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# Performance of The Direct Evaporative Cooler (DEC) Operating in A Hot and Humid Region of Sabah Malaysia

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**ABSTRACT**

In the last decade, energy consumption for air conditioning applications has been dramatically rising because of the growing global population and increasing comfort demand. Consequently, direct evaporative cooling (DEC) technology is emerging as an alternative to vapour compression air conditioners due to its lower environmental impacts, less energy consumption, and lower operating costs. This paper aims to evaluate the efficiency of direct evaporators in hot, humid environments like Malaysia. Inlet and outlet temperatures, saturation efficiency, cooling capability, and feasibility index are all used to evaluate results. The cooling medium was a rectangular honeycomb cooling pad with a length of 34 cm, a width of 25 cm, and a thickness of 3.5 cm. The temperature and humidity during the analysis were between 31 and 35$^{o}$C and 47.5 and 65.5%, respectively. The results showed that the air output temperature varied between 28.4°C and 31.7°C, while the cooling capacity between 0.29 kW and 0.64 kW as well as the saturation efficiency between 46% to 80% could be achieved. The result also showed a feasibility index between 19 to 24. Due to the high value of the feasibility index, this evaporative cooling does not work well in the territory of Malaysia. A direct evaporative cooler may be made to work in humid places like Malaysia by drying the air before the evaporative process using the desiccant dehumidification concept.

## 1. Introduction

Around the world, a wide range of air conditioning options and methods are being investigated to achieve the optimal temperature and humidity levels for thermal comfort and related applications. One of the limitations of an air conditioning system, for example, the Vapour Compression Air Conditioners (VCAC) system is it could cause the release of refrigerants that are harmful to the environment [1-3]. These gases are also responsible for ozone layer depletion and global warming [4-7]. VCAC systems also require high levels of electrical energy [1,8,9] of which are produced mainly from the burning of fossil fuels and contribute to the phenomenon of climate change. Passive cooling techniques had recently gotten attention for studies and development. Sghiouri *et al.,* [10] provided a passive cooling technique to reduce overheating of the clay-straw building, Ameur *et al.,* [11]

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optimized the passive design features for naturally ventilated residential buildings and Ismail *et al.,* [12] discusses an integrated passive design approach that uses green technology such as exterior wall cladding to lessen the cooling requirement for high-rise office buildings.

Evaporative cooling has become increasingly popular in recent years because it offers a more economical experience than conventional air conditioning systems. Compared to conventional air conditioning units, evaporative refrigeration can also operate without polluting ozone compared to refrigeration-based air conditioning systems that emit harmful gases such as chlorodifluoromethane (HCFC). The EC cools the air through the process of water evaporation into the air [13-15].

Evaporative Cooling is a device that cools the air through the process of water evaporation. It is ideal for climates where the air is hot, and humidity is low. The cooling efficiency of evaporation is directly affected by the air speed and temperature of the inlet air dry bulb and the inlet air temperature will decrease the air velocity and the inlet water temperature will increase with the output air dry-bulb temperature [16]. These systems typically have a simple, low-cost, energy-efficient, and environmentally friendly design and construction. It is also claimed to be a suitable alternative to replace VCAC systems for various applications [17], which uses a quarter of the electricity compared to conventional AC systems [8]. The cost of installation and operation of evaporative refrigeration is much lower than that of air conditioning units.

In Malaysia, it is found that the electricity consumption for air conditioning systems accounts for almost 49% of total energy consumption in office buildings. Therefore, evaporator cooling (EC) can be the best option to replace the air conditioning system. To create a human comfort zone, internal temperature and relative humidity play a major role. Rooms with a temperature of 25◦C and relative humidity of 55% are below the comfort zone [18].

Study have shown that performance of EC is low in high humidity climatic conditions [19]. The cooling effect is reduced when the ambient temperature of the wet-bulb is higher than 21°C. This is because the cooling effect is not sufficient to produce internal cooling comfort [20], and the direct EC cannot recycle the indoor air. Several studies on direct evaporative coolers have been conducted by researchers such as Kulkarni and Rajput [21] doing the theoretical investigation of the efficiency of direct evaporative cooling. The study looked at a variety of materials and they conclude that aspen fibred had the highest efficiency of 87.5%, while rigid cellulose had the lowest efficiency of 77.5%. Temperature and cooling power for both materials were 28.8 to 26.5°C, 13408 kJ/h and 56686 kJ/h, respectively.

