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Evaluating the Effect of New Local Materials of Evaporative Cooling Pads

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Abstract: The present study aimed to evaluate the feasibility of celdek pads, luffa pads, straw fiber pads and sackcloth pads as alternative pad materials. Experimental measurements were conducted and the experimental data were quantitative. The experimental work mainly focused on the effects of different types and thicknesses of evaporative cooling pads when used for changing the environmental conditions inside greenhouses. Moreover, the experimental work involved the measurement of environmental parameters *viz.,* temperature, relative humidity, air velocity and pressure drops at different times during the day, using the different thickness parameters of the evaporative cooling pads i.e., 50, 100 and 150 mm and the water flow rates through the pads. The data obtained from the experiments and measurements were analyzed using Statistical Package for the Social Sciences Results deciphered that there was a significant difference between evaporative cooling pad types and cooling efficiency. The Luffa pads yielded an average saturation of 73.67%, whereas other pads yielded the following average saturations: straw fiber pads 71.87%, celdek 70.33% and sackcloth 69%. However, there was a highly significant difference between the pad thickness and cooling efficiency. The results obtained for environmental factors, indicated that there was a significant difference between environmental factors and cooling efficiency. In terms of the effect of air velocity on saturation efficiency and pressure drop, higher air velocity decreases saturation efficiency and increases pressure drop across the wetted pad. Finally, the present study indicated that the luffa pads perform better than the other evaporative cooling pads and have higher potential as wetted-pad material.

Key words: Greenhouses · Temperature and humidity · Heating and ventilation · Greenhouse technology · Greenhouse applications

INTRODUCTION

A greenhouse is a structure used for protecting plants from adverse climatic effects and for supplying a favorable environment for plant production. This technique is necessary to overcome the high hazards of open field production, such as high rainfall, inters solar radiation, weed rivalry, as well as damages caused by diseases, insects, high temperature and relative humidity [1]. Therefore, in such regions, the reduction of air temperature inside a greenhouse or the regulation of the temperature closer to the ambient temperature during summer is necessary for successful crop production. The growth conditions in a greenhouse system are usually achieved by monitoring effective growth factors, such as carbon dioxide, temperature, relative humidity, light and radiation. Greenhouses offer a better possibility for the off-season production of many crops [2]. The increase in air temperature inside a greenhouse with a prevailing high outdoor air temperature in the tropics will stress the greenhouse crops [3]. Thus, lowering the air temperature is a major concern for tropical greenhouse climate management. During the hot season, the temperature of ambient air inside greenhouses and animal houses increases to over 40°C because of thermal stress [4]. In greenhouses, thermal stress negatively affects the emergence, stem strength, flowering and fruit set and sizes of seedlings. High air temperatures in animal houses decreases feed consumption, weight gain and milk and egg yields of animals [5]. In several countries,

