

# Optimization of solar powered air conditioning system using alternating Peltier power supply

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## ABSTRACT

Solar-powered thermoelectric air conditioning systems offer distinct advantages over traditional cooling methods, including thermal comfort, absence of moving parts, and eco-friendliness as they operate on solar energy. Despite these benefits, they exhibit a lower coefficient of performance (COP) compared to conventional systems. In this study, a solar-powered thermoelectric air conditioning system based on the Peltier effect was experimentally investigated in Baghdad during September (39 °C to 32 °C). The system was designed to cool a small 1 m<sup>3</sup> test room. The six Peltier modules were divided into groups, each powered by a different electrical source with varying ON/OFF intervals. The highest COP achieved was 0.649, with an optimal outlet air temperature of 22-23 °C and a 20 minute switching cycle. Notably, the inlet air velocity directly influenced COP and outgoing air temperature. The study also indicated improved performance at reduced air flow, making Peltier air coolers ideal for hot regions.

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## 1. INTRODUCTION

The current use of fossil fuels to provide the world's energy needs has had a significant impact on the upward trend in energy consumption and greenhouse gas emissions as of yet [1], [2]. To solve the current situation, more energy is being consumed in clean forms like solar energy [3], [4], geothermal energy [5], and wind energy [6] should be carried out efficiently to supply new energy and reduce CO<sub>2</sub> emissions [7]. Out of all the energy consumption categories, cooling and space heating account for around 31% and 20% of total energy consumption, respectively [8]. These energy consumptions, such as refrigerated storage, building heating and cooling, and power management, are utilized to maintain the structure's essential distribution of heat during and summertime. Particularly, heating and cooling use up to 70% of the energy used in home buildings [9]. Therefore, it is essential to look for efficient options to reduce the amount of energy used for space heating and cooling. The integration of thermoelectric coolers (TEC) with solar photovoltaic (PV) modules has lately been seen as a potential strategy for solar cooling/heating that can reduce the use of fossil fuels and lower the energy demand in buildings [10]. These systems effectively produce electricity through photovoltaic impact and utilize that electricity to power the TEC for cooling and heating operations [11]. Additionally, it has advantages like low weight, reliability, small size, lack of mechanical moving parts, increased dependability factor, and absence of working fluid [12], [13]. Because of its many advantages over conventional cooling techniques [14], the TEC has attracted a lot of interest recently [15], [16]. These benefits allow the thermoelectric generator (TEG) technology to be used to fully utilize many kinds of heat

sources. However, because the heat source fluctuates, the hot side temperature of TEG is not always consistent, which will significantly reduce output performance [17]. So as the current increases, the cold side temperature decreases and cooling power increase [18]. But the coefficient of performance (COP) decreased [19]. So to increase the system's stability and effectiveness, a TEC-based thermal management system's performance is normally evaluated at its optimal operating current [20], [21]. To get the best cooling power [22].

This is used to assess whether the thermal management system can perform adequately under the most extreme conditions. Thus, the performance of the thermal management system at off peak conditions is also important in selecting a design. The objective of this investigation was to find the greatest performance that could be obtained at a particular point in the electrical power input to the TECs. Irshad *et al.* [23] investigated the thermal performance of a test room equipped with a north-facing thermoelectric air duct (TE-AD) system and a south-facing photovoltaic wall. Input current was changed from 2 to 7 A to investigate the performance. and it was found that when the Peltier was set up with 2 A and 5 V, which is equal to 10 W, the room temperature was between 24 °C and 30 °C, and when the current was increased from 3 A to 6 A, we saw a drop in the room temperature from 29.3 °C to 26 °C. but, when the current reached 7 A, there was a decrease in the thermoelectric unit's cooling capacity. Atta *et al.* [24] investigated the thermal performance of a solar powered TE cooling system. The results indicated that a system operating at 70% of  $I_{max}$  at 11.2 A and 12 V was able to achieve a COP of 0.72 and was capable of reducing the temperature by around 14 °C. Liu *et al.* [25] developed and investigated a thermoelectric air conditioner with a hot water supply that is powered by a PV. The system's COP was discovered to have increased by roughly 4.51 in both the heating and cooling modes. Irshad *et al.* [26] developed a novel TE-AD assisted by a PV system for space cooling in Malaysian climate. The system consists of fifteen thermoelectric modules (TEM), and the PV supplies 300 W, to deliver cooled air to a test room with area 9.45 m<sup>2</sup>. With an increase in the input current from 2 A to 6 A, the system's coefficient of performance raised from 0.67 to 1.15 and its cooling power from 101.34 to 517.24 W. Sungkar *et al.* [27], the performance of thermoelectric refrigeration systems is being investigated. The thermoelectric refrigerator uses six thermoelectric modules. The thermoelectric device's performance was tested at average ambient temperatures of 28 °C with input powers of 40 W (8.2 V and 4.9 A), 72 W (11.4 V and 6.29 A), and 120 W (14 V and 8.73 A). The refrigerator's input power of 40 W produced the maximum COP of 0.182 (optimum and actual COP) in this test, and input power of 120 W (14 V, 8.73 A) produced a compartment temperature of 10.63 °C. Tipsaenporm *et al.* [28] investigated study to improve the performance of the thermoelectric cooler by using direct evaporative cooling of the hot side of the TEM. Their system's cooling performance ranged from 72% to 81%. Using direct evaporative cooling, its cooling capacity was increased from 53 W to 74 W.

