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# Experimental study of operation performance of a low power thermoelectric cooling dehumidifier

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**Abstract**
The present work was performed to apply thermoelectric technology to a low power dehumidifying device as an alternative to the conventional vapor-compression refrigeration systems. The experimental prototype of a small-scale thermoelectric dehumidifier (TED) with rectangular cooling fins was built and its operation performance was studied experimentally. The results showed that the TED experienced two typical thermodynamic processes including the cooling dehumidification and the isothermal dehumidification, where the latter was dominated. It was found that there existed a peak during the variation of the average coefficient of performance (COP) as a function of the input power of the thermoelectric module. Under the present experimental conditions, the COP of the TED reached the maximum of 0.32 and the corresponding dehumidifying rate was 0.0097 g/min, when the input power was kept at 6.0 W. The rapid elimination of condensed liquid-drops on the cooling fins amounted on the thermoelectric module is a major approach to improving the operation performance of the TED.


**Keywords:** Cooling dehumidification, Thermoelectric module, COP, Dehumidification rate.

## 1. Introduction
For the indoor thermal comfort of buildings, the relative humidity is a key control parameter. At present, there exist a number of dehumidifying devices based on the traditional vapor-compression technology. Though these devices are widely applied, they still have many problems to be solved, such as high noise level, strong compressor vibration, and excessive weight and so on [1-2]. In fact, what's more important is the extensive use of CFCs or HCFCs, which has a great negative impact on the present crisis of energy and environment [3].Under this background, it is required to seek for other clean dehumidifying approaches. Thermoelectric cooling technology is just the case in point, which is based on the Peltier effect of semiconductor materials [4]. At present, the thermoelectric cooling technology has been developed rapidly, as an alternative to the conventional systems based on the vapor-compression refrigeration cycles.
For the thermoelectric dehumidification, however, only a few studies were performed. In fact, thermoelectric dehumidifiers have a promising potential in the situations where both a lower power and a smaller space are required. Such applications can be seen in the space crafts, submarines, robots, tunnels, and industrial control cabinets and so on [5-6]. In previous studies, Chen [7] presented a TED with an improved fin heat exchanger, reaching a COP ranging from 0.12 to 0.29. Sumrit [8] tested the performance of a TED in a residential apartment, and obtained a COP of 0.27. In fact, except the difference in the thermoelectric module materials, the better performance of the TED depends mainly on

an optimal layout of heat transfer surfaces. However, too much complex controls on heat transfer usually mean a higher construction cost of TEDs, which may reduce the feasibility in practical applications. The purpose of this work was to test the operation performance of the TED, and to obtain the relationship between the COP and the input power, which is helpful for the optimal design of similar TEDs.

## 2. Experimental system and procedure

### *2.1 Experimental setup*

Figure 1 shows the experimental setup of a small-scale TED. It mainly consisted of a closed cabinet, a thermoelectric module, a DC power meter, a humidifier, a humidiometer, temperature sensors, and a data acquisition system. The cabinet made of organic glass plates was used to simulate a small room. The cabinet was cube-shaped, with 400 mm in length, 400 mm in width, and 400 mm in height. A TEC-12705 type thermoelectric module made of BiTe was used to provide a cold source for dehumidification. The module was 40 mm in length, 40mm in width, and 4mm in thickness, and its maximum working voltage and current were 15 V and 4 A. In order to enhance heat transfer, two rectangular fin heat exchangers were amounted on the heat and cold side of the thermoelectric module, with an extended area of about 91 $cm^2$ and 128 $cm^2$, respectively. A 2.4W axial fan for forced convection was amounted on the fin heat exchanger of the heat side of the TED. In order to eliminate the effect of contact resistances as possible, a thin layer of silicone grease with silver was covered on the heat-transfer surfaces of the TED. An adjustable WYJ-20 type DC power meter was used to electrically driven the thermoelectric module. Its maximum voltage and current output were 20 V and 10 A, respectively.

