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Comparison of Different Greenhouses Cooling Systems under Arid Climate Condition

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Abstract. Under arid climate condition, greenhouses consume considerable amount of water for cooling purposes. This research was conducted to test three cooling systems: cooling pad system, drip cooling system, and fogging nozzle system. The results indicated that acceptable level of cooling was possible by all systems (5 to 12°C reduction in outside condition). Fogging system performed the best. Water consumption reached 16 to 20 (l/day per square meter of greenhouse's floor area) for cooling pad system. Reduction of 61% in water consumption was possible by using Fogging nozzle system instead of cooling pad system. Drip cooling system achieved 28% reduction in water use compared to cooling pad system.

Introduction

Greenhouse's production is one of the most important agricultural practices that is growing fast especially in places suffering of severe hot weather conditions. The common use of greenhouses includes vegetable production (cucumber, tomato and green pepper, etc.), flower's cultivation and special purpose greenhouses such as those used in nursery. In many countries in the Middle East, as the case in Saudi Arabia, the most important application of greenhouses is for vegetable production. This is the case since huge consumption of fresh vegetables is in demand and weather conditions are not favorable for many agricultural products especially during summer time. Most vegetables cannot be stored for long time and many be damaged easily during transportation. Furthermore, the restriction in import and regulation that exists between countries, increase the difficulties facing supplying local markets with acceptable quality vegetables. Also, the basic needs for any locality must be met under any circumstances. Consequently, many countries are forced to have local production in spite of the harsh environment and lack of natural sources.

Under arid climate condition, greenhouses require cooling system installation during summer months and ventilation during winter time. Solar radiation is the main source of energy inside greenhouses. Solar radiation usually reaches 1000 w/m^2. Small fraction (less than 1%) of the incoming energy is used for photochemical reactions, the rest of solar energy can be consumed by evapotranspiration and heating the internal greenhouses space. Cooling system must be installed in order to suppress the sensible heat fast increase. The most popular system of cooling greenhouses over the world is the evaporative cooling pad system. In addition to the cooling pad system, two experimental cooling systems were studied. Description of the evaporative cooling systems applied in this study for greenhouses use are:

Evaporative cooling pad system

It is shown in Fig. 1-a, pad system consists of cooling pad, water cycle, and water pump. Cooling pad is made of cellulose material with different thickness (mostly 10 cm thick with 2 m height and take the length of on side of a greenhouse). Water is supplied at the top of the pad where it can run down vertically through the pad until it is collected at the bottom tank. Then water is recycled through the pad. Cooling pad provides a large surface area where water can be in contact with air. As the air evaporates the water adiabatically, dry-bulb air temperature decreases while its relative humidity increases. At the best condition, cooled air will reach the wet-bulb temperature with relative humidity reaching 100% (saturation). In addition to the vertical application of cooling pad, other types of application exist such as horizontal application of cooling pad but they are seldom applied. Studies for such applications were conducted including studies to define the evaporative cooling pad system efficiency [1]. Other studies were more concerned with the influence of pad systems on greenhouse's environment [2].

The most important advantage of using cooling pad, that it needs no control system. The process takes place naturally with high cooling efficiency. In spite of this advantage, many problems arise. These problems include high cost of maintenance and replacement, efficiency drops substantially during the use. In arid climate where water resources are limited and costly, the limiting factor of cooling pad application is its high consumption of water. This problem arises because of two reasons, the first, recycled water must be replaced during use since high concentration of salt will accumulate as water evaporates continuously and this may cause many problems for cooling pad and recycling system. Secondly, most cooling pad systems suffer a lot of leakage either because of some blockage inside the pad or because of metal corrosion in the recycling system. Consequently, huge amount of water can be lost because of these problems and the quantity of water lost may reach or exceed the water quantity that evaporates during the cooling process especially with aged systems.

