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Experimental Performance Analysis of a Direct Evaporative Cooler

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ABSTRACT

In recent years, the direct evaporative cooler has been introduced because of low energy consumption and easy maintenance. The evaporative cooling system is useful in places where the climate is hot and dry. The objective of this work is to investigate the performance of an evaporative cooler in hot and humid regions. The performance of a direct evaporative cooling system is evaluated with different operating conditions. Rectangular shaped honeycomb cooling pads with a length of 26 cm, width of 20 cm and thickness of 5 cm is used as a cooling media. Parameters for the performance assessment were inlet temperature, saturation efficiency, cooler capacity, feasibility index and output temperature. The results showed that the output temperature of the air varies between 24.9° C and 26.7° C, while the cooling capacity is between 1.06 kW and 2.08 kW and saturation efficiency between67.23% to 77.27% is achievable. The results showed that evaporative cooling is achievable with feasibility index 11.86 ⩽ F*⩽ 17.84. The results show that the evaporative cooler can reduce dry bulb temperature up to a maximum of 7.6°C with relative humidity in the range of 68 % to 77%. The results also affirmed that cooler capacity and the saturation index are higher where the feasibility indexes are comparatively low.

Keywords:
Direct evaporative cooler; feasibility index; performance; saturation efficiency; cooler capacity

1. Introduction

The surrounding air temperature is gradually increasing day by day due to global warming, making its uncomfortable to stay in a room without a proper cooling system. Air conditioners are becoming a primary home appliance across the world to transform the indoor condition to the human comfort range. In order to establish human comfort zone, the indoor temperature and relative humidity play a major role. Room with a temperature of 25 ◦C and 55% relative humidity is considered to be under comfortable zone [1].

Evaporative cooling may offer an alternative to mechanical refrigeration cooling for air conditioning, depending on the climatic conditions and building load characteristics. This concept is enhanced again at the present status when energy-saving and environment-preserving are two subjects in all engineering fields due to its characteristics of zero pollution, energy efficiency, simplicity and good indoor air quality. The evaporative cooling is an energy-saving and

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environmentally friendly cooling technology where the heat is absorbed and the air is cooled through the water evaporation process.

An evaporative cooler is energy savings because the only power-consuming components are fans and water pumps. By only uses water as the working fluid, an Evaporative cooler also an environmentally friendly and energy-efficient [6]. Evaporative cooling methods can be divided into a direct evaporative cooling (DEC) and indirect evaporative cooling (IEC), depending upon whether the air is in contact with water or not.

Malaysia, located at 3°08'20.4"N latitude and 101°41'12.8"E longitude is an equatorial country with tropical climate conditions. A tropical climate country has fairly consistent weather conditions throughout the year, where the average daytime dry bulb temperature, wet bulb temperature, and relative humidity are 32°C, 25°C and 62 % respectively [4]. The lower relative humidity of daytime hours is indicative that evaporative cooling systems can potentially be used to lower indoor temperatures [7].

The need for indoor cooling in Malaysia is imperative for thermal comfort and conventional air conditioning system is used in majority of buildings. Air conditioning energy consumption accounts for 49% of total energy consumption in a typical office building in Malaysia [4]. Therefore, there is a need to study alternative cooling solutions that require lower operational energy, and evaporative coolers are a candidate. Direct evaporative coolers consist of a fan that actively passes air through a wet cooling pad; this effectively lowers the dry bulb temperature and aids thermal comfort. The process is considered adiabatic, meaning there is no heat gain, or heat loss, because sensible heat is converted to latent heat.

Many studies have dealt with the performance of direct evaporative cooling. In Malaysia Mohammad *et al.*, [11] have conducted “Experimental Performance of a Direct Evaporative Cooler Operating in Kuala Lumpur”. The result shows the output temperature of the air varies between 27.5°C and 29.4° C, while the cooling capacity is between 1.384 kW and 5.358 kW.

Julian Saw and Ong Rui Fong studied the Effects and Usefulness of Evaporative Cooling in Malaysia. The investigation was conducted to evaluate the effectiveness of evaporative cooling in providing human thermal comfort based on Fanger’s Predicted Mean Vote – Predicted Percentage Dissatisfied (PMV-PPD) method and Adaptive model in compliance with ASHRAE 55. The results show that the evaporative cooler can reduce dry bulb temperature up to a maximum of 6.6°C and suggest that evaporative cooling systems may be a possible cooling solution in Malaysia given the space has low heat gains.

