Advanced Simulation and Optimization of Greenhouse Environment Control Systems

CFD Insights services

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Objective

The project delves into the domain of greenhouse environment control by comprehensively describing and simulating the conditions within an experimental greenhouse under diverse ventilation and cooling scenarios. Its primary objectives encompass the analysis of climatic parameters, the generation of precise environmental maps, the development of sophisticated simulation models, and the rigorous examination of the energy dynamics within the cooling system. Ultimately, the project aims to enhance the efficacy of natural ventilation and cooling systems for greenhouse environments through informed design refinements.

Methodology

Investigations were conducted on four different treatments related to the greenhouse environment during the summer months of the period spanning : natural ventilation, natural ventilation with internal shading, employment of an evaporative cooling system, and utilization of an evaporative cooling system with external shading.

An in-depth analysis of experimental data was performed to comprehensively understand the greenhouse environment. Data sets collected from specific locations within the greenhouse underwent analysis using the Kriging method implemented through commercial geostatistical software. This analytical approach enabled the generation of temperature and humidity maps across various height levels.

In the numerical approach, a 3D full-scale model of the experimental greenhouse was designed and meshed geometrically. The model incorporated key features of the experimental greenhouse, including pads, fans, frames, covering materials, and individual plants, ensuring a thorough representation of the greenhouse environment.

This geometry can be seen in Figure 1. For completeness sake the temperature and humidity distribution for the case of natural ventilation are shown in Figure 3 and Figure 4 respectively.

Results

Both the examination of experimental data and simulation models revealed that the evaluated cooling system struggled to maintain the greenhouse temperature more than a few degrees below that of the outside air, even at the specified ventilation rate. Despite the greenhouse's relatively short length, noticeable thermal gradients were evident, extending from the evaporative pads to the exhaust fans. Moreover, a distinct thermal gradient was discernible vertically, spanning from the greenhouse floor to its roof.

The simulation outcomes not only emphasized the pivotal significance of the ventilation rate but also elucidated how the unique airflow characteristics within the greenhouse influenced the efficacy of the fan and pad evaporative cooling mechanism. Additionally, it became apparent that the cooling efficiency, as quantified by its correlation to outside air temperature and the internal wet bulb temperature upon entry into the greenhouse, failed to provide a comprehensive understanding of the heat removal mechanisms inherent to the system's operation.

Conclusion

Through the integration of CFD with experimental data analysis, valuable insights have been gained into the performance of cooling systems within greenhouses. CFD allows for a detailed examination of airflow patterns, thermal gradients, and the effectiveness of ventilation strategies, providing crucial information for optimizing greenhouse climate control.

By leveraging CFD, designers can better understand the complex dynamics of greenhouse environments and develop more efficient cooling systems. This underscores the importance of incorporating CFD into greenhouse environment studies to enhance productivity, sustainability, and overall performance.

