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INFLUENCE OF PAD CONFIGURATION ON EVAPORATIVE COOLING SYSTEM EFFECTIVENESS INSIDE A WIND TUNNEL

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ABSTRACT

The current investigation has been conducted to study the influence of pad configuration on the evaporative cooling effectiveness inside a wind tunnel. Three different configurations of pad were designed and they were expressed in terms of vertical, horizontal and multi-horizontal. As well as, the influence of both pad thickness and pad-face air velocity was investigated. A developed wind tunnel was employed as pad-fan evaporative cooling system to fulfill the objectives of study. The experimental results revealed that the multi-horizontal pad configuration has achieved the highest values of cooling potential if it is compared with the other two pad configurations during the whole period of operation. The highest average cooled air temperature inside the wind tunnel was found at pad thickness of 15cm and pad-face air velocity of 1m/s for the multi-horizontal pad configuration. For multi-horizontal pad configuration and 1m/s pad-face air velocity, the mean cooling potential was raised from 7.46 to 11.78^{o}C (+57.91%) by increasing pad thickness from 3 to 15cm. The highest mean values of cooling potential were found at pad thickness of 15cm and pad-face air velocity of 1m/s for the multi-horizontal pad configuration. Saturation efficiency was dramatically raised by increasing the thickness of pad especially for multi-horizontal pad configuration. The required airflow rate was raised by increasing both of pad thickness and pad-face air velocity for all configurations of pad. It has been reached its maximum values when applying the multi-horizontal pad configuration because of the rapid fluctuations taken place in airflow resistance. By increasing pad thickness from 3 to 15cm, for multi-horizontal pad configuration and pad-face air velocity of 1m/s, the static pressure drop across the pad was raised from 31.39 to 70.63Pa (+125%).

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INTRODUCTION

Evaporative cooling is an adiabatic process (no gain or loss of heat) which lowers the dry-bulb temperature while increasing dew point temperature of an air and water vapor mixture ***(Hahn and Wiersme, 1972)***. It has numerous applications of environment control in agriculture, which require more cooling than can be provided by ventilation alone ***(Albright, 1990)***. In Egypt, the pad-fan evaporative cooling system is considered as the most common way in reducing heat stress. Efficient cooler performance is highly dependent upon the pad performance. Since there are no available engineering knowledge about the relationship between the pad configuration and its material type and the evaporative cooler performance. Therefore, it is necessary to pay attention to the configuration of pad and its effect on the investigated system. Generally, meeting pad design requirements to some reasonable or acceptable levels of agriculture is relatively simple. Defining requirements for a high level of performance over a wide range of conditions is difficult. An increase in pad thickness directly increases the resistance to airflow while increasing the contact time of air traversing the pad. However, as air passes through additional thickness of pad, the vapor pressure different decreases. This results in a decrease in the evaporation rate giving element as it continues its path through the pad. The precise relationship is not well known. Increasing pad density enhances overall porosity or capillarity providing more uniform distribution of water. Air velocity through the pads varies at different points within the pad and it is difficult to measure. The velocity entering or exiting from the pad, referred to as pad-face air velocity, is much easier to measure and is commonly used to define pad velocity. It is a basic design parameter used for calculating pad area ***(Hellickson and walker, 1983)***. Utilization of rice straw and palm leaf fibers (Kerina) as pad materials in an evaporative cooling system can contribute in solving the accumulation of some agricultural residues such as rice straw. Also, it can play a fundamental role in the environmental dimension. Temperature reduction for all rice straw treatments was higher than that for Kerina by about 15.467% ***(Darwish, 2006)***. A wind tunnel is a device for producing a controlled stream of air in order to study the effects of movement through air or the resistance to moving air for aircraft, buildings, and other objects. In recent years, many agricultural experiments have involved the simulation of natural environments. Therefore, it is of practical interest to produce a temperature, humidity, and velocity controlled environment using a wind tunnel for agricultural experiments to investigate ***(Leon et al., 1998)***. There are two basic types of wind tunnel, the open circuit and the closed circuit or return flow tunnel. The open circuit tunnel may use a continuous supply of fresh air drawn from the atmosphere through an intake and contraction to the test section and then discharged back to the atmosphere through a diffuser ***(Bain et al., 1971)***. The main aim of the current research was to investigate the influence of pad configuration on the evaporative cooling system effectiveness inside a wind tunnel. Moreover, the specific objectives can be drawn as follows:

1) To investigate the effect of pad thickness and pad-face air velocity on the cooling effectiveness of the investigated system and
2) To experimentally estimate the cooling potential, saturation efficiency, the required airflow rate and static pressure drop for the evaporative cooling system.

MATERIALS AND METHODS

To meet with the objectives of the present study, main evaporative cooling system using pad-fan wind tunnel was constructed and installed at Rice Mechanization Center, Meet El-Deeba village, Kafr El-Sheikh governorate, Egypt during the summer season of 2007.

EXPERIMENTAL TEST APPARATUS:

WIND TUNNEL:

The wind tunnel was mainly developed to simulate pad-fan evaporative cooling systems and to provide direct measurements of system performance. It is a low speed open circuit type with a test section of 2.5m long, 2.5m wide and 0.75m height. It was constructed of welded steel angles (50x50mm) to form tunnel frame with overall length of 6.15m. The constructed frame of the wind tunnel was covered with a 1mm thick iron sheet. A Plexiglas with 3mm thick was employed to cover the iron frame to form the ceiling and walls of the test section. An axial flow fan attached to the frame of the wind tunnel was also used to furnish air to wind tunnel. The rough structure of the wind tunnel is shown in Fig. 1. Construction details of the tunnel can be found in ***Basiouny, 2005***.

PAD CONFIGURATION:

Three different configurations of pad were employed in the present investigation. They were termed as vertical, horizontal and multi-horizontal. To accomplish the group of experiments, the three configurations of pad were alternately constructed with the wind tunnel at the opening of entering air (Fig. 2). The total area of the pad was of $1.8m^2$ (2.4x0.75m) and it was identical for the three pad configurations under study. Meanwhile, for the multi-horizontal one, its total area was divided into three equal pads of $0.6m^2$ (2.4x0.25m). The rice straw was exploited as a pad material for all investigated treatments. As well as, density of pad material was kept constant at about $32kg/m^3$ in accordance with ***Hellickson and walker, 1983*** for all treatments. It was determined by knowing pad thickness and multiplying it by its total area and 32kg rice straw. Rice straw was uniformly distributed between two wire net, one of them is fixed at a steel angle and the other can be fixed through a number of bolts for the purpose of controlling the pad thicknesses. Water flow rate of pad was of about $0.259m^3/h$ and it was kept constant at this value for all investigated treatments. It was selected in accordance with ***Wiersma and Benham, 1974***. The system of supplying water to the vertical pad was fulfilled by using a perforated pipe, which positioned above the pad through its longitudinal axis. While, in relative to the horizontal and multi-horizontal pad configurations, supplying water was done by a number of nozzles fixed through the upper surface of the pad. The system of supplying water to the pad was constructed from water tank and a small pump attached with the tank for the purpose of pumping water to the pad. The water flow rate was controlled by a hand valve.

INVESTIGATED VARIABLES:

The plan of the group of experiments was essentially designed and carried out to acquire some indicators which judge the evaporative cooling process. Those indicators such as cooling potential, saturation efficiency, the required airflow rate and static pressure drop across the pad under the investigated variables. The studied factors and their levels were drawn as follows:

1) Three different configurations of pad namely vertical, horizontal and multi-horizontal;
2) Four different pad thicknesses of 3, 7, 11 and 15cm and
3) Three different pad-face air velocities of 0.75, 1.0 and 1.25m/s.

