# THE COOLING PERFORMANCE OF THE EVAPORATIVE COOLING SYSTEM IN COMBINATION WITH THERMOELECTRIC DEVICES: A CASE STUDY OF DIFFERENT TYPES OF MATERIALS

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## ABSTRACT

In an area with a hot climate, air conditioners provide cool air for a room or building. However, they use working fluids which cause global warming. The purpose of this paper is to investigate the air production from an evaporative cooling system with thermoelectric devices (TEC's). The evaporative cooling system is created by a water spray on top of different types of materials (cooling pad, aluminum rods and balsa rods). Different types of materials are tested in order to attain the best efficiency. After the air passes the evaporative cooling system, the air outlet temperature is decreased and the relative humidity (%RH) is increased. Afterwards, the air passes through the TEC's system. The temperature of the air is further decreased and %RH is decreased. The temperature and %RH is expected to be suitable for a comfort zone. This experiment varies the air inlet temperature, water flow rate and TEC current. However, TEC's play an important role to control the comfort temperature and relative humidity. The TEC's cooling capacity can be improved by increasing its input current. Cooling pads appear to provide the best efficiency for the evaporative cooling system with the same amount as others. The advantages of this system are that it is compact, low cost and environmentally friendly. This combination system between evaporative cooling and TEC can be an alternative of producing cool air.

**Keywords:** evaporative cooling, thermoelectrics

## Introduction

Nowadays, the world faces with the pollution problems. One of the problems came from the vapour compression system working fluids because they are not environmental friendly and they can contribute to global warming. Also, they have moving parts and number of seals.

So, to find the other alternative of producing cooling air is very important. This is the reason of producing the cool air by combining the system of evaporative cooling and thermoelectric coolers (TEC's). TEC's are solid devices which can convert electricity energy into a temperature gradient (Cheng and Huang, 2008). TEC's can be used in different types of applications. However, the Coefficient Of Performance (COP) of TEC's is not so high if compare with the price. So, the TEC's system were not developed much for bulky devices e.g. refrigerators and air conditioners. The advantages of TEC's are small size, light weight and working fluid is not required. TEC's can be both heat recovery and air-conditioning systems for a small scale application for indoor climate. For cooling system, the operating COP of TEC's was around 0.4 (Onoroh et al., 2013) and they can deliver a cooling capacity of 25W (Zhao and Tan, 2014). However, the relative humidity, cooling capacity and COP from the combination two systems (TEC's and evaporative cooling system) is expected to be increased. This combination system would suitable for the hot dry climate area. TEC's is considered as an alternative for a small air conditioning and refrigerator system (Lin and Yu, 2016).

Evaporative cooling system is easy to operate and has low cost. The air's relative humidity can be increased and air's temperature can be decreased by the direct evaporative cooling system (air that is in direct contact to the liquid surface e.g. water sprayed).

From the research of Hajidavalloo (Hajidavalloo and Eghtedari, 2010), the evaporative cooling system can produce cool air in the hot climate by conserve electricity up to 20% (Palmer, 2002).

For this experiment, the combination of TEC's and evaporative cooling provided a comfortable indoor climate. The experiment was stated from water is sprayed on top of different types of materials which are cooling pad, aluminum rods and balsa rods. To seeking, which materials can be provided the best efficiency for the whole system. Also, the evaporative cooling system is working with TEC's system to produce cool air with the comfort relative humidity. The experiments were varied the water flow rate, air inlet temperature and TEC's input current.

This combination system is totally no chemical working fluids and the system can be drive by PV panel. This paper shows the characteristics of this combined system. The experiment showed the real performance under the laboratory conditions.

## Methods

There are two main parts of this system as follow in Figure 1 and 2 which are 1) evaporative cooling system (cooling pad, aluminum rods and balsa rods) and 2) TEC's system. The air inlet (hot air at 36°C, 38°C, 40°C and 42°C) with controlled temperature is got into the evaporative cooling system. The temperature can be adjusted by the heater's controller. Water sprayed on top of evaporative cooling system. The air temperature was reduced and relative humidity was increased. Later, the air was sent to the TEC's system (cold side). The air temperature was further decreased and relative humidity was decreased. The air temperature and relative humidity of the air outlet was aiming to the indoor comfortable condition. Also, both are controlled by water sprayed and TEC's electricity current.

