



## Performance Evaluation of Solar Refrigerator with a TEC Unit Integrated with Finned Heat Pipe used in Sustainable Buildings.

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### ABSTRACT

Refrigerators with thermoelectric cooling reduce high mechanical failure rates and maintenance costs then they don't have any moving parts, in addition to offering efficient cooling and effective temperature management. The search developed a new thermoelectric refrigerator to store drugs and vaccines for medicinal usage. This refrigerator with a Peltier module (12706) operates at 14.4volts, with solar panels providing 21.1 volts and 100 watts of power. The system also includes a 4-liter plastic box with thermal insulation, an internal heat sink, a finned heat pipe heat sink, an aluminum layer, and a voltage regulator. This system also includes a 4-liter plastic box with thermal insulation, an aluminum layer, an internal heat sink, a voltage regulator, and a finned heat pipe heat sink. The efficiency of this refrigerator was measured by two trials. A normal heat sink and a 15-volt, .6-am DC power supply were employed in the second check, the solar panels and a finned heat pipe heat sink were used in the first. Conversely, to the normal heat sink, which had a coefficient of performance (COP)of 0.7, the second test COP was 2.4 at -4oC. The Peltier modules with the finned heat pipe heat sink enhanced the total efficiency by 1.5%.

**Keywords:** Thermoelectric cooler, Finned heat pipe, Refrigerator, Peltier, Photovoltaic cell.

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## 1. INTRODUCTION

The damage caused by a number of conventional energy sources has raised awareness of environmental deterioration. The fundamental component of the thermoelectric phenomena is the capacity to use the Seebeck and Peltier effects to transform thermal energy from temperature gradients into electrical energy. Nolas (2013) [1] states that the Seebeck effect happens after a conductor's ends have different temperatures, which accelerates the diffusion of electrons from the hot junction to the cool junction. According to Terasaki et al. (2005) [2], an electric current applied across the junction of two materials with different thermal properties causes the Peltier effect. Because of since phenomenon, heat is removed from one side of the junction to the other, cooling one while heating the other. Thermoelectric devices used in heating and cooling systems include computer CPU coolers and thermoelectric freezers. The Peltier effect, which instantly changes electrical energy into heat without the need for moving parts, is an efficient and environmentally benign option for some systems. A search by X Q. Ma and colleagues in 2003 [3] indicated that the performance of thermoelectric cooling systems, especially those using Peltier units, is greatly affected by design factors such as contact resistors and the length of the thermoelectric elements. An enhanced theoretical model that accounts for equally electrical and thermal contact resistances displays that the coefficient of performance (COP) decreases with shorter thermo element lengths, though the heat-pumping capacity increases up to a certain point. Increasing the thermoelement length is necessary to balance COP and heat-pumping capabilities. Enhancing heat dissipation from the hot side of the Peltier module can similarly significantly improve COP. As compared to traditional finned dissipaters, it has been shown that using a thermo syphon-based heat dissipation device can increase COP by up to 32% by lowering thermal resistance by 36%. These results show that the thermoelectric cooling system needs to be properly planned and tuned in order to enhance performance and efficiency. Atta (2018) [4], experimental results indicate that a solar-powered thermoelectric freezing box might be a viable and efficient replacement for an off-grid refrigeration system. In a one-hour cooling cycle, the inside temperature for an 18-liter cooler box that was thermally insulated with a 3.8 mm thick layer varied from 22°C to 33°C. The system COP, which changed around 0.2 and 0.6, explained that effective heat management techniques, such as the use of a tiny pin fin heat sink, might



improve performance. Additionally, the study also showed that the cooling system could be directly powered by a photovoltaic energy source, making it suitable for off-grid and cool applications.

The research by Remeli, M.F., Bakaruddin, and others (2020) [5], the solid side of thermoelectric plans was cooled by a tiny water channel. This showed how liquid cooling could enhance the performance of a Peltier-type (12709) thermoelectric device with a maximum current of 9A and a voltage of 15.2V. The cold side temperature dropped to  $-0.1^{\circ}\text{C}$  at a water flow rate of 1.5L/min, and the COP varied from 0.2 and 0.6A thermoelectric refrigerator module. The design by Dongare and others (2018) [6] froze one liter of water in a 500 ml freezing box for 1.5 hours at  $-40^{\circ}\text{C}$ . 16 Peltier thermoelectric modules (12706) are used to cool the icing machine, the research with a COP of 0.77. Four copper refrigeration methods cut the freezing time as little as three thermoelectric refrigerators. Moria, Hazim, and colleagues (2019) [7] presented an innovative way to improve heat circulation and save energy. Photovoltaic (PV)solar panels were used to power the system. Temperature readings range from  $-5^{\circ}\text{C}$  to  $6^{\circ}\text{C}$ , with the highest temperature as  $32^{\circ}\text{C}$  and the lowest being  $29^{\circ}\text{C}$ . The average temperature differential was  $30^{\circ}\text{C}$ , and the COP was 0.42%. The control system reduced the average COP to 0.30%. Thermoelectric refrigerators that use charge gas and heat sink cooling technologies can offer fresh perspectives on environmentally friendly cooling. according to Numan, N. F., Mahdi, and others [8]. By removing compressors and moving parts, these systems prolong their lifespan and lessen the possibility of faults. An experimental evaluation of the cooling capacities of portable thermoelectric chillers employing solar cells, charge management, and data recording was carried out by Chen, Y. L., et.al [9]. Water and a heat exchanger were used to improve cooling. A 250 mL water container's temperature dropped from  $18.5^{\circ}\text{C}$  to  $13^{\circ}\text{C}$  with a COP varying from 0.55 to 1.05 while solar radiation fluctuated between  $450\text{ W/m}^2$  and  $1000\text{ W/m}^2$ . In his discussion of the creation of extremely effective thermoelectric devices, Goldsmid [10] emphasized their potential for the use of renewable energy, especially in the conversion of waste heat into electrical energy. In order to encourage wider usage of thermoelectric technology across several industrial and consumer sectors, this study is concentrated on improving thermoelectric materials and system topologies.



