

DIRECT AND INDIRECT EVAPORATIVE COOLING FOR CLOSED GREENHOUSE DURING THE SUMMER PEAK HOURS

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ABSTRACT

This study investigates experimentally, the effect of direct and indirect evaporative system on the temperature and relative humidity distribution inside a greenhouse. Experimental tests on a full-scale greenhouse of sizes 0.9 m x 0.55 m x 2.4 m (W x H X L) were conducted in October 6 University, 6 October city, Giza, Egypt at summer rush hours were used to obtain spatial distribution of air-temperature. Measurements of temperature distributions at about 63 points inside the greenhouse. One of the main conclusions is that experimental results were preserve the temperature variation below 30 °C during the day rush hours, especially in the area designated for the growth of plants inside the greenhouse.

Keywords: Greenhouse; direct evaporative cooling; indirect evaporative cooling.

1 INTRODUCTION

Soilless agriculture become one of the most important forms of modern agriculture because it has a positive impact on the production of crops with high quality away from the soil diseases that present the exposure of plants and crops to damage. Aquaponics system is one of the most important of these modern agriculture systems, which depends on the growth of plants and fish in the same cycle of water, according to the standard data from FAO [1] it is necessary to maintain a temperature between 27 and 30 to obtain the largest production in the short time.

Evaporative cooling in a commercial greenhouse equipped with a pad-fan system for use during the summer period in arid countries was studied [2]. The volume flow rate through the evaporative pad was determined by the number of air changes per hour (ACH) and it was estimated that 20 number of air changes were sufficient to reach tolerable conditions inside the greenhouse under dry weather conditions. The water required for evaporative cooling and absolute humidity (AH) was also determined.

The temperature and humidity gradients during summer were investigated in a rose production greenhouse equipped with a ventilated cooling-pad system and a half shaded plastic roof. Three portable instruments used for measurements in the total area (50 m * 60 m) to measure temperature and relative humidity inside greenhouse. The cooling performance was achieved up to 80% and the temperature of the greenhouse was lowered by 10 °C than the outside air [3].

Theoretical and experimental studies were conducted in a 24 m² greenhouse with a fan-pad evaporative cooling system of (3 * 1.15) m² area in the west wall and two fans in the east wall. Greenhouse air temperature was reported 4–5 °C lower as compared to the outside conditions in the rectangular zone (zone II) but in the triangle zone (zone I) found the temperature was highest than the outside temperature with almost 5 °C in the day rush hours. Fan-pad cooling parameters such as length of the greenhouse, air mass flow rate, height of the cooling pad was also performed [4].

In another application liquid desiccation with solar regeneration as a means of lowering the temperature in evaporative-cooled greenhouse was studied by [5]. The cooling was assisted by using the regenerator to partially shade the greenhouse. The heat of desiccation was

transferred and rejected at the outlet of the greenhouse. The cycle was analyzed and results given for the climate of the Gulf, based on weather data from Abu Dhabi. The cycle was compared with conventional evaporative cooling and found that the proposed system lowered summers maximum temperatures by 5 °C [5].

Ashish et al [6] was conducted experiments in hot summer conditions at Solar Energy Park, New Delhi, India for empty greenhouse. Statistical analysis has been carried out to validate the agreement of experimental observations with predicted values. It is found that the use of evaporative cooling with a thermal curtain reduces the temperature of greenhouse by 5°C and 8°C in the second zone of greenhouse-1 and 2, However, the temperature inside the greenhouse was higher than the outside temperature except the temperature of rectangular zone in greenhouse 1 the greenhouse temperature was equal to the outside temperature [6].

Hasan et al [7] was studied the efficiency of fan-pad cooling system inside greenhouse by building up internal greenhouse temperature map. The results reveal that temperatures were fell to be 10-12 °C only at 2 pm. Considerable temperatures differences were recorded in areas between the center of the pad and facing the fans at the center of the greenhouse (13 °C at right in front, 8 °C at middle of the pad and 7 °C in front of the fan) [7].

The main objective of the current study is to evaluate the effect of direct evaporative cooling (fan-pad system) with and without indirect evaporative system (cooling tower) on greenhouse thermal pattern.