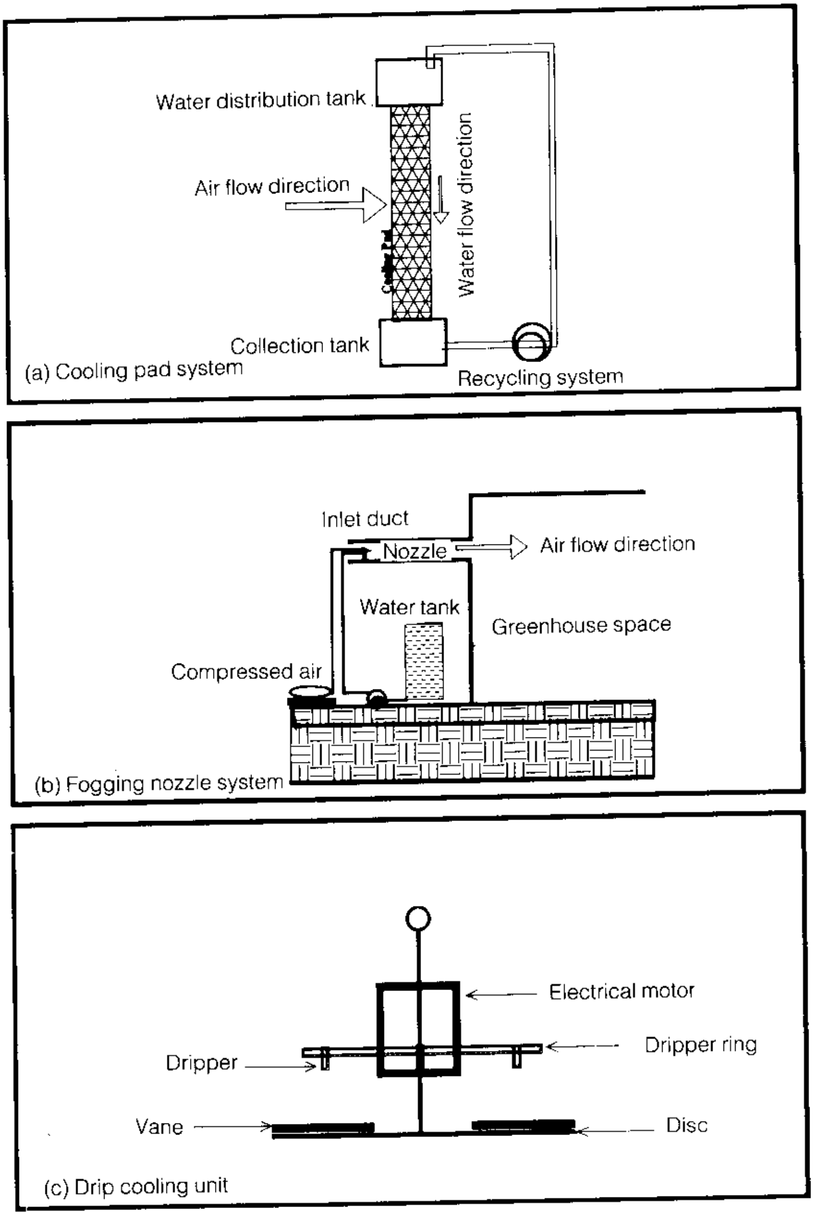

Fig. 1. Schematic diagram for cooling systems.

Duct application fogging system

It is shown in Fig. 1-b, duct application fogging system consists of a duct which can be installed at the air entrance opening with length of 2 to 4 m. At one end, fogging nozzle can be installed and the other end opens at the greenhouse space. Specific amount of water can be injected directly into air stream via fogging nozzle allowing adiabatic evaporation to cool the air and supply greenhouse space with cooled air. Different types of fogging nozzles can be applied. The commonly used are high water pressure nozzles and sonic nozzles where pressurized air can be used to produce fine mist (1 to 50 microns). Control of such systems can be either changed proportional to the water quantity required for saturation of air (this type is very costly and requires a lot of instrumentation and control equipment), or by fixing the water quantity injected at specific flow rate less than the quantity of water required for air saturation. The last method of control is simple and efficient in arid climate since there are no great changes in air condition from day to day. Daily temperature and relative humidity are semi-constant for hot hours during the day. Waker and Cotter [3] evaluated the cooling efficiency for various greenhouses cooling systems and concluded that fogging nozzle system provided the highest cooling efficiency. Wilson and Weaver [4] found that fogging nozzle cooling system was very efficient in cooling broiler houses. Al-Shooshan and Short [5] studied the characteristics of duct application for fogging nozzle systems. Although the fogging systems have a high efficiency in cooling, the high cost associated with installation and the complexity of design and operation may reduce their visibility.