Luo *et al.* [29] performed a numerical analysis of solar thermoelectric ceiling envelopes for cooling and heating modes. Their findings showed that when the PV electric current was raised from 1 A to 2 A, the cooling capacity increased from 48.7 to 104.0 W while the COP climbed from 1.0 to 2.3. The daily usable gain might be reduced by 70.0% with the hybrid PV-thermoelectric ceiling system without incurring additional building or operational expenses. Manikandan *et al.* [30] studied how different current pulse operations affected the performance of the thermoelectric cooler in space cooling applications. The reported results depicted that, in comparison to no-pulse conditions, the TEC's coefficient of performance and cooling power rose by 2.12% and 23.3%, respectively. Cai *et al.* [31] created an air source thermoelectric heat pump system for cold air delivery and hot water supply. It was discovered that the thermal conductivity and specific heat allocations in hot and cold side heat exchangers could have a significant impact on the total cooling capacity and COP. In this work, the Peltiers (TEC) units were divided into groups, each group includes two or three Peltiers, and different electrical powers were introduced for each group under ON/OFF conditions according to different time periods, to obtain the condition that gives optimal performance through the results obtained.

## 2. METHOD AND TOOLS

This section introduces and discusses the thermoelectric air conditioning system based on the Peltier effect, including its components and experimental process. The thermoelectric cooler is designed to provide air conditioning to a 1 m<sup>3</sup> enclosed space. A thermoelectric air conditioner consists of seven solar PV cells with 50 watts of power each, a control unit, a 1 m<sup>3</sup> test room, an air duct with dimensions of 240×22×10 cm, six finned heat sinks for the hot side, six finned heat sinks for the cold side, six pieces of Peltier module type (12,706), and two fans (12 VDC, 2,800 RPM, 1.15 A) for the cold and hot sides. The PV module's characteristics are shown in Table 1. The device was created and built in Iraq and tested outside Baghdad. The system is made up of two unique components: a PV array as shown in Figure 1(a) and a thermoelectric cooling duct unit built of 10 mm thick acrylic with an inside size of (240×10×20 cm) as shown in Figure 1(b).

Table 1. Specification of PV panel

Parameter	Specification
Module	Mono crystalline
Maximum power Pmax (w)	50 W
Maximum power voltage Vmpp (V)	21.6 V
Maximum power current Impp (A)	2.77 A
Short circuit current Isc (A)	2.99 A
Short circuit voltage Vsc (V)	21.6 V
Maximum power tolerance	±5%
Product size	68×51×3 cm



(a)



(b)

Figure 1. Experimental system components; (a) PV panel and (b) air duct

Figure 2(a) shows the Peltier holding plate the plate is 240 cm in length, 22 cm in width, and 1 cm in thickness. Six grooves on the Peltier holder allow it to store six Peltiers. A CNC machine creates the grooves in two volumes: one is 4 cm by 4 cm and has a depth of 1 cm; the other is 5 cm by 5 cm and has a depth of 0.5 cm. Six rectangular heat sinks made of aluminum are attached to the cold sides of TEMs to cool the air, with dimensions of 4×4×2.6 cm and other six rectangular fin heat sinks made of aluminum are attached to the hot sides of TEMs to dissipate the heat with dimensions of 10×10×3 cm. A hose with a length of 3 m is returned from the test room, and it returns part of the cold air exiting from the end of the duct back to the beginning of the cold air duct, as shown in Figure 2(b). There are six identical commercial TECs of the type (TEC1-12706), as shown in Figure 2(c), that are installed in the order shown, one after the other at the level of the surface of the Peltier holder, which is placed horizontally between the hot duct and the cold duct. The specifications of the TEMs are presented in Table 2. A finned heat sink is installed by thermal grease on the hot surface of the TEMs; also, a finned heat sink is installed by thermal grease on the cold surface of the TEMs. The area of the tested room is 1 m<sup>3</sup>, and it is built of plywood with a thickness of 3 cm and is insulated from the inside with foam of 3 cm thickness. Two holes were made in the ceiling of the room, one to receive cold air from the air duct, measuring 22×10 cm, and the second for the purpose of recirculating the air through a return air duct with a diameter of 25 cm, as shown in Figure 2(d).