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the trend of using fan-pad evaporative cooling systems in agricultural buildings is increasing, but the rate of this increase is inhibited by the high costs of commercial pad materials [5]. The use of evaporative cooling pads is a reliable method but requires the greatest power consumption. Evaporative cooling systems are based on the exchange of evaporated water from sensible heat to latent heat, where water is supplied mechanically. The decrease in air temperature is due to the evaporation of water in air. Thus, temperature decreases with increasing humidity, while the enthalpy of air remains constant during the process. Fan pads, fogging systems and roof evaporative cooling are some of the current evaporative cooling methods [6]. Commercially available cooling pads are expensive and accordingly, there is an urgent need to evaluate the performance of suitable locally available materials when used as cooling pads, particularly for rural agricultural buildings. In fact, many studies were carried out to evaluate the use of locally available materials as cooling pads, such as: expanded clay, sawdust, vegetable fiber and coal [7], discarded clay bricks, corn-cob and charcoal [8]; ground sponge, stem sponge, jute fiber and charcoal [9]. Moreover, the reported efficiency of some locally available materials was 79% for charcoal, 48% for hazelnut rind and 96% for wood shavings [10]; 89.6 to 92.8% for coir fiber [11]; 47.22% to 85.51% for fine fabric and 63.88 to 86.32% for coarse fabric [5]; 39.9% for palm fiber, 62.1% for jute [12]. Cellulose pads expanded clay and vegetable fiber were recommended as pad materials for evaporative cooling systems by Tncoco *et al*. [7]. On the other hand and according to the results of the study by Dzivama *et al*. [9], stem sponge showed superior pad material qualities compared to ground sponge, jute fiber and charcoal. Gunhan *et al*. [13] evaluated the suitability of some local materials such as pumice stones, volcanic tuff and greenhouse shading net as cooling pads. They found that volcanic tuff was a good alternative pad material. It gave an evaporative saturation efficiency of 63-81%. Ahmed *et al*. [14] studied sliced wood, straw and celdek cellulose as materials for evaporative cooling pads. Sliced wood pads have more cooling efficiency and crop productivity under greenhouse conditions. From the research studies mentioned above, it become clear that there are no studies about luffa and straw fiber and sackcloth as wetted pad materials. In addition, both pads materials mentioned above are low cost and easy-to-find in world. Therefore, we consider using those materials as evaporative cooling pad in terms of saturation efficiency and pressure drop across wetted pad. Therefore the present study mainly aims to study the evaporative cooling efficiency and environmental factors of celdek pads, luffa pads, straw fiber pads and sackcloth pads as wetted pads in evaporative cooling system. In order to achieve this aim, the following objectives are proposed: To determine the effects of different types and thicknesses of local evaporative cooling pads on the cooling efficiency inside a greenhouse. To assess the optimum water flow rate for the different types and thicknesses of the selected evaporative cooling pads.

MATERIALS AND METHODS

Sudan is located in the northeast part of the African Continent, has many states, this study in Gezira state, it is located in central Sudan between Blue Nile flowing east from Tanah lake from Ethiopia and white Nile flowing westfrom Victoria from Uganda. This study was conducted in the Gezira University in Wadmedani town, Gezira State, Sudan (14° 23'N, 33° 29'E, 405 m above sea level) (Fig. 1).

Fig 1: Map of republic of Sudan showing the location of Wedmedani.
Source: www.thecombtravel.com

