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AIR TEMPERATURE DISTRIBUTION ALONG TWO GREENHOUSES WITH DIFFERENT EVAPORATIVE COOLING MATERIALS

***Gamal M. Abdel-Rahamn**

ABSTRACT

An experimental work was conducted on two identical greenhouses 29 m long, 5.5 m wide and 3.9 m high. Each greenhouse was attached to a horizontal evaporative cooling pad, one with a long wheat straw (WS) and the other with an aspen fiber (AF). The dimensions of each cooling pad were 1.22 m wide, 1.52 m high and 5.5 m long. Two suction fans, each one having a diameter of 0.9 m located on the opposite side of the pad for each greenhouse. The air velocities through the pads were ranged between 1- 3.5 m/s. The main objectives of the present work are to: study the air temperature profile of the cooled air along the greenhouse, the effect of cooling down the greenhouse. Eventually, cooling efficiencies were determined for the two evaporative cooling materials under actual conditions. The air temperature reduction due to the evaporative cooling materials was ranged between 5 - 10 ^{o}C. The obtained results showed that the temperature differences caused by using the two cooling materials were 2 - 4 ^{o}C. The cooling efficiencies were varied between (45 - 75 %) for both materials (WS and AF).

INTRODUCTION

This research work was aimed to evaluate and test different evaporative cooling materials such as long wheat straw (WS) and aspen fibers (AF). In addition cooling efficiencies for the two evaporative materials under specific conditions were considered. However there are some research works executed on the area of evaporative cooling for greenhouse such**;** ***Kittas et al. (2001)*** investigated the temperature and humidity gradients during summer in a commercial greenhouse producing cut roses, provided with a ventilated cooling–pad system and a half–shaded plastic roof. In a steady regime, the cooling process reached 80% efficiency and succeeded in maintaining greenhouse temperatures at 10 ^{o}C lower than outside.

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The physical data were compared with those predicted by an analytical model describing the greenhouse as a heat exchanger. The model helped to understand the particular temperature and humidity profiles of the air flow along the greenhouse. It also suggested that greenhouse roof shading could be avoided in dry climates because the evaporative cooling process was sufficient to prevent overheating. ***Willits (2003)*** modified a model for simulation runs resulted that when evaporative pad cooling is not used, a little advantage is derived from increasing airflow velocities beyond about 0.05 m/s (m^3 m^{-2} s^{-1}). When evaporative pad cooling is used, however, both air and canopy temperatures decline with increasing airflow rates up to 0.13 m^3 m^{-2} s^{-1}, (the highest level considered).
Al-Helal and Short (1999) developed a Computational Fluid Dynamic (CFD) model to study a naturally, forced ventilated greenhouse and greenhouse cooled by evaporative system in arid region. ***Kittas et. al. (2003)*** investigated the greenhouse microclimate, energy savings, and crop transpiration during winter under a glass-covered greenhouse cultivated with a rose region. The results indicate that the plants along with shade could reduce air temperature inside the greenhouse to below the outside air temperature and increase the internal air relative humidity above the outside relative humidity. Four years later greenhouse was provided by an aluminized thermal screen, which saved about 15% of energy. The body of results underlines that the basic effect of the studied screen on crop behavior was the double of the net radiation absorbed by the canopy, with positive consequences on both air and canopy temperature, accordingly on growth, development and sanitary conditions of the rose plants. ***Evans (2004)*** modified an energy balance model based on the field data of evaporative cooling to reduce sunburn (or sun scald) on apples in the Pacific Northwest. The model worked well, although it tended to slightly over predict during times with high adjective heat energy. Results indicated that the model could potentially be used with sensor (e.g., thermocouples) feedback for the initiation, management and control of overture evaporative cooling systems to reduce sunburn and conserve water. ***Arbel et al. (1999)*** employed a control method for the greenhouse system such as a combination of on/off at low pressure (fixed in accordance with the drop size) for condition in which the need for cooling is marginal, and of raising the pressure by means of the pressure regulator for continuous operation when the heat load increases. ***Willits and Gurjer (2004)*** showed that the heat pumps for night cooling increased return on investment to as much as 49.7% due to increased yields. That is an evidence to show the positive effect of cooling even at night time conditions rational usage. ***Boulard et. al (1996)*** modified an approach to predict the microclimate parameters (crop transpiration, the effect heating, natural ventilation and evaporative cooling). They found a good agreement

