ASM Sc. J., 13, Special Issue 4, 2020 for NCAFM2018, 113-117

Thermal and Humidity Management of Mushroom House using Evaporative Cooling System

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Mushrooms are highly influenced by temperature and humidity during growing period. In order to obtain high mushroom yield, good and proper control of indoor air condition of mushroom house is required. This paper discusses the method of controlling indoor air condition of mushroom house. Evaporative cooling systems with negative pressure air ventilation was used in the study. The main parameters considered were indoor air temperature, outdoor air temperature and indoor relative humidity. It was found that the combination of evaporative cooling system and negative pressure air ventilation reduced the indoor temperature up to 5 ◦C and increased the humidity of 10%.

Keywords: thermal management; temperature; humidity; evaporative cooling; mushroom house

I. INTRODUCTION

Mushroom can be grown at indoor or outdoor environment. In modern farming, mushroom is preferably to be cultivated in controlled indoor environment as to maximize the production. It is noted that mushroom growth is highly influenced by air temperature and humidity. Ideal condition for mushroom cultivation is temperature between 22 to 26 ◦C with relative humidity (RH) of 80-90% (Tariqul *et al.*, 2016a). In general, mushroom cultivation is suitable for the location where the ambient temperature and humidity are closer to an ideal mushroom cultivation condition. It is ideally located away from residential area and should be under the shade of tree crops. However, locations that meet these criteria are limited. In addition, farmers need to find new location to cultivate the mushroom in order to increase the production due to space constraint. In Malaysia, the suitable climatic condition for the mushroom cultivation is between October to February due to rainy season that leads to low ambient temperature and high humidity. Unfortunately, during sunny-dry season, which is between March to September, less rain is received. The ambient condition is not suitable for mushroom cultivation during this season.

In order to overcome the seasonal issue, proper thermal management inside the cultivation house is needed. Thermal management is a method to control and manipulate the heat based on the principles of energy balance between the indoor and outdoor environmental conditions. The thermal management system may either conservation of heat or dissipation of heat by means of technology based on thermodynamics activities and engineering material properties approaches. Thermal management technology can be classified into two categories namely passive and active system. Both passive and active systems have own advantages and disadvantages depending on the system requirements.

Active system requires power source to run the system while passive system does not need power source. On the other hand, active system is suitable to manage large heat capacity and passive system work efficiently for low heat capacity. Evaporative cooling system is a passive thermal management system. This system uses heat and mass transfer to control the ambient condition (Pimenta *et al.*, 2003). De Antonellis *et al.* (2016) study the effect of water

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flow rate, humidity and secondary air temperature in evaporative cooling system using cross flow heat exchanger. They found that the evaporative cooling performance is influenced by the water flow rate. De Antonellis *et al.* (2017) investigated indirect evaporative cooling system in the building during summer and found that a significant temperature reduction is achieved at various operating parameters. There are several studies found in the literatures that used evaporative cooling system to control the heat inside the cultivation house. Thepa *et al.* (1999) reported that evaporative cooling system combines with continuous ventilation in- stalled in the Thai-style mushroom house managed to reduce indoor temperature and increase relative humidity at the same time. This is also agreed by Tariqul *et al.* (2016b) where they optimized the humidity level in a mushroom house using the similar method. Apart from that, the airflow movement inside the cultivation house is also important to enhance the heat transfer rate and to obtain a uniform temperature distribution (Jin-Hee *et al.*, 2009). Therefore, this study is to determine the heat and air flow distribution inside the mushroom house to suite with the mushroom cultivation requirement by using evaporative cooling and negative pressure air ventilation.

II. MATERIALS AND METHOD

Evaporative cooling with negative pressure air ventilation inside the house (6 m x 12 m) was used in this study. Negative air pressure was created by using two extraction fans which have power at 1.0 kW each. These fans are located at the end of the house. The direct evaporative cooling system that was implemented in this study is shown in Figure 1.

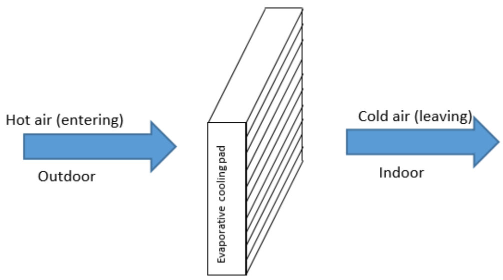

Figure 1. Direct evaporative cooling

Basically, direct evaporative cooling system consists of cooling pad and water circulations system. Outdoor air at high temperature is flow through the cooling pad. Heat from the hot air is transferred to the water that having low temperature. Thus, the air that leaving the cooling pad and goes into indoor having a temperature that lowers than that outdoor air temperature. Based on the Figure 1, the leaving dry bulb temperature is calculated by using Equation (1):

$$T_{LDB} = T_{ODB} - (T_{ODB} - T_{OWB})\eta_{pad} \qquad (1)$$

where T_{LDB} is leaving dry bulb temperature, T_{ODB} is outdoor dry bulb temperature, T_{OWB} is outdoor wet bulb temperature and saturation efficiency of the evaporative cooling pad η_{pad} is defined by,

$$\eta_{pad} = \frac{T_{enter\ evap\ DB} - T_{leave\ evap\ DB}}{T_{enter\ evap\ DB} - T_{leave\ evap\ WB}} \qquad (2)$$

