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THE COOLING PERFORMANCE OF THE EVAPORATIVE COOLING SYSTEM IN COMBINATION WITH THERMOELECTRIC DEVICES: A CASE STUDY OF REDUCED TEMPERATURE ON THE HOT SIDE OF A HEAT SINK

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ABSTRACT

Currently, global warming is considered one of the main environmental problems in the world today. Air conditioners are among one of the major causes of global warming. Producing environmental friendly equipment that can provide cool air would be helpful. One idea is a combined system between an evaporative cooling system and a thermoelectric device (with heat sink). This combined system provides temperatures and relative humidity in a comfort zone. However, the efficiency is slightly lower when compared with conventional air conditioning. This project tries to improve both the evaporative cooling and thermoelectric system. In an evaporative cooling system, the shape of the material is important because it can increase the surface contact area between the air and water. However, the life of the material also needs to be considered. For a thermoelectric system, by improving the efficiency of the heat sink, it will increase the efficiency of the whole system. The basic idea of this combined system is that the hot air is added to the evaporative cooling system which decreases the air's temperature while increasing the relative humidity. Then the air passes through the thermoelectric cooling system, to further decrease the air's temperature, reducing relative humidity. The cooling capacity of the system can be increased by adjusting the thermoelectric current.

Keywords: Evaporative cooling, Thermoelectric, a Heat Sink

INTRODUCTION

There is many devices that can produce cold air. These devices can provide a comfortable life for people. However, it can also cause many problems for the world e.g. greenhouse effect, global warming, noise pollution (from their moving parts). This is the reason why nowadays people are trying to develop devices that can produce cold air but with concerns for the environment.

The combination between an evaporative cooling system and a thermoelectric system is one of the options used to produce cool air (Kimsunthorn, 2016). This combination system works as follows:

The evaporative cooling system: the main part of evaporative cooling system looks like a cooling pad which is made of hard paper. Water is sprayed on top of the cooling pad and plastic net. The air inlet (high temperature) passes through the evaporative cooling system, which causes heat transfer between the air and water. As a result, the air temperature decreases and the Relative Humidity (%RH) increases.

The thermoelectric system: after the air is released from the evaporative cooling system, air then passes to the thermoelectric system. Air temperature further decreases and the %RH decreases.

Once the air is released from both systems, the air temperature and %RH is in the comfort zone. The comfort zone represents the temperature and %RH that's suitable for people in a residence. The comfort zone changes with the seasons. This combined system is quite suitable for hot and dry climates.

The reasons for selecting the evaporative cooling and thermoelectric systems (TEC's) are:

TEC's are solid devices which can convert electric energy into a temperature gradient (Cheng and Huang, 2008). Also, TEC's can be used in different types of applications for producing cool air e.g. air conditioners and refrigerators (Ugur Kemiklioglu & Selim, 2014). The size of TEC's are quite small, they have a light weight and working fluids are not required. Also, the Coefficient of Performance (COP) for TEC's is not high if compared with other cooling systems. Its COP is around 0.4 (Bass et al., 2004). The energy required for TEC's to deliver cooling capacity is about 25W (Zhao & Tan, 2014). For this experiment, the system will attempt to increase the COP by reducing the temperature of the heated portion of the system. Normally, if the temperature of the heated portion is too high, heat will transfer to the unheated side. Thus dropping the COP value.

Evaporative cooling systems have low costs and are easy to install and operate. This combination system is considered a direct evaporative cooling system because air and water are in direct contact with each other via the cooling pad's surface.

This research has attempted to provide an air cooling system which is environmental friendly, more compact and lower cost. However, for people in a building to feel comfortable is also a concern. So, to compare the results of air outlet temperature and relative humidity of the system along with an ideal comfort zone would support the results.

METHODS

Figure 1 represents a two part system. The first part is an evaporative cooling system and the second part is a TEC with heat sink. 7) The parameters that have changed in this experiment are: 1) air inlet temperature, 2) type of material for evaporative cooling 3) water sprayed on top of hot side of heat sink and 4) electric voltage

The air inlet temperature is varied at 36°C, 38°C, 40°C and 42°C (air inlet temperature can be adjusted by the heater, relative humidity as ambient). This air inlet temperature passes to the evaporative cooling system. Once the air has passed the evaporative cooling system, the temperature will decrease because of the heat transfer between air and water sprayed from evaporative cooling system. %RH will increase.

