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Design and Evaluation of Galvanized Metal Sheets as Evaporative Cooling Pads

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Abstract. Evaporative cooling systems using relatively expensive cellulosic paper pads are widely used in residential, commercial and agricultural buildings in Saudi Arabia. However, the fast minerals and dust build up shorten the useful life of these pads. This article describes the design and performance of new alternative non-cellulosic evaporative cooling pads made from galvanized metal sheets. Pad media and top water distribution bath arrangement in the new design differ from other commercially existing evaporative cooling systems. The sheets aligned vertically in a zigzag shape and the gap between the sheets is around 7.5 mm. Water drips from the top distribution bath over the pads through small holes. Outside the air is cooled by evaporating water droplets and moisture retained at the surface of the wetted sheets in the zigzagged air pathways. Performance of three pad's depths (0.15, 0.30 and 0.45 m) was tested. Each test lasted 24 hours and dry-bulb temperature and relative humidity of outside and conditioned air and reservoir's water temperatures were scanned and recorded every ten seconds. At the peak outside air dry-bulb temperatures, the averaged cooling efficiencies (η) at the pad depths of 0.15, 0.30 and 0.45 m were 76, 86 and 88%, respectively.

Introduction

Controlling thermal environment inside poultry houses and greenhouses in hot weather areas is very challenging. Removing excessive heat from the house requires using evaporative cooling pads, misting or fogging systems in conjunction with mechanical ventilation. In hot and dry climates such as the case in Saudi Arabia, evaporative cooling process is the most effective and economical technique of air conditioning. Many residential, industrial, commercial and almost all greenhouses and poultry production houses in Saudi Arabia are equipped with evaporative pad systems made of cellulosic paper [1, 2]. Evaporative cooling is achieved by bringing outdoor air in contact with the wetted medium. Sensible heat in the air is used to evaporate water in contact with the air. The dry-bulb temperature is reduced and humidity of the air is increased. The process is adiabatic because sensible heat is converted to latent heat [3].

The benefits of using cooling systems (pads, misting and fogging) in poultry houses were investigated [4-11]. These studies reported clear benefits of using evaporative cooling in reducing heat stress and ultimately enhancing poultry production.

Although the initial cost of installation of pad systems is very high compared to misting or fogging systems, the temperature reductions (outside-inside) and cooling efficiency are higher using pad systems [12]. Cooling efficiency of misting systems having water pressure ranging from 275 to 1380 k Pa were between 10 and 37% [13]. On the other hand, cooling efficiency ranged between 60 and 95% for a pad system installed in an inlet plenum [14].

Despite the widespread use of pads made of cellulosic paper, performance and useful life of these pads deteriorate very quickly due to using brackish water. The fast mineral, algae and dust build up lead to clogging the pads. The short life of these relatively expensive pads adds a high cost to the growers. Replacing the paper pads with low-priced pads material has been the goal of some researchers. Abdalla *et al*. was the first to try to make use of the abundant and very cheap dates palm leaves and fiber pruned-off trees annually in Saudi Arabia [15]. Al-Helal and Al-Towejeri and Al-Sulaiman studied the possibility of using dates palm leaves and fiber as an alternative to cellulosic paper pads. Results reported in these studies showed the cooling efficiency of palm fiber pads was comparable to cellulosic paper pads [16, 17]. However, these studies lack a long-term performance testing. The major downsides that prevent the commercial productions of palm leaves and fibers as cooling pads are fast clogging and rotten smells, which require frequent replacement of the pads. The main four characteristics to rate pads are cost, life, pressure drop and the cooling efficiency [18]. Liao and Chiu used two alternative pad materials made from coarse and fine fabric PVC sponge mesh. The cooling efficiencies for 15 cm pad thickness coarse fabric PVC sponge varied from 81.75 to 84.48%, whereas 76.68 to 91.64% for fine fabric PVC sponge [19].

Practical experience showed that pads made from cellulosic materials could not withstand the desert's harsh environment and the low-water quality in Saudi Arabia. The scope of this study was to design and evaluate the performance of non-cellulosic evaporative cooling pads made from galvanized metal sheets.

