

Investigation of a novel Thermoelectric Evaporative Cooling Tower System

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ABSTRACT: This paper presents the preliminary investigation of the application of a novel thermal evaporative cooling tower integrated with thermoelectric devices (TECs) and a mop fan to provide a comfortable indoor climate. The mop fan functions by reducing air temperature and increasing relative humidity with the use of water for evaporative cooling. This pre-treated airflow then passed through a TEC unit, which further reduced air temperature and increased the relative humidity. Results from the experiments have shown that comfortable conditions could be obtained by utilising appropriate water spray temperatures and water spray flow rates. The performance of the TECs played an important role during the lab work to control the comfort conditions. The experimental work also showed that the TEC's limited cooling capacity needed to be improved by increasing input current. The system utilizes no environmentally harmful working fluids. It is quiet in operation and relatively maintenance free. The system utilizes DC power making it appropriate for integration with photovoltaic panels.

Keywords: Direct Evaporative Cooling, Thermoelectric, Mop Fan

1. INTRODUCTION

Thermoelectric coolers (TECs) are solid devices which can convert electric energy into temperature gradient. They have been widely used in many applications. However in the early stage after their discovery in 1834, they have not been developed for large space air conditioning applications due to the low cost of vapour-compression systems which have a higher coefficient of performance (COP). However vapour compression system working fluids are not environmentally friendly and contribute to global warming, they also require maintenance due to the number of seals and moving parts. Nowadays the use of thermoelectric devices in mini refrigerators is more popular due to the fact that TEC

systems don't require any working fluid and are much more compact and lighter [1]. Research has been carried out in air-conditioning system [2], heat recovery system [3] and small scale applications for buildings [4][5]. These investigations showed that the operating COP of thermoelectric device was around 0.4 and each device could deliver cooling capacity of 25 W. However, in some arid areas like Middle East, comfortable relative humidity could not be satisfied by simply applying TEC in the field of refrigeration. Their limited cooling capacity can only reduce the temperature of air by a few degrees, with little increase on the relative humidity. Therefore a hybrid evaporative cooling TEC

device is proposal here to increase the cooling capacity and relative humidity.

Evaporative cooling is an easy and low cost method to achieve comfortable indoor climate. Direct evaporative cooling systems can increase humidity and decrease air temperature by contacting with a liquid surface or with a wet solid surface, or even with sprays. [6]. Research carried out by Goswami etc [7] and Hajidavalloo [8] showed that in very hot weather conditions, applying evaporative cooling within the air-conditioning system could save electric energy up to 20%.

The combination of TEC and evaporative cooling could provide a comfortable indoor climate and facilitate the use of TECs as a viable alternative for small scale space air condition systems in hot-dry climates. The system, called thermoelectric evaporative cooling tower, features no chemical working fluids; direct power required which can be supplied from PV panels, etc. This paper investigates the characteristics of this combined system and experimental work will be carried out to show its real performance under the laboratory conditions.

2. DESCRIPTION OF THE SYSTEM AND EXPERIMENTAL SET-UP

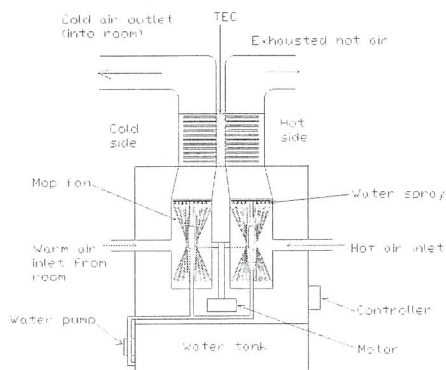


Figure 1: Schematic diagram of thermoelectric evaporative cooling tower

The system consists of two main parts (Figure 1): mop fans and thermoelectric devices. The dry warm room air is sucked into the chamber of mop fan, passing over large surface area of the flexible fibres and is exhausted via centrifugal force. Water is supplied to the flexible fibres, which turns into tiny droplets or mist, increasing the humidity and reducing the temperature of air through evaporative cooling. Then it passes through the cold side of the TECs where more thermal energy is removed, further reducing its temperature to a desirable level. The relative humidity (RH) and temperature of outlet air is controlled by both the spraying of water and the TECs.

On the other side of the system, the hot ambient air is sucked into mop fan as well before passing through hot side of TECs, reducing its temperature and increasing relative humidity and moisture contents, which helps increase the heat transfer efficiency on the hot side of TECs. The primary function of this side of the system is to increase the performance of the TECs by cooling the hot side.

One TEC unit contains 8 pieces of thermoelectric models, for each with dimension of 40 x 40 mm, $V_{\max} = 14.7V$, $I_{\max} = 5.6A$ and $Q_{\max} = 54W$.