2 EXPERIMENTAL SETUP

The experimental setup located at October 6 University, Giza, Egypt (longitude 29.98°, latitude 30.95°) and conducted during peak sunshine hours between 10:00 am and 5:00 pm. The greenhouse is inclined roof type even span, which is made of rectangular iron pipes and Polycarbonate sheets covering material. The greenhouse with an effective floor 3.6 x 2.4 m² with central height and height of the walls were 2.4 and 1.8 m, respectively.

A fan of 350 mm sweep diameter and 1360 rpm with a rated air volume flow rate of 3200 m³/h was provided on the south wall of the greenhouse. Evaporative cooling system corrugated cellulose paper pads located in the northern wall at a height of 0.9 m, length 0.55 m and full width of the greenhouse 2.4 m.

Depending on weather conditions, many buildings can use indirect/direct evaporative air conditioning to provide comfort cooling. Indirect/direct systems achieve from 40 to 50% energy savings in moderate humidity zones (Foster and Dijkstra 1996) [8].

It is often desirable to combine the effects of direct and indirect evaporative processes (indirect/direct). The first stage (indirect) sensibly cools the air, thereby lowering its wet-bulb temperature, and passes it through the second stage (direct) where it is cooled further. [9] (ASHRAE, 2012)

In case (A), water was pumped upwards to the cooling pads and then collected in the water tank for reuse. In case (B) water pumped to cooling tower to decrease the water temperature which used in cooling pads then flows to the water tank for reuse.

In both cases 46 digital temperature sensors (DS18B20) were used with temperatures range from -55°C to +125°C and ±0.5°C Accuracy from -10°C to +85°C, DHT22 relative humidity sensor its accuracy 2-5% on the full-scale range of 0-100% of relative humidity.

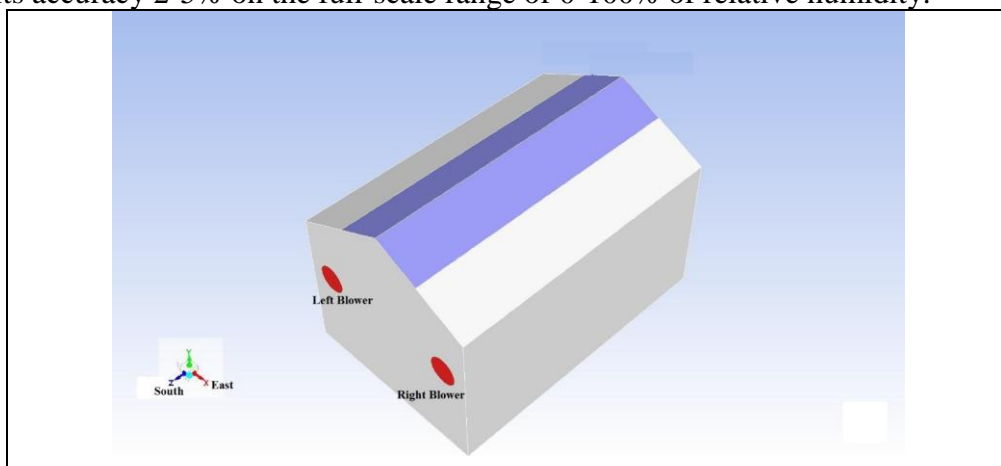


Figure 1 Layout of the greenhouse.

The distribution of horizontal and vertical sensors (DS18B20) was used to measure the temperature as shown in figure 2, horizontal lines were located at height 1.6 m whether the vertical lines were located at the middle at 1.2 m. DHT22 also used to measure relative humidity inside and outside the greenhouse. Measuring sensors were distributed as follow:

Location	Number of Sensors	Sensor Type
Walls	5	DS18B20
Roof	2	DS18B20
Horizontal line	5	DS18B20
Vertical line	7	DS18B20
Middle of greenhouse	2	DS18B20 and DHT22
Outside greenhouse	2	DS18B20 and DHT22

The experiments were carried out on 30 August for case (A) and 1 September for case (B). Weather temperature trend for October 6 City during the experimental study, for case (A) the high and low temperature was 33°C and 23°C respectively and for case (B) was 33°C and 24°C. [10]

