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Performance Evaluation of PV Panel Powered Dual Thermoelectric Air Conditioning System

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H I G H L I G H T S

- It is possible to reach a temperature of 22°C with a cop of 0.64 during the cooling mode
- In the heating mode, a temperature of 31°C can be obtained with a cop of 0.87
- The TEACs more suitable for heating applications than for cooling applications

A R T I C L E   I N F O

A B S T R A C T

Thermoelectric air condition system (TEACs) powered by solar photovoltaics is useful for thermal comfort applications, especially when there is a direct energy source like sunlight. This paper presents experimental investigations of solar-powered thermoelectric air conditioning for both cooling and heating modes. The experiments were carried out in a test room whose volume is 1 m^3 under the climatic conditions of the city of Baghdad. In the summer, the thermoelectric device functions as a Peltier cooler. The cold side absorbs the heat from the inside to lower the room's temperature. As for winter, the heat is released from the thermoelectric Peltier module by reversing the current applied to the thermoelectric Peltier to raise the room's temperature. In this work, the thermoelectric air condition system was supplied with different electrical power supply values with time intervals between the ON/OFF operations. The results showed that the system could heat and cool the air well in different operation conditions. The lowest temperature (22°C) is achieved in the cooling mode, with a Coefficient of Performance (COP) of 0.64 and an exergy efficiency of 0.47. In contrast, in the heating mode, the highest temperature is (31°C) with a COP of 0.87 and exergy efficiency of 0.75. This simple and eco-friendly method can minimize the cooling and heating load in the room.

1. Introduction

Thermal comfort is more important in buildings, offices, houses, and living rooms. To achieve luxury and comfort for people, it is necessary to provide an appropriate atmosphere and thermal comfort commensurate with various circumstances [1-3]. Conventional air conditioning systems also contribute significantly to the amount of electricity consumed at homes in most countries [4]. It also contributes to global warming [5,6]; with relation to the greenhouse effect and the possibility of ozone depletion, there is significant CO_2 released into the atmosphere because of the usage of conventional air conditioning systems [7]. The above problems can be overcome by thermoelectric air conditioning systems operated by solar photovoltaic panels (PV), which are environmentally friendly and more economical [8-10]. A thermoelectric cooling device instantly transforms electrical energy into thermal energy according to the Peltier effect [11-12]. It has the advantages of being eco-friendly, has no compressor part, does not require recurring replenishment, less maintenance, is extremely lightweight and small in size, having high reliability, no moving parts, and no noise or vibration. Direct current (DC) electric sources can power it. Duan et al. [13] investigated an air conditioner (radiant type) that contained TE modules. Their technology can be utilized as a heater and a cooler simultaneously. Concluded that the TE radiant air conditioning system might have a COP that is comparable to that of traditional systems. Liu et al. [14] conducted a numerical evaluation of a prototype thermoelectric cooling system and discovered that the best COP value of this system was approximately 0.7-0.8 and that the extender block had a substantial effect on the COP. Sun et al. [15] demonstrated a unique radiant heating terminal integrated with a TEC and examined its operation in the real-world situations. This terminal proved to be more efficient and quicker than the traditional system. Yang Cai et al. [16] investigated a novel thermoelectric air conditioner driven by solar PV panels. And the analytical study examined the effects of solar intensity, the quantity of TEMs, and the surrounding temperature on the thermoelectric air conditioner's output power. It was found that the system's minimal energy and energy efficiency values in the winter heating mode were 1.67 and 0.24, respectively, which were 143% and 22.2% greater than those in the summer cooling mode. But, the systems' coefficient of performance (COP) is still lower than the traditional vapor compression devices [17]. So, recent studies have focused on enhancing thermoelectric air

conditioning performance in recent years. Liu et al. [18] 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. Luo et al. [19] studied a radiant thermoelectric ceiling panel for heating and cooling modes. Their research showed that increasing the electrical flow from 1 A to 2 A resulted in an increase in cooling power from 48.6 to 104.1 W and COP from 1.06 to 2.29 in cooling mode. But, in the heating mode, the system's heating power varied from 165.6 W/m^2 to 343 W/m^2, and the system's COP varied from 1.51 to 1.8 under the operating current conditions of 2 A to 3 A. Mirmanto et al. [20] investigated the performance of a thermoelectric cooler box with various Peltier module placements. The box's volume was 4.891 liters, and the wall thickness was 5 cm. A (360 ml) bottle of water was placed inside the box as a part of the cooling loads. It was concluded that the COP dropped over time and that the Peltier module was best positioned on the cooler box's side wall. Cai et al. [21] 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 significantly impact the total cooling capacity and COP. Selvam et al. [22] investigated a unique strategy for improving the performance of a Peltier cooler under different electric pulse settings using phase change material (PCM). Compared to the Peltier cooler without PCM under pulse operation, the results revealed that the cold side temperature of the Peltier cooler with PCM was drastically reduced from 14.5°C to 17.5°C. Manikandan et al. [23] 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. Irshad et al. [24] developed a novel thermoelectric air duct system (TE-AD) assisted by a photovoltaic (PV) system for space cooling in the Malaysian climate. The system consists of fifteen TE modules, and the PV supplies 300 W to deliver cooled air to a test room with an area of 9.45 m^2. 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. Najafi et al. [25] provided a solar-powered heating and cooling systems (TE). The system for radiant heating and cooling in buildings is based on TE. TE units were put into the ceiling. The system has other advantages that make it a desirable choice for building cooling and heating applications. The above studies elucidated that the performance and efficiency of thermoelectric air-conditioning systems can be improved by gradually increasing the supplied current or by using a variable pulse width of the current, etc. In this study, a thermoelectric air-conditioning duct will be designed, powered by PV solar panels, and several cases of electrical power supply for the Peltier units will be applied, taking different ON/OFF periods for the Peltier units to find the optimal condition for performance and thermal comfort.

