

## THE COOLING PERFORMANCE OF THE EVAPORATIVE COOLING SYSTEM (COOLING PAD) IN COMBINATION WITH THERMOELECTRIC DEVICES

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### ABSTRACT

The purpose of this paper is to produce an air cooling system which is environmental friendly. This paper represents the investigation of the application of an evaporative cooling system with thermoelectric devices (TEC's). This combination system is designed to produce comfort air for an indoor climate. The evaporative cooling system can be created by water spray on top of a cooling pad. Heat is transferred between water and air, causing air outlet temperature to decrease (relative humidity, %RH increase). When the air passes through the TEC's its temperature further decreases (%RH decrease). The variable values are air inlet temperature, water flow rate, and TEC current. In the first stage, the water spray attempt to sets the proper air temperature and humidity to the room's standard. However, TEC's play an important role during the experiment to control the comfort conditions. The experimental work also showed that the TEC's limited cooling capacity needed to be improved by increasing its input current. The advantages of this system are that it is compact, possesses no moving parts, and is environmentally friendly.

**Keywords:** Thermoelectric devices

## Introduction

Thermoelectric coolers (TEC's) are solid devices which can convert electric energy into a temperature gradient (Chin-Hsiang, C. and Shu-Yu, H. 2008). TEC's can be used in different lines of work. TEC has been distributed since 1834. However, TEC's were not developed for bulky devices such as air conditioners or refrigerators. One of the reasons is price. TEC's are considered expensive when measured against their coefficient of performance (COP) (Jou-Yun, L. and Chang-Da, W. 2011). Especially when compared with a vapour compression system which uses working fluids which are not environmentally friendly. Also, there are some problems about noise pollution as a result of their moving parts. These are the reasons why thermoelectric devices might be another alternative for producing cool air. The advantages of TEC's include reduced size, light weight and working fluid is not required (Bao, Y., Herwin, A. and Thanh N. 2008). TEC's is a small scale application for building (Russel M., Ewing E, and Ching, C. 2013) and (Riffat, S., Ma, X. and Wilson R. 2006). TEC's can also be used for heat recovery and air-conditioning systems. TEC's could deliver a cooling capacity of about 25W

(Vian, J., Astrain, D., Rodriguez, A. and Martinez A. 2010) with an operating COP for the thermoelectric device around 0.3-0.5 (J C Bas, D T Allen, S Ghamaty and N B Elsner. 2007) Therefore, the combination between an evaporative cooling system and TEC's is an increase in cooling capacity and relative humidity. It would be suitable for an arid climate and other areas that need cool air.

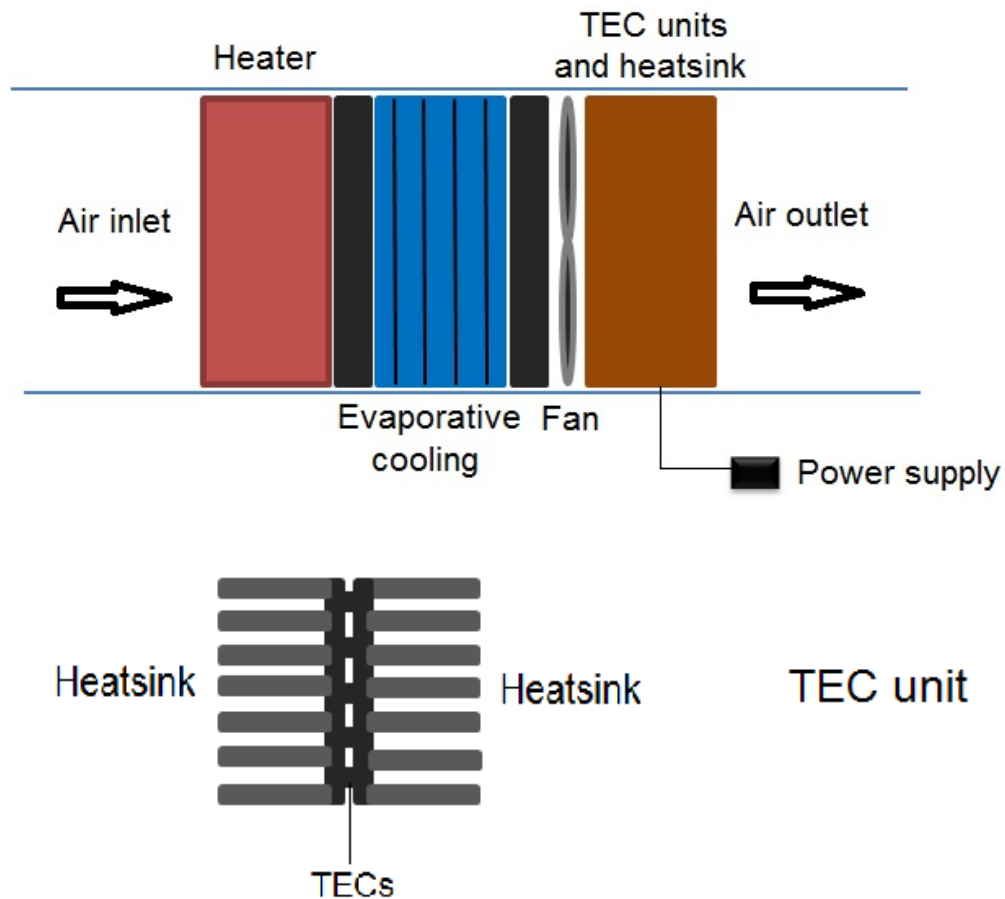
Evaporative cooling is a method used to achieve a comfortable indoor climate. The direct evaporative cooling systems can decrease air temperature and increase relative humidity of the air (air that is in direct contact to the liquid surface). For this experiment, water is dropped on top and passes through cooling pad. Research carried out by Hajidavalloo (Hajidavalloo, E. and Eghtedari, H. 2010) showed that in very hot weather conditions, applying evaporative cooling within the air conditioning system could conserve electricity usage by up to 20%