Materials and Methods

Evaporative cooling system design

Figure 1 shows the designed cooling system. The components of the system are pad media, electrical fan, water reservoir, floater, water supply pipe, electrical pump and top distribution bath. Pad media and top water distribution bath configuration in the new design differ from other commercially evaporative cooling systems. Pad media is made of galvanized metal sheets (0.3 mm thickness). Sixty-three sheets as shown in Fig. 2, aligned vertically in series to give a sharp crisscross as air enters between the sheets. Based on preliminary studies, it has been found that the optimum distance between sheets (gap) was around 7.5 mm. The height of the sheets is 0.50 m. An electrical pump transports water from the reservoir to the distribution bath along the top of the pads. Water drips from the top distribution bath over the pads through small holes. The diameter of each hole is around 1.2 mm and the holes spaced uniformly (1x2 cm). Unevaporated water drops directly back into the reservoir bath beneath the pads. An electrical fan draws warm air to enter through the gabs between the zigzagged sheets. As air flows past the moist pad surfaces, some of the moisture evaporates into the air stream. Heat is withdrawn from the air during this process and the air leaves the pad at a lower temperature with high moisture content.

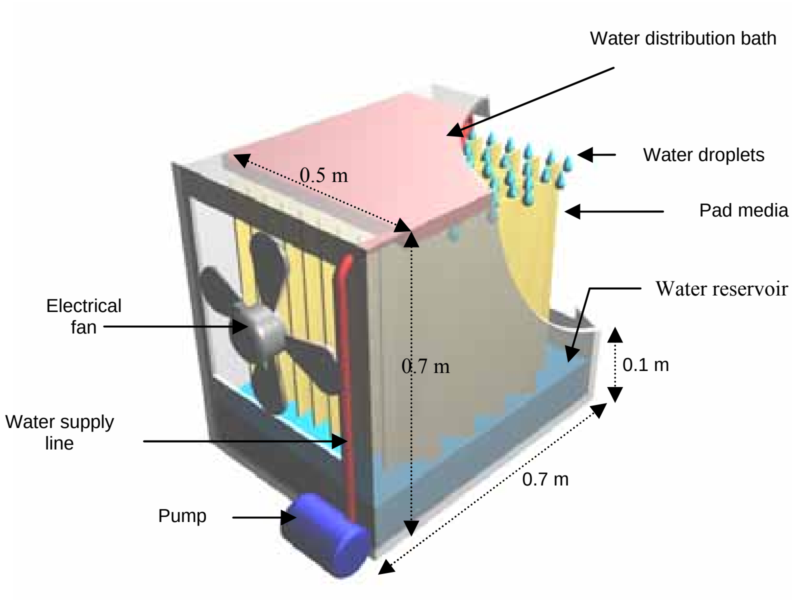

Fig. 1. Components and dimensions of the designed cooling system.

Experimental set-up

The performance of the cooling system was evaluated using the cooling efficiency indicator (η) based on the following equation [20]:

$$\eta = \frac{T_{db-o} - T_{cond.}}{T_{db-o} - T_{wb-o}} \times 100 \tag{1}$$

where:

T_{db-o}= Outside dry-bulb air temperature (°C);

$T_{Cond.}$ = conditioned air temperature (°C);

T_{wb-o}= Outside wet-bulb air temperature (°C).

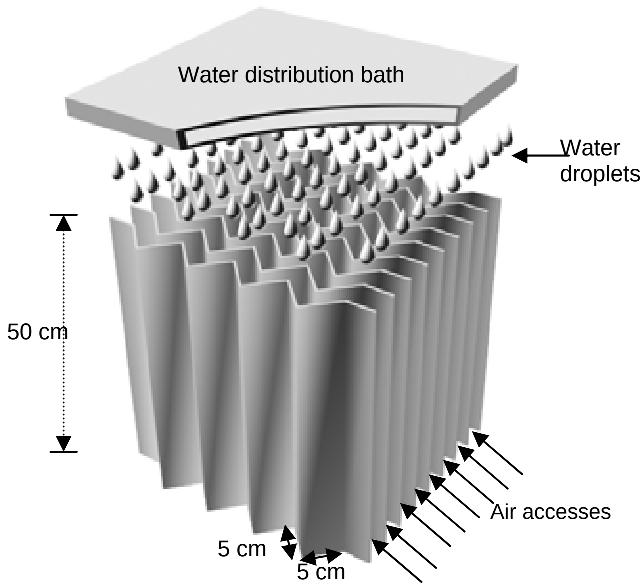

Fig. 2. Galvanized metal sheets pads aligned vertically in series to give a sharp zigzag shape. The air gap betweent he sheets is 7.5 cm.

