บทความวิจัย

การศึกษาการทำงานของระบบทำความเย็นโดยระบบปรับอากาศแบบระเหยของน้ำร่วมกับเทอร์โมอิเล็กทริก

The Study of the Cooling Performance of the Evaporative Cooling System in Combination with Thermoelectric

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บทคัดย่อ

การศึกษาเกี่ยวกับการทำงานร่วมกันระหว่างระบบ evaporative cooling และเทอร์โมอิเล็กทริกเพื่อที่จะผลิตความเย็นให้แก่อาคาร หรือที่พักอาศัยเพื่อที่จะให้อุณหภูมิและความชื้นสัมพัทธ์แก่ผู้ที่อยู่ในอาคารได้ ในส่วนของระบบ evaporative cooling (ใช้แปรงกระจายน้ำเป็นอุปกรณ์) นั้นจะทำหน้าที่ลดอุณหภูมิและเพิ่มความชื้นสัมพัทธ์ให้แก่อากาศโดยการใช้น้ำในการทำความเย็นแบบระเหย จากนั้นอากาศนั้นก็จะผ่านเข้าสู่เทอร์โมอิเล็กทริกเพื่อลดอุณหภูมิของอากาศลงอีกและลดความชื้นสัมพัทธ์ จากผลการวิจัยจึงทำให้เห็นว่าการสเปรย์ละอองน้ำนั้นสามารถที่จะช่วยในการปรับสภาพของอากาศภายในอาคารให้มีความพอดีแก่ผู้อยู่ภายในอาคาร นั้นๆ ได้ แต่อย่างไรก็ตามเทอร์โมอิเล็กทริกนั้นก็เป็นปัจจัยสำคัญในการที่จะทำให้ความชื้นสัมพัทธ์นั้นมีความพอดีแก่อาคาร นอกจากนี้การปรับกระแสไฟฟ้าให้แก่เทอร์โมอิเล็กทริกนั้นก็ยังมีส่วนช่วยในการปรับความเหมาะสมของอุณหภูมิและความชื้นสัมพัทธ์ภายในห้องได้ การวิจัยนี้แสดงให้เห็นว่าระบบการผลิตความเย็นให้แก่อากาศนี้เป็นมิตรกับสิ่งแวดล้อม ไม่มีการใช้น้ำยาที่มีสารเคมีเจือปน อีกทั้งระบบยังไม่ก่อเกิดเสียงรบกวนและค่าทำนุบำรุงรักษาไม่สูงนัก ระบบนี้สามารถที่จะใช้โซล่าเซลล์ในการให้ไฟฟ้าแก่เทอร์โมอิเล็กทริก

คำสำคัญ : ระบบ evaporative cooling เทอร์โมอิเล็กทริก แปรงกระจายน้ำ

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Abstract

This paper investigates of the application of a novel thermal evaporative cooling tower integrated with thermoelectric devices (TECs) and a rotating brush to provide a comfortable indoor climate. The rotating brush functions by reducing air temperature and increasing relative humidity with the use of water for evaporative cooling. This pre-treated airflow then passes through a TEC unit, which further reduces air temperature and decreases 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.

Keywords : Direct Evaporative Cooling, Thermoelectric, Rotating brush

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.

INTRODUCTION

Thermoelectric coolers (TECs) are solid devices which can convert electric energy into a temperature gradient [1]. They have been widely used in many applications. However, since 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) [2]. 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 lighter and more compact [3]. Previous research has been carried out in air-conditioning systems [4], heat recovery systems [5] and small scale applications for buildings [6, 7]. These investigations showed that the operating COP of thermoelectric device was around 0.4 and each device could deliver a cooling capacity of 25 W [8]. However, in some arid areas like the Middle East, comfortable relative humidity could not be satisfied by simply applying TEC to the field of refrigeration. Their limited cooling capacities 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 proposed here to increase the cooling capacity and relative humidity.