The relative humidity inside the cabinet was measured by a HT-3005A type humidiometer with ± 1% accuracy installed at the middle of the cabinet. The temperatures of the cabinet and heat/cold fin heat exchangers were measured by copper- constantan thermocouples with ± 0.1°C accuracy. The temperature data were recorded by a HP 34970A type recorder. All measuring sensors were calibrated carefully during the experimental preparation. The ambient atmospheric pressure was measured by a mercury manometer. According to the Chinese Code for Design of Heating Ventilation and Air Conditioning (GB 50019-2003), the allowable indoor relative humidity should range from 40 % to 65 % in summer and from 40 % to 60 % in winter. Therefore, in this experiment, the lower limit of the relative humidity was set as 40 ±1 %, and the upper limit was set as 98 ±1 % to simulate the situation with a high humidity environment of buildings. Before the experiment, the cabinet was humidified to a high relative humidity by a humidifier. After 10 min, the DC power supply of the thermoelectric module was connected. During the dehumidifying process, the variations of the temperature and relative humidity were recorded at an interval of 5 min.

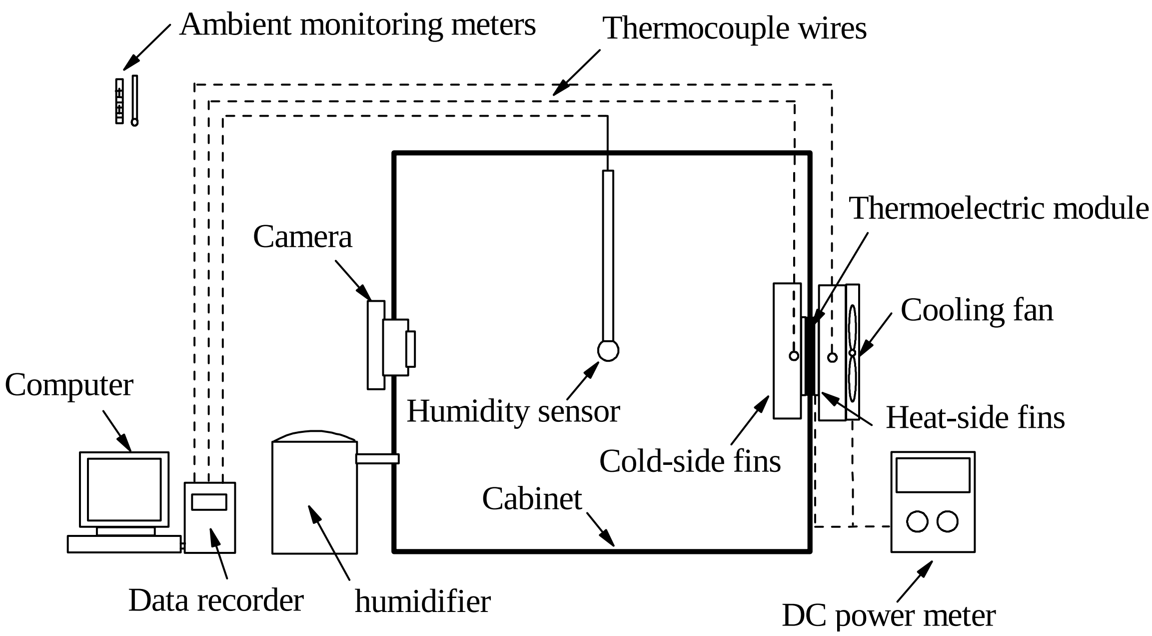



Figure 1. Schematic diagram of the experimental setup of a TED

*2.2 Experimental data reduction*

In order to evaluate the performance of the TED, the COP is defined as

$$COP = \frac{Q_c}{P_{TE} + P_F} \quad (1)$$

where $P_{TE}$ is the power of the thermoelectric module (W), and $P_F$ is the power of the cooling fan(W).
The total heat-transfer rate ($Q_c$) of the fin heat exchanger on the cold side of the TED is calculated as

$$Q_c = h_c A_c \left(t_o - t_c\right) + m_w H_c \quad (2)$$

where $h_c$ is the coefficient of convective heat transfer (W/m$^2$K), $A_c$ is the heat transfer area (m$^2$), $t_o$ is the temperature at the middle of the cabinet ($^o$C), $t_c$ is the average temperature of cold fins ($^o$C), and $H_c$ is the latent heat of condensation (J/kgK).
The dehumidifying rate ($m_w$, kg/s) is calculated as