between the measured and the computed values of air temperature, air humidity and crop transpiration. Agreed with such area of simulation modeling, ***Huhnke et. al. (2004)*** emphasized an indicator often used to measure stressful conditions that is the Temperature-Humidity Index (THI). Using seven years of hourly data from 17 sites in Oklahoma, to provide a tool to determine the effect of employing evaporative cooling to reduce THI levels, a Poisson log-linear regression model was used to predict the average annual hours that an evaporative cooler could reduce THI levels.

MATERIALS AND METHODS

The experiment was conducted on two identical experimental greenhouses, Quenset frame, double polyethylene plastic sheets inflated by a continuous air flow was pumping between these two polyethylene layers, with vertical side wall. Each greenhouse having gross dimensions of 29 m long, 5.5 m wide and 3.9 m high. Each greenhouse was provided by a horizontal evaporative cooling pad located at the west side. The cooling pad dimensions were 5.5 m long (greenhouse width), 1.22 m wide and 1.52 m high. Two suction fans with 0.9 m diameter located on the opposite side of each greenhouse as shown in Fig. (1). The air velocities through the pads were ranged from 1 m/s - 3.5 m/s.

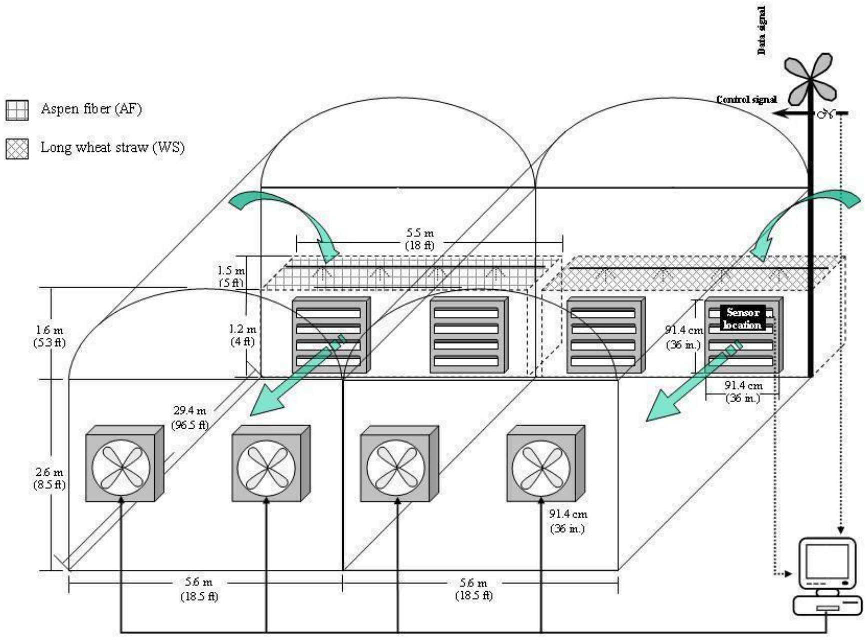

Fig. (1). Evaporative cooling system using two different materials.

