The Novel Design for Cooling System of Greenhouse

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Abstract. Recently, the use of greenhouse is developing. Farming fruits and vegetables using a greenhouse can overcome the unpredictable climate. The plants that need specific air temperature and humidity could grow well inside a greenhouse. As a preliminary study, the effect of circulating water as a thin film at the outer surface of the greenhouse is observed. The water film is intended to cool the greenhouse. In this experiment, there are three models used. The first is the greenhouse (called GH1) with cooling water flowing at the outer surface of greenhouse periodically. The second is a greenhouse (called GH2) without a cooling system and the third is in the open space or natural farming. A water sprayer is installed in each model to water the plants. It sprays periodically. In each greenhouse, three temperature and humidity loggers are installed to measure the air temperature and humidity. The loggers are installed in the middle of the greenhouses with some different heights from the plants. From the experimental results, the air temperature in the greenhouse GH1 decreased compared to the ambient temperature at position 3, while at GH 2 and open space farm N the temperature increased at positions 1, 2, and 3. The average relative humidity was 72%, 68 %, and 47% at GH 1, GH 2, and open space farm (N).

INTRODUCTION

The greenhouse is a plant cultivation system that is useful for getting fresh and good quality fruit or vegetables all the time regardless of the season. Greenhouses are used to grow and protect crops from unpredictable climates and pest disturbances. Therefore, greenhouses are usually designed to be closed and made of glass or plastic. As a result, the space in the greenhouse will experience an increase in temperature [Kawasaki, 2021]. The temperature in the greenhouse is recommended to be uniform, but in Kawasaki's research, 2019 is said to be decreasing vertically and horizontally. From the research, there are certain parts of plants that are sensitive to temperature.

It is known that every type of vegetable or fruit plant requires a special environment to grow [A.J. Both; Telambanua 2014; Zulfahmi 2019]. Temperature and humidity are two important factors to make plants grow well. To control the air condition in the greenhouse, ventilation can be installed in the greenhouse. Ventilation is a natural method of cooling a greenhouse at an inexpensive cost. The difference in air density causes the movement of air or wind and the effect of thermal buoyancy [Ganguly 2011] so that hot air will be replaced by fresh air.

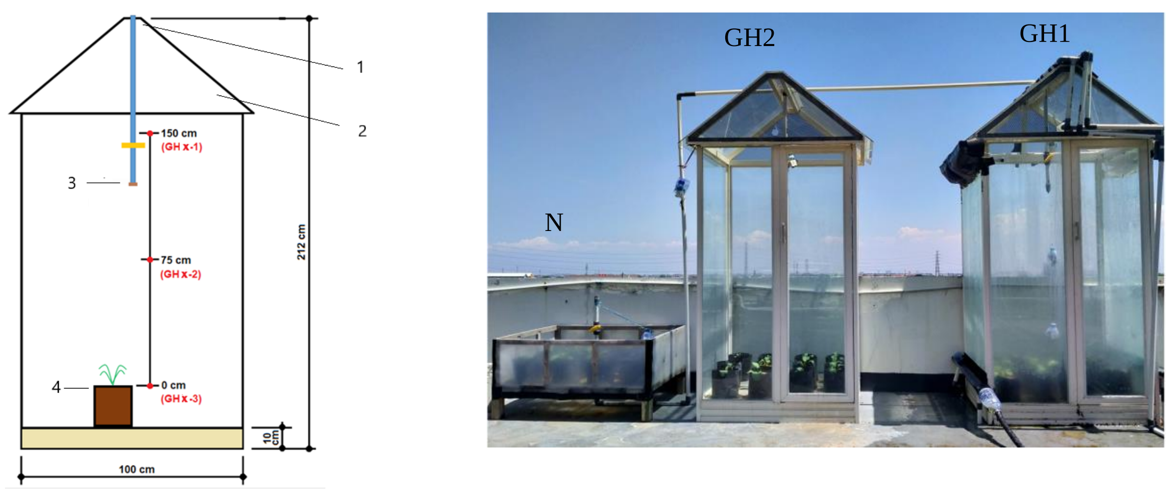
[Akrami 2019] studied the effect of location, number, and size of the ventilation on temperature. The air humidity and air temperature will increase in locations where there is no circulation. Akrami stated that currently there are no ventilators that can meet the temperature and humidity needs of the air in the greenhouse. According to Ganguly 2011, there are two types of ventilation, namely natural ventilation, and fan induced ventilation. Natural ventilation becomes ineffective when the ambient temperature is high enough. This requires fan-induced ventilation. The rate of air exchange depends on the wind speed and the total area of the ventilator [Ganguly 2011].