$$m_w = \frac{m_a\left(\phi_1 - \phi_2\right)}{T} \quad (3)$$

where $m_a$ is the mass of the wet air inside the cabinet (kg), $T$ is the dehumidifying period (s), $\Phi_1$ and $\Phi_2$ are the relative humidity before and after dehumidification (%).
According to the previous study by Bejan [9], the coefficient of convective heat transfer ($h_c$, W/m$^2$K) between adjacent fins and the ambient can be determined by

$$h_c = 0.517\frac{\lambda}{H} Ra^{0.25} \quad (4)$$

where $\lambda$ is the thermal conductivity of air (W/mK), H is the height of fins (m), and Ra is the dimensionless Rayleigh number, and its definition and calculations can be seen in the previous studies by Bejan and Cengel [9-10].

## 3. Results and discussion

*3.1 The analysis of the dehumidifying process of the TED*

Figure 2 shows a typical dehumidifying process of the TED, when the input power of the thermoelectric module is 5.5 W. It can be seen that, except the first 10 min, the average temperature of heat-side fins as well as the cabinet kept relatively steady during the dehumidifying process. The average temperature of cold-side fins appeared a slowly decreasing tendency, and finally reached a steady state. It was also found that the relative humidity experienced two accelerating stages (i.e.98-90% and 70-50%) and two decelerating stages (i.e.90-70% and 50-40%). This phenomenon is related with the condensing behavior of cold-side fins, which is discussed in the later section.
The variation of the relative humidity shown in Figure 2 can also been plotted in the enthalpy-humidity diagram. As shown in Figure 3, the TED experienced two typical thermodynamic processes, including the cooling dehumidification and the isothermal dehumidification. During the cooling dehumidifying process from A to B, the variation of the relative humidity was weak, proceeding from 98 % to 90 %. In contrast, the isothermal dehumidifying process from B to C experienced a major change of the relative humidity varying from 90 % to 40 %. From the point of view of the dehumidifying period, the cooling dehumidification and isothermal dehumidification experienced 44 min and 145 min, respectively. Therefore, the isothermal dehumidifying process is dominated during the operation of the TED.
The above experimental characteristics of the dehumidifying process depended on condensing heat transfer on cold-side fin heat exchangers of the TED. Figure 4 shows the photos of cold-side fins before and after dehumidification. It can be found that there existed many condensed liquid drops on the extended surfaces. At the bottom of local fins, there appeared the liquid-bridge phenomenon. Such an

adherence of condensed liquid drops on the fin surfaces has an important role in the dehumidifying process of the TED, which can be further explained as follows.