2. Procedures and Description of an Experimental System

This section presents the proposed solar-powered thermoelectric air condition system (TEAC`S) and discusses the experimental process and its components. Figure (1) shows the experimental apparatus of the system. The entire system was created and built locally to be tested in Baghdad's outside environment. The designed TEAC`s provides conditioned air to the test room with an area of 1 m^3 as shown in Figure (1-a). The system's main components are six solar PV panels, as shown in Figure (1-b), connected in parallel (Table 1), six (TE) Peltier units, twelve aluminum heat sinks, two brushless DC fans as shown in Figure (1-c), and a test room. The TE modules are installed inside a duct made from acrylic with dimensions (240 x 22 x 10 cm) as shown in Figure (1-d). The TE modules are placed at equal distances inside the Peltier holder, which is installed in the middle of the duct, as shown in Figure (2-a). Twelve rectangular fin heat sinks made of aluminum are connected to the hot and cold sides of the Peltier module to warm or cool the air more efficiently. Thermal grease was used to fix the finned heat sinks on TEM's cold and hot surfaces. Table 2 lists the specifications of the Peltier TE module. As shown in Figure (2-b), the Long Aluminum Ducting is returned from the surface of the test room to the entrance of the thermoelectric air duct to distribute the heat transfer inside the duct regularly and for the outside air temperature to be more conditioned.

Table 1: The characteristics of PV panel

Parameter	Characteristic
Module	Mono crystalline
Maximum power P_{max} (w)	50 W
Maximum power voltage V_{mpp} (V)	21.6 V
Maximum power current I_{mpp} (A)	2.77 A
Short Circuit current I_{Sc} (A)	2.99 A
Short Circuit Voltage V_{SC} (V)	21.6 V
Product Size	68 x 51 x 3 cm

Table 2: The characteristic of the Peltier module (TEC1-12706)

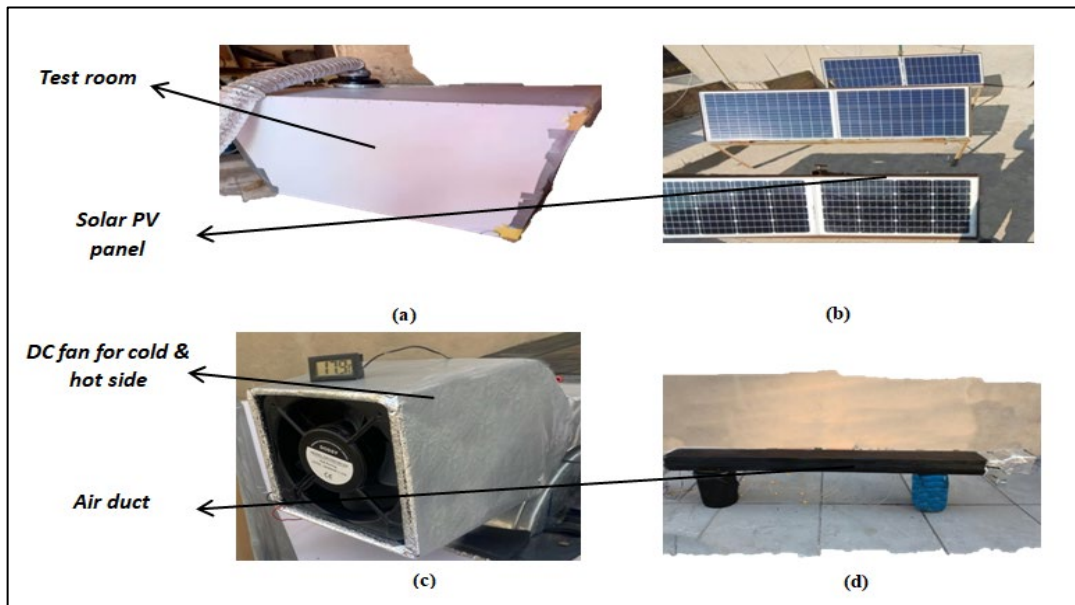| Parameter	Characteristic
Module	TEC1-12706
Maximum Voltage	15.4 V
Maximum Current	6 A
Maximum Power	92 W
Maximum Temperature	138°C

Figure 1: The experimental apparatus of (TEAC`s) : (a) air duct (b) DC fan (c) solar PV panel (d) test room
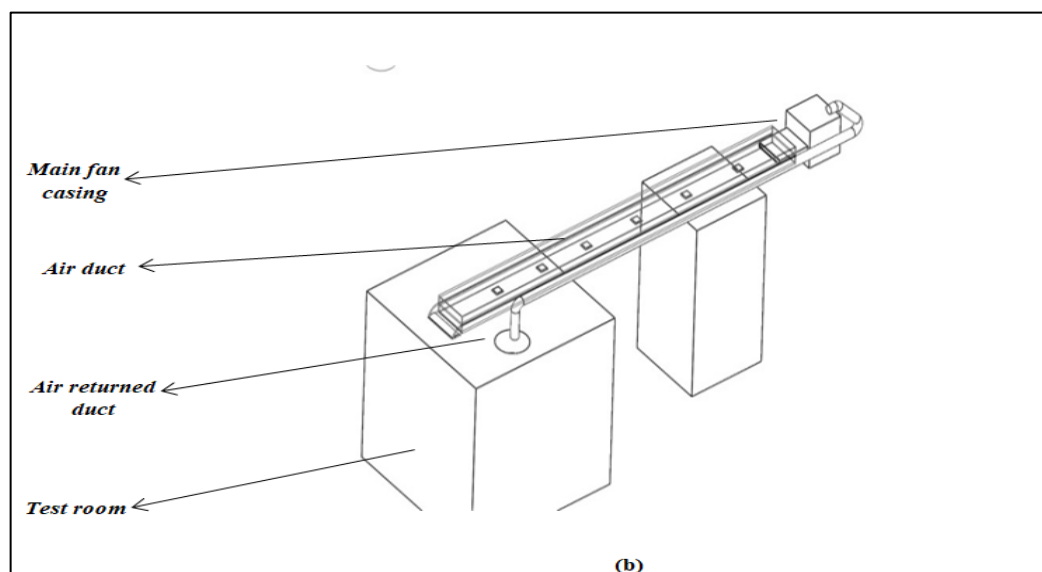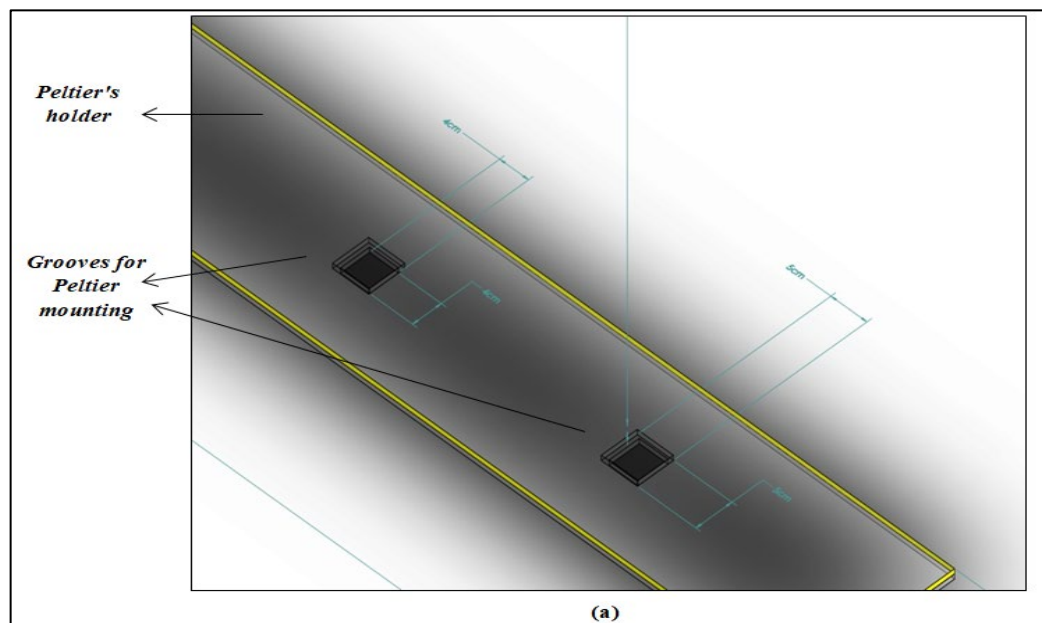