The air flow rate is determined by,

$$SCFM = \frac{Indoor\ sens\ heat\ gain\ (BTUH)}{1.08\ (T_{DI} - T_{LP})Density\ ratio} \qquad (3)$$

where T_{DI} is designed indoor dry bulb temperature and T_{LP} is dry bulb temperature of air leaving the evaporative cooling pad. Equations (1)-(3) are obtained from Wang (2000). Figure 2 shows the experimental setup of the evaporative cooling system and negative pressure airventilation.

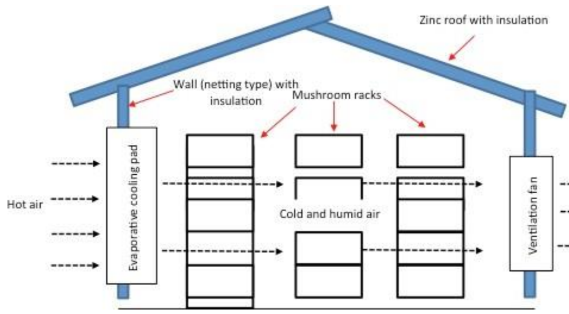

Figure 2. Schematic diagram of the system

Cooling pad was installed at one end of the house and axial extraction ventilation fan was installed at another end. Walls of the house were made from the insulated material and the roof of the house was made from zinc with underneath insulation. Four type-K thermocouples were used in this study. Three thermocouples were fixed at three locations inside the house with 2 m from the floor and at distance 2 m between each thermocouple. One thermocouple is fixed at outdoor to measure the outdoor temperature. Temperatures that measured by the thermocouples were recorded using Hioki datalogger (Memory HiLogger LR8431).

III. RESULT AND DISCUSSION

Figure 3 shows the mushroom house that has been used in this study. The walls and roof of the house was insulated as to reduce the heat gain inside the house that radiated from the solar radiation. This is important to avoid the heat from entering the house, which then could increase the indoor air temperature.

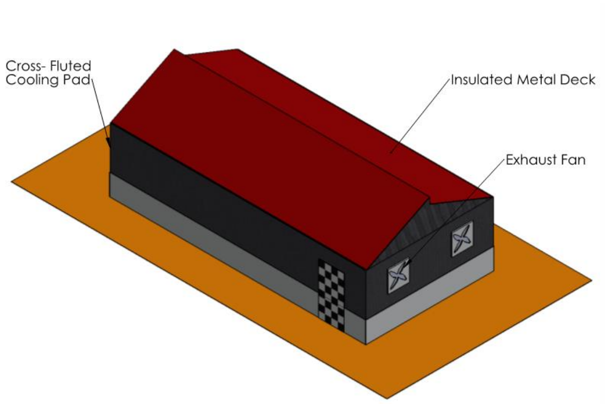

Figure 3. Mushroom house

Figure 4. Location of the extraction fan

Figures 4 and 5, show the location of the extraction fan and evaporative cooling pad respectively.

The extraction fans, which were located at the end of the house, created the negative pressure strategy. This pressure allowed the outdoor air entered the house and spread out evenly to each part of the area. This is important since mushroom pack was arranged in segregated condition. On the other hand, cooling pad was located at the front of the house so that the air would passes through the cooling pad when it entered the house.

Figure 5. Evaporative Cooling pad

During the hot day, the water flowing in the cooling pad absorbed the heat in the air. When the air left the evaporative cooling pad, it flowed towards the extraction fans with high humidity. The water droplet in high humidity air evaporated and reduced the indoor temperature. At the same time, the relative humidity of the indoor air increased.

Flow rate of the water flowing into the cooling pad will be regulated to reduce the humidity inside the house. It is important to be noted that material of the cooling pad also affected the humidity of the house. The better absorbability of the pad the better cooling effect to the house.