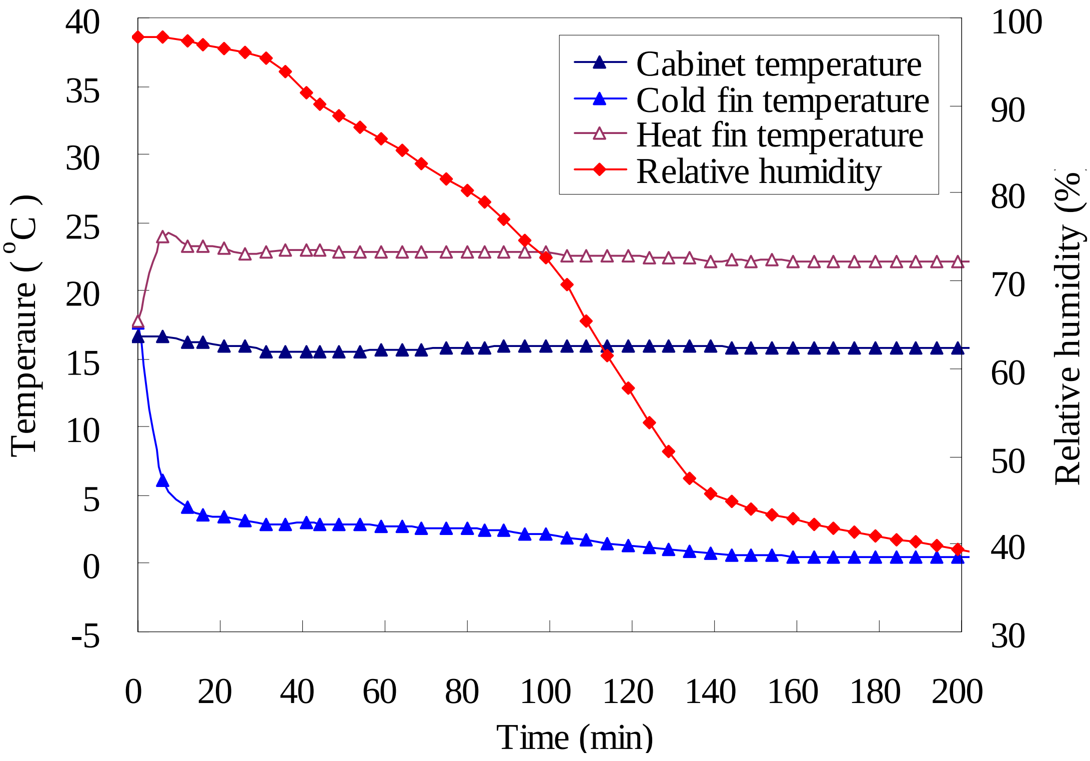



Figure 2. A typical dehumidifying process of the TED

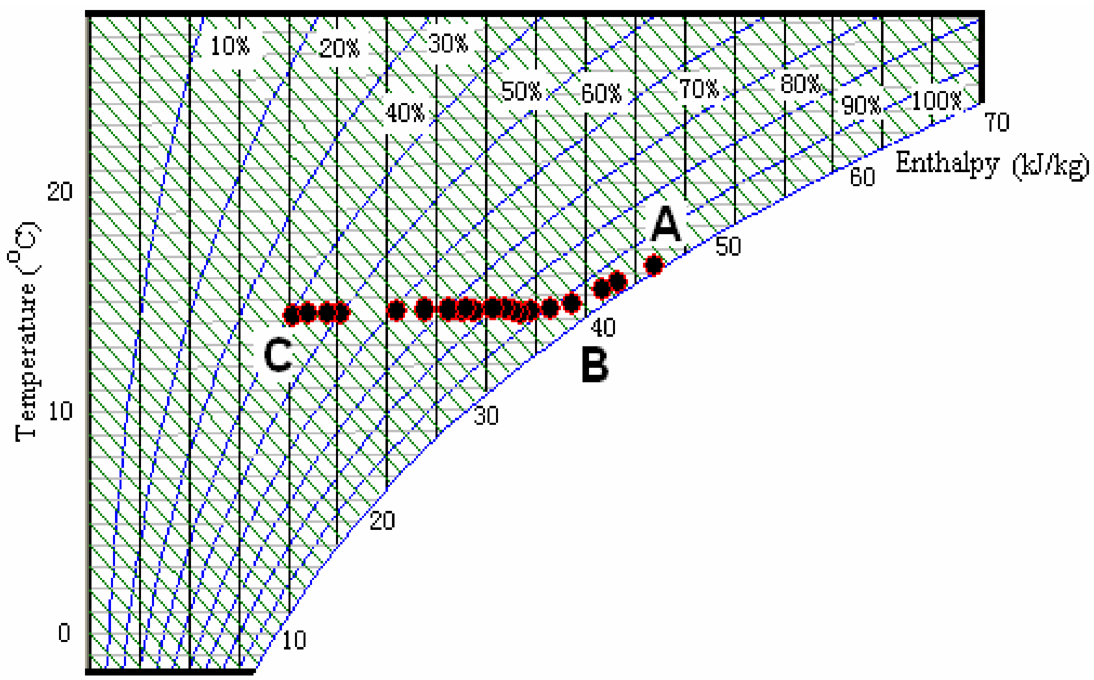
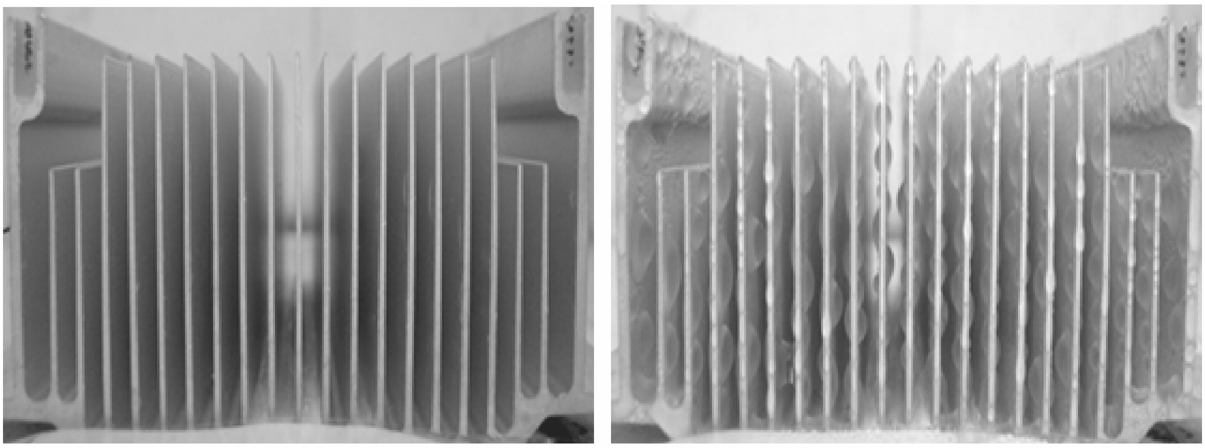



