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ORIGINAL ARTICLE

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Development of cold-hot water dispenser with thermoelectric module systems

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Abstract

In the present study, the results of a cold-hot water dispenser with a thermoelectric module system (TMS) are presented. The cold-hot water dispenser with thermoelectric module system consists of a cold water loop, a hot water loop, a coolant loop, and a thermoelectric module. The thermoelectric cooling and heating modules consist of four and two water blocks, nine and three thermoelectric plates, respectively. The cooling and heating capacities obtained from the cold-hot water dispenser with TMS are compared with those from a conventional cold-hot water dispenser with a compression refrigeration system (CRS). As compared with the conventional cold-hot water dispenser with CRS, the cold-hot water dispenser with TMS can be operated at the minimum cold water temperature of 10 to 13°C and the maximum hot water temperature of 65°C. The obtained results are expected provide guidelines to design cold-hot water dispensers with TMS.

KEYWORDS
cold-hot water dispenser, cooling capacity, thermoelectric module

1 | INTRODUCTION

Compared with the conventional electrical power generators, thermoelectric module offers many advantages, such as environment friendliness, reliability, and absence of moving parts. The cold and hot sides of thermoelectric modules are developed and utilized, especially, to enhance cooling capacity in electronic components. On the other hand, the power input is a function of the cold and hot sides of thermoelectric modules, and the power consumption of these modules is high. Thermoelectric modules find applications in many thermal management systems. Chang et al[1] investigated a thermoelectric air-cooling module for electronic cooling devices. Martínez et al[2,3] experimentally and numerically studied electronic cooling devices with thermoelectric cooling modules. Jieting et al[4] studied power generation cooling with thermoelectric and heat pipes. Jeong[5] optimized the thermoelectric cooling module with a novel one-dimensional analytic model. Li et al[6] applied a thermoelectric cooling module for cooling phase change material (PCM) heat storage for patients with multiple sclerosis (MS). Mohammadian and Zhang[7] analyzed the effect of nanofluids on thermoelectric cooling performance with micro-pin-fin heat exchangers. Tan and Demirel[8] investigated the performance and cooling efficiency of thermoelectric cooling modules on a server central processing unit. Zhang et al[9] studied the thermal performance of a micro-semiconductor laser with a thermoelectric cooling module. Ahammed et al[10] studied the performance of a thermoelectric cooling module embedded with multiport minichannel heat exchanger with nanofluids as coolants for cooling electronic devices. Hu et al[11] experimentally studied a water-cooled thermoelectric cooler for cooling central processing units. Lin and Yu[12] presented a trapezoid-type two-stage Peltier couple for application two-stage thermoelectric cooling. Martinez et al[13] used the thermoelectric cooling module to enhance cooling performance in power generation. Sadighi et al[14] experimentally investigated the cooling feasibility of air flow via a novel air-water based thermoelectric cooling system for different climate conditions. Shen et al[15] studied the applications of thermoelectric technology in buildings. Tsai and Le[16] presented the energy recycling and self-sufficient application of a novel high-power light emitting diode integrated with a thermoelectric generator module. Yilmazoglu[17] numerically and experimentally studied the performance of a prototype thermoelectric heating/cooling unit. Banakar et al[18] applied a thermoelectric module in the cogeneration of heat and power with a Fresnel lens collector in a thermoelectric solar system. Cai et al[19] optimized the thermoelectric cooling module for central processing unit cooling. Gao et al[20] considered the effect of the supplied pulse currents on the hot and the cold stages of a two-stage cascaded thermoelectric coolers (TEC) to seek further increase in temperature drop across the TEC. Gökçek and Şahin[21] experimentally studied the performance of a minichannel water-cooled thermoelectric refrigerator. Ibañez-Puy et al[22] demonstrated the building heating and cooling potential with the vertical configuration of 16 thermoelectric modules. Irshad et al[23] experimentally and numerically investigated a novel thermoelectric air duct system assisted with a photovoltaic system for space cooling in Malaysian weather conditions. Joshi et al[24] and Karwa et al[25] developed a thermoelectric fresh water generator by using thermoelectric cooling module and thermoelectric refrigerator. Liu et al[26] and Sun et al[27] designed the optimal heat exchanger configuration for a heat pipe with an integrated thermoelectric cooling module for cooling of electronic devices. Le et al[28] presented the advantages and disadvantages of three typical heat exchangers in a thermoelectric cooling module. Su et al[29] considered the effect of thermal and electrical contact resistances on the thermoelectric microrefrigerator based on thin-film technologies to address high performance on chip cooling and compatibility with fabrication of microelectronics.