Figure 2: A detailed schematic diagram of the proposed solar TEAC`s : (a) peltier`s holder (b) main part`s of TEAC`s

3. Electrical Controlling System

A Peltier thermoelectric cooler is connected to an electrical control panel linked to a direct current (PV) source, as shown in Figure (3). It allows one to gradually turn the Peltier module on and off according to the length of time the programmer sets. After being programmed by Arduino type (UNO-R3), an 8-channel relay (12VDC) is connected to power the Peltier. The six Peltiers are divided into two groups, each group includes three Peltiers connected in parallel, and the cases of ON/OFF are taken for each group according to periods during which one group is turned on. Another group is turned off periodically, as displayed in Table (3).
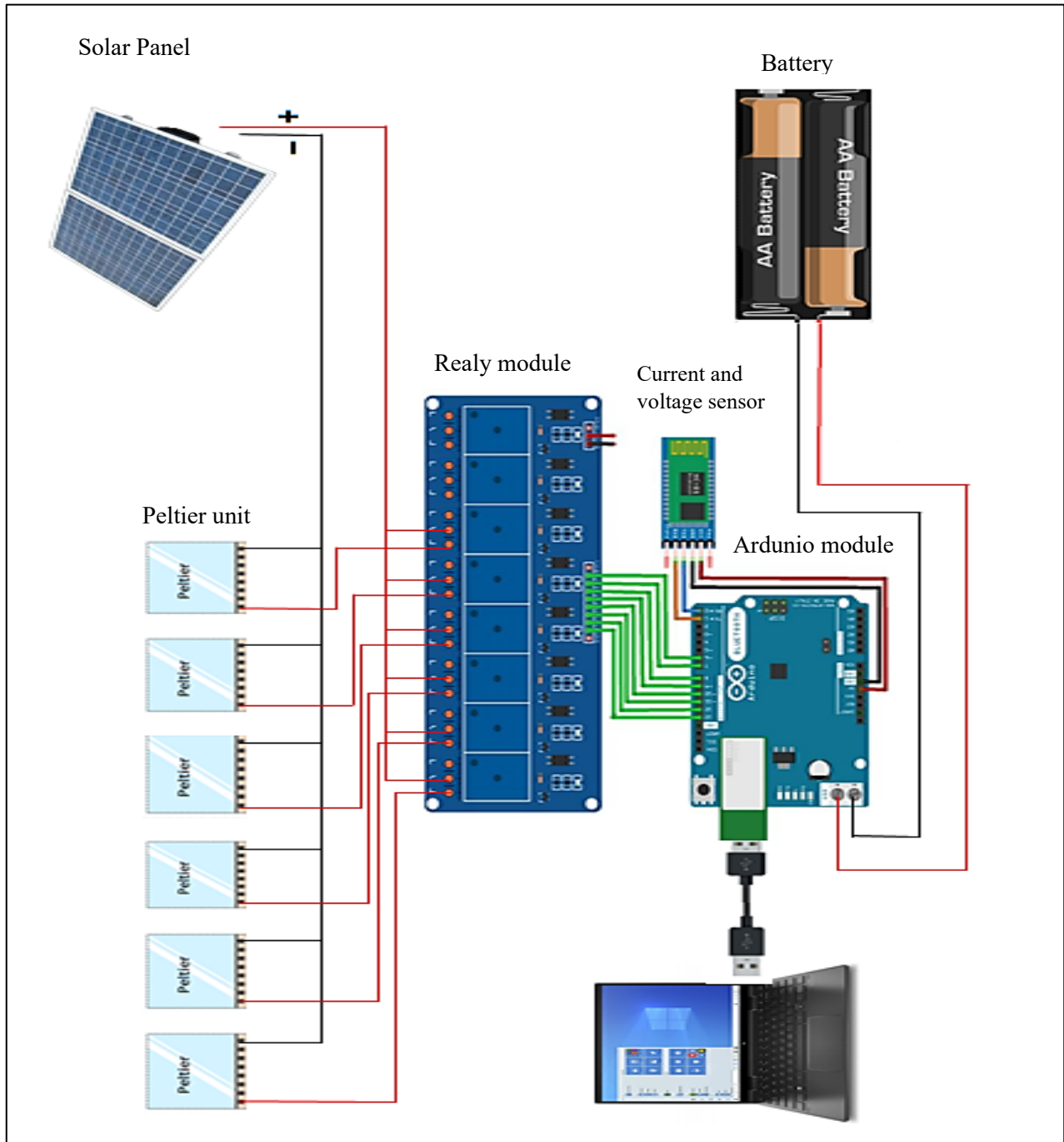
Figure 3: Diagrammatic representation of the electrical control

4. Methodology

In this work, the thermoelectric air conditioning system works by DC, and the source of electrical power is the solar panels, which consist of six panels with a power of 300 watts. The electric power was distributed at different levels for each Peltier group, as depicted in Table (4), and each case was conducted according to the time periods mentioned in Table (3), where these tests were carried out in September for the cooling mode and January for the heating mode to discuss the obtained results. Fourteen thermocouples with an accuracy of $\pm 0.1°C$ were used to measure the temperatures at the cold and hot sides of the Peltier module, the temperature of inlet air to the duct, and the temperature of outlet air. The amount of solar radiation was

gauged using a solar power meter. All measuring devices were calibrated before beginning the work, and then readings were taken.