In a comfortable indoor climate, in order to use TEC's as an alternative for a small refrigerator or air conditioning system (Ugur Kemiklioglu and Selim. 2014), the evaporative cooling system must be combined with TEC's. This combination system is suitable for an arid

climate. This system is environmentally friendly because it doesn't use working fluids (Manoj Kumar Rawat, Himadri Chattopadhyay, Subhasis Neogi. 2013). Also, this system can be driven by PV panels. This paper investigates the results of the combination system between the evaporative cooling system and TEC's. The experiments showed the performance of the system in different laboratory conditions.

## Methods

There are two main parts of this system (Figure 1): a cooling pad and the TEC's. The air (inlet) with a controlled temperature is sucked into the cooling pad and water is sprayed on top of the cooling pad. Water passes to the whole area of the cooling pad. After air passes the cooling pad (evaporative cooling system), the air temperature decreases and humidity increases. Then air passes through the cold side of the TEC's for a further decrease (relative humidity is decreased) of its temperature to a desirable point. The temperature and relative humidity of the outlet air is controlled by both the spraying of water and the TEC's.



**Figure 1** Structure of Evaporative cooling system and TEC units

On the hot side of the TEC's, there is a fan that blows heat out of the hot side of the TEC's. To cool down the hot side temperature can increase the performance of the TEC's.

One TEC unit contains 2 pieces of thermoelectrics (totally 2 units), for each TEC has a dimension of 40 x 40 mm,  $V_{\max} = 14.7V$ ,  $I_{\max} = 5.6$  Amp and  $Q_{\max} = 54V$ .

A thermoelectric module stays between two heat sinks. The heat sinks (with fins) are made of aluminium. The thermal resistance of the TEC's is less than  $0.01^{\circ}C/W$ . All of the TEC's (4 pieces) are connected electrically in a series. Also, two TEC units are connected in a series both electrically and thermally. There is a protection from electric shock by using a waterproof enclosure.

The cooling pad (400mm x 400mm x 100mm) is made from hard paper. It provides a contact surface between the air and water on the surface of the cooling pad (water spray on top of cooling pad). The water flow rate varies in the experiments. 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 ( $Q_{\text{cooling}}$ ) and electrical energy ( $Q_E$ ).

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

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

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 out with and without spraying water on the cooling pad to investigate the results of the system after the water temperature has changed. It also allowed us to study the performance of TEC's.

