International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048
Volume 10, Issue 6, pp 140-149, June-2026
https://doi.org/10.47001/IRJIET/2026.106016

Design & Development of Solar Peltier Plate Refrigerator

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***Abstract* - The growing need for sustainable and energy efficient technologies has accelerated research into alternative refrigeration systems. Conventional refrigeration systems rely heavily on electricity and use refrigerants that contribute to environmental pollution and global warming. This creates a need for sustainable and energy-efficient cooling alternatives, especially for remote and off-grid areas. This paper addresses this issue by proposing a solar-powered Peltier plate refrigerator as an eco-friendly solution for small-scale refrigeration needs. The main objective of the study is to design, develop, and evaluate a compact refrigeration system that operates using renewable solar energy and thermoelectric cooling technology. The system is based on the Peltier effect, where a temperature difference is created when electric current passes through a thermoelectric module. The setup includes a solar photovoltaic panel, Peltier module, heat sinks, cooling fans, temperature sensors, and battery. The methodology involves designing the system, assembling components, and conducting experimental testing under varying environmental conditions to evaluate performance based on temperature difference. However, performance is influenced by ambient temperature and heat dissipation efficiency. In conclusion, the solar-powered Peltier refrigeration system presents a sustainable, portable, and low-maintenance cooling solution. Although it is less efficient compared to conventional systems, its eco-friendly operation and suitability for off-grid applications make it a promising alternative. This study contributes to the development of green refrigeration technologies and supports the transition toward renewable energy-based solutions.**

Keywords: Peltier module, Water cooling, Refrigeration, Solar Energy, Solar-Powered Refrigerator, Peltier Effect, Thermoelectric Cooling, Renewable Energy, Solar Photovoltaic; Sustainable Cooling, Green Refrigeration, Off-Grid Applications.

I. INTRODUCTION

Refrigeration plays a vital role in modern society, particularly in food preservation, medical storage, and industrial applications. Conventional refrigeration systems primarily operate on the vapor compression cycle, which involves the use of refrigerants such as chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs). These refrigerants have been identified as major contributors to ozone layer depletion and global warming. Additionally, conventional vapor compression systems are highly dependent on uninterrupted electrical power and involve complex mechanical components, leading to increased energy consumption, maintenance requirements, and operational costs. Their reliance on chemical refrigerants also raises serious environmental concerns. At the same time, currently available thermoelectric refrigeration systems, although environmentally friendly, exhibit low efficiency, inadequate heat dissipation, and limited cooling performance. These challenges create a gap between the availability of cooling technologies and their effective use in rural, portable, and low-power applications, highlighting the need to address these performance and accessibility issues through improved system design.

In recent years, thermoelectric refrigeration has gained attention as an alternative cooling technology. It is based on the Peltier effect, where a temperature difference is created across a thermoelectric module when direct current flows through it. This solid-state cooling method eliminates the need for refrigerants and mechanical compressors, resulting in a compact, lightweight, and low-maintenance system. However, thermoelectric systems generally suffer from lower efficiency compared to conventional methods. This study is done to create an eco-friendly and low-cost refrigeration system that can work without regular electricity. Normal refrigerators use a lot of power and harmful gases, which are not good for the environment and are difficult to use in rural areas. This project uses solar energy and a Peltier module to develop a small, portable cooling system. The aim is to provide an easy and reliable solution for storing food and medicines in places where electricity is not available, and also to improve the performance of thermoelectric cooling systems.

In future, this study can be extended to improve the efficiency and performance of the solar Peltier refrigerator by using advanced thermoelectric materials and better heat sink

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Volume 10, Issue 6, pp 140-149, June-2026
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designs for effective heat dissipation. The system can be upgraded to support larger storage capacity and enhanced insulation to maintain lower temperatures for longer durations. Integration with battery storage can ensure continuous operation during low sunlight conditions. Additionally, smart monitoring systems can be added for temperature control and energy management. The technology can be widely applied in real-life areas such as vaccine storage, food preservation, and portable cooling in rural and remote locations. Further research can also focus on reducing cost, improving reliability, and making the system suitable for commercial and large-scale applications.