The air will then pass through the TEC's system. The air temperature will further decrease and %RH will then decrease. The experiment has been adjusted to different electric voltages on TEC's system (15V, 30V and 45V). The experiment was contained both with and without water sprayed on top of the hot side of the TEC's heat sink (Figure 2). Figure 3 shows components of the whole system. After the experiments concluded, the results (outlet temperature and %RH) were compared with the comfort zone (Table 1).

Table 1 Comfort temperature and relative humidity (Alahmer et al., 2011)

Environment	Relative Humidity (%RH)	Temperature (°C)
Winter	30%	20.5 – 25.5
	60%	20 – 24
Summer	30%	24.5 – 28
	60%	23 – 25.5

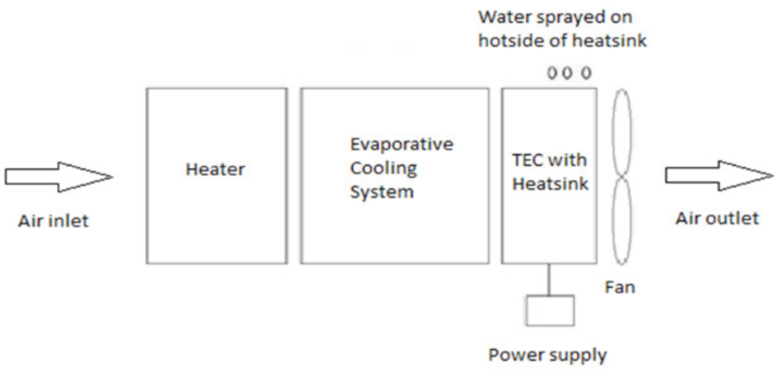

Figure 1 Two main systems

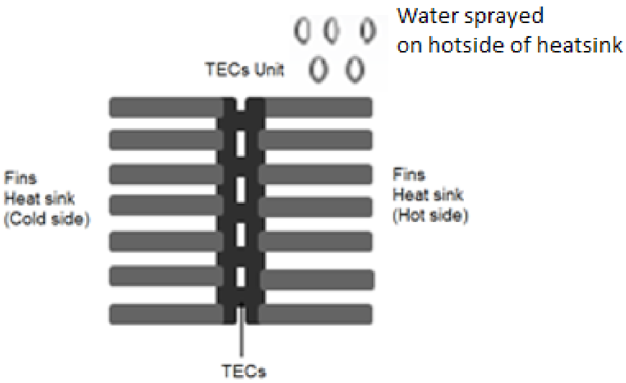

Figure 2 With and without water sprayed on top of the hot side of the TEC's heat sink

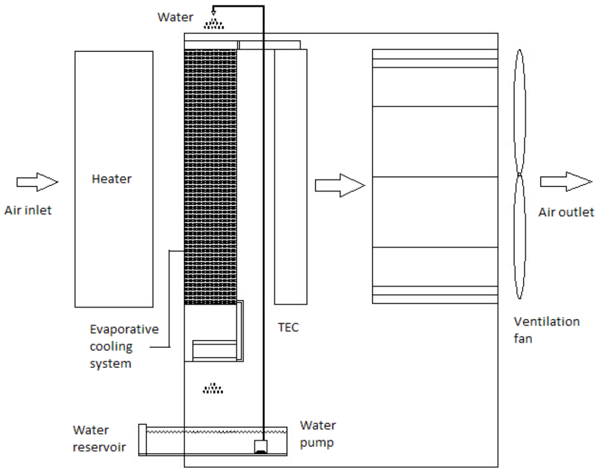

Figure 3 The evaporative cooling system in combination with thermoelectric devices

For the evaporative cooling system the two different components, the cooling pad and plastic net (Figure 4). The dimensions of the cooling pad are 400mm x 400mm x 100mm and the dimensions of the plastic net are 400mm x 400mm x 100mm.