Another way to reduce the air temperature inside the greenhouse is to use cooling systems, such as evaporative cooling and fan-pads evaporative cooling studied by [Ganguly 2011] and water aquifers studied by [Senthi 2006]. Evaporative cooling systems are based on the sensible heat and latent heat of the water being evaporated. This method can reduce the air temperature and increase air humidity [Ganguly 2011]. However, the increase in air humidity should be another concern because it can be a medium for the growth of some microorganisms [Senthi 2006, Ganguly 2011]. In fan-pads evaporative cooling systems, a draught fan is mounted on one side of the greenhouse and the cooling pad is on the opposite wall. This method can reduce the temperature in the greenhouse by 4-5°C [Ganguly 2011]. Another cooling system used in greenhouses is the fogging and misting system. This system uses an evaporative cooling system, but it uses a small droplet or mist size. This method can lower the air temperature inside the greenhouse by up to 5°C on a sunny day and increase its relative humidity by up to 20% [Ganguly 2011]. This requires a lower initial cost than a pad-fan system [Toida 2006]. Another cooling method is evaporative cooling of the roof where it uses a water film when water is circulated on the roof. The temperature inside the greenhouse decreased to 4-5°C analytically [Sutar 1995].

In this research, a new cooling system is proposed. Greenhouses are usually cooled inside. However, this paper will discuss the results of greenhouse cooling on the outer surface of the roof and walls. Two small greenhouses as models and open space or natural farm were built in the same location. Thus, the plants will live in the same environment. A new model of the greenhouse cooling system is observed. The cooling system is applied to lower the air temperature and increase the relative humidity inside the greenhouse. The outer roof and walls of the first greenhouse (called GH 1) are surrounded by thin water flowing over them. Another greenhouse (called GH 2) is set up without running water outside. Then, the comparison of the two greenhouses with open space or natural plants (called N) was studied. The air temperature and relative humidity inside the greenhouse are parameters that are studied and compared with natural plant systems referring to the surrounding environment.

METHODS

Greenhouse Model Design



(a) greenhouse model (b) the GH1, GH2, and open space farm (N)

FIGURE 1. The experimental apparatus used

The greenhouses GH 1 and GH 2 are made of glass for the surface and aluminum for the frame. The size of the greenhouse is 100 cm x 80 cm x 210 cm as shown in Figure 1 (a). There are small holes (1) on the top of the roof and sides of the roof triangle (2) of each greenhouse for ventilation. The air trapped in the greenhouse will exit the greenhouse through both parts. A water pump is used to circulate water through a half-inch diameter pipe. Figure 1 (b) shows the piping system that delivers water to the sprinkler (3) and the outer wall of the roof and sidewall of

GH1, while the front wall, which is the door, is not flowed by water. GH2 is a comparison greenhouse, there are no cooling walls of the greenhouse. The pipe in addition to flowing wall cooling water also drains water through sprinklers (3) to water the plants. Sprinkles are installed over plants in every greenhouse and on open-air farms. The loggers are installed at three-level points as shown in Figure 1(a). They are used to measure air temperature and humidity inside the greenhouses. The notation GHx-1 indicates the placement of the logger at the top point, GHx-2 at the midpoint, and GHx-3 above the plant. Three loggers were installed at three points on GH1 and GH2, one logger was installed in open ground (N) and one was placed in the vicinity to measure the ambient air temperature (TS) and humidity (Rh-S).

Experiment Set Up

This experiment was used for a preliminary study of the greenhouse cooling method. This method uses a water film that flows from the top of the roof side of the greenhouse and is channeled to all three outer wall surfaces. The experiment was conducted during the summer of 2021 on the balcony of the fifth floor of a building in an urban area in Surabaya, Indonesia.

