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Design & Development Of A Low-Cost Solar Refrigerator For Medicine Storage In Rural Areas & And The Army

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Abstract—This paper presents the design and development of a low-cost, energy-efficient solar-powered refrigerator aimed at addressing the refrigeration needs of rural and military areas where conventional electricity is unavailable. The system integrates a 12W photovoltaic panel with a thermoelectric cooling module (TEC1-12706), aluminum heat sinks, CPU fans, and a 12V rechargeable battery. The refrigerator maintains a temperature suitable for preserving medicines and perishable goods. The design emphasizes portability, cost-effectiveness, and environmental sustainability. Experimental results demonstrate effective cooling and battery backup performance under varying conditions.

Keywords—Solar refrigerator, thermoelectric cooling, Peltier module, rural technology, renewable energy, off-grid cooling.

1. INTRODUCTION

Refrigeration involves extracting heat from a given area or substance to achieve a temperature lower than that of the surrounding environment. Unlike conventional systems that rely on compressors or refrigerant fluids to transfer heat, thermoelectric refrigeration utilizes solid-state technology based on the Peltier effect. This effect is observed when a direct current is passed through a junction of two different semiconductors, resulting in heat absorption on one side and heat dissipation on the other.Use the enter key to start a new paragraph. The appropriate spacing and indent are automatically applied.

Thermoelectric coolers (TECs), also known as Peltier devices, offer several advantages over traditional refrigeration systems. As they do not contain moving parts, these systems are quieter, more durable, and less prone to mechanical failure. Furthermore, since they operate without refrigerants such as chlorofluorocarbons (CFCs), they present an environmentally friendly alternative that eliminates the risk of ozone layer depletion.

One of the key benefits of thermoelectric refrigeration is its compactness and precise temperature control, often within ±0.1°C. While their energy efficiency is generally lower compared to conventional systems, their simplicity and versatility make them ideal for specific applications—especially where size, weight, and reliability are critical. For example, TECs are used in electronics cooling, scientific imaging equipment, aerospace systems, and niche medical storage solutions.

In aerospace applications, thermoelectric modules help manage the thermal load created by sun-facing components and equipment in high-temperature environments. Similarly, in imaging devices like digital cameras and CCD sensors, they minimize thermal noise to enhance sensitivity and image quality.

Moreover, in small-scale or low-capacity refrigeration systems—where conventional vapor-compression systems lose efficiency—thermoelectric technology becomes more favorable. With better control over compartment temperatures, they are particularly suitable for storing sensitive items like food or insulin.

This project focuses on integrating thermoelectric cooling with solar energy. The system draws power from solar panels and stores it in a battery. When the sun is unavailable, the battery powers the cooler efficiently, ensuring continuous operation with minimal energy consumption. This approach is ideal for off-grid applications in rural and military areas where stable electricity access is limited.

2. LITERATURE SURVEY

Solar-powered refrigeration systems have gained traction due to their potential to provide sustainable cooling solutions in off-grid and rural areas. Various researchers have explored thermoelectric cooling and energy management strategies to enhance system efficiency.

R. Mehenge [1] designed a solar-powered thermoelectric refrigeration system targeting pharmaceutical preservation, emphasizing portability and thermal stability for thermolabile substances. Similarly, P. Taywade [2] conducted experimental work on portable solar refrigeration units for rural regions, demonstrating their practicality and effectiveness in tropical environments.

P. R. Kumar [3] developed a compact solar thermoelectric refrigerator, focusing on system integration and energy efficiency. K. Rokde [4] proposed a Peltier-based eco-friendly refrigeration unit optimized for rural use, utilizing minimal resources and energy.

K. M. Mohiuddin [5] investigated aluminum heat sink designs in conjunction with thermoelectric generators, identifying optimal fin structures to improve heat dissipation. Battery storage and performance were discussed by S. Kitaronka [6], highlighting the reliability of lead-acid batteries in solar systems.

Thermal management through forced air cooling was analyzed by Bansal [7], with a specific focus on DC fan applications in high-performance computing systems, relevant to thermoelectric module cooling. C.-K. Jeon [8] examined the insulation properties of glass wool and mineral wool, validating their effectiveness in minimizing heat transfer in confined environments.

S. P. Prakash [9] compared two common Peltier modules—TEC1-12706 and TEC1-12715—under experimental setups, offering insights into their cooling capacity and energy consumption trade-offs. Battery charging efficiency from 12V solar sources was evaluated by R. V. Romero [10], confirming stable energy storage performance suitable for small-scale refrigeration.

These studies collectively provide a robust foundation for developing an affordable and effective solar refrigerator using thermoelectric technology, guiding both component selection and system architecture.

3.WORKING SETUP

The first and most crucial step in the working of a solar refrigerator is the conversion of sunlight into usable electricity. This is achieved using a solar panel, which consists of photovoltaic (PV) cells made of semiconductor materials like silicon. When sunlight hits the PV cells, it excites the electrons, creating a flow of electric current through the circuit. This electricity is direct current (DC), which is stored in a 12V rechargeable battery. The stored energy is later used to power the cooling system, ensuring continuous operation even when sunlight is unavailable (such as during the night or cloudy days).