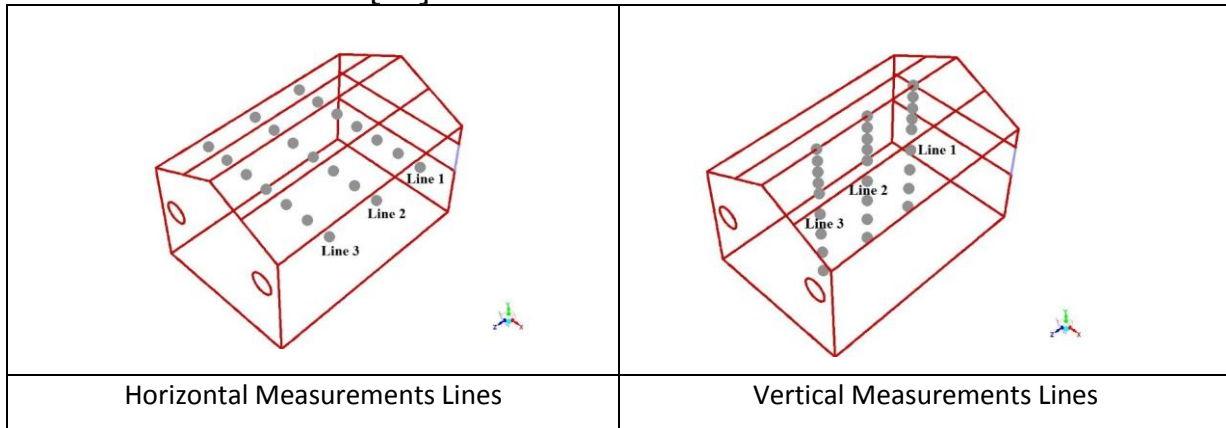


Figure 2 Horizontal and Vertical Measurements Lines.

3 Results and discussion

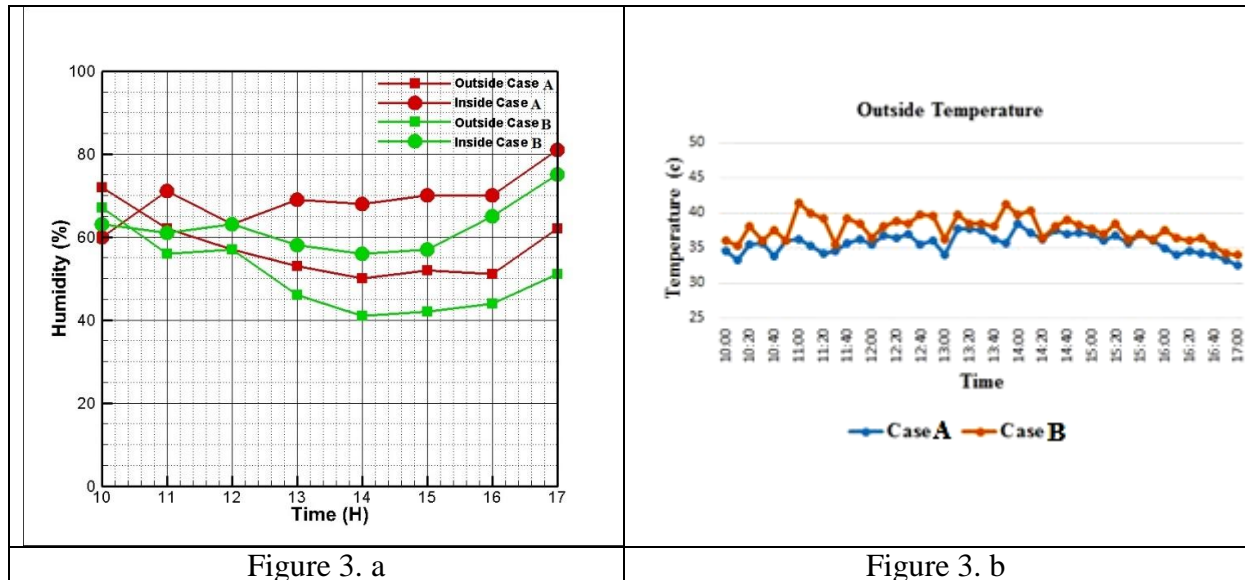


Figure 3 Outside and inside humidity, outside temperature for case (A) and case (B).