Elnaggar (2024) [11] discovered that operating modes have a big impact on thermoelectric refrigerator performance. The Economic mode logged the highest coefficient of performance (COP) at a temperature difference of 8°C, whereas the Fast mode (non-Economic) logged the lowest COP with a temperature difference of 26.4°C, while cooling more quickly. The other modes produced intermediate COP values of 12.5°C, 18.2°C, and 23°C., minimum, medium, and Fast. Cooling speed and energy efficiency may be balanced by selecting the appropriate operating mode. Using a temperature control system also reduced energy use and enhanced efficiency based on the time of year. Alrefae (2025) [12] evaluated the integration of cooling fans with heat pipes (HPS) on the system's hot and cold sides. A cold-side temperature of 278K, a cooling rate of 26.26W, and a COP of 0.53 were the results of these modifications. Also, a 12-liter prototype, which achieved a COP of 0.4 indoors and 0.45 outdoors, showed how effective these upgrades are for portable and small refrigerated applications. These variations have a big effect on the ecosystem. In the future, thermoelectric refrigeration systems are expected to be necessary for energy conservation and sustainability. These systems offer a clean and eco-friendly cooling solution by doing away with the requirement for traditional compressors and refrigerants. Furthermore, improvements in Peltier module efficiency and heat sink design will continue to enhance performance, decrease thermal losses, and promote the wider use of thermoelectric refrigeration as a globally friendly and energy-efficient substitute. This will lessen the long-term carbon impact and help achieve sustainable development goals. This study describes the creation of a solar-powered thermoelectric refrigerator that uses a Peltier 12706 module and 100 W photovoltaic panels. It similarly has a Freon gas-charged heat sink and aluminum-wrapped heat pipes to improve heat dissipation on the hot side. Two tests were conducted: an outdoor trial using solar panels and a conventional heat sink, and a laboratory trial using a 15 V/6 A DC supply with the gas-charged heat sink. The addition of the aluminum layer and gas-charged cooling channels reduced the internal temperature to 7°C, increased the COP from 0.7 to 2.4 at a  $\Delta T$  of 4°C, and developed total efficiency by 1.5%. These effects indicate that the heat sink considerably improves the performance and efficiency of solar thermoelectric refrigerators, making them best suited for medical and off-grid applications. With improved cooling efficiency, the device involves less energy to maintain a specific temperature, leading to

lower electricity consumption and reduced environmental improves. the system will produce fewer carbon emissions connected with electricity generation.

## 2. EQUATIONS GOVERNING

The global interest in sustainable energy alternatives has controlled to a rise in the development of alternative refrigeration systems that decrease reliance on fossil fuels. Thermoelectric refrigeration, which uses the Peltier effect and has no moving parts, provides an environmentally favorable choice. Thermoelectric refrigerators are perfect for isolated locations since they can operate off the grid when fueled by solar energy. By an emphasis on determining its cooling capacity and coefficient of performance (COP), this study attempts to measure the effectiveness and performance of a solar-powered thermoelectric refrigerator.

### 2.2 Cooling System Calculations:

The performance of the Seebeck Coefficient, expressed as [13,16]:

$$\alpha = \frac{\Delta V_{max}}{T_h - T_c} \quad Eq. (1)$$

Where:

- $\alpha$  = Seebeck Coefficient.
- $\Delta V_{max}$  = difference voltage of thermoelectric cooler (TEC-12706) module.
- $T_h$  = hot side temperature of the thermoelectric cooler.
- $T_c$  = cold side temperature of the thermoelectric cooler.

$$R_m = \frac{T_h - \Delta T_{max}}{T_h} \times \frac{V_{max}}{I_{max}} \quad Eq. (2)$$

Where:

- $R_m$  = Electric resistivity.
- $\Delta T$  = Thermoelectric temperature variations.

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

Where:



$K_m$  = Thermal conductivity between the hot and cold sides.

$V_{max}$  = Maximum voltage of thermoelectric.

$I_{max}$  = Maximum current of the thermoelectric module.

Determine the cooling capacity system, defined as: [13].

$$Q_c = (\alpha I T_c) - (T_h - T_c) \quad Eq. (4)$$

$$\Delta T = (T_h - T_c) \quad Eq. (5)$$

Where:

$Q_c$  = The capacity.

$\Delta T$  = Temperature difference between the two points in Peltier (Kelvin).

Work of Peltier thermoelectric can be obtained by.

$$W = \alpha I (T_h - T_c) + (I^2 R_m) \quad Eq. (6)$$

Where:

$W$  = Work of Peltier.

$R_m$  = Thermal resistance.

$$COP = \frac{Q_{cold}}{W} \quad Eq. (7)$$

Where:

$COP$  = Coefficient of performance [14].

$Q_{cold}$  = The amount of heat absorbed or removed from the cold side (Watt).

The dimension of the thermoelectric cooler box is equal to (20×20×10) cm or (4 Liter), and the average temperature is determined by the equation:

$$T_m = \frac{T_h + T_c}{2} \quad Eq. (8)$$

Where:

$T_m$  = Mean temperature of the hot and cold junction.

### 2.3 Solar Cell Calculations:

$$E_{x\ in} = G \left( 1 - \frac{4}{3} \right) \frac{T_{amb}}{T_{sun}} + \frac{1}{3} \frac{T_{amb}}{T_{sun}} \wedge 4 \quad Eq. (9)$$

Where:

$T_{sun}$  = Temperature of the sun is equal to 6000 k.

$T_{amb}$  = Ambient temperature of the [15].

$G$  = Solar radiation.