Figure 3. The dehumidifying process in the enthalpy-humidity diagram



(a) before dehumidification (b) after dehumidification

Figure 4. Photos of cold-side fins before and after dehumidification

At the initial dehumidifying process, the temperature of cold-side fins dropped rapidly, which promoted the vapor condensation inside the cabinet. This indicated that a number of liquid drops was created and adhered on the fin surfaces. Soon these liquid drops became a thin layer of liquid film, driven by the surface tension. Such a liquid film was a great thermal resistance and then led to a weak heat and mass transfer between the fin surfaces and the ambient inside the cabinet. As a result, the dehumidifying rate began to decrease, and this was the so-called first decelerating stage ranging from 90% to 70%. When the film became thicker and thicker, the runoff flow along the gravity direction was dominated. The fin surfaces became relatively clean again. At the same time, the temperature of cold-side fins still remained a steady low temperature close to 0 $^{o}$C. Thus, the dehumidifying process began to accelerate for the second time. Repeatedly, when the liquid film on the fin surfaces became thick enough, the dehumidifying process experienced the second decelerating stage till the dehumidification was ended. From the analysis above, it can be seen that a rapid elimination of condensed liquid-drops on the cooling fins amounted on the thermoelectric module is a major approach to improving the performance of the TED. Such efforts can be realized by using superhydrophilic (SH) or super-water repellent (SWR) surfaces [11-12]. Related experimental work is expected to be reported in our later studies.

*3.2 The analysis of the dehumidifying performance of the TED*

Figure 5 compares the dehumidifying processes under different input powers of the thermoelectric module. It can be seen the dehumidifying period depends strongly on the input power of the thermoelectric module. In this experiment, when the input power was 6.0 W, the dehumidifying period reached the minimum of 120 min. In contrast, for the input powers lower or higher than 6.0 W, the dehumidifying period showed an increasing tendency. For instance, the dehumidifying period was 180 min at 5.0W and 150 min at 7.0W, respectively. This result can be explained by the characteristics of thermoelectric module materials.

For a thermoelectric module, the heat absorption from the ambient consists of two sources. One is from the Peltier effect, which is proportional to the current through the module. Another is from the Joule effect, which is proportional to the square of the current through the module [4]. When the input power is too low, the Peltier effect is weak, resulting in a low dehumidifying rate. On the contrary, when the input power is too high, the Joule effect is dominated, resulting in a high heat load imposed on the heat-cold heat exchangers. Once the heat generated can not be released into the ambient, the extra heat will be transferred by heat conduction towards the cold side, and finally weaken the condensing heat transfer on the fin heat exchanger. Therefore, for the minimum dehumidifying period, there is an optimal input power of the thermoelectric module.