4.1 Uncertainty Analysis

The degree of uncertainty (V) in the measured value brought on by biases and precision errors (eprecision) was estimated. While the bias error is related to the accuracy and calibration of the measuring devices, the precision error is related to the repeatability of the estimation. Due to the short amount of time the experiment was conducted outside, it was challenging to make highly accurate predictions for particular weather conditions. For this reason, multiple investigations and estimates were made to determine various variables' precision errors. As a result, the estimations' uncertainties were determined using only bias error. R is a linear function represented by n independent normally distributed variables v_i, for establishing a method to calculate uncertainty due to bias error [26] , see Table 5.

Table 3: Scheduling Peltier groups according to the on and off periods

Day	Group	State	Time	Notes
	First group	ON	10 min	
First day	Second group	OFF	10 min	The process continues
	First group	OFF	10 min	cyclically
	Second group	ON	10 min	
	First group	ON	15 min	
Second day	Second group	OFF	15 min	The process continues
	First group	OFF	15 min	cyclically
	Second group	ON	15 min	
	First group	ON	20 min	
Third day	Second group	OFF	20 min	The process continues
	First group	OFF	20 min	cyclically
	Second group	ON	20 min	
	First group	ON	25 min	
Fourth day	Second group	OFF	25 min	The process continues
	First group	OFF	25 min	cyclically
	Second group	ON	25 min	

Table 4: Scheduling of input power to the Peltier groups

Case	Input power to 1st group	Input power to 2nd group
(200+100) watt	200 watt	100 watt
(100+200) watt	100 watt	200 watt

Table 5: Measurement uncertainties and relative errors

Parameter	Standard value (x)	Uncertainty (∂x)	Relative error ($\partial x / x$)
Solar radiation, $G_t (W/m^2)$	700-910	± 2	1.2
T_{cold} (℃)	22-24	± 0.10	0.55
T_{hot}(℃)	12-31	± 0.10	0.35
T_{in}(℃)	20-31	± 0.10	0.44
$E_x\%$	0.01-0.75	± 0.005	0.001
COP	0.105-0.87	± 0.0005	0.00011

$$R = R\ (v_1, v_2, v_3, \dots\dots, v_n) \tag{1}$$

The uncertainty in R is related to the uncertainties in individual variables, which can be estimated using the second-power equation.

$$\partial R = [(\frac{\partial R}{\partial v_1} \partial v_1)^2 + (\frac{\partial R}{\partial v_2} \partial v_2)^2 + \dots\dots + (\frac{\partial R}{\partial v_n} \partial v_n)^2] \tag{2}$$

5. Governing Equations

Various coefficients are taken into account when cooling or heating the air with a thermoelectric air conditioner, such as the system cooling power (Q_c), heating power (Q_h), the input power that is taken across the whole Peltier module (W), the performance coefficient (COP), and so on.

The see-beck effect coefficient (α) is represented as:

$$\alpha = \frac{V_{max}}{T_h} \tag{3}$$

where: V_{max}: The maximum voltage of (TEC`s) peltier module, $T_h$: The temperature of hot side of (TEC`s) peltier module

The thermal conductivity is represented as:

$$K = \frac{V_{max}}{2\Delta T_{max}} \times \frac{T_h - \Delta T}{T_h} \times I_{max} \tag{4}$$

where: $\Delta T = (T_h - T_c)$: The difference between hot and cold temperature of (TE) Peltier module, I_{max}: The maximum current of (TE) Peltier module

The electrical resistance is represented as:

$$R = \frac{T_h - \Delta T}{T_h} \times \frac{V_{max}}{I_{max}} \tag{5}$$

Now, using the equation below, determine the system cooling power (Q_c) and heating power (Q_h):

$$Q_{cold} = n \left((\alpha \times I \times T_c) - (\frac{1}{2} \times I^2 \times R) - (K \times \Delta T) \right) \tag{6}$$

$$Q_{hot} = n \left((\alpha \times I \times T_h) - (\frac{1}{2} \times I^2 \times R) - (K \times \Delta T) \right) \tag{7}$$

Where, I: The current of (TE) Peltier module, R: The electrical resistance, K: The thermal conductivity, and n: The number of (TE) Peltier modules. The amount of input power that is taken across the whole Peltier module (W) is represented as:

$$W = n[\alpha(T_h - T_c) + (I \times R)] \tag{8}$$

The coefficient of performance (COP) equation is represented as:

$$COP_{cold} = \frac{Q_c}{W}$$
$$\tag{9}$$

$$COP_{hot} = \frac{Q_h}{W} \tag{10}$$

The exergy of the PV system is the input exergy and can be represented as:

$$Ex_i = AG \left[1 - \frac{4}{3} \left(\frac{T_{amb}}{T_{sun}} \right) + \frac{1}{3} \left(\frac{T_{amb}}{T_{sun}} \right)^4 \right] \tag{11}$$

where, A: Area of the PV panel (m^2), G: Solar radiation ($\frac{w}{m^2}$), T_{sun}: The temperature of the sun (6000 K), and T_{amb} = is the ambient temperature.

The exergy output equation can be represented as:

$$Ex_o = Q_c \left(1 - \frac{T_C}{T_{amb}} \right) \tag{12}$$

The following equation provides the exergy efficiency:

$$Ex\% = \frac{Ex_o}{Ex_i} \times 100 \tag{13}$$

6. Results and Discussion

Experimentally, the performance evaluation of a solar-powered thermoelectric air conditioning system was implemented under the same operating conditions mentioned in Tables (3) and (4). The system was tested under the climate of the city of Baghdad in September for the cooling mode and January for the heating mode, where the test was conducted from 8 AM to 3 PM under clear weather. The test results were used to explain the temperature behavior of the cold and hot sides of the Peltiers unit in the two cases mentioned in Table (3). The same results were processed to evaluate how the parameters such as exergy efficiency (Ex%), cooling and heating power (Q_h & Q_c), output temperatures (T_{out}), and coefficient of performance (COP) vary between the two cases. These results were compared with those obtained in [27,28].