According to a review of the literature, most researchers have investigated the application of thermoelectric in various applications. In the present study, the results of a cold-hot water dispenser with a thermoelectric module system (TMS) are presented. The cooling and heating capacities obtained from the cold-hot water dispenser with a TMS are compared with those from the conventional cold-hot water dispenser with a compression refrigeration system (CRS). The obtained results are expected to provide guidelines to designing cold-hot water dispensers with TMS.

2 | EXPERIMENTAL APPARATUS AND TEST PROCEDURE

2.1 | Experimental apparatus

As shown in Figure 1, the experimental apparatus of the cold-hot water dispenser with TMS and with CRS consisted of a cold water loop, a hot water loop, a coolant loop, and a TMS. The cold-hot water dispenser with a thermoelectric module is shown in Figure 2. For the cold water loop, the cold water is suctioned from the water tank, and it flows into the thermoelectric cooling module (cold side) to decrease temperature. Then, it flows back into the cold water tank while the coolant flows into the thermoelectric cooling module (hot side) and flows into the radiator for heat ventilation into the atmosphere and flows into the thermoelectric heating module (cold side) to decrease temperature; it then flows into the thermoelectric cooling module again. For the hot water loop, the water pump is used to circulate the hot water loop, which flows into the thermoelectric heating module (hot side) and then returns into the hot water tank. The cold-hot water temperatures are controlled by solid states, which control each TMS. The variations of cold and hot water temperatures obtained from TMS are compared with those from CRS. The cold and hot water dispenser with CRS diagram is shown in Figure 3; it can be seen from the figure that the cooling and heating of water are performed with CRS and an electric heater.

2.2 | Test section

The thermoelectric cooling and heating module systems are shown in Figure 2. The thermoelectric cooling module system consisted of four water blocks and nine thermoelectric plates. The water blocks were fabricated from the longitudinal aluminum fins with the dimensions of $10 \times 40 \times 120\ mm^3$. Three thermoelectric plates were attached at each side of the water block with a high thermal conductivity special glue. For the thermoelectric heating,

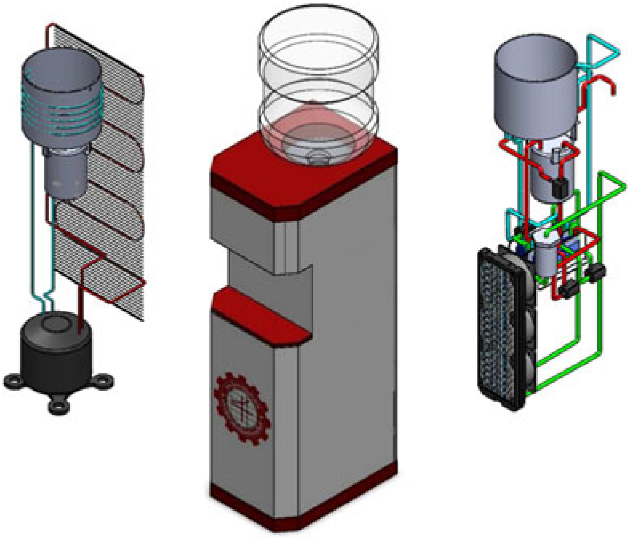

FIGURE 1 Hot-cold water dispenser with CSR and TMS loops. CRS, compression refrigeration system; TMS, thermoelectric module system [Color figure can be viewed at wileyonlinelibrary.com]

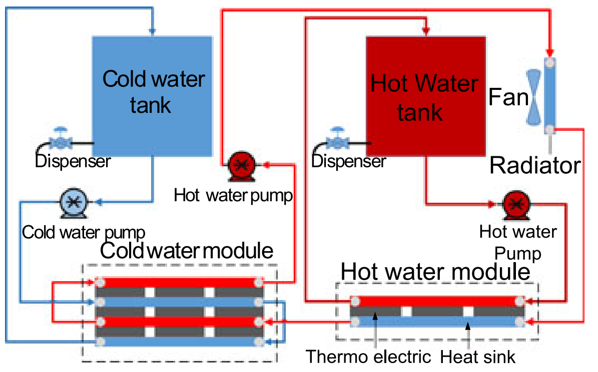

FIGURE 2 Diagram of the experimental apparatus of hot-cold water dispenser with thermoelectric module system (TMS) [Color figure can be viewed at wileyonlinelibrary.com]

the module system consisted of two water blocks and three thermoelectric plates. The thermoelectric plates with dimension of 40 × 40 mm^2, 10 A were used in the present study. The cold and hot water temperatures were measured by type T thermocouples with the accuracy of 0.1% of full scale. Type T thermocouples were precalibrated with a dry box temperature calibrator with 0.01°C precision.