The pad-fan evaporative cooling system was operated for each treatment from hour 9 to hour 18 during the summer period from 11/07/2007 to 15/08/2007.

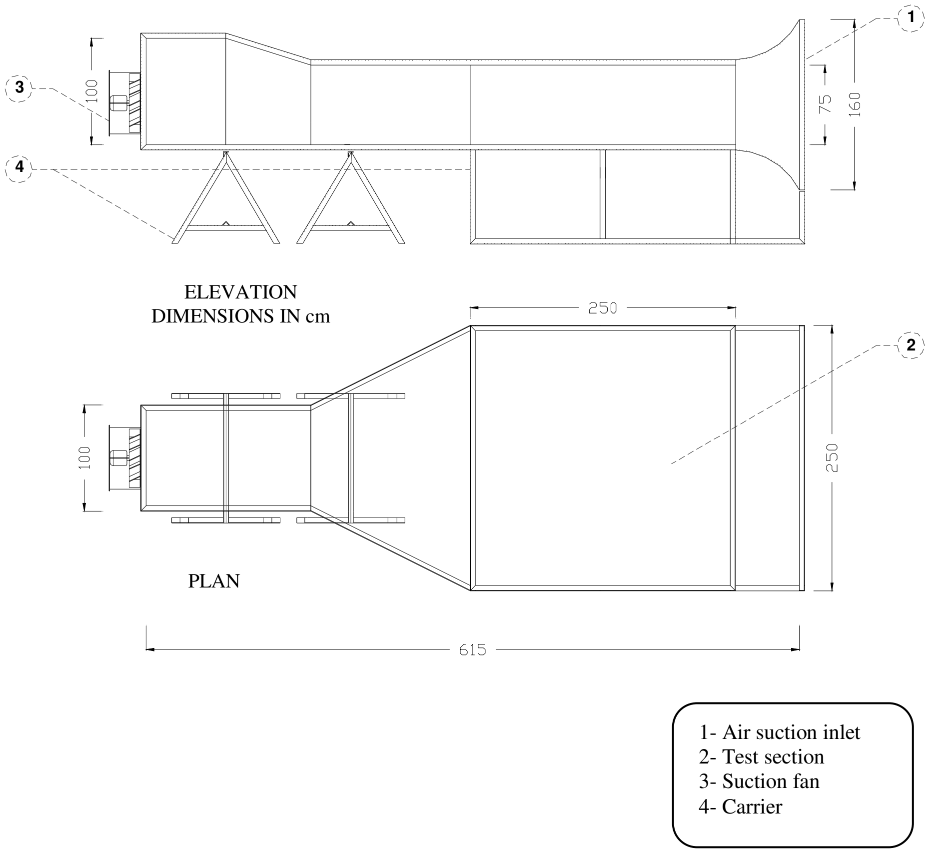


Fig. 1: A geometrical drawing of the wind tunnel.

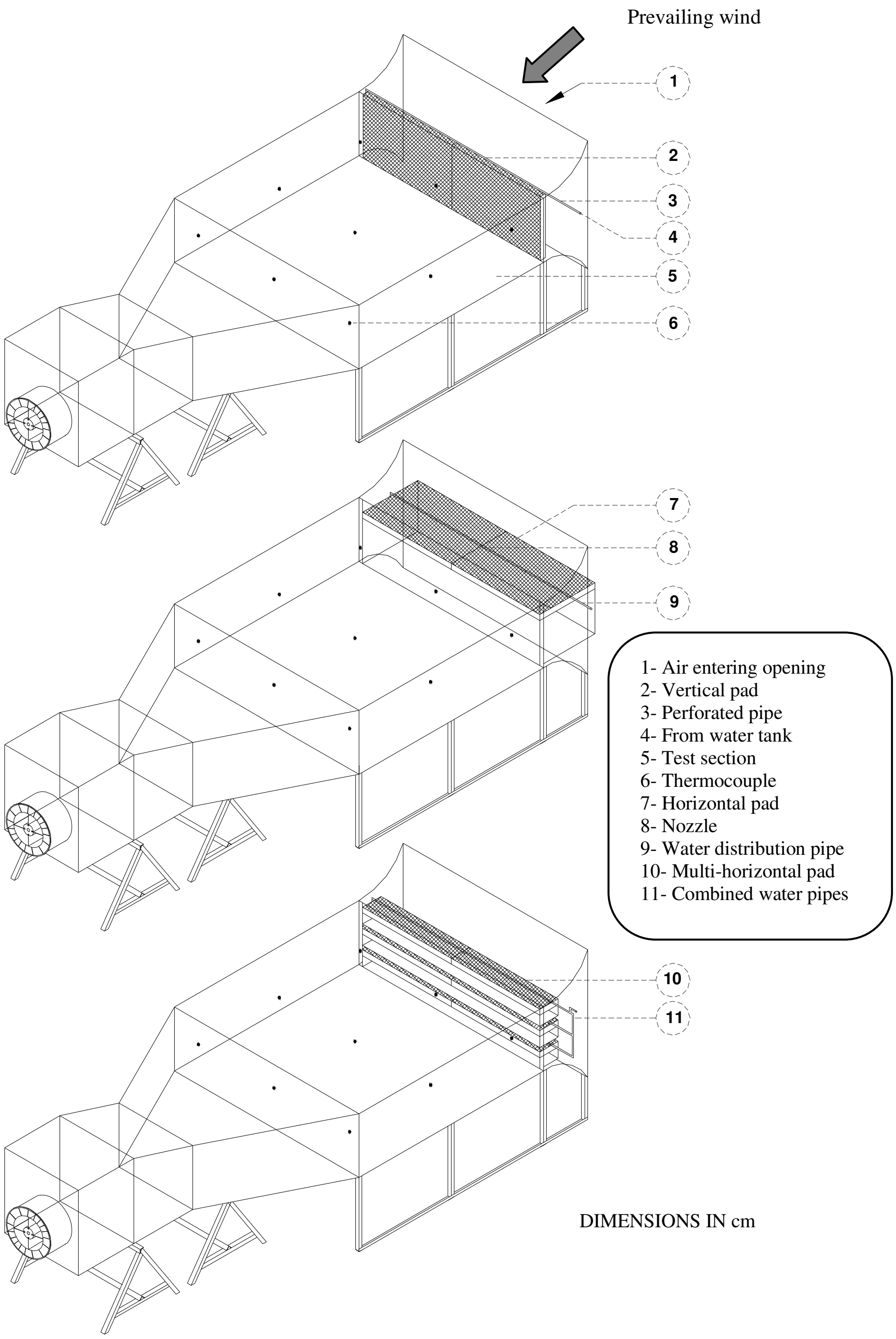


Fig. 2: A perspective drawing of the experimental test apparatus for evaporative cooling measurements.

MEASUREMENTS AND INSTRUMENTATION:

AIR TEMPERATURE:

Using J-type thermocouples and a digital thermometer (Model HH-26J-USA) did the measurement of air temperature. The unit has a wide range of -80 to 760^{o}C and it was used for recording air temperature outside and inside the wind tunnel. Nine thermocouples were employed to measure dry-bulb temperature inside the test section of wind tunnel. Two thermocouples were placed outside the wind tunnel for measuring the ambient dry and wet-bulb temperatures. Using psychrometric principles, the air relative humidity was determined by knowing both of dry and wet-bulb temperatures.

