Control optimization model for greenhouse microclimate

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Abstract: In this paper, greenhouse microclimate change is studied and discussed in the context of greenhouse. Based on the hydrodynamic model and mathematical model, a climate-like control model with adjustable parameters is established. The greenhouse environment under different conditions was simulated by adjusting the numerical parameters. In this paper, a glass greenhouse with a length of 10 meters, a width of 3 meters and a height of 2 meters is simulated. Due to the need to consider greenhouse crops, this paper uses the finite difference method to establish a mathematical model of "no crops" in the greenhouse, and the distribution of temperature and wind speed in the greenhouse can be observed through the cross-sectional data. Based on this, crops are added in this paper and the factors of crop canopy are taken into account. Taking the crop canopy as a porous medium model, the temperature field and velocity field are updated based on Dracy's law, and the temperature and humidity distribution model is established by simulation. The relevant parameters were adjusted to make the whole greenhouse reach a more suitable environment for the healthy growth of plants. Combined with the location, size and number of greenhouse fans for discussion and analysis, the team adjusted the number of fans and the position of the two fans to make the temperature and wind speed distribution in a relatively appropriate situation, meet the "U" shape, which has certain rationality and scientific. By analyzing the greenhouse environment and how to use mathematical models to solve the related problems of fluid dynamics and heat conduction, and using simulation to simulate, a series of theoretical and simulation results are analyzed, and the relevant optimization scheme is designed. Based on this model, the model can be verified by experimental data and can be extended to more complex physical models.

Keywords: Fluid Dynamics; Heat Transfer Model; Darcy's Law of Penetration; Homogeneous Porous Medium; Simulation Test

1. Introduction

The yield of greenhouse crops is affected by many climatic factors, and good plant growth requires suitable temperature and wind speed. In the agricultural production process, the greenhouse plays a key role, to a certain extent, is a key factor to improve crop yield and quality. For greenhouses, the right temperature and appropriate wind speed are conducive to crop production. Other environmental factors are also affected, therefore, it is necessary to optimize the location of the greenhouse fan and the outlet speed of the warm air in the greenhouse design, so as to realize the appropriate value of the climate factors such as wind speed and temperature in the greenhouse and improve its uniformity. Therefore, under this premise, this paper establishes and studies the control optimization model for greenhouse microclimate control, and analyzes its influencing factors, so that the climate in the greenhouse reaches the environment suitable for crop growth[1-3]

2. Wind speed and temperature modeling in greenhouse based on dynamic hydrology

2.1 Analysis of greenhouse environment and solution model

According to the mathematical model of the temperature and wind speed distribution in the crop-free glass greenhouse proposed by the greenhouse environmental background, the two-dimensional part of the 3D model constructed below is analyzed. The greenhouse diagram is shown in FIG. 1.

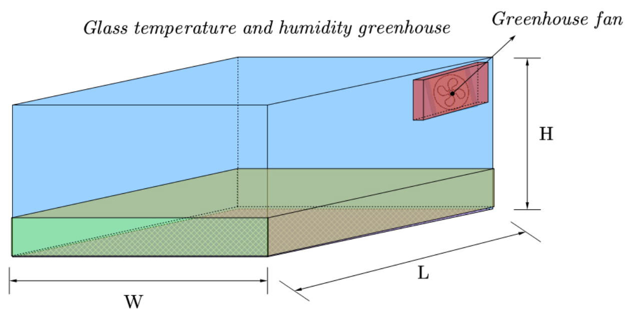


Fig 1. Greenhouse diagram

Through the analysis, consider the following three aspects:

First: Fluid dynamics (wind speed distribution): The fluid dynamics Navier-Stokes equation is used to describe, the most basic of which is that it describes the motion of the fluid, and its vector expression is[4]

$$\frac{\partial V}{\partial t}+(V\cdot\nabla)V=f-\frac{1}{\rho}\nabla\rho+\frac{\mu}{\rho}\nabla^2V\,, \qquad (1)$$

Second: Heat conduction and convection (Temperature distribution): thermal conduction is a heat transfer phenomenon when there is no macroscopic motion in the medium. The air flow law in the greenhouse satisfies the thermal conduction differential equation, the most typical of which is the thermal conduction differential equation and Fourier's law. Described by the subequation, the heat energy transferred to the heat is caused by the air flow caused by the fan, and the transfer mainly occurs on the surface of the soil and room temperature.