Direct evaporative cooling efficiency effected by speed and the dry-bulb temperature of frontal air, and the temperature of the incoming water because decreased air velocity and incoming water temperature will increase with frontal air dry-bulb temperature [3].

Dai and Sumathy [19] used a mathematical model to predict and discuss the interface temperature of the falling film in a cross-flow direct evaporative cooler and results show that the system performance could be improved by optimizing the mass flow rates of the feed water and processed air, as well as the different dimensions of the pad.

The smaller the Feasibility index F* evaporative cooling number, the more feasible the evaporative cooling system [13]. It indicates the evaporative cooling potential to give thermal comfort. According to Watt [16], F* comfort cooling; 11 F* 16 for relief (lenitive) cooling and for F* >16 not recommended for the use of evaporative cooling systems. In Malaysia, average daytime F* is 18, just outside the recommended margins. Thus, Malaysian climate conditions are not favourable for evaporative cooling systems. This study seeks to experimentally study the effectiveness of direct evaporative cooling in providing thermal comfort.

2. Direct Evaporative Cooling (DEC)

The principle of DEC is to convert sensible heat to latent heat. Non-saturated air is cooled by heat and mass transfer, which increases by forcing the moment of air through an enlarged liquid water surface area for evaporation by using fans or blowers. Figure 1 shows the schematic diagram of direct evaporative cooling system where water is running in loop and the makeup water entering the sump to replace evaporated water must be at same adiabatic saturation temperature of the incoming air. In DEC, heat and mass transferred between air and water decreases the dry bulb temperature of air and increases its humidity, keeping the enthalpy constant in an ideal process.

An environmental condition such as inlet temperature and relative humidity, pad material, pad thickness and density, pad air face velocity and water flow in pads was the factors that affect the performance of the evaporative cooling system [12].

An evaporative cooler can become more effective when temperatures are high, relative humidity is very low, water is available for the purpose and air is conductive [14].

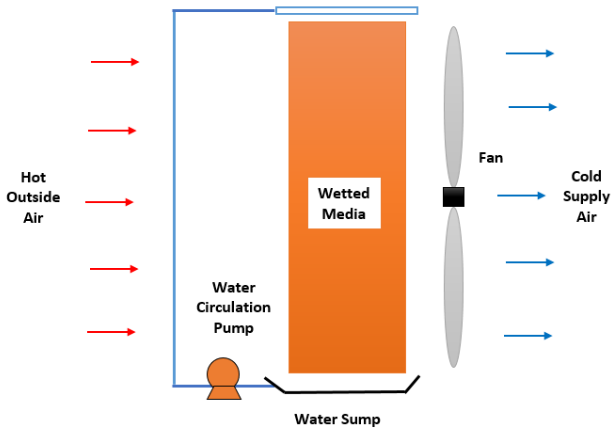

Fig. 1. Schematic diagram of direct evaporative cooler

3. Methods and Experimental Setup

The study was carried out in Kolej Komuniti Kota Marudu, Sabah at location of 6.0367°N, 116.1186°E and the measurement was taken between 10:00 am and 03:00 p.m. The experiment was conducted in the month of October. The direct evaporative cooling that was used for study consists consisted mainly of axial fan at the end of unit and a pump to sprinkle water on the upper side of the pad. Air passes through the unit in horizontal configuration. The evaporative cooling was made of metal sheet. A honeycomb cooling pad was used as cooling media with a length of 26 cm, width of 20 cm and thickness of 5 cm. The 21-Watt axial fan were made to run at around 2500 rpm and 10-Watt, 220 V AC submersible pump has a flow rate of 800 L/H.

Experimental tests were carried out to evaluate the performance of the direct evaporative cooling unit. To measure the air temperature and relative humidity at inlet and outlet points of the evaporative cooling unit, readings of the two type-K thermocouples with accuracy of ± 0.1°C as well as the, dry- and wet-bulb temperatures for ambient air were recorded using the sling psychrometer. Anemometer was installed at the inlet point of the evaporative cooling unit to measure the air velocity. The mass flow rate of air entering the evaporative cooling unit was determined by using the air velocity and the cross-section area of the inlet duct. Pyrometer was used to record the solar radiation in the test location.