Cooling Media design and properties:

In the current research work, two different evaporative cooling materials were used and placed inside the horizontally. One was a commercial evaporative material Aspen Fiber (AF) and the other one is Wheat Straw (WS). These pads's thickness were tested to ensure the same pressure differences before data collection taken place. Both thickness and air velocity through the two evaporative materials were designed to permit the recommended air velocity by the ***ASAE*** standards values. The pads were held on a wire hanger frame to support it within a metal frame. Mean time, WS and AF were put onto the top of a horizontal cooling window (evaporative pad). Each evaporative bad were subjected to six mini-sprinklers hanged at 20 cm high above the horizontal evaporative pad right to the centerline longitudinally as shown in Fig. (1). These mini-sprinklers were works on a timer base as 6 sec/min, with total discharge of 25 L/h.

Evaporative material water holding capacity:

A primarily experiment was carried out to explore the water holding capacity (saturation rate) of the WS compared with AF to estimate the maximum wetness and the spraying interval timing. This pre-test experiment was based on damping two small samples of each evaporative material (0.5 kg each) in a bucket of water for 24 hours to ensure the maximum wetness capacity. It taken out and wait until the end of droplets. Then simply weigh again versus different time to get the maximum water holding capacity.

Mathematical Analysis:

The mathematical analysis of this work was based on the fact of combination heat and mass transfer appears if phase changes occur. This was especially for consideration of evaporation process under forced convection. In order to clarify the concept of forced convection of heat and mass transfer a steady state solution was presumed to justify the forced convection heat and mass transfer. The cold air coming from the evaporative cooler, gradually heats up through the greenhouse due to solar radiation incident. This heat added can be determined as the following (***Kittas et. al., 2003***):-

$$Q_{se} = V\ r_{air}\ C_p\ (T_o - T_i) \quad (1)$$

Where:

Q_{se}	heat released from the incoming air	(kJ/s)
V	incoming air flow rate	(m^3/s)

ρ_{air}	air density	(kg/ m^3)
C_p	specific heat at constant pressure	(kJ/kg. ^oC)
T	air temperature	(^oC)

$$V = C_d \, A \, N_p \, U_{air} \quad (2)$$

Where:

V	air flow rate	(m^3/s)
C_d	discharge coefficient	---
A	cooling opening area	(m^2)
N_p	number of cooling opening	---
U_{air}	incoming cooling air velocity	(m/s)

The sensible and latent heat transfer of the air stream as a function of time from the cooling pad throughout the entire greenhouse length can be computed using the following equations(***Kittas et. al., 2003***):-

$$Q_{se1} = (V/A_g) \, \rho_{air} \, C_{pair} \, (T_m - T_p) \quad (3)$$

This is for the first half of the greenhouse (from the cooling pad " T_p " to the middle of the greenhouse " T_m"), on the other hand from the middle to the suction fan "T_f" can be calculated from the following equation (***Kittas et. al., 2003***):-

$$Q_{se2} = (V/A_g) \, \rho_{air} \, C_{pair} \, (T_f - T_m) \quad (4)$$

Where:

A_g	ground surface area of the greenhouse	(m^2)
ρ_{air}	air density	(kg/m^3)
C_{pair}	specific heat of air	(J/kg.K)

Sensors specification:

The dry-bulb and wet-bulb temperatures were measured using Type-K thermocouple. The incoming 3 air velocity were measured through the cooling pads were measured for both greenhouses using a hot-wire anemometer (LI-COR Inc., Lincoln, NE, USA). All sensors were tested and calibrated for the experiment's circumstances. The computer scanned all sensors every 30 seconds and averages the data every 15 minutes.

RESULTS AND DISCUSSIONS

Evaporative cooling is considered as the most reliable cooling system for greenhouse growers. These due to, running simplicity, maintain and durability even under dusty environment plus temperature uniformly distributing in the greenhouse. The present work was focused on the effective day time periods between 8:00 am and 7:00 pm (8 -19 clock). The meteorological data and engineering or physical parameters such as; ambient air relative humidity, ambient air temperature, incoming cooling air velocity, air pressure drops throughout the pad, pad's material, water holding capacity and water release were taken into consideration. Added to the driven values affecting the cooling process and related to the evaporative pad heat and mass balances. Consequently, the discussion had argued some engineering points such as; air temperature pattern for WS and AF along greenhouse. Also greenhouse air temperature profile against out side air was considered. Sensible heat throughout two evaporative materials WS and AF has been discussed as steady state forced convection.

