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Effect of Using Pad Manufactured from Agricultural Residues on the Performance of Evaporative Cooling System

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ABSTRACT

The present study was carried out to investigate the performance criteria of rice straw (RS) and palm leaf fibers (PLF) as pad materials of a pad and fan evaporative cooling system. Pad thickness and pad face air velocity were taken into consideration. Reducing heat stress in terms of temperature reduction (T and ΔT), saturation efficiency (SE) of the pad and unit of the evaporative cooler performance (Unit ECP) were the main criteria to judge pad materials.

The results revealed that:

For both pad materials, the highest value of temperature reduction was achieved with 15 cm pad thickness and 0.5 m/s pad face air velocity; while the lowest value occurred with 3 cm pad thickness and 0.5 m/s pad face air velocity. The cooling effect for all rice straw treatments was higher than that for palm leaf fibers. It ranged from 5.67 °C (278.67 K) to 8.66 °C (281.66 K) for all rice straw treatments, while in palm leaf fiber treatments it ranged from 5.01(278.01 K) to 7.50 °C (280.50 K).

The saturation efficiency decreased by increasing pad thickness for all pads made from palm leaf fibers. Two multiple regression equations were developed to describe the relationship between SE and pad face air velocity (V), pad thickness (d), outside air relative humidity (RHo) and outside air dry bulb-temperature.

The highest and lowest mean unit evaporative coolers performance values (Unit ECP) were found for rice straw pad with 15 cm thickness, 1.05 m/s pad face air velocity and 3 cm pad thickness, 0.3 m/s pad face air velocity, respectively.

Evaporative cooling pad material is a method to reduce heat stress in agricultural structures. Rice straw pad material is better than palm leaf fibers from the view point of cooling effect and saturation efficiency in most treatments.

Keywords: Evaporative cooling, Pad materials, Air velocity, Relative humidity, Temperature, Saturation efficiency.

INTRODUCTION

Evaporative cooling is one of the common methods that can be used to reduce heat stress inside agricultural structures. It is based upon the process of heat absorption during the evaporation of water addition to fan and pad specifications to control the temperature within the comfort zone via heating process or cooling process. Many factors affect the evaporative cooling systems such as using pad-fan system as weather conditions, pad material, pad thickness and density and pad face air velocity.

Benham and Wiersma (1974) studied the effect of pad face air velocity on the efficiency of pad-fan cooling

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system, mounted vertically. They used four different pad face air velocities; namely 0.51, 0.76, 1.02 and 1.27 m/s. They found that an effective pad face air velocity would be 1.02 m/s. As pad–face air velocity increases, the thickness of the water film decreases, resulting in increased heat transfer and evaporation rates and a corresponding increase in saturation efficiency .

Timmons et al. (1981) used a pad-fan evaporative cooling system with a cooling efficiency of 84% and a pad face air velocity of 0.69 m/s in two summer broiler trials. First trial was in May where outside conditions were moderate (outside temperature ranged from 26 to 29°C. Second trial was in June where outside conditions were extreme (outside temperature higher than 32°C). They found that mass gains of the cooled birds were 0.30 and 0.14 kg for the two trails, respectively.

Wiersma and Short (1983) reported that saturation efficiency (SE) can be calculated from psychometric charts. It helps in describing the efficiency of coolers but it can not determine the cooling capacity. Therefore, a measurement identified as evaporative cooler performance unit (ECP) is sometimes used to rate the performance of coolers in terms of thermal energy deduced in a specific time per 1° C temperature reduction.

Sharaf (1994) studied the effect of pad thickness on evaporative pad cooling system effectiveness, using four-pad thicknesses; namely 2, 4, 6 and 8 cm. SE increased by increasing pad thickness, but there was a limit pad thickness for a specific pad-face air velocity beyond which the SE decreased.

Alchalabi (1996) compared between two 10 and 20 cm thick types of vertical pad material. He mentioned that the best selection was using pad with depth of 20 cm and 1.5 m/s pad face air velocity. Cooling efficiency was 91% and 65% at 20 and 10 cm pad thicknesses, respectively.

Uğurlu and Kara (2000) used pad-fan evaporative cooling system in battery cage house. The pads reduced air temperature by 4.2 to 16.2°C relative to the outside daily maximum temperature. The average reduction in air temperature was 10.6 °C. The average evaporative cooling efficiency of the pads was 87.5%. Interior temperatures in the cages decreased by 5.4 to 6.4 °C when external temperatures were 30 °C or higher.

Abdel-Rahman (2000) evaluated and examined two evaporative cooling materials. These materials were aspen fibers and long wheat straw. He found that both evaporative materials had almost the same cooling performance with an average value of 22%. The maximum and minimum cooling performance values for both evaporative materials were 35% and 15%, respectively.

El-Soaly (2002) compared two different buildings, the first building had an evaporative cooling system using palm fibers pad, while the second one depended on natural ventilation. He found that the mean reduction of temperature was 7 °C and 2.6 °C on the first and fifth of July for the first building and the second building, respectively. Relative humidity in the cooled house was higher than that for the natural house by 13.4% as a mean value.

Meanwhile, Liao and Chiu (2002) found that pad face air velocities greater than 1.75 m/s tended to pull free water into the air stream because air pressure always increases at high velocity.

The commercial pads are usually complicated to manufacture and they are costly and not readily available. More recently, new cellulose paper designs have been developed to make evaporative cooling more efficient. Therefore, there is a paramount need to evaluate the use of locally available materials (field residues) as pad media that can be constructed as a hand-made system. Agricultural residues such as rice straw and palm leaf fibers may be considered among the local materials suitable for this purpose. Benefiting from these agricultural residues is not only through their use as evaporative cooling pad materials, but this also plays an important role in environment conservation. So, the main objective of the present study was to construct an evaporative cooling system belonging to pad and fan systems using rice straw and palm leaf fibers as pad materials to reduce heat stress in agricultural structures. The specific objectives can be summarized as follows: to investigate the feasibility of using rice straw and palm leaf fibers as pad materials of an evaporative cooling system, determine their performance criteria and study the effect of pad material, pad thickness and pad face air velocity on the performance of this evaporative cooling system.