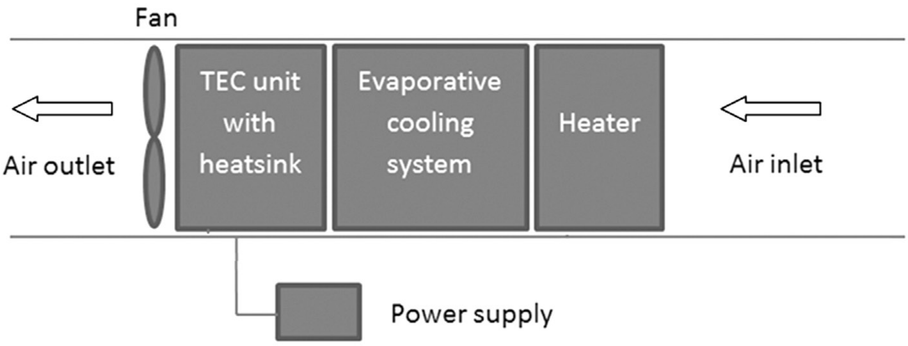


**Figure 1** Main component of two systems

On the hot side of TEC's, the fan was connected with the TEC's system. The fan was released the hot air out of the system. The well performance of the TEC's system was maintained by the fan.

There are 2 units of TEC's system. One unit contains 2 pieces of TEC's (totally 4 TECs in the system). The size of TEC is 40 x 40, $V_{max}$ = 14.7V, $I_{max}$ = 5.6 Amp and $Q_{max}$ = 54V. Thermal resistance of TEC's is less than 0.01°C/W.

TECs were set at the middle of heat sinks (made of aluminium). The fans were connected at the side of heat sinks, to release the hot air and cool air. These 2