Air temperature profile throughout the greenhouses:

Air temperature measurements were taken at the cooling pad (T_P), greenhouse middle (T_M) and greenhouse end (T_F) in the rear of the suction fans (at the crop support level) two meters high from the ground. The harmonic fluctuation between the three curves of T_P, T_M and T_F for both AF and WS evidently noticed as shown in Figures (2) and (3). The incoming cooling air temperature was 9 ^oC as a maximum below the outside air temperature (T_O). Meantime, there was fairly correlation relationship between AF and WS with R^2= 0.80. Cooling efficiencies (η_{cool}) as shown in fig. (4) for both WS and AF were fluctuated between 45-75%, which based on the following equation:-

$$\eta_{cool} = \{(T_o - T_p)/(T_o - T_{wet})\}X100 \quad , \% \qquad (5)$$

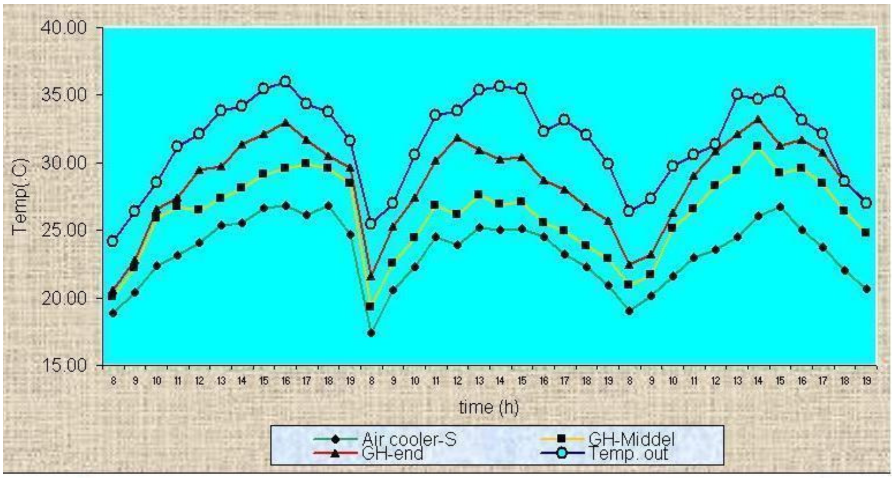

Fig. (2). Air temperature profile along 1st greenhouse with WS (3-5 August)

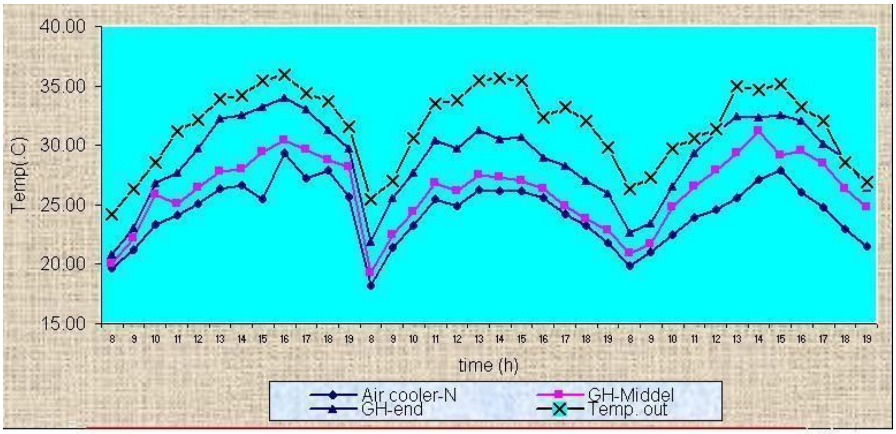

Fig. (3) Air temperature profile along 2nd greenhouse with AF (3-5 August)

Where, T_{wet} is the wet bulb temperature in ^{o}C of outside air. That is mean, both evaporative materials in term of cooling functioning are almost the same. However there were slight differences in engineering factors, as it shown in fig. (4). Nevertheless, the temperature differences between T_P, T_M and T_F as an average for WS were 2-3 ^{o}C lower than AF as shown in figures (2) and (3). There were 5-9 ^{o}C temperature difference between T_P and outside T_O for the two evaporative cooling materials WS and AF as shown in fig. (7).