MATERIALS AND METHODS

Experiments were conducted at Denosher village – El-Mehalla El-Kobra- Gharbia Governorate in Egypt. Data were collected from 23 June to 16 July during summer 2004. Experiments were carried out to investigate the potential of using agricultural residues as pad materials in an evaporative cooling system.

Four pad thicknesses of 3, 6, 10 and 15 cm, and pad–face air velocities of 0.3, 0.5 and 1.05 m/s were considered in the study. Performance criteria were determined and used to judge the efficiency of evaporative cooling system in reducing heat stress that can occur inside some agricultural structures as weather conditions, pad material, pad thickness and pad face air velocity.

Experimental Units

Two rooms (experimental units) were constructed. Each one(having dimensions of 5.70 m long, 4.20 m wide and 2.75 m high) was prepared in such a way to represent an agricultural structure to be cooled (Figure1). Longitudinal axis of the structure was oriented to East-West direction. Two suction fans (single speed, directly driven, 50 cm diameter and 2 m^3/s calibrated discharge) were installed on the leeward sides of the two rooms. The corresponding two pads were installed on the opposite sides of the two rooms toward the prevailing winds. The dry and wet-bulb temperatures inside the structure were measured at eighteen different points; nine of them at a height of 0.25 m from the floor (lower level) and the reminder nine at a height of 1.92 m from the floor (upper level) as illustrated in (Figure 2). Each experimental unit was equipped with one type of the evaporative cooling pads, so that the two different pads can be operated at the same time.

Pad Construction

Rice straw (RS) and palm leaf fibers (PLF) were investigated as pad materials. Two vertical pads (2.92 x 1.12 m) were fabricated manually by filling the pad material (RS or PLF) in a wire net at a specific pad thickness to provide a constant pad density of about 32 kg/m^3. For instance, for (d) cm pad thickness, the total pad volume is calculated. The required density of the pad material remained at a constant value of 32 kg/m^3 and then the required mass was determined as follows:

Required pad mass =

Total pad volume * pad density=

2.92 * 1.12 * (d/100) * 32 (kg) ……..(1)

where :d = pad thickness (cm).

The resultant pad mass was uniformly distributed within the wire net to construct the pad having the specific thickness (d) cm. The prepared pad was constructed and fixed in a steel frame (steel angle 3 * 3 * 2 mm) equipped with steel screen and having the capability of matching with the pad thickness by means of screw bolts .

A water distribution system consisting of a water tank, a water control valve and a perforated water pipe was used to uniformly distribute water over the pad. The water tank is filled by a connection with a domestic tap. Water passed from the tank through a water control valve to the perforated pipe and fell upon the pad via the corrugated and perforated steel sheet. The last assured that the water can reach the whole pad thickness. Pad was continuously kept wetted by adjusting the water flow rate at a fixed value of about 0.0984 m^3/h by means of the water control valve. Excessive water was received in a gutter located below the pad and drained out. Main components of the water distribution system are shown in Figure (3).

MEASUREMENTS

Temperature and Relative Humidity

Ordinary thermometers (with a range of -20 to 50° C) were used to determine air temperature and air relative humidity at 36 different points. Eighteen thermometers were used to measure dry and wet-bulb temperatures inside each experimental structure at different locations as illustrated in Figure (2). Two thermometers were placed outside the structures for measuring the outside dry and wet-bulb temperatures which were used to determine the air relative humidity. A digital hygrometer (model TFA) was also placed outdoor for directly determining outside air relative humidity.

Pad Face Air Velocity

A digital fan anemometer (model TFA) was employed to measure pad face air velocity and to calibrate the axial fan installed on the southern wall as a part of the evaporative cooling system. It had the range of 0.20 to 30 m/s with the precision of 0.02 m/s.

Cooling Potential (Cooling Effect)

Cooling potential was expressed as the air temperature reduction (ΔT). The temperature reduction of the air when passing through the evaporative cooling pad was calculated as follows (Wang, 1993):

$$\Delta T = T_{in} - T_{out} \qquad (2)$$

where:

ΔT = temperature reduction, i.e. cooling potential (°C).

T_{in} = dry bulb temperature of air entering the cooling system (°C).

T_{out} = dry bulb temperature of air exiting the cooling system (°C).

Air Relative Humidity (RH)

Dry and wet bulb temperatures were measured and used as inputs to PLUS computer program (Albright, 1990) to obtain the air relative humidity data depending on psychometric chart relations. Regarding the outside air relative humidity, it was recorded directly from the digital hygrometer.

Ratio of Temperature Reduction to Airflow Rate ($\Delta T/Q$)

To judge the evaporative cooling system in reducing dry bulb temperature under different air flow rates and to permit comparisons on the base of air flow rate, ratio of temperature reduction to air flow rate was the new suggested criterion or parameter to cope with the variation in airflow rate among all treatments. It was computed using the following formula:

$$\Delta T/Q = (T_{in} - T_{out}) / Q \qquad \ldots\ldots\ \ldots\ldots\ldots\ldots(3)$$

where:

$\Delta T/Q$ = ratio of temperature reduction to airflow rate ($°C.s/m^3$);

ΔT = $T_{in} - T_{out}$ (°C); Q = airflow rate (m^3/s).

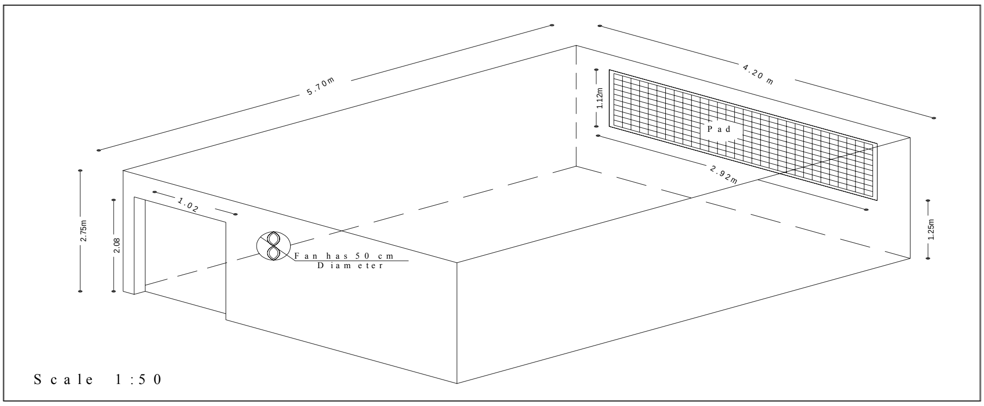

Figure (1): A schematic diagram of an experimental room representing an agricultural structure to be cooled.