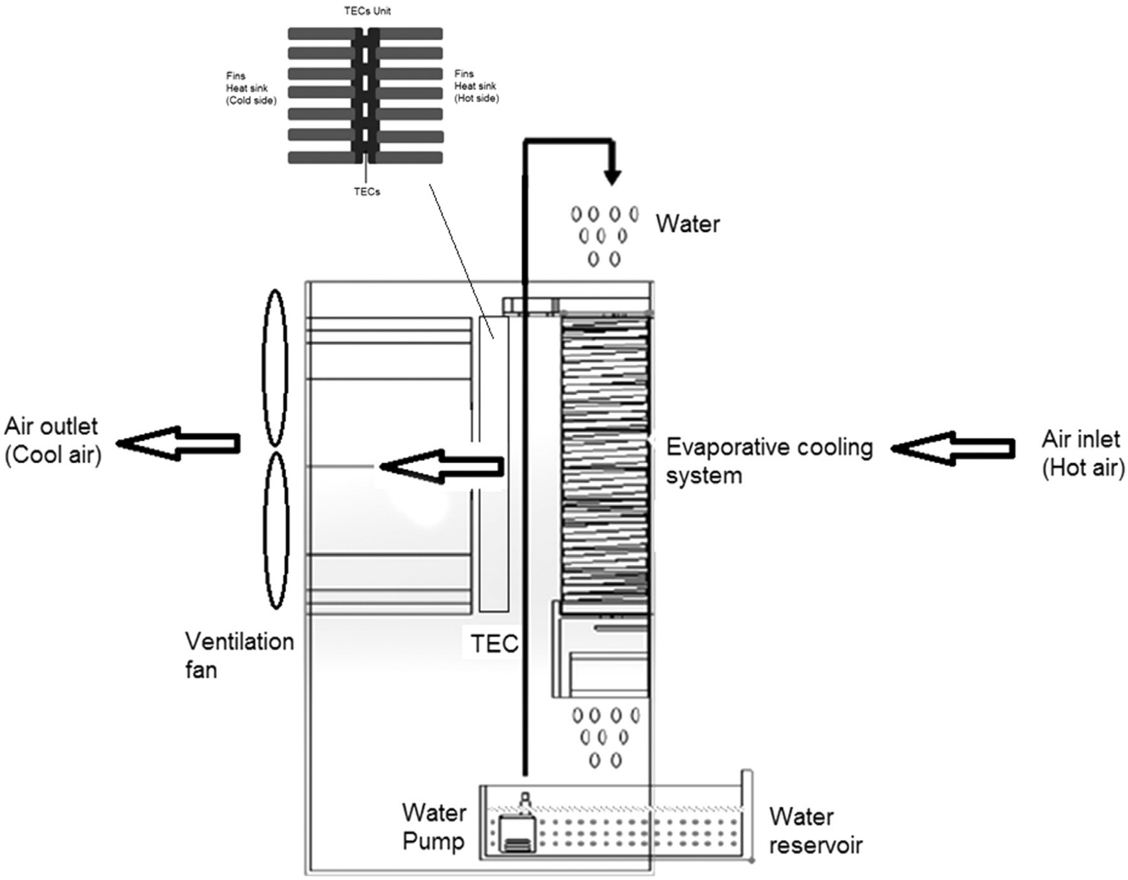


**Figure 2** Overall of the system

TEC's units were connected in a series both electrically and thermally. The waterproof equipment was applied on the system to prevent an electric shock.

Evaporative cooling system, there are 3 types of material for evaporative cooling system which are 1) The cooling pad, size was 400mm x 400mm x 100mm. Cooling pad is made from hard paper 2) Balsa rods size was 10 mm and length 430 mm (53 rods) and 3) Aluminium rods, diameter 10 mm 430 mm length, 53 rods (Figure 3). Size of evaporative cooling system was 80 cm x 60 cm x 40 cm.

The water flow rate, air inlet temperature and electricity current are varied in the experiment.

The air flow rate of the cooling pad was 0.78 kg/s, aluminum rods and Balsa rod was 0.9 kg/s. The difference of the air flow rate was affected by the shape of evaporative cooling materials.

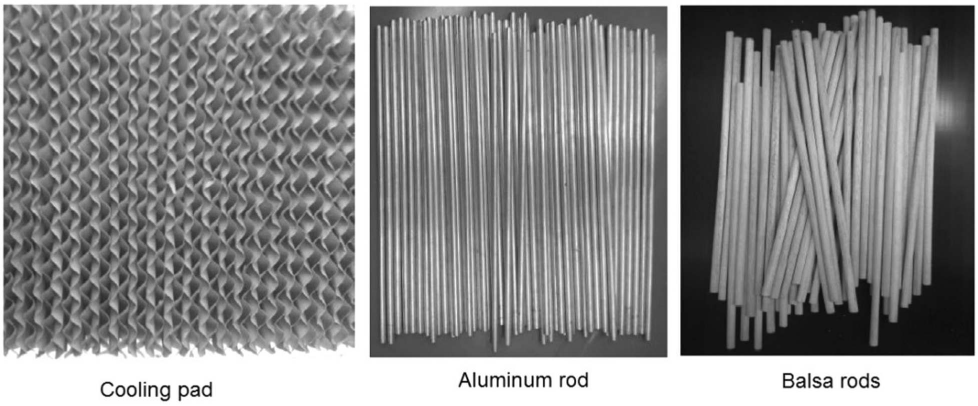


**Figure 3** Material for evaporative cooling systems

However, the electricity current was kept lower than 50V for the safety reasons due to moisture on the TEC's. The cooling capacity and cooling performance of the system can be calculated by the ratio of cooling capacity ($Q_{cooling}$) and electrical energy ($Q_E$).

To find the cooling capacity and electrical energy

This experiment keeps a power supply for TEC lower than 50V for safety reasons (there is some moisture on the TECs). The cooling performance of the system can be calculated by the ratio of cooling capacity ($Q_{cooling}$) and electrical energy ($Q_E$) (Attar and Lee, 2016).

$$COP = \frac{Q_{cooling}}{Q_E} \quad (1)$$

$$Q_{cooling} = m \times (h_3 - h_1) \quad (2)$$

where

$m$ is the mass flow rate of air

$h_1$ is the inlet of specific enthalpy of cold air

$h_3$ is the outlet of specific enthalpy of cold air

## Results and Discussion

The laboratory work was carried with different types of materials (cooling pad, aluminum rods and balsa rods) for evaporative cooling system. To investigate which materials provided the best efficiency for this evaporative cooling system. Later, the air from evaporative cooling system was sent to the next stage which is TEC's system.