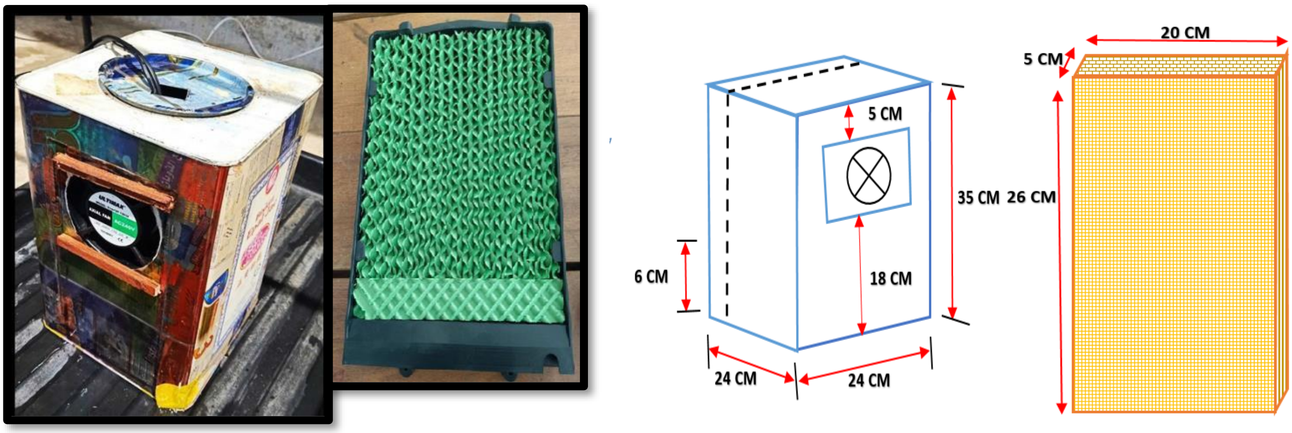

Fig. 2. Photograph of a direct evaporative cooling and its pad

4. Performance Evaluation

The DEC cooling efficiency (ε) is defined as the ratio of the air temperature difference and the difference between dry-bulb and wet-bulb inlet air temperatures, as shown in Eq. (1).

$$\varepsilon = \frac{T1 - T2}{T1 - Twb} \times 100 \quad (1)$$

The dry bulb temperature of the outlet air can be calculated using Eq. (2) [16].

$$T_2 = T_1 - \varepsilon_{DEC} (T1 - T_{wb1}) \quad (2)$$

Cooling capacity is the rate where the heat is removed, while temperature remains constant. Cooling load or cooling capacity is calculated using Eq. (3).

$$Qc = m_a C_{pa} (T_1 - T_2) \quad (3)$$

Feasibility index (F*) is specified in Eq. (4):

$$F^* = T_{wb} - (T_1 - T_{wb}) \quad (4)$$

where:

Qc = cooling capacity (kJ/h)
ma = air flow rate (kg/s)
C_{pa} = Specific heat of air (J/kgK)
T_1 = Evaporative inlet dry bulb temperature, °C
T_2 = Evaporative outlet dry bulb temperature, °C
T_{wb} = Evaporative inlet wet bulb temperature, °C

The smaller the F* number, the more feasible the evaporative cooling system. It indicates the evaporative cooling potential to give thermal comfort. The greater the difference between the two temperatures, the greater is the evaporative cooling effect. According to Watt [16], the comfort cooling is when the F* is at ≤ 10. The relative (lenitive) cooling is when the F* is at 11 ≤ F* ≤ 16, while

F* > 16 is not recommended for the use of evaporative cooling systems. In Malaysia, the average daytime F* is 18, which is exceeding the recommended margins [16].

5. Results and Discussion

The constructed system was tested to assess its performance. The experimental readings of dry-bulb temperature of the inlet and outlet air, solar radiation, saturation efficiency and cooling capacity were recorded and shown in Table 1. Table 2 summaries the average, maximum and minimum values. During the experimentation, the inlet air conditions of the dry bulb temperature was between 29.5°C to 33.5°C, the air relative humidity was between 68 % to 77 %, and the solar radiation was between 333.5 to 903.7 W/m^2. The average air velocity during the experiments was 4.55 m/sec and the water mass flow rate was 0.2548 kg/s.

