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Article

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Heat load due to LED lighting of in-door strawberry plantation

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Abstract

This paper investigates heat load due to LED lighting of in-door strawberry plantation. A double-chamber experimental room was designed and constructed at Chiang Mai University, Thailand. There are 180 strawberry plants inside the inner experimental room. Air temperature and moisture of the room can be adjusted using an air conditioner. LED tubes were used to supply light for photosynthesis of the strawberry plant. The air temperature, air moisture, and condensed water from evaporator were measured. Using energy balance and mass balance equations, it was found that, during the use of LED lighting, the condensed water from the experimental room was increased. Calculated heat load of the room were also increased. Approximately 60% of the heat load is from condensation when there is no lighting load. While providing lighting from LED, heat loads from LED and condensation can be almost 100% of total heat load. Increased condensation heat load is the result of evapotranspiration by strawberry plant.

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Keywords: Heat load; LED; In-door plantation; Strawberry

1. Introduction

Strawberry is one of the most popular fruits in Thailand. It is usually cultivated in Northern of Thailand, where the weather is suitable in the winter. The most popular breed is locally available by the Royal Thai Project no.80. This strawberry breed is well known to the sweetness, softness, and aroma. Farmers usually starting plantation during June–July. The strawberry can be harvested during November–February. Official annual production of the strawberry in Thailand is available.

Recent years, unpredictable weather conditions affect the yield and quality of the strawberry. It was observed that increasing average ambient temperature during November to February decreases the sweetness and the softness. Higher ambient temperature also decreases the yield of the strawberry. In addition, the higher temperature also leads

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to increasing number of insects and related plant deceases. On the other hand, there is an increasing demand of strawberry both fresh and frozen forms every year. Therefore, in order to satisfy the increasing demand and provide the higher quality, more efficient technique for strawberry cultivation is needed.

In-door strawberry farming is one of the most interesting alternatives for cultivating high quality strawberry. Most of the on-door strawberry farming reported in the reviewed literatures uses greenhouse technology. Countries in cold climate areas use the greenhouse to capture and store heat from the sun. Gavilán et al. [1] and Lozano et al. [2] attempted to predict evapotranspiration of indoor-grown strawberry using weather data such as solar radiation. Crop coefficient of strawberry cultivation under plastic tunnels was investigated [3]. Different set of weather data from weather stations inside and outside the tunnels were used to calculate crop coefficient. It was found that different source of weather data resulted in different evapotranspiration estimation.

For complete-closed indoor cultivation (so called plant factory), the major concern for this technique is providing artificial lighting as substitution to the sun light. Different Red:Blue ratio LED (Light Emitting Diode) light was investigated [4]. Different ratios of LED wavelengths for optimum leaf and fruit were identified. Higher yields observed in LED exposed plants compared with those under fluorescent lamp illumination were reported by Hidaka et al. [5]. It was due to comparatively higher LED light intensities. Effects of photoperiod and temperature was investigated for four years on ‘Sweet Charlie’ strawberry (*Fragaria × ananassa* Duch.) plug plants for off-season production in a vertical hydroponic greenhouse system in New Jersey, USA, by Durner [6]. The critical photoperiod for ‘Sweet Charlie’ flowering was evaluated by exposing plugs to 4 different photoperiods (7, 9, 11 and 12 h) for 0, 7, 14 or 21 days followed by exposure to 0, 7 or 14 nights of chilling ($<12\text{ }^{\circ}\text{C}$). It was found that conditioning protocol of seven 9 h short days (SD) at 21/21 $^{\circ}\text{C}$ (day/night) followed by seven 9 h SD at 21/12 $^{\circ}\text{C}$ (day/night) can produce more fruit (41%–152%) than non-conditioned controls every year.

Although most of electricity used in LED is converted into light for photosynthesis process, energy is added to the complete-closed cultivation room. The added energy leads to either increased room air temperature and evapotranspiration. Added water from strawberry evapotranspiration to the air-conditioned room increases heat load of the experimental room. It is essential to accurately quantify the added water due to evapotranspiration. There are several techniques that can be used to estimate evapotranspiration [1,7,8]. However, different crops and different cultivation techniques make it difficult to be commonly used, such as growing strawberry in complete-closed indoor cultivation. Thus, the aim of this paper is to investigate the heat load of strawberry due to LED lighting in complete-closed room.

