Biosystems Engineering (2007) **96** (3), 369–377
doi:10.1016/j.biosystemseng.2006.12.001
SE—Structures and Environment

Evaluation of the Suitability of Some Local Materials as Cooling Pads

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(Received 13 December 2005; accepted in revised form 1 December 2006; published online 25 January 2007)

The objective of this study was to evaluate the suitability of pumice stones, volcanic tuff and greenhouse shading net as alternative pad materials to the widely used and commercial one called CELdek. For this purpose, the tests were carried out at four levels of air velocity (0·6, 1·0, 1·3 and 1·6 m s^{-1}) four levels of water flow rate (1·0, 1·25, 1·5 and 1·75 l min^{-1}) and three levels of pad thickness (50, 100 and 150 mm). The tests were made at 30 ± 1 °C and 40 ± 1% relative humidity air conditions. The temperature of water flow was kept constant at 25 ± 2 °C during the tests. According to the results of this study, it can be stated that the volcanic tuff pads are good alternatives to the CELdek pads at 0·6 m s^{-1} air velocity.

1. Introduction

Protected agricultural production is mainly limited due to constraints imposed on the crops and animals by nutrient elements, pathological factors, environmental conditions, *e.g.* environmental conditions of agricultural buildings have a major effect on the quantity and quality of the product. The parameters of the environmental conditions are temperature, relative humidity, light intensity, concentration of some harmful gases in the ambient air (Fehr *et al.*, 1983; Al-Amri, 2000).

In hot climates during the summer months the temperature of the air inside the agricultural buildings can easily exceed 40 °C (Bucklin *et al.*, 1993). During the hot season of the south and west part of Turkey and other Mediterranean countries the temperature of ambient air inside the greenhouses and animal houses increases to over 40 °C causing thermal stress (Dağtekin *et al.*, 1998; Öztürk, 2003). In greenhouses, thermal stress affects stem strength, seed insemination, fruit set and size and flowering negatively. High air temperatures in animal houses reduces feed consumption, decreases weight gain, milk and egg yields (Bird *et al.*, 1988; Huhnke & Harp, 1991; Al-Amri, 2000). For these reasons, various systems have been developed to reduce air temperature and alleviate thermal stress of plants and livestock. The use of evaporative cooling can reduce such temperatures by 4–13 °C (Dağtekin, 1996; Uğurlu & Kara, 2000; Öztürk, 2003). The evaporative cooling system has been accepted effective, practical and economically feasible under hot and arid climatic conditions for many poultry houses and greenhouses (Abdalla & Narendran, 1991; Chraibi *et al.*, 1995; Tinoco *et al.*, 2001; Liao & Chiu, 2002).

Evaporative cooling is a process that reduces the temperature of air by the evaporation of water in the air stream. Heat in the air which is blown across a wet surface (pad) is utilised to evaporate the water, resulting in a reduction in the dry bulb temperature of air and a corresponding increase in the relative humidity. It is an adiabatic exchange of sensible heat to latent heat. Thus, evaporative cooling is generally more efficient where air temperature is high and relative humidity low (Bucklin *et al.*, 1993; Dzivama *et al.*, 1999).

In Turkey, the tendency to use fan-pad evaporative cooling systems in agricultural buildings is increasing, but the rate of this increase is inhibited because of the high cost of the commercial pad materials (CELdek). This seems to be true for many countries (Mekonnen, 1996; Al-Massoum *et al.*, 1998; Chunchai, 1998; Dzivama *et al.*, 1999; Tinoco *et al.*, 2001; Liao & Chiu,

Notation

h	thickness of pad, mm	v	air velocity, m s^{-1}
Q	water flow rate, l min^{-1}	ΔR_H	average relative humidity increase, %
T_1	inlet dry bulb temperature, °C	ΔT	average temperature drop, °C
T_2	outlet dry bulb temperature, °C	η	evaporative saturation efficiency, %
T_{wb}	wet bulb temperature of the inlet air, °C		