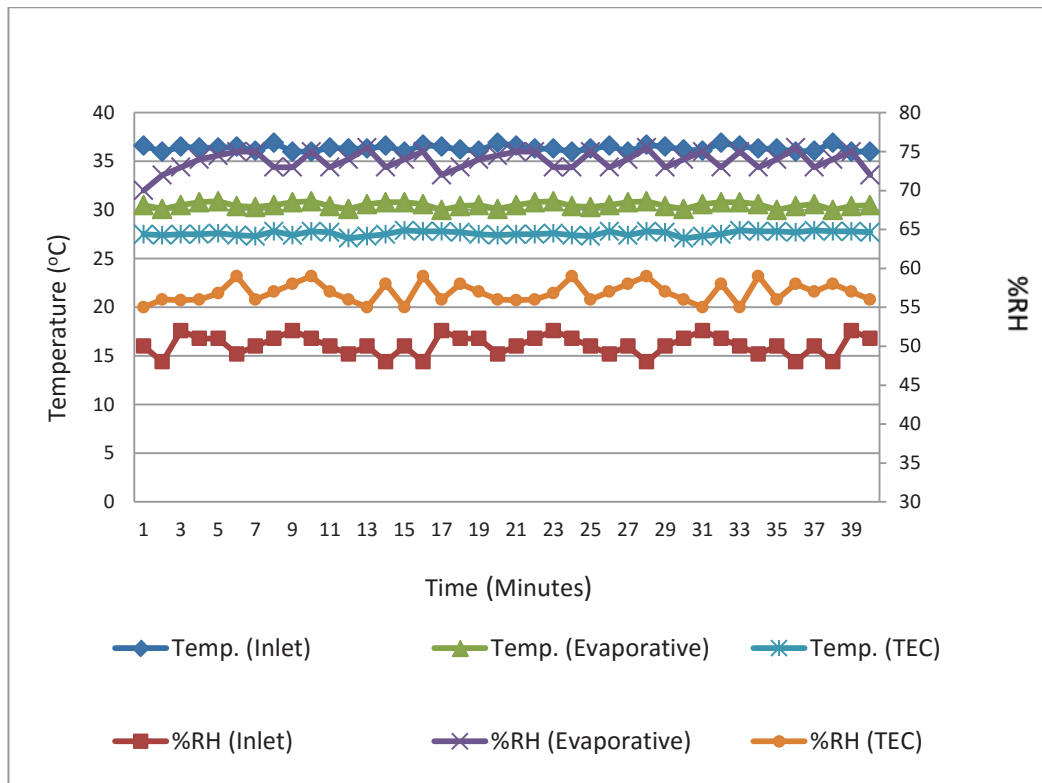
The operating conditions of the laboratory were as follows: Inlet air temperatures were at 28°C, 30°C, 32°C 34°C and 36°C. Water flow rate for spraying water on the cooling pad was 1.5-3 l/min. The power supply for the TEC units were 45 V and 1.9 A (maximum for safety reason). The air mass flow rate was 0.9 kg/s.

Figures 2-3 show the temperature and relative humidity after the cooling pad and TEC units were completed (with and without water sprayed on cooling pad). It also includes the TEC temperature and relative humidity under different operating conditions. It was shown that the outlet temperature with water sprayed on a cooling pad is much lower than without the water being sprayed. After the cooling pad, the air temperature was decreased (heat transferred between the water and the air) and relative air humidity was increased. After the TEC units, air temperature and relative air humidity

were further decreased (condensation). The relative humidity after the TEC units seems too high for a room/building interior. However, it is to be noted that the high value of relative humidity will decrease when this system is applied to a real room/building interior. The value of relative humidity depends on the conditions of the room including size and heat. Normally, the comfort temperature and relative humidity in each climate are as follow in the Table 1.

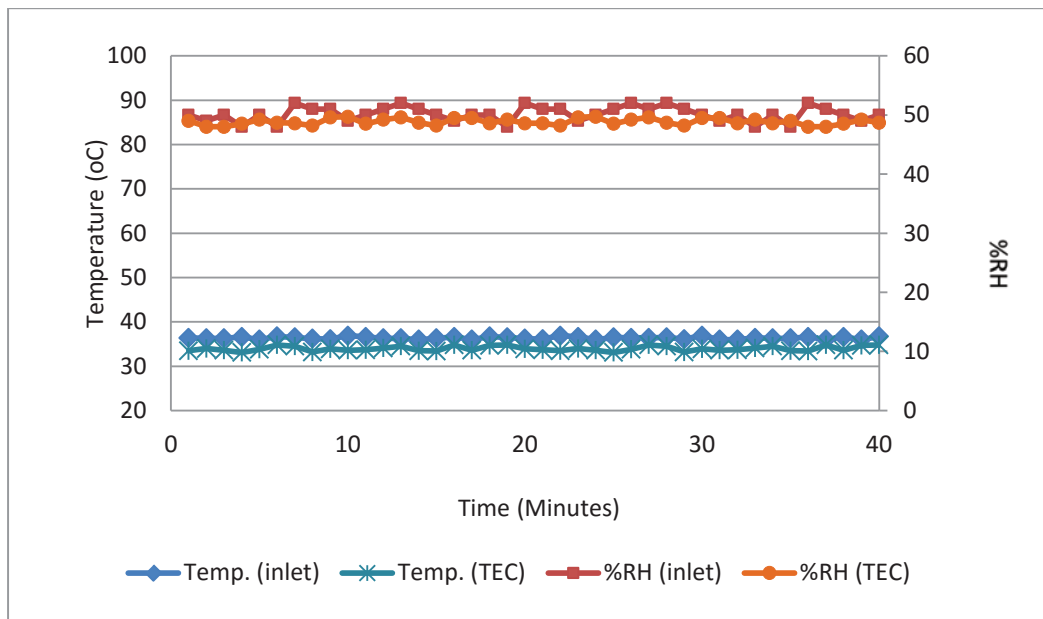
**Table 1** Comfort temperature and relative humidity (McMullan R. 2008: 47).