A rule of thumb suggests that the longer the distance that air passes through wetted pads, the cooler the conditioned air and the higher the pressure drop. To determine the optimum depth of the cooling pad media, we conducted three trials to represent pad's depth of 0.15, 0.30 and 0.45 m. A 24-hour period was the length of each trial. Similar pattern of outside climate conditions were encountered during the three-day experiments (from 15 to 17 of July 2003). Experiments were carried under a shade in Riyadh City, Saudi Arabia, situated at 612 m above sea level (24.67.22N and 46.71.33E).

Measurements and data acquisition

Dry-bulb temperature and relative humidity of outside and conditioned air were measured using two temperature and humidity probes (HMP 45AC, Vaisala, Helsinki, Finland). The sensors were shielded to prevent direct radiation and water droplets from affecting the temperature and humidity readings. Water temperature in the reservoir was measured using temperature probe (107 Probe, Campbell Scientific, Logan, Utah). Sensors were connected to a datalogger (CR10X measurements control system, Campbell Scientific, Logan, Utah). Using the Outside dry-bulb temperature and relative humidity readings, dew point and wet-bulb temperature were calculated from the calculation module provided by the datalogger software program (SCWIN®). Cooling efficiency (η) defined by Eq. 1 was also calculated by the same program. During the trials operations, data were continuously sampled and recorded every 10 seconds. At the end of the trials, data were transferred to a PC for further processing. Air speed before and after its passage through the pads was measured using air velocity transmitter (EE65, ELEKTRONIK, Austria).

Results and Discussions

Figures 3, 4 and 5 show the diurnal changes of measured outside dry-bulb air temperature (T_{db-o}), conditioned air temperature ($T_{cond.}$), reservoir water temperature, calculated wet bulb temperature (T_{wb-o}) and the cooling efficiency (η) of pad's depth of 0.15, 0.30 and 0.45 m, respectively. Table 1 is a summary of minimum, maximum and average of the recorded environmental parameters and the cooling efficiency at the three pad's depths. Clearly, the figures and the table show the outside dry-bulb air temperature during the three-day trials repeated the same pattern with little variations from day to another. The average outside dry-bulb air temperature was around 38^{o}C and the minimum and the maximum temperature were around 31 and 45^{o}C, respectively. Outside relative humidity during the trials ranged from around 7 to 20% with an average of around 11%. Average conditioned air temperatures for pad depths of 0.15, 0.30 and 0.45 m were 22.95, 20.77 and 19.95^{o}C, respectively. Conditioned air relative humidity for pad depths of 0.15, 0.30 and 0.45 m were around 65, 77 and 78%, respectively. Averaged reservoir water temperature ranged from 18.87 to 19.48^{o}C for the three trials.