Kachhwaha and Suhas [22] designed, fabricated medium. The pad thickness and height were achieved for maximum cooling. Chenguang and Agwu [16] evaluated the effect of speed and the dry-bulb temperature of frontal air, and the temperature of the incoming water on the cooling performance of a direct evaporative cooling combined with a wetted medium. The results of the analysis showed that direct evaporative cooling efficiency decreased with frontal air velocity and incoming water temperature and increased with frontal air dry-bulb temperature.

A simplified mathematical model was used by Fouda and Melikyan [23] to discuss the heat and mass transfer between the air and water in a direct evaporative cooler. A comparison between the model results and the experimental results was presented. The results indicate that during a steady-state condition, the cooling efficiency is decreased by increasing the inlet frontal air velocity and increased by increasing the pad thickness. This is because the contact surface between water and air is increased.

Moien *et al.,* [24] studied a two-stage cooling system that consisted of a nocturnal radiative unit, a cooling coil, and an indirect evaporative cooler. The investigation was conducted in weather conditions for the city of Tehran. The results showed that the first stage of the system increased the effectiveness of the indirect evaporative cooler. Also, the regenerative model provided the best comfort conditions.

Dai and Sumathy [3] developed a mathematical model to predict and discuss the interface temperature of the falling film in a cross-flow direct evaporative cooler. Analysis results indicated 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.

Wu *et al.,* [25] proposed simplified cooling efficiency based on the energy balance analysis of air to analyze the heat and mass transfer between air and water film in the direct evaporative cooler. The analysis showed that the frontal air velocity and thickness of the pad module are two key factors influencing the cooling efficiency of a direct evaporative cooler.

A model of the dew point evaporative cooling system was developed by Riangvilaikul and Kumar [19] to simulate the heat and mass transfer processes under various inlet air conditions and the influence of major operating parameters. The model was used to optimize the system parameters and to investigate the system effectiveness when operating under various inlet air conditions.

### *1.1 Direct Evaporative Cooling (DEC)*

Direct Evaporative Cooling (DEC) is powered by electricity, but only a small amount of energy was used for air and water circulation. As a result, it is much less energy-intensive than other conventional cooling systems, resulting in a saving up to 90% of energy [25].

As shown schematically in Figure 1, a typical direct evaporative cooler consists of evaporative media (wettable and porous Pads), a fan that blows air through the wetted medium, a water tank, a recirculation device, and a water distribution system. An adiabatic cooling mechanism is also known as direct evaporative cooling where the water absorbs the sensible heat from the supply air and evaporates, allowing the air temperature to drop and the humidity to rise.

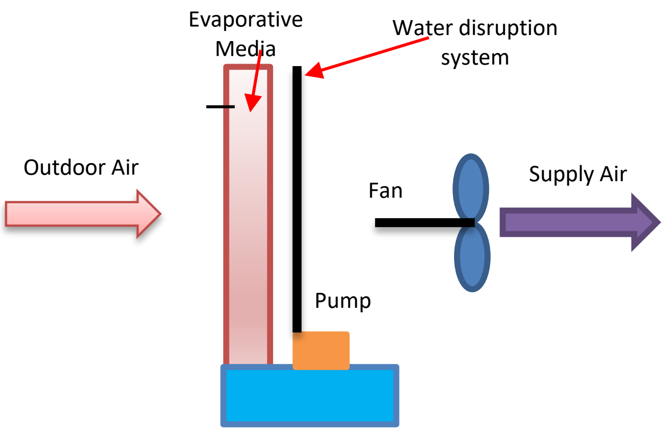


**Fig. 1.** Schematic structure of direct evaporative cooler

In most current commercial DEC coolers, wet-bulb effectiveness will vary from 70% to 95%, depending on the form and thickness of evaporative media, working climate, and supply air flow rate [26]. Random media DEC, Rigid media DEC, and Remote media DEC are the three forms of wet media DEC according to the ASHRAE Handbook-HVAC Systems and Equipment (2008) [20]. Spray (also known as air washer), slinger (a spinning wheel), and drip (misting) systems are the three types of water delivery systems used by DEC coolers [27].