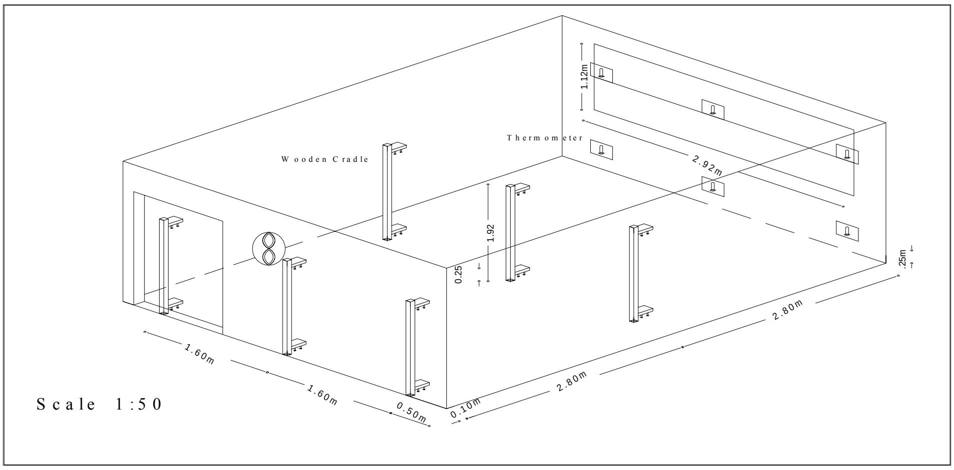

Figure (2): Diagram of thermometers arrangement inside the room.

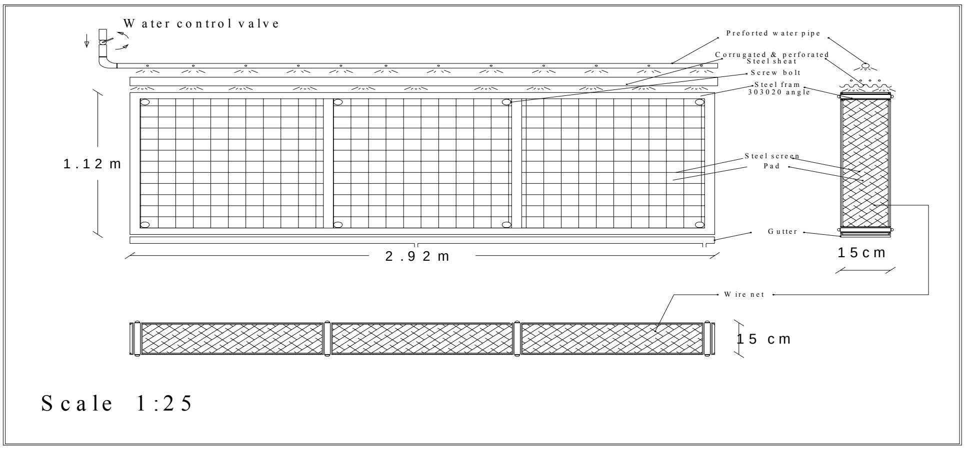

Figure (3): A schematic diagram of pad and water distribution system.

Saturation Efficiency (SE)

Saturation efficiency (SE) as an important criterion to judge the evaporative cooling system was determined for each treatment throughout the operating daytime period. It can be calculated as a temperature difference ratio using the following formula (ASHRAE, 1992; Wang, 1993):

$$SE = (T_{in} - T_{out}) / (T_{in} - T_{W\,b}) \quad \ldots\ldots(4)$$

where:

SE = saturation efficiency (decimal).

$T_{W\,b}$ = wet bulb temperature (°C).

The obtained data collected for SE were analyzed by multiple regression equations and ANOVA.

Unit Evaporative Cooler Performance (Unit ECP)

As sensible heat (Wiersma, 1969):

$$ECP = (Q/V_s) * \Delta T * Cp_{air} \quad \ldots\ldots(5)$$

where:

Q = airflow rate (m^3/s).

V_s = specific volume of air (m^3/kg).

ΔT = temperature reduction (i.e. cooling potential)

= $T_{in} - T_{out}$ (°C).

Cp_{air} = specific heat of air (1.005 kJ/kg.°C).

For measuring the absolute performance under base conditions that permit comparison, an improved measuring unit; namely Unit ECP, was used, (Wiersma, 1969):

$$\text{Unit ECP} = ECP / WBD_C \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots(6)$$

where:

Unit ECP = unit evaporative cooler performance (kJ/°C).

WBD_C = wet bulb depression of cooled air (°C)

= $T_{in} - T_{out}$(°C).

Substituting equation (5) in equation (6), then

$$\text{Unit ECP} = (Q/V_s) * (T_{in} - T_{out}) * Cp_{air} / (T_{in} - T_{W\,b})$$

And by substituting equation (4) in equation (7), then:

$$\text{Unit ECP} = (Q/V_s) * SE * Cp_{air} \quad \ldots\ldots\ldots(7)$$

RESULTS AND DISCUSSION

Temperature (T) and Relative Humidity of Air (RH)

Figures (4) and (5) show the relationship between outside temperature and cooled air temperature as affected by outside air relative humidity for all investigated treatments of RS and PLF pad materials, respectively. The same point symbol represents the cooled air temperature recorded at a specific outside temperature at the same specific range of outside air relative humidity. Each line is the regression line for points recorded at the same specific outside air relative humidity as well. In general, cooling effectiveness achieved by both pad materials was very clear. In addition, increasing outside air relative humidity at the same outside temperature increased cooled air temperature (i.e. depressed the desired cooling process) cooling depression, in terms of increasing cooled air temperature, the rate increases when the outside air relative humidity tends to the higher range as well. This was noticed in increasing the slope of the regression lines by increasing the range of outside air relative humidity. It should be mentioned that all recorded cooled air temperatures lied below no cooling line.

Extrapolations beyond the range of outside temperature corresponding to a range of outside air relative humidity is not recommended.