For the TEC's system, the dimensions and specifications are 40 mm x 40 mm, V_{max} = 14.7V, I_{max} = 5.6 Amp and Q_{max} = 54V. TEC's thermal resistance is less than 0.01^{o}C/W. There are two units of TEC's in the system and there are two pieces of TEC in one unit. In total, there are four TEC's in the system. The TEC's were set in the middle of heat sink (fins), one on the cold side, the other on the hot side. The fan is connected to the hot side of heat sink. Also, water is sprayed on the hot side of the heat sink in some experiments to improve the efficiency of the system. For safety reasons and to avoid the electric shock, all of the electrical equipment was sealed. Also, the electric voltage was not allowed to be higher than 50V.

The air flow rate of the cooling pad was 0.78 kg/s and for the plastic net it was 0.95 kg/s. The reason these figures are required is that it allows the air flow rate to change the shape of material. The water flow rate was 1.5 litres/minute. Water flow rate does not have much of an effect on the results as long as the water can cover the entire area of the evaporative cooling system. The air flow rate came from the same parameter of the fan.

For this experiment, Fluke brand equipment was used to measure the temperature and relative humidity. Fluke brand equipment was used to measure air flow rate. All equipment are from Faculty of Engineering, Thammasat University. All equipment have been calibrated twice a year.

Once the experiments show the results of the temperature and %RH, the cooling capacity ($Q_{cooling}$) and electrical energy (Q_E) can be calculated.

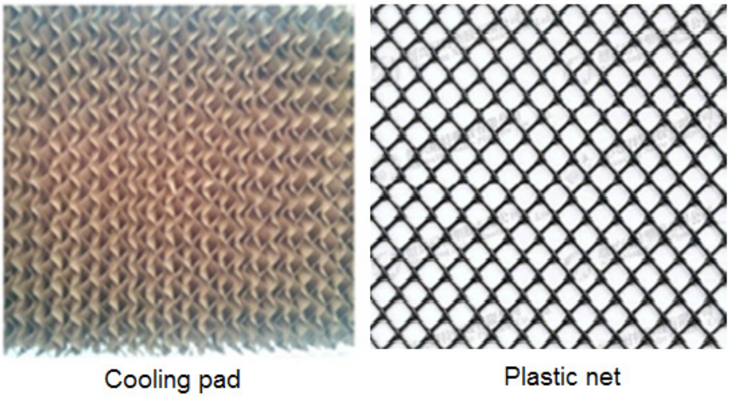

Figure 4 Materials for evaporative cooling system

Figure 4 represents material for the evaporative cooling system which contains a cooling pad and a plastic net. The cooling pad is made of hard paper (it can be called a honeycomb). It can last 1-2 years [from market research by interview seller] even with water constantly sprayed on top. However, since it's made of hard paper it might produce fungi after sprayed with water. The plastic net can last 30-50 years [PlasticsEurope Association of Plastics Manufacturers]. The price of the plastic net is lower than the cooling pad by about 100 baht based on the size following the cost from experiment.

The calculation of the electrical energy and cooling performance of the system

The cooling performance of the system ($Q_{cooling}$) and electrical energy (Q_E) of the whole system can be calculated by (Attar & Lee, 2016)

$$Q_{cooling} = (h_3 - h_1) \times m \quad (1)$$

$$COP = Q_{cooling} / Q_E \quad (2)$$

where: h_1 is the specific enthalpy inlet of the cold air

h_2 is the specific enthalpy outlet of the cold air

m is the air mass flow rate

Note: for this experiment, the electric voltage keeps the maximum at 50V for the safety reason.

RESULTS AND DISCUSSIONS

Table 2-4 shows the results of the experiment which combines an evaporative cooling system with a TEC system.

As mentioned before, there are two different components for an evaporative cooling system, a cooling pad and a plastic net. Different air inlet temperatures pass through the evaporative cooling system. After the air comes out from the evaporative cooling system, the temperature drops and the relative humidity increases by the heat exchange between water sprayed and air. At this phase, the air outlet is not in the range of comfort zone.

From the results we can see the COP value of the plastic net is slightly higher than the cooling pad. However, the working life of the plastic net is much longer and its costs cheaper than the cooling pad.

The water flow that's sprayed on top of the evaporative cooling system does not provide much of an effect to the system unless it can cover the whole area of the evaporative cooling system. The performance of the evaporative cooling system seems more efficient with a higher air inlet temperature.

