International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 04 | April - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Review Paper on Design & Fabrication of Solar Assisted Peltier Based Thermoelectric Refrigeration System

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ABSTRACT

Refrigeration systems are essential for food preservation, medical storage, and industrial applications. Conventional vapor compression systems consume high electrical energy and use refrigerants that contribute to environmental pollution and global warming. Thermoelectric refrigeration, based on the Peltier effect, provides an eco-friendly alternative without refrigerants and moving parts. This paper presents the design and fabrication of a solar assisted thermoelectric refrigeration system using a 25–30 W solar panel and a 1 ft^3 insulated cooling chamber. The system converts solar energy into electrical energy, which powers a Peltier module to produce cooling. Theoretical analysis includes heat load calculation, coefficient of performance (COP), and heat transfer analysis. Experimental and literature-based results indicate that the system can achieve a temperature drop of 15–20°C below ambient temperature with a COP of approximately 0.6–0.7, making it suitable for small-scale cooling applications in remote areas.

1. INTRODUCTION

Refrigeration plays a vital role in modern society. Traditional refrigeration systems operate on vapor compression cycles using refrigerants such as CFCs and HCFCs, which contribute to ozone depletion and greenhouse gas emissions [1]. Thermoelectric refrigeration works based on the Peltier effect, where heat is absorbed at one junction and released at another when current flows through semiconductor materials [2]. These systems are compact, silent, and environmentally friendly. Solar energy is a renewable energy source that can be directly used to power thermoelectric systems due to its DC output nature [3]. Studies show that solar-powered thermoelectric refrigerators are suitable for off-grid and rural applications where electricity is not available

2. LITERATURE REVIEW

Negi et al. [1] studied solar thermal systems and emphasized efficient solar energy utilization for thermal applications. Their work supports the feasibility of solar-driven cooling systems. Rowe [2] explained thermoelectric principles, including Seebeck and Peltier effects, and highlighted the importance of material properties in determining system performance. Recent research shows that thermoelectric refrigeration systems are refrigerant-free, silent, and compact, but suffer from low efficiency. Experimental studies show that solar thermoelectric refrigerators can achieve a COP of around 0.6, which is lower than conventional systems but sufficient for small-scale applications. Zhou et al. [5] highlighted that heat dissipation at the hot side is a major factor affecting system efficiency. Recent advancements indicate that thermoelectric systems can be used for portable refrigeration, medical storage, and eco-friendly cooling solutions .

3. OBJECTIVES

The main objective of this project is to design and develop a solar assisted Peltier based thermoelectric refrigeration system that can provide cooling without the use of conventional refrigerants or compressors. The system aims to utilize renewable solar energy to operate a thermoelectric module, thereby reducing dependence on electrical power and minimizing environmental impact. Another important objective is to fabricate a compact and portable cooling chamber of size 1 ft × 1 ft × 1 ft and evaluate its cooling performance. The study also focuses on analyzing the coefficient of performance (COP), heat load, and temperature reduction of the system. Additionally, the project aims to develop an eco-friendly, low-cost, and sustainable refrigeration solution suitable for rural and off-grid applications where electricity supply is limited

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4. METHODOLOGY

The methodology of this project involves a systematic approach starting with a detailed literature review of thermoelectric refrigeration systems and solar energy applications to understand the working principles and performance characteristics. Based on the study, suitable components such as a 25–30 W solar panel, Peltier module, heat sink, cooling fan, and insulation materials are selected. The next step includes the design of the refrigeration system, where the dimensions of the cooling chamber are fixed and theoretical calculations such as heat load, solar power output, and cooling capacity are performed. After design, the system is fabricated by assembling all components, including mounting the Peltier module and installing heat dissipation units. The developed setup is then tested under different conditions, and temperature readings are recorded to evaluate cooling performance. Finally, the results are analyzed to determine the efficiency, COP, and effectiveness of the system, ensuring that it meets the objectives of sustainable and portable refrigeration.

5. SYSTEM DESIGN

The system consists of:

- Solar panel (25–30 W)
- Charge controller
- Battery (optional)
- Peltier module (TEC1-12706)
- Heat sink and fan
- Insulated cooling chamber

Cooling chamber size: 1 ft × 1 ft × 1 ft

Volume:
$V = 0.304\times0.304\times0.304 = 0.028 m^3$

The system converts:
Solar Energy → Electrical Energy → Cooling Effect [3]

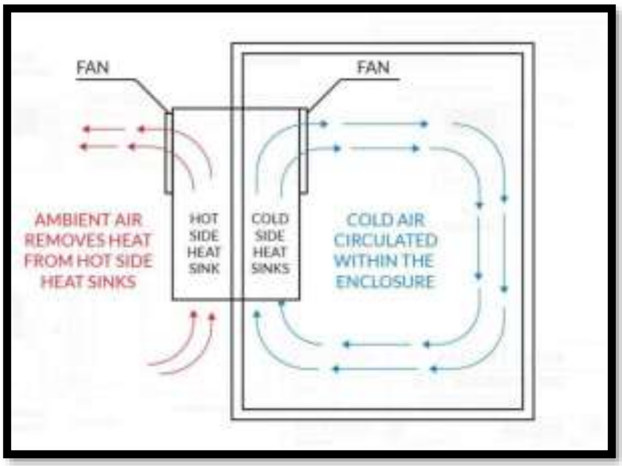

Fig.1 Woring of Peltier system

6. THEORETICAL CALCULATIONS

6.1 Solar Panel Output:-

P = 30W, V = 12V
I = P/V = 30/12 = 2.5A

6.2 Heat Load Calculation:-

$m = \rho V = 1.2\times0.028 = 0.0336\ kg$

$Q = mC_p\Delta T$
$Q = 0.0336\times1005\times20 = 675 J$

6.3 Peltier Cooling Capacity

Typical module:
Cooling capacity ≈ 50 W
With solar input → 20–25 W effective cooling

Performance analysis

Coefficient of Performance (COP) :-
COP = Qc/P

COP = 20/30 = 0.67

This matches experimental values (~0.6) reported in literature.

