids is good.

The calculation method was the non-coupling implicit algorithm with definite constants. The first-order windward scheme is used for the item of pressure, etc. The SIMPLEC (Semi-Implicit Method for Pressure-Liked Equations Consistent) algorithm is selected for coupling pressure and velocity. The accuracy of convergence is chosen to be 0.0001. FLUENT6.3 software was used for solving the mathematical model.

2.3. Boundary Setting

The air in greenhouse was the research object for CFD simulation, and the covering materials, enclosure structure and soil were considered as boundary conditions. Set wall and top covering materials as "wall" style and no-slip boundary, choose convective heat transfer condition, near wall adopts standard wall function method. Set fans as pressure outlet and set wet screen as velocity inlet. Internal shading net was considered as a "wall" boundary with no thickness, with 35 % transmittance, transduction and convection with the air around. Consider floor as "wall" boundary with no heat transfer.

3. Simulation and Result

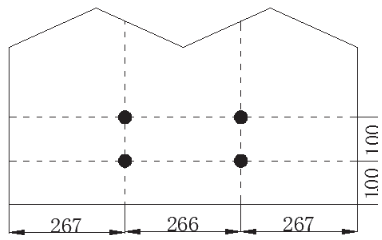
3.1. Experiment Design

Greenhouse experiment was chosen to check the simulated results with the CFD method. Model was built as two-span greenhouse, whose length is 20.0 m, width is 8.0 m, 2 spans altogether, height of the ridge is 4.5 m with the height of eaves gutter being 3.6 m. The similarity of model was proved by Liu Yanzheng 8. The covering materials were the sun board. The thermal parameters of materials were shown in Table 1.

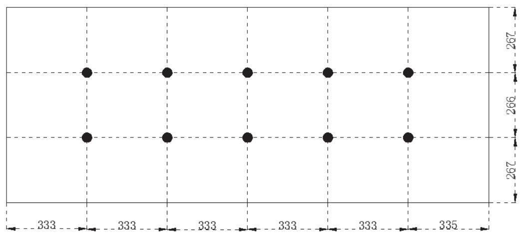
Table 1. Thermal characteristics of the materials

—	Material	Heat transfer coefficient W·(m^2·°C)$^{-1}$	Reflecti-vity	Trans-mittance	Absorp-tion rate
Covering materials	Sun board	3.26	0.2	0.5	0.3
Inner shading net	Aluminized plastic film	3.7	0.45	0.35	0.2
Ground	Soil	2.1	—	—	—

Twenty temperature sensors were set in greenhouse, and the picture of sensor placement was shown in Fig. 2. A temperature sensor was also put into top films, walls around, center of the floor. Four temperature sensors were put 0.3 m away from the wet curtain and fan of the model, and the average value was the imported air humidity and exported air temperature of the fan.



(a) Temperature sensor vertical layoutb (unit: cm)



(b) Temperature sensorhorizontal direction layout (unit: cm)

Fig. 2. The placement of the temperature sensors.

Table 2. Input constant parameters of the model.

Title	Value	Unit
Temperature of the top films	20.7	°C
Temperature of the east side wall	17.8	°C
Temperature of the west side wall	18.0	°C
Temperature of the south side wall	18.3	°C
Temperature of the north side wall	17.0	°C
Indoor air density	1.225	kg/m^3
Indoor air viscosity coefficient	0.0242	kg/(m·s)
Heat transfer coefficient of indoor air	1006.43	$wm^{-1}k^{-1}$
Indoor steam content	29.0	kg/mol
Indoor air acceleration of gravity	9.81	ms^{-2}
Temperature of the greenhouse floor	18.1	°C
Outdoor air temperature	20.6	°C
Atmospheric pressure	101324	Pa

Suppose the wind flows into the greenhouse along horizontal direction, the wet curtain could be divided into 4 parts, respectively measured the wet curtain's export wind speed of the center of each part, then calculated the average result as the export wind speed of the wet curtain. Solar radiation and the heat transfer of internal shading net were considered.

Materials of wall and cover were supposed to take part in heat transfer by conduction. The floor was adiabatic. The boundary conditions of CFD model were wet screen imported temperature, export temperature of fans, environment temperature outside the greenhouse, wall temperature, floor temperature, wet screen imported wind speed. The parameters were shown in Table 2.

3.2. Result

Under mechanical ventilation, the temperature field considering internal shading net, fans and wet pad was simulated, and four treatments were marked TS1, TS2, TS3, TS4. The working conditions and its boundary conditions were shown in Table 3.

Table 3 (a). Test setting.