This paper presents data on air temperature and humidity measured and recorded for four consecutive days at the end of August 2021. Water is flowed and adjusted to form a film of water flowing from the top of the roof to the outer surface of the roof and side walls periodically every one-quarter hour and stopped every fifteen minutes. Watering plants using sprinklers on GH1, GH2 and over plants on natural farms, N for one minute every three hours. water flow regulation is carried out for 24 hours every day.

The recording of air temperature and relative humidity was carried out using eight Elitech RC-4HC loggers. Vertical installation in the center of the greenhouse with a height of 0 cm, 75 cm, and 150 cm from the plant bag/box. Loggers installed in GH1 will be denoted as GH1-1, GH1-2, GH1-3 for a height of 150 cm, 75 cm, and 0 cm respectively from the plant bag. Loggers used in natural farmland will be installed parallel to the crop box. Data will be recorded from 7 am to 7 pm every 30 minutes.

RESULTS AND DISCUSSION

Figure 2 shows the air temperature inside GH1 (T-GH1-1) and GH2 (T-GH2), in an open-space or natural farm (T-N) and its surroundings (T-S). The air temperature inside the two greenhouses increases when the surrounding temperature increases. Based on the position of the air temperature measurement, in GH1 the temperature in the greenhouse is not uniform as expected by the Kawasaki 2019 study. However, from the same research, it is said that the temperature in the greenhouse may not be required to be uniform for all parts of the plant to reduce costs. From Figure 2, the air temperature at position 2 (T-GH1-2) is the highest compared to the air temperature at position 1 (T-2). GH1-1), while the air temperature at position 3 (T-GH1-3) is the lowest and even lower than the temperature outside the greenhouse (TS). The air temperature difference between T-GH1-3 and T-S was 6°C lower, but it increased by 3°C after 5 p.m. The cause of the air temperature in the greenhouse is not uniform is that there is a cooling process on the walls on the roof and sidewalls of the greenhouse and there is passive ventilation located near the logger position 1. The cooling on the wall indicates a decrease in the air temperature, especially in position 2 during the water flow cycle. The cooling effect causes a decrease in the temperature of T-GH1-2 by 4-6°C each time the water starts to flow for the wall cooling process. The high air temperature in position 2 is caused by the position of logger 2 far from the location of ventilation so that it is an area that does not occur circulation. The air temperature of T-GH1-3 reaches the lowest temperature due to the presence of soil which has a lower specific heat than air. The process of spraying through sprinkles makes the soil moist and cooler.

In GH2, the air temperature has a uniform temperature from morning to noon. The difference in air temperature at positions 1, 2, and 3 occurs after 12 p.m. The air temperature of T-GH2-1 has increased until 4 p.m. and then it has decreased again until it reaches the ambient air temperature. The air temperature at position 2 decreases after 12 p.m. The air temperature of T-GH2-3 increased up to 6°C from 7 a.m. to 12 p.m. then the temperature decreased by about 3°C after that.

