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Enhancing COP And Cooling Temperature for Peltier with Decreasing Power, and Chemical Composition Negative Effect by Optimizing Connection, Position Angle, and Voltages

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In Loving Memory of Late Professor Doctor ""Mohamed Refaat Hussein Mahran""

Abstract
The challenge of global energy and global warming has resulted in maximizing the energy utilized to minimize consumption, and the use of thermal cooling is less prevalent, reducing carbon emissions and global warming. Thermoelectric cooling uses the Peltier effect to create a heat flux at the junction of two different types of materials. The Peltier connection technique influences cooling efficiency (parallel - in series). The Peltier location in the refrigeration unit affects the cooling like the various Peltier placements on a straight or vertical line, and that is, the position between two Peltier units is at an angle of 180º or vertical direction of 90º. The various voltages and chemical compositions studied on power, COP, and Tc over time. The results indicated an improvement in COP when a parallel connection at 4 volts using 4 Peltier units and higher Tc when the parallel connection of 4 volts using 4 Peltier units and less power used at 4 volts and the parallel connection is practically equal series connection by using 2 Peltier units. The results also revealed that positioning the Peltier vertically at a 90º degree has a greater efficiency and cooling dispersion than placing it straight line at an angle of 180º inclination.
Keywords: COP, Cooling Capacity, Power Consumption, Thermoelectric module..

1. Introduction

The current global issues affecting sustainable growth include the energy crisis and restrictions on the most effective use of renewable energy resources. Energy demand and supply are increasingly at odds. Due to their reduced environmental effect, several renewable energies have been developed to close this gap, including solar, wind, hydro, cogeneration, etc. **Biswss et al.** designed a solar thermoelectric cooler using solar energy and its cooling capabilities with and without product load were assessed. according to the effects of varying input electric current on cooling capacity, power consumption, and coefficient-of-performance (COP). At the input electric current of 3.5 A, the STEC's cooling capacity, power consumption, and coefficient of performance were 23.8 W, 53.5 W, and 0.44, respectively, (Biswas and Kandasamy 2021).

P. Pounraj et al. investigated an integrated PV/T active solar still was designed and produced; utilizing a solar PV Using a powered Peltier system was the decision. The distilled product is improved by the Peltier in this still. Water is created as a result of the evaporation and condensation processes. Numerous investigations have been carried out. recommended active solar still (with solar PV) has an overall thermal efficiency that is about 30% higher than the current one, while the passive solar still is about 10% higher and has a thermal efficiency that is 17% higher than the projected still, (Pounraj et al. 2018). **Deeksha Singh et al.** demonstrating the relation between solar module efficiency and the thermoelectric cooling effect when used in conjunction (series) with phase-changing material (PCM), Electrical efficiency and panel efficiency are found to exhibit maximum increments of 19.4% and 19.32%, respectively, (Singh et al. 2022).

Zuhair R. Abdulghani showed endeavors are made to provide an experimental-based optimization process for the Peltier air cooler using the well-known Taguchi method Studies show that, for a given total input power, more modules produce a better coefficient of performance (COP). The Peltier

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cooler's cost per cooling unit is reduced by using the optimal number of modules. (Abdulghani 2022).

Abdelkrim Kherkhara et al. using an experimental and numerical technique in order to evaluate the thermoelectric cooler (TEC) control performance and efficiency. The primary outcomes include a maximum coefficient of performance recorded between 0.73 and 0.1 with a temperature range of around 51 °C, when a current of 5 °A is inputted within a regulated temperature range of 0 °C to 30 °C,(Kherkhar et al. 2022).

Huili Wang et al. study Experiments are performed on the effect of local cooling by semiconductor refrigerator on triggering crystallization of super cooled SAT, STP and their binary mixtures with different mass ratios. The results show that SAT has higher discharging temperature and longer discharging time than STP; but STP has less phase separation, better cycling stability and shorter induction period during the crystallization than SAT after repeated melting-freezing cycles. Moreover, the phase separation problem of SAT could be significantly alleviated with the addition of STP, (Wang et al. 2021).