AIR VELOCITY:

A Japanese type hot-wire anemomaster (Model 24-6111) was used to measure pad-face air velocity. The unit is a self-contained direct reading portable instrument, which is capable of measuring velocities from zero to 50m/s with a precision of 0.1m/s.

STATIC PRESSURE DROP ACROSS THE PAD:

It was measured using Pitot-tube which attached with the hot-wire anemomaster. The unit is capable of measuring pressure from zero to 500mm and expressed as a head of water with an accuracy of 0.1mm.

EXPERIMENTAL PROCEDURES:

COOLING POTENTIAL (TEMPERATURE REDUCTION):

The cooling potential can be expressed as temperature reduction. It can be estimated using the following equation:

$$\Delta T = T_{db} - T_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where;

ΔT cooling potential (temperature reduction), ^{o}C;

T_{db} dry-bulb temperature of the ambient air, ^{o}C and

T_c dry-bulb temperature of the cooled air inside wind tunnel, ^{o}C.

The average cooling potential was calculated for each experimental treatment.

SATURATION EFFICIENCY:

It is the ratio of change in saturation achieved to potential change in saturation or wet-bulb depression ***(Hellickson and walker, 1983)***. It was calculated from the following formula:

$$SE = \frac{T_{db} - T_c}{T_{db} - T_{wb}} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where;

SE saturation efficiency, % and

T_{wb} wet-bulb temperature of the ambient air, ^oC.

The average saturation efficiency for each treatment was estimated. Multiple linear regression equations were developed to predict the influence of pad thickness and pad-face air velocity together on saturation efficiency for various pad configurations.

THE REQUIRED AIRFLOW RATE:

An inverter was employed for controlling the airflow rate of the suction fan and hence changing pad-face air velocity. The fan motor was connected with the inverter which changes the frequency and then a difference in the revolutions number of the fan can be easily obtained. The wind tunnel-fan was calibrated for each treatment by measuring air velocity at the outlet of fan. This operation was accomplished using a cylindrical pipe made of sheet-iron and 0.6m diameter. This pipe was fixed at the outlet of fan to record air velocity of the exiting air. The quantity of airflow was determined by multiplying the average air velocity by cross-section area of the cylindrical pipe.

STATIC PRESSURE DROP:

Static pressure drop across the pad (inside wind tunnel), for different pad configurations, was recorded for each pad thickness and pad-face air velocity. It can be determined using the following formula:

$$P = \rho . g . h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where;

P static pressure drop across the pad, Pa;

ρ density of water , 1000kg/m^3;

g acceleration of gravity, 9.81m/s^2 and

h head of water, m.

Single exponential regression equations were developed to describe the relationship between pad thickness and static pressure drop at different pad-face air velocities for each configuration of pad.

RESULTS AND DISCUSSION

AMBIENT WEATHER CONDITIONS:

Table 1 indicates the averaged values of the measured data for both outside (ambient) dry-bulb temperature and outside relative humidity. At the same time, the averaged values of both saturation efficiency and cooling potential were calculated and listed in Table 1 at different pad thicknesses and pad-face air velocities for various pad configurations. The multi-horizontal pad configuration had the best influence in cooling during the whole operating period. This trend was observed for all treatments under study. Standard deviation was determined for the ambient dry-bulb temperature for all treatments and conditions. Its values were ranged from 1.92 to 3.66 ^{o}C. It can be noted that, at pad thickness of 15cm and pad-face air velocity of 1m/s, the average temperature reduction was of 7.16, 7.58 and 8.18^{o}C for vertical, horizontal and multi-horizontal pad configurations respectively. The increment percentage in cooling potential due to using the multi-horizontal pad was of 14.25% in comparison with the vertical one. The lowest average cooled air temperature was found at pad thickness of 3cm and pad-face air velocity of 0.75m/s for the vertical pad configuration. Conversely, the highest one was observed at pad thickness of 15cm and pad-face air velocity of 1m/s for the multi-horizontal pad configuration. From the before mentioned, it can be revealed that the optimum conditions to rise the effectiveness of cooling process inside wind tunnel are the pad thickness of 15cm and pad-face air velocity of 1m/s. It was also noticed that the multi-horizontal pad configuration had the best cooling effectiveness for all investigated factors and conditions. Fig. 3 shows the variation of air temperature and relative humidity as affected by daytime at different configurations of pad when the pad thickness was 15cm and pad-face air velocity was 1m/s. As depicted in Fig. 3, the maximum recorded ambient dry-bulb air temperatures were of 39.19, 39.57 and 38.95^{o}C with a standard deviation of 0.31^{o}C and the corresponding values of the outside relative humidity were of 32.6, 32.6 and 38.9% for the vertical, horizontal and multi-horizontal pad configurations respectively. Meanwhile, the cooled air temperatures inside wind tunnel were of 29.07, 28.78 and 27.17^{o}C for the vertical, horizontal and multi-horizontal pad configurations successively.

Table 1: The measured data and calculated values of the average cooling potential and saturation efficiency at different pad thicknesses and pad-face air velocities for various configurations of pad.

Pad thickness, cm	Pad-face air velocity, m/s	Vertical pad						Horizontal pad						Multi-horizontal pad					
		T_{db}, °C	SD of T_{db}, °C	RH, %	T_c, °C	ΔT, °C	SE, %	T_{db}, °C	SD of T_{db}, °C	RH, %	T_c, °C	ΔT, °C	SE, %	T_{db}, °C	SD of T_{db}, °C	RH, %	T_c, °C	ΔT, °C	SE, %
15	0.75	34.99	3.31	47.83	29.17	5.82	59.71	35.79	3.51	46.70	29.01	6.78	66.59	34.18	3.37	50.00	27.03	7.15	78.85
	1.00	34.97	3.24	48.39	27.80	7.16	76.76	34.35	3.35	47.60	27.32	7.58	79.80	34.73	3.33	49.70	26.56	8.18	89.59
	1.25	34.75	3.32	48.13	28.35	6.40	66.77	33.50	3.50	48.20	28.19	7.22	74.39	34.58	3.66	49.80	27.09	7.48	81.43
11	0.75	34.18	2.90	52.71	29.04	5.14	60.49	34.44	3.24	50.90	28.57	5.87	64.19	35.53	3.46	46.20	28.54	6.99	67.97
	1.00	34.35	2.67	52.35	28.64	5.71	68.45	34.76	3.47	49.70	27.71	7.06	78.36	34.90	3.38	49.10	27.57	7.57	82.57
	1.25	33.79	2.82	54.04	28.57	5.22	63.05	34.65	3.55	50.60	28.23	6.42	69.42	34.60	2.90	48.90	27.67	6.99	74.71
7	0.75	34.61	3.21	50.90	30.81	3.82	42.40	34.36	3.43	50.30	30.31	4.05	44.69	32.88	2.36	54.10	28.60	4.28	52.97
	1.00	34.47	3.39	49.67	29.54	5.42	59.08	34.71	3.15	49.70	28.82	5.88	65.46	33.70	2.73	52.50	27.28	6.42	78.09
	1.25	34.42	3.42	43.88	30.14	4.70	43.10	34.05	3.03	51.70	28.88	5.17	58.91	33.47	1.92	51.60	27.77	5.70	67.86
3	0.75	33.75	2.48	48.30	30.86	2.89	31.00	34.40	2.88	51.10	30.70	3.70	41.71	34.22	3.41	49.90	30.21	4.01	44.29
	1.00	33.64	2.82	46.30	28.93	4.71	48.93	34.16	3.33	52.40	28.64	5.52	65.97	34.40	2.58	50.10	28.37	6.03	67.38
	1.25	34.21	2.84	47.20	30.14	4.08	40.50	33.67	2.85	52.30	29.23	4.44	51.12	33.30	2.65	53.40	28.40	4.90	58.50

