ANALYSING GREENHOUSE VENTILATION USING COMPUTATIONAL FLUID DYNAMICS

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Summary

Greenhouses (GH) are used to shield the crops from excessive cold or heat. They are used for growing certain types of cultivations during the year round. The aim of this study is to design a greenhouse using solar-powered technology to produce a Zero-Liquid-Discharge (ZLD) by using Solar Stills and adding condensers to dehumidify the excess vapoured water. This allows to have small-scale plants to reduce the cost of water treatment while increasing its sustainability. Computational fluid dynamics was used to find the best locations for the dehumidifiers in the GH and design the necessary ventilation. This can help to plan ahead and evaluate the optimal amount of produced water for different sizes of greenhouse before they are constructed physically.

Key Words: Greenhouse, ventilation, CFD

Introduction

In order to design a greenhouse system, it is necessary to analyse the amount of humidity and the optimal locations for the dehumidifiers. Although the technologies applied to greenhouses may vary based on the region and severity of the weather conditions, high temperatures are recorded within the greenhouses in hot climate areas such as the middle east and north African countries. Such greenhouses need to be ventilated [1] to keep the internal temperature of the greenhouse in a steady range, suitable for the plants' growth [2]. The temperature inside the greenhouses is designed in the range of 14°C-35°C, while the humidity range can be in the range of 50-90% for different types of cultivation [3]. When the temperature is raised, the vents can help to decrease it in order to have a steady internal temperature within the greenhouse. In order to analyse the optimal locations for the ventilation, a conceptual greenhouse model was designed using the Computational Fluid Dynamics (CFD) software, ANSYS Fluent v19.2., and the range of humidity, temperature, and wind velocity within the greenhouses was analysed. The wind speed was assigned to be kept as 0.1–0.3 m/s as another requirement for the plant growth [4].

Materials and methods

The general materials used in the greenhouse CFD model were glass and soil. The relevant properties of these materials are summarised in Table 1.

Table 1: Properties of glass and soil used in the model

Property	Glass	Soil
Density/ kg m^{-3}	2400	1500
Specific heat capacity/ J kg^{-1} K^{-1}	753	800
Thermal conductivity/ W m^{-1} K^{-1}	1	0.5

This model was designed based on a single-span, with the ridge of the greenhouse running parallel to the length of the greenhouse. The greenhouse also had roof and side vents the dimensions of which are summarised in Table 2.

Table 2: greenhouse dimensions used in the model

Dimension	Value
Length/ m	8.25
Width/ m	6.4
Eaves height/ m	2.15
Ridge height/ m	3.75
Side vent size/ m	0.5
Roof vent size/ m	0.5

In the model, the radiation heat flux in the soil was determined based on the information from the literature. The effective heat flux from the soil to the air in the greenhouse was determined based on a location close to the equator where the ground would have a strong heat flux. The calculation started with the theoretical solar irradiance on Earth, and then accounted for the effect of the absorption in the atmosphere and the zenith effect (the extra distance the radiation travels through the atmosphere as a result of the location not being on the equator). The albedo effect was also accounted for. A set of assumptions were made for these calculations as:

- The solar radiation was not affected by the solar constant – the actual solar radiation varies with time.
- The sun was assumed to be a perfect black body.
- The sun-earth distance was assumed to be constant.
- The greenhouse was assumed to be at sea level.
- The sky was assumed to have no turbidity.

Based on the above assumptions, a heat flux of 500 $W.m^{-2}$ was applied in the CFD model, as a boundary condition for the floor of the greenhouse in all simulations. This is similar to values used in other literature [5]. The 2D ventilation model was used to analyse many effects of different boundary conditions on the velocity and temperature of the air in the greenhouse. The model studied the effect of ventilation perpendicular to the axis of the greenhouse ridge. The model was first set up by defining the equations to be solved, and the boundary conditions of the greenhouse. The initial model was set to a steady-state pressure solver model. The energy equation and a standard k-ε model were used with standard wall treatments. The material properties shown in Table 1 were used in the model. To simulate the effect of the natural convection due to the difference in air temperatures, the Boussinesq approximation was used, with air density of 1.225 kg m^{-3}, and a thermal expansion coefficient of 0.0034 $K^{-1,}$ and g=0.81m/s in the negative x direction. The boundary conditions were set as 1 ms^{-1} velocity at the inlet, with the roof inlet angled downwards at 23º, to simulate the effect of open vents. The outlets were set as pressure outlets.

