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Thermoelectric Cooling System for Vehicle Cabin during Parking Powered by Solar Photovoltaic Energy

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ABSTRACT

When an automobile is parked in an open area, the temperature inside the cabin rises because heat is carried inside by convection, conduction, and solar radiation that enters via the windows. Elevated temperatures within the car's interior are not only harmful to passengers, but they can also deteriorate the plastic dashboard and electronic devices. A cooling fan, window film, and a sheet of aluminum foil to cover the windshield are utilized to reduce the amount of heat that builds up within the vehicle cabin. This research used a thermoelectric cooler powered by solar photovoltaic energy. The system consisted of two panels 660 watt, two GEL batteries 200 Ah, a solar charger, six thermoelectric modules, fins, and fans. The results show that the temperature inside the vehicle cabin lowered by 4°C without using the conventional air conditioning system, which used harmful refrigerants. The maximum coefficient of performance was 0.0138.

1. Introduction

Significant temperature changes in the car cabin depend on the surrounding temperatures. Therefore, in every case, the car's cabin must have air conditioning. When a vehicle is parked outside in the summer, the interior experiences significant temperature changes [1]. The worst effect of parked cars is found when they are parked under the sunlight for a long time in the summer, for instance, outside offices, shopping centers, and educational institutions. It is unbearable for drivers and passengers to come and just sit in the cabin's interior [2]. The dashboard, seat covers, and other accessories will release toxic gasses that are dangerous to the passengers when the temperature inside the cabin rises rapidly. If parents forget their children or pets, they might die [3,4]. This considerable rise in cabin temperature increased the cooling load, requiring more fossil fuel and producing more harmful CFC emissions [5,6]. Even in electric vehicles, the running of the cooling system will decrease the mileage by 35% to 50% [7].

Solar energy is one of the renewable resources that can be developed [8]. The quantity of energy that the earth receives in an hour may cover the world's energy needs for nearly a year; this is approximately 5000 times the total amount of energy that the earth receives from all other sources

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[9]. It can simply be used to power any cooling system in the case of parked cars [10,11]. Sharma *et al.,* [12] developed a method for installing a cooling system that was environmentally beneficial. Raut and Walke [13] created a cooling system placed on a standard automotive air conditioner blower. Stancila *et al.,* [14] employed the Peltier effect, based on a thermoelectric module, to cool the vehicle's cabin. Hakim and Samgita [15] developed a cabin cooler based on thermoelectric to reduce the temperature inside the cabin. Ingole *et al.,* [16] conducted an experimental investigation on a thermoelectric module-based solar heating and cooling system. Fathima *et al.,* [17] utilized the solar power extracted from a solar panel to power a system that controlled the interior vehicle temperature. To overcome the problem of harmful fuel and refrigerant emissions, Yogesh *et al.,* [18] developed a car air conditioning system based on the thermoelectric effect. Rifky and Heriyani [19] transformed solar energy into electrical energy, which was then utilized to cool the car's interior. Srivastava *et al.,* [4] created a thermoelectric cooling/heating system powered by solar energy for cars parked in open areas using COMSOL Multiphysics software. Saidi and Redzuan [20] analyzed the using a thermoelectric cooling system to improve the COP value, through the simulation method used to analyze the airflow through a chamber. The results showed that the COP value can achieve more than 2. Based on the literature discussed above, it is clear that solar energy is a common alternative for car cooling systems, and using thermoelectric technology for automotive air conditioning can offer a single, maintenance-free cooling solution powered directly by solar energy.

Thermoelectric cooling is one of the different of cooling techniques that have been developed continuously to achieve different applications and it is based on the Peltier effect which is electricity converted into thermal energy [21,22]. The thermoelectric modules are light in weight, convenient, compact in size, highly reliable, have no harmful emissions to the environment, and are noise-free (no moving part) [4,18,23].

According to the suggested technique, solar energy has the most potential for powering the cooling system needed for parked vehicles. Further, the novelty of the proposed thermoelectric system.