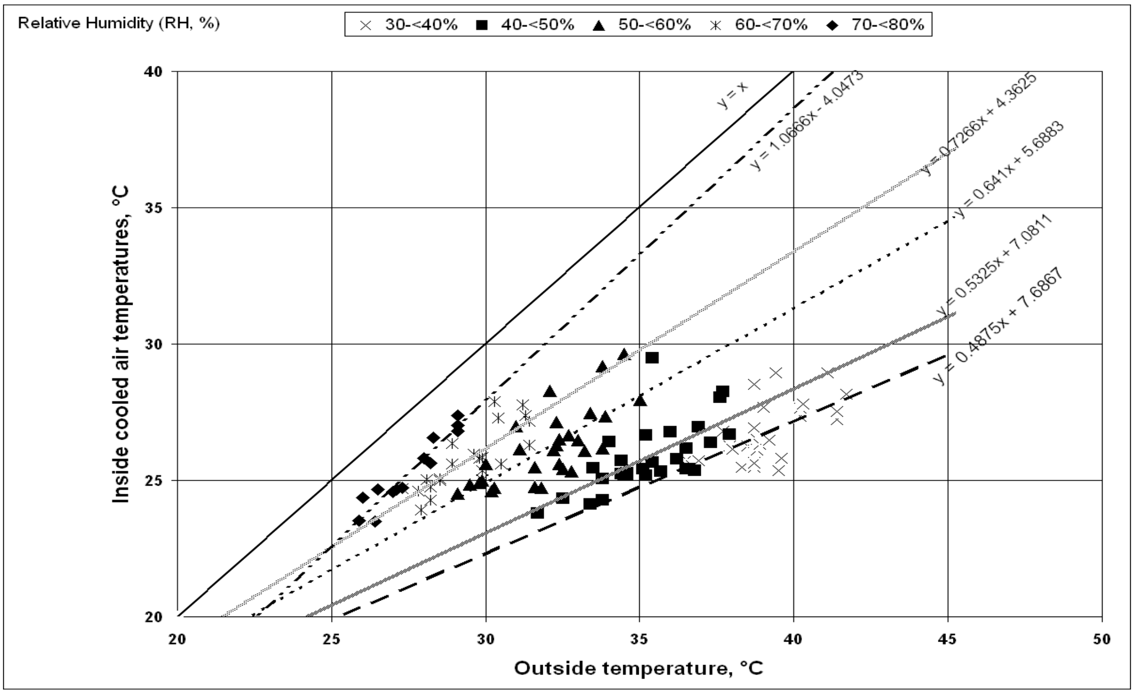

Figure (4): Relationship between outside and cooled air temperatures as affected by outside air relative humidity for all investigated treatments of rice straw pad materials .

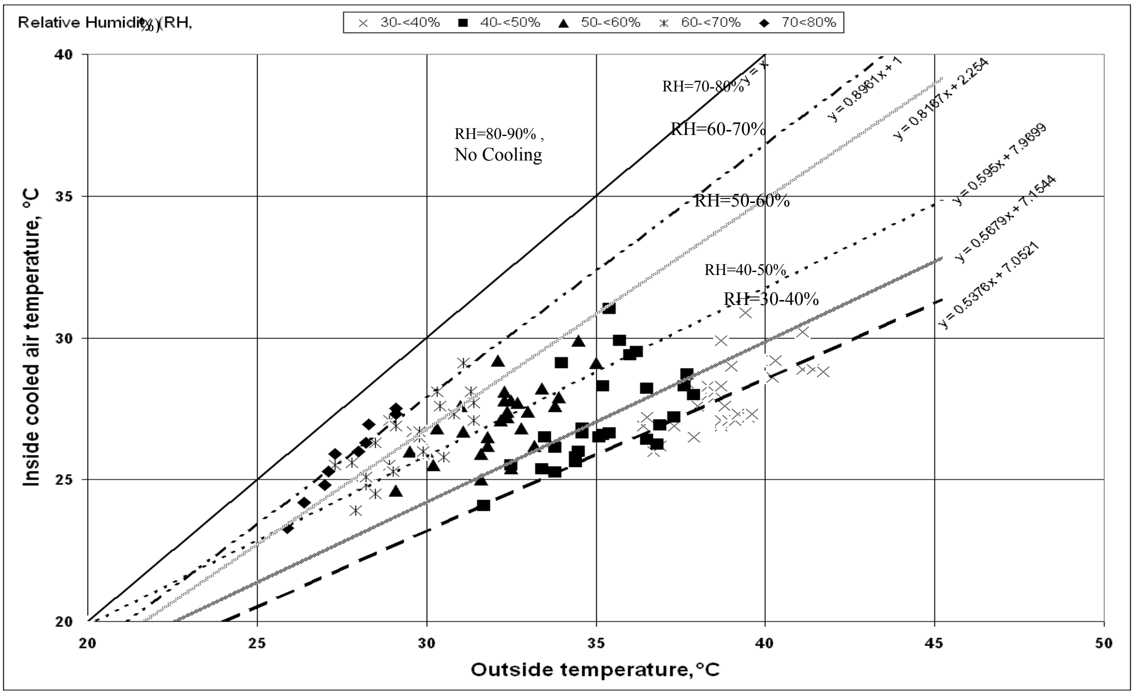

Figure (5): Relationship between outside and cooled air temperatures as affected by outside air relative humidity for all investigated treatments of leaf palm fibers' pad materials.

Cooling Potential (Cooling Effect)

Cooling potential observed (Table1) indicated a temperature reduction; i.e. cooling effect (ΔT) average and standard deviation (SD) during the operating period for both pad materials at various pad thicknesses and pad face air velocities. Mean values of upper and lower levels proved that RS was better than PLF in reducing air temperature. Mean values of about 8.66 °C and 7.50 °C were found as a maximum air temperature reduction for RS and PLF, respectively. For RS pad material with 3 cm pad thickness, the maximum mean of ΔT was found to be 8.27 °C and occurred at 0.3 m/s pad face air velocity. Increasing pad face air velocity to 0.5 and 1.05 m/s resulted in mean values of upper and lower levels of about 5.76 and 6.93 °C, respectively. At 6 and 10 cm pad thicknesses, changing pad face air velocity from 0.3 to 1.05 m/s had a small effect on ΔT values of upper and lower levels. The same trend was found for PLF pad material. For RS pad material, and based on the mean values of ΔT for upper and lower levels, it was observed that the higher the thickness was, the higher was the pad face air velocity required to get more temperature reduction. It seemed that there was no fixed trend between pad thickness and pad face air velocity. This is due to the contradiction effect of the higher kinetic energy corresponding to the highest air velocity and the contact time between air and water films on the pad fibers. Increasing pad face air velocity passing through the pad media breaks the films between pad fibers and consequently increases the water vapor transfer to the air stream which in turn increases temperature reduction. On the other hand, increasing pad face air velocity decreases the contact time between air and water films. This provided a good chance for air to carry on more water depending on its thermal specifications. Another cause of difficulty for distinguishing pad thicknesses and pad face air velocity to point out unique recommended values was the variation in outside temperature and relative humidity of air for each treatment as well as the variation in airflow rate.