Third: Boundary conditions: The soil on the side wall of the greenhouse and the bottom of the greenhouse was used as the boundary conditions of the wall. The main mode of energy exchange between these surfaces and the outside environment is through air convection and heat conduction.

2.2 Establishment of model

Based on the analysis of the model and the environment under this condition, the following three mathematical models are proposed.

① Hydrodynamic model

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u}=-\nabla p+\mu\nabla^2\mathbf{u}\,, \qquad (2)$$

Note: ρ is the air density of the greenhouse at this time, $\mathbf{u}$ is the velocity field of this environmental pair, p is the air pressure, and μ is the dynamic viscosity of the air.

② Heat transfer model

$$\nabla\cdot(k\nabla T)+\rho C_p(\mathbf{u}\cdot\nabla)T=Q\,, \qquad (3)$$

Note: T is the temperature field, k is the heat conductivity of the air in this environment, ρ is the density, C_p is the specific heat capacity, and Q is the internal heat source. Since the system is an independent glass greenhouse, it is assumed that the internal environment is not affected by the internal heat source, that is, the energy of the internal heat source Q is 0.

③ .Boundary condition

Restatements in question are available. Thus:

■ For the wind speed of the inlet, the initial temperature is 40 degrees Celsius and the wind speed is 2m/s.

■With the outer glass of the greenhouse and the bottom soil set as the wall conditions, it is assumed that the bottom soil is normal and there is no sudden condition that interferes with the wind speed, that is, the exchange of energy is conducted with the whole greenhouse through convective heat.

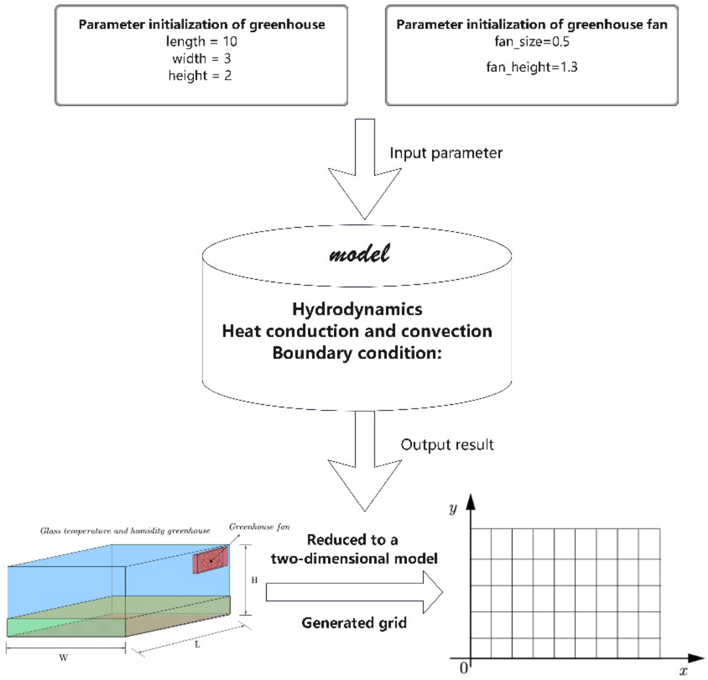


Fig2 Three phase of overtaking process

Initialization parameter

According to the background environment and known conditions of the topic, enter the length, width and height of the glass greenhouse. Set the size and position of the fan module. The resolution of the given space is calculated and the number of grid points and the distance between them are obtained. As shown in formula (4)

$$\begin{cases} length = 10 \\ width = 3 \\ height = 2 \\ fan\ size = 0.5 \\ fan\ height = 1.3 \\ nx = 100 \\ ny = 80 \end{cases} \quad (4)$$

Notes: The length, width and height of the greenhouse are length, width and heigth respectively. fan size is 0.5*0.5. fan height represents the height between the fan center and the bottom surface. The number of grids is 100 and 80.