6.1 Heating Mode

6.1.1 Temperature output for TEAC`s

Figure (4) reveals the temperature output of TEAC`s in the heating mode for the two cases, as mentioned in Table (4) for all periods mentioned in Table (3). Through Figure (4-a) for the case (200+100) watt, the output air temperatures are almost equal for all the three time periods referred to in Table (3). Still, in the case (100+200) watt in Figure (4-b), a difference can be noticed

in the temperature values that are relatively higher than the temperatures in the case (200+100) watt. This is because there is a balance in the distribution of electrical power to the first and second Peltier groups, where the first group close to the fan is equipped with a lower electrical power (100) watt that makes the incoming air warmer before it passes to the second group that is equipped with a higher electrical power (200) watt, which increases the temperature of the air passing through it as it gives more heating power. The highest temperature recorded was 31°C in the case of (20 min – ON/OFF). This is because the air remains inside the air duct for a longer period, which allows for more efficient heat exchange between the surface of the peltier and the air.

6.1.2 Coefficient of performance (COP) for TEAC`s

Figure (5) illustrates the change in the coefficient of performance (COP) of the thermoelectric air condition system for the two cases of input power supply to Peltier groups throughout the day. The results obtained in the case of (200+100) watt, as shown in Figure (5-a), manifested that the TEAC`s coefficient of performance (COP) for the 10, 15, and 20 min ranged from 0.21 to 0.58, from 0.18 to 0.55, and from 0.12 to 0.49, respectively during the day. And, the results obtained in the case of (100+200) watt, as evinced in Figure (5-b), there is an improvement in the performance coefficient, as the (COP) ranged from (0.39) to (0.65) for the period of 10 min, from (0.15) to (0.68) for the period of 15 min, and from (0.27) to (0.87) for the period of 20 min in comparison with COP obtained in [28], which is the best result of the performance coefficient obtained. This is due to the balance of the electrical power distribution between the Peltier groups, which increases the temperature difference between the Peltier surfaces, which in turn increases the heating power (Qh). This increases the performance coefficient (COP), directly proportional to the temperature difference [29].
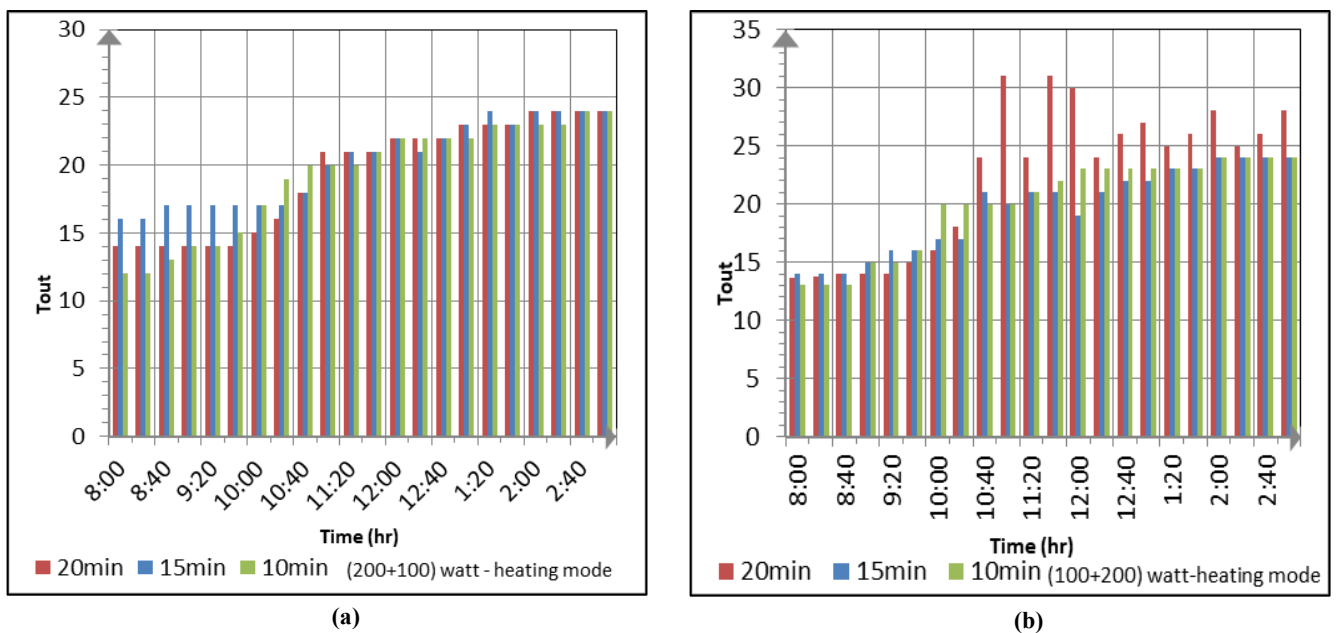

(a)   (b)

Figure 4: The output temperature of TEAC`s for heating mode for two cases: (a) 200+100 watt and(b) 100+200 watt

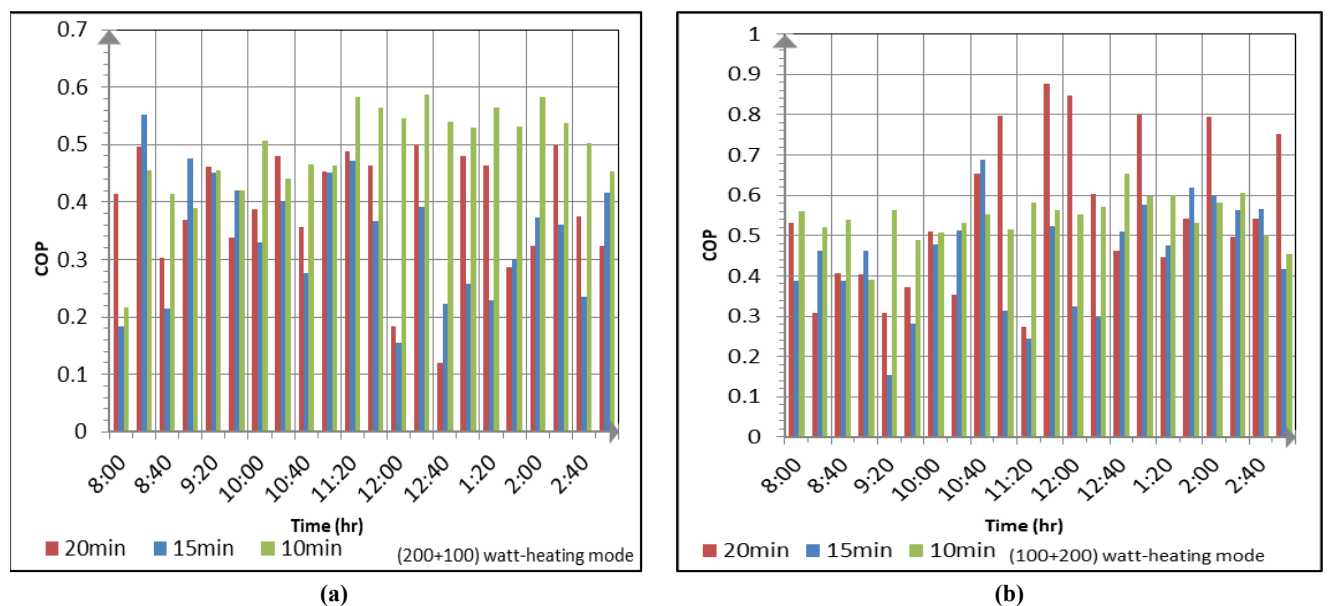(a)   (b)