$E_{x\ in}$  = Exergy input.

$$E_{x\ out} = QC \left( 1 - \frac{T_c}{T_{amb}} \right) \quad Eq. (10)$$

Where:

$E_{x\ out}$  = Exergy output.

$T_{amb}$  = Ambient temperature for the device.

$$E_{x\ efficiency} = \frac{E_{x\ out}}{E_{x\ in}} \quad Eq. (11)$$

Where:

$E_{x\ efficiency}$  = Exergy efficiency.

## 3. EXPERIMENTAL PROCEDURE

### 3.1 Thermoelectric Refrigerator

The experimental setup consists of a portable thermoelectric refrigerator powered by photovoltaic (PV) solar panels, fabricated and locally constructed for outdoor testing in Baghdad. The system comprises two main components: the thermoelectric refrigerator box unit and the PV array. The refrigerator unit, insulated with plastic, has a capacity of 4 liters and dimensions of  $20 \times 20 \times 10$  cm. After assembling all mechanical and electrical components, as shown in Fig. 1, the positive and negative terminals of the solar panels were connected to the thermoelectric refrigerator, enabling electricity to flow to the Peltier module, as specified in Table 1. A Peltier 12706 module (Fig. 1), a gas-free heat sink, a voltage regulator, a fan, and a conductive substance are all part of the refrigeration system's actual implementation. To stabilize the

system and increase the cooler's thermal conductivity, this conductive substance is positioned between the Peltier module and the heat sink.

Table 1 Specification (12706) Thermoelectric Cooler.

Parameter	Specification
Peltier module	12706
$Q_{max}$	50 Watts
$I_{max}$	6.4A
$V_{max}$	14.4 V
$\Delta T_{Peltier}$	66°C



Figure 1: Internal components of the refrigerator.

A 4-channel thermal gadget tracks the progressive drop in temperature that occurs when power passes through the Peltier module. The Peltier's inner side, which is involved in the refrigerator design, realizes a temperature reduction due to heat transfer, but the outer side, which is connected to the fan (as seen in Fig. 2), experiences a rise in temperature. The fan enhances overall performance through reducing the refrigerator's internal temperature and increasing its efficiency by dispersing the heat that builds up at the Peltier's hot end. Especially, this test makes use of a conventional, non-gas-charged aluminum heat sink together with a fan and a heat-conductive material used for Peltier installation. Both these elements enhance the system's efficiency and demonstrate cutting-edge methods for thermoelectric refrigeration.

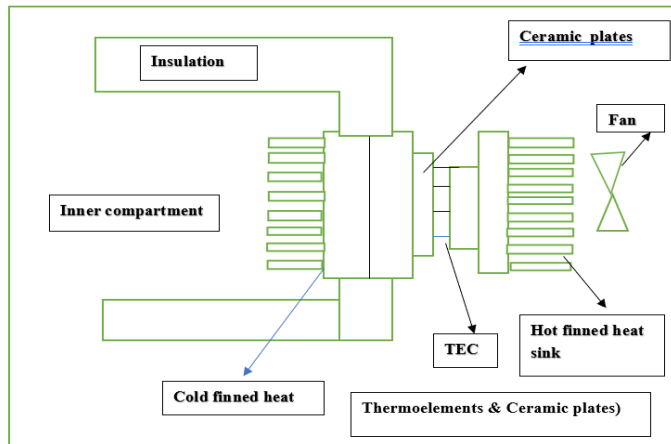


Figure 2: Installation of part.

The refrigerator was tested during the second and third months under external conditions, with radiation levels recorded on each test day. The refrigeration performance of the unit was evaluated using a continuous current supplied by two parallel-connected solar panels. Additionally, PV module parameters were measured at the Energy Center research facility, under incident solar radiation of 898 W/m<sup>2</sup> and a cell temperature of 41.1°C, using a solar analyzer 400, as shown in Fig. 3. For accuracy in the experiment, the thermocouple had an accuracy of ±0.1°C, the voltmeter had an accuracy of ±0.5%, and the solar meter had an accuracy of ±5%. Measurements were taken in March 2022.

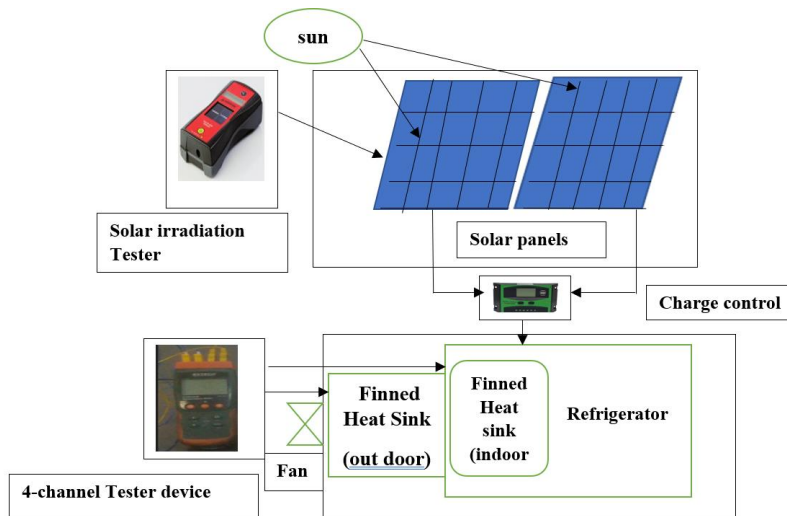


Figure 3: Schematic diagram of the experimental setup.



## 4. RESULT & DISCUSSION

### 4.1 Experimental Outdoor Procedure

The weather conditions during the experimental test included ambient temperature and solar radiation, measured from 8 a.m. to 3:30 p.m. during daylight hours. The tilt angle of the solar panels was set to 30 degrees south, in alignment with the sun path in Iraq, as shown in Fig. 4.