2.3 | Experimental test method and uncertainty analysis

In the experiments, the hot and water mass flow rate was kept constant at 0.015 kg/s. For specific cold and hot water temperatures in two water tanks at 12°C and 65°C, respectively, the transient cold and hot water temperatures at various water consumptions (200, 400, 600, and 800 mL) have been recorded with a data acquisition system in test rooms with and without air conditioning systems. The variations of cold and hot water temperatures obtained from TMS are

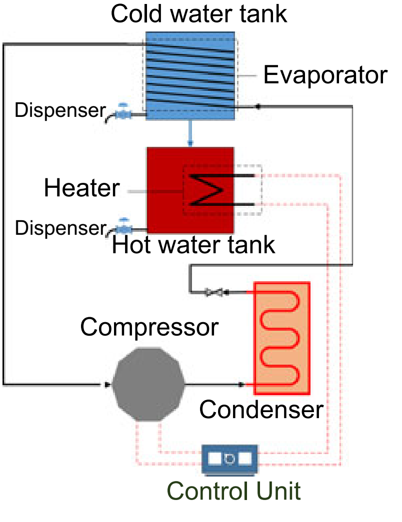

FIGURE 3 Diagram of the experimental apparatus of hot-cold water dispenser with a compression refrigeration system (CRS) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Accuracy and uncertainty of measurements

Instrument	Accuracy (%)	Uncertainly
Power supply, V	0.2	±0.5
Thermocouple type T	0.1	±0.1
Data logger, °C	0.1	±0.1
Multimeter	0.1	±0.05

compared those from CRS. The uncertainty and accuracy of the measurement are given in Table 1. Uncertainty estimates can be done by considering the errors of the instruments, the measurement variance, and calibrations errors.

3 | RESULTS AND DISCUSSION

For the cold-hot water dispenser with TMS in the test room temperature of 24°C (with air conditioning system), experiments were performed on the cooling capacity of the cold-hot water dispenser with TMS by considering the cold and hot water temperature variations with various cold water consumption conditions (500, 1000, and 1500 mL). It can be seen from the figure that the water temperature tends to decrease to 10°C (setting temperature) as the water flow enters the cold side of the thermoelectric cooling module. After a temperature drop of 10°C, the thermoelectric cooling module stops working and meanwhile the cold water consumption rate is 500 mL. It can be seen that after cold water is used, the water from the water tank flows into the cold water loop, which results in higher cold water temperature (cold water loop). As cold water temperature is higher than the setting temperature, the thermoelectric cooling module starts working to chill the water in the loop, so the cold water temperature tends to decrease to the setting temperature in the cooling period time of 15 minutes. After the cold water temperature is chilled to the setting temperature, the cold water consumption rates are 1000 and 1500 mL, respectively. The variation of cold water temperature obtained from the cold-hot

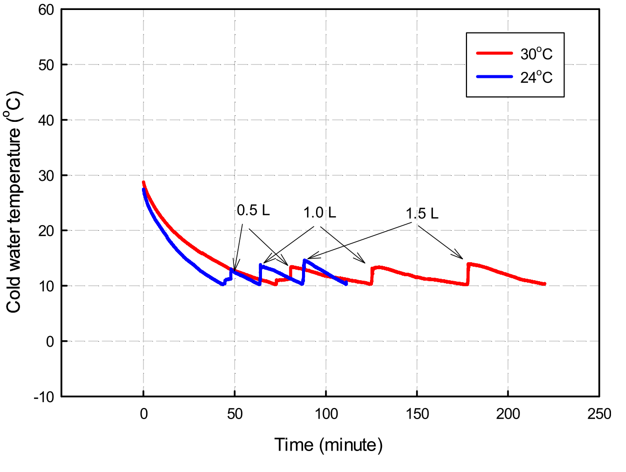

FIGURE 4 Variation of cold water temperature with period time at different room temperatures for 500, 1000, and 1500 mL water consumptions [Color figure can be viewed at wileyonlinelibrary.com]