To achieve the objectives of this research endeavor an experiment was carried out to evaluate the effects on cooling efficiency of greenhouses when using different types and thickness of local evaporative cooling pads and also the effect on environmental factors such as temperature, relative humidity, air velocity and pressure drops and also effect of the water quantity during the summer period. The experimental work was mainly concerned about the effect of types and thickness of evaporative cooling pads (namely: celdek cellulose, straw fiber, Sackcloth pads and luffa sponges pads), when used to change environmental conditions inside the greenhouses. All experiments were conducted in steady state and all of the tests were achieved in triplicate. The experimental work involve measurement of both environmental parameters (temperature and relative humidity and air velocity and evaporative cooling pads using [celdek cellulose (CP), straw fiber (SP), Sackcloth pads (SaP) and Luffa sponge pads (LSP)] as wetted pads media with different thickness i.e., 50, 100 and 150mm and water flow rates through the pads and four levels of air suction velocity *viz.,* 0•7, 1•0, 1•5, 1•75 m s^{-1}. The measurements were taken from 10 am to 3pm during the day, this periodrepresents themaximum temperaturesinsummer were investigated. Each pad material was filled independently in especially galvanized iron frames to make an evaporative sealed unit. The thicknesses were 50, 100 and 150 mm. The front and the back faces of the cartridges were covered with iron wire sieve and it size was 10mm by 10mm during the tests, measurement sections and evaporative pad sealed units were inserted into special frames that were placed in the wind duct and the connection edges sealed against air escape andthe other part ofthe wind ductexposed ofoutdoor airconditions,so that theairinsideof the ductandpassingon the padsis the same asthe outside air. The water inlet was fixed on the top of this frame and the water was distributed over the upper face of the evaporative pad sealed unit by a tube, the water evenly onto the pad face. During the experiments, drained water was collected in a tank and re-circulated by a centrifugal pump. The evaporative pads were wetted before each test and the recording of the measured data was started at least 10 min after each test run started. The cooling efficiency was measured tunnel system under a steady-state condition. The test section was designed to accommodate 50, 100 and 150 mm thick sealed units of the test pads. Measurement sections were spaced 1500 mm apart from each face of the pad sealed units. Each measurement section contained the measuring points including dry bulb temperature and the relative humidity of air. In each section there were five hygrometers and all hygrometers were calibrated before recording the data of temperature and relative humidity inside and outside. Air velocity in the wind duct was measured by vane-type anemometer. Its measuring range was 0.7 to 1.75ms^{-1} and accuracy was ±0•1 ms^{-1} Anemometer was placed 1500 mm away from the face of the pads. The static pressure drop of the airflow during the passing through the pad media was measured by using Anemometer all these devices were calibrated before testing started. The cross-sectional shape of the air duct was a hollow rectangle. The surfaces of the duct were made of transparent Plexiglas sheet for easy viewing, inside of the duct has a cross-section of 300 mm by 300 mm and a length of wind duct was 1.5 m an axial suction fan of 500 mm diameter driven by a 3-phase electric motor was fitted at one end of the duct and the distance between the fan and discharge face of the pad was 2 m. The velocity of the inside air of wind duct was controlled by changing the rotational speed of the fan.

Experimental Procedures: The experiments to determine the effects of types and thickness and water flow rate, air velocity on the evaporative cooling efficiency of the selected pad media *viz.,* celdek cellulose (CP), straw fiber (SP), Sackcloth pads (SaP) and Luffa sponge pads (LSP) were carried out at four levels of air velocity i.e. 0•7, 1•0, 1•5, 1•75 m s^{-1} and three levels of pad thickness i.e. 50, 100, 150 mm were studied. The evaporative saturation efficiencies of the pad media were determined by using the equation.

Statistical Analyses: Analysis of collected data was carried out by Statistical Package for the Social Sciences (SPSS) software version 16. One way ANOVAs and multiple regression and correlation analysis were carried out to determine the level of significance and combined effect of the parameters (thickness, water flow rate and pressure drops) on the evaporative saturation efficiency of the pad media.

Steady State of Analysis of Cooling Concepts: Thermal cooling of a greenhouse is required in the case of excess heat trapped inside the greenhouse. An excess heat trapped inside the greenhouse mainly depends on month of the year. The levels of cooling depend on the month of year. For more effective cooling other concepts namely roof, pad- fan cooling and earth air heat exchanger etc. Group one first zone includes (5. Chamber room,

6. Air inlet, 7.motor push the air, 8. Thermo hygrometers, 9. Water meter, 10. Water outlet, 11. Pump, 12. Water tank, 13. Pads frame). Group two second zone include (1. Power input (motor), 2. Exhaust fan, 3. Anemometers, 4. Water inlet (water pipe).

Evaporative Cooling Efficiency: This is defined as the ratio of the actual dry- bulb temperature reduction to the theoretical maximum at 100%. ASHRAE [15] showed that the efficiency is the ability to access coolant temperature dry air passing to the temperature wet or is the ability to access the coolant on the air passing through it to the saturation state. It is calculated as the following equation:

$$\mu = \frac{T_1 - T_2}{T_1 - T_{wb}} \times 100 \qquad (1)$$

Where:

μ = evaporative saturation efficiency in %.
T_1 = inlet dry bulb temperature °C.
T_2 = outlet dry bulb temperature °C.
T_{wb} = wet bulb temperature in °C.

The values of the T_{wb} were determined by using psychometrics chart.

