DEVELOPMENT OF NIGHT COOLING SYSTEM FOR GREENHOUSE USING COOL AIR AND WATER FROM AN ABANDONED COAL MINE

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ABSTRACT

This study was to develop the most effective cooling system which is needed to cool greenhouse during summer night to get early blooming of strawberries. Various cooling systems were designed and constructed to utilize the cool air and water from an abandoned coal mine. Cooling systems built for this study were an evaporative cooling system with pad, cooling system using a small or large radiator, and duct cooling system using cool air drawn from coal mine. These systems were individually tested to investigate their effects on cooling greenhouse during summer night. Also, a combined cooling system was tested with operating an evaporative cooling system, small radiator, and duct cooling system simultaneously.

The results in this study showed that individual cooling systems such as evaporative cooling system, small radiator, and cooling duct had about the same effect on cooling greenhouse. The combined system had little better cooling effect than that of individual cooling system except the large radiator. The most effective system for cooling of greenhouse was obtained with using a large radiator as the heat exchanger. With operating a large radiator, temperature inside the greenhouse was dropped to about 15 - 16°C while outside temperature was 23 - 24°C during summer night.

Key Words : Greenhouse Cooling, Night Cooling System, Abandoned Coal Mine, Cool Air, Cool Water

INTRODUCTION

In Korea, it is necessary to strengthen the international competitiveness in agriculture as a counterplan for the opening of importation for agricultural products since a compromise of UR negotiation. Therefore, a lot of ways for the solution have been considered in each area of agricultural fields. In Kangwon-Do, Korea, many abandoned coal mines were produced because of the recession of coal-mining industry. This economic recession in coal-mining areas has been considered as an important social problem that can not be overlooked. Therefore, the abandoned mines should be firmly investigated for the possibility of industrial utilization.

The greenhouse facilities are intensive type of technology and capital. However, it is considered that growing plants in greenhouse is suitable in agricultural situations of Korea. To grow plants in greenhouse is one of the agricultural fields which have the international competitiveness. Recently, consumption of fresh fruit and vegetable has been widely increased due to the rise of the national income and living standard. It is expected that agriculture, using greenhouse will be greatly increased in the near future. The cost of energy is considered as the great part of expense in the operation of greenhouse which produces vegetable and fruits. Therefore, if cool air and water drawn from an abandoned coal mine can be used for environmental control of greenhouse, the cost of energy for cooling will be minimized. Also, in coal-mining areas, the economic benefit will be great in producing agricultural products in greenhouse commercially.

In cooling greenhouse, the cost for operation of commercial air-conditioning system is very high. However, it is expected that the cooling system utilizing cool air and water drawn from abandoned mine is very economic. Also, its cooling effect is better than that of ventilating fan (Walker et at., 1976). There are several different ways on cooling greenhouse: 1) an evaporative cooling system; 2) mist cooling system; 3) cooling system using heat exchanger under or above the ground; and 4) ventilation system using fan.

Evaporative cooling system moves air through a screen or spray of water in such a manner that evaporation of water occurs. This system is usually applied in the less humid parts of the United States (Buffington, 1983). Mist cooling system eliminates evaporative heat in the house by spraying tiny water droplets into the greenhouse. It is known that efficiency of the mist cooling system has almost the same as that of evaporative cooling method (Gates et al., 1991).

It has been studied for a long time about the use of earth-tube heat exchanger for cooling greenhouse or livestock building (Scott et al., 1965; Walker and Buxton, 1977). Several ways were applied to increase the rate of heat transfer in this heat exchanger. That is, the total rate of heat transfer can be enhanced by extending the surface of the heat exchanger and the heat transfer coefficient with increasing fluid velocity. Most studies on heat exchanger above the ground for cooling greenhouse and livestock building have focused on air-to-air or air-to-liquid heat exchanger (Bergstrom and Walker, 1987; Moysey and

Wilson, 1980; Overhultz and Fehr, 1987). Therefore, it is expected that the automobile radiator can be effectively used as the heat exchanger above the ground for cooling greenhouse.

In Japan, strawberries have been grown on highland mountain to stimulate early blooming at low temperature during summer night. However, to replace this technology, growing plants on highland mountain, it has been studied for the method inducing early blooming of strawberry in greenhouse with artificial cooling system.

A lot of abandoned mines exist in Kangwon-Do, Korea. Cool air and water can be easily drawn from these abandoned mines. Also, it is considered that night cooling system utilizing cool air and water from abandoned coal mine can be effectively used to stimulate early blooming of strawberries in greenhouse. The objective of this study was to develop the most effective cooling system which is needed to cool greenhouse during summer night to get early blooming of strawberries.