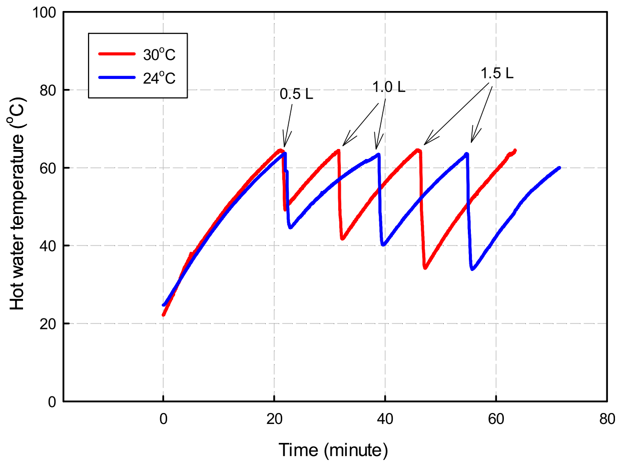

FIGURE 5 Variation of hot water temperature with period time at different room temperatures for 500, 1000, and 1500 mL water consumptions [Color figure can be viewed at wileyonlinelibrary.com]

water dispenser with TMS for different room temperatures is shown in Figure 4. It can be clearly seen from the figure that the cooling period time tends to increase with increasing cold water consumption rate. In addition, the blocking heat dissipation into the atmosphere (higher atmosphere temperature) at the radiator of the system, the cooling period time tends to increase. Similarly, the variation of hot water temperature obtained from the cold-hot water dispenser with thermoelectric heating module system is shown in Figure 5. At the setting hot water temperature of 65°C, the hot water temperature tends to decrease as hot water consumption rates are 500, 1000, and 1500 mL, respectively. This is because the flowing turns water into the hot water loop. In addition, it can be seen that the blocking heat dissipation into the atmosphere (higher atmosphere temperature) at the radiator of the system is a good effect for the hot water loop. Therefore, a higher test room temperature results in a decreased heating period time.

Figure 6 shows the variation of cold water temperature for various cold water consumption rate every 5 minutes. It can be seen that the cold water temperature slightly increases as the

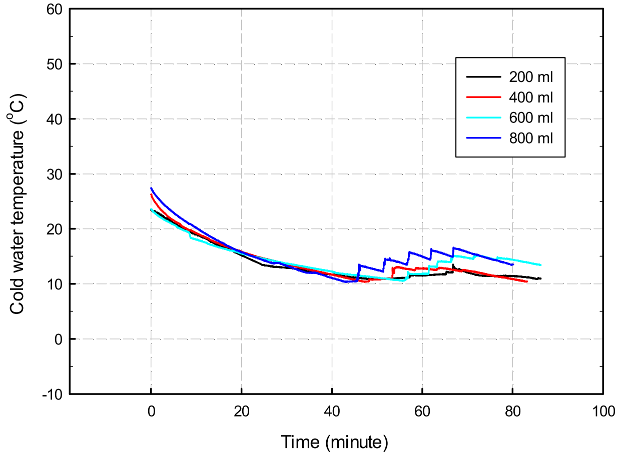

FIGURE 6 Variation of cold water temperature for different water consumptions every 5 minutes [Color figure can be viewed at wileyonlinelibrary.com]

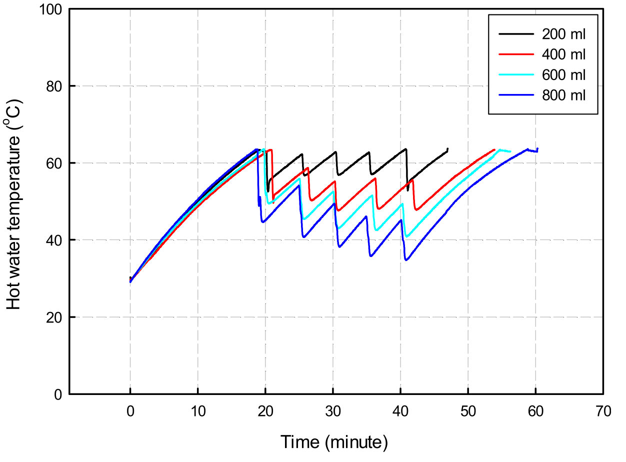

FIGURE 7 Variation of hot water temperature for different water consumptions every 5 minutes [Color figure can be viewed at wileyonlinelibrary.com]