Drip cooling system

Drip cooling system is another method of cooling which applies the cooling directly to the greenhouse space. Droppers as shown in Fig. 1-c are used to introduce water on rotating disc at relatively low speed (1500RPM). As a result of the centrifugal force generated by disc rotation, small drops (50 to 200 microns) are generated and released to greenhouse air. As these drops evaporate, sensible heat was converted to latent heat and the internal air cooled to the desired temperature. The control for this system is similar to that of fogging system which was discussed in (2).

Study Objective

Based on the previous introduction, the main objective of the research was to evaluate the performance of the three methods of greenhouses cooling under arid climate condition. Specifically to determine each system characteristics in cooling and water conservation.

Theoretical Analysis and Procedures

For an evaporative cooling system, the process is fully explained by the Psychrometric relations and best illustrated by the Psychrometric Charts. According to [6] and [7] psychrometric relations can be defined. Then water quantity required to saturate air during an adiabatic process (as illustrated in Fig. 2), can be calculated as follows:

$$\Delta W = W_s^* - W \tag{1}$$

Where W*s and W are saturation humidity ratio at wet-bulb temperature and humidity ratio at specific condition respectively. For continuous air flow rate of m_a, kg_a/sec, the rate of water injection for adiabatic cooling, $\dot{Q}_w$, can be found as follows:

$$\dot{Q}_w = \frac{60000 \Delta W_2^* \,.\, \dot{m}_a}{\rho_w}\ , \text{l/min} \tag{2}$$

Where ρ_w is water density, kg/m^3

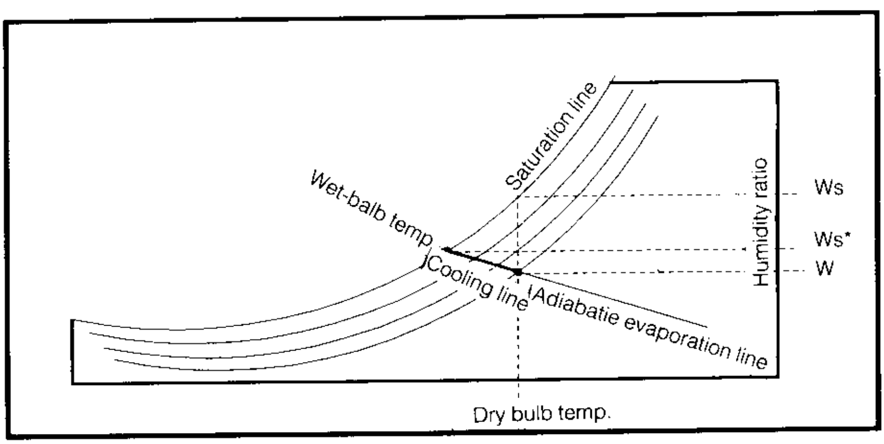

Fig. 2. Schematic diagram of adiabatic cooling process.

Carrying out the previous calculation under real time measurements of the environmental condition yields the exact water quantity required for cooling which can be injected into the ventilation system or into greenhouse space.