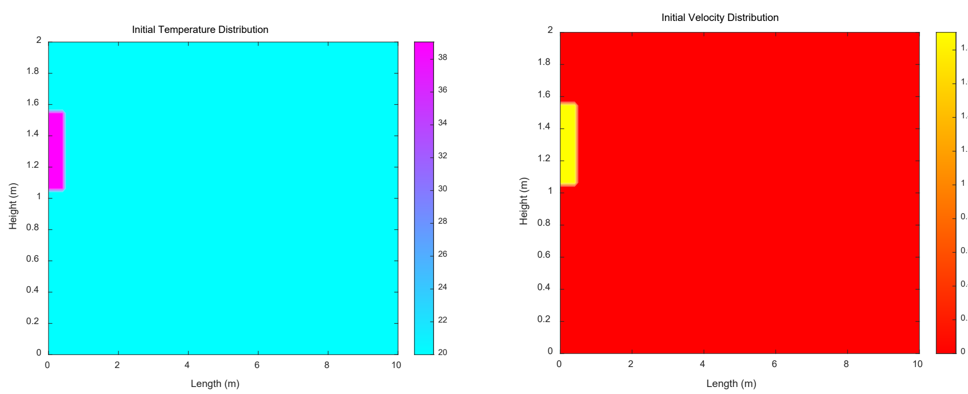


Fig 3 Initial distribution of temperature and wind speed

As shown in Figure 3, the initial distribution of temperature and wind speed in the initial model that has not yet started iteration, the temperature at the fan is 40 degrees Celsius and the wind speed is 2m/s.

Grid initialization

According to the existing conditions, set the initial temperature to 20 degrees Celsius and the speed to 0m/s.

Set boundary condition and steady state distribution solution

The parameter setting of the fan and the temperature setting of the temperature are entered into the model, and the constant fall is obtained by a steady state solution.

After the simulation simulation of MATLAB, the stability of the iteration was obtained when the iteration was 6665 times.

The final steady-state distribution of wind speed and temperature displayed on a cross-section at a height of 0.5 meters in the greenhouse is obtained, as shown in Figure 4.

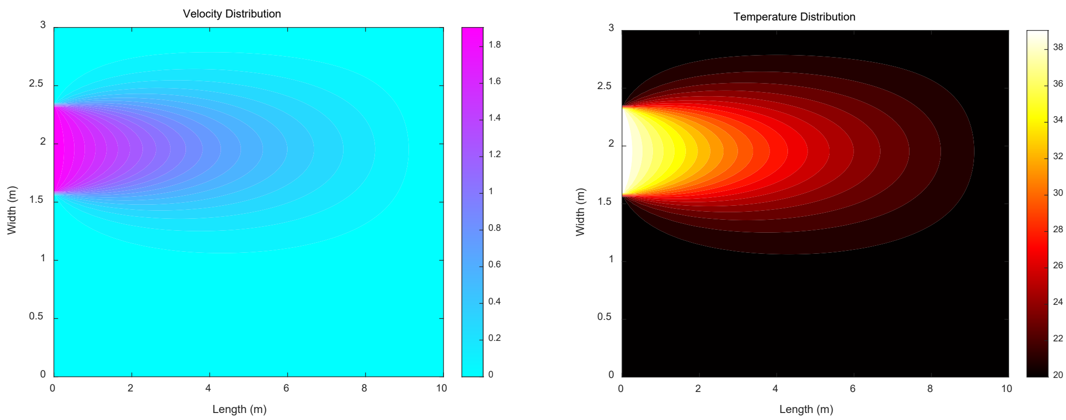


Fig 4 The final steady-state distribution of wind speed and temperature

In order to more intuitively analyze the changes of temperature and wind speed, we visualized the distribution situation as a three-dimensional situation, as shown in Figure 5。The general model of artificial neural network consists of four basic elements, which are:

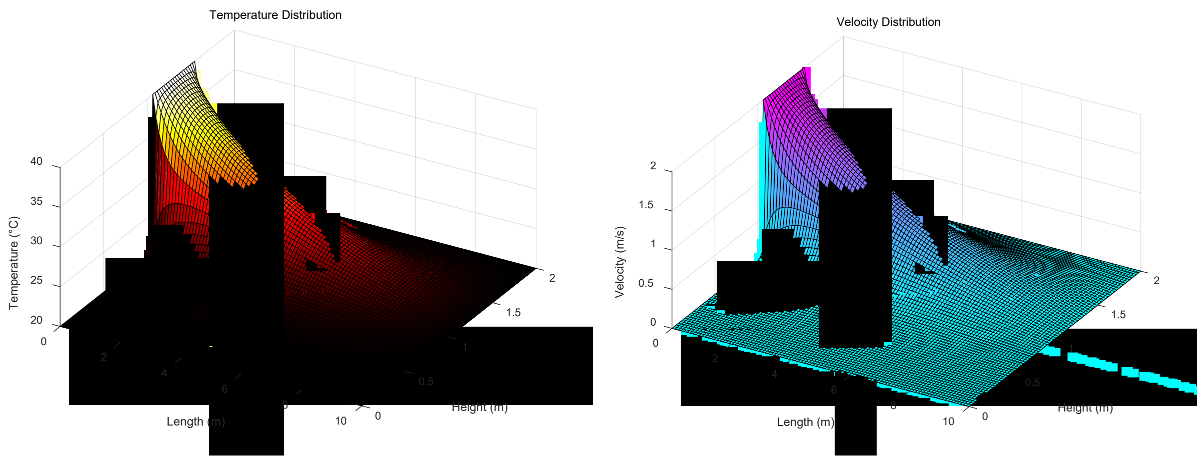


Fig 5 Temperature and Velocity Distributions

3. Solution of crop canopy influence model based on Darcy theorem

3.1Establishment of theoretical model based on analysis of crop canopy

When crops are grown in a greenhouse, the canopy resistance of the crop should be considered to analyze the heat transfer characteristics and wind speed characteristics of the air temperature in the greenhouse. The model is simplified as 8m*2m*0.5m(length * width * height) and placed in the center of the greenhouse. The suitable wind speed for crop growth in the greenhouse is 0.3-1m/s, and the suitable temperature is 23-26°.

A mathematical model is established based on Darcy's law to solve the temperature and wind speed distribution in the glass greenhouse where crops are grown. The crop canopies of plants affect wind speed and temperature profiles due to the characteristics of air flow and heat transfer. Therefore, the canopy can be assumed to be a porous medium and Darcy's law can be used to solve the model analysis. Figure 6 shows this diagram[5-7].

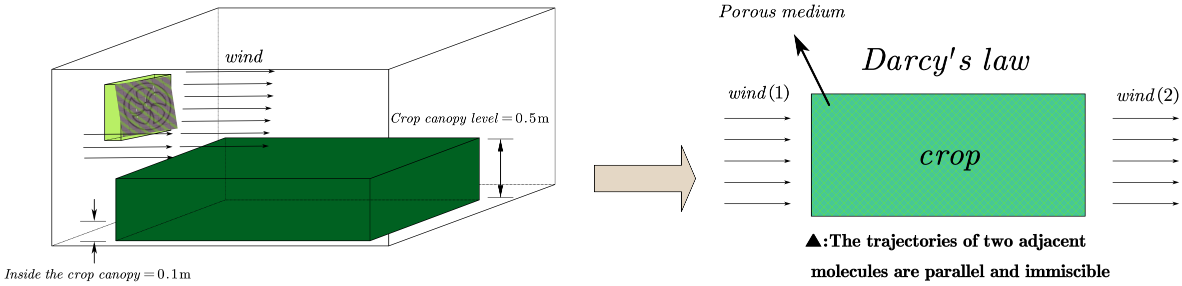


Fig 6 Diagram of Darcy's law acting on crops

3.2 A new parameter model is established based on the analysis

Through analysis, this paper modifies some parameters, and obtains the following three mathematical relation expressions, and applies them to the model.

■ Darcy's law

$$\mu\frac{\mathbf{u}}{k_m}+\nabla p=\rho \boldsymbol{g} \quad (5)$$

Note: μ is the aerodynamic viscosity, k_m is the permeability of the porous medium, $\mathbf{u}$ is the flow rate in the porous medium, p is the air pressure, ρ is the air density, g is the acceleration of gravity, and $10 m/s^2$ is taken here.

■ Heat transfer equation

$$\nabla\cdot(k\nabla T)+\rho C_p\mathbf{u}\cdot\nabla T=Q_m \quad (6)$$

Note: T is the temperature, k is the heat conductivity, C_p is the specific heat capacity, $\mathbf{u}$ is the velocity field, and Q_m is the heat generated due to crop metabolism.

■ Boundary condition

For the air above and below the crop canopy, different boundary conditions need to be set to simulate the situation, so the updated equation needs to be applied to the location of the crop canopy.