After the air passes the evaporative cooling system, it moves to a TEC system. The higher voltage of the TEC system is better for further reducing air inlet temperatures and dropping the relative humidity until it's in range of the comfort zone. Most of the results fell within the comfort zone. However, some cases were not in the comfort zone. So, the recommended parameters include electricity at 45V because at this voltage, all the results fall within the comfort zone. Also, increasing the voltage provides a higher temperature and increased COP. However, the maximum voltage that can be applied to the TEC system must be checked before starting the experiment for safety reasons. This experiment uses a 45V maximum voltage.

Table 2 TEC voltage = 15 V and current = 0.5A

Table 2.1 Cooling pad without water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	43	30.1	73	25	48	22.0	0.36
38	44	31.2	73	26.1	49	25.8	0.39
40	45	32.2	74	28.3	50	27.6	0.40
42	44	33.1	74	29.3	50	30.8	0.51

Table 2.2 Cooling pad with water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	44	30.3	74	23.7	49	25	0.41
38	43	31.1	74	24.8	48	28	0.46
40	45	32.3	74	26.8	48	31.7	0.52
42	44	33.4	75	28	48	34.7	0.57

Table 2.3 Plastic net without water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	44	30.3	74	25.2	48	21.3	0.35
38	45	31.1	74	26.3	48	26.2	0.43
40	45	32.4	74	28.2	48	26.6	0.44
42	44	33.4	73	29.4	49	31.6	0.52

Table 2.4 Plastic net with water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	43	30.5	73	23.5	47	25.2	0.42
38	44	31.3	74	24.5	47	29.8	0.49
40	43	32.3	75	26.3	48	31.2	0.52
42	43	33.3	75	28.2	48	33.1	0.55

Table 3 TEC voltage = 30 V and current = 1.2 A

Table 3.1 Cooling pad without water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	43	30.2	74	25.2	49	21.3	0.35
38	44	31.3	73	26.1	49	25.8	0.43
40	44	33.3	72	28.3	50	26.6	0.44
42	45	35.2	73	29.4	50	31.6	0.52

Table 3.2 Cooling pad with water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	45	30.3	71	23.8	45	27	0.45
38	44	31.4	73	24.7	46	29.8	0.49
40	44	33.3	72	27	46	31.3	0.52
42	44	35.5	72	28.1	45	36	0.6

Table 3.3 Plastic net without water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	43	30.5	73	25.4	45	22.5	0.37
38	43	31.6	72	26.3	46	24.1	0.4
40	43	33.4	72	28.1	46	28	0.46
42	44	35.4	73	29.2	46	33	0.55

Table 3.4 Plastic net with water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	43	30.2	73	23.6	46	25.5	0.42
38	44	31.5	74	24.5	46	30.2	0.5
40	44	33.2	73	27.2	47	30.4	0.5
42	45	35.3	73	28.3	46	36	0.6

Table 4 TEC voltage = 45 V and current = 1.9 A

Table 4.1 Cooling pad without water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	44	30.4	73	22.3	46	28.6	0.47
38	43	31.5	73	23.2	46	31.7	0.52
40	44	32.2	74	25.4	46	34.5	0.57
42	44	33.3	74	26.2	45	39.7	0.66

Table 4.2 Cooling pad with water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	45	30.2	74	21.5	47	30.4	0.5
38	43	31.3	74	22.1	46	33.6	0.56
40	44	32.6	74	23.7	46	37.6	0.62
42	44	33.4	75	25	46	41.6	0.69

Table 4.3 Plastic net without water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	42	30.5	75	22.4	45	27.1	0.45
38	43	31.2	75	23.5	46	31.1	0.51
40	43	32.3	76	25.2	46	33.8	0.56
42	44	33.4	75	26.5	46	38.7	0.64

Table 4.4 Plastic net with water sprayed on heatsink

Air inlet temp. (°C)	%RH (inlet)	Air outlet temp. (°C) Evaporative cooling	%RH (outlet) Evaporative cooling	Air outlet temp. (°C) TEC	%RH (outlet)	$Q_{cooling}$ (W)	COP
36	44	30.3	46	21.2	46	30.5	0.5
38	43	31.4	46	22.5	46	33	0.55
40	42	32.5	45	23.4	47	36	0.6
42	43	33.6	45	25.1	46	48.6	0.81

Most of the experimental results are in the comfort zone (Table 1).