Ratio of Temperature Reduction to Airflow Rate (ΔT/Q)

Because of the variation in airflow rate applied in each treatment, it was considered to determine the temperature reduction per unit of airflow rate. This procedure may provide a better criterion for comparison between the studied factors. The ratio of temperature reduction to airflow rate (ΔT/Q) throughout the operating period for both pad materials at different pad thicknesses and pad face air velocities are illustrated in Table (2). Each value of (ΔT/Q) in Table (2) represents an average of 18 values corresponding to the 18 measuring points inside the experimental structure. In general, the unity of airflow rate has more capability to reduce temperature in case of RS pad material. The exception was found at 6 cm pad thickness with 0.5 m/s and 1.05 m/s pad face air velocities and at 15 cm pad thickness with 0.3 m/s pad face air velocity, since (ΔT/Q) was higher for PLF than that for RS. As mentioned before, the variation in airflow resistance due to the variation in pad thickness plays an important role in this phenomenon.

Table (1): Average air temperature reduction (ΔT) and standard deviation (SD) during the operating period for both pad materials at various pad thicknesses and pad face air velocities.

Pad thickness (cm)	Pad face air velocity (m/s)	Outside temp., °C	SD, °C	*R S*						*P L F*					
				Upper Level (ΔT, °C)	S D	Lower Level (ΔT, °C)	S D	Mean		Upper Level (ΔT, °C)	S D	Lower Level (ΔT, °C)	S D	Mean	
								ΔT	SD					ΔT	SD
3	0.3	33.51	4.21	7.73	3.82	8.80	3.91	8.27	3.87	5.90	3.34	8.03	3.70	6.96	3.52
	0.5	30.93	2.75	5.18	1.84	6.16	1.89	5.67	1.86	4.09	1.56	5.93	2.04	5.01	1.80
	1.05	32.57	3.73	6.36	3.29	7.50	3.21	6.93	3.25	4.83	2.69	6.69	3.05	5.76	2.87
6	0.3	35.21	4.81	6.69	4.00	8.59	4.23	7.64	4.11	6.03	3.72	8.05	4.18	7.04	3.95
	0.5	33.46	4.27	7.15	4.11	8.32	4.17	7.73	4.14	6.04	3.54	8.15	4.00	7.09	3.77
	1.05	32.98	3.79	6.32	3.51	7.61	3.52	6.96	3.51	6.00	3.25	7.42	3.50	5.67	3.37
10	0.3	33.50	4.40	7.42	4.03	7.34	4.15	7.38	4.09	6.01	3.81	7.37	3.93	6.69	3.87
	0.5	34.41	4.56	7.31	3.95	7.59	4.01	7.45	3.98	5.65	3.55	7.34	4.10	6.50	3.82
	1.05	33.25	4.30	6.84	3.85	8.15	4.14	7.49	4.00	5.24	2.68	7.39	3.93	6.32	3.07
15	0.3	33.19	4.36	7.36	3.36	8.25	3.63	7.80	3.50	6.10	3.53	7.43	4.02	6.54	3.78
	0.5	37.29	5.83	7.96	4.92	9.36	5.53	8.66	5.23	6.71	4.53	8.28	5.23	7.50	4.88
	1.05	34.58	4.82	7.45	4.20	8.45	4.36	7.95	4.28	5.84	3.89	7.32	4.20	6.58	4.05

Table (2): Average ratio of temperature reduction to air flow rate(ΔT/Q) during the operating period for pad materials, pad thicknesses and pad face air velocities.

Pad thickness (cm)	Pad face air velocity (m/s)	(ΔT/Q) °C.s/m^3	
		RS	PLF
3	0.3	17.97	5.90
	0.5	5.25	3.80
	1.05	4.71	4.03
6	0.3	10.47	5.72
	0.5	4.80	4.93
	1.05	4.14	4.56
10	0.3	8.02	7.04
	0.5	4.81	4.42
	1.05	6.09	4.05
15	0.3	5.13	6.19
	0.5	5.09	4.20
	1.05	4.52	4.09

Saturation Efficiency (SE)

Average saturation efficiency during the operating period for both pad materials with various pad thicknesses and pad face air velocities are shown in Table (3). The higher values of SE for RS pad material was 76.51% with 3 cm pad thickness and 0.3 m/s pad face air velocity when outside air temperature was 33.51 °C and outside air relative humidity was 49.77% as shown in Table (3). The higher value of SE for PLF pad materials was 68.70% with 6 cm pad thickness and 1.05 m/s pad air velocity when outside air temperature was 32.98 °C and outside air relative humidity was 53.65% as shown in Table (3). Also, the change of airflow rate has an effect on this phenomenon.

Figures (6) and (7) illustrate saturation efficiency as affected by pad thickness at different ranges of relative humidity of the outside air for rice straw and palm leaf pad materials, respectively. Saturation efficiency decreased by increasing pad thickness for all treatments of rice straw pad material. However, some exceptions were found at 0.3 m/s pad face air velocity when the outside air relative humidity ranged from 70 to 80%, at 0.5 m/s pad face air velocity when the outside air relative humidity ranged from 40 to 50 % and at 1.05 m/s pad face air velocity when the outside air relative humidity ranged from 60 to 70% and from 70 to 80%. It should be mentioned that the corresponding outside dry-bulb temperature for each value of SE was not the same at the different pad thicknesses and the different ranges of outside air relative humidity. Such experimental conditions may have an effect that leads to the above-mentioned exceptions. However, regression analysis showed that outside dry-bulb temperature had no significant effect on SE as shown in Figure (6).