3.3 Practical simulation and model solving

The execution block diagram of the program is shown in Figure 7.

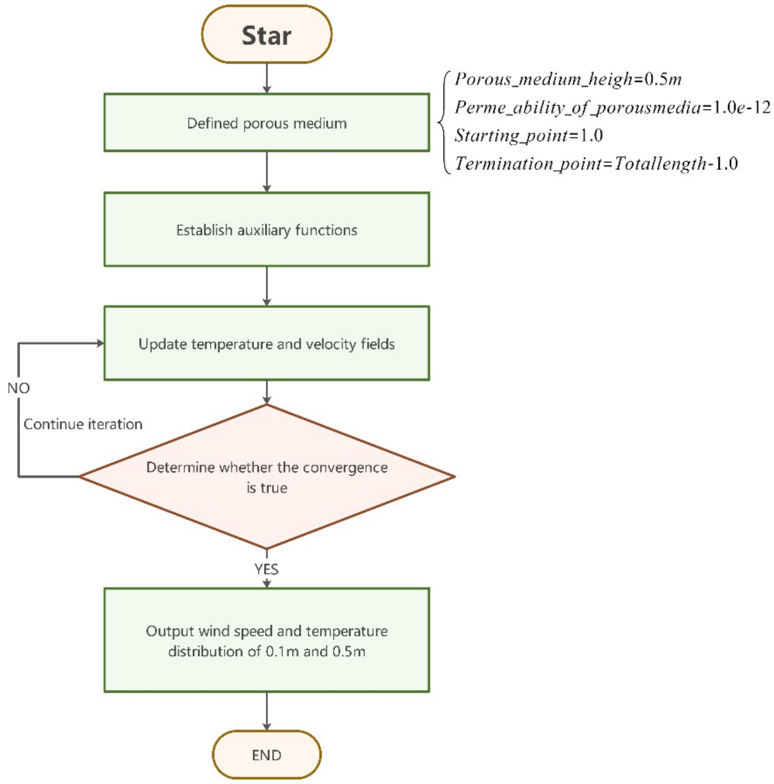


Fig7 The actual simulation of the program block diagram

The parameters of the equation were put into the MATLAB program (see the appendix for the specific program), and the following results were obtained.

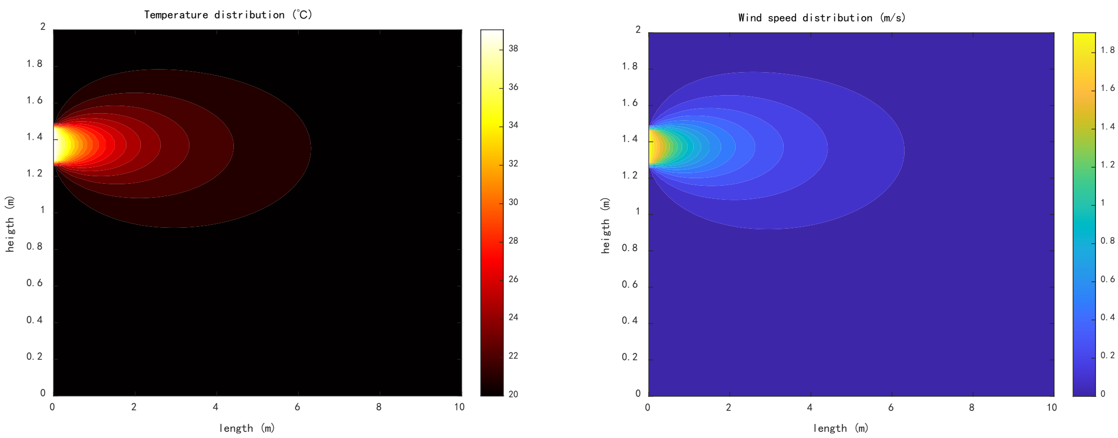


Fig8 Simulated test results

Figure 8 shows the overall distribution at this time. Under this condition, the temperature and wind speed transformation of 0.5m and 0.1m cross sections are obtained, as shown in Figure 9.