Evaporative cooling is an easy and low cost method to achieve a comfortable indoor climate. Direct evaporative cooling systems can increase humidity and decrease air temperature through contact with a liquid surface, a wet solid surface, or even with sprays [9]. Research carried out by Goswami etc [10] and Hajidavalloo [11] showed that in very hot weather conditions, applying evaporative cooling within the air-conditioning system could conserve electricity usage by up to 20% [12].

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 air condition systems in hot-dry climates. The proposed system, called a thermoelectric evaporative cooling tower, features no chemical working fluids nor is direct power required which can instead be supplied from PV panels, etc. This paper investigates the characteristics of this combined system and experimental work which will be carried out to show its real performance under the laboratory conditions.

DESCRIPTION OF THE SYSTEM AND EXPERIMENTAL SET-UP

The system consists of two main parts (Figure 1): rotating brush and thermoelectric devices. The dry warm room air is sucked into the chamber of rotating brush, passing over a 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

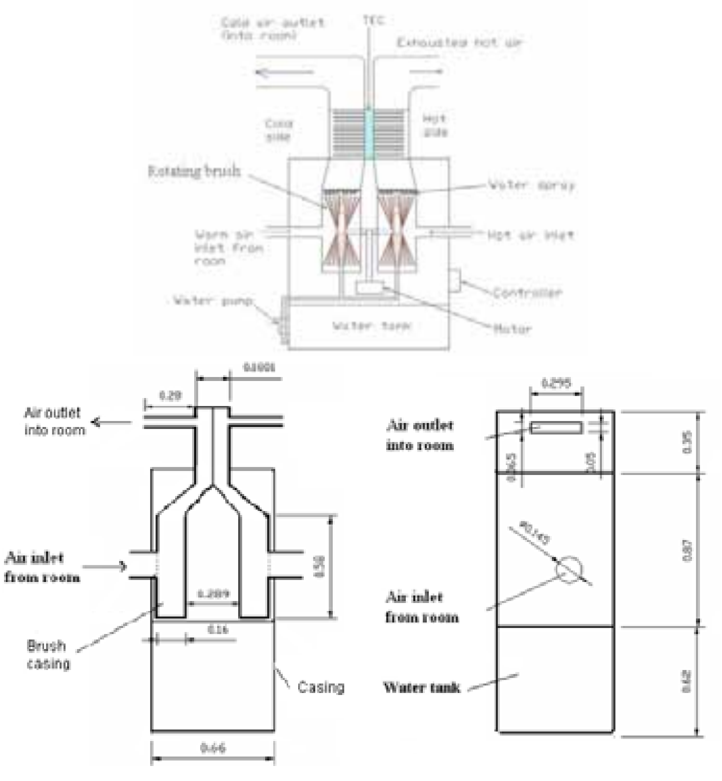

Figure 1: Schematic diagram of thermoelectric evaporative cooling tower (scale is in metre)

On the other side of the system, the hot ambient air is sucked into a rotating brush before passing through the hot side of the TECs, reducing its temperature and increasing relative humidity and moisture content, which helps increase the heat transfer efficiency on the hot side of the 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 thermo-electrics, for each with dimension of 40 x 40 mm, V_{max} = 14.7V, I_{max} = 5.6Amp and Q_{max} = 54V.

Each thermoelectric module is sandwiched between two heat sinks, which are made of aluminium with fins; having an overall thermal resistance of less than 0.01 ºC/W. The eight thermoelectric modules are connected electrically in a series. The two TEC units are connected in series both thermally and electrically. The TECs are in a waterproof enclosure.

The rotating brush (fibre diameter of 1.5mm, fibre number of 2700, coating area of 1.21m^2, 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 the rotating brush 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 the system can be evaluated by calculating the ratio of the cooling capacity ($Q_{cooling}$) provided by the system to the electrical energy (QE) consumptions of the TECs and rotating brush.

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

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

where m is the mass flow rate of air and h1 and h3 are the inlet and outlet specific enthalpy of cold air respectively.