2002; Al-Sulaiman, 2002). Therefore, there is a need to evaluate the locally available cheap materials using as pads, particularly in rural agricultural buildings. For this reason, there are many previous studies on locally available materials were evaluated to provide alternative pad media. Some of the important previous studies on locally available pad materials can be listed with their evaporative cooling efficiencies in brackets as cardboard (79%), hazelnut rind (48%) and wood shavings (69%) (Dağtekin *et al.*, 1998); expanded clay, sawdust, vegetable fibre and coal (Tinoco *et al.*, 2001); discarded clay brick, corn-cob and charcoal (Chunchai, 1998); clay particles, wood shavings and sack (Mekonnen, 1996); ground sponge, stem sponge, jute fibre and charcoal (Dzivama *et al.*, 1999); coir fibre (89·6–92·8%) (Liao *et al.*, 1998); fine fabric (47·22–85·51%) and coarse fabric (63·88–86·32%), polyvinyl chloride (PVC), sponge (Liao & Chiu, 2002); palm fibre (38·9%), jute (62·1%) and luffa (55·1%) (Al-Sulaiman, 2002); aspen fibre (Al-Massoum *et al.*, 1998). Compared the cellulose pads, expanded clay and vegetable fibre were recommended as pad materials for evaporative cooling systems by Tinoco *et al.* (2001). According to the results of the study of Dzivama *et al.* (1999), stem sponge showed superior pad material qualities compared to the ground sponge, jute fibre and charcoal.

A pad material should be porous enough to allow free flow of air. It should be able to absorb water and allow evaporation. It should have maximum amount of wetted surface area for an adequate period of air water contact time to achieve near saturation. The material should be locally available and inexpensive. Moreover, it should allow easy construction into required shape and size (Liao *et al.*, 1998; Dzivama *et al.*, 1999). Bearing in mind these properties, some locally available materials such as pumice stones, volcanic tuff and greenhouse shading net were chosen as alternative pad materials for testing in this study. The evaporative cooling performances of these materials were not investigated in previous studies. The objective of the present study was to evaluate the performance of each material and to identify a suitable alternative to replace the use of commercial cellulose pads (CELdek).

Table 1
Some physical properties of selected pad materials for the present study

Material	*Particle size, mm*	*Moisture, %*		*Density, kg m^{-3}*	
		Dry	*Wet*	*Dry*	*Wet*
Pumice stones (coarse)	20–40	2·1	36	340	476
Pumice stones (fine)	10–30	2·1	36	360	504
Volcanic tuff	15–25	0·4	21	295	406

2. Materials and methods

2.1. *Materials*

Some physical properties of pumice stones and volcanic tuff pad that were selected as an alternative pad media are summarised in Table 1. The sun shading ratio of greenhouse shading net is 0·50 and the angles of the slope of the air and water paths of CELdek® are 30° by 60°.

2.2. *Method*

2.2.1. *Construction of the evaporative pads*

Each pad material was filled separately in specially galvanised steel frames to create an evaporative cartridge. The active surface area of these cartridges was 500 mm by 500 mm and the thicknesses were 50, 100 and 150 mm. The front and the back faces of the cartridges were covered with galvanised wire sieve. The size of the holes of the sieve was 8 mm by 8 mm. During the tests, evaporative pad cartridges were inserted into special frames that were placed in the wind tunnel and the connection edges sealed against air leakage. The water inlet was fitted on the top of this frame and the water was distributed over the upper face of the evaporative pad cartridge by a tube, with many holes to drip the water evenly onto the pad face.

A drainage hole was also made in the bottom of this frame. During the experiments, drained water was collected in a tank and re-circulated by a centrifugal pump through an adjustable gate valve and flexible tube.

The water flow rate was changed with the adjustable valve. The temperature of the water circulating through the pad was stabilised at 25 ± 2 °C.

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 in a laboratory wind tunnel system under a steady-state condition. The complete system is shown schematically in *Fig. 1*. The test rig comprises the following subsections: a steady-state test air conditioning chamber, a measurement section and an air duct.

The dimensions of the air conditioning chamber were 3 m by 3 m by 6 m and all of its surfaces were isolated to stop flow of heat. The chamber has an electrical heater (12·5 kW) and a steam generator (50 kg h^{-1}). All experiments were conducted at 30 ± 1 °C air temperature and 40 ± 1% humidity conditions that are the long-term averages of the summer months in Izmir–Turkey at 14:00 h. The heater and steam generator were operated and controlled automatically by the computer to keep the air temperature and humidity of the ambient air conditioning chamber under desired steady-state conditions.

The test section was designed to accommodate 50, 100 and 150 mm thick cartridges of the test pads. In the front and the back of the cartridges were the measurement sections. Measurement sections were spaced 500 mm apart from the each face of the pad cartridges (*Fig. 1*). Each measurement section contained the measuring points including wet and dry bulb temperature and the relative humidity of air. In each section there were nine copper–constantan thermocouples (T type) to measure dry and one for wet bulb temperatures and one hygrometer sensor (Hygrotest 600 ver.4. Testo GmbH&Co., Germany). One thermocouple junction wrapped with cotton gauze and wetted by siphon action for wet bulb temperature. All thermocouples were calibrated. The accuracy of the humidity sensors was ±3%. In each section thermocouples were located on the same cross sectional area with 150 mm apart. Sensors of the hygrometers were located in the middle of this area. Measurement of all points were centralised and logged on a data-acquisition system (PCL-818HG and PCLD-8115, Advantech Automation Corp., USA). Temperature control and data acquisition as well as the general supervision of the unit start-up and shutdown of the electric heater and injection of steam into the air were all done through the relay output board (PCLD-885, Advantech Automation Corp., USA) and GENIE data-acquisition software.