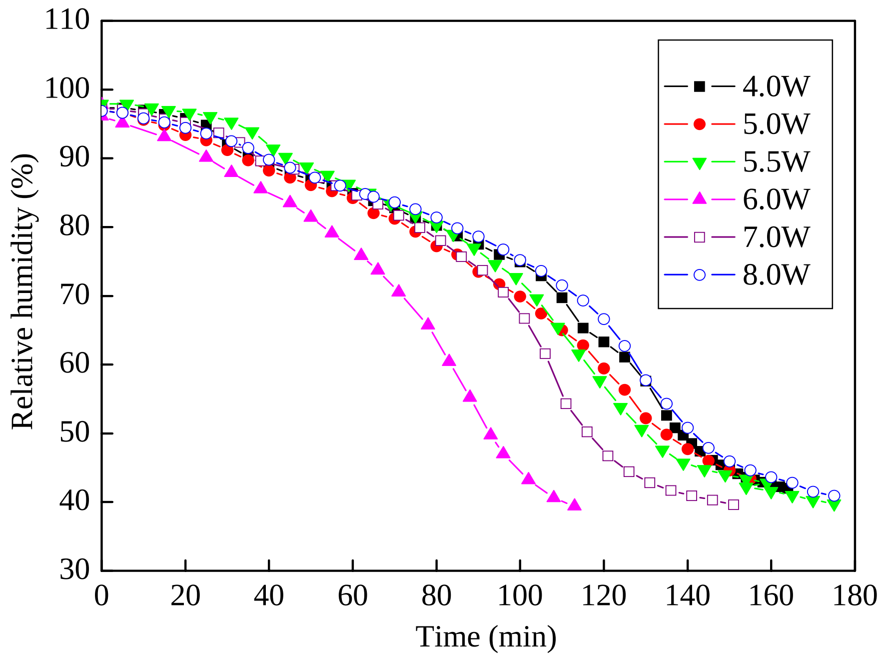



Figure 5. Dehumidifying processes under different input powers of the thermoelectric module

Figure 6 compares the variations of COP under different input powers of the thermoelectric module. It can be seen that the COP of the TED increases rapidly during the initial stage, then keeps a slowly growing tendency till reaching the maximum level, and finally drops quickly. For instance, when the input power was 6.0 W, the COP began to accelerate at 80 min, which was the start of the second accelerating stage shown in Figure 5, and reached the maximum of 0.32 at about 100 min, which was just the end of the second accelerating stage shown in Figure 5. For the most dehumidifying period, however, the COP remained an average level of about 0.17, about half of the maximum level. When the input power increased to 7.0 W and 8.0 W, the corresponding COP reduced to 0.26 and 0.20, respectively. This experimental phenomenon can fully reflect the working mechanism of the TED where the complex heat and mass transfer related with condensation on the cold-side fin heat exchanger is a critical influencing factor. Compared with the previous results obtained by Chen [7] and Sumrit [8], the present experimental COP was higher.

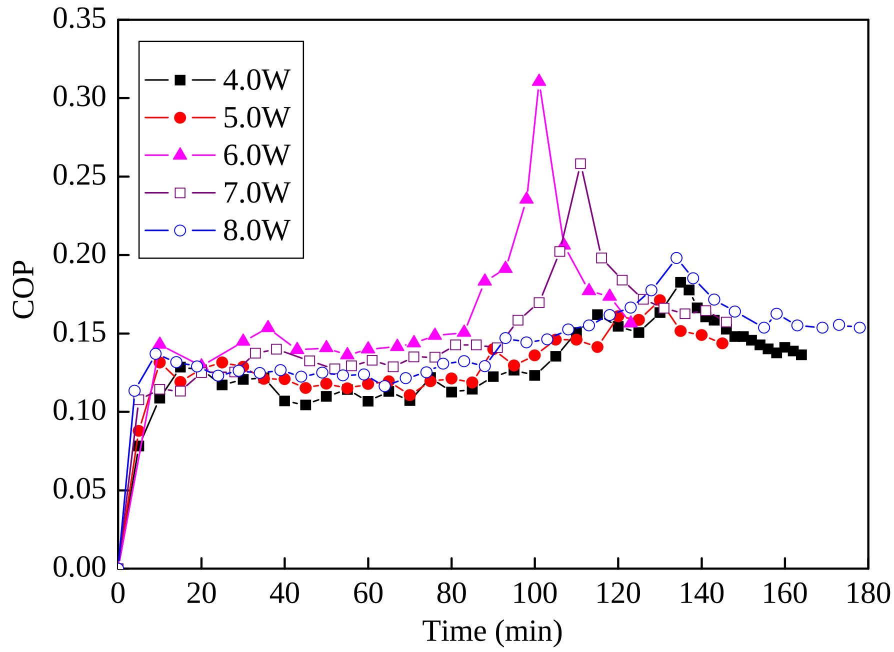



Figure 6. Variations of COP under different input powers of the thermoelectric module

