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# Modified pulse operation of thermoelectric coolers for building cooling applications

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ABSTRACT

This paper presents a modified pulse operation of the thermoelectric cooler (TEC) for building space cooling application. In the normal pulse operation of a thermoelectric cooler, a current pulse is given as the input, but in the modified pulse operation, along with the pulse current, the hot side heat transfer coefficient is also pulsed. A numerical model for the thermoelectric cooling system is developed assuming one-dimensional unsteady state heat transfer having convective heat transfer boundary condition at its hot side and constant heat flux boundary condition at its cold side. Then the thermoelectric cooling system is studied with variable pulse current ratio, cooling load, variable pulse width and with dissimilar pulse shapes. The result shows that, for a typical operating condition with the modified pulse operation, the thermoelectric cooling system can provide an average cooling power of 600 W with the COP of 1.01, which are 23.3% and 2.12% higher than the normal mode of operation (i.e. without current pulse) respectively. This study also found that the rectangular-shaped pulse can provide higher average cooling power and COP when compared with the ramp and exponential pulse.

## 1. Introduction

The use of thermoelectric coolers for building space cooling can be an alternative option to the conventional vapour compression refrigeration (VCR) systems, since it does not use any refrigerants, it is compact and provides noiseless operation. However, its coefficient of performance (COP) is lower when compared with the conventional VCR systems due to the low figure of merit (Z) of thermoelectric materials [1]. The thermoelectric cooling systems have been compared with the conventional vapour compression cooling system, vapour absorption cooling system and Stirling cycle cooling systems and it was found that the COP of the thermoelectric cooler system is lower when compared with the other above mentioned cooling systems [2–4]. These studies also suggested that, if the figure of merit of the thermoelectric materials are improved from the present commercially-available bismuth telluride alloy based thermoelectric coolers, which has an average dimensionless figure of merit (ZT) of 0.7 to higher than 3. Then the COP and the cooling power of thermoelectric coolers can be improved significantly, with a great potential to replace the conventional air-conditioning systems for building space cooling applications.

The design of thermoelectric coolers using number of transfer units for electronic cooling has been proposed by Cai et al. [5]. Wang et al. [6] have studied the cooling of light emitting diode using a thermoelectric cooler package, and found that the thermoelectric device is more sensitive to the operating current. Attar and Lee [7] have theoretically studied and experimentally verified the thermoelectric cooler for automotive cooling application with the cooling power of 400 W and COP of 1.27. Maneewan et al. [8] have experimentally studied a compact thermoelectric air conditioner with the operating temperature of 301 K, cooling power of 29 W and COP of 0.34, and also estimated the payback time of this system to be 0.75 years. Cosnier et al. [9] have numerically and experimentally studied the thermoelectric cooling and heating systems and found that the COP of the thermoelectric cooler may vary from 1 to 0.3 when the temperature difference between its hot and cold side varies from 15 K to 30 K. Gillott et al. [10] have experimentally studied the thermoelectric air-conditioner with the average cold side temperature of 295 K, cooling load of 220 W and COP of 0.46.

To improve the COP of thermoelectric cooling systems for building cooling applications, researchers have integrated various techniques such as thermal energy storage and evaporative cooling with the thermoelectric air-conditioning system. Tipsaenporm et al. [11] have used the direct evaporative cooler to supply cold

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**Nomenclature**

| | |
|---|---|
| $h$ | heat transfer coefficient (W m$^{-2}$ K$^{-1}$) |
| $m$ | mass (kg) |
| $A$ | area (m$^2$) |
| $C$ | specific heat (J kg$^{-1}$ K$^{-1}$) |
| $D$ | density (kg m$^{-3}$) |
| $I$ | current (A) |
| $K$ | thermal conductance (W K$^{-1}$) |
| $L$ | length |
| $M$ | number of infinitesimal sections of the thermoelement |
| $N$ | number of thermoelectric cooler modules |
| $P$ | electrical power (W) |
| $Q$ | heat (W) |
| $R$ | electrical resistance ($\Omega$) |
| $T$ | temperature (K) |
| $U$ | overall heat transfer coefficient (W m$^{-2}$ K$^{-1}$) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | seebeck coefficient (V K$^{-1}$) |
| $k$ | thermal conductivity (W m$^{-1}$ K$^{-1}$) |
| $\rho$ | electrical resistivity ($\Omega$ m) |
| $\sigma$ | electrical conductivity (S m$^{-1}$) |
| $\Delta$ | difference |