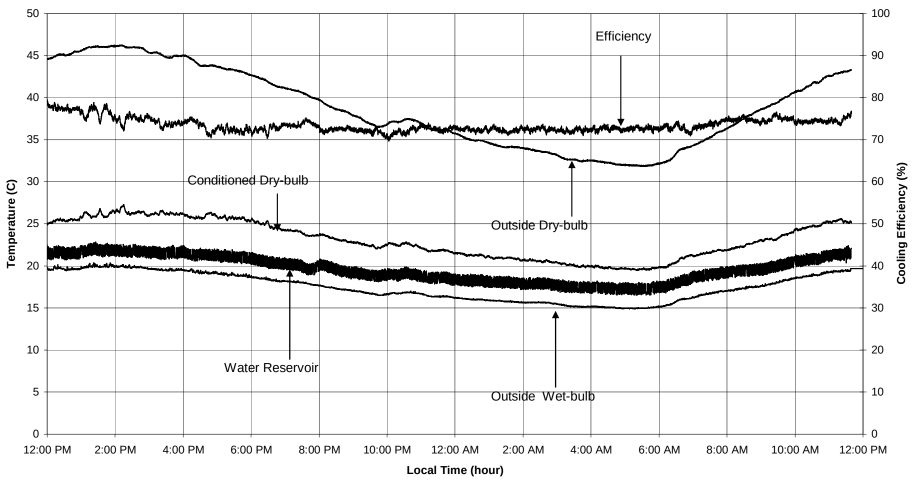

Fig. 3. Tiurnal outside dry and wet bulb air temperatures, conditioned dry-bulb temperature, water reservoir temperature, and cooling efficiency at 0.15 m pad's depth.

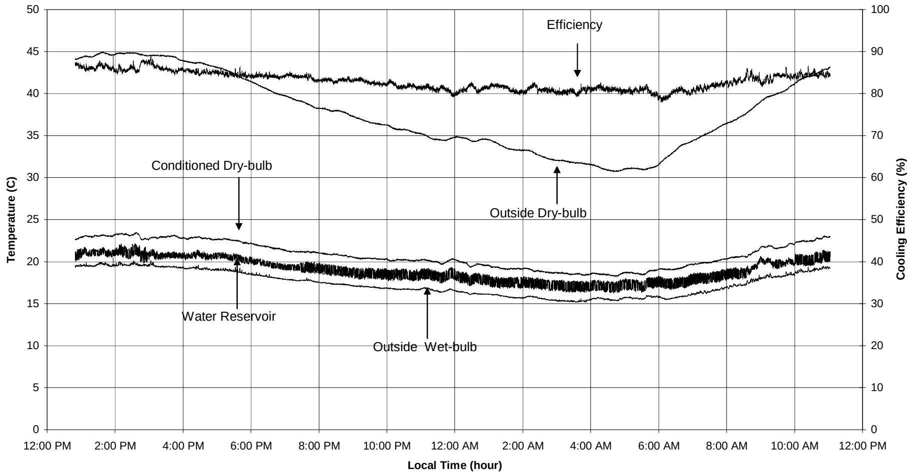

Fig. 4. Diurnal outside dry and wet-bulb air temperatures, conditioned dry-bulb temperature, water reservoir temperature, and cooling efficiency at 0.30 m pad's depth.

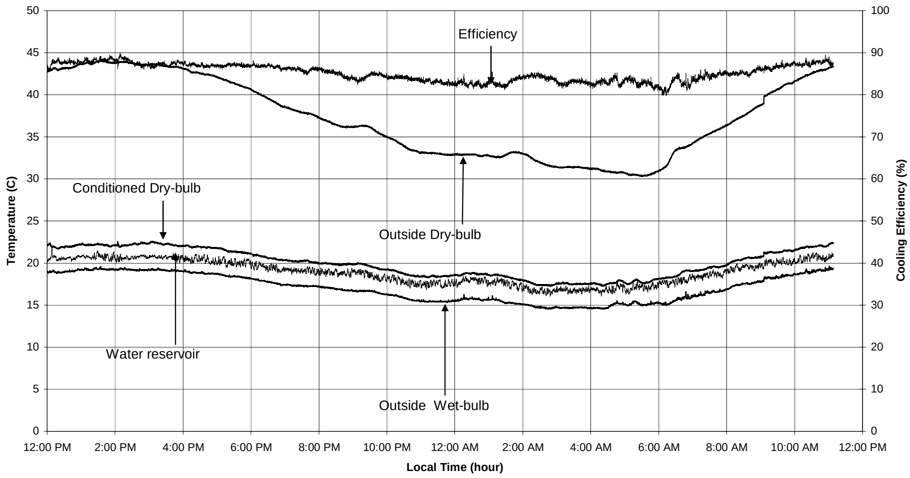

Fig. 5. Diurnal outside dry and wet-bulb air temperatures, conditioned dry-bulb temperature, water reservoir temperature, and cooling efficiency at 0.45 m pad's depth.