Experimental Arrangement

Figure 3 shows the arrangement used in this experiment. The study was carried out at Agriculture College, Research Station at Melida (43.8E Longitude, 26.4 Latitude and 750 m Elevation), King Saud University/Qassim Branch. The experiment included the following:

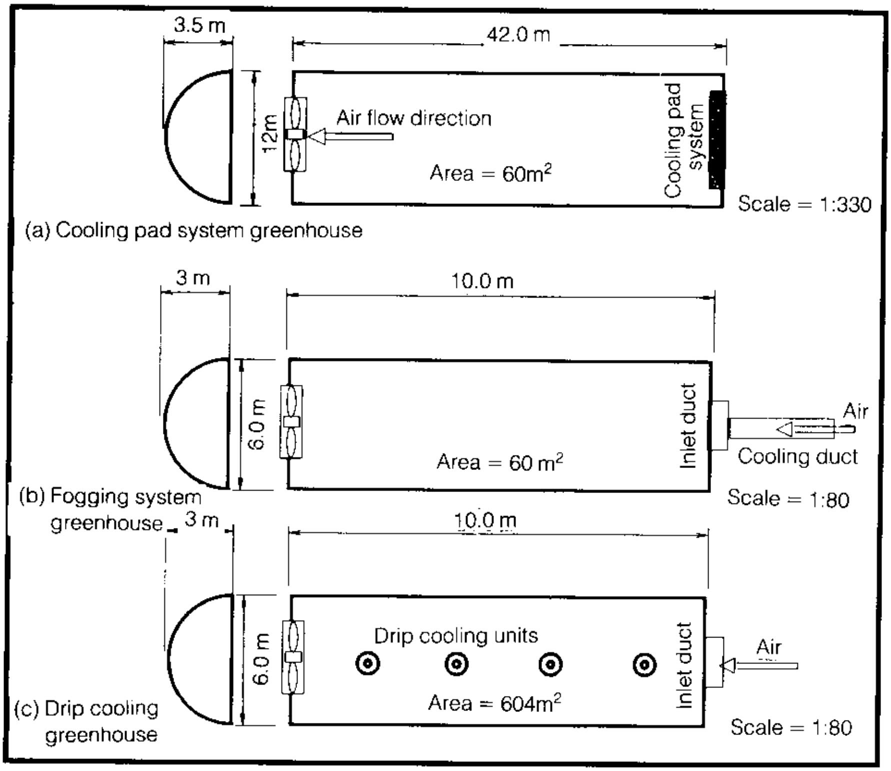

Fig. 3. Schematic diagram of the experimental greenhouses.

Greenhouses description

Three greenhouses were used as shown in Fig. 3. Each greenhouse was designed to fit specific cooling system. Polyethylene film (200 micron) covering material was used for each greenhouse. A commercial greenhouse was used with cooling pad system installed. The other two greenhouses were experimental and each one was fitted with specific cooling system. Fixed air flow rate (commercially available) was used for all greenhouses (2.5 $m^3/min.m^2$ of greenhouse's floor area).

Cooling systems description

Three evaporative cooling systems were used with the following specifications:

1. Evaporative cooling pad system

One commercial greenhouse was fitted with vertical cooling pad system with the following aspects:

a) 2.0 m height, 8 m width, and 10 cm thickness,
b) Air flow velocity through the cross sectional area of the inlet pad = 0.86 m/s,
c) 0.5 HP electric pump was used for recycling water through the pad with flow rate = 0.25 l/s.m^2 of pad area.
d) Cooling pad efficiency was 72%.

2. Fogging nozzle system

A sonic nozzle was used to generate very fine mist. As described by [5], the nozzle was gas-driven acoustic oscillator for atomizing liquids. It was capable of producing very fine mist (1 to 50 microns in diameter). The main features of nozzle's operation were:

a) Nozzle main orifice diametre (air outlet) = 2.0 mm,
b) Air pressure used 606 KPa,
c) Water pressure was very low < 100 KPa,
d) Water flow rate = 0.323 l/min.

3. Drip cooling system

During the experiment, four drip units were used (15 m^2 of greenhouse ground area per drip cooling unit). Each unit consisted of an electrical motor (ELCO MOD N5-131347, 220/240 VAC, 50/60 Hz, 0.18 A, 5/33 W, 1300-1550 RPM), an aluminum disc (250 mm diameter, 3 mm thick), four vanes (110 mm length, 6 mm height), a dropper ring (distributor), and four droppers. During the operation, the following features were used:

a) Disc speed = 1500 RPM
b) Angular velocity = 157.6 rad/sec,
c) Water flow rate per unit = 0.08 l/min,
d) Droplet size = 50 to 100 microns.