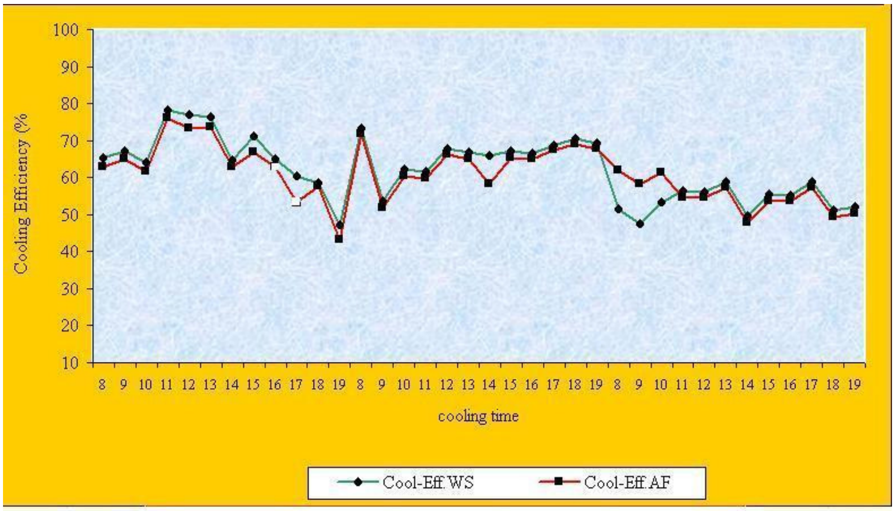

Fig. (4) Cooling efficiency of the two evaporative materials

Relative humidity pattern throughout the greenhouses:

It was noticed that the air relative humidity (RH) for both greenhouses WS and AF were fluctuated between 30-40% at the end of the greenhouse to 80-

90% after the cooling pad, where the greenhouse middle was located in between as it shown in fig. (5) and (6). The outside RH values as an average were about 30 – 35 % at day time up to 60-70 % at night time. While it was varied between 60-90 % during day time for both greenhouses due to the effect of water added by the evaporative cooler as indicated in fig. (8).

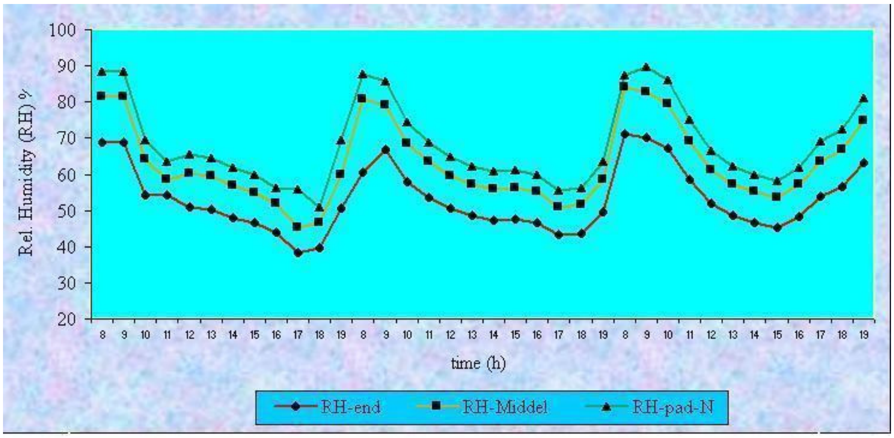

Fig.(5) Relative humidity profile along 1st greenhouse with SW (3-5 August)