The pressure taps were located on the surfaces of the wind tunnel with 50 mm apart from the both faces of the cartridge. The static pressure drop of the airflow during the passing through the pad media was measured by using micro-manometer (Miniskop, Debro GbmH, Germany) with an accuracy of 0·01 mm [H_2O].

Air velocity in the wind tunnel was measured by vane-type anemometer. Anemometer was placed at the discharge side of the wind tunnel and 1500 mm away from the face of the pads. Its measuring range was 0–20 ms^{-1} and accuracy was ±0·1 ms^{-1}.

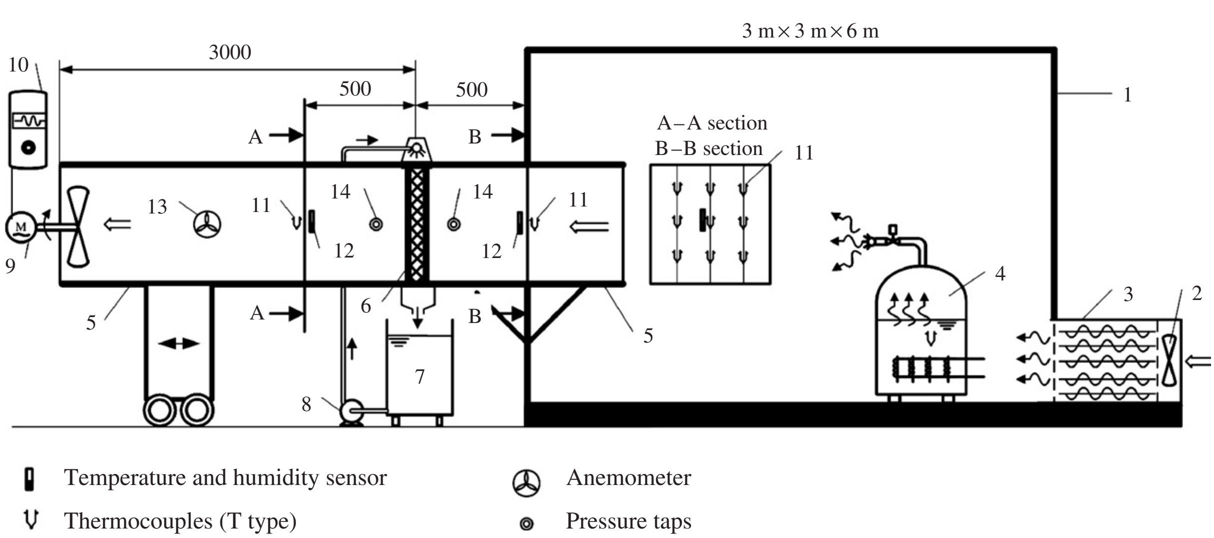

Fig. 1. Schematic representation of the steady-state test air conditioning chamber: (1) air conditioning chamber; (2) fan; (3) air heaters; (4) steam tank; (5) air duct; (6) pad material; (7) water tank; (8) centrifugal pump; (9) axial air suction fan; (10) electronic fan motor speed controller; (11) thermocouples (T type); (12) temperature and humidity sensor; (13) anemometer; (14) pressure taps

The cross-sectional shape of the air duct was a hollow rectangle. One of the surfaces of the duct was made of transparent Plexiglass sheet for easy viewing and the others were made of 20 mm thick wooden sheet. The inside of the duct has a cross-section of 500 mm by 500 mm and a length of 4 m (*Fig. 1*). An axial suction fan of 450 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 3 m. The velocity of the inside air of the wind duct was controlled by changing the rotational speed of the fan. The speed of the fan motor was changed and controlled by a special electronic device (Commander SE 2D20D220, Control Techniques, UK).

2.2.2. *Experimental procedure*

The experiments to determine the effects of the water flow rate, air suction velocity and pad thickness on the evaporative cooling efficiency of the selected pad media (coarse pumice stones, fine pumice stones, volcanic tuff, shading net and CELdek) were carried out. Four levels of water flow rate (1·0, 1·25, 1·5, 1·75 $l\,\mathrm{min}^{-1}$), four levels of air suction velocity (0·6, 1·0, 1·3, 1·6 $\mathrm{m\,s}^{-1}$) and three levels of pad thickness (50, 100, 150 mm) were investigated. All of the tests were achieved in triplicate.