It can be concluded that, the multi-horizontal pad configuration achieved the best cooled air temperature inside wind tunnel with a reduction percentage of 6.54 and 5.59% in relative to the vertical and horizontal ones respectively. Fig. 4 indicates the variation of air temperature and relative humidity as affected by daytime at different configurations of pad at pad thickness of 3cm and pad-face air velocity of 0.75m/s. As illustrated in Fig. 4, the maximum recorded ambient dry-bulb air temperatures were of 36.62, 37.95 and 38.68°C with a standard deviation of 1.04°C and the corresponding values of the outside relative humidity were of 39.5, 40.8 and 36.5% for the vertical, horizontal and multi-horizontal pad configurations respectively. Meanwhile, the cooled air temperatures inside wind tunnel were of 34.01, 33.98 and 33.85°C for the

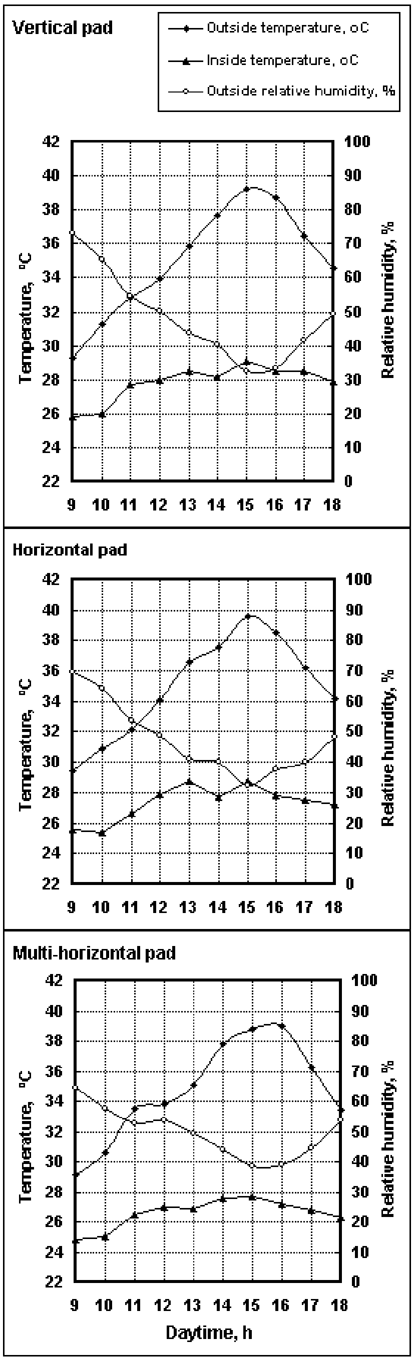


Fig. 3: Variation of air temperature and relative humidity as affected by daytime at different configurations of pad when the pad thickness was 15cm and pad-face air velocity was 1m/s.

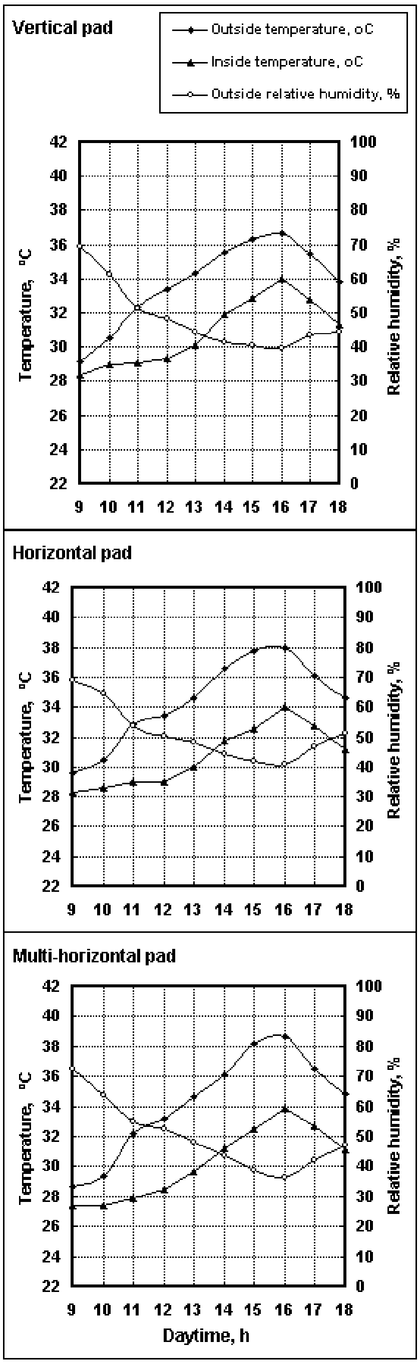


Fig. 4: Variation of air temperature and relative humidity as affected by daytime at different configurations of pad when the pad thickness was 3cm and pad-face air velocity was 0.75m/s.

vertical, horizontal and multi-horizontal pad configurations successively. As a conclusion, the vertical pad configuration has revealed the worst cooled air temperature inside wind tunnel in relative to the other two ones.

COOLING POTENTIAL:

Temperature reduction was determined to describe the cooling potential of the investigated system. Figs. 5 to 8 illustrate the variation of the average cooling potential as affected by daytime at different pad configurations and various pad-face air velocities for all pad thicknesses. As depicted in Figs. 5 to 8, the multi-horizontal pad configuration achieved the highest values of temperature reduction if compared with the other two configurations of pad. As well as, its highest values were noticed around hour 16. By increasing pad thickness, the values of temperature reduction were absolutely raised. For example, at hour 16 and pad-face air velocity of 1m/s for multi-horizontal pad configuration, its values were increased from 7.46 to 11.78^{o}C (+57.91%) by increasing the thickness of pad from 3 to 15cm. Pad-face air velocity of 1m/s achieved the highest values of temperature reduction if compared with 0.75 and 1.25m/s for all of pad configurations and its thicknesses. On the other hand, temperature reduction values were of 10.23, 10.67 and 11.78^{o}C for vertical, horizontal and multi-horizontal pad configurations respectively at hour 16 and pad thickness of 15cm and pad-face air velocity of 1m/s. The increment in temperature reduction due to configuration of pad was of 15.15% for multi-horizontal in relative to the vertical one. This means that changing the configuration of pad plays an essential role for judging the effectiveness of the investigated system. Also, it can be noted that the values of temperature reduction were gradually raised from hour 9 up to hour 16, after that its values were dramatically lowered up to hour 18. Temperature reduction was strongly influenced by the outside dry-bulb temperature and hence the investigated parameters. Its lowest values were found around hour 9 during the daytime for vertical pad configuration at pad thickness of 3cm and pad-face air velocity of 1.25m/s. Based on cooling potential, the multi-horizontal pad configuration in pad-fan evaporative cooling system can be satisfactorily used. Variation in the ambient weather conditions