Table 1
Experimental data and the performance parameters

Time	T_1(^{0}C)	T_{WB}(^{0}C)	T_2(^{0}C)	Efficiency (%)	F*	Q_C (KW)
10.00 a.m.	29.5	23.55	25.5	67.23	17.60	1.063
10.15 a.m.	29.8	23.72	25.6	69.08	17.64	1.175
10.30 a.m.	30.2	24.02	25.7	72.82	17.84	1.423
10.45 a.m.	30.4	22.77	25.2	68.15	15.14	1.551
11.00 a.m.	30.7	22.86	25.0	72.70	15.02	1.741
11.15 a.m.	31.0	23.24	25.4	72.16	15.48	1.610
11.30 a.m.	31.5	22.84	24.9	76.21	14.18	1.990
11.45 a.m.	31.7	22.73	25.6	68.00	13.76	1.640
12.00 p.m.	32.0	22.98	25.7	69.84	13.96	2.017
12.15 p.m.	32.2	23.35	25.4	76.84	14.50	1.780
12.30 p.m.	32.5	22.19	25.8	64.99	11.88	2.269
12.45 p.m.	32.8	23.12	25.9	71.28	13.44	1.908
1.00 p.m.	32.9	23.21	25.8	73.27	13.52	1.964
1.15 p.m.	32.9	22.99	25.4	75.68	13.08	1.935
1.30 p.m.	33.3	22.58	25.7	70.90	11.86	2.073
1.45 p.m.	33.3	22.63	26.0	68.42	11.96	1.991
2.00 p.m.	33.4	23.79	26.4	72.84	14.18	1.958
2.15 p.m.	33.5	23.82	26.7	70.25	14.14	2.029
2.30 p.m.	33.3	24.37	26.4	77.27	15.44	1.983
2.45 p.m.	32.8	23.32	26.0	71.73	13.84	2.103
3.00 p.m.	32.8	23.61	25.9	75.08	14.42	2.381

The variation of the dry bulb temperature between inlet air temperature and outlet air temperature is shown in Figure 3. It is possible to obtain a maximum temperature difference up to 7.6°C at relative humidity of 42.5 %, and minimum temperature difference up to 2.1°C at a relative humidity of 81.1 %.

The variation of the dry bulb temperature between inlet air temperature and outlet air temperature is shown in Figure 3. It is noticeable that it was possible to obtain the maximum temperature difference up to 7.6°C at a relative humidity of 42.5 %, and the minimum temperature difference up to 2.1°C at a relative humidity of 81.1 %.

Table 2
Value of the experimental test for average, maximum and minimum

Technical parameters	Performance		
	Average	Max	Min
Dry-Bulb Inlet T_1 (^{O}C)	32.02	33.5	29.5
Web-bulb Inlet T_{WB} (^{O}C)	23.22	24.37	22.63
Dry-Bulb Outlet T_2 (^{O}C)	25.71	26.7	24.9
Solar Radiation (W/M^2)	620.88	903.7	333.5
Efficiency (%)	71.65	77.27	67.23
Feasibility Index (F)	14.42	17.84	11.86
Cooling Capacity Q_C (KW)	1.84	2.38	1.06
Air Velocity (m/s)	4.55	5.39	4.03
Relative humidity RH (%)	71.53	77	68

The performance of saturation efficiency with the time is illustrates by graph in Figure 4. The performance of an evaporative cooler was evaluated from the value of saturation efficiency. The outlet dry-bulb temperature has a direct effect on the saturation efficiency of the evaporative cooler. The variation of saturation efficiency with time is shown in Figure 4, the efficiency is between 67.23 % to 77.27 % range.

Numerous researches had proven that saturation efficiency of commonly used cooling pad materials fall within 50 % to 90 % (Kulkarni, R. K. & Rajput, S. P. S. 2011).

The maximum saturation efficiency was recorded at the time 2:30 p.m., with a dry-bulb temperature and relative humidity of 36°C and 74 %, respectively. The saturation efficiency decreases with increasing the mass flow rate of air.

