Optimizing the Arrangement of Two-Stage Thermoelectric Coolers through a Genetic Algorithm

Yi-Hsiang CHENG** and Chunkuan SHIH**

This study presents a new approach that uses a genetic algorithm (GA) to optimize the arrangement of two-stage thermoelectric coolers (TECs). Three practical configurations of two-stage TECs, 1) with two stages electrically connected in series, 2) with two stages electrically separated from each other and 3) with two stages electrically connected in parallel, were studied. Parameters, the applied electrical current and the number of thermocouples in each stage, were optimized to maximize the cooling capacity and the coefficient of performance (COP). The optimal parameters of each two-stage TECs were determined for each target cold-side temperature, and the maximum cooling capacity and the maximum COP were thus reached. The results of the optimization show that the electrically separated two-stage TECs yield the maximum cooling capacity, whereas the two-stage TECs that are electrically connected in series and electrically separated both produce the maximum COP. The optimal design of two-stage TECs can be realized using GA, and this method has considerable potential in designing a complex TEC system.

Key Words: Two-Stage Thermoelectric Coolers, Arrangement Optimization, Genetic Algorithm, Cooling Capacity, Coefficient of Performance (COP)

1. Introduction

Many optoelectronic devices, such as CCDs, multi-element IR detectors and other planar electro-optic elements, must be operated at low temperature. Therefore, thermoelectric coolers (TECs) have been applied to such electronic devices to create a steady, low-temperature operating environment. Commercially available TECs can produce a maximum temperature difference of around 70 K. This temperature difference may not meet desired requirements, so two- or multi-stage TECs are applied to increase the temperature difference\(^1\).

Two- or multi-stage TECs have been arranged in several configurations, such as with stages electrically connected in series, with stages electrically connected in parallel and with stages electrically separated from each other\(^2\). In those configurations, heat is removed from the cold side of the colder stage, and this heat is continuously transferred to the hot side of the hotter stages. Two parameters, the maximum cooling capacity and the maximum coefficient of performance (COP), are of particular interest in characterizing TECs\(^3\). Xuan et al.\(^2\)–\(^5\) and Chen et al.\(^5\)–\(^6\) investigated the maximum temperature difference, the maximum cooling capacity and the maximum COP of two-stage TECs. Based on the configurations of two-stage TECs, these works employed derivative methods that involved complicated procedures for optimizing the parameters of interest.

Recently, genetic algorithms (GAs) have been used as optimization techniques, and have been extensively applied to solve various complex problems\(^7\)–\(^10\). These methods are based on the evolutionary principles of natural genetics and natural selection\(^11\). Unlike in the derivation of analytical formulae, GAs start with a population of randomly generated solutions, form the new solutions by performing crossover and mutation operations, and then select the most fitting solutions. GAs use a probabilistic transient rule to realize global optimization, and they are effective in solving non-linear problems. Therefore, this study applies a GA to optimize the arrangement of two-stage TECs.

This study focuses on optimizing the arrangements of three two-stage TECs, to maximize the cooling capacity and the COP. The parameters, the internal structures...
and the supplied electrical currents, were optimized. The theoretical formulae derived in earlier works(3), (4) for two-stage TECs have been written in dimensional forms, such that each term in the formulae has a physical meaning. The optimal parameters obtained from GA were also compared with the available results presented in the literature.

The paper is arranged as follows. Section 2 presents the assumptions and reviews the theory. Section 3 describes the optimization methodology based on GA and its iteration procedures. Then, the results obtained using the GA are compared with those obtained analytically. Section 4 provides optimal parameters for various target cold-side temperatures. Finally, conclusions are drawn.

Nomenclature

- \( A \): cross-sectional area of thermocouples, m\(^2\)
- \( \text{COP} \): coefficient of performance
- \( I \): input current of the TEC, A
- \( K \): thermal conductance of thermocouples, W/K
- \( N \): number of thermocouples
- \( Q \): cooling/heating capacity, W
- \( r \): ratio of number of thermocouples between the hotter stage and the colder stage
- \( R \): electrical resistance of thermocouples, \( \Omega \)
- \( t \): ratio of electrical current in the hotter stage to that in the colder stage
- \( T \): temperature, K

Greek symbols
- \( \alpha \): Seebeck coefficient, V/K
- \( \rho \): electrical resistivity, \( \Omega \)m
- \( k \): thermal conductivity, W/mK