Saturation efficiency decreased by increasing pad thickness for all treatments of palm leaf fibers pad material as shown in Figure (7). The following two multiple regression equations were developed to describe the relationship between SE and pad face air velocity (V), pad thickness (d), outside air relative humidity (RHo) and outside air dry bulb-temperature:

$$SE_{RS} = 100.6355 + 5.845534*V + (-0.946378*d) + (-0.730879*RHo) + 0.288985\ T_{db} \quad [R^2=0.75]\ldots(8)$$

$$SE_{PLF}\ 116.0946 + 1.97201*V + (-0.99238*d) + (-0.881110*RHo)+(-0.99854T_{db}) \quad [R^2=0.69]\ldots(9)$$

where:

SE_{RS} = saturation efficiency for rice straw pad material.

SE_{PLF} = saturation efficiency for palm leaf fibers' pad material.

Table (3): The average saturation efficiency (SE) for both materials at various pad thicknesses and pad face air velocities under different conditions.

Pad thickness (cm)	Pad face air velocity (m/s)	Outside conditions		Saturation efficiency (SE), (%)	
		Temperature (° C)	Relative humidity (%)	RS	PLF
3	0.3	33.51	49.77	76.51	65.40
	0.5	30.93	56.70	63.34	63.40
	1.05	32.57	53.35	71.42	59.38
6	0.3	35.21	48.48	65.40	60.25
	0.5	33.46	50.75	71.73	65.60
	1.05	32.98	53.65	71.79	68.77

		Outside conditions		**Saturation efficiency (SE), (%)**	
Pad thickness (cm)	**Pad face air velocity (m/s)**	**Temperature (° C)**	**Relative humidity (%)**	**RS**	**PLF**
10	0.3	33.50	50.77	68.21	60.98
	0.5	34.41	52.25	70.47	60.06
	1.05	33.25	50.62	69.57	58.72
15	0.3	33.19	46.65	60.24	56.58
	0.5	37.29	46.68	64.14	56.32
	1.05	34.58	48.76	69.30	55.49

Regression analysis showed that the outside air relative humidity had the highest effect on SE followed by pad thickness, pad face air velocity and outside air dry-bulb temperature as illustrated in Tables (4 and 5).

Table (4): ANOVA of multiple regression for rice straw as pad material.

Source	SS	df	MS	F	P
Total	21435.840299	131			
Regression	16081.990809	4	4020.4977023	95.371229455	***.0000
V	169.8417549	1	169.8417549	4.0288586581	*.0469
d	874.72185523	1	874.72185523	20.749495446	***.0000
RHo	15017.749018	1	15017.749018	356.23977268	***.0000
T_{db}	19.67818069	1	19.67818069	0.4667910355	.4957 ns
Error	5353.8494901	127	42.156295198		

Table (5): ANOVA of multiple regression for palm leaf fibers as pad material.

Source	SS	df	MS	F	P
Total	24448.606166	131			
Regression	17053.891236	4	4263.4728089	73.222707277	***.0000
V	2.2123727524	1	2.2123727524	0.0379962368	.8458 ns
d	1053.3860008	1	1053.3860008	18.091302147	***.0000
RHo	15995.943411	1	15995.943411	274.72118025	***.0000
T_{db}	2.3494508318	1	2.3494508318	0.0403504744	.8411ns
Error	7394.7149302	127	58.226101813		

*** high significance, * low significance ($P<0.005$).

Unit Evaporative Cooler Performance (Unit ECP)

Despite of the higher value of SE for RS apparent when using 3 cm pad thickness and 0.3m/s pad face air velocity, this value of SE corresponding to the lowest Unit ECP increased by increasing thickness from ECP at the same specifications as shown in Tables (3) and (6). This is due to the lowest airflow rate which was 0.46 m^3 /s for the mentioned treatment.