The core cooling mechanism of this solar refrigerator is thermoelectric cooling, which relies on a Peltier module (TEC1-12706). This module operates on the Peltier effect, where the passage of electricity through two dissimilar semiconductor materials creates a temperature difference. When DC electricity flows through the Peltier plate, one side of the module absorbs heat (cold side), while the other side dissipates heat (hot side). The cold side is placed inside the refrigerator chamber, allowing heat to be absorbed from the stored medicines or food. The hot side is attached to an aluminum heat sink with a CPU fan, which helps in efficiently dissipating the absorbed heat to the surrounding air. The amount of cooling depends on the voltage applied and the thermal resistance of the materials used. Since Peltier modules work without refrigerants or compressors, they are eco-friendly, compact, and require minimal maintenance.

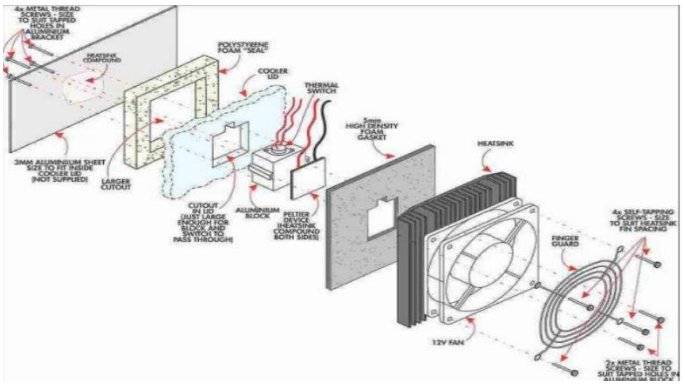

Fig. 1 - Explode view of peltier setup

3.1 Peltier device

The cooling mechanism of the refrigerator relies on the Peltier module (TEC1-12706), which operates on the thermoelectric effect. This module is installed inside the refrigerator compartment, with one side acting as a cooling plate and the other side requiring a heat sink for effective heat dissipation

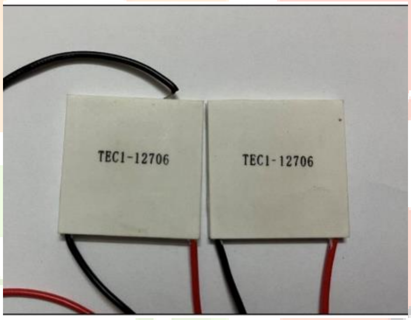

Fig. 2- Peltier device

3.2 Solar panel& charge controller

Converts sunlight into electrical energy. A 12W solar panel is used to charge the battery and power the cooling system.

Fig. 3 - Solar panel& charge controller

3.3 Battery

Stores the energy generated by the solar panel. A 12V lead-acid battery is used to ensure continuous operation, even during low sunlight conditions.

Fig. 4. Battery12V

3.4 Heat Sink

Absorbs and dissipates heat generated by the Peltier module. An aluminium heat sink is used for efficient heat dissipation.

Fig. 5. Aluminium Heat Sink

3.5 CPU Fans

Helps in active heat dissipation from the heat sink to maintain the cooling effect. Two fans are used: one for heat dissipation and one for internal air circulation.

Fig. 6. CPU FANS

3.6 Temperature Sensor

Monitors the internal temperature of the refrigerator. Ensures proper cooling and prevents overheating.

Fig. 7. Temperature Sensor

3.7 Insulation Material (Glass Wool)

Iron coil insulation is used instead of traditional insulation materials. It helps in maintaining the internal temperature by reducing heat transfer. Ensures better thermal stability and energy efficiency

Fig 8. Insulation Material

3.8 Experimental Setup

The fabrication process involved careful integration of each component following the design specifications. Electrical connections were securely made using insulated wires,ensuring minimal resistance losses and safe operation

Fig, 9.EXPERIMENTAL SETUP

3.9 Connection

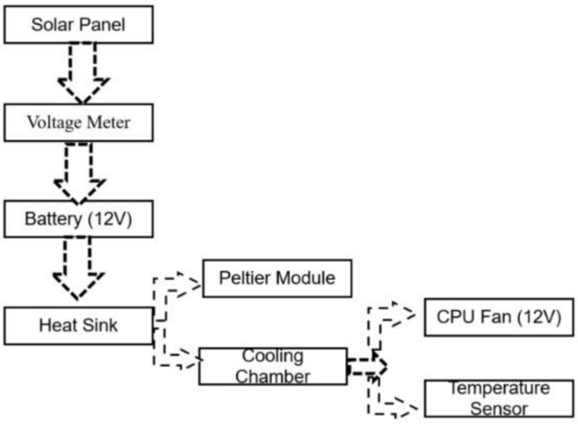

Fig.9.Connection

4.0 CALCULATION

STEP 1: ENERGY INPUT FROM SOLAR PANEL SOLAR PANEL POWER:

12W AVERAGE SUNLIGHT HOURS (EFFECTIVE): 6 HOURS/DAY (ASSUMING OPTIMAL CONDITIONS)

ENERGY GENERATED PER DAY:

E SOLAR = POWER * TIME = 12W * 6 = 72 WH

STEP 2: BATTERY CAPACITY

BATTERY VOLTAGE: 12V BATTERY

CAPACITY: 7AH

STORED ENERGY:

EBATTERY = VOLTAGE * CAPACITY= 12V * 7AH = 84 WH

TOTAL AVAILABLE ENERGY (SOLAR + BATTERY): ETOTAL = 72 + 84 = 156 WH

STEP 3: POWER CONSUMPTION OF COMPONENTS

1.PELTIER MODULE (TEC1-12706): 30 W (60 W FOR 2)

2. CPU FANS (4 PIECES, 12V EACH, 0.25A): PFAN = 4 * 12V * 0.25A = 12W

TOTAL POWER CONSUMPTION: PTOTAL = 60W + 12W + 2W = 74W

5.0 RESULTS AND OBSERVATIONS

TIME (MINTUES)	INTERNAL TEMPERATURE (0^0C)
0	30^0C
10	25^0C
20	20^0C
30	15^0C
40	12^0C
45	9^0C

TABLE NO 5.1 RESULT

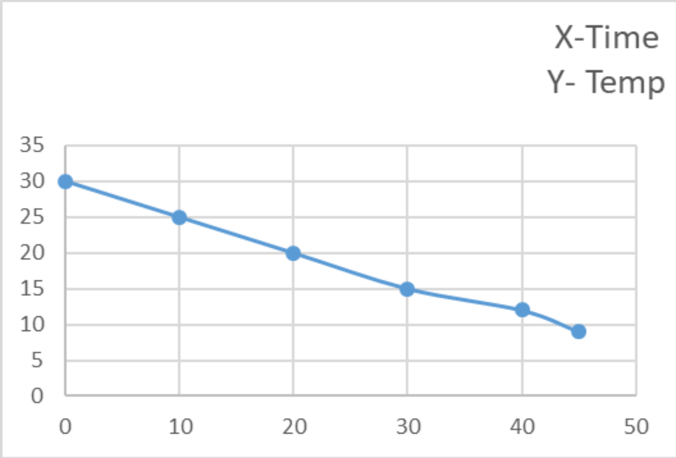

Fig no 5.1 Graph Time & Temperature

- At time 0 min, the internal temperature is 30°C (starting point, likely room temperature).
- By 10 minutes, it drops to 25°C, showing the cooling system has started reducing the temperature. 41
- At 20 minutes, it reaches 20°C, continuing a steady decline. • By 30 minutes, the temperature is 15°C, showing consistent cooling.
- At 40 minutes, it drops further to 12°C, but the rate of cooling slightly slows down (smaller temperature drop compared to earlier).
- By 45 minutes, it's 9°C, indicating that the system is approaching its lower cooling limit or set

5.1 Overall Observation:

- The graph would show a negative slope, with the curve gradually flattening as time an increase, which is typical for cooling — fast drop initially, slower change as it nears the system's minimum capacity.
- This behavior often indicates thermal inertia or system limits, where cooling becomes less efficient the closer it gets to its minimum possible temperature.

6.0 CONCLUSION

The solar refrigerator developed in this project successfully demonstrates an ecofriendly and cost-effective cooling solution for rural areas and military applications. By utilizing solar energy as the primary power source, the system eliminates dependency on conventional electricity, making it a sustainable alternative for medicine storage in remote locations.

The 3D modeling and design in SolidWorks helped in visualizing the assembly and optimizing the component layout for better efficiency. The Peltier module (TEC1-12706), combined with a heat sink and CPU fans, effectively created a cooling effect, ensuring stable temperature conditions suitable for storing medicines.

The prototype was tested for temperature regulation and power consumption, showing promising results. The low cost and easy maintenance of this refrigerator make it a viable solution for regions with limited power supply

7.0 FUTURE SCOPE

The future scope of the Solar Refrigerator for Rural Areas and the Army includes several advancements and improvements to enhance efficiency, reliability, and adaptability. Here are some key points:

1. Higher Efficiency with Advanced Peltier Modules

- Replacing the TEC1-12706 with more advanced Peltier modules (like TEC1- 12715 or multi-stage Peltier modules) can improve cooling efficiency.
- Using dual Peltier arrangements for better temperature control.

2. Smart Monitoring and Automation

- Integrating an IoT-based system to monitor and control the temperature remotely via a mobile app.
- Adding automated temperature regulation based on real-time data.

3. Energy Optimization

- Implementing Maximum Power Point Tracking (MPPT) for efficient solar power utilization.
- Using Lithium-ion or LiFePO4 batteries instead of lead-acid for better energy storage and longer lifespan. aster relief operations.

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12.Fig.3 Solar Panel https://images.app.goo.gl /oPzyXagyBGe1qveM7