The evaluation of the cooling performance of the selected pad media was done according to the two main criteria. The first criterion was the saturation efficiency and second was the static pressure drop.

The evaporative saturation efficiencies of the pad media were determined by using the following equation (Koca *et al.*, 1991; Kittas *et al.*, 2001; Al-Sulaiman, 2002; Öztürk & Başçetinçelik, 2002):

$$\eta = \frac{T_1 - T_2}{T_1 - T_{wb}} \tag{1}$$

where η is evaporative saturation efficiency in %; and T_1, T_2 and T_{wb} are inlet dry bulb temperature, outlet dry bulb temperature and wet bulb temperature in °C of the inlet air, respectively. The values of T_1 and T_2 are the averages of the temperatures that were measured by the thermocouples continuously during the experiments with the speed of 10 measurements per second for each one and recorded intermittently every minute during the experiments. The values of the T_{wb} for each T_1 and relative humidity of incoming air were determined by using Akton psychrometric chart (AKPSYCH3) software.

Duncan tests and multiple regression analysis were carried out to determine the level of significance and combined effect of the three parameters (thickness, water flow rate and velocity) on the evaporative saturation efficiency of the pad media.

3. Results and discussion

3.1. *The effect of air suction velocity on the evaporative saturation efficiency*

According to the effects of the air velocity on the evaporative saturation efficiency of pad materials, the pads can be listed from the highest efficiency to the lowest as

fine pumice stones > volcanic tuff > coarse pumice stones > CELdek > shading net

The 150 mm fine pumice stones pad has the highest efficiency (93·1%) at 1·75 $l\,\mathrm{min}^{-1}$ water flow rate and 1·0 $\mathrm{m\,s}^{-1}$ air velocity condition.

The results indicated that the evaporative saturation efficiency of the pads decreases slightly with the increase of air suction velocity from 0·6 to 1·6 $\mathrm{m\,s}^{-1}$ except coarse pumice stones (*Fig. 2*). This negative relationship between air velocity and saturation efficiency is statistically significant for the pads at a thickness of 50 mm (probability $P<0{\cdot}05$), but it is not significant for the thicker pads at 95% probability level. Generally higher efficiencies are obtained with thicker pads, and slower air velocities. This result reflects greater evaporative rates as air takes more time to travel through the pad (Dai & Sumathy, 2002).

Depending on the relationship between evaporative saturation efficiency and air suction velocity, mentioned above, temperature drop of air passing through the pad decreases with the increase of air velocity and increases with the increase of pad thickness approximately 4–9 °C as shown in Table 2.

The relative humidity of airflow increases as it passes through the pad media as the result of evaporation. The results of the measurements of the relative humidity indicated that relative humidity difference increases with the increase of the thickness of pad and decreases with the increase of air velocity approximately 28–59% as shown in Table 2.

During the tests, velocities greater than 1·3 $\mathrm{m\,s}^{-1}$ tended to pull free water into the air stream.

3.2. *The effect of water flow rate on the evaporative saturation efficiency*

The results of the tests conducted to evaluate the effects of the water flow rate on the evaporative saturation efficiency of pad materials indicated that there is no significant effect of the water flow rate chosen in present study on the saturation efficiency except the shading net at 95% probability level (*Fig. 3*). Some previous studies indicate that the saturation efficiency is increased with the increase of the water flow rate until the pad is sufficiently moist (Mekonnen, 1996; Dzivama