There is many TE cooling research that combines theoretical and experimental data. To create a more effective heat exchanger, typical shell and tube heat exchangers were modified to use a tubular TE device composed of tilted multilayers of BST/Ni as the tubes, (Huang, Chin, and Duang 2000) (Riffat and Ma 2003) (Takahashi et al. 2013).

Astrain et al. exposed A computational analysis was performed on a thermoelectric refrigerator with an internal volume of 15 m^3 to determine the effect of the heat exchanger investigated on the overall consumption of the refrigerator and its efficiency. The findings show that effective heat exchanger optimization can result in significant gains in TEC efficiency, (Astrain et al. 2016).

Chen et al. presented A model of internal and external irreversible thermoelectric generator-driven thermoelectric refrigerator The COP is no longer constant and declines monotonically with an increase in the total number of thermoelectric devices, whilst the cooling load is less and no longer proportionate to the total number of thermoelectric units, (Chen, Meng, and Sun 2012). **A. Çağlar** designed a portable TE refrigerator the temperature and COP of the TE refrigerator are examined for the best operational settings throughout a 60-min time period using the orthogonal fractional factorial experiment design approach. Results reveal that although the COP lowers from 0.351 to 0.011, the air temperature inside the TE refrigerator drops from 293 K to 254.8 K, (Çağlar 2018).

Mohammad Hemmat Esfe et al. the main goal of this research is to determine how altering the thermoelectric cold surface temperature affects the amount of water produced by condensation from the air. Twelve numerical samples with temperature variations between one and twelve degrees Celsius on the thermoelectric cold surface were evaluated for this purpose. The surrounding air's temperature and relative humidity in all Samples are kept at constant temperatures of 35 °C and 80%, respectively, (Hemmat Esfe, Esfandeh, and Toghraie 2021).

Carson et al. study a laboratory experiment was conducted to determine the impact of the orientation of the cold side heatsink on the rate of water collection. On the side of heat rejection, a single finned heatsink-fan combination was employed. A heatsink with fifteen fins, a fanned plate with four fins, and uncoated and Polytetrafluoroethylene (PTFE) coated flat plates were utilized on the cold side, (Hand and Peuker 2019).

Lumin Shi et al. presented a Peltier module obtains a high value of COP only for a small range of applied DC voltage. Indeed, increment of DC voltage sharply reduces its COP. Hence, to get a high total COP for a large-scale commercial Peltier air cooler (for example input power of 1000 W) each individual Peltier module should work with a small input DC voltage. This means, a greater number of Peltier modules should be employed in a real cooler to reduce the allocate DC voltage for any individual Peltier module. However, this means higher capital, maintenance, operating and maybe final cooling cost, (Shi et al. 2023).

Improved the functioning and create a TE cooler for cooling electronics by applying a topology optimization approach. Based on evaluations of voltage, current, and temperature, (Soprani et al. 2016) (Diş, litaş, S.; Ahıska 2016). A parabolic method was developed to calculate the peak efficiency of TE modules based on temperature, current, and voltage data, (Tipsaenporm et al. 2012). used a simple evaporative cooling system, which increased COP by 20.9%, (Tan and Zhao 2015). Proposed a phase change material (PCM)-integrated TE cooling system for space cooling, Where PCM served as a heat sink during the daytime cooling phase to minimize TE module hot side temperature and stored cold thermal energy at night the experimental performance of a mini-channel water-cooled-TE refrigerator was tested for various voltages and flow rates, (Gökçek and Şahin 2017). Studied heat dissipation strategies for eliminating waste heat from a TE device's cold side A TE freshwater generator were created, (Joshi et al. 2017). For use by dwellers of humid and coastal environments with relative humidity values greater than 60%. They require a lot of electricity, employ liquid refrigerants that have significant environmental effects, and are difficult to create as portable and lightweight outdoor equipment