The data taker recorded the experiment results (temperature inlet, temperature outlet, relative humidity inlet and relative humidity outlet)

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 rotating brush 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 a key element of the system, its performance was also studied.

The standard operating conditions for the system were as follows: 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 the 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 the 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 sprayed on both sides is much lower than when water is sprayed only on the hot side. In the case study, the TEC unit could only deliver a few degrees of temperature change while the relative humidity stayed at a similar level. For the system that has no water spray, the air outlet temperature at cold side kept increasing due to that TECs drop in performance as the heat from the hot side was conducted over to cold side. The rotating brush with water sprayed 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 sprayed on both sides appears to be too high for room/building interior if all the room air were to be supplied by the proposed system. However, it is to be noted that the high percentage of RH will decrease when there is an increase in room volume. For the system with water sprayed only on the hot side, the relative humidity is already in the comfortable range.

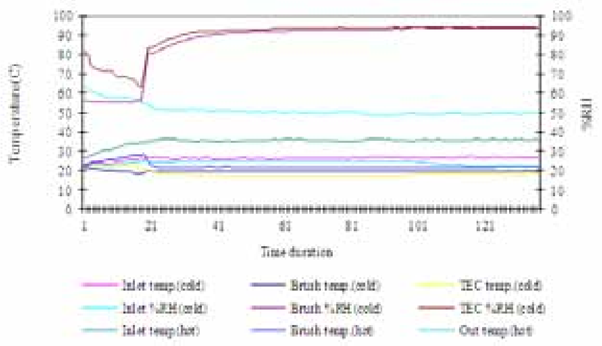

Figure 2 : Graph of temperature and RH against time for water sprayed on both rotating brushes

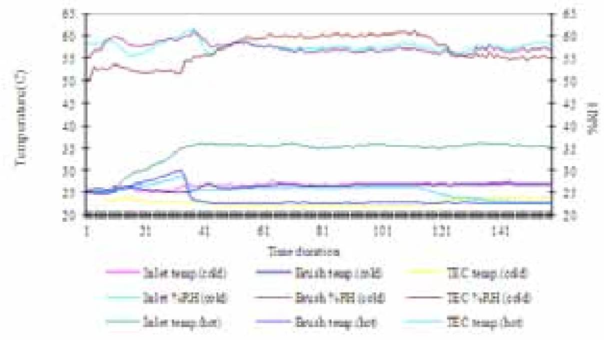

Figure 3: Graph of temperature and RH against time for water sprayed on cold side rotating brush

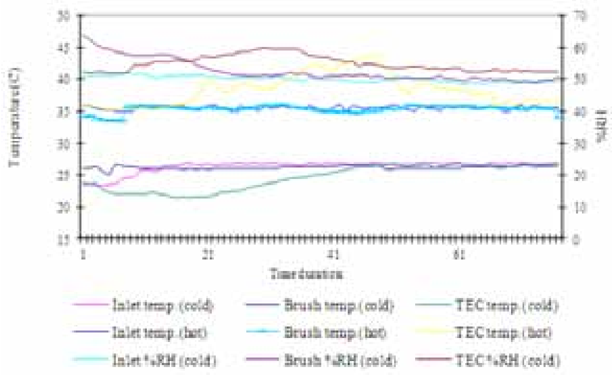

Figure 4 : Graph of temperature and RH against time for no water sprayed on rotating brush

The energy consumption for the water circulating pump is relatively low and therefore the cooling COP with water sprayed on both sides is much higher than when water is sprayed only on the hot side or when no water is sprayed at all, as shown in Figures 5-7. That means water spray has a significant effect on the cooling system. For experiments without water sprayed on either the cold or both sides, the rotating brush only functions as a blower to induce air flow, with low cooling capacity. By comparing the cooling capacity of the three experiments, it is clear that the experiment with water sprayed on both sides gives the best cooling capacity. While the experiment with no water sprayed is not effective at all, showing the 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 moisten the air and reduces the airflow temperature which in turn leads to an improved performance of TEC.