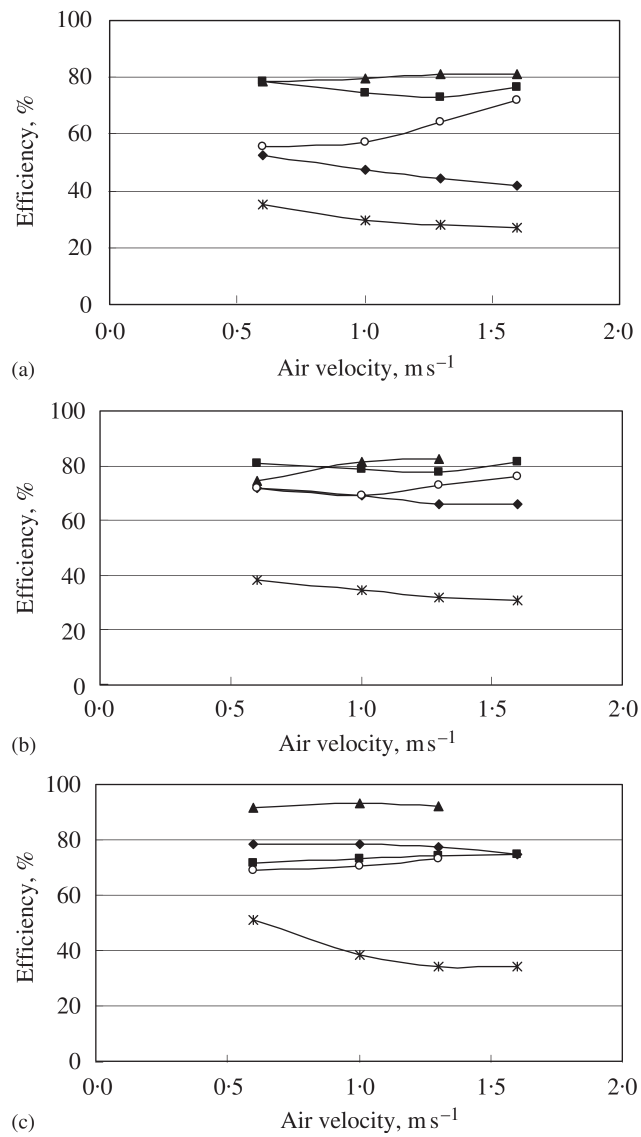

Fig. 2. The effect of air suction velocity on the evaporative saturation efficiency at 1·75 l min^{-1} flow rate and (a) 50 mm, (b) 100 mm, (c) 150 mm pad thickness; ◆, CELdek; ⁎, shading net; ■, volcanic tuff; ○, coarse pumice stones; ▲, fine pumice stones

et al., 1999). The result obtained in the present study show that the amount of the water flow rates chosen were enough to thoroughly wet all pads, except the shading net.

3.3. *The effect of pad thickness on the evaporative saturation efficiency of pads*

The results of the tests conducted to evaluate the effects of the pad thickness on the evaporative saturation efficiency of pad materials indicated that efficiency increases slightly with the increase of pad thickness. This result could be due to the fact that with thin pads, the porosity of the pad is enough to allow fast passage of air thus reducing the heat exchange period of evaporation. On the other hand, increasing the pad thickness reduces the porosity of pad and increase the passing time of air which increases the heat exchange period, subsequently improving the evaporation and cooling efficiency. These results were in agreement previous literature studies on evaporative cooling pad systems (Dzivama *et al.*, 1999; Liao & Chiu, 2002). The effect of the pad thickness on the saturation efficiency is significant at 99% probability level. The results of the Duncan's tests made by using the saturation efficiencies for each pad thickness for all test conditions are shown in Table 3.

3.4. *Static pressure drops of airflow through the pad*

The results of the tests conducted to evaluate the effects of the air velocity and the pad thickness on the static pressure drop of airflow are shown in Table 4.

The pressure drop values of the pads at 50 and 100 mm thickness are closer with respect to the 150 mm thick pads. This result is very similar to the results of the study done by Liao and Chiu (2002).

According to the effects of the pad materials on the static pressure drop of airflow, the pad materials can be listed from the lowest drop to the highest as shown below:

CELdek < shading net < volcanic tuff < coarse pumice stones < fine pumice stones

The pads made of both pumice stones have the highest airflow resistance with respect to the others and there is no significant difference between the resistances of these two pad media at the same thickness and same air velocity conditions ($P < 0{\cdot}05$).

The results indicated that the pressure drop values of airflow increases with the increase of air suction velocity (*Fig. 4*), and water flow rate (*Fig. 5*) significantly ($P < 0{\cdot}05$). Air velocity has the major effect on the pressure drop while the water flow rate has the minor.

3.5. *Choosing the suitable pad media for cooling systems*

It is expected that an evaporative cooling system must decrease the air temperature to the desired degree by minimum power consumption and expenses. Thus, an ideal pad media must have the highest evaporative saturation efficiency and the lowest airflow resistance. For this reason, when selecting the optimal pad media

Table 2
Average temperature drops ΔT and relative humidity increases ΔR_H, of airflow at 1·75 $l\,min^{-1}$ water flow rate