RESULTS AND DISCUSSION

Effect of Water Flow Rate on the Cooling Efficiency of Different Pad Types and Thickness: The water rate flow selected in the present study showed a significant effect on cooling efficiency at 0.01 probability level. The amount of the selected water flow rates was enough to wet the pad area completely and thoroughly. Fig. 2 shows that LP produced higher water flow rate, followed by SaP, CP and SP. These results are in line with those reported by Dzivama *et al*. [9], wherein the cooling efficiency is increased with increasing water flow rate until the pads are suitably moist. This result also supports the idea of Gunhan *et al*. [13] that is; the amount of the selected water flow rates is enough to wet the pads completely and thoroughly. A significant difference was found between all different thicknesses of evaporative cooling pads and cooling efficiency ($p < 0.01$) (Fig. 3). This result could be attributed to the increase in evaporative cooling padthickness that increasedthepassing time of air and therefore reducedthe speed ofthe airflow and decreased pad porosity. Gunhan *et al*. [13] obtained similar results. However, the increase in the rate of water flow increased the relative humidity and reduced the surface area exhibition to the air from the inlet.

Effect of Evaporative Cooling Thickness: The result indicated that there was a high significant relationship between cooling pad thickness and cooling efficiency ($r = 0.927$, $p < 0.01$). In addition, pad thickness was found to have a significant relationship with most of the environmental parameters and cooling pad thickness showed a positive relationship with relative humidity, water quantity and pressure drop. Increasing pad density improves the overall porosity and capillarity of the cooling pad, thereby producing a uniform distribution of water. However, higher water flow and high resistance to air flow is required. These results are in agreement with the study on evaporative cooling pad systems reported by Dhia [16]. Temperature, air velocity and thickness inside the greenhouse were negatively

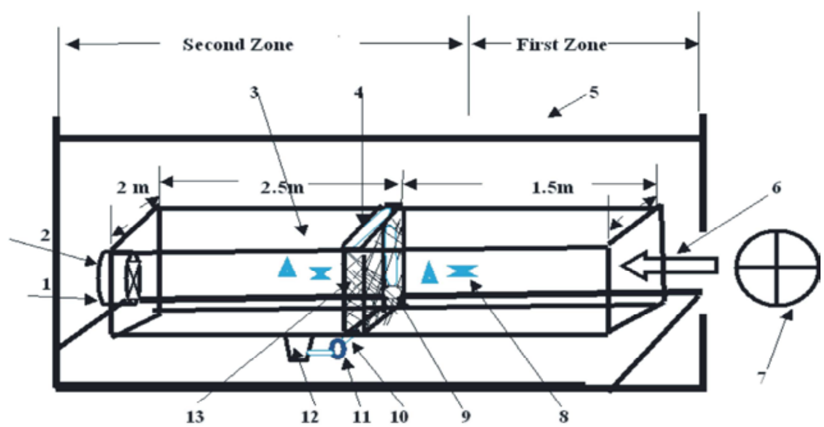

Fig 2: Scheme of Steady State.
1. Power input (motor), 2. Exhaust fan, 3. Anemometers, 4. Water inlet (water pipe), 5. Chamber room, 6. Air inlet, 7.motor push the air, 8. Thermo hygrometers, 9. Water meter 10. Water outlet, 11. Pump, 12. Water tank, 13. Pads frame.

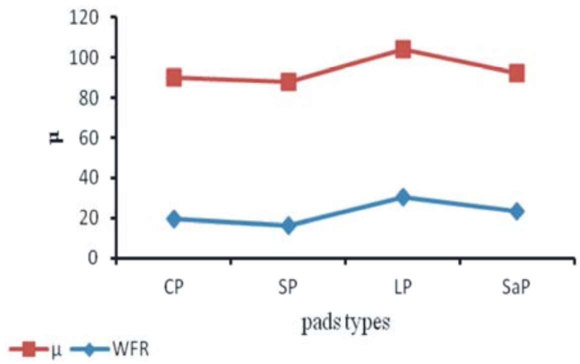

Fig 3: The effect of water flow rate on cooling efficiency according to pads types.