Measurements and instrumentation

Data acquisition was possible via a datalogger (Omega-700). An IBM compatible computer was used in conjunction with the datalogger to collect data every 5 minutes.

Measurement of dry-bulb and wet-bulb temperatures was profound by using thermocouples type-T. Sensors were shielded of radiation by using especial vented enclosure. Air conditions were defined for each greenhouse in addition to outside condition.

Air flow rate was measured by Solomat hot wire anemometer and from which volumetric air flow rate was obtained. For RPM measurement, Solomat optical sensor was used.

Water consumption was evaluated for each greenhouse by using separate water supply tank for each greenhouse and water consumption was evaluated by the change in water volume.

Weather data was obtained from nearby weather station. Data included outside dry-bulb temperature, relative humidity, incoming total solar radiation incident on a horizontal surface, wind speed, wind direction and soil average surface temperature.

Results and Discussion

The experiment was executed during June and July 1994. The results are presented here with two considerations. First, the results will be discussed with systems performances and efficiency, the other is the rate of total water consumption for cooling systems.

Cooling systems performance

Arid climate conditions typically have similar summer conditions as those are presented in Fig. 4. Temperature exceeded 40°C and soil temperature peek exceeded ambient temperature. Solar irradiance reached 1100 w/m^2 at noon. Very low relative humidity is presented with minimum below 10%. Wind speed was generally calm with some activity at mid day.

Regarding the illustrated weather conditions, Fig. 5 shows typical summer day performance for the three cooling systems under testing. The operation was continuous for 24 hr in order to present results for full day condition.

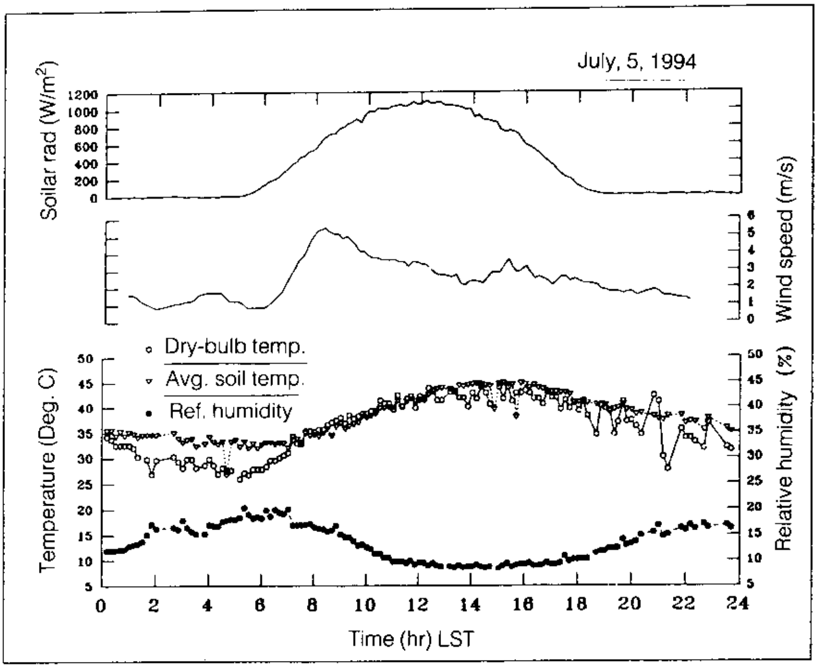

Fig. 4. Typical weather condition during summer at Qassir area.