Subscripts
- \( a.v.e \): average
- \( c \): colder stage
- \( c,c \): cold side of the colder stage
- \( c,h \): hot side of the colder stage
- \( h \): hotter stage
- \( h,c \): cold side of the hotter stage
- \( h,h \): hot side of the hotter stage
- \( m \): contact junction between two stages
- \( n \): n-type thermoelectric material
- \( T \): total number
- \( p \): p-type thermoelectric material

2. Mathematical Modelling

A traditional TEC can typically produce a maximum temperature difference of around 70 K. Several types of two-stage TECs can be constructed to extend the temperature difference:

1) first type: two TECs are electrically connected in series, as shown in Fig. 1.
2) second type: two TECs are electrically separated from each other, as displayed in Fig. 2.
3) third type: two TECs are electrically connected in parallel, as presented in Fig. 3.

The following are defined to provide a general description of the three types of two-stage TECs.

- \( N_c \): number of thermocouples in the colder stage
- \( N_h \): number of thermocouples in the hotter stage
- \( I_c \): electrical current applied to the colder stage
- \( I_h \): electrical current applied to the hotter stage
- \( N_T \): total number of thermocouples

![Fig. 1 Schematic diagram of the first type of two-stage TECs](image1)

![Fig. 2 Schematic diagram of the second type of two-stage TECs](image2)

![Fig. 3 Schematic diagram of the third type of two-stage TECs](image3)
2.1 Assumptions

The following assumptions are made to simplify the calculations.

1) The thermocouples in the two-stage TECs are geometrically similar.

2) P- and n-type thermoelectric materials have identical properties, except that the polarities of their Seebeck coefficients are opposite.

3) The total number of thermocouples is constant; that is, the summation of \( N_c \) and \( N_h \) is equal to \( N_T \).

4) The leakage of heat from the thermocouples to the surroundings is neglected.

5) The Thomson effect is neglected.

6) The thermal and electrical contact resistances between each contact surface are neglected.

2.2 Theory

The operation of TECs is based on the Peltier effect. When an electrical current is passed through a pair of p- and n-type thermoelectric materials, a temperature gradient is established in the material. This phenomenon will result in the cooling of one side and the heating of the other side. In two-stage TECs, the heat is absorbed at the cold side of the colder stage, pumped to the hotter stage, and then removed to the surroundings. The two-stage TECs are considered to be two combined single-stage TECs, and each stage is composed of numerous thermocouples.

Based on the assumption that all thermocouples of two thermoelements have the same length and cross-sectional area, the dimensional heat balance equations for the cold side and the hot side of each stage can be derived from the differential equations, which state the heat transport and heat balance in the thermoelements, and are as follows \(^{(12)}\):  

\[
Q_{c,c} = I_aT_{c,c} - \frac{1}{2}I^2 R - K(T_{c,c} - T_{c,c})N_c, \quad (1)
\]

\[
Q_{c,h} = I_aT_{c,h} + \frac{1}{2}I^2 R - K(T_{c,h} - T_{c,c})N_c, \quad (2)
\]

\[
Q_{h,c} = I_aT_{h,c} - \frac{1}{2}I^2 R - K(T_{h,c} - T_{h,c})N_h, \quad (3)
\]

\[
Q_{h,h} = I_aT_{h,h} + \frac{1}{2}I^2 R - K(T_{h,h} - T_{h,c})N_h, \quad (4)
\]

where \( Q_{c,c} \) is the cooling capacity at the cold side of the colder stage; \( Q_{c,h} \) is the rate of release of heat at the hot side of the colder stage; \( Q_{h,c} \) is the cooling capacity at the cold side of the hotter stage, and \( Q_{h,h} \) is the rate of release of heat at the hot side of the hotter stage; \( T_{c,c} \) and \( T_{c,h} \) represent the temperatures of the cold and hot sides of the colder stage; \( T_{h,c} \) and \( T_{h,h} \) denote the temperatures of the cold and hot sides of the hotter stage; \( T_{m} \) is the temperature of the junction between two stages; \( \alpha, R, \) and \( K \) are the Seebeck coefficient, the electrical resistance, and the thermal conductance, respectively. The above thermoelectric material properties can be determined by

\[
\alpha = \alpha_p - \alpha_n, \quad (5)
\]

\[
R = \left( \rho_p + \rho_n \right) \frac{L}{A} \quad (6)
\]

\[
K = (k_p + k_n) \frac{A}{L} \quad (7)
\]

where the subscripts p and n indicate the properties of p- and n-type semiconductor; \( A \) and \( L \) are the cross-sectional area and the length of the thermoelectrics, respectively.