The operating conditions of the laboratory were as follows: 1) The water temperatures was 20°C (water temperature can be controlled by another TEC system). Water flowrate for spraying on top of evaporative cooling system material were 1.5 and 3 l/min, 2) Inlet air temperatures were at 36°C, 38°C, 40°C and 42°C, and 3) The maximum power supplies for the TEC units were 45V and 1.9A for safety reason.

One experiment took 45 minutes. To find the average of the results of 45 minutes. The water flow rate did not affect much to the results, as long as the water covers all the surface area of evaporative cooling material.

Usually, the comfort temperature and relative humidity in each climate are as follow in the Table 1.

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

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

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

**Table 2.1** Cooling pad

| 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 | 25.1 | 49 | 19 | 0.32 |
| 38 | 45 | 31.3 | 72 | 26.2 | 49 | 21 | 0.36 |
| 40 | 43 | 32.1 | 74 | 28.2 | 50 | 22.5 | 0.38 |
| 42 | 44 | 33.1 | 73 | 29.3 | 50 | 24 | 0.41 |

**Table 2.2** Aluminium rods

| 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 | 32.2 | 76 | 27.2 | 53 | 17 | 0.29 |
| 38 | 45 | 32.3 | 77 | 28.1 | 52 | 19 | 0.32 |
| 40 | 43 | 33.1 | 77 | 30.2 | 53 | 20 | 0.34 |
| 42 | 44 | 34.0 | 75 | 31.2 | 53 | 22 | 0.37 |

**Table 2.3** Balsa rods

| 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 | 31.1 | 74 | 26.2 | 49 | 18 | 0.31 |
| 38 | 45 | 31.2 | 73 | 27.1 | 50 | 20 | 0.34 |
| 40 | 43 | 32.1 | 74 | 29.2 | 51 | 21 | 0.36 |
| 42 | 44 | 34.1 | 74 | 30.2 | 50 | 23 | 0.39 |

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

**Table 3.1** Cooling pad

| 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 | 23.2 | 49 | 20.5 | 0.35 |
| 38 | 45 | 31.1 | 72 | 24.1 | 48 | 22 | 0.37 |
| 40 | 43 | 33.2 | 74 | 26.3 | 48 | 23.5 | 0.4 |
| 42 | 44 | 35.2 | 74 | 27.1 | 49 | 25 | 0.43 |

**Table 3.2** Aluminium rods

| 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 | 32.1 | 75 | 26.1 | 52 | 19 | 0.32 |
| 38 | 45 | 33.2 | 76 | 27.2 | 52 | 21.5 | 0.37 |
| 40 | 43 | 34.2 | 75 | 29.2 | 51 | 22 | 0.38 |
| 42 | 44 | 35.3 | 77 | 30.1 | 51 | 24 | 0.41 |

**Table 3.3** Balsa rods

| 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 | 31.3 | 74 | 25.3 | 49 | 18 | 0.31 |
| 38 | 45 | 31.2 | 73 | 26.2 | 49 | 20 | 0.34 |
| 40 | 43 | 32.3 | 74 | 28.2 | 50 | 21.5 | 0.37 |
| 42 | 44 | 33.1 | 73 | 29.1 | 50 | 22.5 | 0.38 |

**Table 4** TEC Voltage = 45 V and current = 1.9 A

**Table 4.1** Cooling pad

| 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 | 30.3 | 72 | 22.2 | 46 | 22 | 0.38 |
| 38 | 45 | 31.3 | 73 | 23.1 | 46 | 23.5 | 0.4 |
| 40 | 43 | 32.1 | 73 | 25.2 | 46 | 24.5 | 0.42 |
| 42 | 44 | 33.2 | 72 | 26.2 | 45 | 26 | 0.44 |

**Table 4.2** Aluminium rods

| 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 | 32.3 | 75 | 24.2 | 45 | 20 | 0.34 |
| 38 | 45 | 32.2 | 76 | 25.2 | 45 | 22.5 | 0.38 |
| 40 | 43 | 33.2 | 76 | 28.3 | 46 | 23.5 | 0.4 |
| 42 | 44 | 34.1 | 76 | 29.1 | 46 | 25 | 0.43 |

**Table 4.3** Balsa rods

| 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 | 24.1 | 47 | 19.5 | 0.33 |
| 38 | 45 | 31.3 | 74 | 25.2 | 48 | 21 | 0.36 |
| 40 | 43 | 33.1 | 74 | 27.2 | 48 | 22.5 | 0.38 |
| 42 | 44 | 35.2 | 73 | 29.1 | 48 | 23.5 | 0.4 |

Table 2-4 shows the average results for different conditions. The results show the cooling pad was the best material for evaporative cooling system to reduce the air outlet temperature. The second best is balsa rods. The cooling pad can provide more surface areas than the other materials. The Balsa rods can absorb more water than aluminium rods. However, the price of cooling pad is the highest and the working life is shorter than the other materials.