Air velocity, $m\,s^{-1}$	*Thickness, mm*	*CELdek*		*Shading net*		*Volcanic tuff*		*Coarse pumice stones*		*Fine pumice stones*	
		ΔT, °C	*ΔR_H, %*	*ΔT, °C*	*ΔR_H, %*	*ΔT, °C*	*ΔR_H, %*	*ΔT, °C*	*ΔR_H, %*	*ΔT, °C*	*ΔR_H, %*
0·6	50	4·97	37·21	2·67	17·82	5·92	55·29	4·49	44·90	6·57	58·34
	100	6·06	58·21	3·02	19·80	6·66	58·81	5·42	54·12	7·66	58·51
	150	7·34	58·78	4·42	29·51	5·49	52·92	5·67	49·77	8·54	59·01
1·0	50	4·69	33·58	1·92	12·54	5·77	45·64	4·32	36·61	6·34	51·41
	100	6·10	50·89	2·29	14·72	6·87	58·06	5·39	47·80	7·47	55·77
	150	7·22	58·88	3·42	23·94	5·61	48·33	5·82	48·09	8·90	59·14
1·3	50	3·91	28·83	1·72	11·54	5·51	42·52	4·31	35·96	6·10	47·32
	100	5·94	46·94	1·94	13·00	6·73	57·10	5·38	45·52	7·42	57·58
	150	6·98	57·70	3·10	19·77	5·91	47·64	5·99	52·41	8·66	58·93
1·6	50	3·99	27·38	1·96	12·29	5·26	40·36	4·12	34·62	5·99	45·99
	100	5·70	44·93	1·97	11·82	6·64	56·22	5·47	45·04	—	—
	150	6·38	53·21	3·38	20·53	5·98	47·81	—	—	—	—

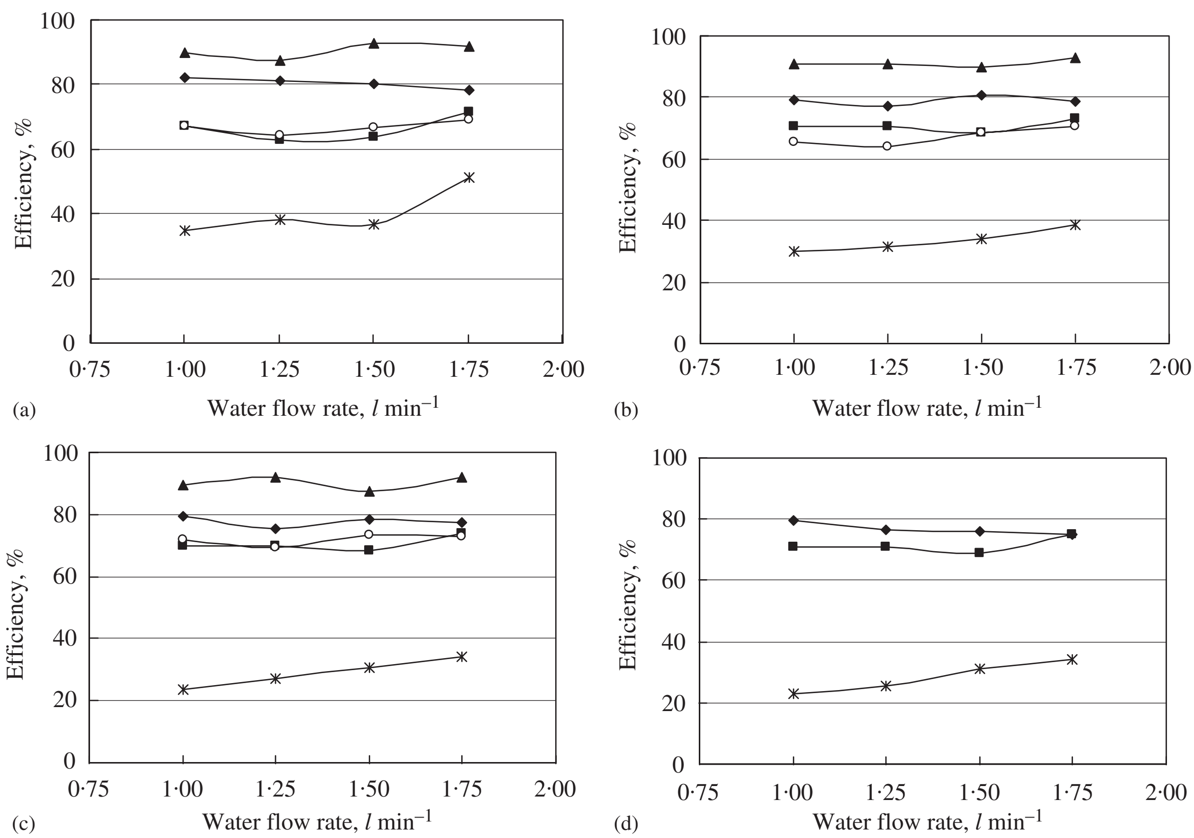

Fig. 3. The effect of water flow rate on the evaporative saturation efficiency at (a) 0·6 $m\,s^{-1}$, (b) 1·0 $m\,s^{-1}$, (c) 1·3 $m\,s^{-1}$, (d) 1·6 $m\,s^{-1}$ air velocity and 150 mm pad thickness; ◆, CELdek; ⁕, shading net; ■, volcanic tuff; ○, coarse pumice stones; ▲, fine pumice stones

for cooling systems of agricultural buildings evaporative efficiency and resistance against airflow of the pad materials must be considered together.