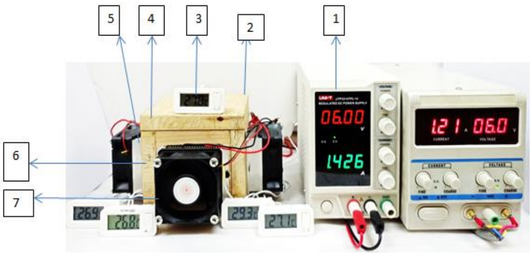
(Mirmanto, Syahrul, and Wirdan 2019) (Aboelmaaref et al. n.d.).

Through the study, it was found that with the continuous use of the Peltier element, damage to the Peltier element occurs as a result of changes in the chemical properties of the Peltier element. To improve the efficiency of the Peltier and rationalize energy consumption, different positions of the Peltier element were studied at an angle of 90 and at an angle of 180 to find out the most appropriate position. Connecting the Peltier in parallel and in series was studied to avoid changes in the chemical properties.

2. Materials and method

2.1. Cooling system description

The photographic picture of the experimental configuration is shown in Fig. (1).



1-power supply 2-S.S. box 3-sensor 4-wood box
5-heat sink 6-peltier element 7-fan

Fig. (1): Photographic picture of experimental setup

The suggested system comprises a refrigerator box and four thermoelectric units (TU), with cooling provided by a Peltier element (TEC1-12706). N-P junction semiconductors are frequently welded to copper conductors. Dimensions: (4×4×4) mm, Max. Voltage: 14.4V DC, Max. Current: 6A, Temperature range: 30:70 °C. RB is made up of two boxes: an exterior box made of wood and an inside box made of stainless steel, with thermal insulation (Foam) sandwiched between them to prevent cooling loss. While the TU consists of a Peltier element, the heat sink fins are constructed of aluminum, and the fan size is (6.5×6.5×2.5).

To obtain low temperatures on the cold side of the Peltier element, the hot side must be cooled. As a result, on the hot side of the Peltier element, a fan is often used. Finally, MD is a digital millimeter for measuring voltage and current. A digital thermometer is used to measure the temperature. A PV module, control unit, Peltier device, thermally insulated chamber (cooling load), and heat sink are the components of the proposed system. Although Al_2O_3 is an electrical insulator, it possesses a high heat conductivity (30 $Wm^{-1}K^{-1}$). Aluminum oxide is insoluble in water. figure 2 the present experimental setup is depicted schematically.

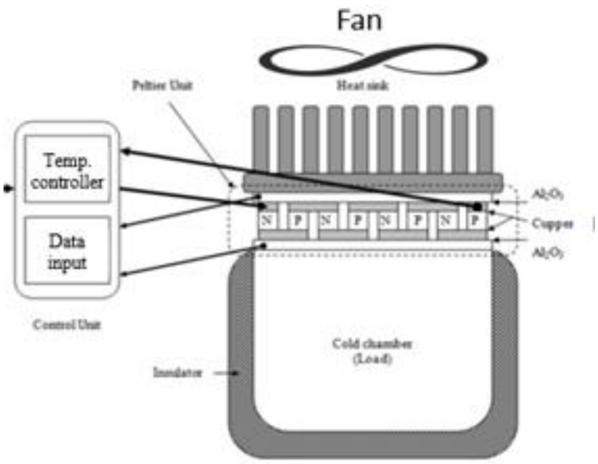


Fig. (2): schematical diagram of experimental setup.

2.2. Thermoelectric Cooling

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. Figure (3) shows a picture of Peltier element.