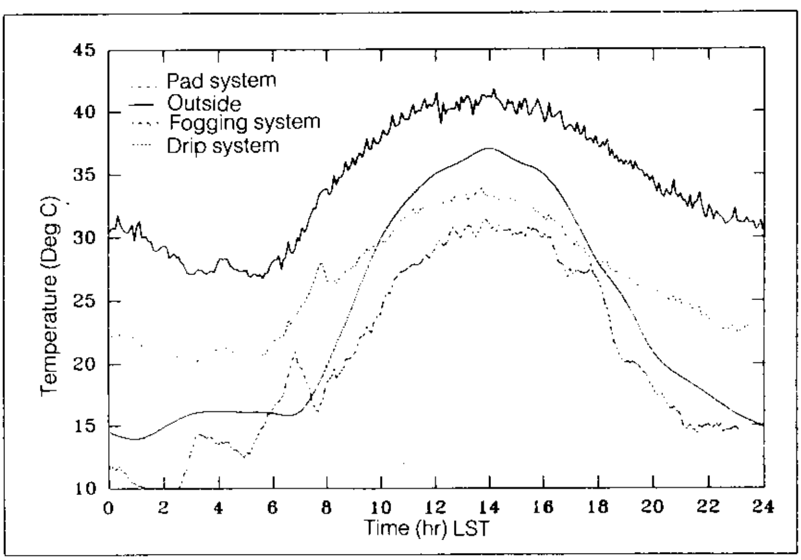

Fig. 5. Typical summer day performance of cooling systems.

In general, cooling systems achieved reasonable level of cooling under all conditions (5 to 12°C) given that there were no plants growing inside the greenhouses. This is very important since the highest cooling load required for greenhouses occurs during transplanting and plants full growth will improve cooling systems performance due to plants energy absorption (may reach 50 to 75% of solar radiation incident on plants leaf [8]). Best cooling was found with fogging nozzle system with reduction in outside temperature of 12°C. At all conditions, this system was superior. This was the case since fogging nozzles were capable of producing very fine mist allowing air stream to carry them with no loss to precipitation on any surface. This resulted in reduction of water loss and provided a very efficient adiabatic evaporation process.

Drip cooling system performed better than cooling pad system during high temperature hours (9 am to 5 pm). The rest of the day, cooling pad was more effective in reducing temperature than that of the drip cooling.

These results can be explained as follows: fogging system was capable of producing very fine mist which can evaporate at any time while they are carried by air movement of 0.5 to 1 m/sec and no condensation problem existed inside the greenhouse space. As a result, excellent level of adiabatic cooling achieved. Cooling pad is usually located at the air entrance opening and minimum temperature can be found directly after air passes through the cooling pad. After this point, air will be heated. As outside temperature increases, pad efficiency decreases since air ability to evaporate more water is higher and cooling pad dimensions are constant. Consequently, the reduction in cooling pad performance compared to drip system can be justified by considering pad system efficiency reduction at high outdoor temperature and the ability of drip cooling system to apply water droplets directly into greenhouse space and allow the adiabatic evaportion to cool the air which increases with the increase in air temperature level. At lower level of temperatures as shown in Fig. 5, cooling pad performed better than that of the drip cooling system. This is the case since more water droplets produced by drip system found their way to ground and their size must be reduced to allow air to carry them until complete evaporation achieved. This case can be modified by increasing disc speed to improve the drip cooling performance.

Total water consumption

Total water use can be defined as water consumed in each system including water evaporated effectively by system and any losses as it is the case under applications, however, most leakage was minimized by careful maintenance. Figure 6 shows daily water consumption by the three cooling systems (Under the conditions illustrated in Fig. 4. The graph presents the daily water consumption as a function of average daily