According to the data obtained, the highest evaporative saturation efficiency and the working condition of the selected pad materials are shown in Table 5.

Table 3
The effect of pad thickness on the evaporative saturation efficiency

Thickness, mm	*Evaporative saturation efficiency, %*				
	*CELdek**	*Volcanic tuff**	*Fine pumice stones**	*Coarse pumice stones**	*Shading net**
50	46·1[a]	68·0[a]	77·7[a]	56·1[a]	25·2[a]
100	68·3[b]	77·9[b]	79·0[b]	68·6[b]	30·0[b]
150	78·5[c]	69·7[c]	90·6[c]	72·1[c]	32·8[c]

*Values with the same letter are not significantly different at a probability, $P < 0{\cdot}01$

Table 4
Average pressure drop values of air flow through the dry pad media

Air velocity, m s^{-1}	*Thickness, mm*	*Pressure drop, Pa*				
		CELdek	*Shading net*	*Volcanic tuff*	*Coarse pumice stones*	*Fine pumice stones*
0·6	50	1·5	5·2	10·3	8·7	15·6
	100	1·8	12·2	10·8	11·8	19·8
	150	2·8	25·7	29·5	19·6	22·7
1·0	50	4·7	26·0	28·3	27·2	49·2
	100	6·4	38·0	31·9	36·7	56·8
	150	8·1	61·2	73·0	54·3	67·1
1·3	50	9·8	45·9	40·9	38·4	62·3
	100	11·0	55·1	46·5	57·7	83·6
	150	15·4	104·0	97·6	75·0	92·3
1·6	50	16·2	71·3	74·6	71·4	107·1
	100	18·4	84·7	84·3	107·2	148·4
	150	22·6	148·3	154·6	124·3	152·9

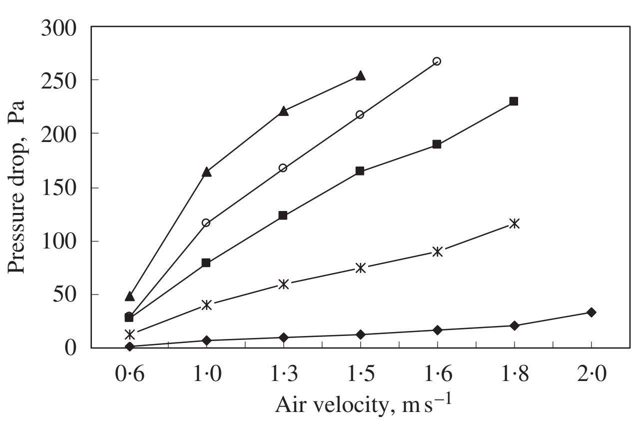

Fig. 4. The effect of air velocity on pressure drop at 1·0 l min^{-1} flow rate and 100 mm pad thickness; ◆, CELdek; ⁕, shading net; ■, volcanic tuff; ○, coarse pumice stones; ▲, fine pumice stones

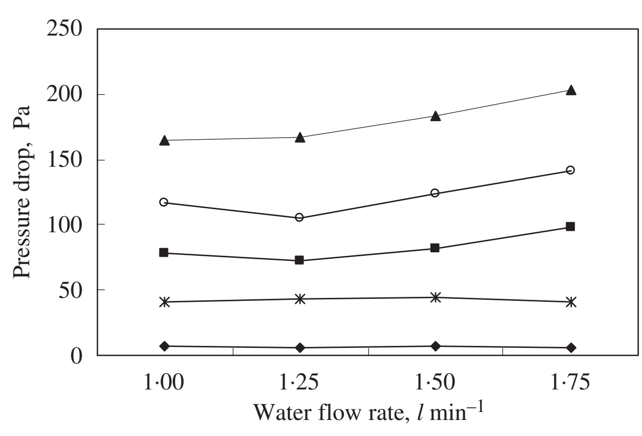

Fig. 5. The effect of water flow rate on pressure drop at 1·0 m s^{-1} air velocity and 100 mm pad thickness; ◆, CELdek; ⁕, shading net; ■, volcanic tuff; ○, coarse pumice stones; ▲, fine pumice stones

