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Advancement in Thermoelectric Innovation: Crafting a Portable Climate Control System

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Greenhouse gas emissions are on the rise globally due to increasing demands for electricity, vehicle usage, desertification, and inadequate waste management practices. In response to these challenges, a portable heater and cooler utilizing the thermoelectric effect have been developed. This device comprises four thermoelectric Peltier modules, a heat sink with four fans, two batteries, a charge controller, and a solar panel. The four Peltier modules, each capable of 50 watts, are interconnected in series and parallel configurations on the cover of a thermocol box. To ensure effective heating and cooling throughout the workspace, all modules are equipped with heat sinks and fans operating at 12V and 0.28A. To optimize thermal transfer, the Peltier modules are sandwiched between heat sinks using thermal paste, resulting in one side becoming hot and the

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other cold when power is supplied. These sandwich configurations are placed atop the thermocol box. Testing of the portable cooler and heater was conducted under various load conditions, including no load, 1 liter of water, and 2 liters of water, with batteries, for both cooling and heating. The fully charged batteries can power the entire experimental setup for 21 hours in each scenario. During cooling, the device achieved a minimum working area temperature (thermocol box) of 18.8°C under no load conditions and a minimum water temperature of 18.6°C for 1 liter of water. In heating mode, the experimental setup reached a maximum working area temperature of 42.4°C and a maximum water temperature of 33.3°C for 1 liter of water.

Keywords: Thermoelectric effect; peltier effect; peltier module; heat sink; solar photovoltaic system; battery; voltage stabilizer.

1. INTRODUCTION

Refrigeration is the process of extracting heat from a substance under controlled conditions, aiming to lower and maintain its temperature below that of its surroundings. It encompasses the scientific discipline focused on temperature reduction and maintenance in a given area or material [1-3]. Thermoelectric heating or cooling technology has recently regained attention due to its distinctiveness compared to traditional methods such as vapor compression and electric heating or cooling systems [4,5]. Thermoelectric (TE) Modules, solid-state devices functioning as heat pumps for both cooling and heating, operate based on the Peltier Effect occurring at the junctions of two semiconductors. A significant advancement in thermoelectricity occurred in 1821, credited to German scientist Thomas Seebeck [6-9]. He noted that when two dissimilar metals formed a closed circuit and their junctions were subjected to different temperatures, an electric current would flow continuously through the circuit.

There are three types of thermoelectric effects that occur:

1. The See beck Effect
2. The Peltier Effect
3. The Thomson Effect.

1.1 Peltier Effect

Conversely, the Peltier Effect is mainly associated with thermoelectric systems used for cooling or heating purposes. It functions by transferring heat between two unlike conductors or semiconductors as an electric current flow through a closed-circuit loop containing these materials. In this phenomenon, heat is taken in at one junction and conveyed to the opposite junction, leading to either heating or cooling depending on the direction of the electric current flow.

When comparing the two effects:

The Thomson Effect pertains to the creation of a voltage variance resulting from a temperature gradient, whereas the Peltier Effect concerns the movement of heat due to the passage of an electric current through a junction.

- Joule heating, which increases quadratically with current, leads to irreversible heat production within a conductor, unlike Peltier heat, which exhibits a linear relationship with current.
- The Seebeck Effect, which transforms heat flux into an electric current, differs from the Peltier Effect, where an electric current trigger either a heating or cooling effect based on its direction of flow.

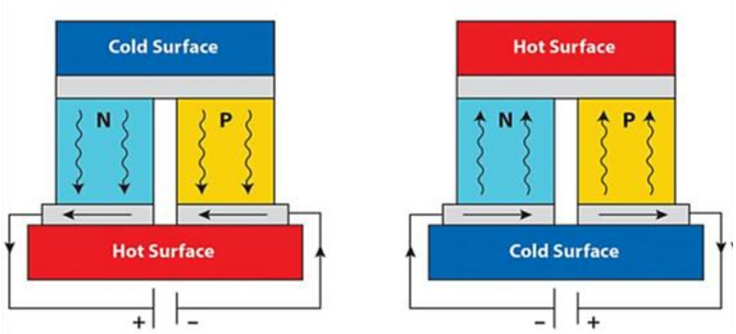

Fig. 1. Peltier effect

2. MATERIALS AND METHODS

In this study, the utilization of the thermoelectric refrigeration concept augmented by solar panel technology is explored. The solar panel system operates on the fundamental principle of solar cells, which harness photovoltaic (PV) cells to convert incident light into electrical energy. The generation of electron-hole pairs occurs upon illumination of the solar panel, with the quantity of these pairs being directly proportional to the brightness or intensity of light. Consequently, electrons migrate towards the N-type semiconductor while holes migrate towards the P-type semiconductor. The accumulation of both electrons and holes at the electrodes induces a potential difference, leading to the flow of current when a wire is connected. This generated current is then stored by a battery for subsequent utilization by the thermoelectric refrigerator.

In experimental investigations, the efficiency of solar cells integrated into thermoelectric refrigeration systems is significantly influenced by variables such as solar exposure intensity and the temperature gradient between the hot and cold sides of the thermoelectric module. The assessed refrigerator demonstrates the capacity to maintain temperatures within the refrigerated compartment within the range of 14 to 39 degrees Celsius, achieving a coefficient of performance (COP) of approximately 0.3 under specified operational conditions.