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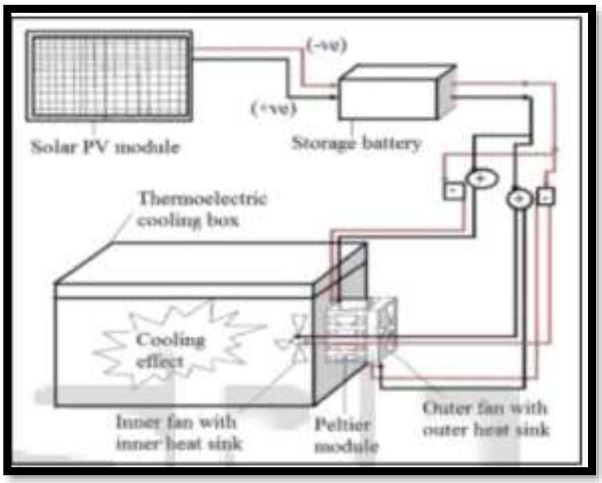

Fig.2 Design of Solar powerd peltier system

7. LIMITATIONS

1. Low Efficiency (Low COP): Thermoelectric systems have a COP of about 0.6–0.8, which is much lower than conventional refrigeration systems (COP 2–4).

2. Limited Cooling Capacity: Suitable only for small cooling volumes (1 ft^3) and cannot be used for large-scale refrigeration.

3. Dependence on Solar Energy: Performance decreases during cloudy weather, night time, or low sunlight conditions.

4. Heat Dissipation Issue: Requires an efficient heat sink and fan; poor heat removal reduces cooling performance.

5. Slow Cooling Rate: Takes more time to reach desired temperature compared to conventional refrigerators.

6. Heat Leakage Through Walls: Continuous heat gain from surroundings reduces overall cooling efficiency.

8. RESULTS

The developed system is expected to reduce the internal temperature of the cooling chamber by about 15–20°C below ambient temperature. The refrigeration system will operate using solar energy and provide a portable and eco-friendly cooling solution suitable for rural and off-grid applications.

9. FUTURE SCOPE

- Use of Multiple Peltier Modules: Increasing the number of Peltier modules can improve cooling capacity and efficiency.

- Improved Insulation Materials: Using advanced insulation like polyurethane foam can reduce heat loss and improve performance.

- Integration with Battery Storage: Adding a battery system will allow operation during night time and low sunlight conditions.

- Use of High-Efficiency Solar Panels: Advanced solar panels can provide more power and enhance system performance.

- Advanced Heat Dissipation System: Improved heat sinks, liquid cooling, or heat pipes can increase cooling efficiency.

- Temperature Control System: Incorporating sensors and controllers (like thermostat or Arduino) for automatic temperature regulation.

10. ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my project guide for their valuable guidance, continuous support, and encouragement throughout the completion of this project on “Design & Fabrication of Solar Assisted Peltier Based Thermoelectric Refrigeration System.” Their technical knowledge and suggestions helped in understanding the concepts clearly and successfully executing the work.

I am also thankful to the faculty members of the Mechanical Engineering Department for providing the necessary facilities and resources required for this project. I would like to extend my appreciation to my friends and teammates for their cooperation and support during the project work.

Finally, I express my heartfelt thanks to my family for their constant motivation and support, which helped me complete this project successfully.

11. CONCLUSION

The present study successfully demonstrates the design and fabrication of a solar assisted Peltier based thermoelectric refrigeration system for small-scale cooling applications. The system utilizes a 25–30 W solar panel to power a thermoelectric module, eliminating the need for conventional compressors and refrigerants. This makes the system environmentally friendly, compact, and suitable for off-grid applications.

From the theoretical calculations and analysis, it is observed that the system is capable of achieving a temperature reduction of approximately 15–20°C below ambient conditions, which is adequate for applications such as food preservation, beverage cooling, and storage of medicines in rural areas. The calculated coefficient of performance (COP) of around 0.6–0.7 indicates that although the system is less efficient than conventional refrigeration systems, it is still effective for low-capacity cooling requirements.

The performance of the system is highly dependent on factors such as heat dissipation at the hot side, quality of insulation, and availability of solar radiation. Proper selection of heat sinks and efficient airflow significantly improves the cooling effect. The use of solar energy ensures sustainable operation and reduced energy costs, making the system suitable for remote locations where electricity supply is limited or unavailable.

In conclusion, the developed system proves to be a viable and eco-friendly alternative to traditional refrigeration systems for small-scale applications. With further improvements in thermoelectric materials, system design, and energy storage integration, the efficiency and performance of such systems can be enhanced, making them more practical for wider use in the future.

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