Figure 6 shows the indoor air temperature of the mushroom house operated with the evaporative cooling system. To investigate the effect of evaporative cooling system, three thermocouples (K-type) have been installed at three locations inside the mushroom house. During the experiment, the outdoor air-dry bulb temperature was recorded at 34°C and the relative humidity was 80%. Before the evaporative cooling system was running, the average indoor air temperature was at 33°C. The average indoor air temperature was 1°C less than outdoor air temperature due

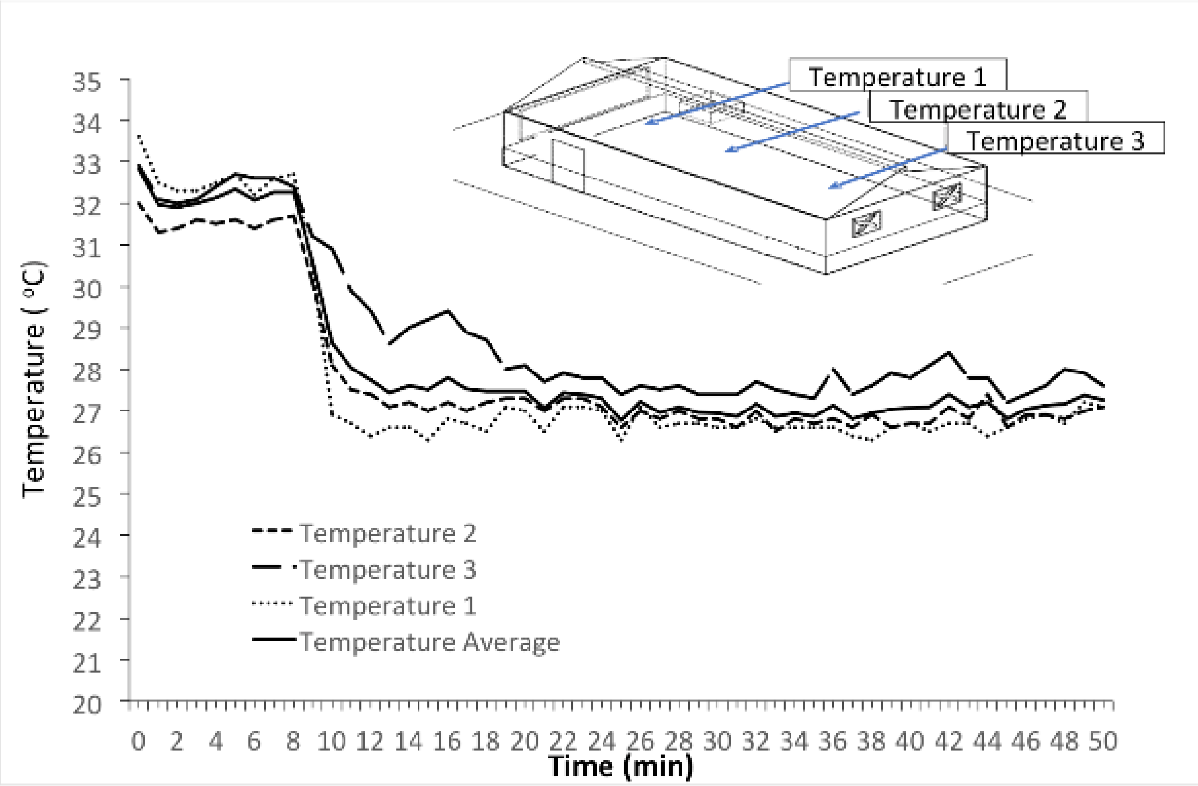

Figure 6. Indoor air temperature at various locations

due to the insulation that was installed at the roof and walls. After eight minutes evaporative cooling system was running, temperatures at all locations were recorded. It was found that the indoor air temperature decreased at an average of 5°C compared to the initial indoor air temperature before the evaporative cooling system was operated. As can be seen in Figure 6, the indoor air temperature maintained below 50°C throughout the next 40 minutes of evaporative cooling operation. This shows that the evaporative cooling system successfully reduces the indoor air temperature by 5°C. It can also be observed all three locations of the measured temperature gave almost the same values. This indicates that indoor air was distributed evenly in the mushroom house.

Moreover, the indoor air humidity was recorded at 90% while the system running. This was 10% greater than the outdoor air humidity. The increment on indoor air humidity is important for the mushroom to grow. Low indoor air humidity would reduce the mushroom yield. Following the observation for both temperature and humidity of air between indoor and outdoor, it clearly shows that the evaporative cooling system is successfully working.

IV. CONCLUSION

The evaporative cooling system for the mushroom house was studied experimentally using the actual mushroom growing house condition. In this study, it was found that the indoor air temperature and humidity was significantly affected by the evaporative cooling system. Lower indoors air temperature and higher indoor air humidity are relatively suitable for growing mushroom. Furthermore, negative pressure strategy is successfully distributed indoor air evenly in the mushroom house. It is verified by observing the recorded temperature at three locations in the mushroom house. Therefore, it can be concluded that the evaporative cooling system is suitable to provide suitable indoor air conditions for mushroom growth.

V. ACKNOWLEDGEMENT

The authors would like to acknowledge the Ministry of Higher Education and Universiti Pertahanan Nasional Malaysia for their financial support under Private Public Research Network PPRN/2016/TK/01.

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