The outside and inside humidity were measured for both cases as shown in (figure 3.a), also the average outside temperature was illustrated in (figure3.b). It is obvious that the outside

temperature of case (B) is higher than case (A) with about 2 °C, therefore case (A) has higher outside relative humidity than case (B) with about 6.8%.

Due to the cooling process, it is noticed that the average relative humidity difference between inside and outside the greenhouse for case (A) and (B) was about 12% for each case. In case (B) despite the increase the outside temperature, the average difference in relative humidity was maintained and this is due to the operation of cooling tower. Maximum outside temperature was at 11 am and 2 pm in case (A) and case (B) also.

The temperature variation inside the greenhouse for horizontal and vertical line 1 at the summer season rush hours is shown in figure 4. Due to the cooling process, it was observed that at 10 am temperature distribution in the vertical and horizontal line of case (A) was higher than that at 11 am. But, for case (B) the temperature distribution was almost equal. According to this observation it can clarify that the using of cooling tower with fan-pads system can maintain temperature stable during working hours rapidly. Also, the effect of sun position can be predicted in the horizontal line (1) at 10 and 11 am, when the sun position is at east, the temperature on the east point at 2.4 m in the horizontal line was higher than the temperature at the west point at 0 m, its noted that the difference changes over time to became the lowest temperature difference between the eastern side and the western side of the greenhouse at 3 pm.

It was observed that temperature Reduced inside the greenhouse regarding the outside temperature in vertical line 1 for case (A) and (B) especially for the point at height 1.2 m, the average temperature difference between outside and inside greenhouse at this height was reduced in case (A) with almost 7 °C and 9.23 °C for case (B). It is noticed that the maximum temperature difference was at 11 am and 2 pm for both cases and this difference was 8 °C at 11 am and 9 °C at 2 pm for case (A), and 12.7 °C at 11 am and 11.6 °C at 2 pm for case (B). The greenhouse effect was observed on the difference between temperature at the surface of the earth and temperature in the highest greenhouse in vertical line 1.

There is a slightly variations in temperature measurements of horizontal and vertical line 2 in shown in figure 5 from 10 am till 3 pm in both cases which mean good temperature control in either case (A) or case (B).

The change of temperature in the vertical line 2 at 1.6 m was less than 30 °C, the average difference between the outside and inside temperature in case (B) was found to be 9.33 °C. The highest difference between the outside and inside temperature at 11 am and 2 pm and it was 13 °C and 11 °C respectively.

Due to the fans effect on line 3 the temperature variation of horizontal line 3 was higher than in horizontal lines 1 and 2 as showed in figure 7.

The greenhouse effect in the third section rise the temperature near the ground and lowering the temperature at the top, that is make the range of temperature differences changes between 30 °C and 35 °C in the third vertical line. Also, it can be predicted that there's a lack of greenhouse effect in vertical line 3 than other vertical lines, the difference between the temperature near the ground surface located at 0 m and the highest point at 2.4m was almost 7 °C .

On the other hand, the average temperature inside greenhouse did not exceed 30 °C during the day rush hours.

