Performance evaluation of a small backyard hydroponics greenhouse using automatic evaporative cooling system

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Abstract. This work studied the automatic greenhouse evaporative cooling system in hydroponics for household. The objectives of this study were to design the automatic feeding nutrient solution system and determine the performance of automated greenhouse evaporative cooling system for a small backyard. The microcontroller (Arduino Uno R3) was used in both systems and the dimensions were the same design as a 1 m of width, 2 m of length and 1.75 m of height especially for household. In the study, the conventional cultivation hydroponics had been constructed in parallel to be a reference of a study. The results show that the automatic feeding nutrient solution system (AFNSS) can precisely control the flow rate at 6±2% LPM. In addition, the automated greenhouse evaporative cooling system (AGECS) also effectively maintains the planting conditions for hydroponics and the control performance index (J) is 0.14 when setting temperature at 29.0±1°C. Finally, the lettuce production in AGECS gives the statistical significance at 0.05 and payback period of this system is 3.3 years. For this design, the automatic system is simple to control and reliable, more productive, and not dependent on seasons, as well as renewable electricity sources, then, it is practical for home vegetable gardeners.

1. Introduction
In the present, as people are aware of their health, the eating and living are more important. Then, the demand for fruits and vegetables is increasing in the future. Furthermore, these are effects the urban society, traffic jam, limited of area and time, as well as, more stressful. One of the solutions for urban society is home-grown vegetable which can plant like hobbies. According to the limited area, the hydroponics is one of the best solution for planting because of rudimentary backyard setups. For hydroponics technique [1], the system is a water cultivation circulating of a nutrient solution through shallow channels with their root directly exposed to the solution in a closed-loop system. Moreover, in comparison, the hydroponic yields 11 ± 1.7 times higher production, uses 12.5 ± 3.8 times less water but requires 82±11 times more energy compared to conventional agriculture [2]. In order to reduce the labor, the automated hydroponic system had been created for indoor plant growth [3]. To illustrate, the system was effectively automated using microcontrollers and sensors to maintain conductivity and pH throughout 24 hour for a whole of production cycle. Furthermore, to improve reliability and remote monitoring, an internet of thing (IoT) [4, 5] had been created to monitor and control from remote distance. The fully automated hydroponic system had successfully showed and maintained the conditions needed for the test plants. According to the conditions of hydroponic planting, the system can be cultivated for indoor or outdoor farming. However, for the extreme weather or out of season, the greenhouse incorporated with hydroponics had been constructed not only to prevent the plant from
outside climate but also to control the conditions inside [6, 7]. Consequently, the system can effectively control temperature and relative humidity for planting conditions. As mention above, the hydroponics used more energy than conventional cultivation. Then, the renewable energy, solar power, solar photovoltaics, has been used to be the source of power supply in the electricity of system to reduce the operation cost [10] and the payback period was less than 5 years.

In the study, the automated greenhouse evaporative cooling system in hydroponics was created to compare the growing rate with conventional cultivation hydroponics. In the system, the automatic feeding nutrient solution system had been designed to control the effective flow rate for green oak lettuce. Moreover, the automatic greenhouse evaporative cooling system was study the performance to control the planting conditions of hydroponics. Finally, the statistics and the economics analysis had been done in the evaporative cooling system to show the practical system.

2. Experimental setups and procedure

In this section, there were two systems built and tested simultaneously. One was the automated greenhouse evaporative cooling hydroponics which consisted of the Automatic Feeding Nutrient Solution System (AFNSS) and the Automated Greenhouse Evaporative Cooling System (AGECS). Another one was the conventional cultivation hydroponics which consisted of only AFNSS. Furthermore, the cultivations were done in parallel, in order to compare data. The dimension of both systems were the same design as a 1 m of width, 2 m of length and 1.75 m of height. In the study, the experiment setups were carried out to investigate the performance of the automated greenhouse evaporative cooling system on hydroponics and compare the growing rate with the conventional hydroponics. The solar cell was used to be the power supply in the experiments. The experiment setups of conventional setting was almost the same as normal hydroponics except there was the feeding nutrient solution system as shown in figure 1. In addition, the feeding nutrient solution system was also installed in the automated greenhouse evaporative cooling system as shown in figure 2.