The application of evaporative coolers in hot-humid weather conditions has been discussed by several researchers [7,25,27]. However, literature searches on evaporative performance in the

Malaysian weather system yield limited results. In 2011, Rachman *et al.,* [28] conducted a feasibility study on solar assisted desiccant and evaporative cooling technology in Malaysia, they reported a COP of 0.6 and confirms the potential use of the technology in Malaysia weather system. Then, Abdul Rahman *et al.,* [28] in 2013 analyzed the experimental performance of a direct evaporative cooler operating in Kuala Lumpur. The cooler consists of a cellulose pad with a surface area of 100 $m^2$ per unit volume. The performance of the evaporative cooler was evaluated in terms of output temperature, saturation efficiency and cooling capacity. The output temperature lies in the range of 27.5°C and 29.4°C, and the cooling capacity is between 1.384 KW and 5.358KW. However, this work does not use the feasibility index *F** which is an important factor in determining evaporative cooling potential. Thus, the current study aims to evaluate the efficiency and potential of direct evaporators in hot, humid weather such as in Sabah, Malaysia with the inclusion of the feasibility index as a tool.

## 2. Methodology

### *2.1 Equipment Setup*

The Direct Evaporative Cooling (DEC) that was used in this research work was arranged as in Figure 2. The DEC consisted of a cooling pad arranged parallelly, in-between an axial fan and an air inlet as shown in the figure. The water pump passed through the water distributor and sprinkle water on the upper side of the pad. Air passes through the unit in a horizontal configuration. The evaporative cooling was made of an acrylic sheet. The cooling pad used was a honeycomb cooling pad with 34 cm length, 25 cm width and 3.5 cm thickness. The 65-Watt axial fan was made to run at around 2500 rpm and the 10-Watt, 220V AC submersible pump has a flow rate of 1400 L/H