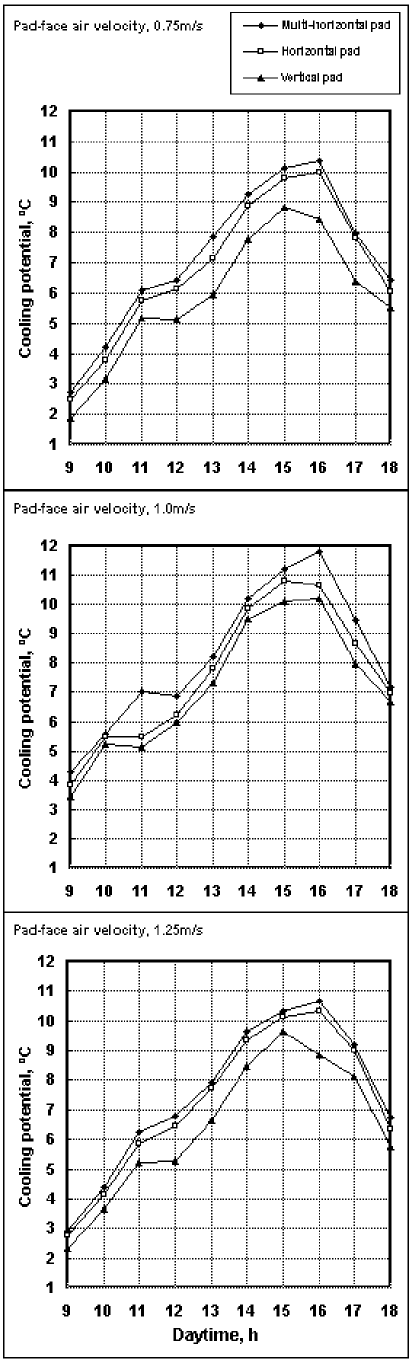


Fig. 5: Variation of cooling potential as affected by daytime at different configurations of pad and various pad-face air velocities when the pad thickness was 15cm.

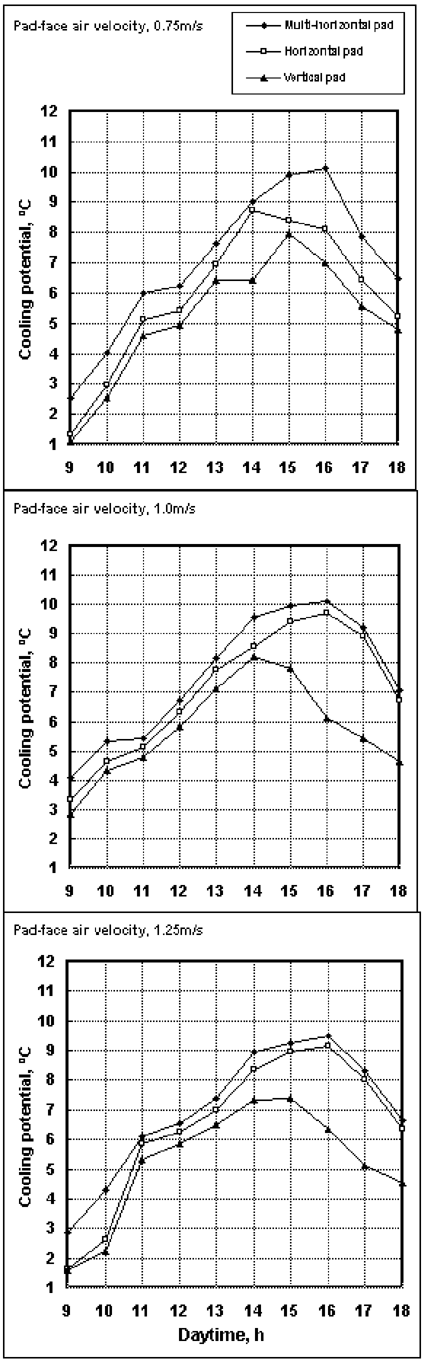
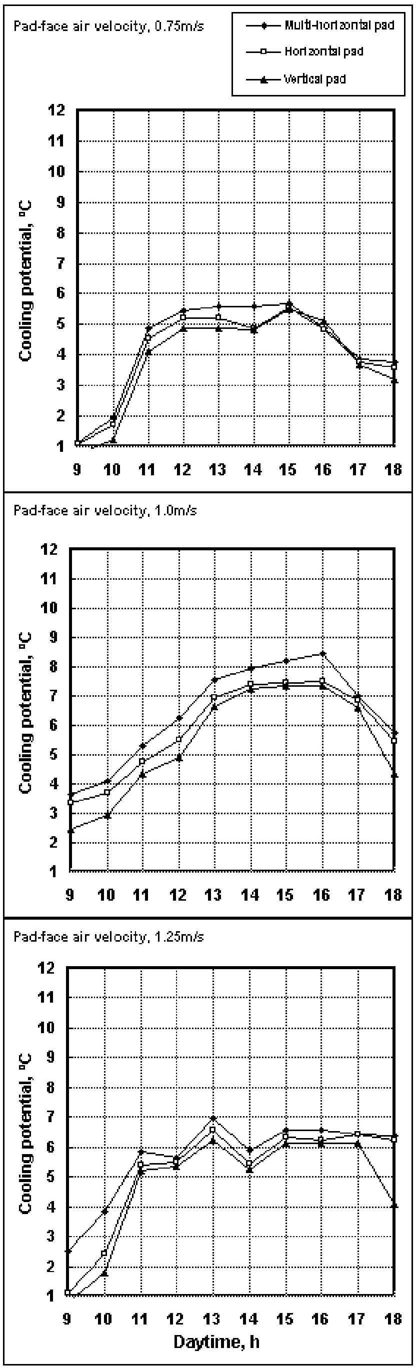


Fig. 6: Variation of cooling potential as affected by daytime at different configurations of pad and various pad-face air velocities when the pad thickness was 11cm.



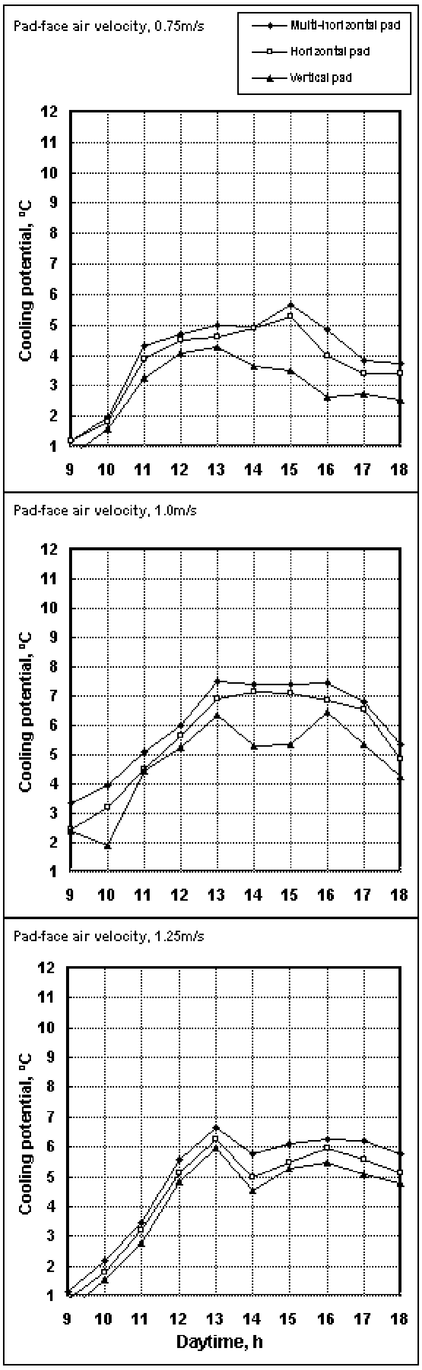


Fig. 7: Variation of cooling potential as affected by daytime at different configurations of pad and various pad-face air velocities when the pad thickness was 7cm.