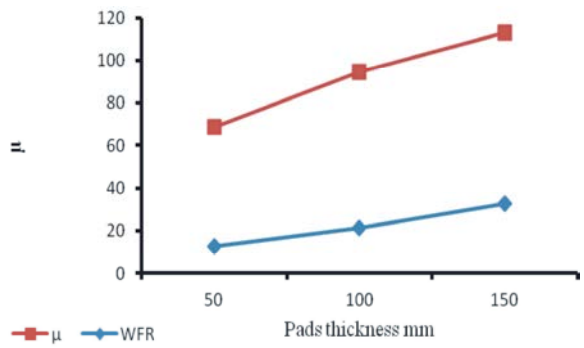

Fig 4: The effect of water flow rate on cooling efficiency according to thickness.

correlated. The saturation efficiency decreased with increasing air velocity and pad thickness. In addition, wetted pads with 150 mm thickness resulted in better saturation efficiency compared with those of 50 mm and 100 mm thickness because wetted pads with 150 mm thickness provide higher contact surface area between air and water. Lower air velocity provides more time for the air to contact and absorb the water from the surface of wetted pads. Thus, reducing air temperature and increasing water evaporation provides higher saturation efficiency. These results are also in line with those presented by Liao and Chiu [5].

Effect of Evaporative Cooling Pads Types on Cooling Efficiency: Table 2 shows the regression analysis used to evaluate the effect of cooling pad types on cooling efficiency inside the greenhouse. The type of cooling pad was found to have a significant effect on cooling efficiency inside the greenhouse. The type of cooling pad was found to be a significant parameter in predicting the cooling efficiency inside the greenhouse. Therefore, cooling is a 100% natural cooling process accomplished by the evaporation of water into air. Water is allowed to

Table 1: The effect of pads thickness on cooling efficiency.

	Evaporative saturation efficiency %			
Thickness mm	Celdek	Straw fiber	Luffa	Sackcloth
50	54^{a}	55^{a}	60^{a}	50^{a}
100	72^{b}	73^{b}	77^{b}	72^{b}
150	80^{c}	78^{c}	89^{d}	80^{c}

*The values with same letter not significantly difference at a probability, *p< 0.01.*

Table 2: Effect of cooling pad types on cooling efficiency.

	B	t	Sig.	VIF
Types	0.232	27.657	0.000	1.00
R^2	0.982			
F	697.657			
Sig. F	0.000			
Durbin-Watson	0.288			

flow down the pads at the same time as dry outside air is pulled across the pads, producing cool and fresh air. The unique flute design of the pads permits a very high surface area of the water to encounter an equally high surface area of air, thereby resulting in a very high evaporation rate. This evaporation efficiency is as high as 92% with 150 mm thick pads, which allows for large drop in dry bulb temperature as the energy required to evaporate the water into the air is taken from the air. The drier the outside air, the better the cooling effect achieved and the higher the humidity of the outside air, the lower the resultant cooling effect [17].

Effect of Evaporative Cooling Pad Types on Environmental Parameters: Table 3 proves that cooling pad types significantly affect other environmental parameters inside the greenhouse. Cooling pad types affected pressure drop (21.9%), water quantity and temperature inside the greenhouse.

Effect of Environmental Indoor Parameters on Cooling Efficiency: The results obtained are shown in Table 4. Environmental parameters explained 74.1% of the cooling efficiency inside the greenhouse. In addition, all parameters inside the greenhouse significantly affected cooling efficiency. These parameters include temperature, relative humidity, water quantity, pressure drop and air velocity inside the greenhouse. Regression analysis to examine the effect of environmental parameters on cooling efficiency inside the greenhouse was also shown in Table 4. It is found that environmental parameters explained 74.1% of cooling efficiency inside the greenhouse (R^2= 0.741, F= 39.708, p<0.01). However, it was also found that all parameters inside the

Table 3:Effect of cooling pad types on environmental parameters.