The assumption that \( T_{c,c} = T_{h,c} = T_{m} \), and the elimination of the temperatures \( T_{c,h} \) and \( T_{h,h} \) from Eqs. (1) – (4) by setting \( Q_{c,c} = Q_{h,c} \), yields a junction temperature \( T_{m} \) of

\[
T_m = \frac{K(T_{c,c} + rT_{h,h}) + (r^2 + 1)\frac{1}{2}I^2 R}{K(r + 1) + I_a(r - 1)} \quad (8)
\]

Finally, the heat balance equations can be rewritten as

\[
Q_{c,c} = I_aT_{c,c} - \frac{1}{2}I^2 R - K(T_{m} - T_{c,c})N_c, \quad (9)
\]

\[
Q_{c,h} = I_aT_{c,h} + \frac{1}{2}I^2 R - K(T_{m} - T_{c,c})N_c, \quad (10)
\]

\[
Q_{h,c} = I_aT_{h,c} - \frac{1}{2}I^2 R - K(T_{h,c} - T_{h,c})N_h, \quad (11)
\]

\[
Q_{h,h} = I_aT_{h,h} + \frac{1}{2}I^2 R - K(T_{h,c} - T_{h,c})N_h. \quad (12)
\]

The efficiency of two-stage TECs is measured by measuring its COP, which is the total heat transferred through the thermoelectric device divided by the electric input power. The COP of two-stage TECs is thus calculated from

\[
\text{COP} = \frac{Q_{c,c}}{(Q_{h,h} - Q_{h,c}) + (Q_{c,c} - Q_{c,c})} = \frac{Q_{c,c}}{Q_{h,h} - Q_{c,c}} \quad (13)
\]

where \( Q_{h,h} - Q_{h,c} \) is the electric input power to the hotter stage, and \( Q_{c,c} - Q_{c,c} \) is the electric input power to the colder stage.

The material properties are considered to be dependent on the average temperature, \( T_{ave} \) given by \( T_{ave} = (T_{c,c} + T_{h,h})/2 \), and can be obtained by applying the experimental formulation of MELCOR, USA \(^{(13)}\):

\[
\alpha_p = -\alpha_n = (22224.0 + 930.67T_{ave} - 0.9057T_{ave}) \times 10^{-9}, \quad (14)
\]

\[
\rho_p = \rho_n = (5112.0 + 163.4T_{ave} + 0.6279T_{ave}) \times 10^{-10}, \quad (15)
\]

\[
k_p = k_n = (62605.0 - 277.7T_{ave} + 0.4131T_{ave}) \times 10^{-4}. \quad (16)
\]

Notably, \( I_c \) equals \( I_h \) for the first type of two-stage TECs, and no computational restriction applies to the second type during the calculation. For the third type of two-stage TECs, each stage receives the same voltage, and so must follow the following relationship

\[
I_cR + \alpha(T_{m} - T_{c,c}) = [I_hR + \alpha(T_{h,c} - T_{m})]r. \quad (17)
\]
Equation (17) can be rearranged as
\[ t = \frac{I,R + \alpha T_m(1 + r) - \alpha(T_{c,c} + rT_{h,h})}{rI,R}. \] (18)

3. Optimization

3.1 Optimization algorithm and processes

Two-stage TECs have been used in numerous electronic systems, so the cooling capacity and COP of the two-cascade TECs are important in considering applications. This study optimizes the arrangements of the three types of two-stage TECs - with two stages electrically connected in series, with two stages electrically connected in parallel and with two stages electrically separated. The parameters to be optimized are the electrical current and the number of thermocouples of each stage.

A new approach that uses a GA is proposed to optimize two-stage TECs. GAs are probabilistic search algorithms that combine the mechanics of natural genetics and natural selection. Those algorithms begin with a population of parameter sets, and perform a multiple-directional search. Rather than use mathematical treatments to find optimal solutions, GAs use payoff strategies to find the fittest solutions. Two genetic operators, crossover and mutation, are applied to explore all solution space effectively. Each parameter set has a fitness value, and fitter parameter sets are more likely to be selected and regenerated in the next generation. GAs use evolution operators to perform global search for complex problems.