## 2.1. Control and data logger system

The temperature of the cold and hot sides of each of the six Peltiers, the temperature of both the inside and outside air, and the temperature of the tested room and its surroundings are monitored and recorded by sixteen thermocouples (type K). A Peltier thermoelectric cooler is connected to an electrical control panel that is linked to a direct current (PV) source. It allows one to gradually turn the Peltier module on and off according to the length of time set by the programmer. After being programmed by the Arduino type (UNO-R3), an 8 channel relay (12 VDC) is connected to power the Peltier. The six Peltiers are divided into two and three groups; each group includes three and two Peltiers connected in parallel, as illustrated in Table 3 and the cases of ON/OFF are taken for each group according to the time periods during which one group is turned on and the other group is turned off periodically, as displayed in Table 4.

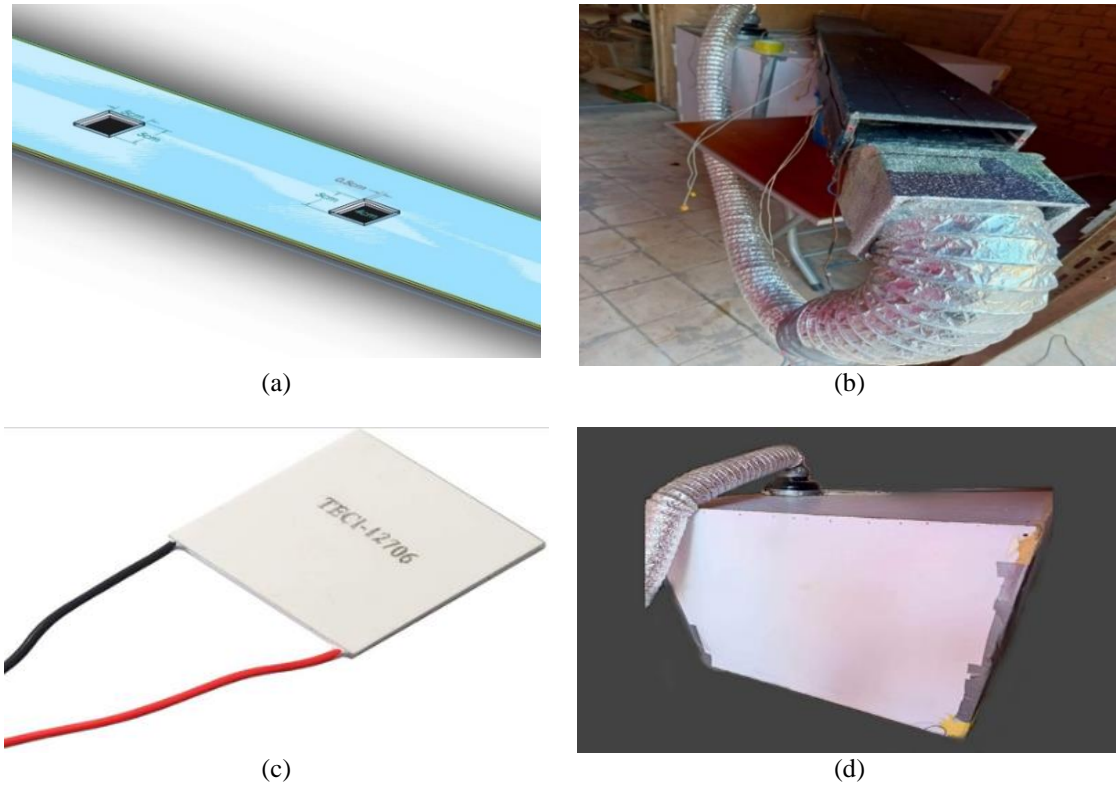


Figure 2. The experimental apparatus of thermoelectric air condition system; (a) Peltier holder plate, (b) returner duct for cold air, (c) Peltier module, and (d) tested room

Table 2. Specification of Peltier module (TEC1-12706)

Parameter	Specification
Peltier module	TEC1-12706
Maximum voltage	15.4 V
Maximum current	6 A
Maximum power	92 W
Maximum temperature	138 °C

Table 3. Scheduling of input power to the Peltier groups

Case (watt)	Input power to 1 <sup>st</sup> group (watt)	Input power to 2 <sup>nd</sup> group (watt)	Input power to 3 <sup>rd</sup> group (watt)
(200+100)	200	100	-
(100+200)	100	200	-
(150+100+50)	150	100	50

Table 4. Scheduling Peltier groups according to the on and off periods

Day	Group	State	Time (min)	Notes
First day	First group	ON	10	The process continues cyclically
	Second group	OFF	10	
	First group	OFF	10	
Second day	Second group	ON	10	The process continues cyclically
	First group	ON	15	
	Second group	OFF	15	
Third day	First group	OFF	15	The process continues cyclically
	Second group	ON	15	
	First group	ON	20	
	Second group	OFF	20	
	First group	OFF	20	
	Second group	ON	20	