Table 2-4 shows the results from different conditions, mainly they have a different TEC voltage, different components (evaporative cooling system) and are with and without water sprayed on the heat sink.

The results show that the plastic net provided slightly better results than the cooling pad. It also showed that the cost of a plastic net is lower than a cooling pad and has a longer life. However, both can provide similar surface areas for the evaporative cooling system.

Figure 5 shows the temperature and %RH of a cooling pad and plastic net. From the experimental results, it would be recommended to use a TEC voltage of 45V because it is better at further reducing air temperature to be in the comfort zone. This is within the range of voltage safety from electric shock. However, if the system does not need further temperature reduction, the system can maintain a voltage at 15V or 30V.

Figure 6 shows the $Q_{cooling}$ and COP of a cooling pad and plastic net. The COP of both the cooling pad and plastic net with water sprayed on hot side of heat sink is much better than no water sprayed.

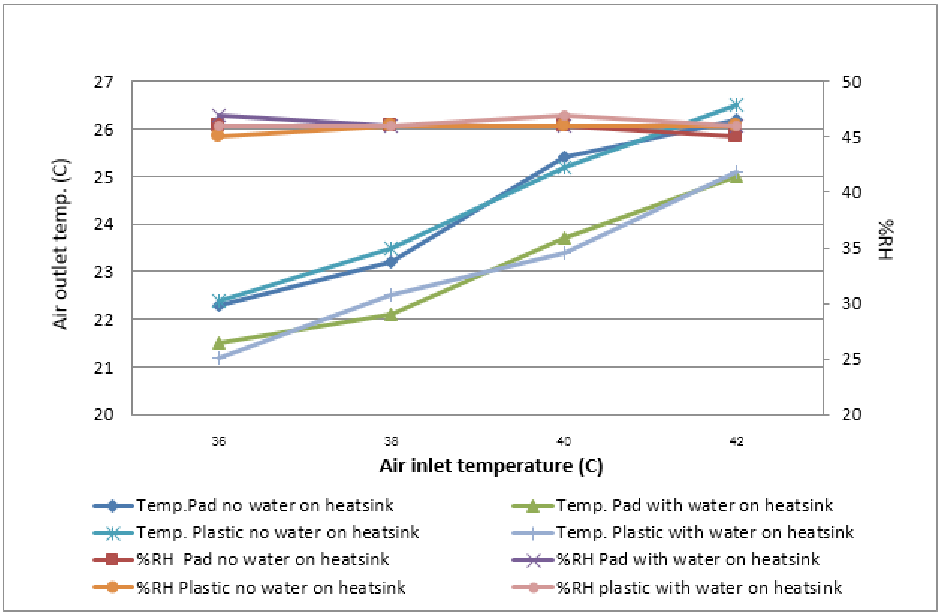

Figure 5 The relationship between air outlet temperature and %RH of cooling pad and plastic net (TEC voltage of 45V)