Results and discussion

In order to analyse the optimal location for designing the vents, several parameters such as the inlet wind velocity, side ventilator height and roof ventilator height should be considered. In what follows, the effects of inlet wind velocity are presented (Figure 1). The analyses are based on the inlet size of 0.5m length and a height of 1m.

Inlet air velocity: 0.2 ms^{-1} **Inlet air velocity: 1ms^{-1}** **Inlet air velocity: 0.2ms^{-1}, with the humidifier effects**

Temperature profile

Velocity profile

Humidity profile

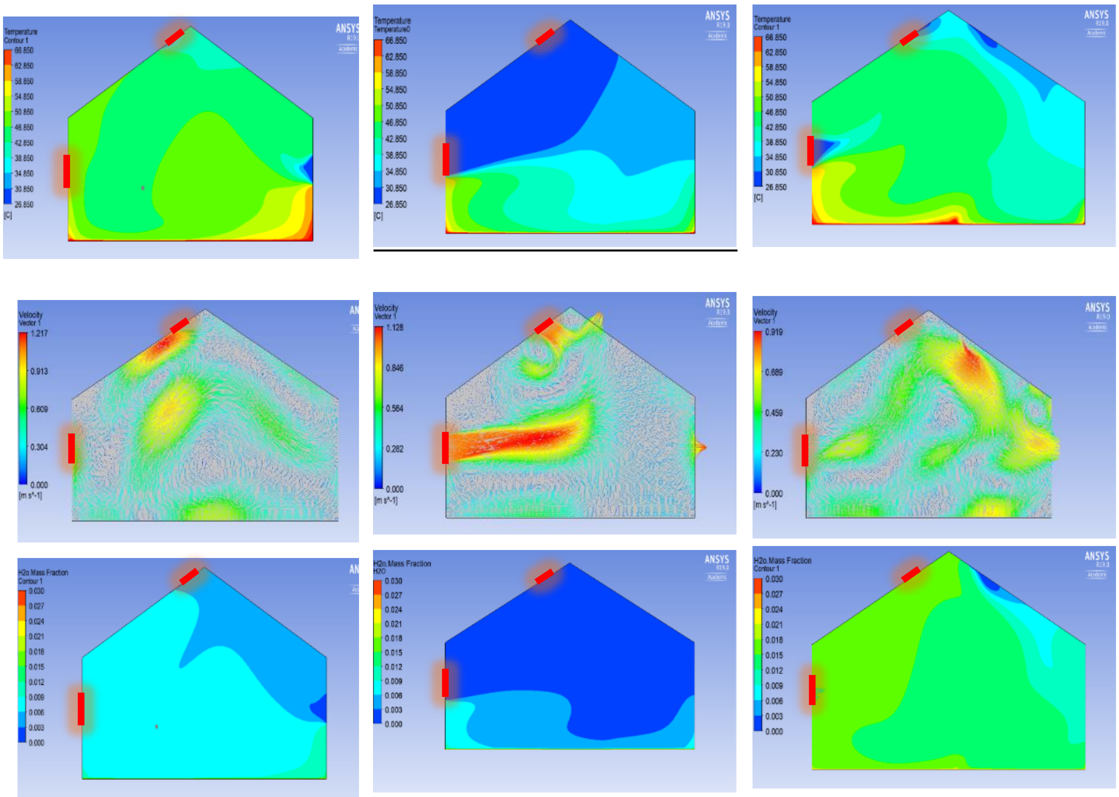

Figure 1: Inlet wind velocity effects on the temperature, velocity and humidity profiles

The preliminary results show the effects of air conditions on the humidity, velocity and temperature profiles. By using the condenser, the excess humidity can be dehumidified to keep the temperature range and air velocity suitable for the plnats growth. The results show that the humidity rate is higher at the opposite corners of the inlet locations within the greenhouse which shows a suitable spot for designing the condensers. At the same time, the temperature within those regions is higher as no circulation is embedded in those regions. Therefore, assigning the outlets in those regions would be highly recommended. Based on this specific study, the velocity can be controlled by adding the humidification to the system.