Fig. 8: Variation of cooling potential as affected by daytime at different configurations of pad and various pad-face air velocities when the pad thickness was 3cm.

and airflow rate has been resulted in difficulty of distinguishing between pad thickness and pad-face air velocity. Fig. 9 illustrates the relationship between the mean cooling potential and pad thickness for different pad configurations and various pad-face air velocities. The mean values of temperature reduction were of 7.16, 7.58 and 8.18^{o}C for vertical, horizontal and multi-horizontal pad configurations respectively at pad thickness of 15cm and pad-face air velocity of 1m/s. As a conclusion, the highest mean values of cooling potential were found at pat thickness of 15cm and pad-face air velocity of 1m/s for multi-horizontal pad configuration. But its lowest mean values were obtained at pad thickness of 3cm and pad-face air velocity of 0.75m/s for vertical pad configuration.

SATURATION EFFICIENCY:

Fig. 10 shows the variation of the average saturation efficiency as a function of pad thickness for different pad configurations and various pad-face air velocities. In general, the multi-horizontal pad configuration achieved the highest values of saturation efficiency in comparison with the other two pad configurations for all treatments. Also, saturation efficiency was increased by increasing pad thickness especially for multi-horizontal pad configuration. As depicted in Fig. 10, it can be observed that there was a limiting in pad-face air velocity for each specific pad thickness, beyond which the saturation efficiency can be lowered. Saturation efficiency can be considered as a direct function for the time of air-water contact and pad-face air velocity. Hence, when pad-face air velocity is raised, the evaporation rate was increased by increasing heat and mass transfer, but the time of air-water contact was decreased. This means that there was an urgent need for increasing the pad thickness to substitute the malfunction in this process. The highest saturation efficiency was of 89.59% occurred at pad thickness of 15cm and pad-face air velocity of 1m/s for the multi-horizontal pad configuration. Conversely, its lowest value was of 31% occurred at pad thickness of 3cm and pad-face air velocity of 0.75m/s for the vertical pad configuration. Values of saturation efficiency were of 76.76, 79.80 and 89.59% for vertical, horizontal and multi-horizontal pad respectively at pad thickness of 15cm and pad-face air velocity of 1m/s. The increment

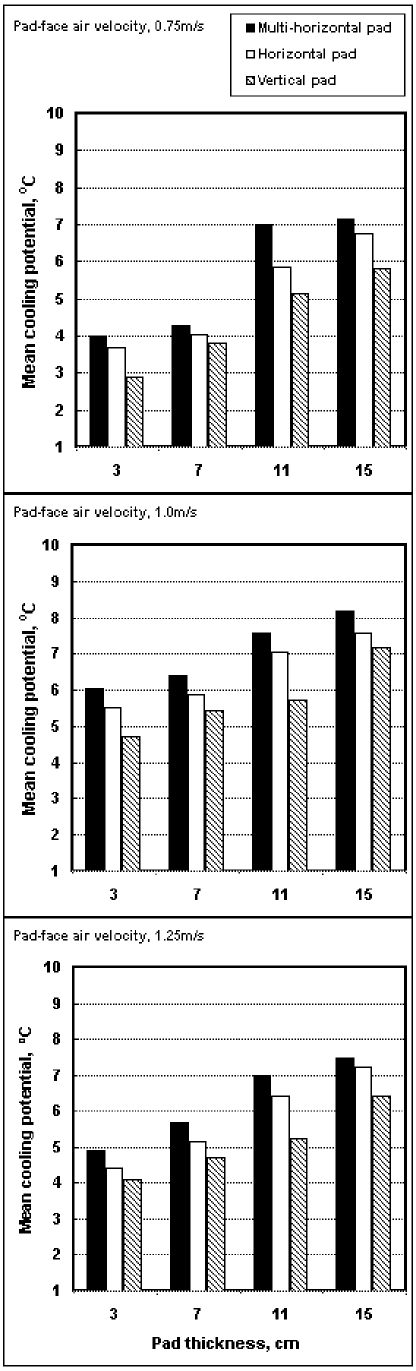


Fig. 9: Variation of mean cooling potential as affected by pad thickness for different pad configurations and pad-face air velocities.

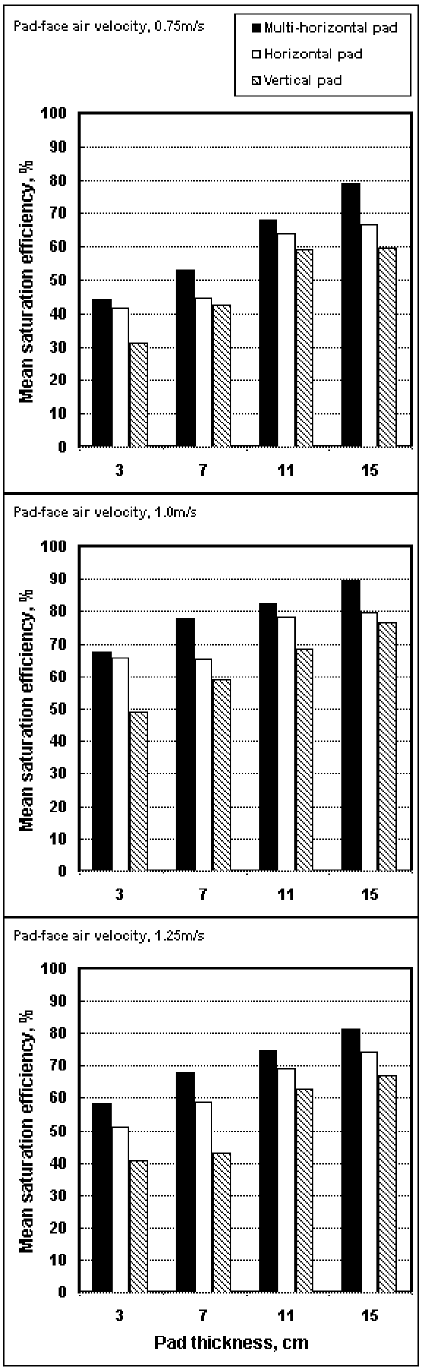


Fig. 10: Variation of mean saturation efficiency as affected by pad thickness for different pad configurations and pad-face air velocities.

occurred in saturation efficiency due to employing the multi-horizontal pad configuration was of 16.71% if compared with the vertical one. On the other hand, at constant pad-face air velocity of 1m/s and for multi-horizontal pad, when the pad thickness was increased from 3 to 15cm, saturation efficiency was raised from 67.38, to 89.59% (+32.96%). Meanwhile, it was raised from 78.85 to 89.59% (+13.62%) by increasing pad-face air velocity from 0.75 to 1m/s at pad thickness of 15cm for the multi-horizontal pad configuration. Saturation efficiency was highly influenced by both of pad configuration and its thickness more than pad-face air velocity. Recently, from Fig. 10, it can be concluded that the highest saturation efficiency was found at pad-face air velocity of 1m/s for the multi-horizontal pad configuration. Three multiple linear regression equations were developed to describe the relationship between mean saturation efficiency as a dependent variable and both of pad thickness and pad-face air velocity as independent variables. The linear relationship was written as in the following quadratic form:

$$SE = a_o + b_1T + b_2V + b_3TV + b_4T^2 + b_5V^2 \quad \text{……………………..……} \quad (4)$$

Where;

SE mean saturation efficiency, %;

T pad thickness, cm;

V pad-face air velocity, m/s;

a_o y-intercept and $b_{(1\text{-}5)}$ regression coefficients.