MATERIALS AND METHODS

The cooling experiment was conducted in greenhouse which was covered with insulating material and a layer of polyethylene film to reduce heat loss. The plane view of greenhouse which presents the installed locations of cooling systems and fixed places of thermocouples for temperature measurement are shown in fig. 1. The temperature was measured in breeding room of the strawberries, outside and inside of greenhouse, and for outlet water and air of cooling systems. Data acquisition system was used to measure the temperature. Inside temperature of greenhouse was measured at 0.3 and 2.3m above the ground. In August, 1995, the experiment was carried out in greenhouse which was constructed near the abandoned coal mine in Kangwon-Do, Korea. To determine the most effective system to cool greenhouse during night, various cooling systems were constructed and tested. Cooling systems tested in this experiment are as follow:

1. Cooling system using a small radiator

The fan with capacity of $50m^3$/min was installed at the front of a small radiator(a radiator of Sonata II automobile: 60 × 45 × 2.5 cm). Cool water of about 12.5°C drawn from coal mine was flowed into the radiator. This radiator was used as the heat exchanger which cools air passing the radiator surface. Inside the greenhouse, warm air sucked by fan from left side of radiator was cooled by passing through the right side with contacting radiator surface. Then, cool air was scattered inside the greenhouse through a plastic tube which was attached at the right side of radiator. One end of the tube was fixed at the right side of the radiator and the other end was connected to a side of the greenhouse. The tube had the diameter of 50cm. It was suspended on a wire near the ridge. To scatter cool air uniformly inside greenhouse, holes with diameter of 2cm were perforated along the entire length of tube.

2. Evaporative cooling system using pad

Evaporative cooling pad was fixed inside a rectangular box which was made with iron sheet. Fan with capacity of 45 m^3/min was installed at the front of evaporative pad. A pipe with closely spaced holes was fixed at the top of a box. Cool water drawn from coal mine were uniformly scattered on the pad through a pipe. Warm air sucked at the front of pad was cooled by passing pad. Then, cooled air was uniformly spreaded inside the greenhouse through a plastic tube which was installed at the rear side of evaporative cooling system.

3. Duct cooling system

Fan with capacity of 45m^3/min was installed inside a duct which was made with iron plate. The diameter of a duct was 50cm. The cool air drawn from coal mine was uniformly scattered inside greenhouse.

4. Combined cooling system

This is the combined cooling system which operates evaporative cooling system, small radiator, and duct cooling system simultaneously.

5. Cooling system using a large radiator

At the front of the large radiator(125 × 80 × 45cm), two fans with capacity of 50m^3/min were installed. Cool water of 12.5°C drawn from coal mine was passed through a large radiator which was used as an heat exchanger. The flow rate of water flowing into the radiator was 0.0003 m^3/s. Warm air was sucked into the front of the radiator at the velocity of 3.83m/s. Then, air cooled by passing the surface of the radiator was scattered into the greenhouse.

RESULTS AND DISCUSSION

1. Cooling system using a small radiator

The results obtained from cooling experiment using a small radiator are shown in fig. 2. During night, temperature of outside air and breeding room without cooling system was at the range of 25 - 28°C. Water temperature at the outlet of radiator was about 14°C. Air temperature before passing the radiator surface was about 22°C. But, air was cooled to about 18°C after passing the radiator surface. This drop of air temperature are due to heat loss of air passing the radiator surface which was cooled by water. Inside temperature of greenhouse measured at 0.3 or 2.3m above the ground was at the range of 21 - 22°C which was 5 - 7°C lower than that of outside air.

2. Evaporative cooling system using pad

Fig. 3 shows the results obtained from cooling experiment using an evaporative cooling system. Temperature of outside air and breeding room was at the range of 20 - 30°C. Water temperature at outlet of cooling system was about 13 - 14°C. Air temperature before and after passing this system was about 21°C and 17 - 18°C, respectively. This decrease of air temperature is due to the absorption of heat from warm air which is needed to evaporate cool water. Inside temperature of greenhouse measured at 0.3 or 2.3m above the ground was about 22°C which was 4 - 9°C lower than that of outside air.

3. Duct cooling system

The results of experiment using cool air drawn from coal mine are presented in fig. 4. After 8:00 p.m., the temperature of outside air and breeding room was at the range of 18 - 22°C. Inlet temperature of duct cooling system was about 17°C. Air temperature inside greenhouse measured at 0.3m above the ground was about 18°C. These results show that the cooling effect was relatively low when cool air drawn from coal mine was used to cool greenhouse. It is considered that the effect of duct cooling system was low due to the small temperature difference between air from coal mine and inside air of greenhouse.