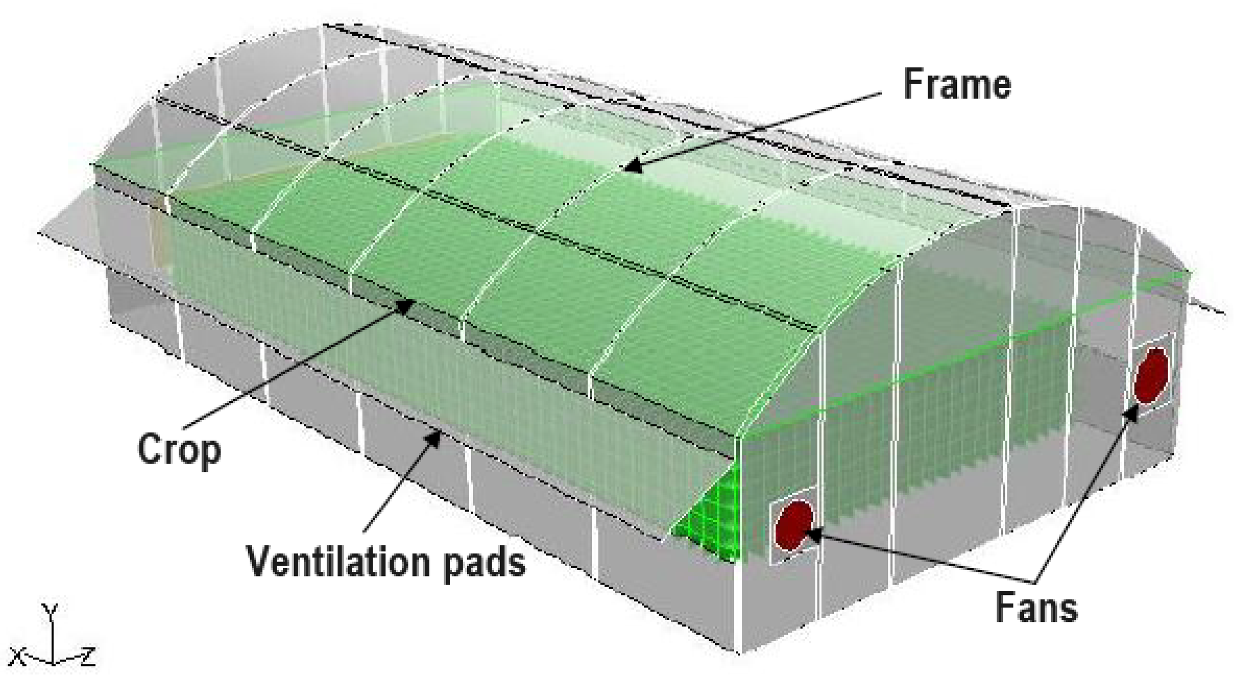

Figure 1:Greenhouse Geometry

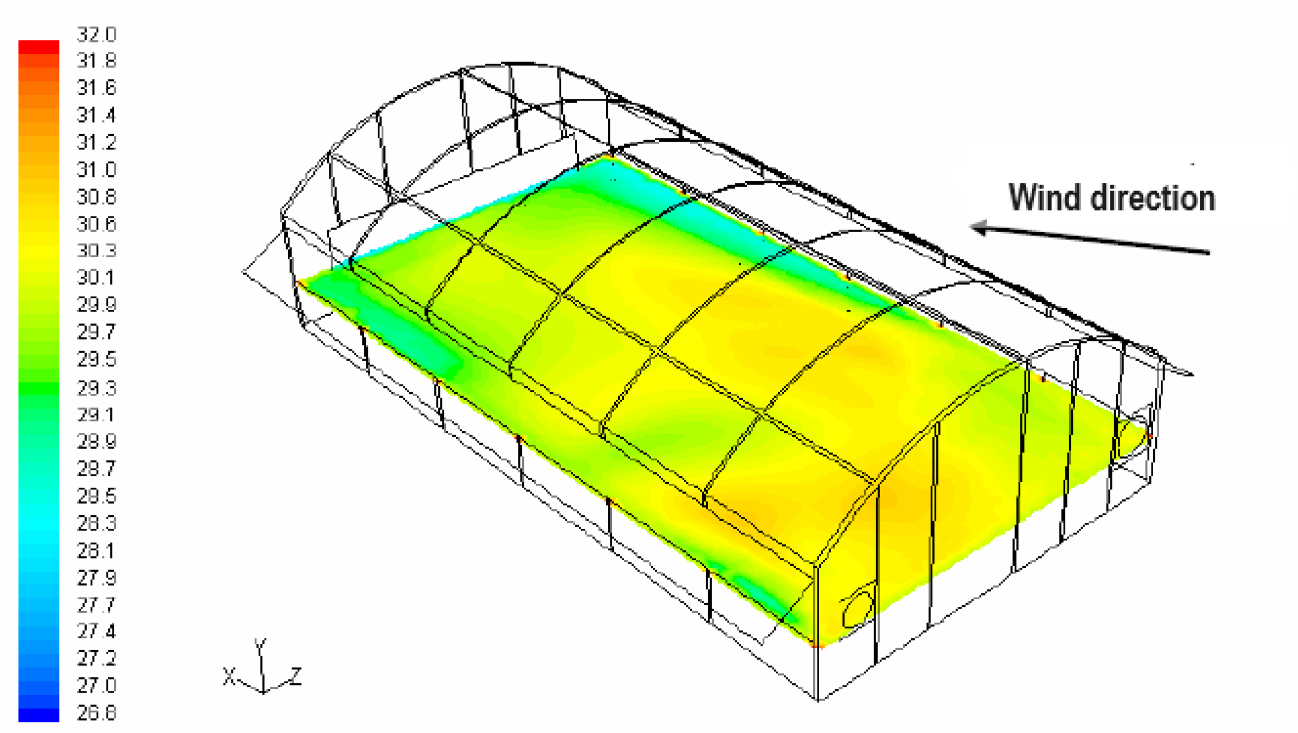

Figure 2:Temperature distribution on a height of 1 meter