Each thermoelectric model is sandwiched between two heat sinks, which are made of aluminium with fins with overall thermal resistance of less than 0.01 °C/W. Eight thermoelectric modules are connected electrically in series. Two TEC units are connected in serial both thermally and electrically. The TECs are in a waterproof enclosure.

The mop fans (fibre diameter of 1.5mm, fibre number of 2700, coating area of 1.21m², length of the mop of 95mm, diameter of core of 65mm and diameter of mop wheel of 260mm) provide a very large contact surface between the air and water on the surface area of each mop. The speeds of mop fans vary in the experiments. Because of the moisture on both sides of the TECs,

the power supply for TECs is kept below 50V for safety reasons.

The cooling performance of system can be evaluated by calculating the ratio of the cooling capacity ($Q_{cooling}$) provided by the system to the electrical energy (Q_E) consumptions of the TECs and mop fans.

$$COP = \frac{Q_{cooling}}{Q_E}$$

where

$$Q_{cooling} = m \cdot (h_3 - h_1)$$

where m is the mass flow rate of air; h_1 and h_3 are the inlet and outlet specific enthalpy of cold air respectively.

3. RESULTS OF LABORATORY TESTING

Laboratory work was carried out with and without water spraying on the cold side while water was supplied to the hot side mop fan and also for no water spraying on both sides. The effects of water temperature on the system performance were also investigated. As the TEC is key element of the system, its performance was also studied.

The standard operating conditions for the system were: Inlet air temperatures on the cold and hot sides of the TECs were 26 °C and 35 °C respectively. The motor speed was chosen at 1420 RPM and water flow rate for spraying was 3 l/min to supply sufficient mist when air passed through. For safety reasons as mentioned above, the power supply for TEC units was 45 V and 1.9 A.

Figures 2, 3 and 4 show the inlet, mop, TEC temperatures and relative humidity under different operating conditions with water spray on both, hot side only and no water spray. It was shown that the outlet temperature with water spray on both sides is much lower than water spray only on hot side. In the case study, the TEC unit can

only deliver a few degrees of temperature change while the relative humidity stays at a similar level. For the system that has no water spray, the air outlet temperature at cold side keep increasing due to that TECs drop in performance as the heat from hot side was conducted over to cold side. The mop fan with water spray on both sides can decrease the air temperature greatly due to evaporative cooling and low water temperature.

Another effect of the water spray is that it also increases the relative humidity significantly. Relative humidity from water spray on both sides appears too high for room/building interior if all the room air were supplied by the proposed system. However, it is to be noted that the high percentage of RH will decreases when there is an increase in volume of room. For the system with water spray only on the hot side, the relative humidity is already in the comfortable range.

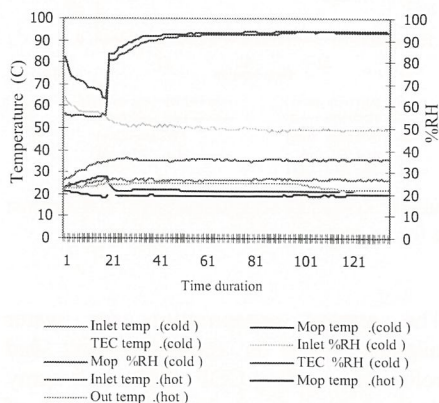


Figure 2: Graph of temperature and RH against time for water sprayed on both mop fans

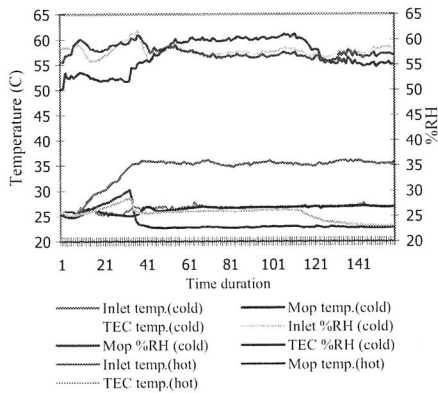


Figure 3: Graph of temperature and RH against time for water sprayed on cold side mop fans

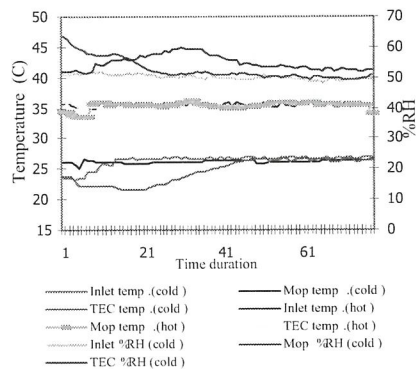


Figure 4: Graph of temperature and RH against time for no water sprayed on mop fans

The energy consumption for water circulating pump is relatively low and therefore the cooling COP with water spray on both sides is much higher than that of water spray only on hot side and no water spray at all, as shown in Figures 5-7. That means water spray has a significant effect on the cooling system. For experiments without water spray on cold and both sides, the mop fan only functions as a blower to induce air flow, with low cooling capacity. Comparing the cooling capacity of the three experiments, it is clear that the experiment with water spray on both sides give the best cooling capacity. While the experiment with

no water spray is not effective at all, showing limited capacity of the TEC system.