Figure 4-6, it shows the temperature and %RH of a cooling pad, aluminium rods and balsa rods. During the TEC voltage 15 V and 30V are not recommended because temperature and %RH are not in comfort zone (Table 1). During the TEC voltage 45 V is recommended because most of temperature and %RH are in comfort zone.

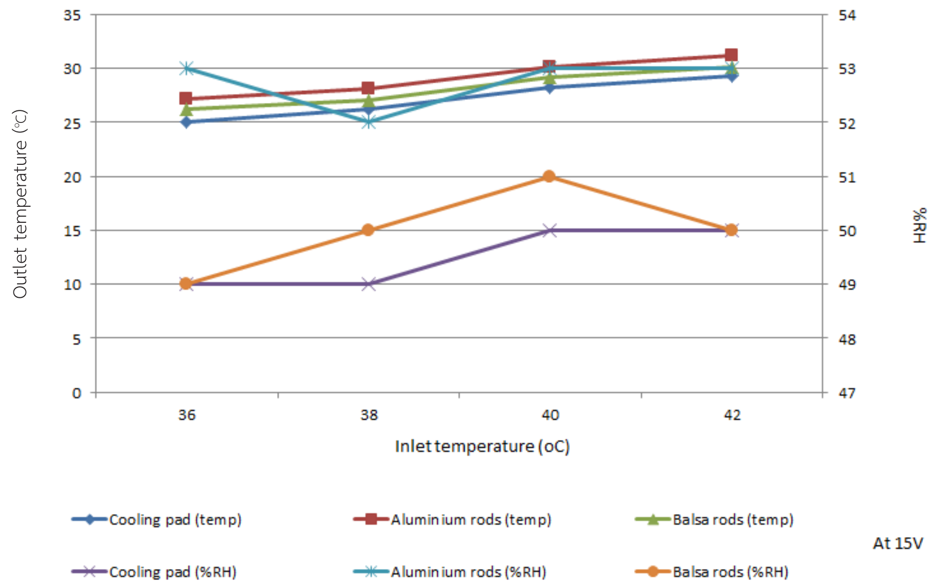


**Figure 4** Outlet temperature and %RH of TEC at voltage = 15V and current = 0.5A

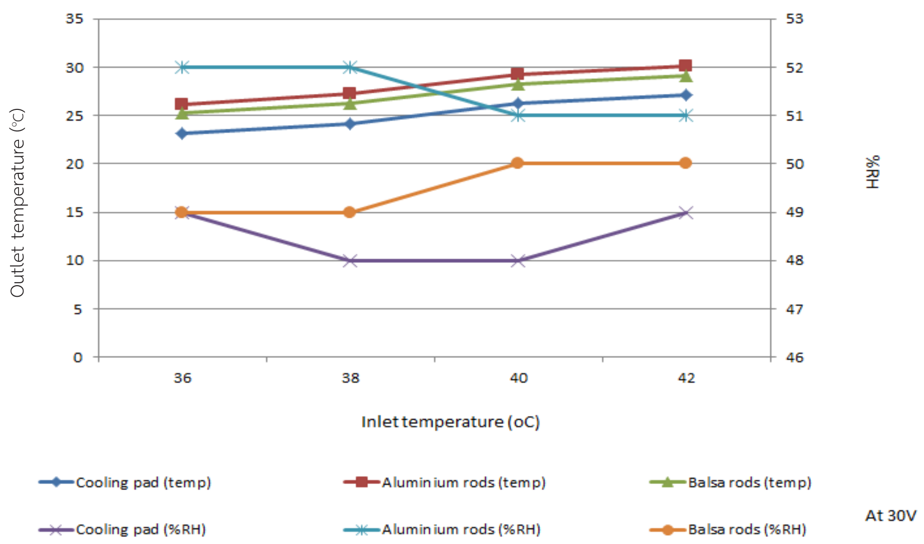


**Figure 5** Outlet temperature and %RH of TEC at voltage = 30V and current = 1.2A

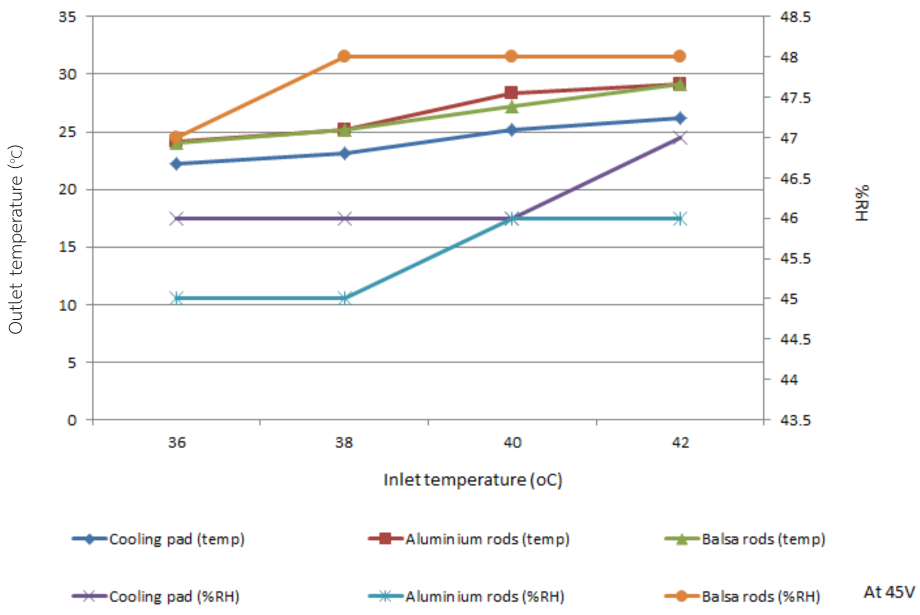


**Figure 6** Outlet temperature and %RH of TEC at voltage = 45V and current = 1.9A

## Conclusions

Cooling pad, most results are in comfort zone however, it is depending on which climate in that area. The water flow rate did not affect much to the results both temperature outlet and relative humidity. As long as, the whole evaporative cooling materials are filled by water. Water temperature is important to reduce air temperature at evaporative cooling system. The water temperature will affect the air outlet temperature. The lower temperature provides a lower air outlet temperature. However, evaporative cooling provided a high relative humidity. So, it may not suitable for some climate area. Then the TEC's system is play an important role to further reduce air temperature and relative humidity (condensation) for suitable for the indoor building.

The system can get to the comfort zone. The COP seem not high if compare with air conditioning. However, this combination system is much more environmental friendly.