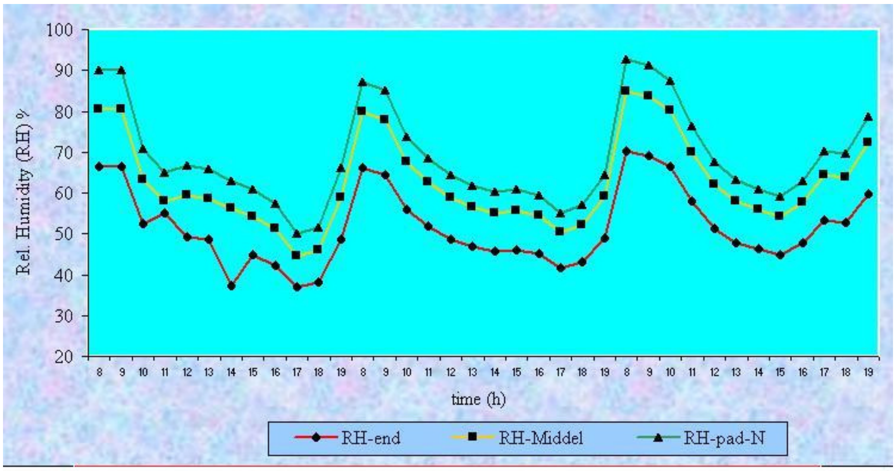

Fig. (6) Relative humidity profile along 2nd greenhouse with AF(3-5 August)

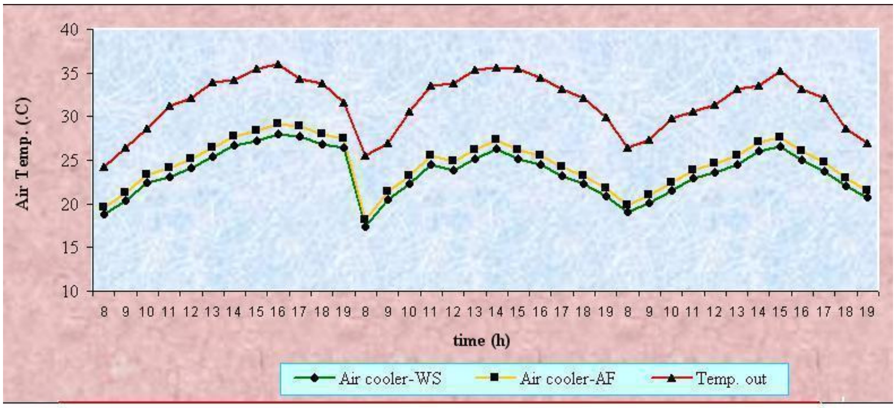

Fig. (7) Air temp. differences between the two evaporative materials and outside

Mass and energy balance:

The present work was explored as steady state solution. Based on the air relative humidity (RH) distribution along the two greenhouses as shown in figures (5) and (6), the air relative humidity decreased from pad side to the end side (fan side). Agreed with the natural air physical properties the RH at the evaporative pad (saturation process) side was higher than the greenhouse middle and end side (fan side). The maximum air temperature depression was recorded at these points as shown in figures (2) and (3). Considering equations (3) and (4) for sensible heat transfer between the evaporative cooling, middle and of the greenhouse as revealed in figures (9) and (10). It was obvious that the rate of sensible heat along the greenhouse for WS was higher than the AF one, it was increased from the middle to the end of the greenhouse 50-400 W/m^2 for the AF greenhouse while it was 100 - 450 W/m^2 for WS greenhouse. Also it was noticed that the second half of the greenhouse (between the middle and suction fan) particularly at noon and around noon time (maximum of solar radiation). This means that the WS as an evaporative cooling material was more efficient to remove sensible heat from the greenhouse. On the other hand, the first section of the greenhouse from evaporative pad to the middle of the greenhouse, the rate of sensible heat values were varied between 25-200 W/m^2 and 50-250 W/m^2 for both AF and WS greenhouse, respectively.