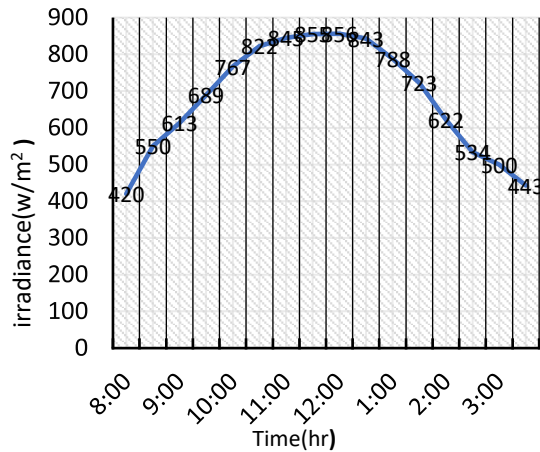


Figure 4: The relationship between radiation and time throughout the day.

Two solar photovoltaic (PV) panels were connected in parallel to generate direct current (DC) electrical energy. Already, both panels were connected to power the mini-cooler refrigerator, the solar analyzer logged their illuminated current-voltage (I-V) curves and evaluated their performance, as indicated in Table 3. As shown in Fig. 4, the experimental equipment comprises a portable thermoelectric refrigerator that is powered by photovoltaic solar panels and built locally for outdoor testing in Baghdad.

The I-V curve of a solar panel characteristically exhibits a progressive drop in current (second column) as the voltage in the first column rises. The solar irradiance and cell temperature at the time of measurement affect the values in the third and fourth columns ( $V_{mp}$  and  $I_{mp}$ ). Although higher temperatures tend to lower voltage, higher irradiance tends to increase current. The current dramatically drops as the voltage increases in the last rows (readings 12 to 15), which might be a symptom of increased cell temperature or decreased irradiance.



Table 3: Test two solar panels connected in parallel using a solar 4000 device.

No	V (Volt)	I (Ampere)	V STC (Volt)	ISTC (Ampere)
1	3.79	5.223	0	5.82
2	3.94	5.218	5.44	5.81
3	4.84	5.221	6.34	5.82
4	6.95	5.214	8.46	5.81
5	9.76	5.211	11.26	5.8
6	11.47	5.201	12.98	5.79
7	13.13	5.192	14.64	5.78
8	14.2	5.178	15.7	5.77
9	15.98	5.075	17.48	5.65
10	16.26	5.017	17.76	5.59
12	17.88	4.385	19.39	4.88
13	18.82	3.617	20.32	4.03
15	19.01	3.444	20.51	3.84

The change in energy production from the combined system, which comprises a mini-cooler refrigerator unit and a photovoltaic module, is given in Figure 5. The PV module's power output improves as solar radiation intensity raises, improving the cooling power (heat transfer  $Q_{cold}$ ). Figure 5 illustrates how the cold side temperature of the Peltier module influences the energy production, which follows the trend of solar radiation. The maximum energy production at 1:40 PM is around 12 watts, which translates to a  $Q_{cold}$  of 113 watts. The energy production decreases to around 7.4 watts, or 180 watts, through 3:25 PM. The dynamic link between solar radiation intensity and the PV-powered mini-cooler system's energy production is examined in this section. It highlights the Peltier module's function in the thermal response and shows how changes in solar input impact both electrical generation and cooling performance ( $Q_{cold}$ ).

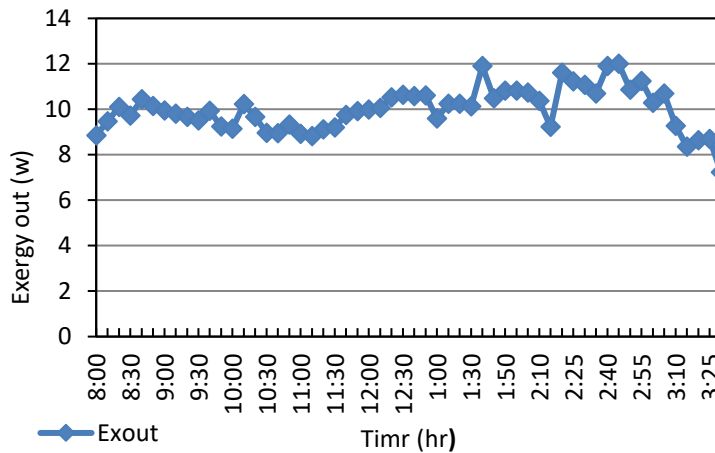


Figure 5: The relationship between radiation and time throughout the d Exergy out change with time [17].

The above graph discusses the daily variations in exergy efficiency of a solar-powered cooling system, emphasizing how the rise in temperature at noon affects efficiency reduction and increases energy loss due to thermal imbalance between the hot and cold sides of the Peltier module.

Figure 6 illustrates the variation in energy efficiency of the combined system. It is clear that at midday, exergy efficiency is at its lowest (0.01%) since the mini-refrigerator's energy output is insufficient in comparison to the sun's extremely high consumption of energy. This specifies that the system's exergy degradation rises slowly during the day and peaks at noon. When the Peltier module's hot and cold sides reach their maximum temperature differential, the system becomes more stable. The energy efficiency reaches a peak reach to 0.022% at 3:00 PM.

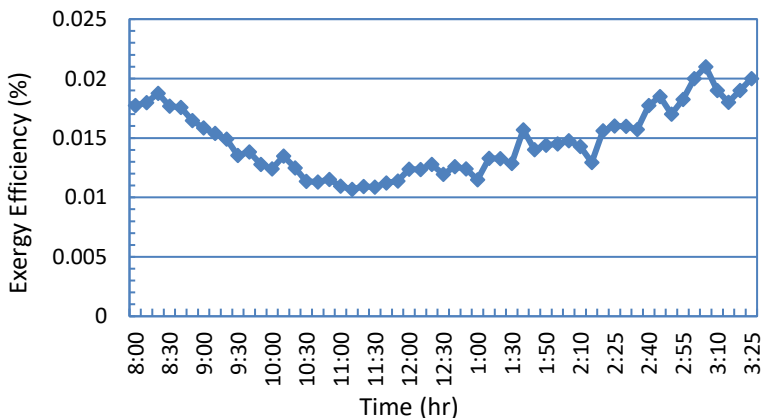


Figure 6: Exergy efficiency change with time [17].