Figure 5: The COP for TEAC`s for heating mode for two cases: (a) 200+100 watt and (b) 100+200 watt

6.1.3 Exergy efficiency for TEAC`S

The basis for the exergy concept presents in the introduction to the second law of thermodynamics. So, the definition of exergy is if one assumes that a system interacts with its surrounding environment, then the greatest theoretical work can be obtained from this system until this system and its surroundings reach a state of equilibrium [30]. Figure (6) elucidates the exergy efficiency for TEAC`s for the two cases, as mentioned in Table (4), and for all three intervals mentioned in Table (3). It can be observed that the degree of change in the thermoelectric air condition exergy efficiency when the power input supply to Peltier groups is (100+200) watts, as shown in Figure (6-a), ranges from a minimum value of (0.02%) to a maximum value of (0.55%) for 10 min, form a minimum value of (0.01%) to a maximum value of (0.34%) for 15 min, and form a minimum value of (0.01%) to a maximum value of (0.32%) for 20 min. And, when the power input supply to Peltier groups was (200+100) watts, as shown in Figure (6-b), better results were obtained, ranging from a minimum value of (0.05%) to a maximum value of (0.47%) for 10 min, from a minimum value of (0.03%) to a maximum value of (0.34%) for 15 min, and form a minimum value of (0.05%) to a maximum value of (0.75%) for 20 min, which represents the greatest exergy efficiency value obtained. This is because the thermoelectric air conditioner that operates in the case of (200+100) watts suffers from less energy loss than the thermoelectric air conditioner that operates in the case of (100+200) watts. As a result, one can conclude that the TEAC's energy efficiency has increased in the case of the (200+100) watt TEAC's as opposed to the (100+200) watt TEAC's. This makes the use of energy in this system more efficient.
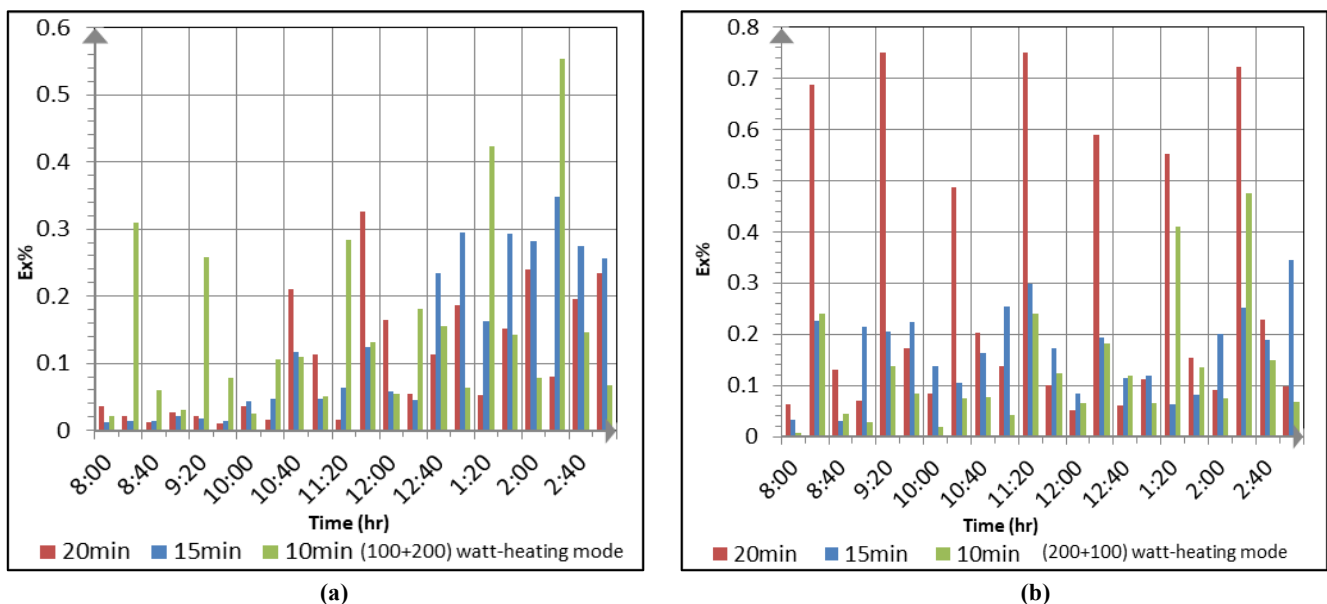

(a)   **(b)**

Figure 6: The exergy efficiency for TEAC`s for heating mode for two cases: (a) 200+100 watt and (b) 100+200 watt