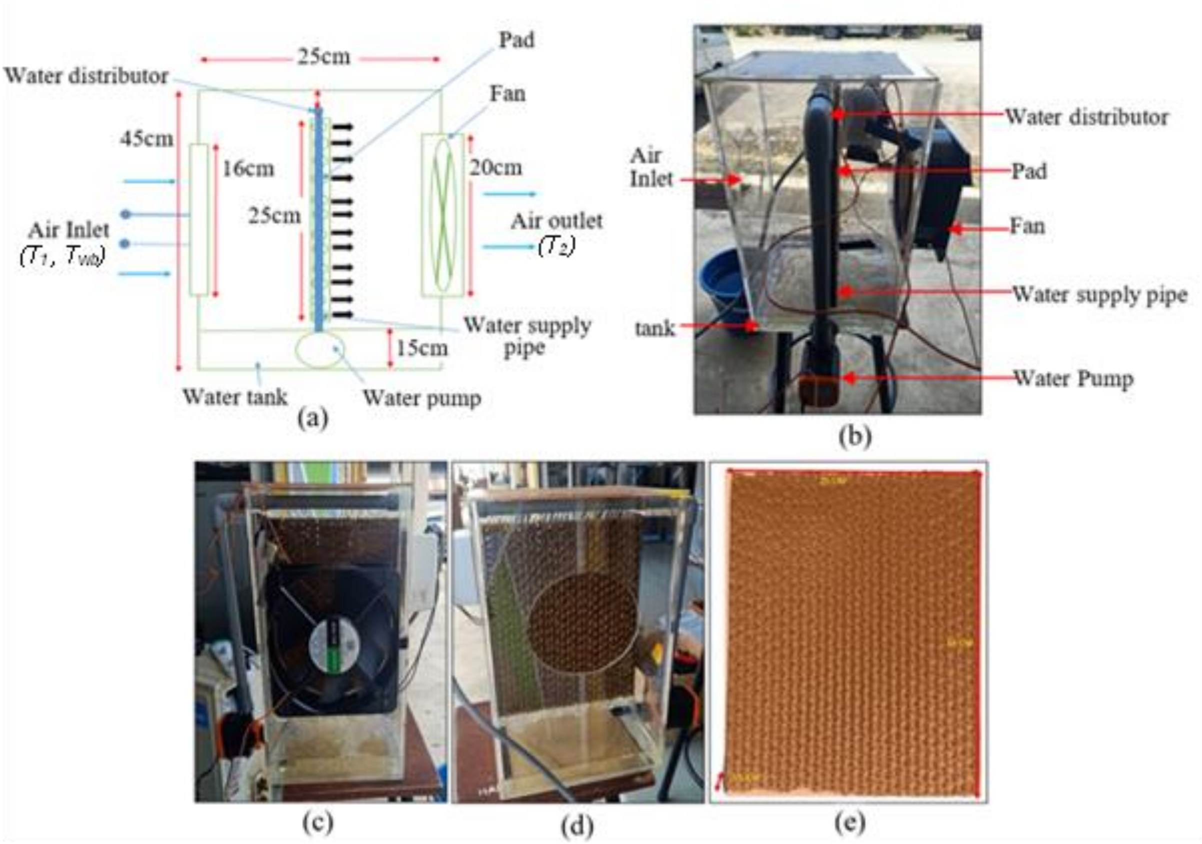


**Fig. 2.** (a-b) Schematic diagram and image of the Direct Evaporative Cooling [DEC] arrangement, (c) side view showing fan placed parallel to the pad, (d) side view showing air inlet parallel to the pad, (d) cross-section of the pad

### 2.2 Experiment Methodology

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 April 2021. 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 (Fluke 54 II B) with an accuracy of ± 0.1°C was used. The dry- ($T_1$ & $T_2$) and wet-bulb ($T_{wb}$) temperatures for ambient air were recorded using the sling psychrometer (TOP GAUGE WHM 1018). Anemometer (UT363) was installed at the inlet air 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. Solar Power Meter (SM206-SOLAR) was used to record the solar radiation in the test location.

### 2.3 Performance Evaluation

The *DEC* cooling efficiency ($\varepsilon_{DEC}$) or saturation efficiency is defined as the ratio of the air temperature difference and the difference between dry-bulb and wet-bulb inlet air temperatures. If the direct evaporative process were 100% efficient, the outlet dry-bulb ($T_1$) temperature would equal the inlet wet-bulb ($T_{wb}$) temperature [27]. Since the evaporative process is not 100% efficient the saturation efficiency is defined by

$$\varepsilon_{DEC} = \frac{T_1 - T_2}{T_1 - T_{wb}} \times 100 \tag{1}$$

where; $T_1$ and $T_2$ are the dry bulb temperatures of inlet and outlet air, while $T_{wb}$ represents the wet-bulb temperature of inlet air, By using this equation, the saturation efficiency of the air cooler with different water temperatures can be calculated. Cooling capacity is the rate where the heat is removed, while the temperature remains constant. Cooling load or cooling capacity, $Qc$, is calculated using Eq. (2),

$$Qc = m_a C_{pa} (T_1 - T_2) \tag{2}$$

where $m_a$ is the mass flow rate and $C_{pa}$ is the specific heat capacity of air. The Coefficient of performance (*COP*) of the EC process is described as the ratio of the obtained cooling capacity and power used during experiments. The total power input is obtained by calculating the sum of the power consumption of the fan and water pump used in the experimental system as indicated by Eq. (3).