The values of predicted regression coefficients are listed in Table 2 for three different configurations of pad. The relative closeness of each multiple relationship was measured by the coefficient of multiple determination (R^2).

Table 2: The regression coefficients for predicting the mean saturation efficiency as affected by various configurations of pad.

Pad configuration	y-intercept (a_o)	Regression coefficients					Determination coefficient (R^2)
		b_1	b_2	b_3	b_4	b_5	
Vertical	-176.3761	+3.7470	+415.393	-0.2070	-0.0603	-201.480	0.9503
Horizontal	-186.0959	+2.7340	+457.189	-0.6910	-0.0076	-216.320	0.9220
Multi-horizontal	-197.7499	+4.7511	+473.298	-2.1520	-0.0215	-217.360	0.9808

AIRFLOW RATE:

As the applied airflow rate is varied in each treatment, it was considered to provide a better criterion for comparison among the investigated factors. Also, the variation in airflow resistance due to the variation occurred in pad configuration plays an important role in this phenomenon. Fig. 11 shows the relationship between the required airflow rate and pad thickness for each pad-face air velocity under different pad configurations. As depicted in Fig. 11, in general, the required airflow rate was increased by increasing both of pad thickness and pad-face air velocity for all configurations of pad. The multi-horizontal pad configuration achieved the highest values of the required airflow rate in relative to the other two pad configurations at all pad thicknesses and pad-face air velocities. When pad thickness was constant at 15cm and pad-face air velocity was of 1m/s, the required airflow rate was of 1.53, 1.62 and 1.88m^3/s for vertical, horizontal and multi-horizontal pad configurations successively. The increment in the required airflow rate due to multi-horizontal pad configuration was of 22.88% if compared with the vertical one. But when pad thickness was increased from 3 to 15cm, for multi-horizontal pad and pad-face air velocity of 1m/s, it was raised from 1.71 to 1.88m^3/s (+9.94%). On the other hand, when pad thickness is constant at 15cm and for multi-horizontal pad configuration, the required airflow rate was raised from 1.71 to 1.97m^3/s (+15.2%) by increasing pad-face air velocity from 0.75 to 1.25m/s. Briefly, it can be stated that the highest required airflow rate was obtained at pad thickness of 15cm and pad-face air velocity of 1.25m/s under the condition of multi-horizontal pad configuration (Fig. 11). The only reason due to the variation in the required airflow rate is the fluctuations occurred in airflow resistance.

STATIC PRESSURE DROP:

Airflow resistance is considered as an important parameter, which is directly related to static pressure drop and influencing the cooling performance of the system. As illustrated in Fig. 12, in general, static pressure drop was increased as both of pad thickness and pad-face air velocity were raised for all pad configurations. Fig. 12 shows the relationship between static pressure drop and pad thickness at each pad-

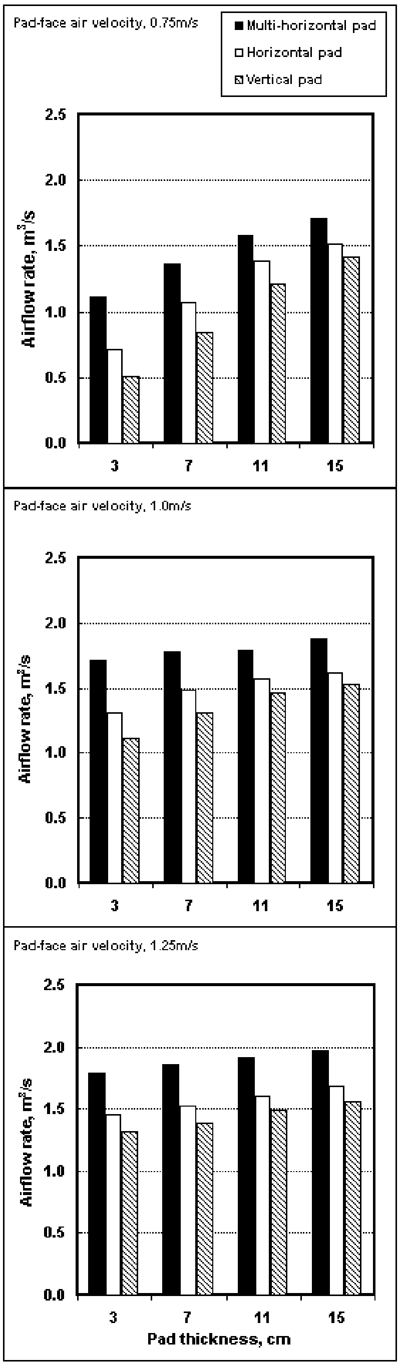


Fig. 11: The required airflow rate as a function of pad thickness and pad-face air velocity for different pad configurations.

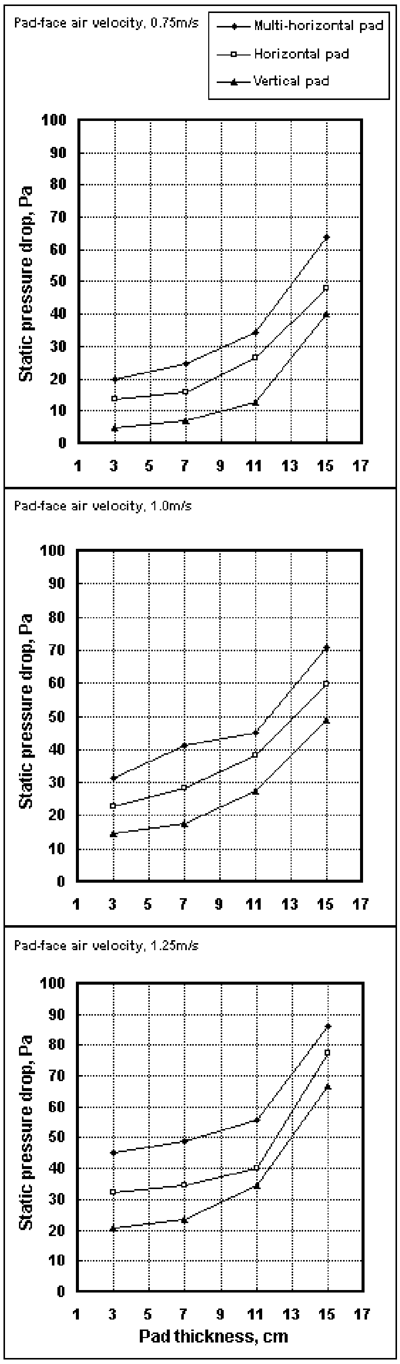


Fig. 12: Static pressure drop as a function of pad thickness and pad-face air velocity for different pad configurations.