Treatment	Test setting		
	Internal sunshading net	Fan	Wet screen
Ts1	0	1	0
Ts2	1	1	0
Ts3	0	1	1
Ts4	1	1	1

Note:"o" is cut-off state;"1 "is opening state. wet curtain wind speed is measuring 6 average point of wet curtain spacing; fan blast wind speed divided area of fan blast into four groups, measuring average of every center data.

Table 3 (b). Its boundary conditions.

Treat -ment	Boundary conditions					
	Wet screen tempe-rature (℃)	Wet screen wind speed (m/s)	Fan blast tempera-ture (℃)	East side tempe-rature (℃)	West side tempera-ture (℃)	Top tempera-ture (℃)
T_{s1}	15.2	0.23	16.2	18.4	17.8	18.2
T_{s2}	15.5	0.46	16.6	17.6	17.0	19.0
T_{s3}	9.8	0.39	14.7	16.0	13.1	21.5
T_{s4}	9.7	0.42	14.7	14.9	11.6	21.1

The temperature distributions of 1 m and 2 m horizontal section and center of the fan were shown in Fig. 3-6.

From Fig. 3-6 (a), the results showed that the temperature near the wet screen is higher than the temperature near the fan. The temperature of the area near the side wall especially at the corner was obviously higher than that of the center of the greenhouse. The temperature of 1m high at the center of greenhouse was uniform, and the temperature of the area near the wet curtain was low. From Fig. 3-6 (b), the results showed that the temperature changing trends of the two spans were nearly the same. The temperature of the inlet of the wet curtain was the lowest, in the process of the wind reached the outlet of the fan, and the temperature of horizontal direction increased gradually. When the internal shading net was open, the effect of mechanical ventilation on the air on the top of the greenhouse was little, so the temperature was high, while the temperature under the shading net was uniform.

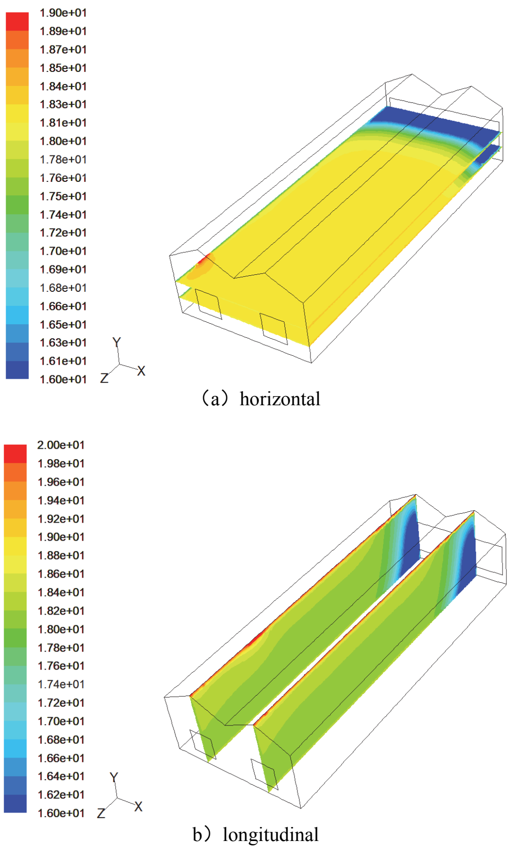


Fig. 3. Greenhouse temperature distribution under working condition TS1.

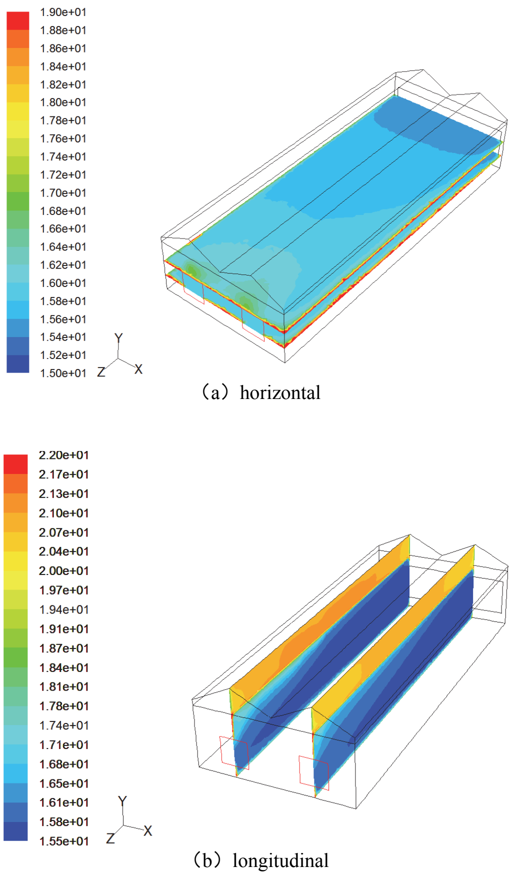


Fig. 4. Greenhouse temperature distribution under working condition TS2.