For the planting, the system consisted of the circular troughs that were 1.7 m long, with diameter of 6.35 cm. The circular trough was drilled for a single row of 1.5-cm diameter holes, spaced 10 cm apart. Furthermore, each trough could hold 15 plants and one greenhouse contained a total of 60 plants. The germination of green oak lettuce was 7-14 days and transferred to the troughs at 14 days old. In addition, the lettuce was harvested at 45 days old.

AFNSS of hydroponics consisted of feeding nutrient solution tank, nutrient solution tank, sensor measuring the solution level, control system controlling the solution level, and a pump sending solution to feeding nutrient solution tank. To illustrate, the feeding nutrient solution tank had been constructed to control the nutrient solution level in order to keep the constant flow rate of nutrient solution. Moreover, nutrient solution tank stored nutrient solution coming back from the troughs and sending back to the feeding nutrient solution tank by a pump. In this system, the system had been designed by fixed the flow rate of nutrient solution at 6.0 ±10% LPM because this flow rate is significant in growing rate [9]. The nutrient solution level was controlled using microcontroller (Arduino Uno R3) with ultrasonic sensor. In the operation, the solution level from feeding system had been measured by ultrasonic sensor. When the solution level is below than the lower limit, the solution will be pumped into the feeding tank to maintain the solution level. On the other hand, when the solution level is higher than upper limit, the pumping system will be stopped.

AGECS comprised of feeding water system, cooling pad, and ventilation fan. In the study, the greenhouse conditions were set at 25-30°C and 60-80% RH because of the best growing rate conditions of lettuce. To illustrate, the water storage tank was the cement tank that kept underground to maintain the water temperature at 22-23°C and feeding water tank was a clay pot which also held low temperature. Initially, the automatic system had been set the operation temperature at 29±1°C. In the operation, the evaporative cooling system will be started when the temperature inside the greenhouse is higher than 29.0 °C. Then, the feeding water system and ventilation fan are automatically switched on sensor sending the command to run the feeding water system and ventilation fan in order to reduce the temperature inside greenhouse. On the other hand, if the temperature is less than 29.0 °C, the automated
The system will stop feeding water system and ventilation fan. Therefore, the system will be automatically operated in continuous cycle.

**Figure 1.** The hydroponics with feeding greenhouse nutrient solution system.  
**Figure 2.** The hydroponics with automated evaporative cooling system.

### 3. Governing equations
According to the evaporative cooling system, the efficiency and control performance index has been calculated to show the performance of the automatic system. Additionally, the AFNSS also has been shown the relationship between the flow rate and nutrient solution level.

For the AGECS, the direct evaporative cooling is used and can be determined the efficiency of the system as the following.

$$\eta = \frac{T_{\text{atm}} - T_{\text{room}}}{T_{\text{atm}} - T_{\text{wb,atm}}}$$  \hspace{1cm} (1)

Where the efficiency ($\eta$) is defined by the ratio of the difference between ambient temperature ($T_{\text{atm}}$) and room temperature ($T_{\text{room}}$) to the difference between ambient temperature ($T_{\text{atm}}$) and wet bulb of ambient temperature ($T_{\text{wb,atm}}$).

The control performance index ($J$) is the performance assessment of greenhouse evaporative cooling system. In this study, it has been defined by the average temperature difference between temperature inside greenhouse ($T_{\text{room}}$) and set point temperature ($T_{\text{set}}$) at 29.0±1°C.

$$J = \frac{1}{t_{f} - t_{i}}\int_{t_{i}}^{t_{f}} (T_{\text{room}} - T_{\text{set}}) \, dt$$  \hspace{1cm} (2)

Where $t_{i}$ and $t_{f}$ are time at the beginning and final of operation.

Ideally, for the best system, the control performance index should be zero. However, this system indicated the accept value should not exceed than ±1°C.

The nutrient solution feeding system designed using the steady flow energy equation is expressed as the following.

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + h_L$$  \hspace{1cm} (3)

In the design, location 1 is at the bottom of nutrient solution feeding tank and the location 2 is at the outlet of nutrient solution feeding tank as shown in figure 1. When the constants had been substituted in the equation (3), the relationships between nutrient solution level ($h$) and outlet velocity ($V_2$) can be shown in equation (4)

$$h = 0.944V_2^2 - 0.25$$  \hspace{1cm} (4)
4. Results and discussions
In this section, the experiment showed the performance of AFNSS and AECGS. In addition, the comparison of growing rate between the automated greenhouse evaporative cooling hydroponics and the conventional cultivation hydroponics also were discussed.