$$COP = \frac{Q_c}{W_P} = \frac{Q_c}{(W_{fan} + W_{pump})} \tag{3}$$

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

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

The disparity between dry and wet bulb temperatures increases with the decrease in relative humidity. The small $F^*$ indicates better cooling performance in comparison with the higher value. It indicates the evaporative cooling potential to give thermal comfort. ($T_1$-$T_w$), wet bulb depression; $T_1$ inlet dry bulb temperature; $T_w$ wet-bulb temperature. The greater the difference between the two temperatures, the greater is the evaporative cooling effect [29]. This number, therefore, shows the ability for evaporative cooling to provide human beings thermal comfort [30-31]. The work of Camrago *et al.,* [32] highlights the following ranges of the *F** concerning cooling for human thermal comfort

| | |
|---|---|
| $F^* \leq 10$ | Recommended for comfort cooling |
| $11 \leq F^* \leq 16$ | Recommended for relief (lenitive) cooling |
| $F^* > 16$ | Not recommended for the use of evaporative cooling systems |

### 3. Results

The Direct Evaporative Cooling (*DEC*) system as shown in Figure 2 was tested to assess its performance. The experimental environment such as the solar radiation, air velocity, and relative humidity could directly give effect to the experimental results, thus the reading of these parameters are monitored throughout the experiment. The experimental period was carried out for 5 hours, between 10 am to 3 pm where the solar radiation was at its optimum range as shown in Figure 3(a). The average solar radiation within the experimental period was 620.88 W/m$^2$ as shown in Table 1.

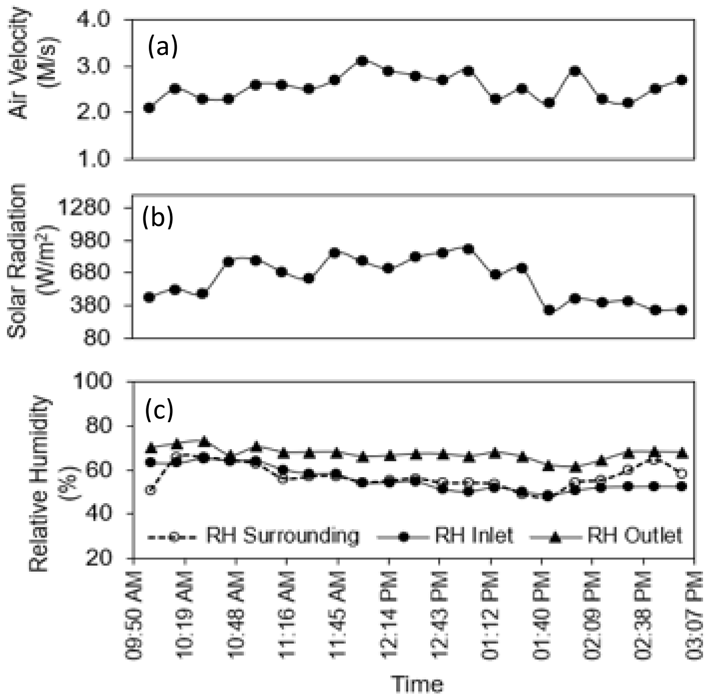


**Fig. 3.** Changes of (a) Solar Radiation, (b) Air Velocity, and (c) Relative Humidity of surrounding, inlet, and outlet, with time

**Table 1**
Value of the experimental test for average, maximum and minimum

| Technical parameters | | Performance | | |
|---|---|---|---|---|
| | | Average | Max | Min |
| Measured Parameter | Solar Radiation (*W/m²*) | 620.88 | 903.70 | 333.50 |
| | Air Velocity (*m/s*) | 2.55 | 3.10 | 2.10 |
| | Relative humidity of surrounding, *RH* (%) | 54.67 | 65.5 | 47.50 |
| | Dry-Bulb Inlet, $T_1$ ($^{O}$C) | 33.00 | 35.00 | 31.00 |
| | Wet-bulb Inlet, $T_{WB}$ ($^{O}$C) | 27.50 | 29.00 | 26.00 |
| | Dry-Bulb Outlet, $T_2$ ($^{O}$C) | 29.38 | 31.70 | 28.40 |
| Calculated values | Cooling Efficiency, $\varepsilon_{DEC}$ (%) | 70.89 | 80.00 | 46.00 |
| | Cooling Capacity, $Q_c$ (*kW*) | 0.51 | 0.64 | 0.29 |
| | Coefficient of Performance, *COP* | 0.68 | 0.85 | 0.34 |
| | Feasibility Index, *F** | 21.14 | 24.00 | 19.00 |