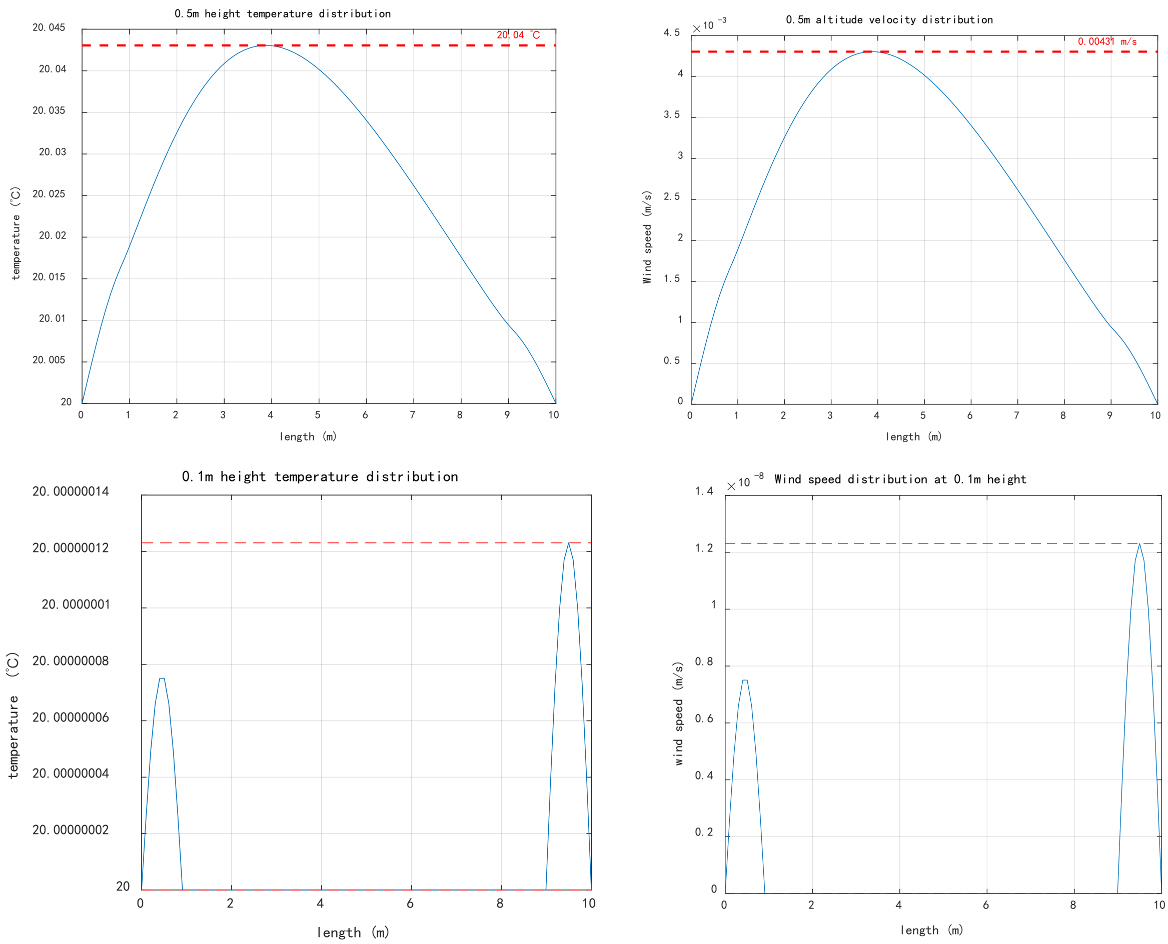


Fig9 Temperature and wind distribution of 0.1m and 0.5m height

4. Solution of crop canopy influence model based on Darcy theorem

4.1 Optimization and establishment of microclimate control model

① Greenhouse fan size

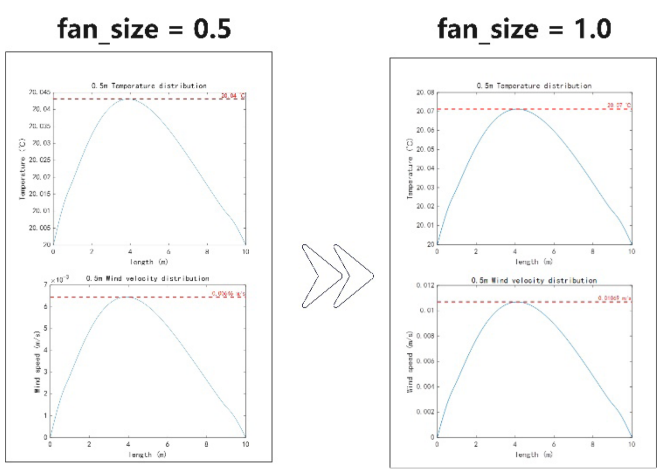
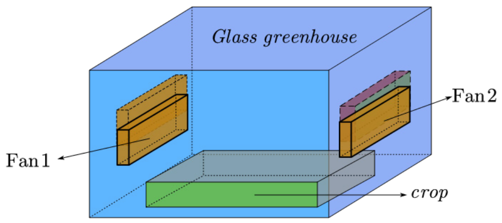


Fig10 Greenhouse fan size change before and after the picture

It is found that when the size is doubled, the change in wind speed and temperature is small, the wind speed is from 0.00646 to 0.0109, the transformation is small, and when the greenhouse fan is doubled, the consumables are also large, by considering the temperature and humidity at 0.5m and 0.1m, as well as the consumables used, changing the size of the greenhouse fan is not a scheme worth considering[8].