6.2 Cooling mode

6.2.1 Temperature output for TEAC`s

Figure (7) portrays the change in the temperature output of the thermoelectric air condition system in the cooling mode throughout the day for each of the two cases (200+100) watts and (100+200) watts. Through Figure (7-a), in the case of (1200+100) watts, one can notice at the beginning of the day that the output air temperature is between 22°C and 23°C, as the ambient air temperature reaches 29℃ and the intensity of solar radiation is 700W.m^{-2} After 9:00 AM, when the ambient temperature increases to 31°C and the radiation remains 700 W.m^{-2}, it is noted that the increase in the output air temperature is 1°C. After 11:20 AM, when the ambient temperature becomes 32°C and the radiation is 910 W.m^{-2}, it is observed that the return of temperature stability is between 22°C and 23°C for each of the periods (15 & 20 min) and between 23°C and 24°C for the period of 10 min. In the case of (100+200) watt, as shown in Figure (7-b), one can notice an improvement in the outside air temperatures, as the outside air temperature ranged between 22°C and 23°C from 8 am to 11:20 AM, after 11:20 AM, when the degree of ambient temperature and radiation intensity reached 32°C and 910 W.m^{-2}. It can be seen that the output air temperature is stable between 22°C and 23°C for a period of 15 min, which is considered the best period for the two cases (200+100) watt and (100+200) watts. This is because the air remains inside the duct for a period that allows removing the largest amount of heat. Although the 20 min is a longer period, it causes stress to the belt and increases the temperature of the hot side, which in turn raises the temperature of the cold side. The cold air temperature obtained in this work is a simple approximation to the temperatures obtained in the asymptotic work [27].
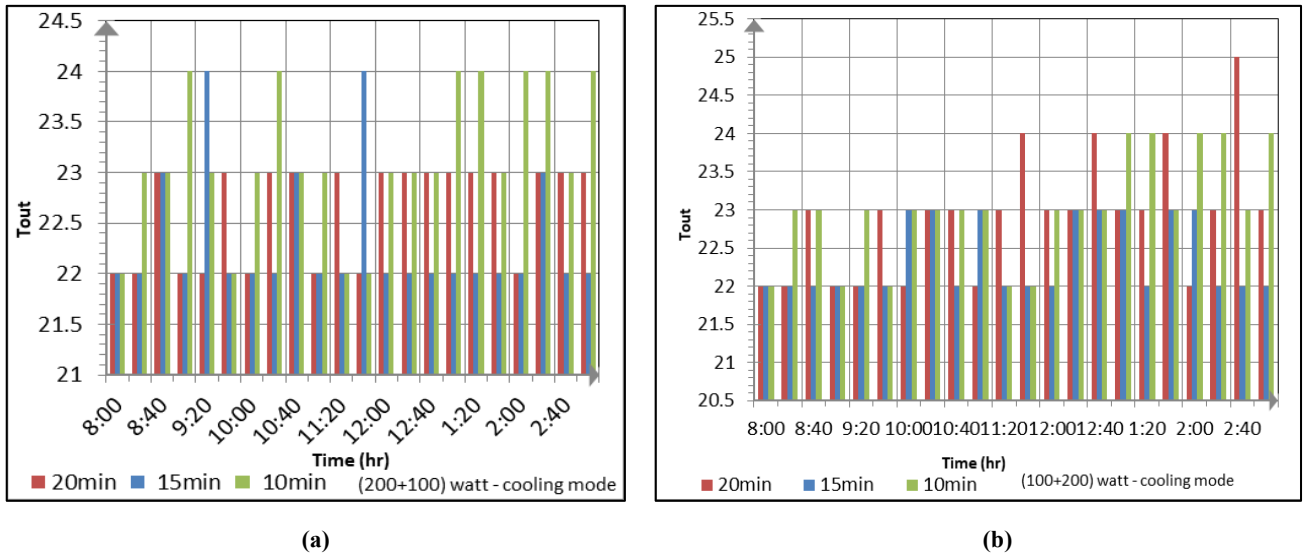
(a)　　　　　　　　　　　　　　　　　　**(b)**

Figure 7: The output temperature of TEAC`s for cooling mode for two cases: (a) 200+100 watt and (b) 100+200 watt

6.2.2 Coefficient of performance (COP) for TEAC`s

In Figure (8), the coefficient of performance (COP) of the TEAC system is plotted as a function of the cooling power of the system. The COP was calculated using Eq. (7) presented in the governing equations section. The magnitude of the ambient temperature was varied from 29°C to 32°C. Through Figure (8-a), in the case of (1200+100) watt, the COP values ranged from the lowest value (0.105) to the highest value (0.473) at 10 min, from the lowest value (0.4) to the highest value (0.51) at 15 min, and from the lowest value (0.30) to the highest value (0.64) at 20 min. This represents the improved results over the results achieved by the case (100+200) watts, as it reached the lowest value (0.26) and the highest value (0.44) at 10 min, the lowest value (0.20) and the highest value (0.47) at 15 min, and the lowest value (0.30) and the highest value (0.40) at the 20 min. It is observed from Figure (8-b) that the COP of the TEAC system increases at the case (200+100) watts and at a period of 20 min, which has the largest cooling capacity; it reaches 24.1852 W, where the COP is (0.649). The results obtained in this work are more improved than those obtained in the similar work [27].

6.2.3 Exergy efficiency for TEAC`S

Exergy is the maximum theoretical work that can be done as it interacts to reach the equilibrium as defined previously. It can be observed in Figure (9) that the degree of change in the thermoelectric air condition exergy efficiency when the power input supply to Peltier groups is (100+200) watt, as shown in Figure (9-a), ranges from a minimum value of (0.23%) to a maximum value of (0.44%) for 10 min, from a minimum value of (0.20%) to a maximum value of (0.47%) for 15 min, and from a minimum value of (0.30%) to a maximum value of (0.47%) for 20 min. When the power input supply to Peltier groups is (200+100) watts, as shown in Figure (9-b), better results were obtained, ranging from a minimum value of (0.10%) to a maximum value of (0.47%) for 10 min, from a minimum value of (0.4%) to a maximum value of (0.51%) for 15 min, and from a minimum value of (0.30%) to a maximum value of (0.649%) for 20 min, and this reflects the highest exergy efficiency value attained. This is because the system efficiently utilizes the whole energy to convert it into cooling energy with the least possible energy losses and improves the effectiveness of the system's energy utilization.
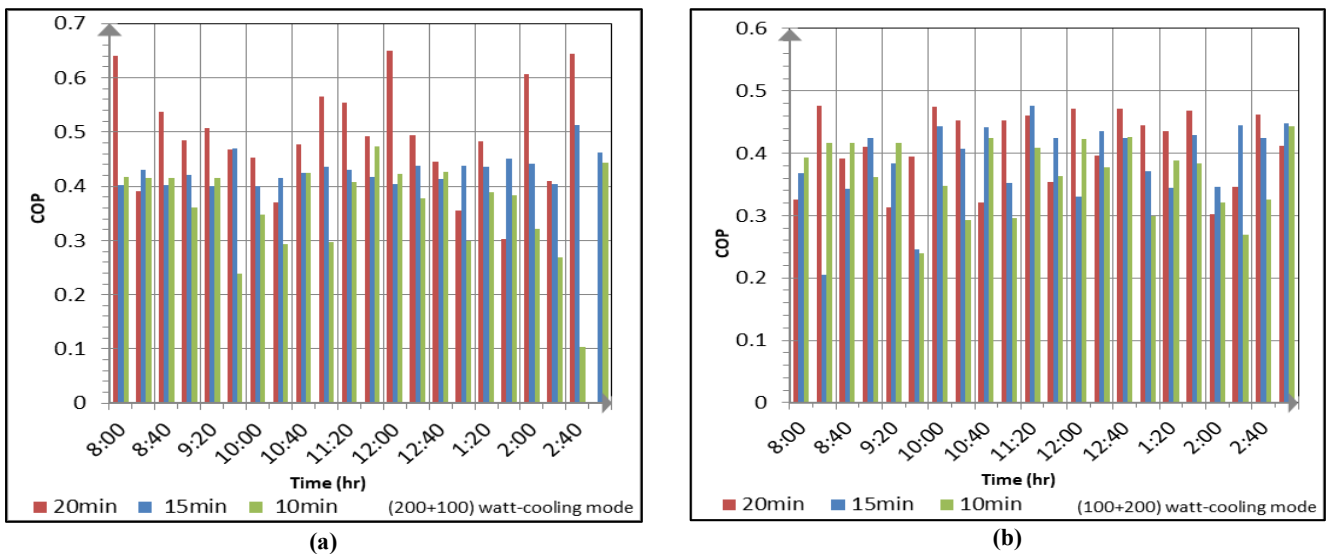