for the case of natural ventilation

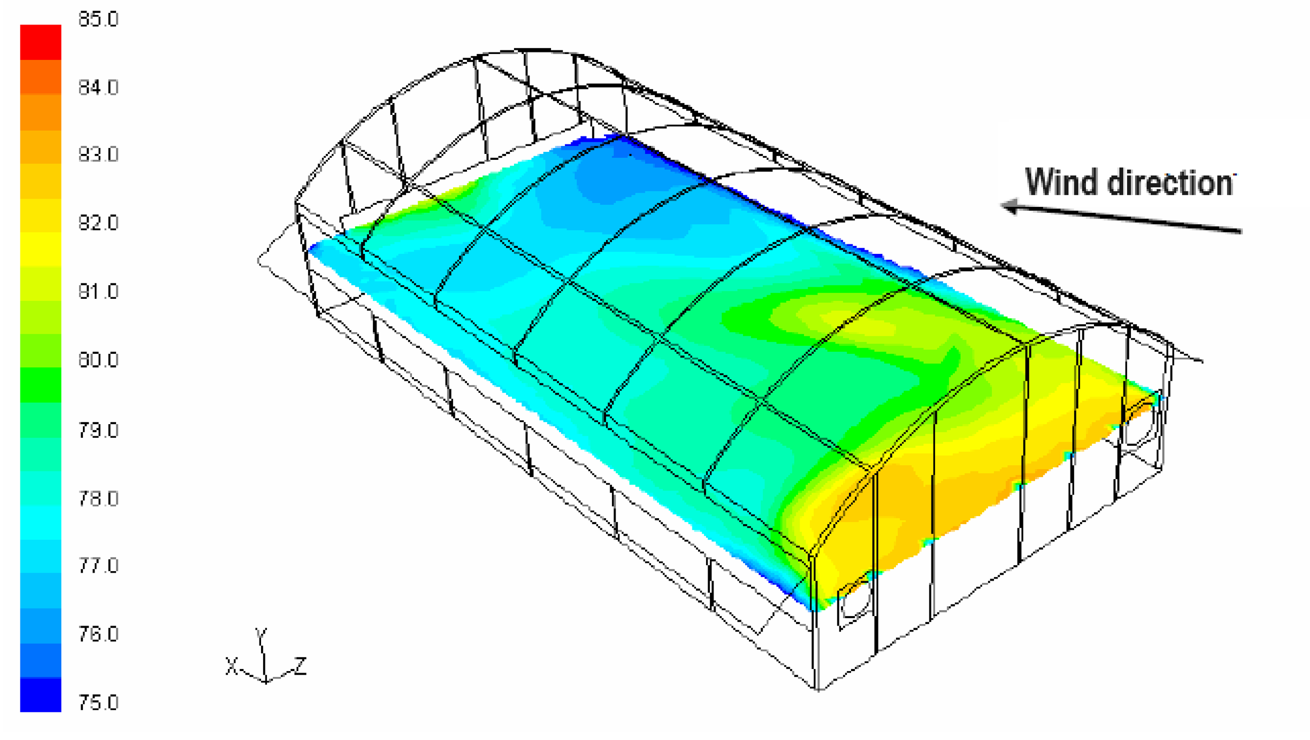

Figure 3:Humidity distribution on a height of 1 meter for the case of natural ventilation