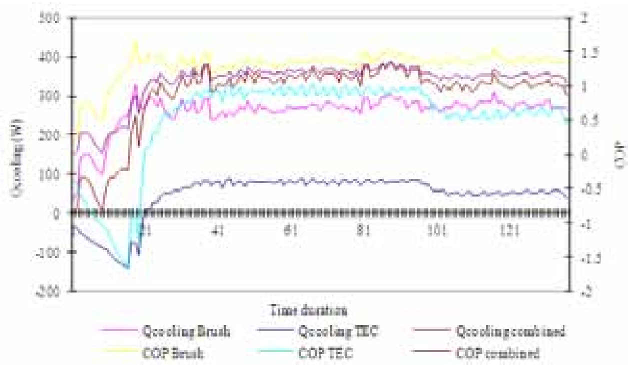

Figure 5: Graph of $Q_{cooling}$ and COP against time for water sprayed on both rotating brush

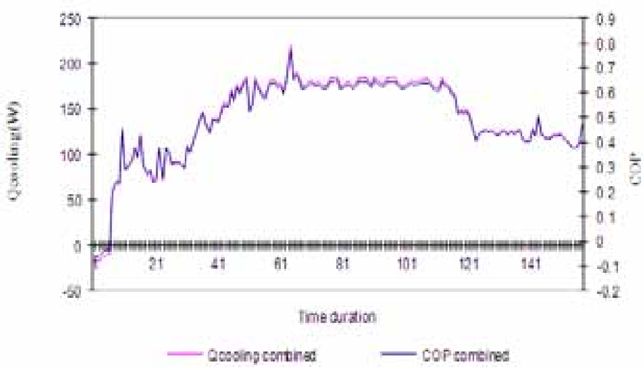

Figure 6 : Graph of $Q_{cooling}$ and COP against time for water sprayed on cold side of rotating brush

Figure 7 : Graph of Qcooling and COP against time for no water sprayed on rotating brush

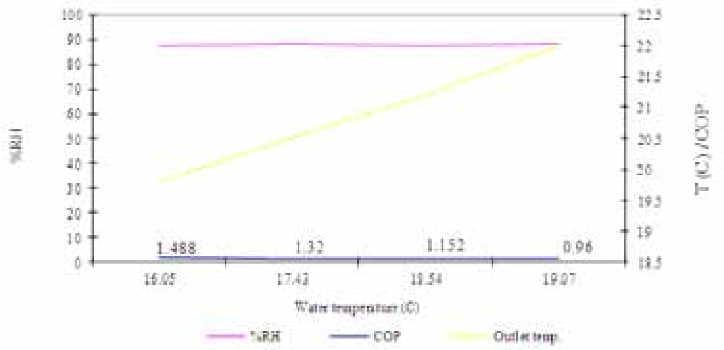

Figure 8 : The effect of water spray temperature on RH, COP and outlet temperature

CONCLUSION

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

The experimental study showed that direct evaporative cooling with water spray could provide air with a low temperature and a high relative humidity. A combined system with TECs shows that potentially 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. Moreover, electrical insulation should be

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carefully considered to safely operate the system in wet conditions. The temperature of the water should be monitored to avoid high temperatures, which would promote bacteria growth such as Legonellar. A UV light filter could also be employed to kill bacteria.

The performance of the combined system (evaporative cooling system and thermoelectric system) is better than that of an independent evaporative cooling system. This is because the thermoelectric system plays an important role in further reducing temperature and relative humidity. The right humidity is important for maintain a comfortable environment for the people who live room/building. For further research, the Evaporative Cooling System in combination with Thermoelectric device should be tested with the model room. A light bulb could be used to simulate the heat generated by a human body. Furthermore, to conduct a test with a model room would be a more realistic experiment, perhaps yielding further useful results.

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