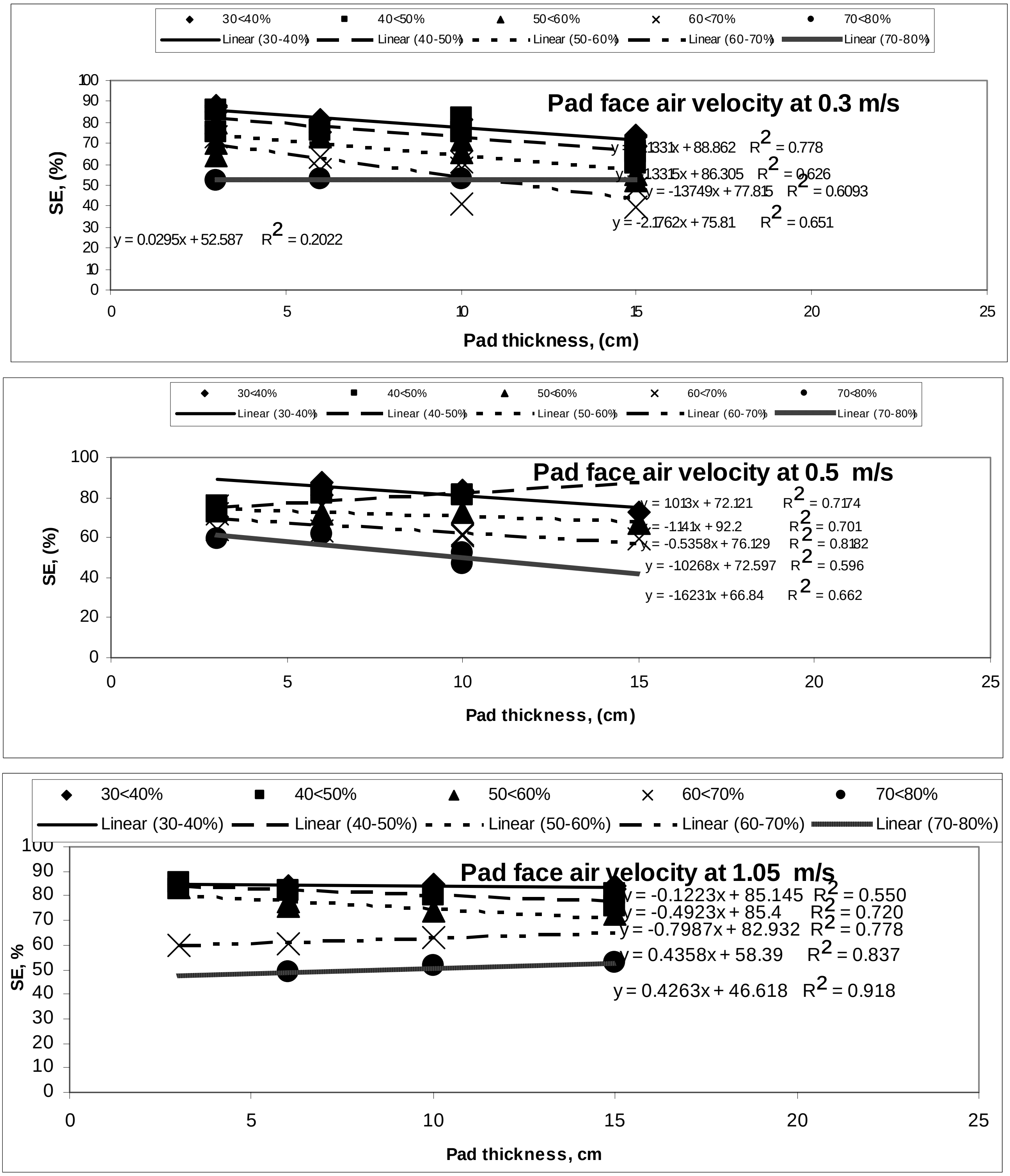

Figure (6): Saturation efficiency (SE) for rice straw pad material as affected by pad thickness at different ranges of relative humidity of the outside air.

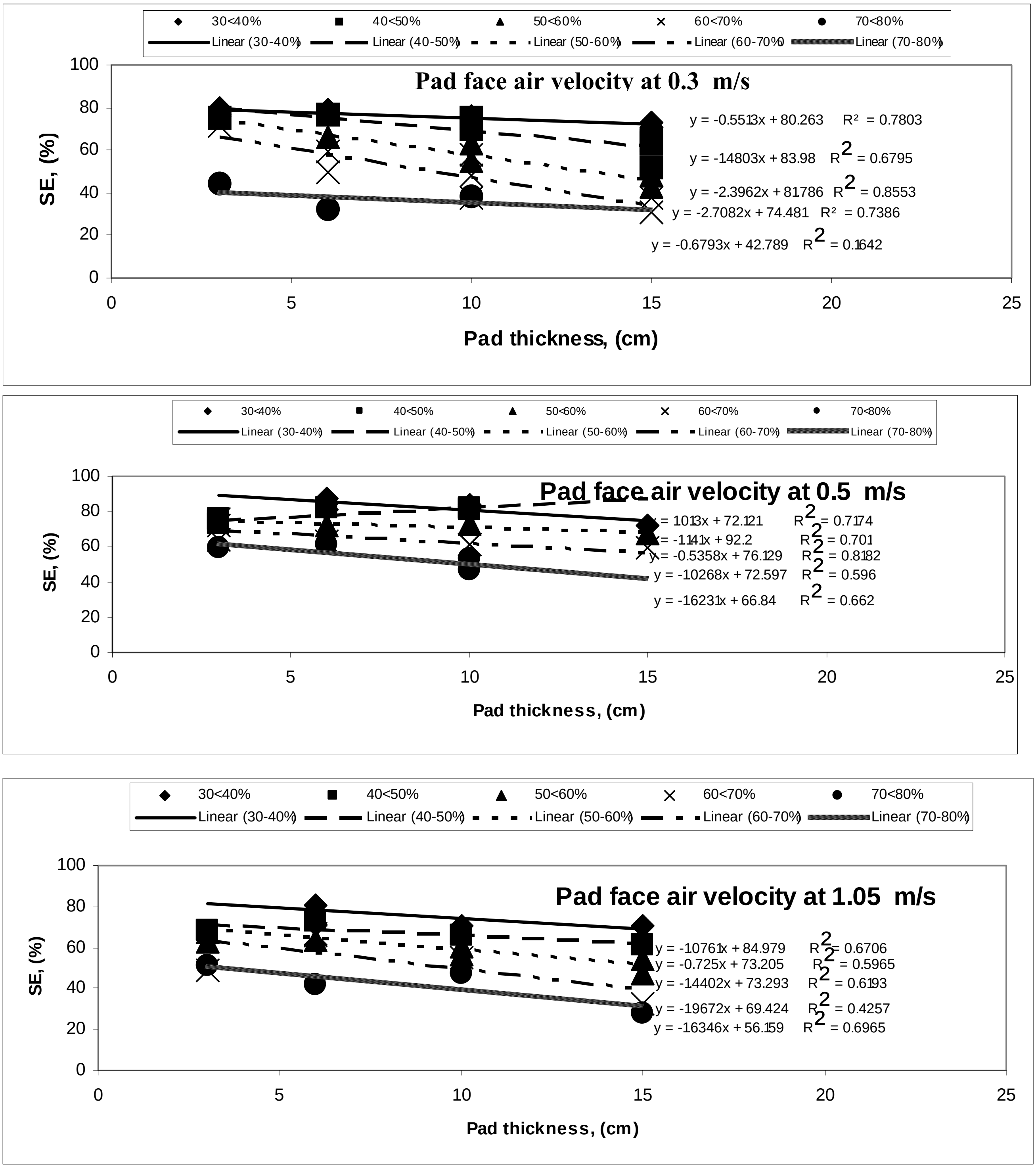

Figure (7): Saturation efficiency (SE) for palm leaf fibers' pad material as affected by pad thickness at different ranges of relative humidity of the outside air.

Table(6) indicates Unit ECP averages during the operating period for both pad materials at various pad thicknesses and pad face air velocities. Unit ECP increased by increasing thicknesses from 3 cm to 6 cm and decreased again at 0.5 and 1.05 m/s pad face air velocities. This result means that 6 cm is the preferred thickness depending on the value of Unit ECP. For PLF, increasing the thickness leads to decrease the value of Unit ECP at 0.3 m/s pad face air velocity. However, increasing pad thickness from 6 cm to 10 cm caused increasing Unit ECP at 0.3 m/s pad face air velocity. By eliminating variations associated with local conditions, one may say that the presented results are in agreement with the results of Wiersma and Short (1983).