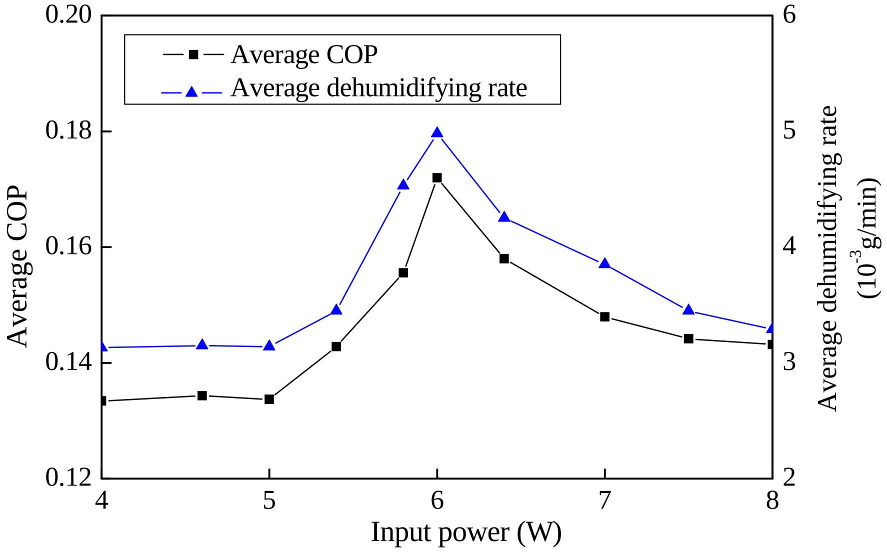



Figure 7. Variations of the average COP and the average dehumidifying rate under different input powers of the thermoelectric module

Figure 7 further shows the variations of the average COP and the average dehumidifying rate under different input powers of the thermoelectric module. In the present experiment conditions, the average dehumidifying rate was about 0.005 g/min at the input power of 6.0W, though the maximum reached 0.0097g/min. It should be noted that the performance of practical TEDs varies greatly in the present studies. A generally acceptable COP of TEDs ranges from 0.1 to 0.6[13]. In addition, Vian [14] established a numerical model of a TED. Through optimizing the heat transfer, a COP of 0.8 was obtained in the computation conditions. As far as the author's knowledge, this value is the highest in the available literatures. Therefore, compared with Vian's theoretical prediction, there is still a great space for the performance improvement of the present TED. In contrast, the COP of conventional dehumidifiers usually ranges from 0.7 to 1.3 [15]. On the other hand, at present the figure of merit (ZT) of most commercial thermoelectric materials is lower than 1.0. For instance, the ZT of BiTe used in this experiment was about 0.6. However, the value of ZT has been improved to 2.4 for some novel thermoelectric materials [16]. It can be expected that, with a continuing advance in the thermoelectric technology, the performance of the TED will be improved drastically. In summary, despite that the COP obtained by the present experimental setup is at a relatively low level, a lower power TED is of certain commercial interest. From the present experimental results, it can be seen that, during the use of thermoelectric cooling technology, the relative humidity can be controlled more accurately through an adjustable input power, which provides an important approach to improving the indoor thermal comfort of buildings.

## 4. Conclusion

TEDs have a promising potential in the situations where both a lower power and a smaller space are required. The present work was performed to develop a low power TED as an alternative to the conventional vapor-compression refrigeration systems. From the experimental results discussed above, the following conclusions can be obtained:

(i) The TED experienced two typical processes including the cooling dehumidification and the isothermal dehumidification, but the latter was dominated. The relative humidity experienced two accelerating stages and two decelerating stages. This phenomenon is related with the condensing behavior on the extended surfaces of the cold-side fin heat exchanger.

(ii) There exists a peak during the variation of the COP as a function of the input power of the thermoelectric module. Under the present experimental conditions, the COP of the TED reached the maximum of 0.32 and the corresponding dehumidifying rate was 0.0097 g/min, when the input power was kept at 6.0 W.

(iii) There is still a great space for the performance improvement of the present TED. The effective elimination of condensed liquid-drops on the cold-side fins is a major work in the future.

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