The studies show that employing a gas-charged heat sink (like Freon) improves the temperature differential between the two sides of the Peltier module and maximizes heat transfer efficiency by decreasing heat buildup on the hot side. This development is a major step in increasing thermoelectric cooling system efficiency, particularly in applications that need for accurate and affordable cooling. The coefficient of performance (COP) fluctuation for a typical heat sink without Freon gas is depicted in Figure 7. The COP is at its lowest between 8:00 AM and 12:40 PM, at roughly 0.5 and 0.42, respectively. A normal heat sink, a fan, and a refrigerator of the same size were used for the test. However, at 12:05 PM, Figure 12 shows the effects of cooling the Peltier module with flowing gas inside the heat sink tubes with a COP of 1.6. This setup performs far better than a standard heat sink.

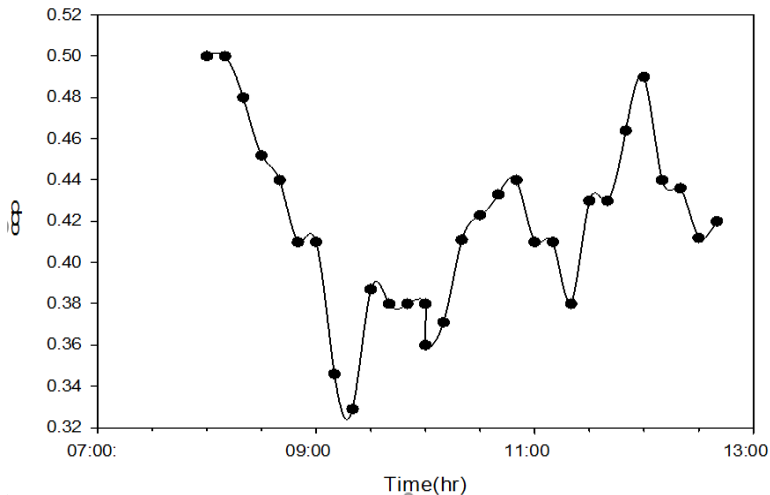


Figure 7: Coefficient of performance with heat sink without gas-charged Freon.

#### 4.2 Laboratory Test

A test using a Peltier module of type (12706) is shown in Figure 8; Table 1 provides specifications. The continuous-current power source that powers the thermoelectric refrigerator guarantees a steady electrical supply and improves system performance. The refrigerator's metal heat sink effectively controls heat. The heat sink is filled with Freon gas (R-22). Before the pipes are gradually filled with the appropriate gas while the pressure is being monitored, a vacuum pump is used to remove air and moisture from the system. After that, the system is tested to ensure proper operation. This stage is essential for cooling since the Peltier module's temperature increases after the refrigerator

has been operating for a brief amount of time. The heat sink is filled with freon gas (R-22). Before the pipes are regularly filled with the suitable gas, though the pressure is being checked, a vacuum pump is used to remove air and humidity from the system. The system is then examined to make sure it is operating properly. When the refrigerator has been operating for a little while, the Peltier module's temperature rises, making this step important for cooling. The refrigerator's outside cooling is further enhanced with an external fan. In a closed gas refrigeration cycle, the gas is compressed to increase its temperature before being sent through a cooling area to shed heat. After that, the gas expands and cools even more. The ideal Carnot cycle, which explains how work is transformed into cooling in closed thermal systems, is the basis for this procedure. Finally, Figure 9 depicts how the refrigerator is connected to a 15-volt, 6-amp (DC) power source for lab testing.



Figure 8: Peltier 12706 module.

#### 4.3 Experiment Component:

1. Plastic Box (Refrigerator) with a capacity (4 Liters).
2. Two solar panels (for outdoors installation).
3. Finned external gas heat sink for (indoor testing).
4. Fans and heat sink for (outdoor testing).
5. Internal heat sink (installed on the inner wall of the refrigerated compartment).
6. Power supply (for lab testing).
7. Multimeter device.
8. 4 Channel thermometer.
9. Peltier (12706).

From improving heat transmission from the Peltier module to the surrounding environment, this combination significantly enhances cooling performance in thermoelectric refrigerators. This enhances system efficiency, lowers energy consumption, and improves the efficacy of temperature reduction.

The system is better for cooling performance and efficiency are critical since it maximizes heat transport and ensures stable cooling.

The thermoelectric refrigerator energy efficiency is further enhanced by improving thermal performance, which drops energy consumption.[16].

Figure9 specifies, heat sink finned exchangers are considered state of the rate cooling technology solution, especially for systems that employ heat conductive materials like Peltier modules. Fins enhance heat dissipation and cooling efficiency by expanding the surface area of the heat exchanger. When paired with a gas charge, such as Freon, the benefits for cooling performance and heat dispersion are enhanced.

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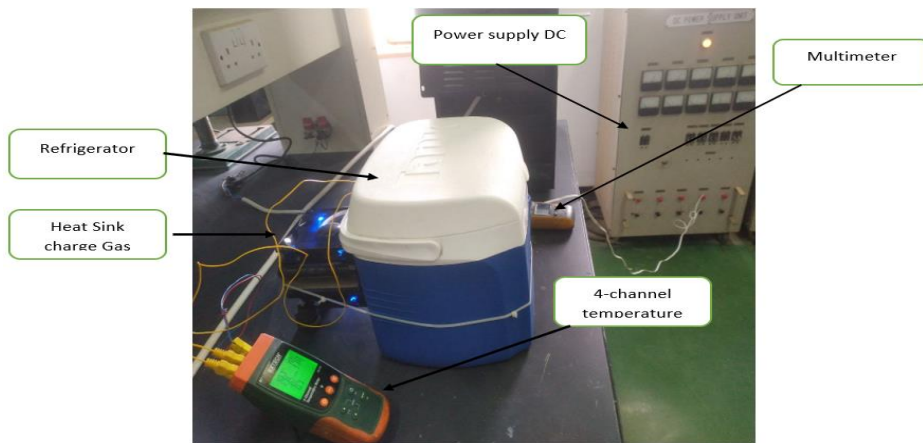


Figure 9: Test Rig with capacity 4 Liter.