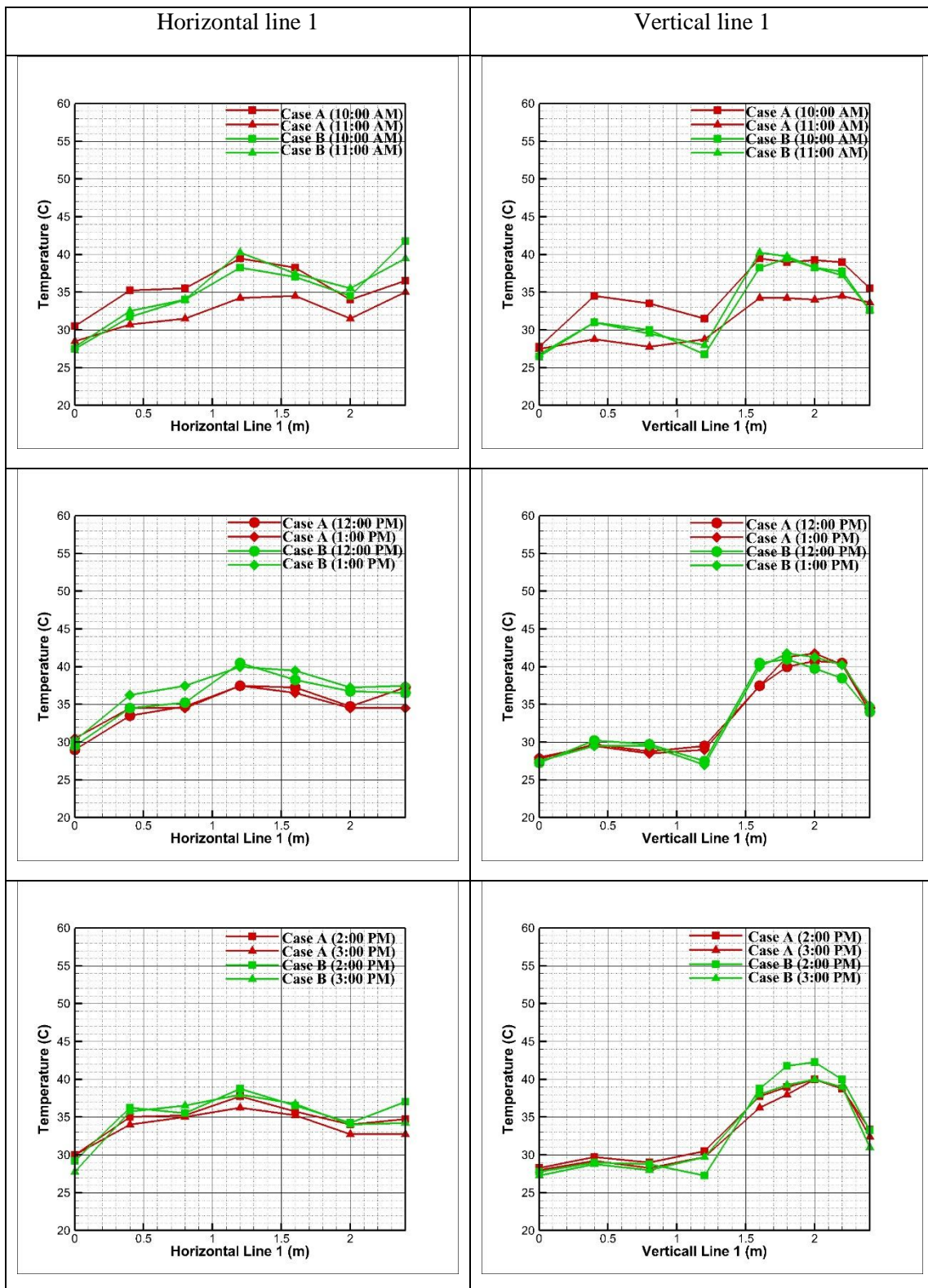


Figure 4 Temperature variation for case 1 and case 2 at horizontal line 1 (Y=1.6m and Z=0.9m) and vertical line 1 (X=1.2m and Z=0.9m).