(a)　　　　　　　　　　　　　　　　　　**(b)**

Figure 8: The COP for TEAC`s for cooling mode for two cases: (a) 200+100 watt and (b) 100+200 watt
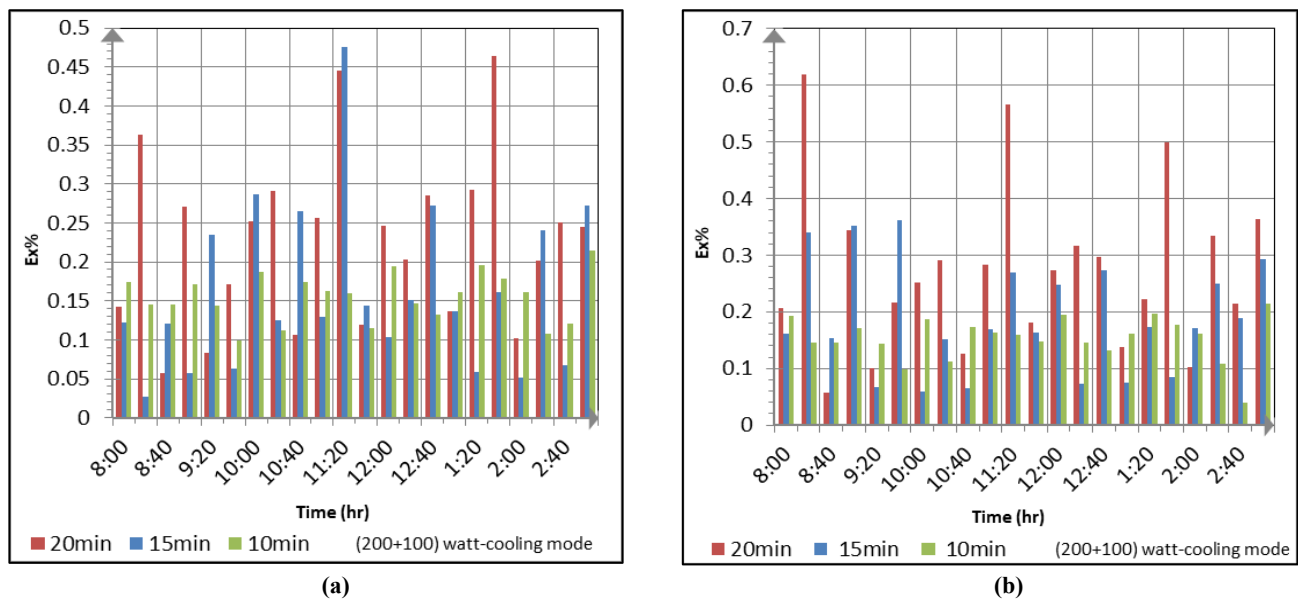
Figure 9: The exergy efficiency for TEAC`s for cooling mode for two cases: (a)200+100 watt and (b)100+200 watt

7. Conclusions and Future Works

Through using the technique of power distribution and taking different time intervals through the process ON/OFF between the groups of Peltier, this research studies and evaluates the performance of solar-powered thermoelectric air conditioning system for cooling and heating air by using different values of the input power supply to indicate the performance of the system. According to the results obtained, it is observed that the system performance improved when the output air temperature was reduced to 22°C in the cooling mode and to 31°C in the heating mode. In addition, some of the following conclusions can be noticed:

1) The distribution of input power and the time duration of the ON/OFF process between the Peltier groups affect the coefficient of performance (COP), the output temperature (Tout), and the exergy efficiency of the thermoelectric air condition system.
2) The (200+100) watt at 20 min-time duration interval is the best case for the cooling mode where the output air temperature ranges between 23°C and 22°C with a (0.64) coefficient of performance (COP). The system's exergy efficiency was 0.61, which means that the system is efficient in exploiting energy and ambient conditions to produce cooling power.
3) The case of (100+200) watt at 20 min-time duration interval is the best for the heating mode where the output air temperature reached 31°C with a (0.87) coefficient of performance (COP). The system's exergy efficiency was 0.32.
4) From the previous conclusions (2 & 3) and the results obtained, it can be said that this system is more efficient in heating applications than in cooling applications.

Through the above work and after the results obtained, there are several future works to ensure better performance of the system by using different types of heat sinks, such as those filled with liquid nitrogen or various gases of Freon, to achieve the lowest possible cold temperature and reduce the hot temperature of TEC thermoelectric cooler by improving its performance coefficient. Also, the use of an air duct design with smaller dimensions, which reduces the distance between each Peltier, as well as increasing the number of Peltier units to eight, can be investigated to ensure more heat generation and ensure a better heat exchange process with the air, which improves the performance even more.

Author contributions

Methodology M. Salman and M. Ahmed; Software M. Salman; Formal Analysis M. Mahdi and M. Salman; Writing-Original Draft Preparation M. Salman; Writing-Review and Editing, Analysis M. Mahdi and M. Ahmed. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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