This work utilizes GA to treat the optimization of two-stage TECs as an unconstrained problem. The main parameters in each of the three groups are presented below.

**Group A. Fixed Parameters**
1) temperature at the cold side of the colder TEC \(T_{c,c}\);
2) temperature at the hot side of the hotter TEC \(T_{h,h}\);
3) total number of thermocouples of both stages \(N_T\).

**Group B. Variables**
1) electrical current applied to the colder TEC \(I_c\);
2) electrical current applied to the hotter TEC \(I_h\);
3) number of thermocouples of the colder TEC \(N_c\);
4) number of thermocouples of the hotter TEC \(N_h\).

**Group C. Objective Functions**
1) cooling capacity, as given by Eq. (9);
2) COP, as given by Eq. (13).

The optimization calculation starts with a population \(P\) of \(n\) randomly generated individuals \(P_n\), which represent \(n\) potential solutions. Following the terminology of organic evolution, the operations of crossover, mutation and selection are performed on the population. Each individual is submitted into the objective function whose value represents the fitness of the individuals. In this study, the individuals in a population are \(P = [I_c, I_h, N_c, N_h]\). Notably, the relationship of \(N_c\) and \(N_h\) must satisfy the criterion \(N_c + N_h = N_T\). The GA coded herein was implemented as follows, to maximize the cooling capacity and COP.

1) Real number encoding: a population of feasible individuals, \(P = [I_c, I_h, N_c, N_h]\), is randomly generated.
2) Arithmetic crossover: the affine combination is selected for use in this GA, and it is implemented by combining two chromosomes \(P_1\) and \(P_2\) as follows
\[ \bar{P}_1 = \beta_1 P_1 + \beta_2 P_2, \]
\[ \bar{P}_2 = \beta_1 \bar{P}_2 + \beta_2 \bar{P}_1, \]
where \(\beta_1 + \beta_2 = 1\).
3) Non-uniform mutation: each potential individual solution \(x_i\) is replaced by a real value \(x'_i\), which is randomly selected from between two bounds \([x'^{L}_i, x'^{U}_i]\). Non-uniform mutations are more severe in earlier generations than in later generations. Mutation operates independently on each individual by probabilistically perturbing each individual as follows
\[ x'_i = x_i + \Delta(g, x'^{U}_i - x_i), \]
or
\[ x'_i = x_i + \Delta(g, x_i - x'^{L}_i), \]
and \(\Delta(g, y) = y \cdot b \left(1 - \frac{g}{G}\right)^d\)
where \(b\) is a random number in \([0, 1]\); \(g\) is the generation number; \(G\) is the total number of generations, and \(d\) is the degree of non-uniformity.
4) Top pop-size selection: the objective function of each parameter set is calculated and treated as the corresponding fitness. The best \(n\) individuals are selected according to fitness, and are used to produce next population.

3.2 Tests of genetic algorithm

The initial settings used in testing the GA coded in this work were taken from Xuan’s work(4). Accordingly, the temperatures of the cold side of the colder stage and of the hot side of the hotter stage were set to 240 K and 300 K, respectively; the ratio of the cross-sectional area to the length of the thermocouples was \(1.8 \times 10^{-3}\) m. The TECs were optimized by considering the usage of material or the limitations on cost for practical purpose, so the total number of thermocouples of the two stages was set to 50 for use in a general electronic system. The first type of two-stage TECs herein can be regarded as pyramid-styled TECs in Xuan’s work. Equations (9)–(13) yield Figs. 4 and 5, which present the effects of the ratio of the number of thermocouples between the two stages \(r\) and the electrical currents input to the two stages \(I\) on the cooling capacity and the COP. These two figures indicate that the cooling capacity and the COP initially increase with \(r\), and then decrease as \(r\) is increased further. Restated, the cooling capacity and the COP can reach their maximum at specific values \(r\) and \(I\).
This study used GA to search out the optimal parameters for two-stage TECs. In the implementation of GA, the population size and the maximum number of generations for evolution must be determined. Furthermore, the crossover operator and the mutation operator are applied under some probabilities $P_{cs}$ and $P_{mt}$, to randomly construct a new set of solutions. The crossover and mutation rates are initially in the range 0.1 to 0.9 normally, with the mutation rate smaller than the crossover rate. After the efficiency of the GA coded herein was tested, the population size was set to 20, the number of generations was limited to 200, and the crossover rate and mutation rates were chosen as 0.6 and 0.2, respectively.