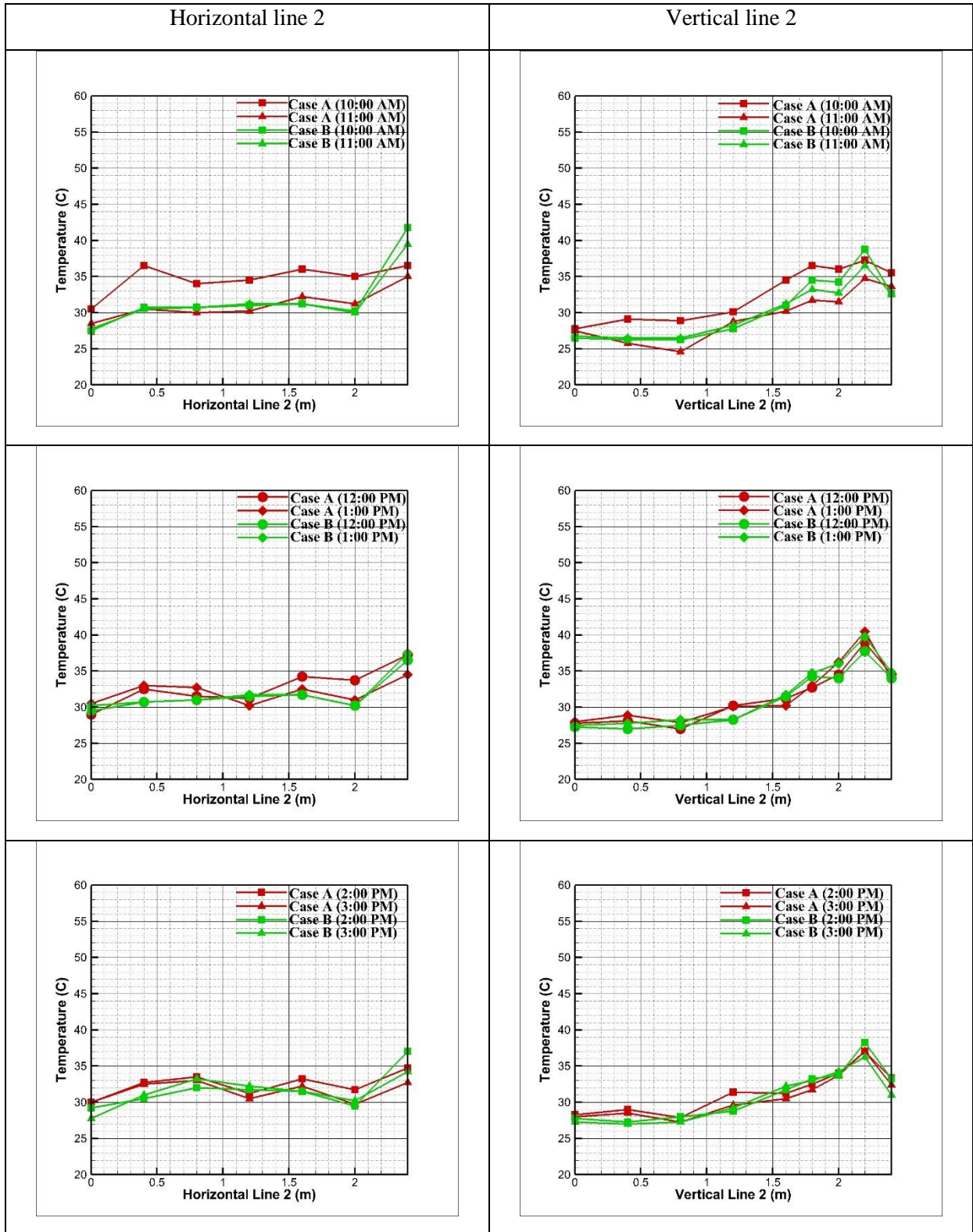


Figure 5 Temperature variation for case 1 and case 2 at horizontal line 2 (Y=1.6m and Z=1.8m) and vertical line 2 (X=1.2m and Z=1.8m).