Table (6):The average unit evaporative cooler performance (Unit ECP) for both materials at various pad thicknesses and pad face air velocities under different conditions.

Pad thickness (cm)	Pad face air velocity (m/s)	Outside conditions		Pad material	
		Temperature (° C)	Relative humidity (%)	Unit ECP for RS (kW/°C)	Unit ECP for PLF (kW/°C)
3	0.3	33.51	49.77	21.97	47.71
	0.5	30.93	56.70	45.99	51.25
	1.05	32.57	53.35	65.41	52.31
6	0.3	35.21	48.48	29.41	45.65
	0.5	33.46	50.75	71.79	58.39
	1.05	32.98	53.65	74.14	62.57
10	0.3	33.50	50.77	39.07	58.22
	0.5	34.41	52.25	67.11	54.16
	1.05	33.25	50.62	53.35	56.40
15	0.3	33.19	46.65	57.15	39.12
	0.5	37.29	46.68	66.82	52.67
	1.05	34.58	48.76	75.23	54.87

CONCLUSION

From the experimental results, it can be concluded that an evaporative pad cooling system using rice straw or palm leaf fibers as pad material is a suitable method to reduce heat stress in agricultural structures. Also, the present study indicates that rice straw pad material has higher performance than palm leaf pad material. Therefore, we can utilize rice straw as pad material depending on two facts. The first fact is that utilizing rice straw as pad material conserves the environment. The second is that rice straw is more available and less costly than other natural or industrial pad materials.

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أثر استخدام الوسادة المصنعة من المخلفات الزراعية على أداء نظام التبريد التبخيري

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ملخـص

تهدف الدراسة الى إمكانية استخدام قش الأرز و ألياف أوراق النخيل (الكرينه) كوسادة لنظام تبريد تبخيري و تحديد معايير الأداء الخاصة بهما، وذلك لخفض الإجهاد الحراري في المنشآت الزراعية، مما يساهم بشكل ما في حل مشكلة تراكم تلك المخلفات الزراعية من ناحية أو التخلص من هذه المخلفات بالحرق و بالتالي إحداث تلوث للبيئة من ناحية أخرى.

تم استخدام وحدتين متماثلتين كمنشأ زراعي بأبعاد (5.7×4.2×2.75 م) من الطوب الأحمر والخرسانة المسلحة وعمل وسادتين بمساحة (2.92×1.12م) الأولى من قش الأرز والثانية من ألياف أوراق النخيل (الكرينه) بسمك 3، 6، 10، 15 سم.وزود النظام بمروحة ذات قطر 0.5 م في الحائط المقابل لتقوم بسحب الهواء من المنشأ و الذي يمر من خلال الوسادة بسرعات 0.3، 0.5، 1.05 م/ث.

تم تسجيل درجات الحرارة الجافة و الرطبة في ثماني عشرة نقطة داخل المنشأ وكذلك درجات الحرارة الجافة والرطبة للهواء الخارجي كل ساعة ابتداء من الساعة التاسعة صباحاً و حتى السابعة مساء لكل معاملة. وقد تم حساب كل من الرطوبة النسبية، دليل درجة الحرارة- الرطوبة، كفاءة التشبع، معدل أداء المبرد التبخيري والنسبة بين خفض درجة الحرارة و معدل سريان الهواء.

وأظهرت النتائج أن خفض درجة الحرارة لجميع معاملات قش الأرز كان أعلى منه لجميع معاملات ألياف أوراق النخيل(الكرينه) و قد ترواح هذا الخفض في درجة الحرارة من 5.67 إلى 8.66°م لجميع معاملات قش الأرز، بينما تروا ح هذا الخفض في درجة الحرارة في جميع معاملات ألياف أوراق النخيل (الكرينه) من 5.01 إلى 7.50°م.

كان متوسط كفاءة التشبع لمعاملات قش الأرز أعلى منه لمعاملات ألياف أوراق النخيل (الكرينه)، وقد تراوح من 60.24٪ إلى 76.51٪ ومن 55.49٪ إلى 68.77 ٪ و ذلك لكل من قش الأرز و ألياف أوراق النخيل (الكرينه) على الترتيب.

لجميع المعاملات لنظام التبريد التبخيري المقترح (نوع مادة الوسادة، سمك الوسادة، سرعة هواء وجه الوسادة)، وكما هو متوقع، وجدت زيادة في الرطوبة النسبية تعد التأثير السلبي لمثل هذا النظام المقترح. وقد كانت أقل قيمة متوسطة للرطوبة النسبية داخل المنشأ 73.79٪ وذلك عند استخدام وسادة من ألياف أوراق النخيل (الكرينه) ذات سمك 15 سم و سرعة هواء عند وجه الوسادة مقدارها 0.3 م/ث.و بلغت أقصى قيمة متوسطة 86.63٪ عند استخدام وسادة من قش الأرز ذات سمك 3 سم و سرعة هواء عند وجه الوسادة مقدارها 0.3 م/ث.

أما أعلى قيمة متوسطة للنسبة بين خفض درجة الحرارة ومعدل سريان الهواء فقد بلغت 17.97°م/(م^3/ث) وذلك عند استخدام وسادة من قش الأرز بسمك 3 سم و سرعة هواء عند وجه الوسادة مقدارها 0.3 م/ث ، وبلغت أقل قيمة لنفس

النسبة 3.8 °م/(م^3/ث) وذلك عند استخدام وسادة من ألياف أوراق النخيل (الكرينه) ذات سمك 3 سم و سرعة هواء عند وجه الوسادة مقدارها 0.5 م/ث.

كما وجد أنه عند استخدام وسادة ذات سمك 15سم وسرعة هواء عند وجه الوسادة مقدارها 0.5 م/ث، تم الحصول على أعلى قيمة لخفض درجة الحرارة وكذلك على أعلى قيمة لوحدة أداء المبرد التبخيري؛ بينما كانت أقل قيمة عند استخدام وسادة ذات سمك 3 سم و سرعة هواء عند وجه الوسادة مقدارها 0.5 م/ث للمادتين كلتيهما.

الكلمات الدالة: التبريد التبخيري، مادة الوسادة، سرعة الهواء، الرطوبة النسبية، درجة الحرارة، فعالية التشبع.

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