4. Combined cooling system

The experimental results obtained by simultaneously operating small radiator, evaporative cooling system, and duct cooling system are shown in fig. 5. During night, temperature of outside air and breeding room without cooling system was at the range of 25 - 28°C. Inside temperature of greenhouse measured at 0.3 or 2.3m above the ground was at the range of 20 - 21°C. With the operation of the combined cooling system, inside temperature of greenhouse was decreased by 4 - 8°C in comparison with that of outside air and breeding room. Air temperature at outlets of small radiator and evaporative cooling system was about 17 - 18°C which temperature of about 3°C was dropped in comparison with the inlet temperature of 20 - 21°C. The water drawn from coal mine with the temperature of about 12.5°C was flowed into a small radiator and evaporative cooling system. Water temperature at outlets of small radiator and evaporative cooling system was at the range of 13 - 15°C. Thus, it is concluded that temperature of greenhouse was cooled by absorbing heat needed for raising the water temperature of 0.5 - 2.5°C from inside air of greenhouse. However, the duct cooling system had low cooling effect because the temperature difference between air from coal mine and inside air of greenhouse was small.

5. Cooling system using a large radiator

The results of cooling experiment using a large radiator are shown in fig. 6. The night temperature of outside air and breeding room without cooling system was at the range of 23 - 24°C. Inside the greenhouse, air temperature measured at 0.3 and 2.3m above the ground was at the range of 15 - 16°C. With using a large radiator, night temperature in the greenhouse was dropped by about 7 - 9°C in comparison with that of outside air. Inside the greenhouse, air temperature before passing the surface of radiator was about 21°C. However, after passing radiator, air temperature was dropped to 15°C with decreasing the temperature by 6°C. Air temperature inside greenhouse measured at 2.3m above the ground was about 1 - 2°C lower than that measured at 0.3m. It is considered that this difference of temperature was induced because radiator was installed at the upper part of greenhouse.

CONCLUSIONS

The results in this study showed that individual cooling systems such as evaporative cooling system, small radiator, and duct cooling system had about the same effect on cooling greenhouse. The combined system had little better cooling effect than that of individual cooling system except the large radiator. The most effective cooling system for cooling of greenhouse was obtained by using a large radiator as the heat exchanger. With operating a large radiator, temperature in the greenhouse was dropped to about 15 - 16 °C while outside temperature was 23 - 24°C during summer night.

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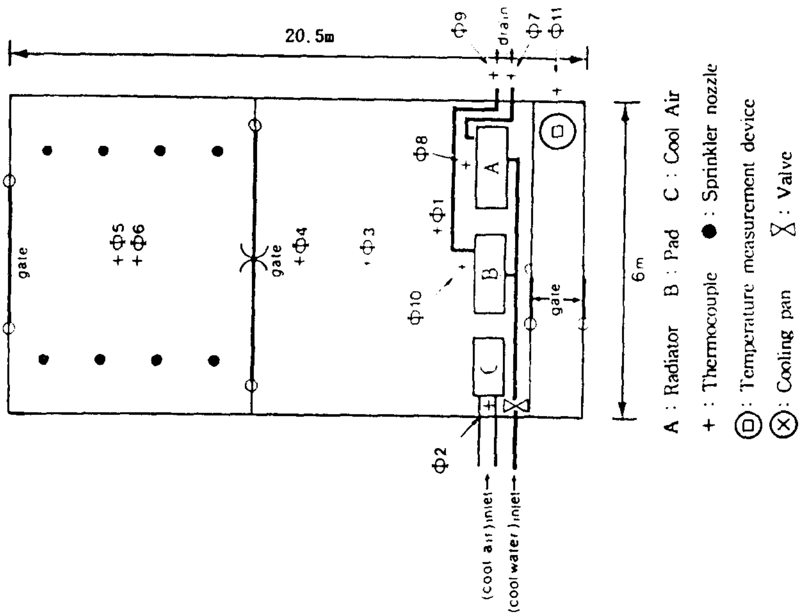

Fig. 1. Plane view of greenhouse showing positions of thermocouple and cooling systems.