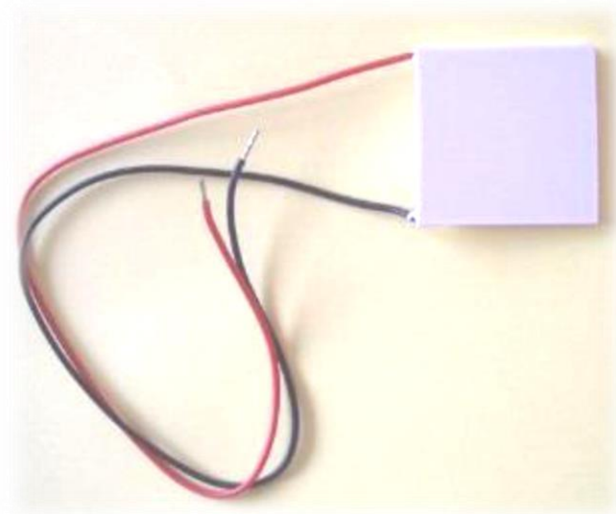


Fig. (3): Picture of Peltier element.

A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other side against the temperature gradient (from cold to hot), with consumption of electrical energy. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). The Peltier device is a heat pump: when direct current runs through it, heat is moved from one side to the other. Therefore, it can be used either for heating or for cooling (refrigeration), although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cools. This technology is far less commonly applied to refrigeration than vapor-compression refrigeration is. The main advantages of a Peltier cooler are its lack of moving parts or circulating liquid, and its small size and flexible shape (form factor). Its main disadvantage is that it cannot simultaneously have low cost and high-power efficiency.

2.3. Method

side. Figures (4) and (5) show the characteristics of the heat sink and fans. The type and technical aspects of Peltier element are shown in Fig. (3) and Table 1, respectively. Many experiments are carried out by using variable voltage (4-14) V, No. of Peltier's (1-4) and initial temperature. Figure (6) depicts relationship between Voltage and current for Peltier element with fan and fan only. Once the fans are adjusted to a specific voltage, the current is steady and does not change over time. However, the current of the Peltier element decreases at the first minute of the experiment. Before starting experiments, put 0.25L of water in the box and recorded its temperature, adjusting the Voltage at specific value (4-14) V, and recorded ambient temperature and the current of the Peltier element and the fans. Temperature of water, hot side of Peltier and current are recorded every 5 minutes. The duration of an experiment is 45 minutes.

3. Results and Discussion

The results of all the experiments are classified: as the effect of variable Voltage (4,6, and 8) V by using No. of Peltier elements (2, 3, and 4) on the cooling temperature and the COP, at different connections.

Table (1) Experimental results of Voltage, initial temperature, and calculated COP values using different connection (series -parallel).

No.	Parameters				Results		
	V/Peltier (V)	No. of Peltier	Connection Type	Time (min)	I (A)	ΔT (ºC)	COP (%)
1	4	2	parallel	45	1.833	12.5	66.30%
2	4	2	series	45	0.89	9.2	50.25%
3	6	2	parallel	45	2.5	13.7	35.52%
4	6	2	series	45	1.38	12.6	29.59%
5	8	2	parallel	45	3.815	16.2	20.64%
6	8	2	series	45	1.8	14	18.90%
7	4	3	parallel	45	2.66	15.7	57.38%
8	4	3	series	45	0.864	11.2	42.01%
9	4	4	parallel	45	3.538	18.2	50.01%
10	4	4	series	45	0.888	16	43.79%

Table (2) Experimental results of Voltage, initial temperature, and calculated COP values using different position for Peltier (180 -90).