To determine if the pad depth has an effect on the cooling efficiency, two sets of data were analyzed by one-way analysis of variance (ANOVA) using (Minitab Inc., 1994). The first data set represents the cooling efficiency at the highest outside dry-bulb air temperature peak (from 12:47 PM to 1:46 PM), while the second data set represents the cooling efficiency at the lowest outside dry-bulb air temperature dip (from 3:45 AM to 4:44 AM). The difference between treatment group (pad's depth of 0.15, 0.30 and

Table 1. Minimum, maximum and average of the environmental parameters and cooling efficiency recorded during the three trials

	Pad's Depth (m)								
	0.45			0.30			0.15		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Outside dry-bulb temperature (°C)	30.3	44.15	37.18	30.7	44.95	37.66	31.8	46.26	38.42
Outside wet-bulb temperature (°C)	14.51	19.63	17.01	15.16	20.49	17.37	14.9	20.38	17.33
Outside relative humidity (%)	7.44	18.89	11.28	7.17	19.5	11.59	6.5	14.16	10.23
Conditioned dry-bulb temperature (°C)	17.21	22.6	19.95	18.25	23.46	20.77	19.45	27.28	22.95
Conditioned relative humidity (%)	69.34	85	78.15	69.8	82.8	77.19	52.97	73	64.68
Reservoir water temperature(°C)	15.89	22.33	18.87	16.24	22.17	18.96	16.53	22.82	19.48
Cooling efficiency (%)	79.9	89.8	85.17	77.9	89.3	82.92	69.7	78.8	73.29

0.45 m) means of 360 points were compared using Tukey multiple comparisons. Figure 6 shows the mean values of the cooling efficiency (±SEM) of the two data sets. It was clear that the pad depth has a significant effect ($P<0.0001$) on the cooling efficiency. Averaged conditioned air temperature decreased from 22.95 to 20.77°C and averaged cooling efficiency increased from 73 to 83% when pad depth increased from 0.15 to 0.30 m. However, when pad depth increased from 0.30 to 0.45 m, the degree of increase in cooling efficiency becomes smaller. Averaged conditioned air temperature decreased from 20.77 to 19.95 °C and averaged cooling efficiency only increased from 83 to 85%.

To test if there was a drop in pressure as air passed through the cooling pads, air face velocity at full fan speed was measured before and after air passed the pads. For the three trials air speed before the air passed the cooling pads was around 4 m sec^{-1} and after the air passed the cooling pads air speed ranged from 2.8 to 3 m sec^{-1}.

Conclusion

We presented in this work a novel design of evaporative cooling pads using non-cellulosic pads media. The tests in this study gave very good cooling efficiency results compared to reported results of commercial cellulosic pads. The cooling efficiency for the three pads depths ranged from 73% to 89%. In the new designed pads arrangement, it is easier to remove salt deposition and dust build up over the pads surfaces. Certainly, this will give longer useful life compared to the commercially available cellulosic pads. Metal sheets may not be the ideal choice of non-cellulosic media because they are heavy in weight and tend to corrode with time. However, the good results obtained from this study are the cornerstone that will help in our efforts to find the best viable alternative non-cellulosic pad's materials that are cheaper in price, lighter in weight, longer in useful life, as well as highly efficient in cooling than cellulosic pads.