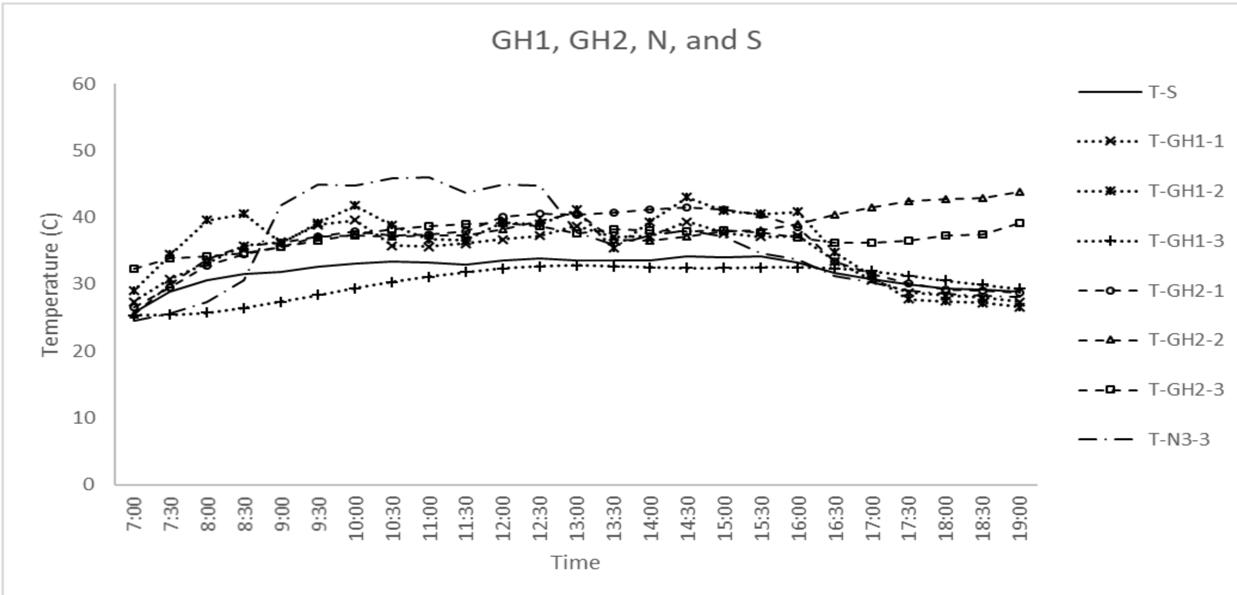


FIGURE 2. The Air temperature inside of greenhouses, on natural farm, and its surrounding

The differences between greenhouse GH1 and GH2 are that the temperature at position 1 of GH1 is lower than GH2. While at position 2, the air temperature in GH1 fluctuates when cooling water flows while the air temperature in GH2 increases. The similarity between the two greenhouses is that both temperatures are above the T-S temperature.

At position 3, the air temperature of T-N3-3 is highest, especially in the morning until noon. The difference in the increase in air temperature until it reaches 13°C from T-S. The high temperature at T-N3-3 can occur because (1) open-space (N) gets direct sunlight and (2) soil where plants grow more absorbs solar energy and increases its temperature. While the air temperature of T-GH2-3 increased about 3-12°C. The increase in air temperature of T-GH2-3 occurs because the solar radiation received in GH2 was kept inside. The passive ventilation and sprinkler sprays have not been enough to decrease the air temperature in the greenhouse during summer. This founding fits with Akrami [Akrami 2019]. The air temperature of T-GH1-3 decreases by 2-5°C compared to the air temperature of TS due to the cooling process. Therefore, the cooling water is found to be effective to lower the air temperature inside the GH1. The plants could be kept inside a greenhouse to meet the required air conditions. It could be a great opportunity to do urban farming in the cities using a greenhouse. However, when The surrounding and air temperature at point 3 inside GH1, GH2, and the N was decreasing as the solar radiation was decreasing i.e., from 1 p.m.

The relative humidity of air (RH) inside GH1 and GH2, in an open-space farm and its surroundings, is shown in Figure 3. In the morning at 7 a.m. RH is the highest in all greenhouses and their surroundings around 80-90%. In the afternoon after 4 p.m., the RH increases gradually until it reaches 65 – 80%. RH decreases as the air temperature increases. The RH of the air at point 1 inside the two greenhouses is lower than at point 2 because it is close to the opening that serves as passive ventilation. The RH of the air at point 2 is higher because it is close to the sprinkler that sprays water on the plants. In greenhouse GH2, there are interesting things, RH at positions 2 and 3 have the same tendency, while at position 1 has the same tendency as the relative humidity of surroundings. This is maybe caused by position 1 being close to the ventilation so that Rh will approach environmental conditions, while at positions 2 and 3 both are far from the ventilation location, and it can be said that the air is trapped there.