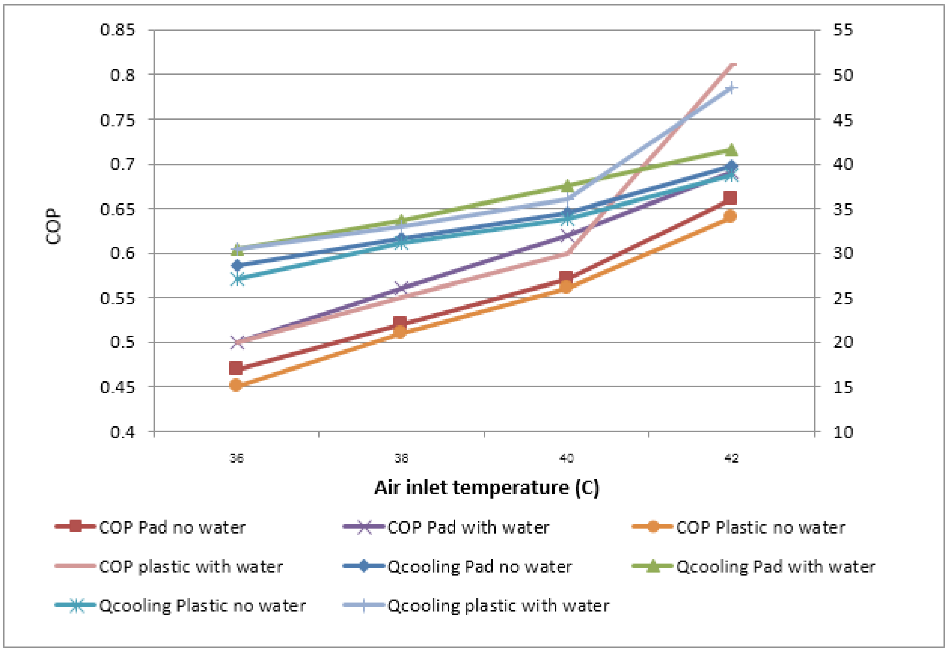

Figure 6 The relationship between $Q_{cooling}$ and COP of cooling pad and plastic net (TEC voltage of 45V)

The air inlet temperature has changed but the relative humidity is similar because the air inlet temperature was set by a duct heater with relative humidity as ambient. From the experiment results, higher air inlet temperature provided better $Q_{cooling}$ and COP. It is because it's leading a higher value of temperature difference between air inlet and air outlet. So, this system is more suitable for a higher value of air inlet temperature.

Most of the experimental results are in the comfort zone. To further reduce air temperature by applying higher power to the TEC's system. However, safety needs are a concern. A higher power output from a TEC can increase the rate of $Q_{cooling}$ and COP.

The $Q_{cooling}$ and COP that can provide the best performance for the TEC is a system containing a plastic net (for the evaporative cooling system), TEC voltage at 45V and water sprayed on top of the hot side of a heat sink. Because it can provide a higher temperature difference (between the air inlet and outlet), higher $Q_{cooling}$ and COP. It also provides the relative humidity in the area of the comfort zone.

Normally the COP of an air conditioner is about 3.0 (Ha & Jeong, 2015), which is higher than our preferred TEC system. Also, the cost of our TEC system is lower and more environmentally friendly. Therefore, it is clear that our TEC system would be preferred over a typical air conditioner.

CONCLUSIONS

This combined system between an evaporative cooling system and TEC system can provide the temperature and relative humidity for the comfort zone. When the air inlet passes through the evaporative cooling system, the air temperature decreases and the relative humidity increases. Afterwards, the air passes through a TEC system and the air temperature is further reduced and relative humidity drops.

Material of evaporative cooling: the plastic net provided more contact area between the air and water. Therefore, there is more area for the heat exchange. The air outlet provided a lower temperature and the $Q_{cooling}$ and COP of the system became higher. A plastic net is more suitable for an evaporative cooling system because it can provide a sufficient surface area for the evaporative cooling system. The water flow rate that is sprayed on top of the evaporative cooling system is not so important as long as water can be sprayed to cover the entire surface area.

The TEC voltage can provide a better performance with higher voltage in terms of further reducing air temperature. However, it depends on the preferred air temperature required inside the room/residence.

Higher electric voltage provided a lower temperature at the cold side of the thermoelectric system. Therefore, $Q_{cooling}$ and COP became higher when the system used a high electric voltage. However, Electric safety is also very important. So, the system needs to consider the maximum electric voltage that can be applied to the system. It also needs to be concerned about sealing the system, to avoid water getting into the electric parts.

The water sprayed on top of the hot side of a heat sink is good in terms of COP. The reason is, if the temperature on hot side of heat sink is not high, then the temperature won't transfer to the cold side of the heat sink. However, the system needs to be concerned about costs because it might need to add more water pumps used to spray water on the hot side of the heat sink.

Air inlet temperature: high air inlet temperature provided a higher value of temperature difference than the $Q_{cooling}$ and COP of the system, which were higher also. At high air inlet temperatures, it is able to show a better performance of the whole system. However, to adjust the TEC voltage depends on the climate of each area.

Water sprayed on top of hot side of heat sink: if the temperature of hot side of heat sink is too high, it will transfer to cold side of the heat sink. So, to cool down the temperature on hot side of the heat sink made a $Q_{cooling}$ and COP higher than without water sprayed on hot side.

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