2. Aim of Study

The aim of research is to study the performance of thermoelectric cooling system for vehicle cabins using solar photovoltaic energy.

3. Experimental Work

The experimental work was done at Wasit University/College of Engineering on 19 November 2023. The proposed system consisted of two PV panels 660 watt to convert the solar energy into electrical energy, two GEL batteries 200Ah to store the electric energy, a solar charger to control the battery charging and the consumption load, six thermoelectric modules 6A to reduce the car cabin temperature, fins to dissipation the heat of hot and cold sides of the thermoelectric modules, and fans to decrease the fins temperature as shown in Figure 1 and Figure 2.

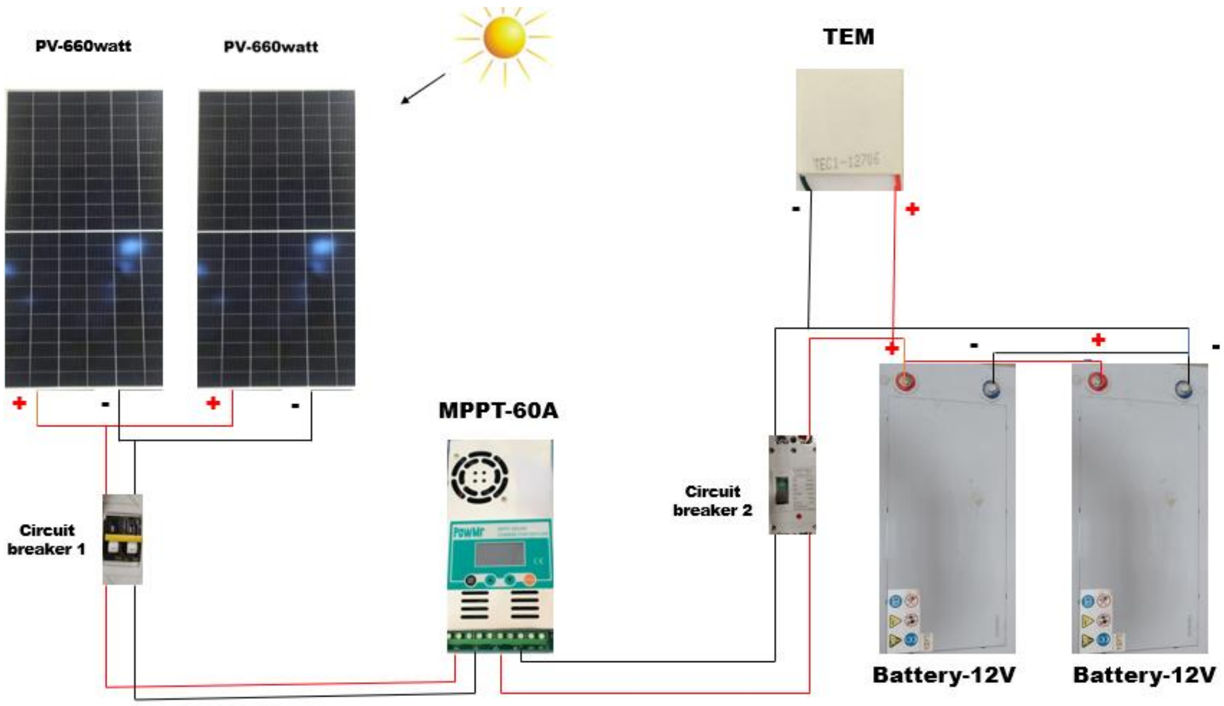

Fig. 1. Schematic diagram of the system

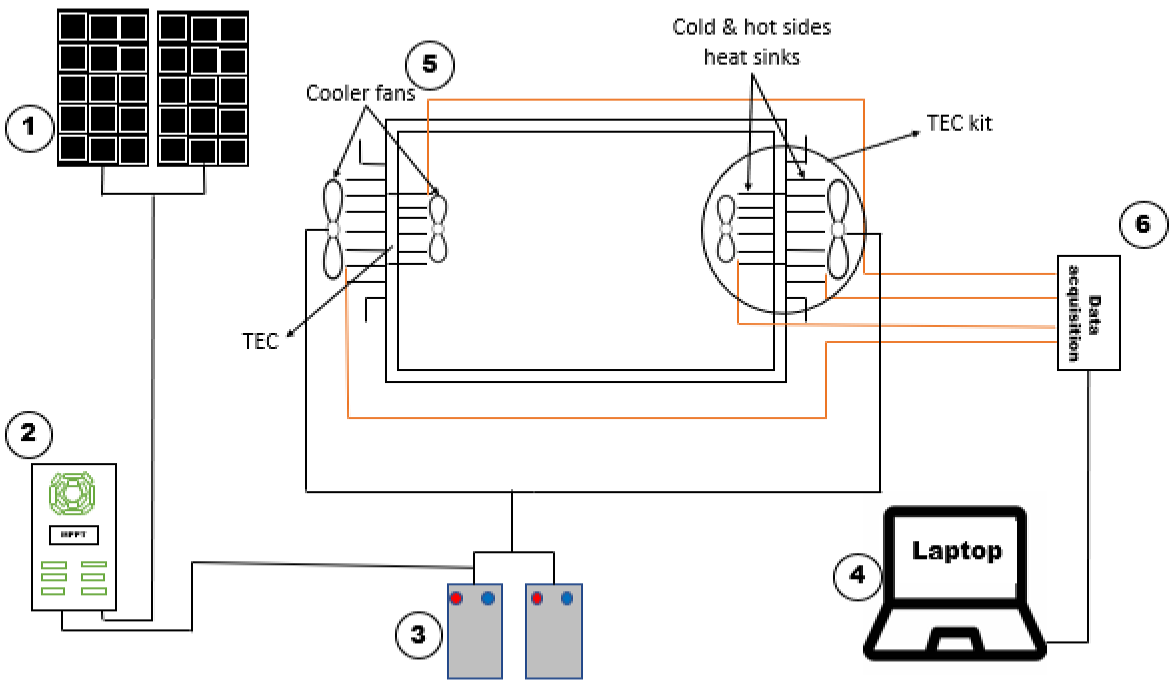

Fig. 2. Schematic diagram for the front view of the cooling duct: 1. PV panels, 2. Solar charger MPPT, 3. Gel batteries, 4. Laptop, 5. Cooling duct, and 6. Data acquisition

The solar panels installed on the vehicle roof are shown in Figure 3 below:

Fig. 3. Solar panels on the vehicle roof

One of the car windows was replaced with a wooden plate, and drilled the wooden plate 60mm *60 mm was to install the cooling duct 540*60*60 mm, which is aluminum coated and composed of six pieces of thermoelectric modules; their features are shown in Table 1, 40*40mm fan fixed on the cold side fins, six TEC Kits which consisted of a DC fan 12V 0.15A, outer cover for fan, hot side fins 116*100*23mm, cold side fins 40*40*26mm, thermal insulation gasket, thermal grease to install the TEM without any b effect on the thermal conductivity of it, and a pack of screws as shown in Figure 4 below:

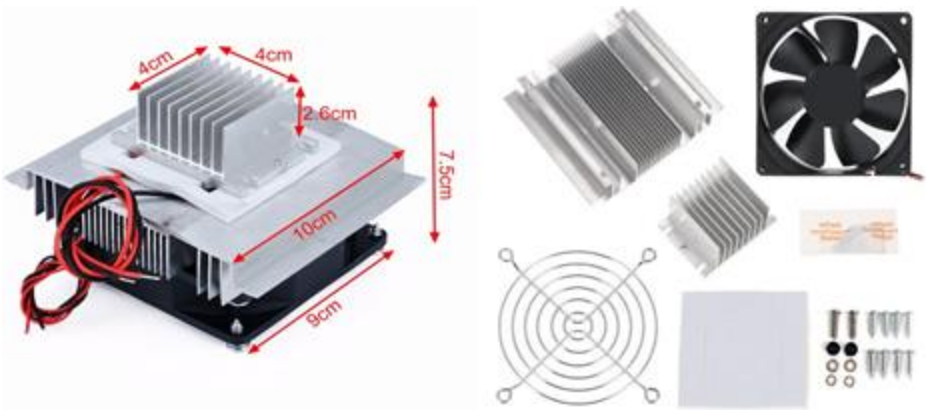

Fig. 4. TEC kit

Table 1
The features of TEC

Characteristics of TEC	Values(unit)
Model number	TEC1-12706
Operating voltage	12(V)
Maximum current, Imax	6(A)
Maximum voltage, Vmax	15.4(V)
Maximum power	92 (W)
Maximum temperature	138(^{o}C)
Dimensions	40*40* 3. 4(mm)

The two ends of the cooling model were opened to allow the air to inlet from the ambient to the vehicle cabin by free convection passing through the cold side fins and fans, as shown in Figure 5, Figure 6, and Figure 7.

The system operated for 30 minutes to reduce the cold side temperature of TECs; after that, the cooling fans inside the duct were operated to withdraw the cooling from the cold sides of TECs to be pushed by the air entering the duct as a result of free convection.

Fig. 5. Cooling duct

Fig. 6. The component of the cooling duct

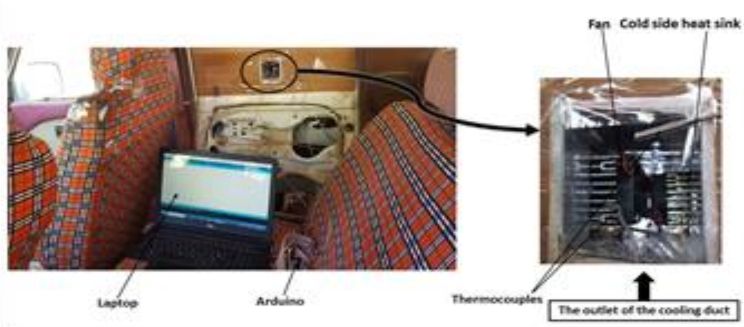

Fig. 7. The location of the cooling duct

4. Results and Discussions

Figure 8 shows the relation between solar radiation, ambient temperature, and time during the work. The solar radiation grew steadily from 8:45 a.m. to 9:15 a.m., increasing the ambient temperature. After that, there was a disturbance rise due to the clouds until the solar radiation was 268 W/m^2. Then, the solar radiation completed the increment steadily until it reached 340.9W/m^2 at 10:45 a.m.

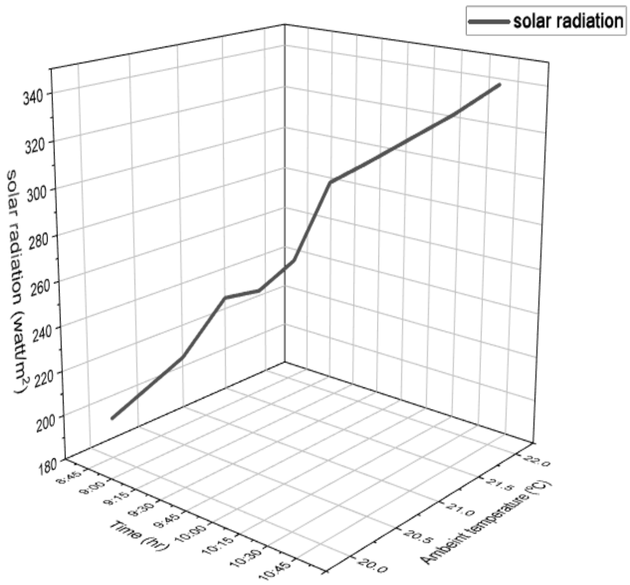

Fig. 8. The relation between solar radiation and time

The relationship between the total current and the temperature of the cold side is linear, as the current decreases as the temperature of the cold side decreases, as shown in Figure 9. The total current decreased from 29.5 A to 24.9 A by lowering the cold side temperature until it was zero degrees centigrade because of the decrease in the applied load. After that, Tc raised to 12.75 °C due to operating the fans inside the cooling duct. Then the temperature decreased until it reached 4.25 °C, and the current was 23.8 A.