The air relative humidity inside of the greenhouse at position 3 (RH-GH1-3 and RH-GH2-3) is higher than the humidity of the air in the open space (RH-N3-3) or the surrounding air (RH-S). The air relative humidity for all models is highest in the morning, at 07.00. Humidity decreases gradually with time. From Figure 3, it is known that the relative humidity of the air is most stable at point 3 which occurs in GH1 with 9% of the maximum difference. The difference was 18% and 16% in Rh in GH2 and open space N, respectively. Based on the average RH for 12 hours at position 3 in GH1, GH2, and open-space farm (N) were 73%, 68%, and 47%, respectively. Those are less than 90% because when the humidity is more than 90%, microorganisms can grow, but if the humidity is too low then the plants cannot grow well [Both, Ganguly 2011, Telaumbanua 2014, Wahono 2014]. So that the greenhouse with water cooling on the outer surface can increase the humidity needed to grow plants in it, especially for mustard greens [Telaumbanua 2014].

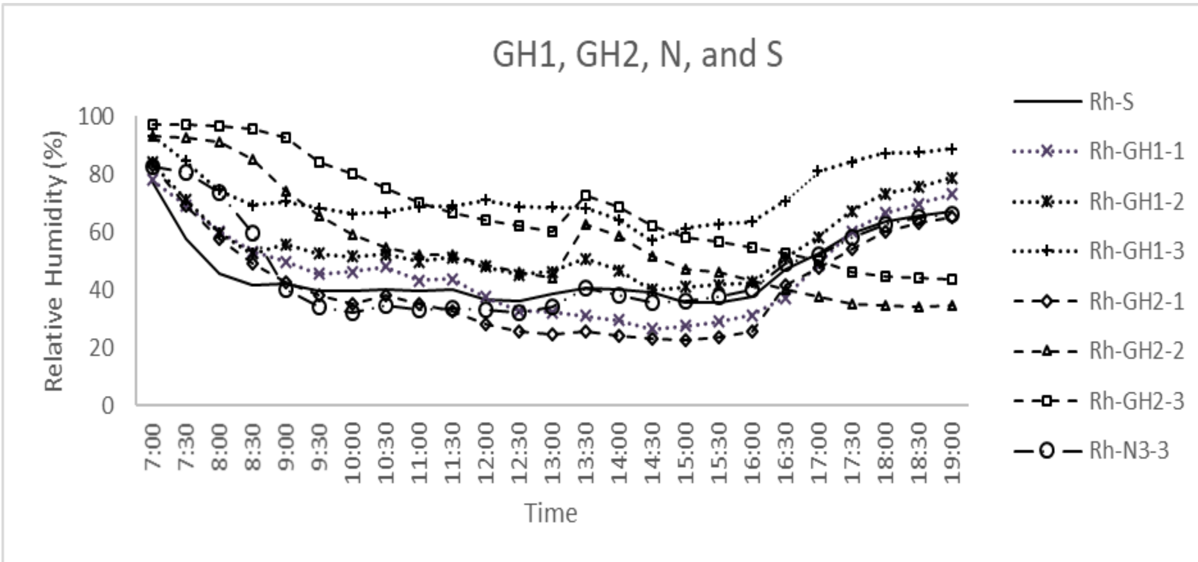


FIGURE 3. The air relative humidity inside of the greenhouses, on natural farm, and its surrounding

CONCLUSION

From the experiments conducted during the summer, the air temperature inside the greenhouses GH1 and GH2 at positions 1 and 2 is higher than the surrounding temperature, but the air temperature at position 3 can be lower by up to 6°C. In GH2 the temperature in the greenhouse increases up to 5°C while in the open space farm N the temperature is 13°C above the ambient temperature. In greenhouse GH1, the temperature at position 2 fluctuates when cooling water flows through the walls, while in GH2 the temperature in the greenhouse is relatively stable. The relative humidity of the air inside the GH1 at position 3 is almost stable at 80% compared to GH2 or N. The relative humidity at position 1 is not much different for all models. The average relative humidity of the air above the plant RH at point 3 in GH1, GH3, and natural land (N) were 73%, 68%, and 47%, respectively. Cooling water applied to the outer surface of the roof and three walls has been shown to cool the air and increase the relative humidity near the plants in the greenhouse. This can be a great opportunity to do urban farming in the city using greenhouses.

ACKNOWLEDGMENTS

The authors are grateful for getting the research grant from Petra Christian University.

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