For the case of no water spray on the hot side of TECs, due to the high temperature on hot side, the duration of the experiment cannot be longer as there is a possibility of damaging the TEC.

Figure 8 shows the effect of water temperature on the outlet temperature, relative humidity and the COP. As it can be seen, water inlet temperature has a direct linear influence on the water outlet temperature. The water functions to moist air and reduces the airflow temperature which in turn leads to improve performance of TEC.

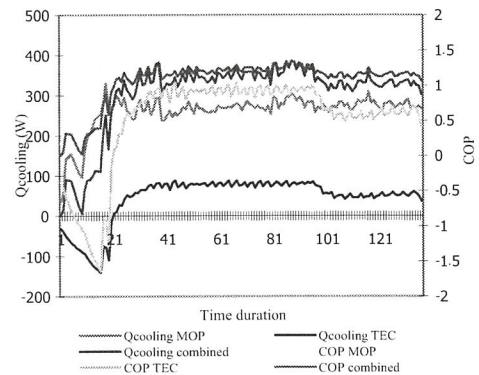


Figure 5: Graph of $Q_{cooling}$ and COP against time for water sprayed on both mop fans

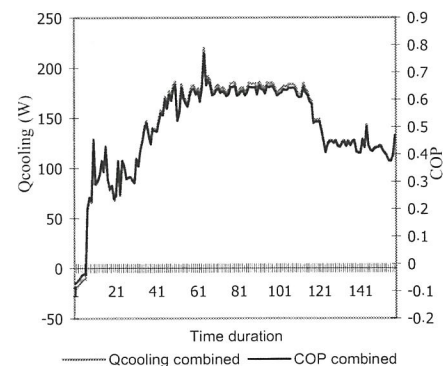


Figure 6: Graph of $Q_{cooling}$ and COP against time for water sprayed on cold side of mop fans

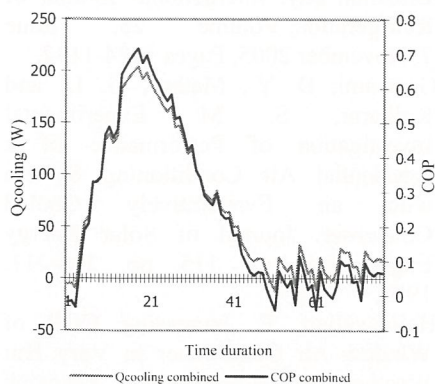


Figure 7: Graph of $Q_{cooling}$ and COP against time for no water sprayed on mop fans

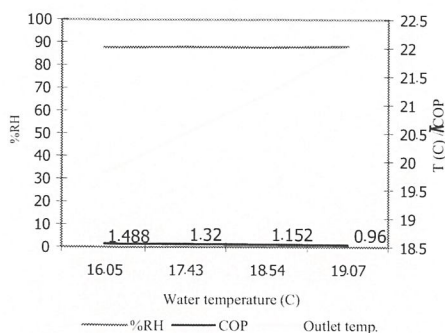


Figure 8: The effect of water spray temperature on RH, COP and outlet temperature

4. CONCLUSION

The work presented in this paper shows an investigation of a thermoelectric evaporative cooling tower for hot dry climate conditions. The preliminary work was conducted under the laboratory conditions and conclusions from the work are as follows:

The experimental study showed direct evaporative cooling with water spray could provide air with the low temperature and high relative humidity. A combined system with TECs shows that potential comfortable air can be provided.

Water temperature affects the outlet air temperature directly. Lower temperatures of water contributed to higher COPs. But in the dry and hot areas, water with low temperatures can only be found in wells from deep underground, a fact that should be considered in a final system design.

TECs have potential to play an important role in controlling the accurate temperature of a hybrid evaporative cooling systems. However in this preliminary work, the TEC's performance was restricted by the maximum input voltage, which led to the low cooling capacity. More work is required to improve the maximum power output of the TECs, while electric insulation is carefully considered for safe operation of the system in wet condition. The temperature of water should be monitored to avoid high temperatures which would promote bacteria growth such as *Legionella*. A UV light filter could also be employed to kill bacteria.

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