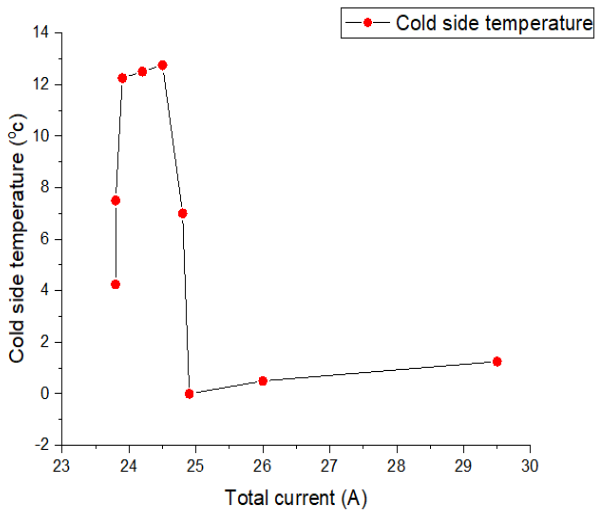

Fig. 9. The relation between the cold side temperature and total current

The variation between the ambient temperature and inlet velocity is explained in Figure 10. The ambient temperature regularly increased from 20 to 21 °C, and the inlet velocity rose from 0.35 m/s to 0.49 m/s. After that, the ambient temperature raised from 21 to 21.8 °C with approximately steady inlet velocity. Then, the ambient temperature increased from 21.8 to 22 °C, and the inlet velocity grew from 0.492 to 0.501 m/s.

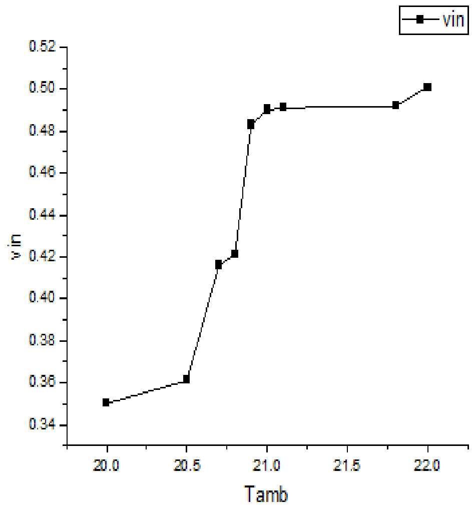

Fig. 10. The relation between inlet velocity and ambient temperature

Figure 11 presents the relation between the cold side temperature and the hot side temperature. The cold side temperature decreased from 1.25 °C to 0 °C, and the hot side temperature raised from 32 °C to 31.9 °C. After that, the cold side temperature increased and reached 12.75 °C, and the hot side temperature dropped to 31.5 °C because of the operation of the fans inside the cooling duct, which circulated the ambient air and passed it through the cold side fins. Then Tc started to drop regularly until it became 4.25 °C with a decline in Th to 31 °C. Therefore, the relation between Tc and Th is linear.

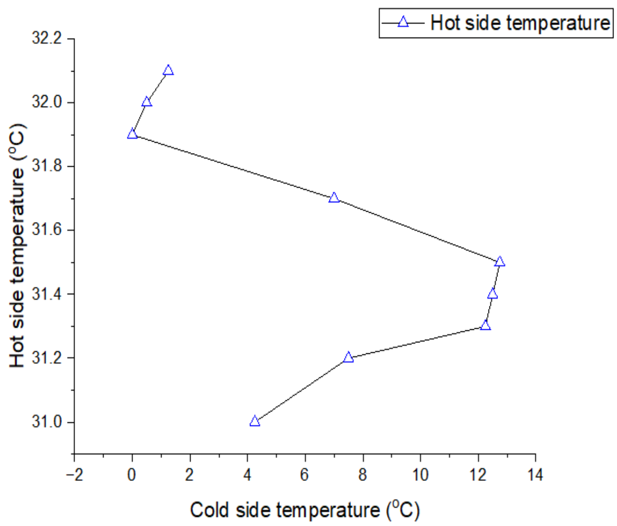

Fig. 11. The relation between hot side temperature and cold side temperature

Figure 12 shows the relation between temperature difference and coefficient of performance. COP increased steadily from 0 to 0.01371, and the temperature difference raised from 0 to 4 °C. Therefore, the relation between ΔT and COP is linear, as shown in Eq. (1) and Eq. (3).