### 3. GOVERNING EQUATIONS

During the process of air cooling by thermoelectric air-conditioner many coefficient's are being considered. such as, system cooling power ( $Q_c$ ), amount of work across Peltier module ( $W$ ), and COP. The see-beck effect coefficient ( $\alpha$ ) is expressed as (1):

$$\alpha = \frac{V_{max}}{T_h} \quad (1)$$

Where  $V_{max}$  is the maximum thermoelectric module voltage of thermoelectric module,  $T_h$  is hot junction temperature of thermoelectric module. The electrical resistance is expressed as (2):

$$R = \frac{T_h - \Delta T}{T_h} \times \frac{V_{max}}{I_{max}} \quad (2)$$

Where  $\Delta T = T_h - T_c$  is difference between hot and cold temperature of thermoelectric Peltier module and  $I_{max}$  is the maximum current of thermoelectric Peltier module. The thermal conductivity is expressed as (3):

$$K = \frac{V_{max}}{2\Delta T_{max}} \times \frac{T_h - \Delta T}{T_h} \times I_{max} \quad (3)$$

Now to determine ( $Q_c$ ) system cooling power in (4):

$$Q_{cold} = n \times ((\alpha \times I \times T_c) - (1/2 \times I^2 \times R) - (K \times \Delta T)) \quad (4)$$

Where ( $I$ ) is the current of thermoelectric Peltier module,  $R$  is the electrical resistance,  $K$  is the thermal conductivity,  $\Delta T$  is the difference between hot and cold temperature of thermoelectric Peltier module and  $n$  is the number of Peltier module. The amount of work across Peltier module ( $W$ ) is expressed as (5):

$$W = n [\alpha (T_h - T_c) + (I \times R)] \quad (5)$$

The COP is obtained (6):

$$COP = \frac{Q_c}{W} \quad (6)$$

### 4. RESULTS AND DISCUSSION

The performance of the solar powered thermoelectric Peltier air conditioner system is tested experimentally under the same operating conditions with each of the internal heat sink, exterior heat sink, air duct, fan, and Peltier module (12,706). The electrical board was programmed to run one group of thermoelectric Peltier devices every 10, 15, and 20 minutes using an ON/OFF concept to disperse the  $Q_{cold}$  for heat transfer with high capacity on the wall inside the air duct. The system was evaluated under local external conditions from 8:00 a.m. to 3:00 p.m. The test results were utilized to demonstrate the temperature behavior for the cold and hot sides in the two scenarios (with power distribution and time duration varying). The same findings are analyzed to examine changes in metrics including the COP, the output temperature of air flow to find the best performance situation for the system. These results were compared with the result obtained in [32], [33].

#### 4.1. The effect of power distribution (200+100) watt and different interval time

Figures 3 and 4 show the variation of COP and  $T_{out}$  for the 10, 15, and 20 minutes ON/OFF time intervals throughout the day for the distribution of power (200+100) watts. Through Figures 3 and 4, in the case of 10 minutes, the value of COP ranged from 0.19 to 0.44, while the outlet air temperature ranged from 22 °C to 24 °C. In the case of 15 min, the value of COP ranged from 0.4 to 0.46, while the outlet air temperature ranged from 22 °C to 24 °C. However, at 20 min, the COP varied from 0.30 to 0.64, and the outlet air temperature value ranged from 22 °C to 23 °C. We can see that the highest COP is 0.64 and the lowest  $T_{out}$  is 22 °C, which was achieved at the case of 20 minutes. These results are the best compared with the cases of (15) and (10) minutes. So, the best period of time that can be taken to switch on and off between the two groups of Peltier to connect (200+100) watt is 20 minutes. This is because the first groups of Peltiers takes up 66% of the power supply, and when it works for a period of 20 minutes, it absorbs heat and the temperature of the cold side of it continues to decrease, which works to reduce the temperature of the cold air duct. So, the heat removal factor increases when the current and the time duration increase [34].