No.	Parameters					Results		
	V/Peltier (V)	No. of Peltier	Connection Type	Peltier Angle (º)	Time (min)	I (A)	ΔT (ºC)	COP (%)
1	4	2	parallel	180	45	1.884	11.3	58.31%
2	4	2	parallel	90	45	1.833	12.5	66.30%
3	6	2	parallel	180	45	2.479	13.2	34.51%
4	6	2	parallel	90	45	2.518	13.7	35.26%
5	8	2	parallel	180	45	3.787	15.6	20.02%
6	8	2	parallel	90	45	3.815	16.2	20.64%
7	10	2	parallel	180	45	4.573	16.6	14.12%
8	10	2	parallel	90	45	4.596	18.4	15.57%
9	12	2	parallel	180	45	5.718	18	10.20%
10	12	2	parallel	90	45	5.548	18.2	10.63%
11	14	2	parallel	180	45	6.294	17	7.50%
12	14	2	parallel	90	45	6.478	17.9	7.68%

Table (2) displayed the results of laboratory experiments conducted under certain conditions at an ambient temperature of 30.9 °C, at different voltages, and using a different number of Peltier at a specified time of 45 minutes. with two angles (180- 90º)**.**

Given that COP is the most important comparative measure for cooling systems, it is used as a quality standard to improve performance. The number of Peltier elements, voltage difference, as well as ambient temperature are operational elements that have a significant impact on the COP of the system. With different connections

These variables have different impacts on the COP and should therefore be optimized. Table 1 shows the voltages for the Peltier and fan studies, as well as the starting temperature and calculated COP values. Where V is the total voltage of the Peltier and fan, I represents the average current, and T represents the temperature difference. Using two Peltier devices at 4 volts, the temperature was reduced. Using two, three, and four Peltier units with different voltages (4, 6, and 8V) and the best COP is 66.3%, which was the highest COP in the experimental study by using two Peltier at 4volt.

Figure (4) showing the effect of time on efficiency the figure depicts using (two, three and four) Peltier in different connection (series- parallel) connection at different voltage (4,6and 8) V also the figure shows that the highest efficiency was obtained during the first 5 minutes of the start of operation 525%, and then the efficiency gradually decreases. The COP increases sharply near the starting point, then achieves the peak and goes down Also, we note that the highest efficiency was by using a four Peltier at 4 volts with series connection, and the lowest efficiency 63% was by using a two Peltier at 8 volts with parallel connection. At a specified time of 5 minutes

Figure (5) depicts the variation in cooling temperature with time The graphic shows (two, three, and four) Peltier units in different connections (series-parallel) at different voltages (4, 6, and 8) V. From the figure the best cooling was at 4 volts by using four Peltier units at parallel connection the temperature decreases from (30.9 to 12.7) ℃ and the lowest cooling temperature was at 4 volts by using two Peltier at series connection the temperature decreases from (30.9 to 21.7) ℃ at 45 min. It is also clear from the figure that the parallel connection is better than the series connection.

Figure (6) illustrates the variation of power consumption with time at different connection The figure displays (two, three, and four) Peltier units connected in different ways (series-parallel) at different voltages (4,6, and 8) V. The figure shows that the power consumed in the different connection is close to a few differences as the voltage increases. from the figure, it is clear that the lowest energy consumption in the series connection by using two Peltier at 4 Volt, and the most energy consumption is the parallel connection by using two Peltier at 8 Volt.

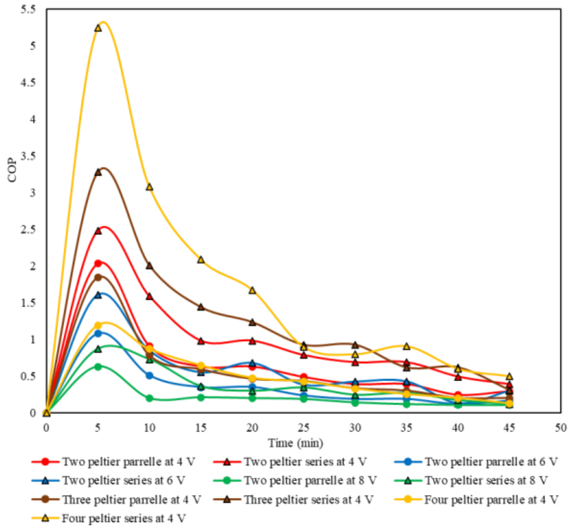


Fig. (4): Effect of time on COP at different connection.