*Subscripts*

| | |
|---|---|
| $a$ | environment |
| $b$ | base plate |
| $c$ | cold side of TEC |
| $dt$ | infinitesimal time |
| $dx$ | infinitesimal length |
| $gen$ | generation |
| $h$ | hot side of TEC |
| $i$ | node number |
| $in$ | input |
| $m$ | mean/average |
| $n$ | *n* type material |
| $o$ | reference |
| $out$ | output |
| $p$ | *p* type material |
| $t$ | time |
| $C$ | ceramic |

*Superscripts*

| | |
|---|---|
| $n$ | incremental time |

air to the hot side of the thermoelectric cooler to assist the heat removal. This technique has improved the cooling power of the thermoelectric cooler by 40.6% and the COP by 20.9%. However, the COP of this system was still low as 0.52 with the cooling load of 74.5 W. Tan and Zhao [12] have studied the integrated thermal energy storage-assisted thermoelectric cooling system where the phase change material is used to store the cold energy during the night and then that coldness is used in the day time to assist the heat rejection from the hot side of the thermoelectric cooler with average cold side temperature of 296 K. This technique have improved the COP of the thermoelectric cooler from 0.5 to 0.78 (56%). Even though, these techniques improved the COP of the thermoelectric cooler, the integration of evaporative cooler/thermal energy storage makes the system bulky and adds to the operation complexity. The solar operation of the thermoelectric cooler for building cooling application with the cooling load of 589 W for a room sized $2.8 \times 2.7 \times 2.6$ m$^3$ has been studied by Irshad et al. [13,14]. This system has a COP of 0.68 and the cooling load of 498 W with the average cold space temperature of 298 K.

The pulse operation of the thermoelectric cooler can provide cold side temperature lower than the cold side temperature at steady state conditions. When the pulse current is applied to the thermoelectric cooler, the cold side temperature drops immediately because of Peltier cooling and then it increases to a peak value and gets peak overshoot because of accumulation of Joule heat in the thermoelement and Fourier heat conduction through the thermoelements from hot side to the cold side. Then the peak overshoot in cold side temperature decays to its steady state value as shown in Fig. 2(b). The cold side temperature has such profile, because the reaction time of Peltier cooling in the junction is much faster than the Fourier heat conduction. Snyder et al. [15] have numerically and experimentally studied the pulse thermoelectric cooling and showed that this technique can provide low cold side temperature which is comparable to the cold side temperature of a two-stage thermoelectric cooler. Yang et al. [16] have derived the expressions for the time to reach the minimum temperature and the holding time with the pulse operation of thermoelectric cooler. This study also analysed the influence of pulse shape and the thermoelement with variable cross section area on the temperature profile of the thermoelectric cooler. Ma et al. [17] have studied the continuous pulse operation of the thermoelectric cooling system and found that the periodic super cooling can be obtained, if the TEC is operated in the continuous current pulse mode. Shen et al. [18] and several others [19–22] have theoretically studied and experimentally demonstrated the pulse operation of the thermoelectric coolers. All these studies on pulse operation of thermoelectric coolers are envisioned to make use of the lower cold side temperature for thermal management of electronics/lasers.

### *1.1. Proposed methodology*

The studies on pulse operation of thermoelectric coolers proved that it can provide excess cooling for the period of the pulse width. Therefore, if the excess cooling (which is at lower temperature) is utilized at relatively higher temperature (~288 K) for the building cooling applications, the average cooling power can be improved which would result in the improved COP.

It was found that the thermoelectric cooling systems for building cooling applications have relatively lower COP. It was also identified that, if the cooling power of the thermoelectric cooler increases, the COP will decrease, but, for building cooling applications, the COP and the cooling power are equally important. It can be argued that the cooling power of the thermoelectric cooling system can be increased by adding more number of thermoelectric modules. However, it should be noted that, the effect of adding more number of modules to improve the COP of the system is uncertain and it also increase the capital cost of the system. Therefore, in this paper a new operating technique of the thermoelectric cooler is proposed which can improve the COP and cooling power of the thermoelectric cooler simultaneously without adding more thermoelectric modules. This is the novelty of the present research.

## 2. Thermodynamic modelling for pulse operation of thermoelectric cooler

Fig. 1 shows the schematic of the thermoelectric cooler system for the building space cooling application. The thermoelectric properties and the dimensions of the thermoelectric device are given in Table 1. Here thermoelectric properties of commercially available bismuth telluride ($Bi_2Te_3$) has been used in this study.