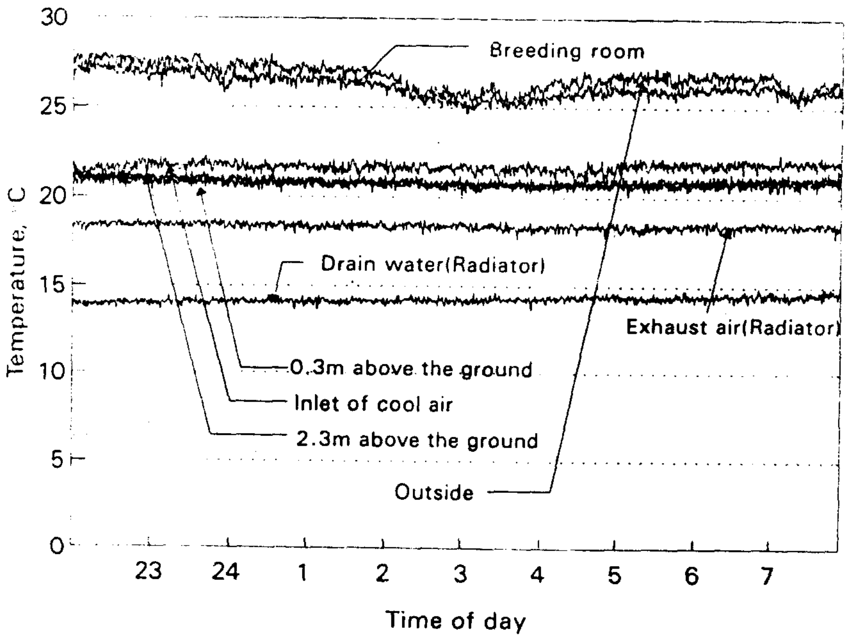

Fig. 2. Temperature distribution in greenhouse during operation of cooling system using a small radiator.

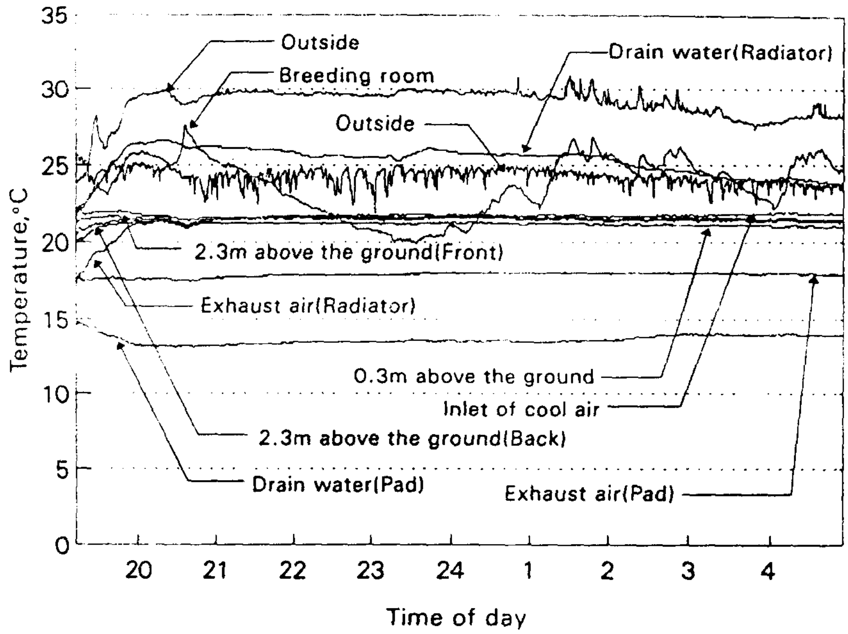

Fig. 3. Temperature distribution in greenhouse during operation of evaporative cooling system.