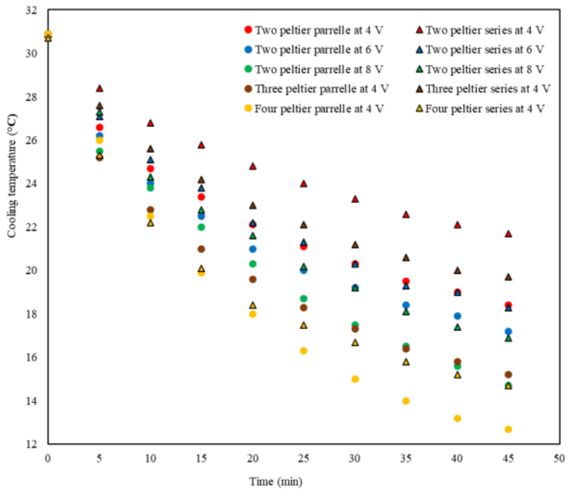


Fig. (5): Variation of cooling Temperature vs time at different connection.

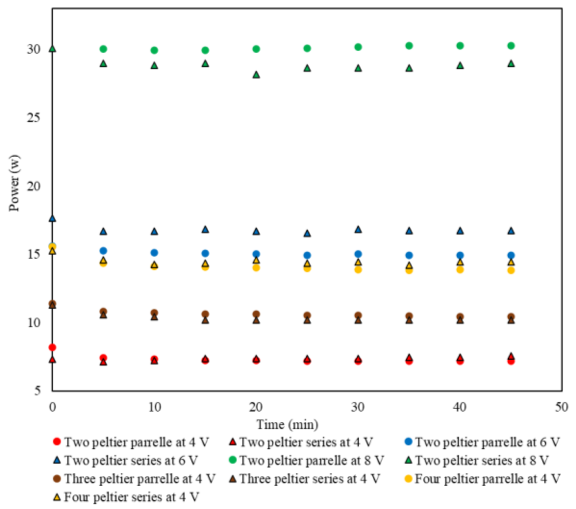


Fig. (6): effect of time on the power consumption at different connection.

Figure (7) display the variation of temperature and power consumption by using two Peltier elements with position angle (90°) at variable Voltage (4, 6, 8, 10, 12 and 14V) is displayed in fig. (5). It is noticed that, at Voltage =10 V, temperature of water decreases from 30.9 °C to 12.5 °C, (optimum cooling value) for the cooling duration and the Peltier units average current is 4.59 A. While at 4 V, the average current through the Peltier element is 1.833A and the optimal COP is 66.3%. When the input Voltage is increased, the current increased, but COP decreases.

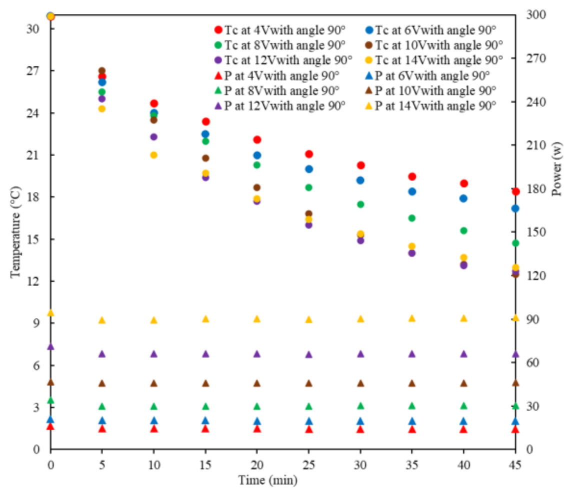


Fig. (7): effect of time on the cooling temperature and power consumption at Peltier angle 90°.