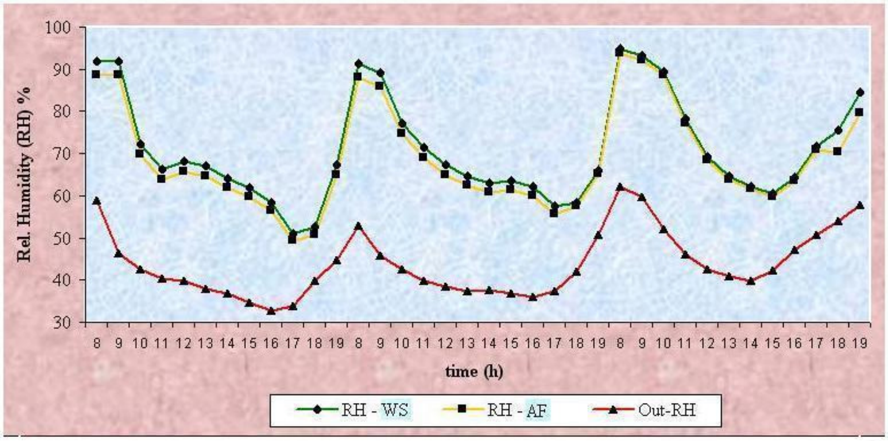

Fig. (8) Relative humidity differences between the two evaporative materials and outside