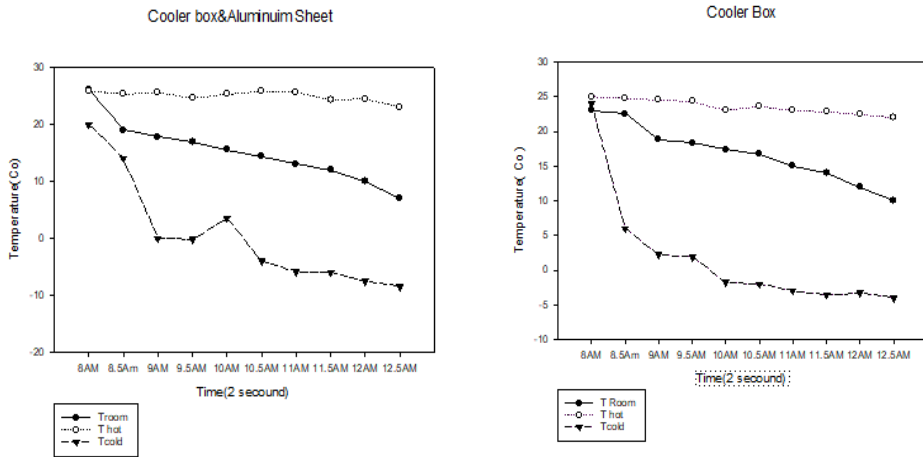


Figure 10: (A, B) the relationship between ambient, cold, and hot temperatures on the Peltier with time of day with & without aluminum sheet.

The system tested without any thermal load within the refrigerator is depicted in Figure 10-A. The heat exchanger was placed in the cooling chamber between the Peltier module and the refrigerator's inner wall. This configuration enhanced heat conductivity and made it possible for the refrigerator's inner surfaces to distribute cold more effectively. On a bright day, precisely March 25, 2023, the temperature changes for the hot side, cold side, and ambient circumstances are depicted in the image. interestingly, both the hot and cool sides showed their highest temperatures about 11:00 AM. The voltage provided by the photovoltaic (PV) panel affects the thermoelectric cooling unit's thermal behavior, then it is not the only factor subsizing to the highest temperature on the hot side. The hot side peaked at 25 °C about 11:00 AM, which was also the moment when the PV panels' maximum electrical power production and solar irradiance were at their highest. The hot side of the Peltier module naturally reaches its maximum temperature through the buildup of heat from the electrical input (from the PV panel) and ambient solar heating. On the other hand, the cold side reached a low temperature of around -5°C due to efficient cooling and heat absorption.

According to the experimental findings, the PV panel's voltage delivered to the thermoelectric cooling unit during the outdoor test was around 16.78 volts (Vmpp). This voltage equals the maximum power point of the panel and is perfect for running the TEC-12706 module.

As shown in Figure 10-B, aluminum foil can be used to improve conductivity and refrigerator wall cooling. At 10:30 AM, the cold side temperature with aluminum foil was -4°C, the temperature difference was 29.3°C, and the

thermal resistance was  $61.61 \Omega$ . But without the aluminum foil, thermal resistance rose to  $25.6 \Omega$ , and the temperature on the cold side dropped to  $-2^\circ\text{C}$  for the same span of time. The cold side temperature dropped significantly as a result of this reduction in thermal resistance, indicating how well aluminum foil enhances heat transfer and raises the refrigerator's cooling capacity [8].

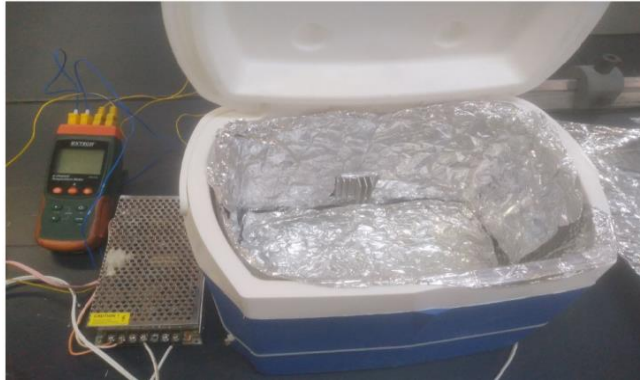


Figure 11: The effect of wrapping the walls of the refrigerated with aluminum foil on low temperatures.

Figure 11 depicts how putting aluminum foil for wrapping the walls of the refrigeration unit may successfully reduce temperatures. After four hours of operation, the temperature of the cold side wall dropped to  $7^\circ\text{C}$ , which contributed to the overall decrease in temperature from  $8^\circ\text{C}$  to  $-8.5^\circ\text{C}$ . This illustrates how aluminum foil significantly reduces refrigeration unit temperatures and improves cooling efficiency. The thermal conductivity of aluminum foil, resulting in more effective heat transfer from the refrigerator's inside to the Peltier module's cooling surface, explains the temperature decrease seen in Figure 14. The Peltier's cold surface and the air inside the refrigerator have less thermal resistance when the inside walls are covered with aluminum. This results in deeper and faster cooling by improving the uniform distribution of cold air and accelerating the absorption of heat from the stored region. The reflective quality of aluminum also helps to reduce radiative heat absorption from surrounding areas, increasing overall cooling efficiency. The coefficient of performance (COP) deviation during the course of the day is shown in Figure 12. With a temperature differential of almost  $22.3^\circ\text{C}$  in less than five minutes, the COP hits a minimum of 0.28 at 11:00 AM. At 12:05 PM, the temperature differential between the hot and cold sides



achieves its maximum value of 26°C, resulting in the maximum COP of roughly 1.6. At 1963.3W, the COP rises with refrigerant energy but rapidly falls with growing power input. This suggests that when the temperature differential between the hot and cold sides grows, the COP reduces.