Since the high-capacity fans used for aeration and ventilation of the glasshouses and poultry houses generally generate total pressure at about 30 Pa (Nelson, 1978; ACME, 1995; Yağcıoğlu, 1999), this situation must be taken into consideration when choosing pad media for evaporative cooling systems of these buildings. In all test conditions, it was observed that the pressure drop values of airflow through CELdek were

Table 5
The highest evaporative saturation efficiency and the working conditions of selected pad media

Pad media	*Saturation efficiency, %*	*Pad thickness, mm*	*Air velocity, $m\,s^{-1}$*	*Water flow rate, $l\,min^{-1}$*	*Pressure drop, Pa*
Fine pumice stones	93·1	150	1·0	1·75	225·6
CELdek	82·1	150	0·6	1·0	2·9
Volcanic tuff	81·1	100	1·6	1·75	203·9
Coarse pumice stones	76·1	100	1·6	1·75	266
Shading net	51·3	150	0·6	1·75	38·1

Table 6
Average evaporative saturation efficiencies of volcanic tuff and shading net for three pad thickness (50, 100, 150 mm) and at 0·6 m s^{-1} air velocity conditions

Water flow rate, $l\,min^{-1}$	*Evaporative saturation efficiency, %*	
	Volcanic tuff	*Shading net*
1·00	65–77	31–37
1·25	63–76	29–38
1·50	64–80	27–37
1·75	72–81	35–38

less than 30 Pa, while the other pads had the airflow resistance less than the same level at 0·6 m s^{-1} air velocity conditions.

According to the results of the present study, it can be said that the most reliable pad media is commercial cellulose pads (CELdek) from the point of view of the high-evaporative saturation efficiency and the lowest-pressure drop level. To evaluate a mathematical model to determine the evaporative saturation effectiveness of the CELdek pads, an equation was developed by using statistical regression analysis and curve-fitting techniques, which is shown below

$$\eta = -2{\cdot}45\,Q - 5{\cdot}71\,v + 0{\cdot}32\,h + 41{\cdot}78 \qquad (2)$$

where: η is the evaporative saturation efficiency in %; Q is water flow rate in $l\,\mathrm{min}^{-1}$; v is air velocity in m s^{-1}; and h is thickness of pad in mm. The value for the coefficient of determination r^2 is 0·91 and the model is valid in the $1{\cdot}0 < Q < 1{\cdot}75\,l\,\mathrm{min}^{-1}$ water flow rate, $0{\cdot}6 < v < 1{\cdot}6$ m s^{-1} air velocity and $50 < h < 150$ mm pad thickness range.

The results also indicate that volcanic tuff and shading net can be considered as alternative pad materials instead of CELdek at 0·6 m s^{-1} air velocity working conditions. Shading net is less suitable than volcanic tuff because of the extremely low saturation efficiency level. As a comparison, the average minimum and maximum values of the evaporative saturation efficiency of the pads made by volcanic tuff and shading net at the suggested 0·6 m s^{-1} air velocity condition are shown in Table 6.

4. Conclusion

The following conclusions can be drawn from this study.

(1) The commercial cellulose pads (CELdek) have less than 30 Pa pressure drops in all conditions and approximately 80% evaporative saturation efficiency for 150 mm pad thickness. When this values take in to consideration CELdek shows the best pad material characteristics compared to the other four local alternative pad materials.
(2) Volcanic tuff is a good alternative pad material with a evaporative saturation efficiency ranging from 63% to 81% under the working conditions the airflow velocity is about 0·6 m s^{-1}. However, further investigations are required to optimise the particle size, the thickness of the pad and the static pressure of the system.
(3) The evaporative saturation efficiency increases with the increase of pad thickness but it decreases slightly with the increase of airflow velocity. For instance evaporative saturation efficiency values for 50, 100 and 150 mm pad thickness in CELdek were found 46·1%, 68·3% and 78·5%, respectively. No significant effect of the water flow rate on the saturation efficiency of the pads between the limits of the water flow rates was observed in this study.
(4) The pressure drop values of airflow increases with the increase of air suction velocity, pad thickness and water flow rate at significant level (probability $P < 0{\cdot}05$). Air velocity has the major effect on the pressure drop but the water flow rate has the minor. The pressure drop values of airflow through CELdek were less than 30 Pa in all conditions, while the others pads had the airflow resistance less than the same level at 0·6 m s^{-1} air velocity conditions.

Acknowledgements

This study was supported by the Ege University Scientific Research Unit (Project No. 2002 ZRF 008) and partly by the Ege University Science Centre (EBILTEM), Bornova- Izmir/Turkey.

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