2. Methodology

2.1. Experimental setup

Complete-closed room for indoor cultivation can be identified as a refrigerated space. ASHRAE — The American Society of Heating, Refrigerating and Air-Conditioning Engineers [9] lists the composition of heat load to a refrigerated space as follows; transmission load, product load, internal load, infiltration air load, and equipment-related load. Heat loads due to LED is considered as internal load. There are two components of the internal heat load, which are sensible heat from LED energy consumption and latent heat from evapotranspiration.

In order to investigate the heat load during growing strawberry in indoor condition, energy conservation approach is used. A simplify test room was designed and constructed. The test room used in this paper is double-chamber room. The outer room is used to control ambient for the inner room. The temperature of the outer room is kept constant at 25 $^{\circ}\text{C}$. The inner room (5 m \times 2.25 m \times 2.4 m) is for strawberry plantation, so-called “the grow room”. Expanded Polystyrene Foam Insulation Panel with the thickness of 7.5 mm was used as the wall for both rooms. There are two parallel shelves as shown in Fig. 1 in the grow room. One strawberry was planted in 1.2-Liter plastic container. Chopped coconut peel was used as growing media. LED grow light (total 2.7 kW) was used in the experiment. An air conditioner was used to control the air temperature and humidity inside the grow room.

Nutrient and water supply to strawberries is conducted in a closed chamber. Two different types of growing substrates are selected as coconut coir (pH 5.95, EC 4.91 dS m^{-1} , water holding capacity 59%v/v, total porosity 86%v/v and bulk density 0.09 g cm^{-3}) and growing substrate developed from coconut coir (named as AGM1: pH 5.94, EC 6.78 dS cm^{-1} , water holding capacity 63%v/v, total porosity 70%v/v and bulk density 0.19 g cm^{-3}) for growing strawberries in a plastic pot (1 plant each pot), with total amount of 90 pots of coconut coir and 90 pots

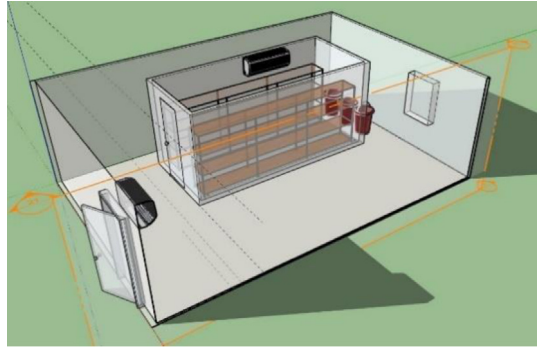


Fig. 1. Simplified strawberry grow room.

of AGM1. Fertigation is automatically drip irrigated four times a day at the following rates: 10 ml per 1 min to 45 pots of coconut coir and 45 pots of AGM1; 10 ml per 2 min to 45 pots of coconut coir and 45 pots of AGM1.

The LED grow light with ratio of 8:2 (red-460 nm to blue-660 nm) is applied and the light intensity (PAR: Photosynthetically active radiation) is set at around $350 \mu\text{mol m}^{-2} \text{s}^{-1}$. There are 180 strawberry containers in the growing room. The strawberry trees in all container are similar in size. They are about 2 months old with not more than 6 leaves per plant (See Fig. 2).



Fig. 2. Strawberry tree and containers inside the grow room.

In each day, duration for temperature setting and LED grow light operation is as shown in Table 1. For watering, there are 6 times a day (07:00, 09:00, 11:00, 13:00, 15:00, 17:00). Each strawberry would receive 10 ml per day. Excess water was drained from the room and weighed.

Table 1. Schedule for temperature and Grow light.