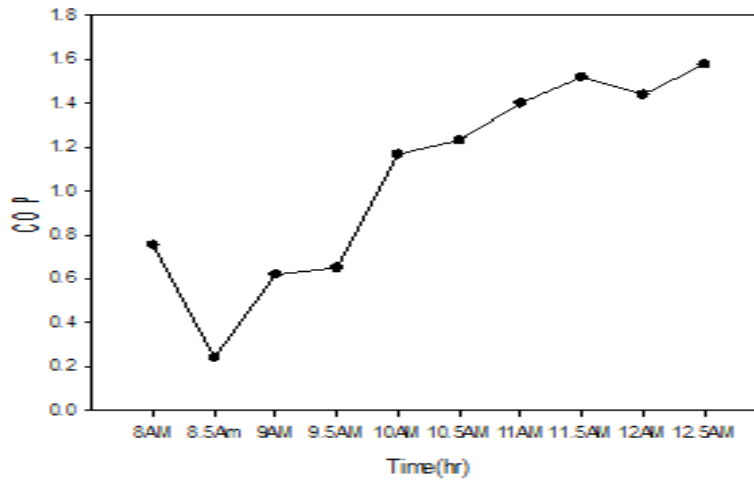


Figure 12: displays the coefficient of performance fluctuation throughout the day with heat sink charge gas Freon.

Figure 13 shows how the coefficient of performance (COP) of a refrigeration unit with a gas-charged heat sink is related to two important factors: the temperature on the cold side (2.49°C) and the heat output (5072 watts). As shown, a decrease in electric resistance and an increase in the temperature difference between the Peltier modules result in a significant enhancement in the COP. This shape suggests that varying these variables might lead to enhanced refrigeration performance.

Cooling energy and COP have a strong association, according to the parallel graphs. This alignment emphasizes how crucial it is to recognize and handle the variables influencing cooling energy and COP in order for effective refrigeration operation.

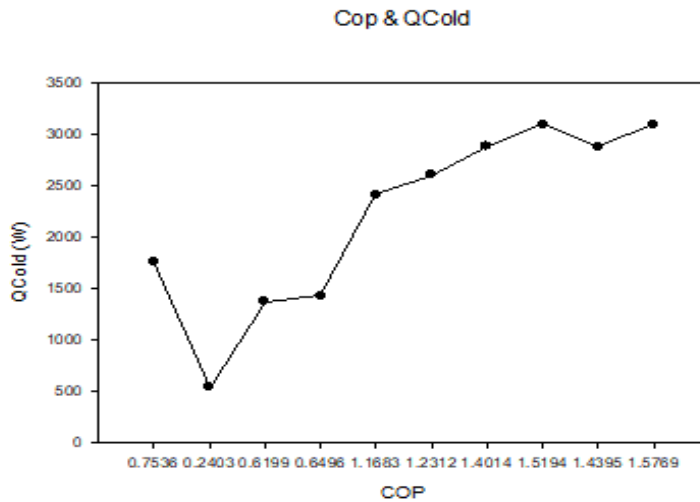


Figure 13: Effect the coefficient of performance with Q<sub>Cold</sub>.

Figure 14 shows how putting an aluminum coating to the refrigerator's inside may increase conductivity between the walls and internal dissipator. Compared to the results in Figure 15, where the COP peaked at 1.6, the greatest coefficient of performance (COP) achieved was 2.4, a significant rise. increase conductivity improves refrigeration efficiency by facilitating more effective heat transfer between the walls and the internal dissipator. This result normally highlights how important it is to raise thermal conductivity in order to maximize the efficiency of thermoelectric refrigeration systems.

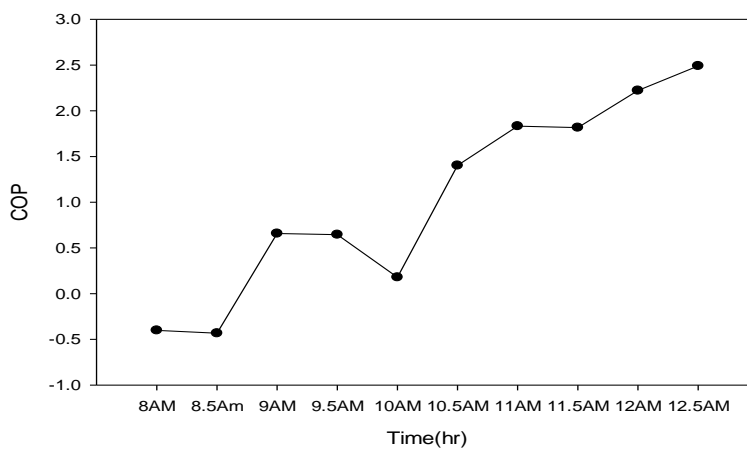


Figure 14: Effect covered refrigerator walls with aluminum foil & use heat sink with gas-Freon.