As shown in Figure 3(b), the changes in the measured air velocity during the experimental period were not Signiant. The average reading was 2.5m/s, with a maximum and minimum reading of 3.10m/s and 2.10 m/s respectively. Figure 3(c) shows that, throughout the experimental period, the relative humidity of the surrounding is between 47.5% to 65.5%. The humidity at the inlet and outlet were also monitored. It was found that the relative humidity at the inlet was comparable to the surrounding, while the relative humidity of the outlet is higher and constant at 67% due to the air being cooled by the wetted pad.

During the experiment, the temperature reading of dry-bulb inlet ($T_1$), wet-bulb inlet ($T_{WB}$) and dry-bulb outlet ($T_2$) were taken and recorded, thus the cooling efficiency ($\varepsilon_{DEC}$), cooling capacity ($Q_c$), Coefficient of Performance (*COP*) and Feasibility Index (*F**) were able to be calculated using the equations discussed in 2.3. Table 1 summarises the average, maximum and minimum values of the calculated parameters, while the changes of the parameter values with time, are shown in Figure 4 to Figure 7.

The comparison of the temperature changes with time for dry-bulb inlet ($T_1$), wet-bulb inlet ($T_{WB}$) and dry-bulb outlet ($T_2$) are shown in Figure 4. In general, the $T_1$ temperature is higher compared to the $T_{WB}$. The average difference is approximately 5.5–6.0% in a relative humidity of ~55%. It is expected that the deference of $T_1$ and $T_{WB}$ may increase when the relative humidity decreased (TRANE. 1979) The dry-bulb outlet temperature ($T_2$) is fairly lower than the dry-bulb inlet ($T_1$). This is expected as the air had passed through the wet-pad. The average percentage of temperature reduction was approximately 3–4% (maximum 6.4 $^{0}$C dropped). Similar results, also obtained by other researchers [18].

One of the parameters used to determine the effectiveness of the *DEC* is the cooling efficiency ($\varepsilon_{DEC}$) or also known as saturation efficiency. The greater the difference between the $T_1$ and $T_2$ values, the better the effectiveness of the *DEC*. It is noticeable that the percentage of $\varepsilon_{DEC}$ throughout the 5 hours experimental period was fluctuating, as shown in Figure 5. This is due to the variation in $T_1$, $T_2$ and $T_{wb}$ reading that is affected by the solar radiation, air velocity, and relative humidity. The value of $\varepsilon_{DEC}$ obtained during the experiment was between 46% to 80%, which gives an average of ~71%.