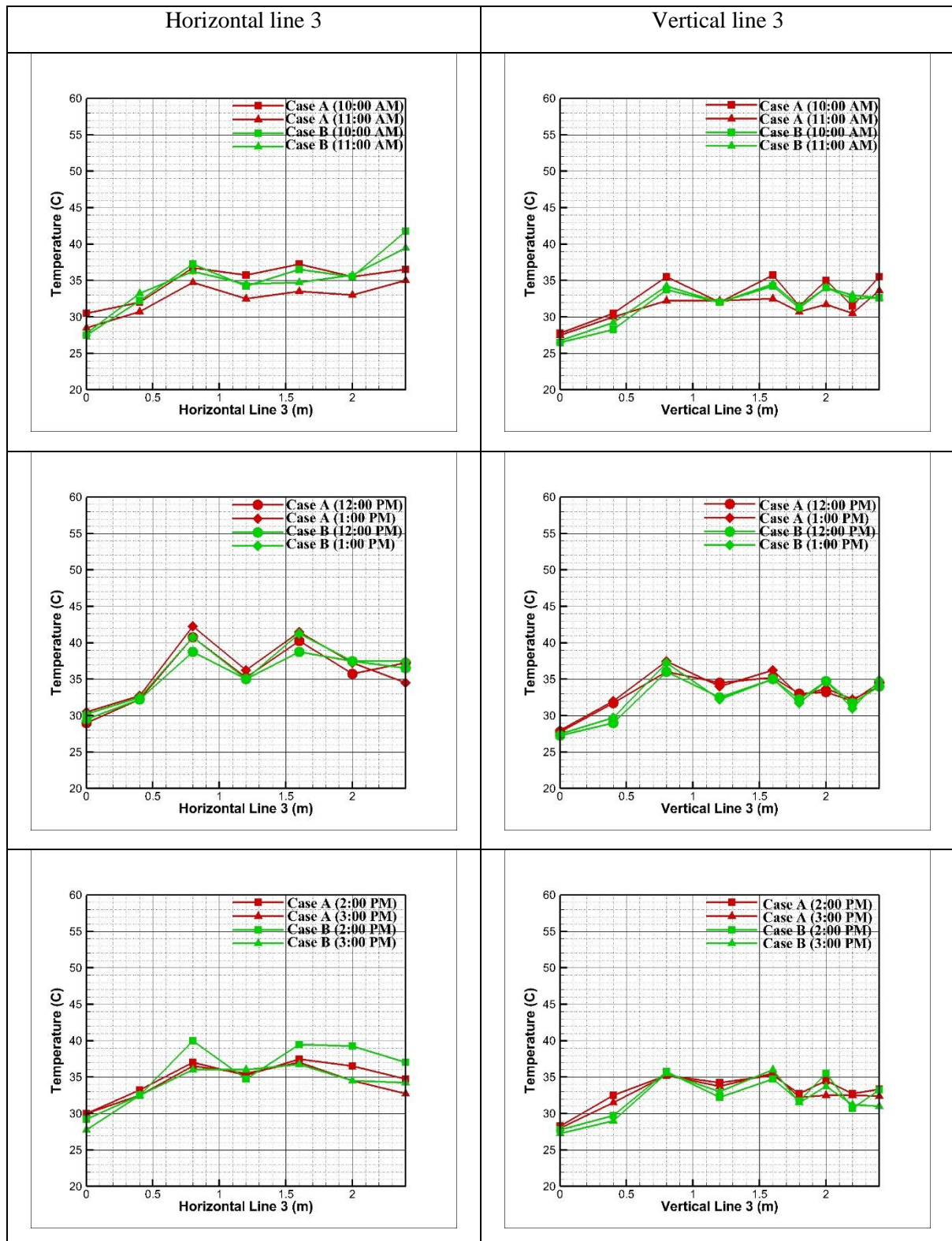


Figure 6 Temperature variation for case 1 and case 2 at horizontal line 3 (Y=1.6m and Z=2.7m) and vertical line 3 (X=1.2m and Z=2.7m).

This model was one of the most acceptable models used in evaporative cooling (Fan-Pads) system only and not to use any resources to help to reduce the rates of greenhouse effect and therefore temperatures, the distribution of temperature sensors in both horizontal

contributed to review temperature changes, the rates of low temperature variation depending on the cooling systems in both cases better than the cases provided.

CONCLUSION

- The performance of direct evaporative cooling (Fan- Pads) system was acceptable for cooling the greenhouse to reach good temperature distribution (not exceed 30°C) inside the greenhouse.
- Using direct evaporative cooling can maintain constant temperature during day peak hours of summer season.
- It is correct to depend on the operation of cooling tower with the fan-pads system for quick access to the required temperature distribution and then depend on fan-pads system only.
- Found high efficiency of the evaporative cooling systems used at high outside temperature.

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