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



**Figure 2** Water sprayed on top of cooling pad

From the results of Figure 2, (temperature outlet and %RH after they passed the TECs), temperature and %RH are considered in the comfort zone (Table 1). However, there are other factors to consider when applied to real conditions pertaining to an indoor building e.g. number of people, outside temperature.



**Figure 3** No water sprayed on top of cooling pad

Figure 4-5 shows the cooling capacity and COP of the system. The cooling capacity of a combined system (evaporative cooling with TECs units) was higher than using only an evaporative cooling system. However, the COP value of the combined system is lower than the evaporative cooling. That is because the TEC's unit cannot work at

its optimum capability and therefore cannot reduce the temperature further.

From Figure 4, the cooling capacity and COP was about the same as the normal thermoelectric cooling system (25 W and 0.3-0.5). However, this combined system (evaporative cooling system with TECs) can adjust the suitable %RH for the room by spraying water.

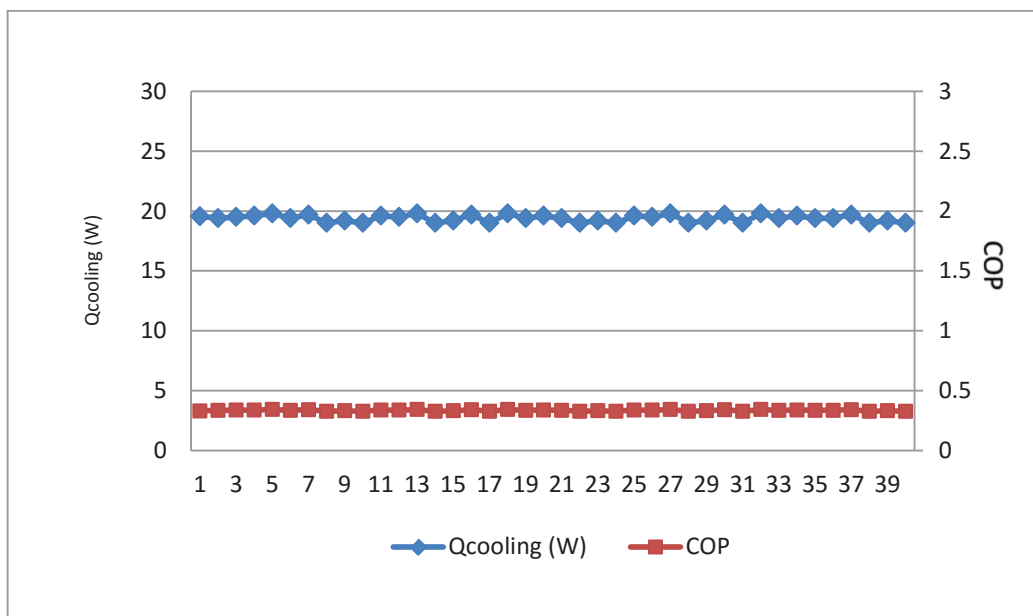


Figure 4 With water sprayed on cooling pad

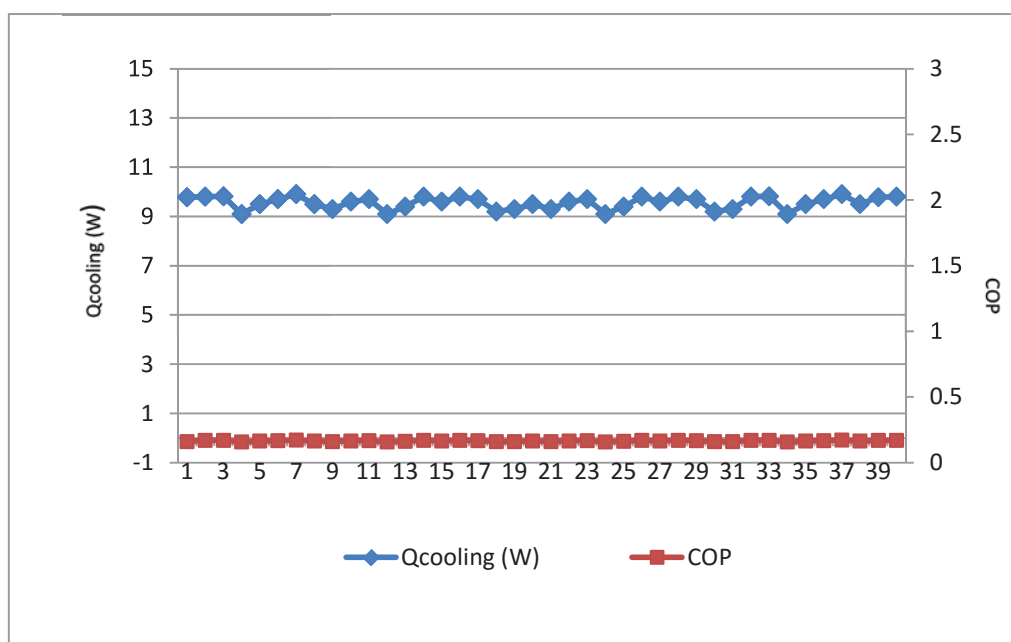


Figure 5 Without water sprayed on cooling pad



The water flow rate (from evaporative cooling system) did not affect the results of the both the temperature outlet and relative humidity by very much, as long as all of the evaporative cooling materials were filled by water. Water temperature is important to reduce the air temperature for the evaporative cooling system. However, evaporative cooling provided a high relative humidity. So, it may not suitable for some climate areas. Therefore, the TEC's system plays an important role in reducing air temperature and relative humidity (condensation) suitable for indoor areas.

The system can achieve a reasonable comfort zone if the COP isn't high when compared with air conditioning. However, this combination system is much more environmentally friendly.

To let the TEC or evaporative cooling work alone is not a good idea because the evaporative cooling may provide too high of a %RH and the TEC would not reduce temperatures as expected.

## Conclusions

This paper represents the investigation of evaporative cooling by using cooling pads with TEC units that provide a suitable application for hot and dry climate conditions. The investigation was conducted under laboratory conditions. The conclusions from the investigation are as follows:

The investigation showed that the evaporative cooling system with water sprayed can reduce air temperature with an increase in relative humidity. A combined system between the evaporative system and TEC units can further reduce the temperature and relative humidity. In some areas, a combined system with potentially comfortable air can be provided.

Water temperature affects the outlet air temperature. The COP value will be higher with a lower water temperature. However, in some areas it may not be able to find a low water temperature, such as hot and dry climates.

The water temperature did not affect the temperature outlet much, as long as the water can was sprayed over the surface area of cooling pad. Also, %RH was slightly increased when applied to a higher water flow rate.

TEC units play an important role in controlling the correct temperature for the whole system and provides the system with a suitable temperature for the room/building interior. For this system, the performance of the TEC units were restricted by the maximum input voltage.

From the experiment, the value of air inlet temperature varied. The higher air inlet temperature can show a better result (more temperature difference between inlet and outlet). Also, a better cooling capacity and COP.

As a result, the cooling capacity may not have been high enough. To improve the maximum power output of TEC units would require future work. Also, to use of a UV light filter may be a good idea for eliminating bacteria in the water (in case the water is reused).

The performance of a combined system (evaporative cooling with TEC units) is definitely better than using only an evaporative cooling system. It is because the TEC units play an important role in further reducing temperature and relative humidity. It results in the temperature and relative humidity value being closer to the comfort zone value.

The right temperature and humidity is important for maintaining a comfortable environment for people. Also, having too high a relative humidity could result in more diseases.

For the next experiment, the combined system can be tested with a model room which would simulate a real indoor building. It would be a more realistic experiment and would yield further useful results. To use solar cells to drive a whole system would make the system even more environmental friendly.

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