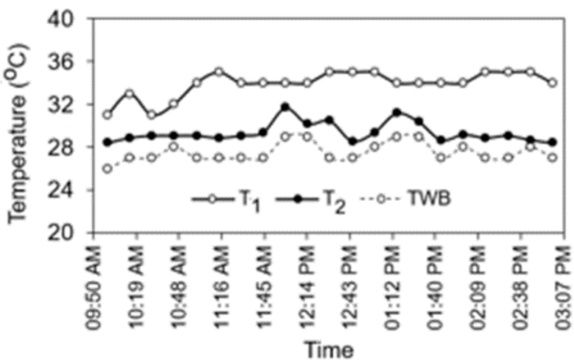


**Fig. 4.** Changes of temperature on a dry-inlet ($t_1$), dry-outlet ($t_2$) and wet-bulb ($t_{wb}$) with time

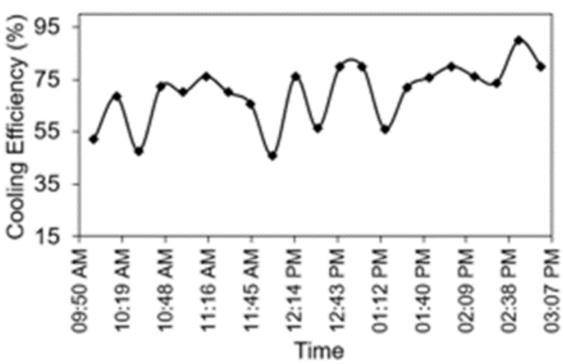


**Fig. 5.** changes of cooling efficiency percentage with time

Based on the $T_1$ and $T_2$ reading, the cooling capacity ($Q_c$) was calculated, and the value of heat being removed throughout the experimental period was $Q_c$ = 0.51kW. The changes of $Q_c$ in the 5 hours experiment period is shown in Figure 6. The Coefficient of performance (*COP*) of the air cooler was calculated based on the ratio of cooling capacity and power used. The better the air cooler, the more heat is being removed for a given amount of work. Therefore, a low water temperature absorbed more heat from the air to evaporate and required the same amount of work done when the temperature of the water is increased. A higher value of *COP* has lower operating costs which is preferable. For the system used in this study, the power of the fan and pump were taken into consideration. The experimental results showed that the COP value of the system is 0.68 Similar results, also obtained by other researchers [32].

Another measurement to determine the effectiveness of the *DEC* is and the Feasibility Index (*F**) value. The variation of the feasibility index with time is shown in Figure 7. The range of *F** throughout the experiment was between 19 to 24, giving an average value of ~21. The value is higher than the recommended value of *F** = 18.

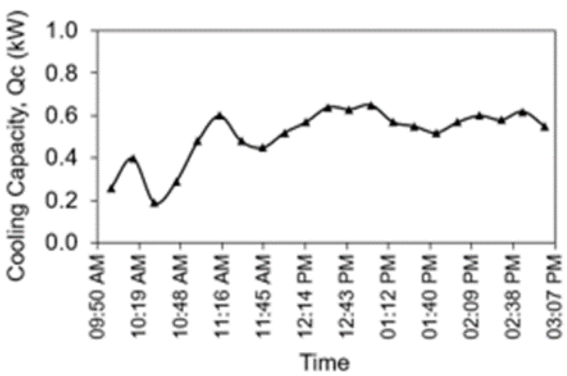


**Fig. 6.** Changes of calculated cooling capacity (*kw*) with time

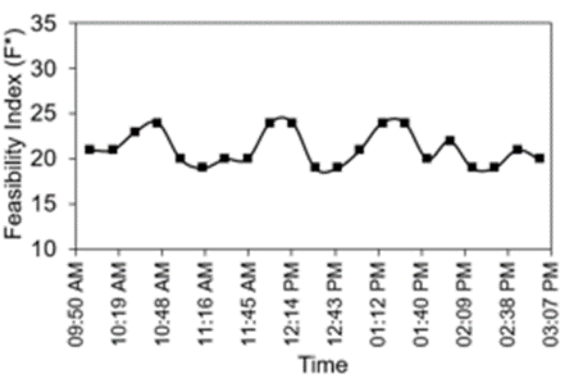


**Fig. 7.** Changes of feasibility index with time

DEC is only suitable for dry and hot climates. In moist conditions, the relative humidity can reach as high as 80%, such a high humidity is not suitable for direct supply into buildings, because it may cause warping, rusting, and mildew of susceptible materials [26]. However, it is possible to improve the DEC 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.

## 4. Conclusions

The Direct Evaporative Cooling (DEC) 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 a 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 the hot and humid region, i.e at Kota Marudu, Sabah (6.0367°N, 116.1186°E). The experiment was carried out between 10 am to 3 pm where the solar radiation was at its optimum range. The average wind velocity was 2.55m/s and the average surrounding humidity was 55% during the experimental period.

The experimental result showed that the application of a direct evaporative cooling unit in hot and humid regions only managed to reduce the dry-bulb temperature between 3% to 4%. The calculated cooling efficiency (εDEC) and cooling capacity (Qc) fluctuated throughout the day, as the value of inlet and outlet dry-bulb and wet-bulb temperature fluctuated, which was partly affected by the changes of surrounding's parameters. The average value of cooling efficiency was approximately 71% and the successfully removed heat was 0.51kW. The DEC Feasibility Index gives an average value of 21, which is above the recommended value.

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