Figure (8) shows the fluctuation in temperature and power consumption when two Peltier elements with position angle (180°) are used at different voltages (4, 6, 8, 10, 12, and 14V). At Voltage =10 V, the temperature of the water lowers from 30.9 °C to 12.5 °C (optimum cooling value) during the cooling time, and the average current of the Peltier element is 4.59 A. The average current through the Peltier element is 1.833A at 4 V, and the ideal COP is 66.3%. When the input voltage is raised, the current rises, but the COP falls.

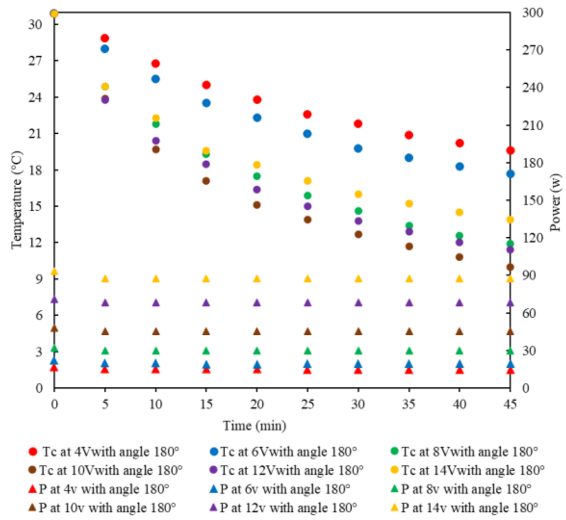


Fig. (8): effect of time on the cooling temperature and power consumption at Peltier angle 180°.

5. Conclusions

The present paper investigates the various Peltier placements on a straight or vertical line, as well as the various Peltier connection methods (parallel - in series) at various voltages (4-6-8) volts. To research this on power, COP, and Tc over time, the results indicated an improvement in COP when parallel connection at 4 volts using 4 Peltier units and higher Tc when parallel connection of 4 volts using 4 Peltier units and less power used at 4 volts and parallel connection is practically equal series connection by using 2 Peltier units. The results also revealed that positioning the Peltier on a straight line at an angle of 180° degrees has a greater efficiency and cooling dispersion than placing it vertically at a 90° degree inclination.

4. Reference

[1]. Abdulghani, Zuhair R. 2022. "A Novel Experimental Case Study on Optimization of Peltier Air Cooler Using Taguchi Method." *Results in Engineering* 16:100627.

[2]. Aboelmaaref, Moustafa M., Mohamed E. Zayed, Ammar H. Elsheikh, Ahmed A. Askalany, Jun Zhao, Wenjia Li, K. Harby, S. Sadek, and Mahmoud S. Ahmed. n.d. "Design and Performance Analysis of a Thermoelectric Air-Conditioning System Driven by Solar Photovoltaic Panels."

[3]. Biswas, Olipriya and Palani Kandasamy. 2021. "Development and Experimental Investigation of Portable Solar-Powered Thermoelectric Cooler for

Preservation of Perishable Foods." *International Journal of Renewable Energy Research* 11(3):1292–93.

[4]. Diş, litaş, S.; Ahıska, R. 2016. "Determination of the Parameters Imax, Vmax and Emax of Thermoelectric Module Using Parabola Algorithm Based on Three Discrete Measurements." *Journal of the Faculty of Engineering and Architecture of Gazi University* 31(4):1063–72.

[5]. Gökçek, Murat and Fatih Şahin. 2017. "Experimental Performance Investigation of Minichannel Water Cooled-Thermoelectric Refrigerator." *Case Studies in Thermal Engineering* 10:54–62.

[6]. Hand, Carson T. and Steffen Peuker. 2019. "An Experimental Study of the Influence of Orientation on Water Condensation of a Thermoelectric Cooling Heatsink." *Heliyon* 5(10):e02752.