Under the specific aforementioned conditions, the optimization of the first type of two-stage TECs produces a maximum cooling capacity of 3.10 W and a maximum COP of $1.68 \times 10^{-1}$. The optimal parameters at the point of maximum cooling capacity are $N_c = 13$, $N_h = 37$ and $I_c = I_h = 7.25$ A. Additionally, the optimal parameters at the point of maximum COP are $N_c = 15$, $N_h = 35$ and $I_c = I_h = 4.05$ A. Figures 6 and 7 plot the convergence curves of the cooling capacity and the COP during optimal search, and reveal that the entire search almost converges after 20 runs. The optimal search in this GA converges so quickly that the optimization processes are time- and cost-effective.

Table 1 compares the optimal parameters and the corresponding performance of the first type of TECs obtained from GA with those from available references to confirm

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<tr>
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<th>GA</th>
<th>Xuan’s results\cite{19}</th>
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<tbody>
<tr>
<td>$N_c$</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>$N_h$</td>
<td>37</td>
<td>38</td>
</tr>
<tr>
<td>$I_c$ (A)</td>
<td>7.25</td>
<td>7.45</td>
</tr>
<tr>
<td>$I_h$ (A)</td>
<td>7.25</td>
<td>7.45</td>
</tr>
<tr>
<td>$Q_{c, \text{Max}}$ (W)</td>
<td>3.10</td>
<td>3.08</td>
</tr>
<tr>
<td>COP</td>
<td>$1.68 \times 10^{-1}$</td>
<td>$1.70 \times 10^{-1}$</td>
</tr>
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</table>
the accuracy of the GA program developed in this study. This comparison demonstrates that the optimal parameters determined by genetic search are almost identical to those available in the literature. However, minor differences in the optimum parameters — including \( N_c \), \( N_h \), \( I_c \) and \( I_h \) — at the maximum cooling capacity are also observed. The optimal parameters for the maximum \( Q_{c,c} \) obtained from GA are of \( N_c = 13 \), \( N_h = 37 \) and \( I_c = I_h = 7.25 \text{ A} \). However, the optimal parameters that maximize \( Q_{c,c} \) proposed by Xuan were of \( N_c = 12 \), \( N_h = 38 \) and \( I_c = I_h = 7.45 \text{ A} \). Such minor differences in the optimum parameters at maximum cooling capacity indeed demonstrates that the approach proposed herein considerably outperforms. Moreover, this procedure demonstrates and verifies the search ability of the GA code implemented herein, and showed that the GA technology is available for optimizing TECs.

4. Results and Discussions

After the GA code was confirmed, the optimization was extended to finding the optimal parameters for the second and the third types of two-stage TECs. Throughout the calculation, the initial settings were the same as those used for the first type of two-stage TECs.

The second type of two-stage TECs is two electrically separated TECs. Table 2 presents the parameter sets that maximize the cooling capacity and the COP. The maximum cooling capacity and maximum COP of the second type TECs are 3.73 W and 1.68×10^{-1}, respectively. Therefore, the cooling capacity or the COP can be maximized by properly combining the parameters.

The third type of two-stage TECs is two TECs electrically connected in parallel. Table 3 presents the optimal parameters, and shows a maximum cooling capacity and the maximum COP are of 1.53 W and of 9.97×10^{-2}, respectively.

The above shows that the second type of two-stage TECs, with separate electrical currents, has the best cooling capacity and has a COP that is similar to that of the first type. These results also support the findings of Xuan.

The optimization considered some specific applications, in which the cold-side temperature was in the range 210 – 230 K. The GA code is employed to optimize the parameters according to the temperature of the cold side of the colder stage, and Table 4 presents the optimal parameters. Table 4 indicates that when the cold side of the colder stage is colder, the number of thermocouples of the colder stage should be lower and the electrical currents applied to both stages further increased. Furthermore, the electrical current applied to the hotter stage always exceeds that applied to the colder stage.