$$Q_c = m^{\circ} * c_p * \Delta T \quad (1)$$

$$W_{in} = I * V \quad (2)$$

$$COP = \frac{Q_c}{W_{in}} \tag{3}$$

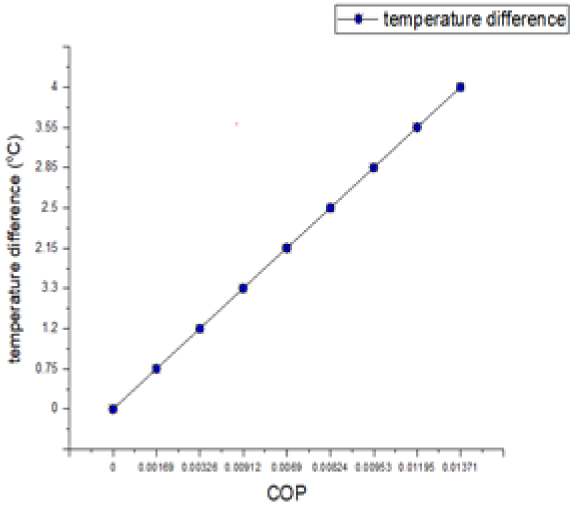

Fig. 12. The relation between temperature difference and coefficient of performance

Figure 13 shows the relation between the cop and the input work. The cop increased steadily from 0 to 0.0037, and the input work decreased from 354 to 298.8. After that, the input work was approximately sable, and the COP fell due to operating the fans inside the cooling duct. Then, the input work dropped sharply to 285.6, with the rise of the COP to 0.0138. The increase in COP was from Eq. (3) (the COP inverse relationship with the input work). The input work declined because it depended on the current and voltage, as shown in Eq. (2).

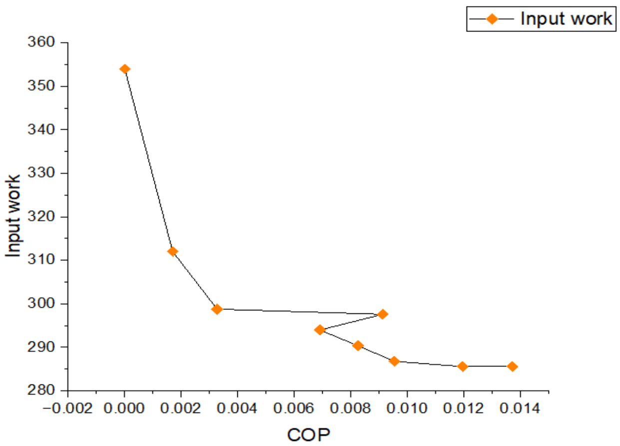

Fig. 13. The relation between input work and coefficient of performance

5. Conclusions

Thermoelectric modules based on the Peltier effect powered by solar energy are used to reduce the vehicle cabin temperature significantly. The low cost of the parts, the long lifespan, rising reliability, and the inexpensive and simple maintenance encourage using this technique.

i. The solar radiation increases with the rise in ambient temperature and daytime.
ii. Photovoltaic current grow with increasing solar radiation.
iii. The vehicle cabin temperature was decreased to 4 °C without operating the vehicle air conditioning system and without fossil fuel consumption.
iv. The consumption current declined with the reduction of the cold side temperature. The minimum current was 23.8 A with a Tc of 4.25 °C.
v. There is a relation between cold side temperature and hot side temperature. The minimum Tc was 4.25 °C with Th of 31°C.
vi. The coefficient of performance increases with decreasing the input work. The maximum COP was 0.0138.

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