Time	Room air temp (°C)	LED grow light
00:01–08:00	18	Off
08:01–17:00	25	On
17:01–24:00	18	Off

Data collected during the experiments includes air temperatures in the grow room and the control room, electricity consumption from the air conditioner, water pumps, LED grow light, and air distribution fan, and condensed water from the air conditioner. The data was collected every 15 min for 18 days.

2.2. Mathematical model

The grow room can be simplified in terms of energy system as shown in Fig. 3. Considering the grow room is a control volume. Energy input/output/generation to the control volume consists of transmission heat through the walls, infiltration, heat of strawberry respiration, heat drawn by evaporator, electricity work from fan, pump, and

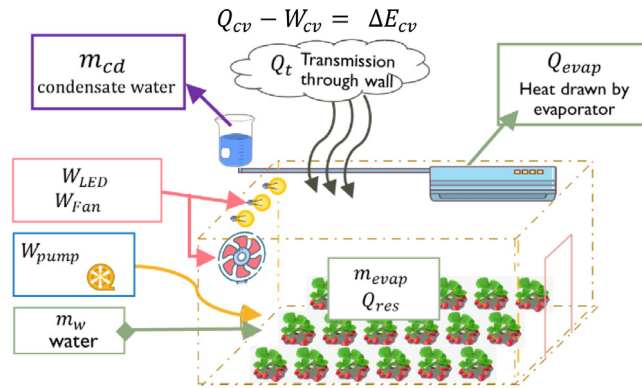


Fig. 3. Energy system of strawberry grow room.

LED grow light. Mass transfer to the control volume consists of evaporations from the growing material and from photosynthesis of the strawberry. The room is considered as transient, therefore, the energy balance of the grow room can be written as follow;

$$Q_{cv} - W_{cv} = \Delta E_{cv}$$

Mass balance is considered from the mass of water added to the control volume, evaporation of the strawberry and growing material and the mass of water extracted from the room via air conditioner. However, measuring the evaporations from both activities from each strawberry container is not simple. Therefore, bulk consideration is applied in this study instead of measuring individual strawberry and grow material in the container. The mass balance of the grow room can be equated as follow;

$$\Sigma \dot{m}_{in} - \Sigma \dot{m}_{out} = \left[\frac{dm}{dt} \right]_{cv}$$

3. Result and discussion

During experiments, it was expected plants would give up moisture to the atmosphere all the time of day. From Fig. 4, during 01:00–08:00, the room temperature is 18 °C, average RH is 77%, and no heat from lighting is provided. The humidity ratio of the air is 0.010 kg_w/kg_{da}. The water condensation rate is approximately 0.1 kg/hr for all 180 strawberry plants. Then, during 08:00–17:00, the room temperature was increased to 25 °C. During this time, the RH was reduced to 60%. Hence, the humidity ratio is about 0.012 kg_w/kg_{da}. Later, during 18:00–24:00, the temperature was decreased to 18 °C and RH was 73%. Hence, the humidity ratio is about 0.009 kg_w/kg_{da}.

In all three periods, the humidity ratio is high during 08:00–17:00, which means that higher amount of water in the air. The high water content in the air is due to high evapotranspiration of the strawberry and evaporation from the growing material. Added moisture in the air was removed by the air conditioner used in the experiment, as can be clearly seen from high condensation rate (0.33 kg/hr for 180 strawberry) during this period. In average, each strawberry plant gives up 1.83 g/hr of water during the LED is on and 0.72 g/hr during the LED is off.

From Fig. 5, typical hourly heat loads entering the grow room and room temperature gathered from the experiments are shown. During the night the temperature if the room is almost constant at the set point, 18 °C. After the grow light is turned ON at 7am, the room temperature slowly increasing. It took almost 7 h until the room temperature reached the set point at 25 °C. The slow increasing of grow room temperature is due to thermal inertia of the room.

During 12:00–17:00, the actual grow room temperature is slightly higher than the temperature of the control room. Therefore, the transmission load become negative, which means the heat is transferred out of the grow room.