Table 4 shows that the second type of two-stage TECs always performs best in terms of cooling capacity. Therefore, in some applications, in which cooling capacity is particularly important, the second type TEC arrangement performs best. In contrast, if the COP is more important, then the first type and second type arrangements perform equally at the specified temperature difference. Hence, ar-

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Examples of the optimal parameters for the second type of two-stage TECs (Consider the maximum cooling capacity and the maximum COP)</th>
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</thead>
<tbody>
<tr>
<td>GA</td>
<td>Max ( Q_{c,c} )</td>
</tr>
<tr>
<td>( N_c )</td>
<td>17</td>
</tr>
<tr>
<td>( N_h )</td>
<td>33</td>
</tr>
<tr>
<td>( I_c ) (A)</td>
<td>5.05</td>
</tr>
<tr>
<td>( I_h ) (A)</td>
<td>1.00×10^1</td>
</tr>
<tr>
<td>( Q_{c,c} ) (W)</td>
<td>3.71</td>
</tr>
<tr>
<td>COP</td>
<td>–</td>
</tr>
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</table>

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<tr>
<th>Table 3</th>
<th>Examples of the optimal parameters for the third type of two-stage TECs (Consider the maximum cooling capacity and the maximum COP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>Max ( Q_{c,c} )</td>
</tr>
<tr>
<td>( N_c )</td>
<td>25</td>
</tr>
<tr>
<td>( N_h )</td>
<td>25</td>
</tr>
<tr>
<td>( I_c ) (A)</td>
<td>5.07</td>
</tr>
<tr>
<td>( I_h ) (A)</td>
<td>6.32</td>
</tr>
<tr>
<td>( Q_{c,c} ) (W)</td>
<td>1.53</td>
</tr>
<tr>
<td>COP</td>
<td>–</td>
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<tr>
<th>Table 4</th>
<th>Examples of the optimal parameters for two-stage TECs under various temperatures of the cold side of the colder stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Type</td>
<td>( T_{c,c} = 230 \text{ K} )</td>
</tr>
<tr>
<td>( N_c )</td>
<td>13</td>
</tr>
<tr>
<td>( N_h )</td>
<td>37</td>
</tr>
<tr>
<td>( I_c ) (A)</td>
<td>4.87</td>
</tr>
<tr>
<td>( I_h ) (A)</td>
<td>4.87</td>
</tr>
<tr>
<td>( Q_{c,c} ) (W)</td>
<td>9.23×10^{-2}</td>
</tr>
</tbody>
</table>

| Second Type | \( T_{c,c} = 230 \text{ K} \) | \( T_{c,c} = 220 \text{ K} \) | \( T_{c,c} = 210 \text{ K} \) |
| \( N_c \) | 14 | 10 | 8 |
| \( N_h \) | 36 | 40 | 42 |
| \( I_c \) (A) | 4.76 | 5.86 | 5.97 |
| \( I_h \) (A) | 5.44 | 6.05 | 7.33 |
| \( Q_{c,c} \) (W) | 9.25×10^{-2} | 4.44×10^{-2} | 1.57×10^{-2} |

| Third Type | \( T_{c,c} = 230 \text{ K} \) | \( T_{c,c} = 220 \text{ K} \) | \( T_{c,c} = 210 \text{ K} \) |
| \( N_c \) | 21 | – | – |
| \( N_h \) | 25 | – | – |
| \( I_c \) (A) | 4.72 | – | – |
| \( I_h \) (A) | 5.77 | – | – |
| \( Q_{c,c} \) (W) | 9.07×10^{-2} | – | – |
ranging the two stages as the first type with suitable parameters conveniently maintains the COP.

Figures 8 and 9 plot the effects of the optimization on cooling capacity and COP. The dashed lines represent the effects of the optimization by GA, whereas the dotted lines represent the performances for a certain parameter set. These figures show that the GA coded in this work can combine appropriate parameters to maximize cooling capacity and COP.

5. Conclusions

This study presents a new approach to optimize the parameters and maximize cooling capacity and COP for two-stage TECs. GA can be used to optimize the number of thermocouples and the applied electrical current in each stage. A comparison of the optimal parameters obtained by the genetic search with those obtained analytically also confirmed the searching ability of the GA code implemented in this work. The optimization results show that the electrically separated two-stage TECs yield the maximum cooling capacity, whereas the two-stage TECs electrically connected in series and the electrically separated two-stage TECs both produce the maximum COP. A GA can perform an optimal search rapidly, such that optimization process is time- and cost-effective. Unlike the complex analytical approach, the new method based on
GA can be used effectively to optimize the parameters of two-stages TECs.

Acknowledgment

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(13) From http://www.melcor.com, Homepage of MELCOR, USA.