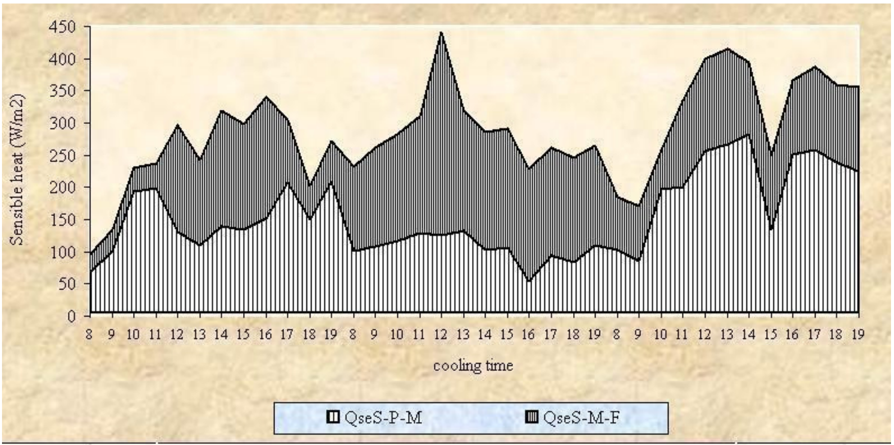

Fig. (9) Sensible heat transfer along the greenhouse for WS

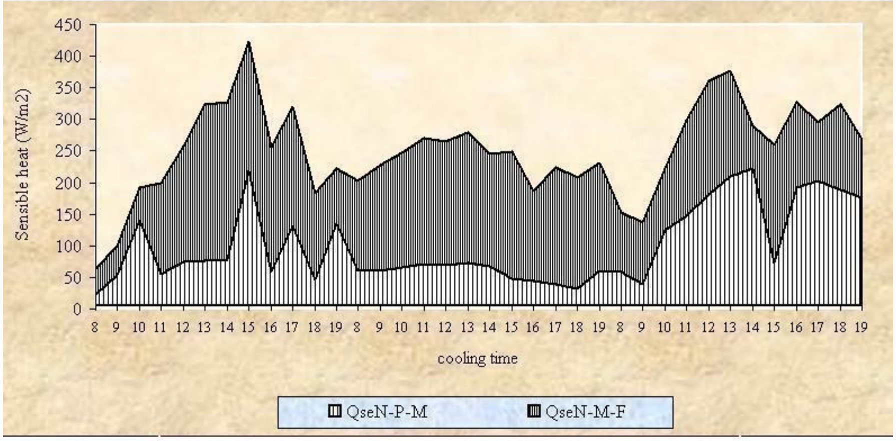

Fig. (10) Sensible heat transfer along the greenhouse for AF

CONCLUSION

Some engineering points such as; air temperature pattern for WS and AF along greenhouse were tested and examined. Also greenhouse air temperature profile against outside air was considered. The incoming cooling air temperature was decreased about 9 ^oC below the outside air temperature (T_O). It was achieved under cooling efficiencies (η_{cool}) for both WS and AF materials of 45-75 % the temperature differences between T_P, T_M and T_F for WS were 2-3 ^oC lower than AF. Also there was 5-9 ^oC temperature differences between T_P and outside T_O for the two evaporative materials WS and AF. The air relative humidity (RH) for both greenhouses (WS and AF) were fluctuated between 30-40% at the end of the greenhouse to 80-90% after the cooling pad, where the greenhouse middle was located in between. The rate of sensible heat along the greenhouse for WS was higher than the AF, it was increased from the pad to the middle of the greenhouse and from the middle to the suction fan as well. This means that the WS as an evaporative cooling material was much more efficient to remove sensible heat from the incoming air to the greenhouse. The rates of sensible heat of greenhouse from evaporative pad to the middle of the greenhouse were varied between 25-200 W/m^2 and 50-250 W/m^2 for both AF and WS greenhouse respectively. Meanwhile, it was from middle to the end of the greenhouse 50-400 W/m^2 for the AF greenhouse while it was 100 - 450 W/m^2 for WS greenhouse.

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الملخّص العربى

توزيع درجةِ حرارة الهواء على طول بيتين محميين مزودين بمواد تَبريد تبخّيرى مختلفة

*** جمال منصور عبد الرحمن**

تم إجراء دراسة تجريبية على بيتين زجاجيين متماثلين بطول ٢٩ م ، وعرض ٥,٥ م ، وارتفاع ٣,٩ م. كُلتا الصوبتين زودت بوسادة تَبريد تبخيري أفقيةِ، حيث قد زودت إحداهما بوسادة من قش القمح (WS) أما الأخرى فقد زودت بوسادة من ألياف نبات الحور(AF). وكانت أبعاد كُلّ من وسادتي التبريد ١,٢٢ م عرض، ١,٥٢ م ارتفاع، وبطول ٥,٥ م . ووضعت فى كل صوبة مروحتى طرد بقطر ٠,٩ م فى الجانب المقابل لوسادة التبريد حيث تراوحت سرعة الهواء خلال الوسائد بين ١ و ٣,٥ م/ث. وتركزت أهدافَ العملِ الحالي فى دراسة توزيع درجات حرارة الهواء المبرد داخل الصوبة ودراسة تأثير التبريد على تخفيض درجات الحرارة داخل الصوبة. أخيرا تم تقدير كفاءة نظام التبريد التبخيرى باستخدام الوسادتين سابقتى الذكر تحت ظروف تشغيل حقيقية. حيث تراوح التخفيض فى درجات حرارة الهواء نتيجة لاستخدام المواد السابقة بين ٥-١٠ م° حيث أظهرت النتائج أن الفروق فى درجات حرارة الهواء نتيجة لاستخدام مادتى الوسائد المختلفتين كانت من ٢-٤ م°. وتراوحت كفاءة عملية التبريد بين ٤٥ – ٧٥ % لكل من الوسادتين قيد الدراسة. وفي أثناء ذلك، أوصت الدراسة بوَجوبُ تُقيّمَ واُختَبارَ طول عمر هذا النوعَ من الوسائد للتَحقق من جودته ومدى صلاحيته للاستخدام.

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