② Greenhouse fan size

$$\textit{Greenhouse fan related parameters}\begin{cases} \textit{fan velocity} = 2.0; \\ \textit{fan temperature} = 40.0; \\ \textit{fan size} = 0.5; \\ \textit{fan height above ground} = 0.65; \\ \textit{fan number} = 2 \end{cases}$$



In general, the height of greenhouse fans was reduced and the number of fans was adjusted to 2, that is, 0.65m, as shown in Figure 11.

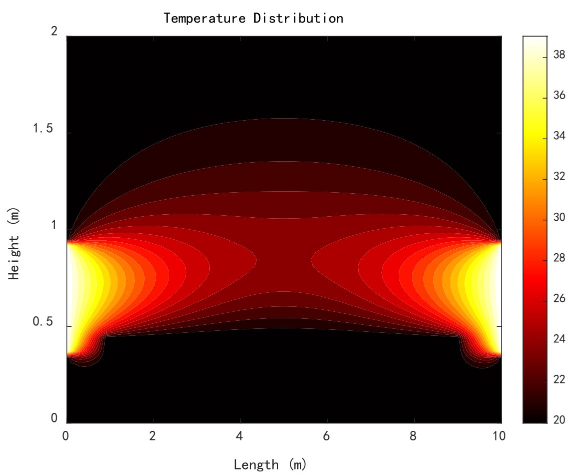


Fig11 The simulation diagram after adjusting the position

The model of the rectifying is solved by the parametric substitution model, and the image of the simulation is shown in figure 12 and figure 13.