[7]. Hemmat Esfe, Mohammad, Saeed Esfandeh, and Davood Toghraie. 2021. "Numerical Simulation of Water Production from Humid Air for Khuzestan Province: Investigation of the Peltier Effect (Thermoelectric Cooling System) on Water Production Rate." *Case Studies in Thermal Engineering* 28:101473.

[8]. Joshi, V. P. S., V. P. S. Joshi, H. A. Kothari, M. D. Mahajan, M. B. Chaudhari, and K. D. Sant. 2017. "Experimental Investigations on a Portable Fresh Water Generator Using a Thermoelectric Cooler." *Energy Procedia* 109:161–66.

[9]. Kherkhar, Abdelkrim, Younes Chiba, Abdelhalim Tlemçani, and Hayati Mamur. 2022. "Thermal Investigation of a Thermoelectric Cooler Based on Arduino and PID Control Approach."

[10]. Mirmanto, M., S. Syahrul, and Yusi Wirdan. 2019. "Experimental Performances of a Thermoelectric Cooler Box with Thermoelectric Position Variations." *Engineering Science and Technology, an International Journal* 22(1):177–84.

[11]. Pounraj, P., D. Prince Winston, A. E. Kabeel, B. Praveen Kumar, A. Muthu Manokar, Ravishankar Sathyamurthy, and S. Cynthia Christabel. 2018. "Experimental Investigation on Peltier Based Hybrid PV/T Active Solar Still for Enhancing the Overall Performance." *Energy Conversion and Management* 168:371–81.

[12]. Shi, Lumin, Azher M. Abed, Mohamed Fayed, Zuhair R. Abdulghani, Ali E. Anqi, Mohamed Amine Khadimallah, Hazim Moria, and Makatar Wae-Hayee. 2023. "Economic Cost Analysis of Air-Cooling Process Using Different Numbers of Peltier Modules; Experimental Case Study." *Case Studies in Thermal Engineering* 41:102627.

[13]. Singh, Deeksha, Harsha Chaubey, Yusuf Parvez, Aditi Monga, and Shruti Srivastava. 2022. "Performance Improvement of Solar PV Module through Hybrid Cooling System with Thermoelectric Coolers and Phase Change Material." *Solar Energy* 241:538–52.

[14]. Soprani, S., J. H. K. Haertel, B. S. Lazarov, O. Sigmund, and K. Engelbrecht. 2016. "A Design Approach for Integrating Thermoelectric Devices Using Topology Optimization." *Applied Energy* 176:49–64.

[15]. Tan, Gang and Dongliang Zhao. 2015. "Study of a Thermoelectric Space Cooling System Integrated with Phase Change Material." *Applied Thermal Engineering* 86:187–98.

[16]. Tipsaenporm, W., C. Lertsatitthanakorn, B. Bubphachot, M. Rungsiyopas, and S. Soponronnarit. 2012. "Improvement of Cooling Performance of a Compact Thermoelectric Air Conditioner Using a Direct Evaporative Cooling System." *Journal of Electronic Materials 2012 41:6* 41(6):1186–92.

[17]. Wang, Huili, Guobing Zhou, Huili Wang, and Guobing Zhou. 2021. "Experimental Investigation on Discharging Characteristics of Supercooled $CH_3COONa\cdot3H_2O$-$Na_2S_2O_3\cdot5H_2O$ Mixtures Triggered by Local Cooling with Peltier Effect." *SoEn* 217:263–70.

5.

Nomenclature

TEMs	Thermoelectric modules
TE	Thermoelectric
COP	Coefficient Of performance
Ti	Initial temperature, °C
cp	Specific heat of water, J kg−1 K−1
I	Current, A
m	Mass of water, kg
$\dot{Q}$	Heat transfer rate, W
Tc	The temperature of Cold junction,
Th	The temperature of Hot junction, °C
t	Time, s
$\dot{W}$	Power consumption, W
T	Temperature, °C
V	Voltage, V
TU	Thermoelectric unit
S.S.	Stainless steel
ΔT	The different of temperature