cold water consumption rate of 200 to 400 mL every 5 minutes. This means that the cooling capacity of the thermoelectric cooling module can cool down to the setting temperature in the cooling period time of 5 minutes. However, as the water consumption is higher than 400 mL every 5 minutes, the cold water temperature increases. This means that the cooling capacity of the thermoelectric cooling module cannot cool down to the setting temperature in the cooling period time of 5 minutes. The variation of hot water temperature for various hot water consumption rate every 5 minutes is shown in Figure 7, and the trends of the results are similar to the cold water temperature as mentioned above. From the results presented in Figures 6 and 7, the cooling-heating capacity of the cold-hot water dispenser with TMSs of 400 mL within a 5-minute cooling period time can be obtained.

The cold and hot water temperatures obtained from the TMS as compared with those from the conventional CRS are shown in Figures 8 and 9 for the cold and hot water consumptions rate 1000 mL. It can be clearly seen from figures that the cold and hot water temperatures

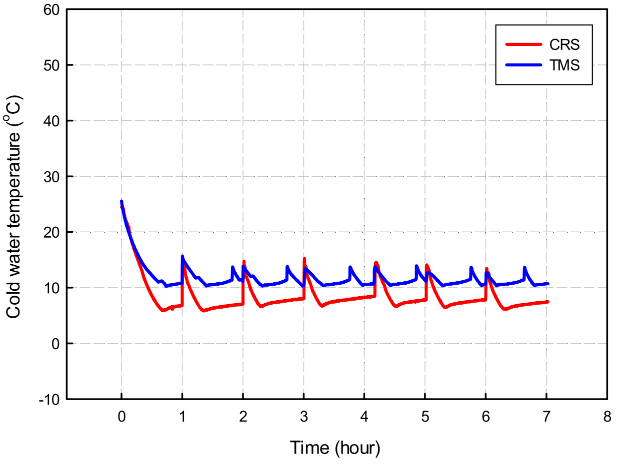

FIGURE 8 Comparison of cold water temperature obtained from the CRS and TMS. CRS, compression refrigeration system; TMS, thermoelectric module system [Color figure can be viewed at wileyonlinelibrary.com]

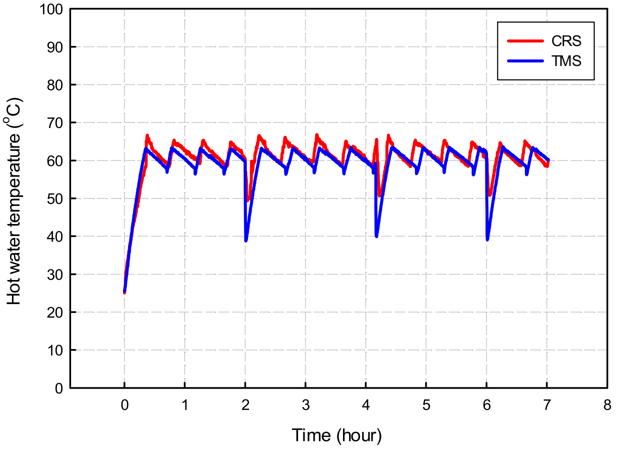

FIGURE 9 Comparison of hot water temperatures obtained from the CRS and TMS. CRS, compression refrigeration system; TMS, thermoelectric module system [Color figure can be viewed at wileyonlinelibrary.com]

obtained from the TMS and the conventional CRS are close for the maximum water consumption rate of 1000 mL in the period time of 1 hour while the energy consumption from the TMS and the conventional CRS are also close.

4 | CONCLUSIONS

In the present study, the results of the cooling and heating capacity of a cold-hot water dispenser with a TMS are presented. The cooling and heating capacity obtained from the cold-hot water dispenser with TMS are compared with those from the conventional cold-hot water dispenser with CRS. At the setting temperature (13°C, 65°C), it can be found that the cooling and heating capacities of the thermoelectric module are approximately 400 mL within a 5-minute period time. The obtained results are expected provide guidelines that will allow designing cool and hot water dispensers with a TMS, which is a new approach to machine design of the cold-hot water dispenser with simple systems.

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