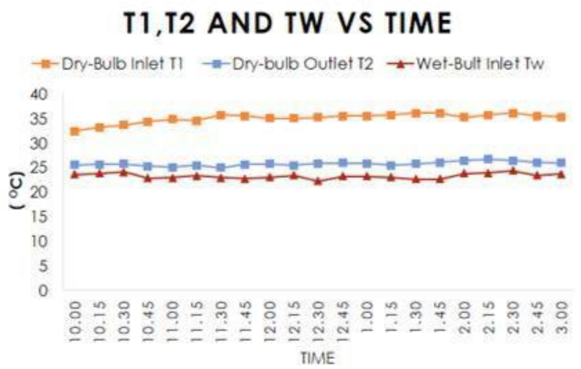

Fig. 3. Dry-bulb inlet, dry-bulb outlet and wet-bulb inlet with time

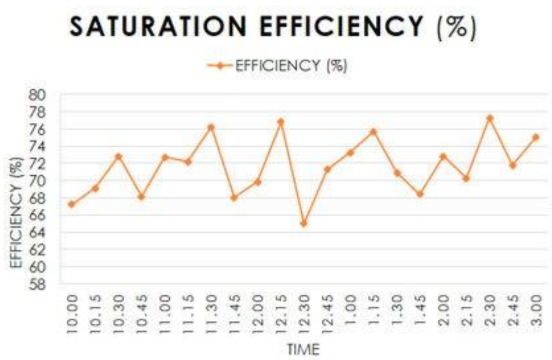

Fig. 4. Performance of saturation efficiency with the time

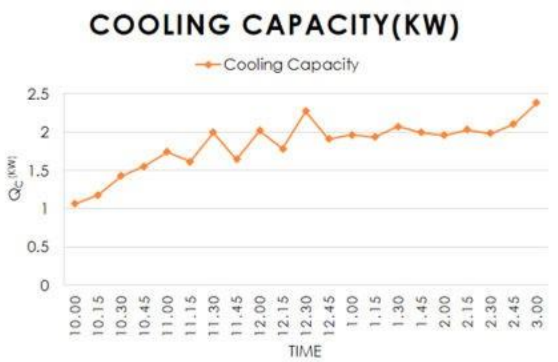

Fig. 5. Variation of cooling capacity with time

Fig. 6. Variation of feasibility index with time

The variation of cooling capacity with the time of test is shown in Figure 5. The graph plot shows that the cooling capacity varies between 1.3 kW and 5.3 kW. The maximum cooling capacity was recorded at the time 1:50 PM, while the minimum cooling capacity was recorded at the time 8:30 AM. The cooling capacity was resultant from the drop in the dry bulb temperature of air.

The variation of feasibility index with time is shown in Figure 6. The F* value remained relatively constants between 10:00 a.m. to 3:00 p.m., ranging from 11.86 to 17.84. This value is well below the F* of the average Malaysian Daytime which has F* = 18. The F* value peaked between 10:00 – 10:30 a.m. The lower the F* number, the more feasible the evaporative cooling becomes. Hence, the most effective time for the evaporative cooler operation is from 11:00 a.m. to 1:45 p.m. In other words, the greater the difference between T_1 and T_w the greater the evaporative cooling effects.

6. Conclusions

Evaporative air cooling system is energy efficient and can be used as an alternative to the conventional system and has a large application potential to provide thermal comfort by cooling and humidification of the ambient air at reduced operating cost. It is not only cheap solution but also sustainable and environmentally friendly for air conditioning. An experimental study was carried out to evaluate the performance of a direct evaporative cooler in humid regions.

Experimental result shows that application of direct evaporative cooling unit in hot and humid regions had successfully decreased the dry bulb temperature up to 7.6°C. The saturation efficiency varies from 67.23 % to 77.27 %, and the cooling capacity ranges is between 1.06 kW to 2.08 kW. The direct evaporative cooler can be applying in humid places like Malaysia by drying the air before the evaporative process using the desiccant dehumidification concept. The evaporative air-cooling system is energy efficient and can be used as an alternative to the conventional system and has a large application potential to provide thermal comfort by cooling and humidification of the ambient air at reduced operating cost.

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