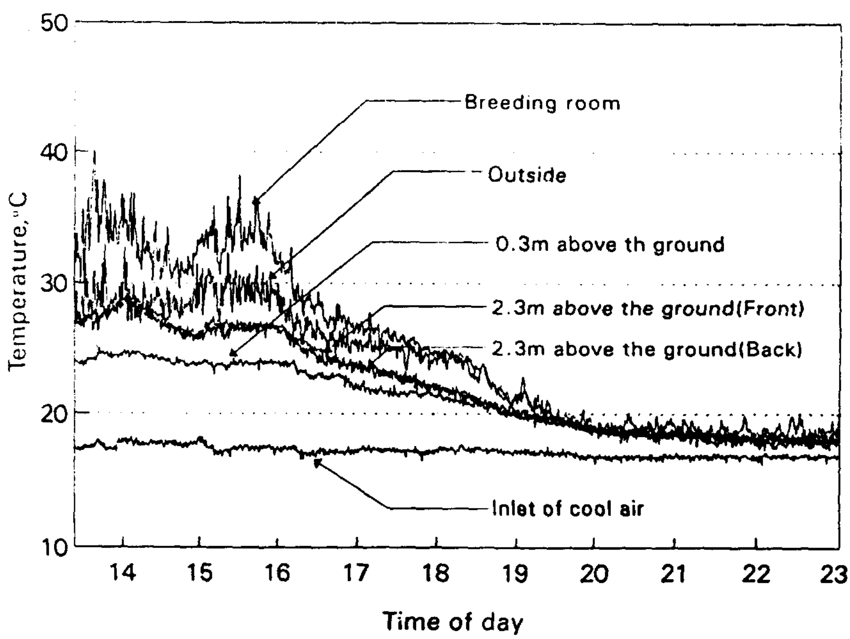

Fig. 4. Temperature distribution in greenhouse during operation of duct cooling system.

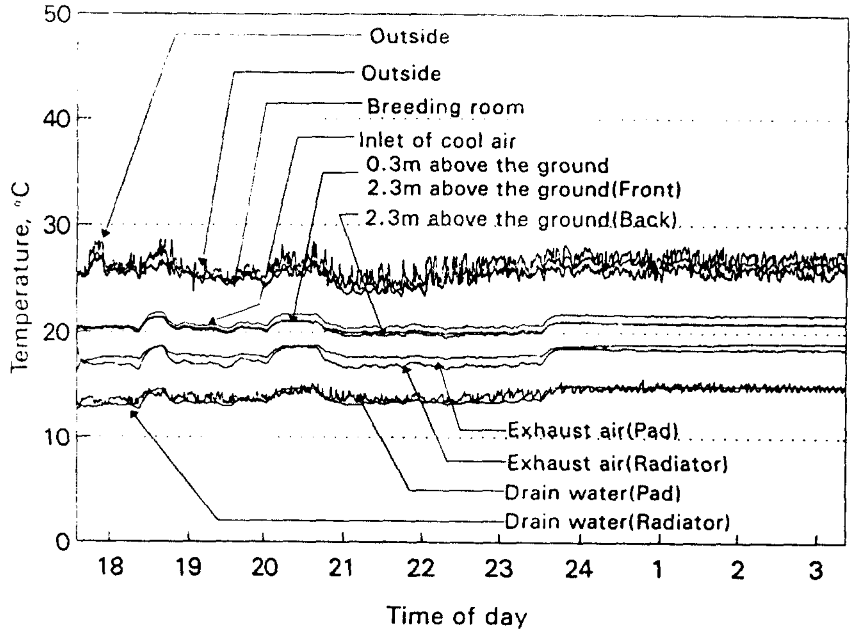

Fig. 5. Temperature distribution in greenhouse during operation of combined cooling system.

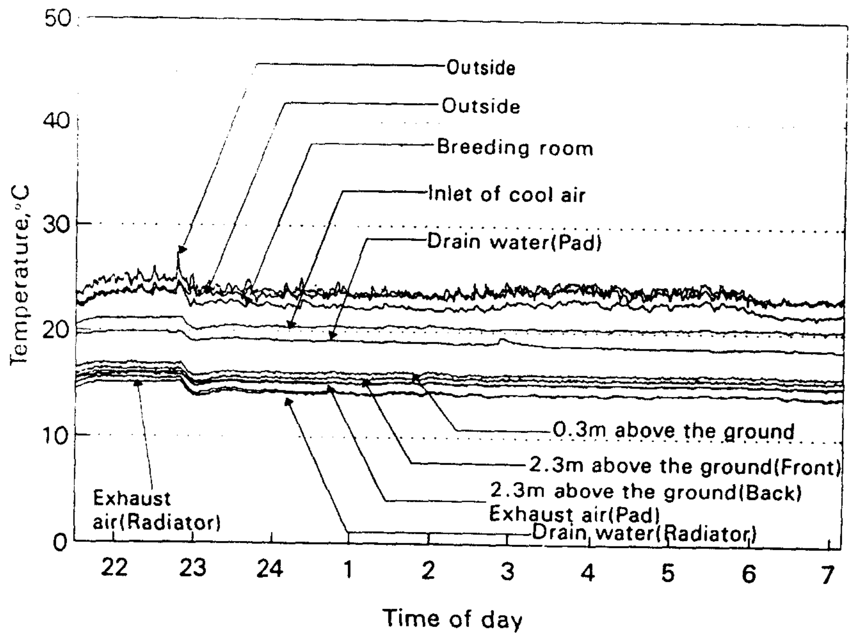

Fig. 6. Temperature distribution in greenhouse during operation of cooling system using a large radiator.