Parameters	R^2	F	Sig. F	B	t	Sig.
T in	0.149	20.617	0.000	-0.530	-4.541	0.000
RH in	0.212	15.447	0.000	3.630	1.203	0.000
WFR	0.082	10.596	0.001	2.524	3.255	0.001
AV in	0.092	11.244	0.002	0.606	2.494	0.002
Pa	0.219	32.999	0.000	19.135	5.745	0.000

* Correlation is significant at the 0.01 level (2- tailed).

Table 4: Effect of environmental parameters to cooling efficiency.

	B	t	Sig.	VIF
T in	-1.614	-6.787	0.000	1.952
RH in	0.379	3.665	0.000	1.615
WFR	0.321	3.709	0.000	2.677
AV in	0.244	2.598	0.001	1.589
Pa	0.351	3.622	0.000	2.820
R^2	0.741			
F	39.708			
Sig. F	0.000			
Durbin-Watson	0.672			

*Correlation is significant at the 0.01 level (2-tailed).

greenhouse can be a significant predictor on cooling efficiency, that are temperature inside the greenhouse (B= -1.614, t= -6.787, $p<0.01$), Relative humidity inside the greenhouse (B= 0.379, t=3.665, $p<0.01$) and water quantity (B= 0.321, t= 3.709, $p<0.01$), drops pressure inside the greenhouse (B=0.351, t=3.622, $p<0.01$) and air velocity inside the greenhouse (B= 0.244, t= 2.598, $p<0.01$).

Suitable Evaporative Cooling Pad Media for Cooling Efficiency: Generally, an evaporative cooling pad system must reduce the air temperature to the preferred point using the least power consumption and expenses. Thus, the suitable pad media must have the highest evaporative cooling efficiency and lowest airflow resistance. Thus, when choosing the optimal pad media for cooling systems of agricultural buildings, the evaporative efficiency and resistance against airflow of the pad materials must be considered. The data on the highest evaporative cooling efficiency and working condition of the selected pad materials. ACME [18] reported that high capacity fans used for aeration and ventilation of glasshouses and poultry houses generally generate a total pressure of approximately 30 Pa. This situation must be taken into consideration when selecting pad materials for evaporative cooling system of these buildings. In all test conditions, the pressure drop values of the air through SaP were observed to be less than 30 Pa, whereas the other pads had high values more than 30 Pa.

CONCLUSION

In conclusion, analysis shows that the pad type significantly affects the cooling efficiency. Luffa pads (LPs) had higher saturation efficiencies compared with the straw fiber (SP), celdek (CP) and sackcloth (SaP) pads. Moreover, the current study proves that pad thickness also has a highly significant effect on cooling efficiency. The results show that thicker pads of 150 mm have efficiencies higher than those of 50 and 100 mm. With regard to the second objective, the results indicate that most environmental factors, particularly temperature and pressure drops, significantly affect the performances of different pad types. Moreover, the current study shows a highly significant relationship between pad thickness and all environmental factors. Pad type, water flow rate and pad thickness were proven to affect efficiency. The efficiency increased when the pad thickness and water flow rate were increased. Moreover, it was found to be significantly related to other environmental factors, such as temperature and relative humidity. It increased when the pressure drops and air velocity increased. The focus of the current paper is on the effect of environmental factors on cooling efficiency and the evaluation of new materials that could be used as local evaporative cooling pads. The following are hereby recommended for future studies. LPs for cooling greenhouses should be used for the following reasons: (1) to provide better temperature and relative humidity conditions, pressure drops and water flow rates inside greenhouses; and (2) to achieve the best saturation efficiency.

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