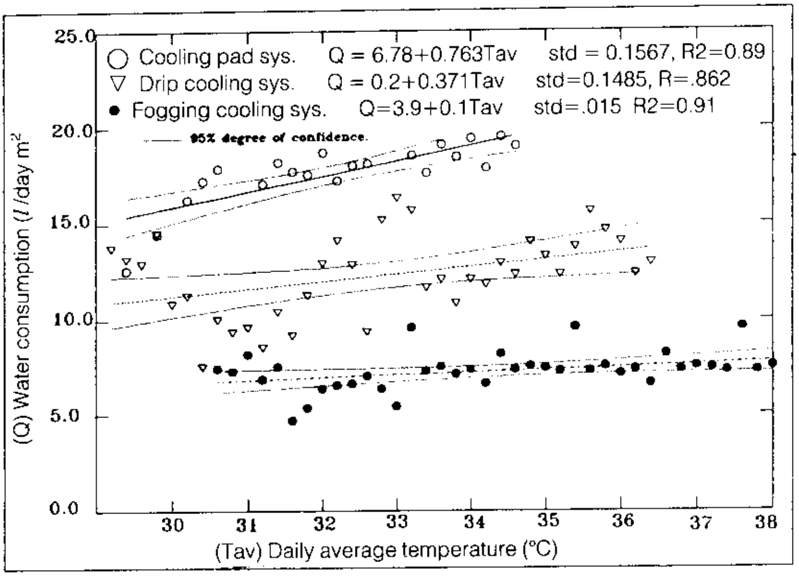

Fig. 6. Daily water consumption by cooling system as a function of average daily temperature .

temperature during June and July 1994. Regression line were added to clarify each system level.

For each system, regression line equation is presented with intercept and slope. Although, the intercept has no physical meaning, slope may represent the deviation of the ideal adiabatic process. Cooling pad system showed highest slope (0.763). This means that, as the temperature increased, more heat was conducted through the pad media increasing the deviation of the ideal adiabatic process. Drip cooling system showed lower slope (0.371) which means that the deviation of the ideal adiabatic process was lower than that of the pad. This was expected since the disc area (which may conduct heat to water) was much smaller than the contact surface area of the pad. The lowest slope (0.1) was shown by the nozzle system. This was expected since nozzle system provided the lowest deviation of the ideal adiabatic process. There was no contact between water droplets and any surface.

Based on Fig. 6, pad system consumed the maximum level of water (16 to 20 l/day) per square meter of greenhouse ground area with average of 18 l/day.m^2). Drip cooling system used moderate level of water (12 to 14 l/day per square meter of greenhouse ground area with average of 13 l/day.m^2). Fogging system consumed the minimum level of water (7.0 l/day per square meter of greenhouse ground area).

It can be concluded that using fogging system as a replacement for cooling pad reduces water use by 61% while using drip cooling in replacement of cooling pad can save up to 28% of greenhouse water consumption. Relative installation cost was evaluated for the three cooling systems for each square meter of greenhouse ground area. Cooling pad cost was SR 78, nozzle system cost was SR 85 and the cost of drip cooling system was SR 75. In spite of the narrow differences in the cost, nozzle system consumed the lowest level of water and achieved the highest cooling level. Consequently, the fogging system is recommended for arid climate conditions.

Conclusion

Based on the previous discussion, fogging nozzle system was found to be the most effective system under arid climate conditions. Applying such system in commercial greenhouses can save up to 61% of water that are being used in cooling pad systems. It can be positioned instead of cooling pad at air entrance duct which will be suitable for large installed projects.

The drip cooling system performed satisfactory results and provided 28% water use reduction compared to cooling pad system. This system can be suitable for small greenhouses since it requires many units to be installed (unit for 15 m^2 of greenhouse ground area) in addition to a network of water and electrical supplies.

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مقارنة نظم التبريد المختلفة للبيوت المحمية تحت ظروف المناطق الحارة والجافة

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ملخص البحث. تستهلك البيوت المحمية تحت ظروف المناطق الحارة والجافة، كمية كبيرة من المياه وذلك لأغراض التبريد. تمت هذه الدراسة لاختبار الطرق المختلفة للتبريد والتي تشمل؛ نظام خلايا التبريد، النظام القرصي والنظام الضبابي. تم الحصول على مستوى مقبول من التبريد بواسطة جميع الأنظمة (٥ إلى ١٢°م تخفيض مقارنة بدرجة الحرارة الخارجية). تم الحصول على أعلى أداء للتبريد بواسطة النظام الضبابي. أعلى استهلاك للمياه كان بواسطة نظام خلايا التبريد وقد بلغ ١٦ إلى ٢٠لتر/ يوم لكل متر مربع من مساحة الصوبة. بلغ التوفير في استخدام المياه ٦١٪ بواسطة استخدام النظام الضبابي كما بلغ التوفير في المياه ٢٨٪ عند استخدام النظام القرصي.