To let TEC or evaporative cooling working alone is not a good idea because evaporative cooling may provide too high %RH and TEC cannot reduce the temperature as expected. For example, from table 2-4, after the air passes the evaporative cooling system, the temperature is around 33°C and the %RH is about 75, which is not in the comfort zone (Table 1). Also, only TEC cannot drop much of the air's temperature.

After air has passed the evaporative cooling system, the air temperature is decreased and relative humidity is increased. Later this air passes to the TEC's system, the air temperature is then further decreased and relative humidity is decreased. Lower water temperature can provide lower air outlet temperature. Usually, the comfort temperature and relative humidity are as follows in the Table 1. To apply higher power to the TEC's system is to further decrease the air temperature. It can be increased to $Q_{cooling}$. However, it was not worth it if compared with the COP.

The cooling capacity and COP of the system of cooling pad seems to be the best. Also, the higher power electricity from TECs provide a better $Q_{cooling}$ but the COP does not make that much of a difference. From the experiment, the higher air inlet temperature can provide better results during the term of higher temperature difference (air inlet – air outlet), higher $Q_{cooling}$ and COP.

The Coefficient Of Performance (COP) value of an air conditioner is about 3.0 (Ha and Jeong, 2015) which is higher than this cooling research system. However, the price of this cooling research system is lower and more environmental friendly.

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