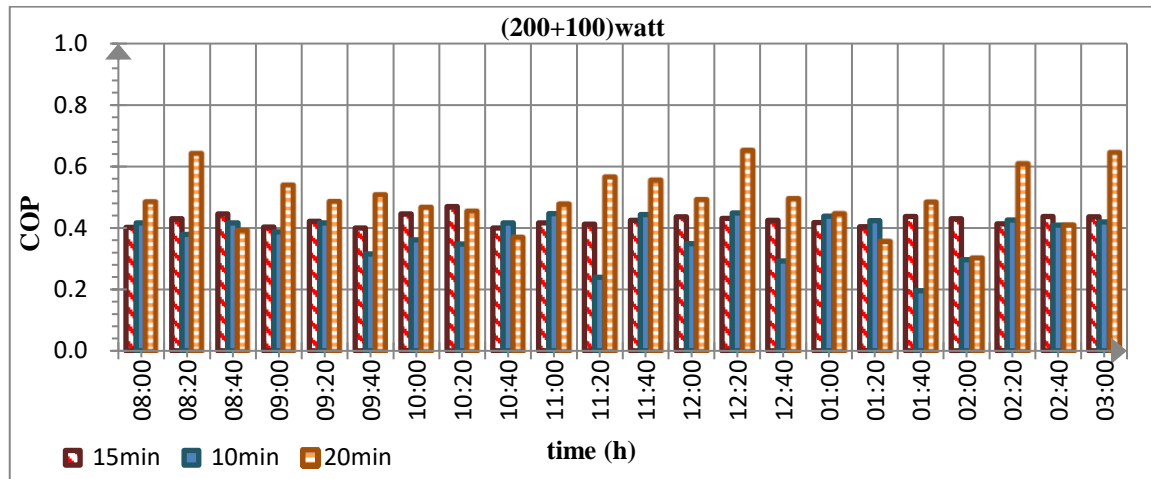


Figure 3. Variation of COP with time for the three intervals (10 min, 15 min, and 20 min)

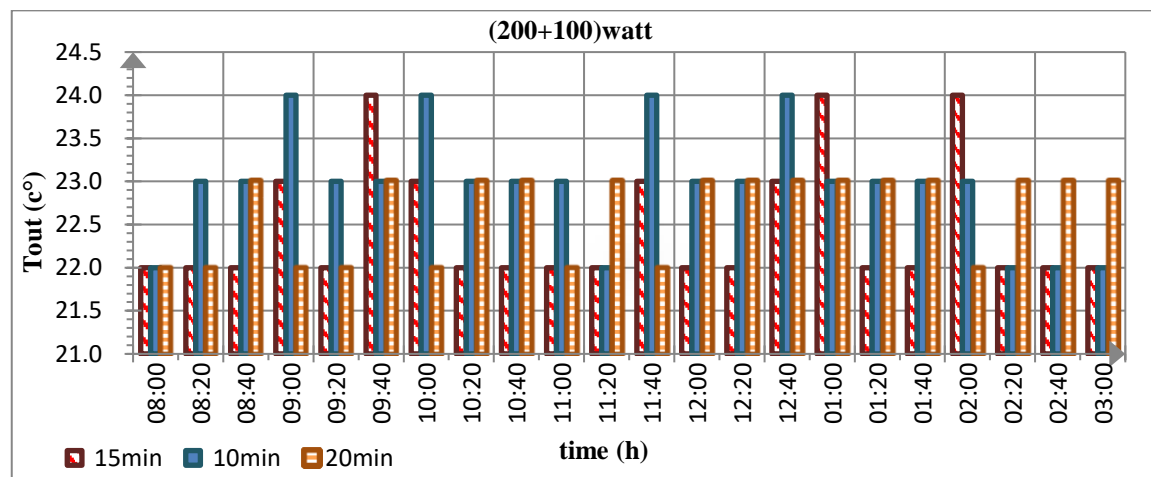


Figure 4. Variation of Tout with time for the three intervals (10 min, 15 min, and 20 min)

**4.2. Power distribution (150+100+50) watt and different interval time**

Figures 5 and 6 show the variation of COP and Tout for the 10, 15, and 20 minutes ON/OFF time intervals throughout the day for the distribution of power (150+100+50) watts. In the case of 10 minutes, the value of COP ranged from 0.23 to 0.489, while the outlet air temperature ranged from 24 °C to 26 °C. In the case of 15 min, the value of COP ranged from 0.16 to 0.51, while the outlet air temperature ranged from 23 °C to 27 °C. However, at 20 min, the COP varied from 0.32 to 0.48, and the outlet air temperature value ranged from 22 °C to 25 °C. The results show that the maximum COP is 0.518 at 15 min, with the minimum temperature (Tout) equal to 22 °C, as shown in Figures 5 and 6. This is because, when dividing the six Peltiers into three groups, the first group is equipped with an electrical capacity of 150 watts, meaning that each Peltier receives 75 watts, and in the case of a constant voltage source of 20 volts, each Peltier in the group operates at the maximum current value of 3.75 A, while the second group is equipped with 100 watts, meaning that each Peltier in the second group works at a current of 2.5 A. As for the third group that works at 50 watts, each Peltier of them works at a current of 1.25 A. This is the best value for the current that is within the range from 1 A to 6 A through which the Peltier operates within the various levels of current supply. This result was also compared to the outcomes in 20 minutes and 10 minutes cases, as shown in Figures 5 and 6. So in the case of (150+100+50) watts, it is the best case in a period of 15 minutes, because in the case of 10 minutes, the Peltier cannot reach a stable state as it is turned off before reaching the peak point of performance. It needs a little more time. In the case of 20 minutes, increasing the time between switching off and on can be proportional to the number of Peltiers.