Side ventilator height above ground **Temperature profile** **Velocity profile**

0.5m

1m

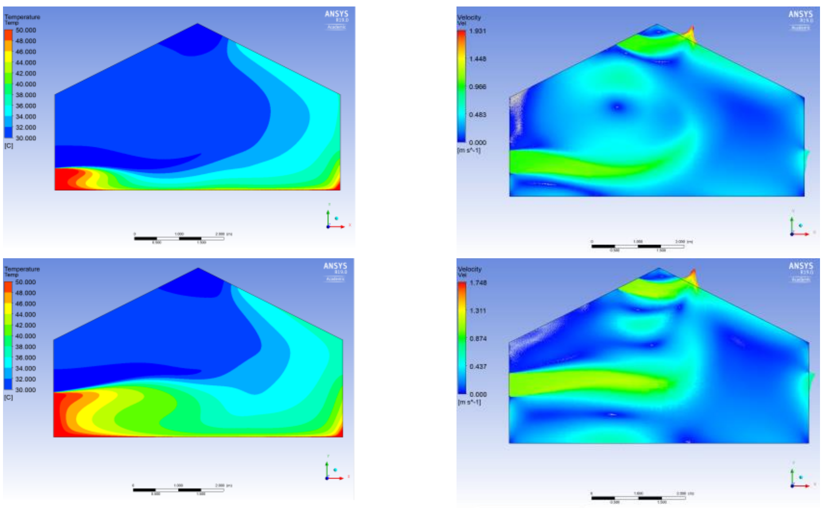

Figure 2: Effects of side ventilator height on the temperature and velocity profiles

Another influential parameter is the height of the side ventilator (Figure 2). The results show by doubling the height of the side ventilator, the regions with maximum temperature are expanded within the greenhouse cavity and it increases the importance of ventilation on the opposite sides. Also, the effects of roof ventilator height are studied (Figure 3). Based on this study, by doubling its distance from the ridge of the greenhouse, the temperature and velocity profiles are slightly changed which shows the greenhouses are not sensitive to these specific dimensions and therefore this parameter can be neglected in ventilation planning.

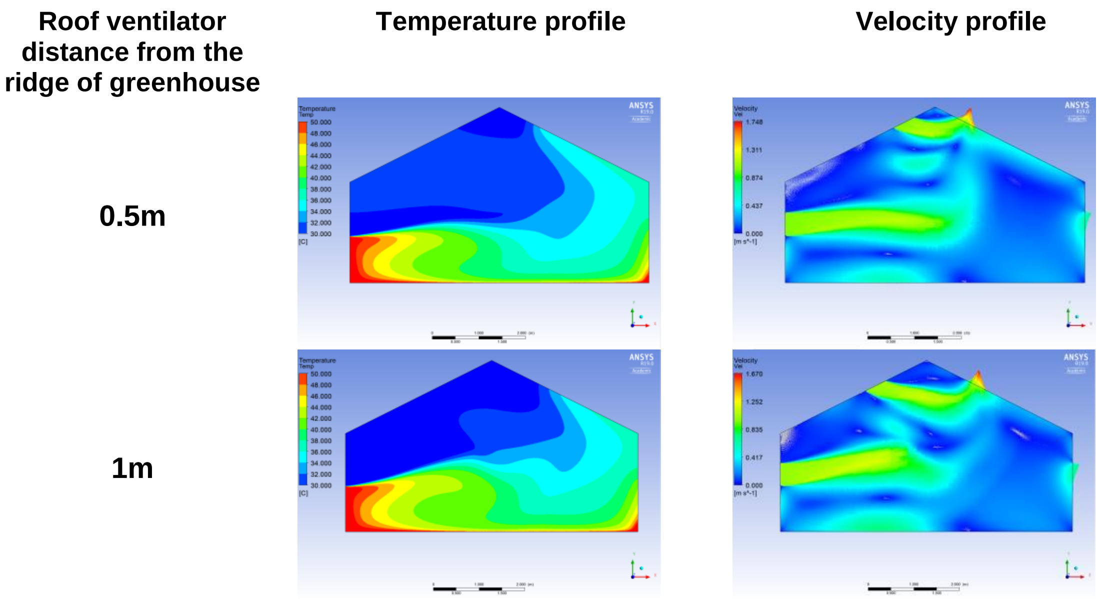

Figure 3: The effects of roof ventilator distance on the temperature and velocity profile

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