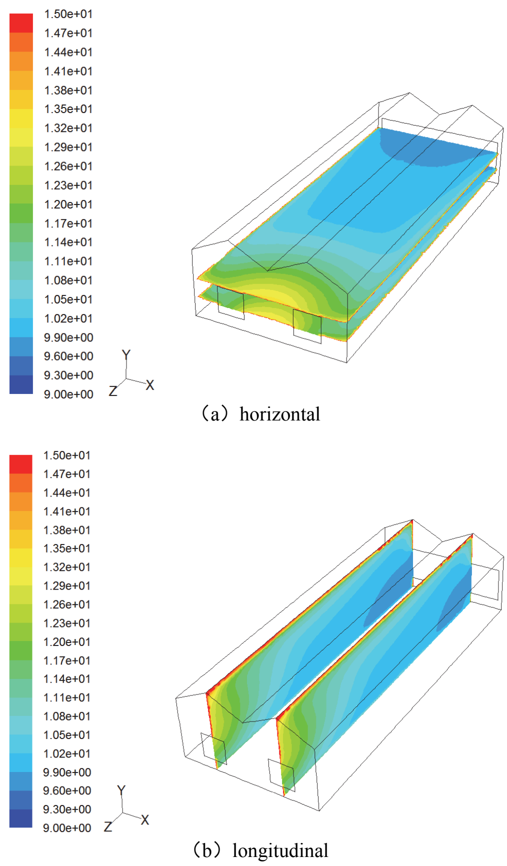


Fig. 5. Greenhouse temperature distribution under working condition TS3.

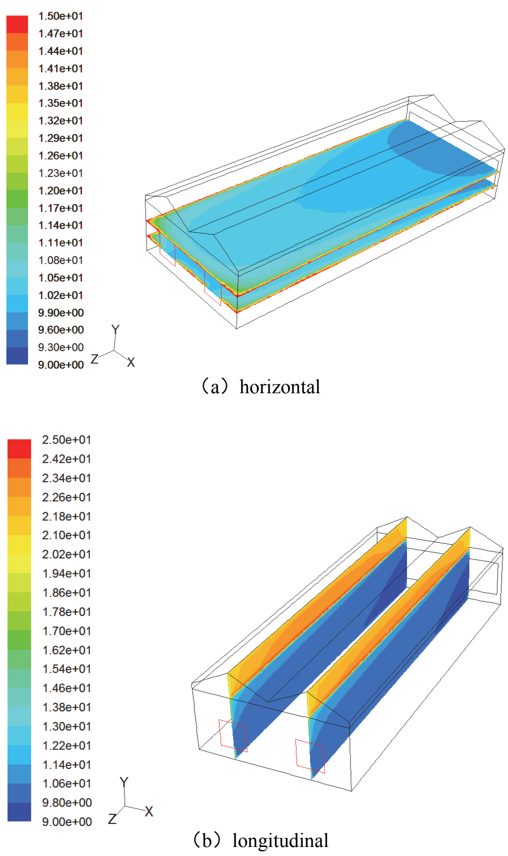


Fig. 6. Greenhouse temperature distribution under working condition TS4.

The distribution of temperature in the greenhouse was closely related to wet screen on the condition of mechanical ventilation.

In summary, the results of simulate temperature distributions under different conditions with CFD method were almost the same as the measured results. Under the same condition, the result of simulation and average measured results was 0.6 °C apart, and the biggest average relative deviation was 4.5 percent of the actual measured results. These further proved the feasibility of chosen model and solving algorithm.

4. Conclusions

From the study of the paper, the following three conclusions could be achieved:

1) The temperature distributions of the two-span greenhouse were simulated under mechanical ventilation considering the internal shading net opened / closed, and the wet screen opened/ closed. The simulated and measured values were 0.6 °C apart, and the biggest average relative deviation was 4.5 percent of the actual measured results. It was found that using CFD method to simulate and analyze mechanical ventilation process of model had good accuracy.

2) The temperature in the greenhouse possessed obvious layer structures with the shade opened, and the temperature in the greenhouse model decreased gradually from the periphery to the center. With the wet screen opened, the cooling effect is obviously in greenhouse.

3) In all condition, the temperature near the fan and the wet curtain is fluctuations obviously, and the temperature distribution in middle of greenhouse is balanced. In all of the sensor placement patterns, the optimal places were at middle of the greenhouse. If perception of greenhouse temperature needed sensitively, the sensor may place at the boundary place in plant growing region.

Acknowledgements

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