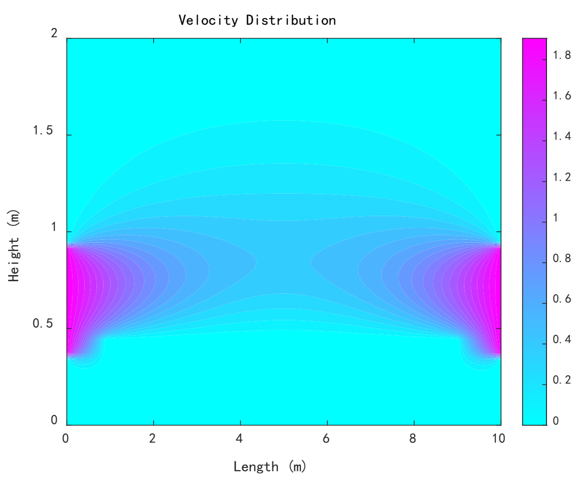


Fig12 Simulation simulation temperature and fraction profile

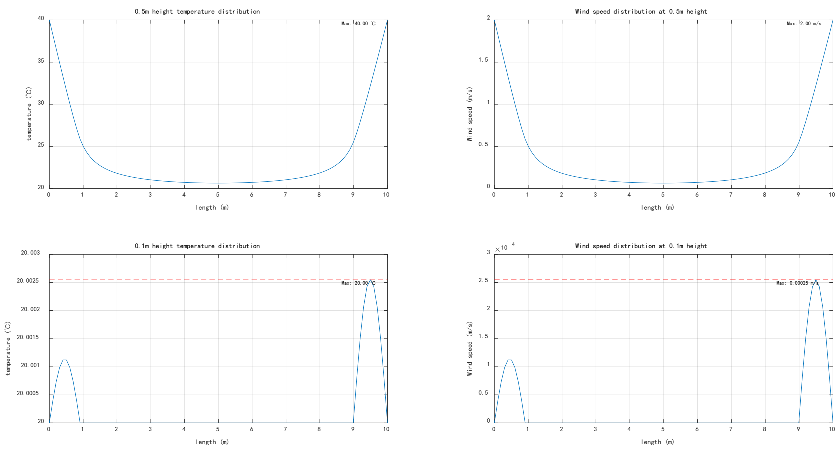


Fig13 Simulation simulation temperature and fraction profile

Through simulation simulation, our team gives the parameters of table 1, which, under this parameter, provide the model that matches the crop in the appropriate growth environment.

Table1 Model parameter

parameter	Numerical value
Fan_velocity	2.0
Fan_temperature	40.0
Fan_size	0.5
Fan_height_above_ground	0.65

5. Conclusions

The visual analysis of the model is better: it can be visually analyzed, and it is shown in the smart screen in the large shed, which shows that the farmers can control the microclimate in the shed through the temperature and humidity of the environment.

The model can be combined with embedded equipmen[9-10]. Since the greenhouse fan has a greater impact on the temperature in the greenhouse, it can be combined with the embedded device and the greenhouse fan, and then the position can be constantly changed according to the data situation, so as to obtain more reasonable and real-time effective results.

Can be multi-condition optimization, combined with a variety of environmental parameters, can use heuristic algorithm or optimization algorithm to find the best parameter value, to develop a more reasonable, scientific and efficient greenhouse control scheme.

References

[1] Singh M C, Singh J P, Pandey S K, et al. Factors affecting the performance of greenhouse cucumber cultivation-a review[J]. International Journal of Current Microbiology and Applied Sciences, 2017, 6(10): 2304-2323.

[2] Liu Y, Li D, Wan S et al. A long short - term memory - based model for greenhouse climate prediction[J]. International Journal of Intelligent Systems, 2022,37(1): 135-151.

[3] Norton T, Sun D W, Grant J, et al. Applications of computational fluid dynamics (CFD) in the modelling and design of ventilation systems in the agricultural industry: A review[J]. Bioresource technology, 2007, 98(12): 2386-2414.

[4] Fatnassi H Boulard T Poncet C et al. Optimisation of greenhouse insect screening with computational fluid dynamics[J]. Biosystems Engineering, 2006, 93(3): 301-312.

[5] Chen Geng. MATLAB implementation of Finite Difference Method for Stokes' first problem [J]. Modern information technology, 2023, 7 (20) : 58-61. DOI: 10.19850 / j.carol carroll nki. 2096-4706.2023.20.013

[6] Yan; Yuen heon; Rokai; Du me-star. Numerical simulation of the dynamic delay characteristics of the fluid dynamic delay of the hyperporous fluid. The journal of northwest industrial university, 2023,41(05) : 905-914.

[7] Yang Qin; Hai-jun zhang. The method of measuring air specific heat capacity ratio of experimental comparison study [J]. Journal of physics experiment, 2020 (6) : 47-50. DOI: 10.14139 / j.carol carroll nki cn22-1228.2020.06.013.

[8] Li Wei; Li Huiling; [WANG Y. Comparison of spatial and temporal distribution of two typical greenhouse environmental factors in South China. Northern Horticulture,2021,(21):49-54.]

[9] Li Liang; Shan Guangcan; Peng Qi; Liu Le; Zhao Lianheng. Bingham fluid permeation grouting diffusion model considering permeability changes of porous media [J/OL]. Journal of railway science and engineering, 1-11 [2023-11-25] HTTP: //https://doi.org/10.19713/j.cnki.43-1423/u.T20230325.

[10] Pang Mingkun; Pan Hongyu; Zhu Shipeng; Ji Xiang; Zhang Tianjun. Determination of pre-Darcy/Darcy/non-Darcy flow patterns of coal gas around extraction borehole [J/OL]. Journal of coal, 1-9 [2023-11-25] HTTP: / / https://doi.org/10.13225/j.cnki.jccs.2023.0695.