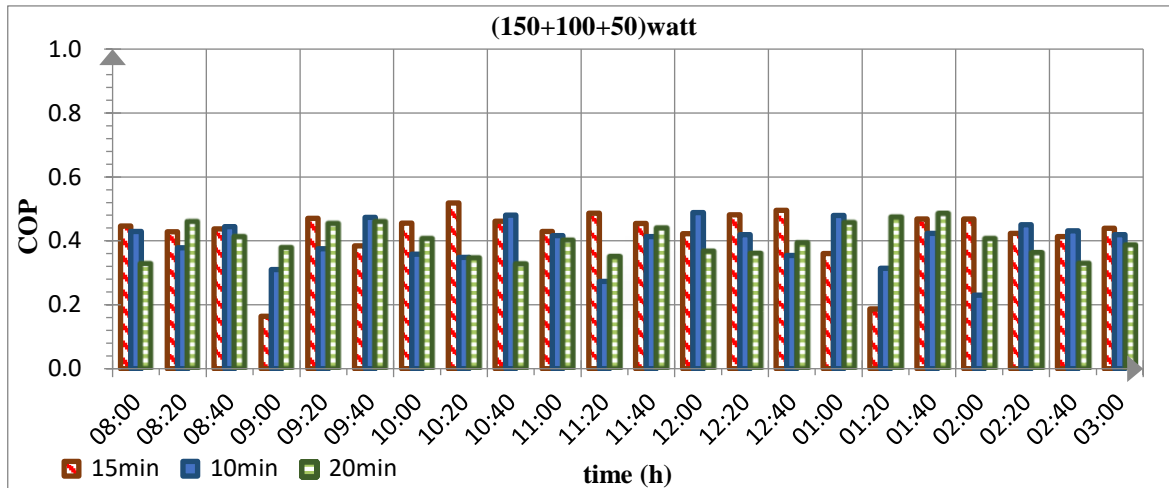


Figure 5. Variation of COP with time for the three intervals (10 min, 15 min, and 20 min)

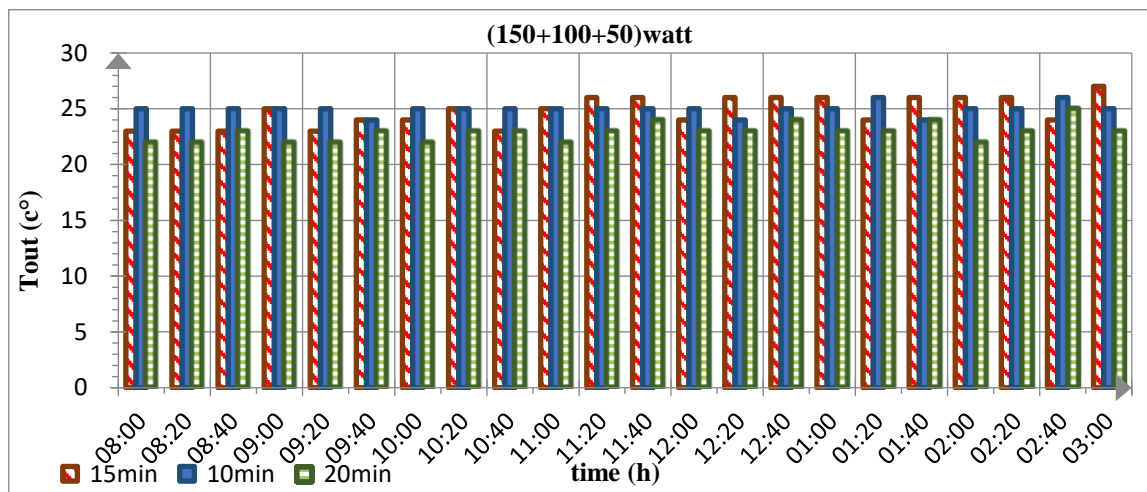


Figure 6. Variation of Tout with time for the three intervals (10 min, 15 min, and 20 min)

#### 4.3. Power distribution (100+200) watt and different interval time

Figures 7 and 8 show the variation of COP and Tout for the 10, 15, and 20 minutes ON/OFF time intervals throughout the day for the distribution of power (200+100) watts. In the case of 10 minutes, the value of COP ranged from 0.19 to 0.44, while the outlet air temperature ranged from 22 °C to 23 °C. In the case of 15 min, the value of COP ranged from 0.20 to 0.464, while the outlet air temperature ranged from 22 °C to 23 °C. However, at 20 min, the COP varied from 0.30 to 0.475, and the outlet air temperature value ranged from 22 °C to 24 °C. We note that at 20 minutes, it achieves the highest COP value of 0.475 and the minimum Tout value of 22 °C. The first group is running for 20 minutes and the second group is turned off. Then turning OFF the first group and running the second group for 20 minutes, it gives the thermo-electric cooler a better performance. It is better than in the previous cases when period of time is 10 and 15 min, and the time period between each OFF and ON is directly proportional to the number of Peltiers module. When comparing the results that appeared in the case (200+100) watt, in which the first group near the fan of cold air receives 200 watt, the highest COP value was achieved with a value of 0.649, higher than in the case (100+200) watt in which the first group near the fan The cold air receives 100 watt, where the temperature difference between the two surfaces of the Peltier is higher, which is inversely proportional to the  $Q_c$ , so it decreases  $Q_c$  relatively, which leads to a decrease in the COP.