2.1 Cooling Load Calculations

Cooling load = Refrigeration Effect = $\mathrm{m} \times \mathrm{Cp} \times \frac{\Delta \mathrm{T}}{\mathrm{t}}$

Where; m= mass, Kg
Cp= specific heat of fluid, kJ/kg-K
ΔT= temperature difference, K
t = time required in sec

This formula gives cooling load and then it is possible to select number of Peltier Modules.

Selection of Number of Peltier Modules:-

1) Mass of water in kg,
2) Cp for Water kJ/kg-K,
3) Temperature Difference in K,
4) Time in second

Number of Modules =

$$\frac{Refrigeration\ Effect\ (W)}{Capacity\ of\ one\ Peltier\ Module\ (W)}$$

For better effect of heating and cooling in this system select 4 Peltier Modules for design of portable cooler and heater by thermoelectric effect for safer side.

Components and Description:-

1. Peltier Module
2. Thermocol Box
3. Cooling Fan
4. Heat Sink
5. Solar Panel
6. Charge Controller
7. Battery
8. Thermal Paste

The section delves into the results obtained from assessing the efficiency of a portable cooler and heater utilizing the principles of the thermoelectric effect. Over the course of our study, spanning from April 1st, 2020 to January 17th, 2020, we executed a comprehensive series of 11 experiments. These experiments entailed both cooling and heating trials, wherein we provided requisite power through two distinct means: a stabilizer drawing electricity from the grid, and a battery sourcing energy from solar power independently of the grid.

3. RESULTS AND DISCUSSION

As evidenced by the data presented in the Tables 1,2, a comprehensive total of 11 experimental trials were conducted, encompassing a variety of heating and cooling procedures facilitated by both a stabilizer connected to the grid and a battery harnessing solar power. Within the scope of the stabilizer-operated cooling experiment under zero load conditions, the recorded minimum temperatures for 1 liter and 2 liters of water were 19.6 ºC and 23.5 ºC, respectively, juxtaposed against the prevailing atmospheric temperatures of 23.5 ºC, 22.8 ºC, and 24.7 ºC, correspondingly. Similarly, during the heating experiment under stabilizer operation, the maximum temperatures achieved for 1 liter and 2 liters of water were 32.5 ºC and 31.2 ºC, respectively, in contrast to the ambient atmospheric temperatures of 18.7 ºC and 19.2 ºC, respectively. Meanwhile, in the context of the cooling trials conducted with the battery under zero load, the minimum temperatures attained for 1 liter and 2 liters of water were 18.8 ºC and 18.6 ºC, respectively, diverging from the atmospheric temperatures of 20.5 ºC and 21.4 ºC, respectively. Likewise, during the heating experiment utilizing the battery under zero load, the maximum temperatures recorded for 1 liter and 2 liters of water were 39.1 ºC and 25.1 ºC, respectively, in contrast to the atmospheric temperatures of 28.6 ºC and 20.9 ºC, respectively.

Table 1. Experimental results with Stabilizer (On grid supply)

	Cooling								Heating					
	Zero load		1 ltr of water			2 ltr of water			1 ltr of water			2 ltr of water		
	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)
Initial Temperature	27.9	25.8	34.5	25.4	22	30.2	27.5	28.2	14.9	16.6	16.2	14.5	16.5	17.8
Final Temperature	19.6	23.5	21.4	23.9	22.8	22.3	24.5	24.7	32.5	40.3	18.7	31.2	39	19.2

Table 2. Experimental results with Battery (Solar power)

	Cooling								Heating							
	Zero load		1 ltr of water			2 ltr of water			Zero load		1 ltr of water			2 ltr of water		
	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)
Initial Temperature	14.3	16.2	24.8	23.1	21.3	28	21.7	19.3	17	20.1	15.4	15.9	14.9	16.2	17.7	18.1
Final Temperature	18.8	20.5	18.6	19.9	21.4	17.7	18.9	20.7	39.1	28.6	25.1	29.3	20.9	19.3	22	20.6

Here;
T_1 = Temperature of water (ºC)
T_2 = Temperature inside thermocol box (ºC)
T_3 = Temperature of atmosphere (ºC)

4. CONCLUSION

The choice of power source significantly impacts the thermal performance of the project. When connected to the grid via a voltage stabilizer, average cooling and heating values are 9.76 ºC and 17.15 ºC, respectively. However, opting for solar PV technology lowers these values to 4.06 ºC for cooling and 11.53 ºC for heating. This suggests that solar PV technology provides more efficient cooling and heating solutions compared to grid power with a voltage stabilizer. Moreover, the battery's capacity to sustain operations for approximately 21 hours under varied atmospheric conditions enhances the project's resilience and autonomy. This feature ensures continuous functionality, especially during power outages or adverse weather conditions, contributing to reliability and uninterrupted service. In conclusion, selecting solar PV technology not only improves the project's energy efficiency but also enhances its resilience through the integration of a reliable battery system. These findings underscore the importance of sustainable energy solutions and robust backup mechanisms in achieving optimal performance and reliability in similar projects.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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