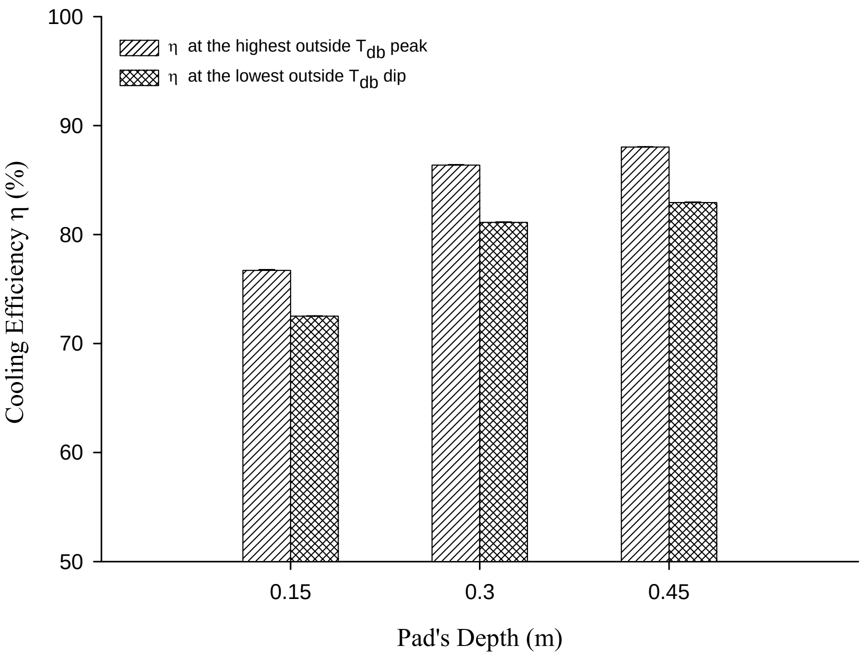

Fig. 6. The effect of different pad depths on evaporative cooling efficiency (η) at the highest and the lowest outside dry-bulb temperature (T_{db}) regions. The η values are mean ±SEM. η values are significantly different (P<0.0001) at different outside T_{db} regions and pad depths. n=360.

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تصميم وتقييم وسائد تـ يد تبخ ي مصنعة من ألواح صاج حديدي لفن

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** قسم الانتاج الحيواني و** قسم الهندسة الزراعية ، كلية علوم الأغذية والزراعة ، .جامعة الملك سعود ، الرياض*

(قدم للنشر في ١٤٢٥/٨/٤هـ؛ وقبل للنشر في ١٤٢٦/٢/٦هـ)

ملخص البحث. تستخدم وسائد التبريد التبخيري السيلولوزية ذات القيمة السعرية المرتفعة نسبياً على نطاق واسع في المملكة العربية السعودية لتبريد البيوت السكنية والمنشآت التجارية والزراعية، بيد أنه من الملاحظ أن العمر الافتراضي لهذه الوسائد يتناقص بدرجة كبيرة نتيجة لسرعة ترسب الأملاح والأتربة عليها، لذا فالغاية الأساسية من هذا البحث هو تصميم وتقييم وسائد بديلة للوسائد الكرتونية تصنع من مواد غير سيلولوزية (ألواح الحديد المجلفن). يختلف التصميم الجديد لنظام التبريد التبخيري عن تلك التجارية في نظام توزيع الماء العلوي وكذلك في المادة الوسيطة. صممت الوسائد باستخدام ألواح من الصاج الحديدي تم ثنيها بتعرجات حادة ومتساوية ومن ثم صفت الألواح عمودياً على مسافات متساوية. المسافة بين كل لوح وآخر ٧,٥ مم حيث يمر الهواء من خلال الأخاديد المتعرجة بين الألواح وتتم عملية التبريد برش الماء فوق وسائد التبريد من خلال الفتحات الصغيرة الموضوعة في أسفل الخزان العلوي، ونتيجة لتبخر قطرات الماء داخل هذه الأخاديد وملامسة الهواء للأسطح الرطبة فإن الهواء الخارج يكون ذا برودة منخفضة ورطوبة عالية، حيث تم عمل اختبار لثلاث أعماق ٠,١٥ و٠,٣٠ و٠,٤٥ م من هذه الوسائد وكانت مدة كل إختبار ٢٤ ساعة وفيها تم قياس درجة الحرارة الجافة والرطبة للهواء قبل وبعد مروره من خلال هذه الأخاديد وكذلك درجة حرارة الماء في خزان الماء كل عشر ثوان. وأظهرت النتائج أن كفاءة التبريد التبخيري عند أعلى درجات حرارة خلال اليوم لعمق ٠,١٥ و٠,٣٠ و٠,٤٥ م كانت ٧٦ و ٨٦ و ٨٨ ٪ ، على الترتيب.