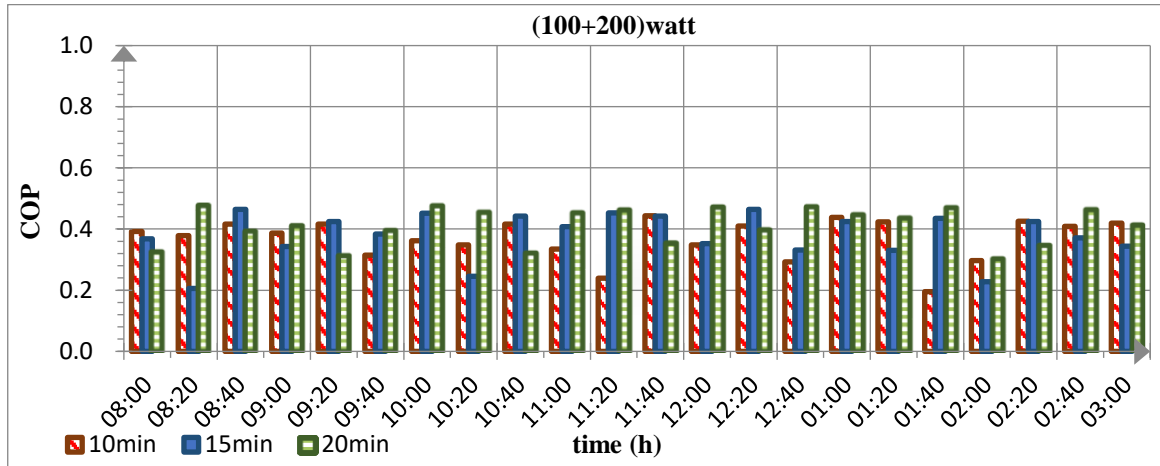


Figure 7. Variation of COP with time for the three intervals (10 min, 15 min, and 20 min)

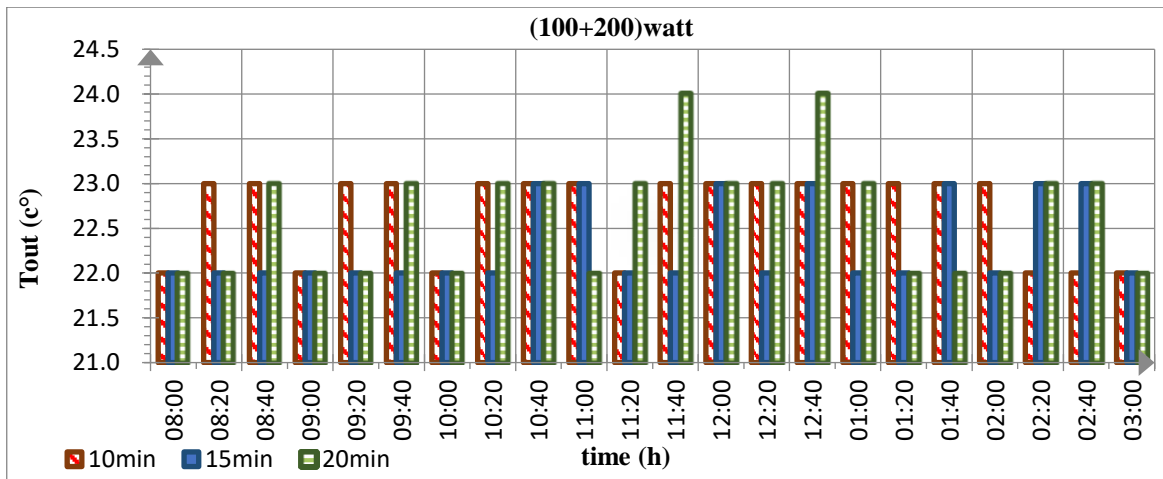


Figure 8. Variation of Tout with time for the three intervals (10 min, 15 min, and 20 min)

**4.4. The effect of air flow on the COP and output temperature**

In this section, the air flow is the only variable parameter, and the other parameters are fixed according to Table 5. The effect of inlet air flow on the COP is shown in Figure 9(a). Decreasing inlet air flow decreases the COP, and the effect of inlet air flow on the output temperature is shown in Figure 9(b). Decreasing of inlet air flow velocity enhances the outlet temperature due to the fact that reducing the velocity of the incoming air increases the convection between the surface of the cold Peltier and the incoming air, which reduces the temperature of the air and increases the cooling capacity ( $Q_c$ ), which reduces the output temperature ( $T_{out}$ ) of air more, but at the same time, as a result of increasing the heat exchange between the surface of the Peltier and the incoming air, the electrical energy consumption is increased by means of a thermoelectric cooler, which leads to a decrease in the COP.