face air velocity for different pad configurations. Multi-horizontal pad configuration had the highest static pressure drop, while the vertical one had the lowest one for all pad thicknesses and pad-face air velocities. At pad thickness of 15cm and pad-face air velocity of 1m/s, static pressure drop was ranged from 49.05 to 70.63Pa (+44%) for vertical and multi-horizontal pad respectively. On the other hand, for multi-horizontal pad configuration and pad-face air velocity of 1m/s, static pressure drop was raised from 31.39 to 70.63Pa (+125%) by increasing pad thickness from 3 to 15cm. While, at constant pad thickness of 15cm and for multi-horizontal pad configuration, static pressure drop was raised from 63.77 to 86.33Pa (+35.38) by increasing pad-face air velocity from 0.75 to 1.25m/s. This means that the static pressure drop was highly influenced by changing both of pad thickness and its configuration. It was strongly resulted when using the multi-horizontal pad configuration. This finding can be attributed to that this configuration of pad had a higher airflow resistance in relative to the other two pad configurations. Table 3 indicates the best fitting equations which describe the relationship between static pressure drop as a dependent variable and pad thickness as an independent variable at each pad-face air velocity for all configurations of pad. The effect of pad thickness on the static pressure drop had the exponential equation as follows:

$$y = ae^{bx} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where;

y static pressure drop across the pad, Pa;

x pad thickness, cm and

a, b constants.

To study and design any evaporative cooling system, these exponential forms are important for simulation procedures. As listed in Table 3, the majority of exponential forms had a coefficient of determination (R^2) higher than 0.9153.

Table 3: Static pressure drop as a function of pad thickness for each pad-face air velocity at different pad configurations.

Pad configuration	Pad-face air velocity, m/s	Equation's constants		Determination coefficient (R^2)
		a	*b*	
Vertical	0.75	2.4102	0.1733	0.9347
	1.00	9.7707	0.1013	0.9533
	1.25	13.4930	0.0976	0.9153
Horizontal	0.75	8.7346	0.1070	0.9400
	1.00	16.8620	0.0806	0.9774
	1.25	23.0970	0.0694	0.7989
Multi-horizontal	0.75	13.4050	0.0968	0.9486
	1.00	25.5380	0.0631	0.9348
	1.25	35.8280	0.0519	0.8637

CONCLUSION

Based on the results of the present study, the following specific conclusions are drawn:

1) The maximum difference between the ambient and cooled air temperatures inside wind tunnel (the highest temperature reduction) was noticed at 15cm pad thickness and 1m/s pad-face air velocity for the multi-horizontal pad configuration. Contrariwise, the lowest one was found at 3cm pad thickness and 0.75m/s pad-face air velocity for the vertical pad configuration.
2) For the multi-horizontal pad configuration and pad-face air velocity of 1m/s, the highest average saturation efficiency was of 67.38, 78.09, 82.57 and 89.59% at pad thicknesses of 3, 7, 11 and 15cm respectively.
3) The highest required airflow rate was found at pad thickness of 15cm and 1.25m/s pad-face air velocity when applying the multi-horizontal pad configuration. Its values were of about 1.71, 1.78, 1.79 and 1.88m^3/s at pad thicknesses of 3, 7, 11 and 15cm successively for the multi-horizontal pad configuration and pad-face air velocity of 1m/s.
4) The highest static pressure drop was noted at 15cm pad thickness and 1.25m/s pad-face air velocity when applying the pad configuration of multi-horizontal. Therefore, its values were of about 31.39, 41.20, 45.13 and 70.63Pa at pad thicknesses of 3, 7, 11 and 15cm

respectively for the multi-horizontal pad configuration and 1m/s pad-face air velocity.

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الملخص العربي

تأثير شكل الوسادة على فاعلية نظام التبريد التبخيري داخل نفق هوائي

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تعتبر عملية التبريد التبخيري من أفضل نظم تهيئة البيئة خاصة لمباني الإنتاج الحيواني والداجنى وكذا البيوت المحمية خاصة عند تعرض هذه المنشآت لموجات حر شديدة في فترة الصيف. وقد تؤدى هذه الموجات الشديدة الحرارة إلى العديد من فواقد المنتج ، ويمكن تقليل هذا الفاقد الناتج عن الإجهاد الحراري وذلك باستخدام تصميمات ذات كفاءة أداء عالية من نظم

التبريد التبخيري. وفى جمهورية مصر العربية يعتبر نظام الوسادة والمروحة من أهم نظم التبريد التبخيري استخداما. لذا كان الهدف الرئيسي من هذا البحث هو دراسة تأثير ثلاثة أشكال مختلفة من الوسادة المستخدمة (الرأسي، الأفقي، والأفقي المتعدد) على فاعلية نظام التبريد التبخيري داخل نفق هوائي يحاكى نظام التبريد التبخيري ذو الوسادة والمروحة. تم أيضا دراسة أربع مستويات من سمك الوسادة وهى 3 ، 7 ، 11 ، 15سم وثلاث مستويات من سرعة هواء وجه الوسادة وهى 0,75 ،1,0 ، 1,25م/ث. تم استخدام قش الأرز كمادة للوسادة. أجريت التجارب بمركز ميكنة الأرز بميت الديبة ، محافظة كفر الشيخ خلال الفترة من 2007/07/11م حتى 2007/08/15م وتراوح متوسط قيم الانحراف القياسي لدرجات حرارة الهواء الجاف الخارجي أثناء هذه الفترة من 1,92 إلى 3,66^{5}م.

وقد تم التوصل للنتائج التالية:-

1) وجد أن أعلى قيم لخفض درجة حرارة الهواء الخارجي وأيضا أعلى فروق بين درجات حرارة الهواء الخارجي والهواء البارد (داخل النفق الهوائي) عند استخدام شكل الوسادة الأفقي المتعدد ، 15سم سمك الوسادة ، 1م/ث سرعة هواء وجه الوسادة ، بينما لوحظ أقل قيم لخفض درجة حرارة الهواء الخارجي وأيضا أقل فروق بين درجات حرارة الهواء الخارجي والهواء البارد عند استخدام شكل الوسادة الرأسي ، 3سم سمك الوسادة ، 0,75م/ث سرعة هواء وجه الوسادة.

2) أقصى كفاءة للتشبع لشكل الوسادة الأفقي المتعدد حوالي 67,38 ، 78,09 ، 82,57 ، 89,59% عند سمك الوسادة 3 ، 7 ، 11 ، 15سم على الترتيب وعند سرعة هواء وجه الوسادة 1م/ث.

3) أعلى معدل سريان هواء مطلوب عند استخدام شكل الوسادة الأفقي المتعدد ، 15سم سمك الوسادة ، 1,25م/ث سرعة هواء وجه الوسادة. حيث بلغت قيم معدل سريان الهواء المطلوب حوالي 1,71 ، 1,78 ، 1,79 ، 1,88م^3/ث عند سمك الوسادة 3 ، 7 ، 11 ، 15سم على الترتيب عند سرعة هواء وجه الوسادة 1م/ث لشكل الوسادة الأفقي المتعدد.

4) أعلى قيم للانخفاض في الضغط الإستاتيكى عند استخدام شكل الوسادة الأفقي المتعدد ، 15سم سمك الوسادة ، 1,25م/ث سرعة هواء وجه الوسادة. حيث بلغت قيم الانخفاض في الضغط الإستاتيكى حوالي 31,39 ،41,20 ، 45,13 ، 70,63باسكال عند سمك الوسادة 3 ، 7 ، 11 ، 15سم على الترتيب عند سرعة هواء وجه الوسادة 1م/ث لشكل الوسادة الأفقي المتعدد.

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