Total heat load of the grow room and air temperature over 24 h can be observed in Fig. 5. It can be seen clearly that during the LED glow light is turned ON, the heat load of the room is high. On average, the heat load from LED

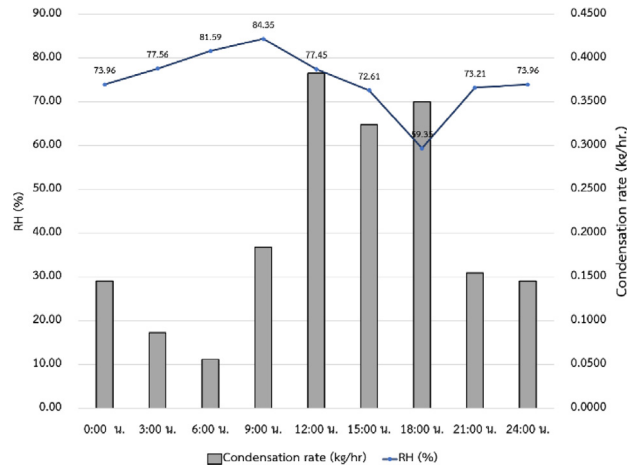


Fig. 4. Condensation rate and Relative Humidity of the air over 1 day.

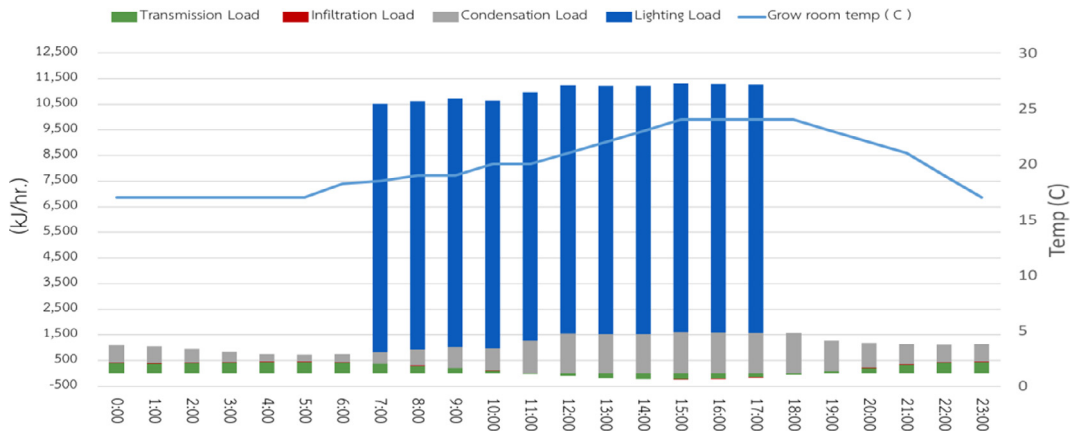


Fig. 5. Typical total load of the grow room and its temperature.

grow light is 78% of the total daily load. Condensation of moisture is the second largest heat load. During LED grow light is turned ON, the condensation load is increased. This implies that the energy from the LED increases the evaporation rate and respiration rate. Although set point of air temperature during the use of LED was increased from 18 °C to 25 °C, which increases the dew point temperature, the rate of condensation is still increased.

Infiltration load is the smallest among all the heating loads. This is due to very few times of the room opening by researchers. In addition, the room is air-tied in order to minimize exchange of room air and the surrounding.

From the total heat load, energy consumption by air conditioner can then be calculated using the performance data of the air conditioner.

4. Conclusion

The energy from LED lighting inside complete-closed room that is used for strawberry cultivation can increase the room air temperature. Both increased room air temperature and energy from LED contributed to increasing of moisture in the air. The increased moisture is from the strawberry transpiration and from the soil. In average, each strawberry plant gives up 1.83 g/hr of water during the LED is on and 0.72 g/hr during the LED is off.

Using energy balance approach, it can be found that LED lighting increased the evapotranspiration and heat loads up to 5 times compared to no LED lighting condition. Approximately 60% of the heat load is from condensation when there is no lighting load. While providing lighting from LED, heat loads from LED and condensation can be almost 100% of total heat load.

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