4.1. The performance of AECGS and AFNSS
The figure 3 shows the relationship between power usage of system and operating time. In the figure, when the temperature is higher than 29.0°C, the automatic system starts to operate the ventilation fan and feeding water system. The compatible operation between the power usage and the greenhouse temperature ($T_{room}$) has been agreement in figure 3 and figure 4. When operation starting, $T_{room}$ reduces less than $T_{atm}$ as shown in figure 4. Theoretically, the minimum greenhouse temperature can be reduced at wet bulb temperature of ambient temperature. Furthermore, the system calculated the control performance index ($J$) when $T_{set}$ at 29.0°C is 0.14. Then, the automated system works well to control the greenhouse temperature.

![Figure 3. The automatic operation on evaporative cooling system.](image3.png)

The figure 5 shows the performance of automatic evaporative cooling greenhouse. Theoretically, as shown in the figure, the optimum temperature and relative humidity of hydroponic plants is 25-30°C and 60-80%, respectively. The results show that the greenhouse can maintain the temperature in the proper range at the different ambient temperature, however, the relative humidity is still higher than...
standard because there are no equipment to control the relative humidity for the greenhouse. For future works, this system should install the fresh air inlet to reduce and control relative humidity in order to maintain the optimum growing plant conditions.

![Greenhouse temperature and relative humidity with variation of ambient temperature evaporative cooling control.](image1)

**Figure 5.** Greenhouse temperature and relative humidity with variation of ambient temperature evaporative cooling control.

The figure 6 shows the relationship between ambient temperature and greenhouse efficiency. In this study, the efficiency of experiment testing and commercial efficiency of evaporative cooling in greenhouse had been compared. The automated greenhouse setting temperature at 29°C, the results show that the greenhouse efficiency depends on the ambient temperature. To illustrate, when the ambient temperature is in range of 30-32°C, the system efficiency is between 50-60%. Furthermore, when the ambient temperature is in range of 33-35°C, the greenhouse efficiency is between 40-50%. According to the results, the greenhouse efficiency was lower than commercial greenhouse [8] because the designed greenhouse was quite so small and the fluctuation of temperature and efficiency had been occurred for this reason.

![Efficiency on variation of ambient of temperature.](image2)

**Figure 6.** Efficiency on variation of ambient of temperature.
According to the AFNSS, the nutrient solution level depends on demand nutrient solution flow rate as shown in equation (4). The flow rate of 24 LPM at the outlet of feeding nutrient solution system has been delivered to four troughs at 6 LPM equally. The figure 7 shows the performance of the ANSFS that can precisely control the flow rate at 6±2% LPM during testing time.

Figure 7. The flow rate of nutrient solution in ANSFS.

4.2. The performance of AECGS and AFNSS
Table 1 shows the dimensions and weight of lettuce. In the table, the height, width, and root length are not different in both groups. However, the evaporative cooling greenhouse gives the significantly higher weight than conventional cultivation hydroponics because the greenhouse can control the suitable temperature conditions for planting.

Table 1. The dimension and weight of lettuce comparison between the automated evaporative cooling greenhouse and conventional hydroponics.

| Descriptions       | Evaporative cooling | Convention |
|--------------------|---------------------|------------|
| Height (cm)        | 30.60               | 24.32      |
| Width (cm)         | 26.29               | 25.21      |
| Root length (cm)   | 18.07               | 14.89      |
| Weight (g)         | 43.43               | 9.34       |

For the economics and statistics analysis, the automatic evaporative cooling greenhouse hydroponic system showed the payback periods of 3.3 years. Moreover, the t-test was used to check the performance of the automatic evaporative cooling greenhouse in higher production of lettuce, p=0.05, with automatic system showing the significantly higher production of lettuce than conventional hydroponics.

5. Conclusions
The AFNSS and AECGS have shown the effective performance of system in hydroponics. The AFNSS shows precisely system to control the flow rate for hydroponics. In order to maintain the planting conditions, the AECGS also works well to keep the hydroponic conditions. Consequently, the hydroponics can be increased the productivity when using the automatic system. For this design, the automatic system is reliable and simple to control, more productive, and not dependent on seasons, as well as renewable electricity sources, then, it is practical for home vegetable gardeners. The hydroponics is not only planted for home-grown vegetable, but it is also environmentally friendly and clean food.
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