2023 Asia and Pacific Mathematical Contest in Modeling

Problem B

Microclimate Regulation in Glass Greenhouses

The yield of greenhouse crops is affected by various climate factors, including temperature, humidity, and wind speed [1]. Among them, suitable temperature and wind speed are crucial for plant growth [2]. In order to regulate climate factors such as temperature and wind speed inside the glass greenhouse, ventilation systems with greenhouse fans are commonly used in the design of greenhouse, as shown in Figure 1. The position of the greenhouse fan and the speed of the warm air outlet affect the distribution and uniformity of the velocity field and the temperature field in the greenhouse. Therefore, how to optimize the greenhouse fan to obtain suitable wind speed and temperature, and improve their uniformity, is an important issue that needs to be solved in current glass greenhouse design.

Figure 1. Glass greenhouse

The glass greenhouse is sealed and placed indoors, without considering external factors such as greenhouse doors, drafts, solar radiation, and other environmental factors. The current design of the glass greenhouse has dimensions of 10m×3m×2m (length×width×height) and the size of the greenhouse fan is 0.5m×0.5m, positioned on the left side of the greenhouse. The center of the greenhouse fan is located 1.3m above the ground, as illustrated in Figure 2. The boundary conditions on the side of the greenhouse fan are set as velocity inlet conditions, blowing warm air at 40℃ in the horizontal direction with an average velocity of 2 m/s. The outer glass and bottom soil of the greenhouse are set as wall conditions, primarily exchanging energy with the entire greenhouse through convective heat transfer and conduction [3]. The initial temperature is set at 20℃. When crops are planted inside the greenhouse, it is necessary to consider the canopy resistance of the crops. The crop model can be simplified as a porous medium with dimensions of 8m×2m×0.5m (length×width ×height) [4], placed in the center of the greenhouse. The suitable wind speed for crop growth inside the greenhouse is 0.3-1m/s, and the suitable temperature is 23-26℃.

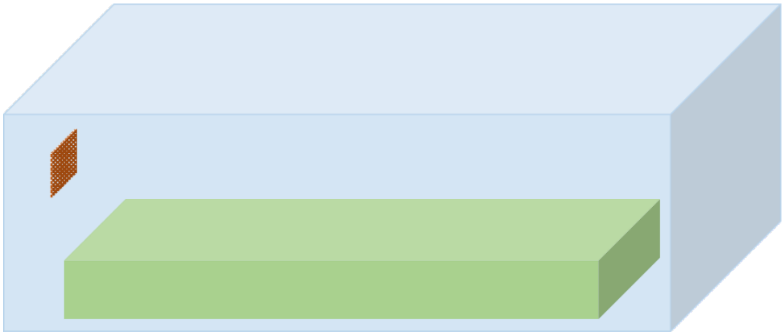

Figure 2. Schematic diagram of glass greenhouse structure

Question 1: Please establish a mathematical model for the temperature and wind speed distribution inside a glass greenhouse without crops. Display the distribution of wind speed and temperature at a cross-section of the greenhouse at a height of 0.5 meters.

Question 2: Please establish a mathematical model for the temperature and wind speed distribution inside a glass greenhouse with planted crops. Present the distribution of wind speed and temperature at two cross-sections within the greenhouse: one at a height of 0.5 meters (crop canopy level) and another at a height of 0.1 meters (inside the crop canopy). Analyze whether the conditions are suitable for crop growth.

Question 3: Please provide the temperature and wind speed distribution inside the glass greenhouse for the following two scenarios and compare them with solution presented in the second question. In Scenario One, increase the velocity of warm air outlet from 2 m/s to 3 m/s. In Scenario Two, lower the position of the greenhouse fan by moving it from 1.3 m to 1 m.

Question 4: Can your team further optimize the greenhouse fan design of glass greenhouse from the number of greenhouse fan, location, wind speed, blowing temperature, specifications and different crops and other factors.

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.