## 5. CONCLUSIONS

The tests were led on a single system, which involved a mini-cooler refrigerator powered by solar PV panels in the first test and a laboratory proses with a DC power source in the second. The results showed that the laboratory test performed well than the outside experiment. Novel technologies, particularly the gas-charged heat sink, were used to reach considerably lower temperatures, suggesting their probable for future portable applications. The gas-charged heat sink greatly improved the refrigerator's design by effectively dispersing heat from the Peltier module. Also, related to the outdoor test conditions, the refrigerator's aluminum foil coating allowed all four walls to cool rapidly. In the initial outdoor solar panel experiment, the system's overall efficiency was just 0.02% and the COP was 1.6. In association, a considerably larger COP of 2.5 and an internal Peltier temperature drop of  $-8.5^{\circ}\text{C}$  were obtained in the laboratory test, which employed a DC power source and covered the refrigerator walls with aluminum .

This research demonstrates that employing a gas-charged heat sink with a modified power source significantly improves refrigerator performance. Optimizing cooling dispersion through novel heat sink designs is also crucial. Heat sinks that are positioned appropriately enhance the refrigerator's overall cooling efficiency, lowering energy consumption and encouraging sustainable operation.

## REFERENCES

- [1] Nolas, G., Sharp, J., and Goldsmid, J. (2013). 'Thermoelectrics: basic principles and new materials developments', Springer Science & Business Media, vol. 45.
- [2] Terasaki, I. (2005) 'Introduction to thermoelectricity', Materials for Energy Conversion Devices, pp. 339-357.
- [3] Ma, X. and Yu, Q. (2003) 'Improving the coefficient of performance of thermoelectric cooling systems: A review', International Journal of Refrigeration, vol. 26, pp. 414-420.
- [4] Atta, R. (2018) 'Thermoelectric cooling. Bringing thermoelectricity into reality', pp. 247-267.
- [5] Remeli, M., et al. (2020) 'Experimental study of a mini cooler by using Peltier thermoelectric cell', IOP Conference Series: Materials Science and Engineering, vol. 788, pp. 012076.



- [6] Dongare, V., et al. (2018) 'Design and development of thermoelectric refrigerator', International Research Journal of Engineering and Technology, vol. 5.
- [7] Moria, H., et al. (2019) 'Experimental study of solar based refrigerator using thermoelectric effect', Energy Procedia, vol. 158, pp. 198-203.
- [8] Numan, N., Mahdi, M., and Ahmed, M. (2023) 'Thermoelectric refrigerator driven by a solar panel using electrical control the refrigeration system (on, off)', AIP Conference Proceedings, vol. 2834.
- [9] Chen, Y., et al. (2014) 'Experimental investigation on thermoelectric chiller driven by solar cell', International Journal of Photoenergy.
- [10] Goldsmid, H. (2017) 'The physics of thermoelectric energy conversion', Morgan & Claypool Publishers.
- [11] Elnaggar, A., et al. (2024) 'Efficient portable thermoelectric refrigerator developed with a temperature control system mode at best COP for different seasons and conditions of the year', International Journal of Ambient Energy, vol. 45.
- [12] Alrefae, M. (2025) 'Enhanced performance of a thermoelectric module with heat pipes for refrigeration applications', Energies, vol. 18.
- [13] Julian, H. (2009) 'Introduction Thermoelectricity', Springer Berline.
- [14] Rodríguez, E., et al. (2022) 'Modelling the exergy of solar radiation: a review', Energies, vol.15.
- [15] Koroneos, C., Spachos, T., and Moussiopoulos, N. (2003) 'Exergy analysis of renewable energy sources', Renewable Energy, vol. 28, pp. 295-310.
- [16] Liu, L., Meng, X., and Zhuang, M. (2022) 'Analysis and verification of Seebeck effect and Peltier effect co-existence on a thermoelectric device', 2022 7th International Conference on Power and Renewable Energy (ICPRE), pp. 1113-1117.
- [17] Numan, N., Mahdi, M., & Ahmed, M. (2022) 'A comparative experimental study analysis of solar based thermoelectric refrigerator using different hot side heat sink', Engineering and Technology Journal, vol. 40, pp. 90-98.

## تقييم أداء التلاجة الشمسية مع وحدة TEC مدمجة مع أنبوب حراري ذو زعانف يستخدم في المباني المستدامة.

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### المستخلص

تُقلل التلاجات المزودة بنظام تبريد كهروحراري من معدلات الأعطال الميكانيكية المرتفعة وتكاليف الصيانة لعدم احتوائها على أجزاء متحركة، بالإضافة إلى توفيرها تبريداً فعالاً وإدارة دقيقة لدرجة الحرارة. وقد طُوّرت تلاجة كهروحرارية جديدة لتخزين الأدوية واللقاحات للاستخدام الطبي. تعمل هذه التلاجة، المزودة بوحدة بلتير (١٢٧٠٦)، بجهد ١٤,٤ فولت، بينما تُوفر الألواح الشمسية ٢١,١ فولت و ١٠٠ واط من الطاقة. يشتمل النظام أيضاً على صندوق بلاستيكي سعة ٤ لترات معزول حرارياً، ومشتت حراري داخلي، ومشتت حراري مزود بأنبوب حراري ذي زعانف، وطبقة من الألومنيوم، ومنظم جهد. وقد قُيِّمت كفاءة هذه التلاجة من خلال تجربتين. في التجربة الثانية، استُخدم مشتت حراري عادي ومصدر طاقة تيار مستمر ١٥ فولت، ٠,٦ أمبير، بينما استُخدمت الألواح الشمسية ومشتت حراري مزود بأنبوب حراري ذي زعانف في التجربة الأولى. في المقابل، بلغ معامل الأداء (COP) للمشتت الحراري العادي ٠,٧، بينما بلغ معامل الأداء في الاختبار الثاني ٢,٤ عند درجة حرارة -٤ درجة مئوية. وقد حسَّنت وحدات بلتير المزودة بمشتت حراري ذي أنابيب حرارية مزودة بزعانف الكفاءة الإجمالية بنسبة ١,٥٪.

**الكلمات الرئيسية:** مبرد حراري كهربائي، أنبوب حراري ذو زعانف، تلاجة، بلتير، خلية كهروضوئية.