Effect of air velocity and direction for indirect evaporative cooling in tropical area

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Abstract. In this research, experimental study of heat absorption rate caused by indirect evaporative cooling is performed by varying the velocity and direction of air. The ambient is at average temperature and relative humidity of 28.7 °C and 78% respectively. The experiment is conducted by attaching wet medium on the top of material reference plate with the dimension of 14 x 8 cm with 5 mm thickness. To get evaporative cooling effect, the air flow is directed to the wet medium with velocity from 1.6 m/s to 3.4 m/s with the increment of 0.2 m/s. The direction of air is set 0° (parallel), 45° (inclined), and 90° (perpendicular) to the wet medium surface. While the experiment is being performed, the air temperature, top and bottom of plate temperature are measured simultaneously after steady state condition is established. Based on the measurement result, heat absorption is calculated by analysing the heat conduction on the material reference. The result shows that the heat absorption rate is increased by higher velocity. Perpendicular direction of air flow results the highest cooling capacity compared with other direction. The maximum heat absorption rate is achieved at 13.9 Watt with 3.4 m/s velocity and perpendicular direction of air.

1. Introduction
The largest energy consumption in building is on air conditioner sector which is estimated 40 to 50% of total energy consumption [1]. In tropical area, the air conditioner is mainly for cooling the spaces thus the thermal comfort is achieved. Currently, the most common technology for air conditioner is vapor compression refrigeration heat pump since the COP is very high and flexible to use. However, it still consumes large of electrical energy for compressor. One of the alternative cooling technologies is evaporative cooling system which has very large COP at 15-20 [2].

Evaporative cooling is the phenomena of simultaneous heat and mass transfer [3]. The concentration difference between water and air causes the evaporation rate. The heat transfer rate is required for evaporation so that temperature difference must exists and resulting the cooling effect. In tropical area, the average relative humidity is about 70 to 80%. To avoid the increasing of humidity, indirect evaporative cooling is more suitable in this condition.

The development of indirect evaporative cooling technologies and studies have been performed by researchers and engineers. I Maclaine-Cross et al studied the general theory of wet surface and use it for indirect evaporative cooling [4]. J. F. J Alonso et al developed the simulation model for indirect evaporative cooler [5]. N. J. Stoitchkov et al studied the effectiveness of cross flow plate heat
exchanger for indirect evaporative cooling [6]. X. C. Guo et al analyze the parameter affecting the indirect evaporative coolers [7].

The aim of this study is to investigate the effect of velocity and direction of air on indirect evaporative cooling phenomena. The study is performed at unconditioned ambient tropical area. Heat absorption is then calculated from measured data of experiment. Comparison between experimental conditions are then compared.

2. Experimental setup and procedure

Figure 1 shows the scheme of experimental setup. The experiment was conducted in tropical area at 78% average relative humidity and 28.7 °C ambient temperature. The direction of air were varied from 0° (parallel), 45° (inclined), and 90° (perpendicular) to the wet medium surface. The experiment was set so that heat absorption equals to heat conduction at the material reference.

![Experimental setup](image)

Figure 1. Experimental setup: (a) parallel flow (0°), (b) inclined flow (45°), (c) perpendicular flow (90°).

Stainless steel as material reference was used as base plate since its thermal conductivity is well known. The dimension of material reference is 14 x 8 cm with 5 mm thickness. Wet medium was attached on the top of base plate. The air was flown on the top of wet medium by using electrical fan to get the evaporative cooling effect on the surface. The voltage of fan was adjust so that air had velocity of 1.6 m/s to 3.4 m/s with the increment of 0.2 m/s. After the steady state condition had been established, T-type thermocouples were used to measure the temperature of top base plate (T₁), bottom base plate (T₂), ambient (T₃). To get the average temperature difference, T₂ and T₃ were measured at ten different locations (no. 1 to 10 at stainless steel) along the length of base plate.

Heat is absorbed from the bottom to the top of base by evaporative cooling. Since the thickness of base plate is very thin, so it is assumed that heat absorption equals to conduction heat transfer rate from the bottom to the top of base plate. Therefore, the heat absorption rate is calculated by equation (1):

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Q_{\text{abs}} = \frac{kA(T_2 - T_1)}{L}
\]

where \(k\), \(A\), and \(L\) are thermal conductivity, surface area, and the thickness of base plate respectively.

3. Result and discussion
After the steady state condition, the result shows that the top and the bottom of base plate temperature are lower than ambient temperature, shown in Figure 2. When the air flows on the top of wet medium, water contained in wet medium is evaporated and causes evaporative cooling effect [3]. The curve temperature of top and bottom base plate are relatively the same with the curve of ambient temperature with the offset of temperature difference. It means that ambient temperature is strongly effect the temperature resulted by evaporative cooling effect.

Figure 2. Temperature difference between ambient, top and bottom of hot plate for: (a) parallel, (b) inclined (45°), (c) and perpendicular flow.

The effect of air velocity and direction to the heat absorption of evaporative cooling is shown in Figure 3. Horizontal axis is related to the air velocity and vertical axis is related to heat absorption of evaporative cooling. Blue, red, and green lines show the direction of air for 0°, 45°, and 90°. The result shows that the higher velocity causes higher heat absorption. Meanwhile, the perpendicular direction causes the highest heat absorption compared with other direction. The combination condition of highest velocity and perpendicular direction results the highest heat absorption at 13.9 Watt.

Figure 3. Effect of air velocity and direction to heat absorption.
The heat absorption is proportional to the evaporation rate of water contained in wet medium. Higher velocity with perpendicular direction causes the highest evaporation rate, therefore the heat absorption is higher as well.

4. Conclusion
The apparatus and experiment to investigate the effect of velocity and direction of air to the evaporative cooling effect in tropical area has been constructed and analysed in this study. The result shows that the higher cooling capacity is achieved at higher velocity with perpendicular direction. The velocity and direction of air affect the evaporation rate, so that evaporative cooling heat absorption is also affected. The maximum cooling capacity from this experiment is 14 W which is resulted by 3.4 m/s of air velocity with perpendicular direction to the wet medium surface. The same study using another method is recommended for further study.

References
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