Table 5. Range of variable parameters

Air flow rate $m/s$	Power supplied for 1st Peltier group (watt)	Power supplied for 2st Peltier group (watt)	Time duration between ON/OFF (min)
5	200	100	20
2	200	100	20



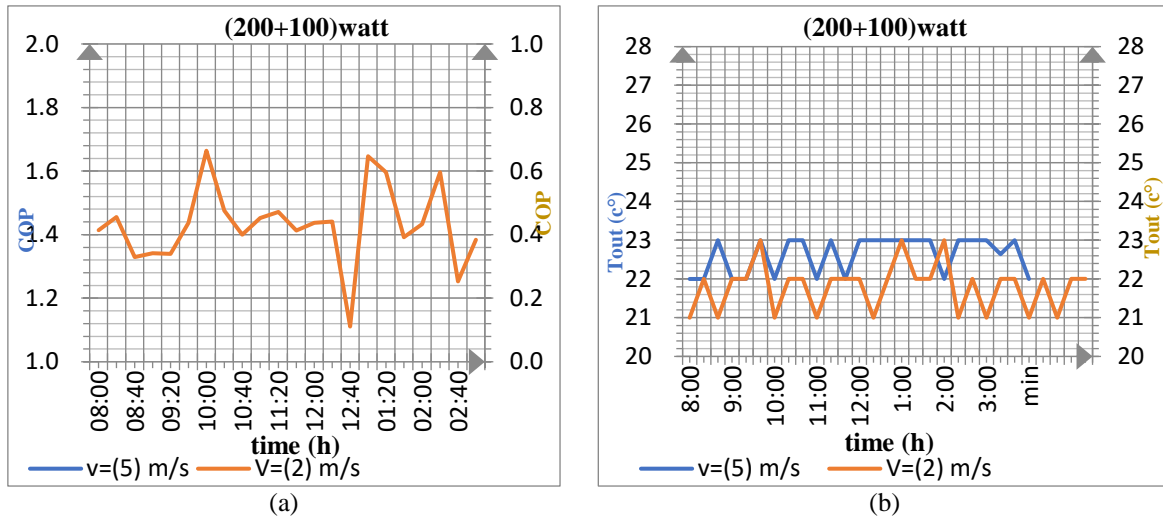


Figure 9. Effect of variation air flow in; (a) COP and (b)  $T_{out}$

## 5. CONCLUSION




The performance of a thermoelectric air cooler is investigated. The technology system has the ability to lower the room's temperature. The study's goal has been met with a design that takes a varying amount of time between each on/off operation and is built around the goal of power distribution to the Peltier groups. The different power distribution and time interval processes and their results have been discussed previously. It was observed that the system performance was improved and the outlet air temperature was reduced to between 22 °C and 23 °C; the COP was 0.649 when the power was distributed in the case of (200+100) watts, and the time duration between each ON/OFF Peltier group is 20 minutes, in comparison with 10 and 15 minutes, which have maximum COP values of 0.44 and 0.46, respectively. In comparison with the best results obtained with the distribution of (150+100+50) watts with an ON/OFF time of 15 minutes, where the highest value of COP was 0.51, the lowest values for  $T_{out}$  were recorded with an ON/OFF time of 20 minutes at a temperature of 23 °C to 27 °C. When distributing (100+200) watts, the largest COP value was at 0.475 with an on/off time of 20 minutes, and the best  $T_{out}$  temperatures were 22 °C to 23 °C with an on/off time of 15 minutes. While the change in air velocity had an effect on each of the COP and  $T_{out}$ , the velocity of the air entering the air duct is directly proportional to the  $T_{out}$  while it is inversely proportional to the COP. Overall, it can be said that the suggested thermoelectric air cooler driven by PV might be viewed as a suitable alternative with additional benefits over the conventional vapor compression system, including high thermal comfort standards, active flexibility, no moving components, and refrigerants-free operation. The current study is useful for the investigation of TEACs in low-scale applications in air conditioning systems. It is advised that the TEMs' material thermophysical characteristics be improved in order to increase their potential for use in air conditioning applications.

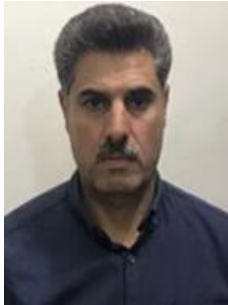
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