II. LITERATURE REVIEW

The findings of this study demonstrate that the solar Peltier plate refrigerator is an effective and eco-friendly alternative to conventional refrigeration systems, particularly for off-grid and rural applications. The system successfully utilized solar energy to power a thermoelectric module, achieving a noticeable temperature reduction from 34.3°C to approximately 16–18°C within 30 minutes. This confirms its capability to provide reliable cooling for perishable items such as food and medicines. the research highlights the potential of solar-powered thermoelectric refrigeration as a cost-effective and sustainable solution, with scope for further improvements in efficiency and performance.[1]

The study follows an experimental and design-based methodology involving the fabrication of a mini solar refrigerator using a Peltier module. A photovoltaic solar panel is used to generate electrical energy, which is stored in a battery and supplied to the system. The setup includes components such as a heat sink, cooling fan, and control unit to regulate temperature. Performance evaluation is conducted by observing cooling efficiency, temperature variation, and system operation under different conditions.[2]

Design and Development of Solar Powered Thermoelectric Refrigeration System for Rural Region: This study focuses on designing an ecofriendly solar thermoelectric refrigeration system using Peltier modules powered by solar energy, addressing environmental concerns of traditional refrigerants and proposing a renewable energy cooling approach. [3]

The research introduces the integration of phase-change materials (PCMs) with solar-powered refrigeration systems to address the major limitation of solar energy its intermittent availability. It provides a systematic classification of solar refrigeration technologies and analyzes different system configurations and components in detail. The evaluation of PCM integration strategies, including selection criteria based on thermal properties such as latent heat, phase-change temperature, and conductivity. The study also highlights performance enhancement techniques and presents a comparative analysis of existing approaches, identifying research gaps and suggesting future improvements. Overall, the paper advances the field by combining thermal energy storage with solar cooling to improve efficiency, reliability, and continuous operation.[4]

Research paper demonstrates that a solar-powered Peltier plate refrigeration system is a feasible and eco-friendly solution for low-capacity cooling applications. The system achieved a temperature reduction from approximately 30°C to 14–16°C with a maximum temperature difference of about 20–24°C and a COP in the range of 0.35–0.55. Performance was found to be strongly dependent on solar radiation and effective heat dissipation at the hot side. Although the system exhibits lower efficiency compared to conventional refrigeration, its advantages such as absence of refrigerants, low maintenance, and operation on renewable energy make it suitable for portable and off-grid applications.[5]

The research introduces a portable, solar-powered thermoelectric refrigeration system specifically designed for rural and off-grid applications, which distinguishes it from conventional studies focused on stationary setups. The lies in the integration of compact photovoltaic power with a lightweight Peltier-based cooling unit, enabling mobility and ease of use in remote areas. Additionally, the work emphasizes low power consumption with direct solar operation, reducing dependence on grid electricity, while maintaining an eco-friendly approach by eliminating refrigerants. The study also contributes by targeting practical rural usability, including simplicity, cost-effectiveness, and portability, rather than only theoretical performance analysis.[6]

This review paper provides a comprehensive consolidation of thermoelectric module principles and applications, with a focused explanation of the Seeback and Peltier effects in practical cooling systems. The key contribution lies in systematically comparing thermoelectric refrigeration with conventional vapor compression systems, highlighting advantages such as compactness, reliability, and environmental safety. Unlike experimental studies, the paper offers a broad analytical perspective by integrating findings from multiple research works, helping to identify current limitations like low efficiency and guiding future improvements in thermoelectric materials and system design.[7]

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This research presents a novel integration of a solar-powered Peltier refrigeration system with real-time remote monitoring, enhancing both energy efficiency and system reliability. The key finding is the use of sensor-based monitoring (temperature and power parameters) to optimize performance and ensure stable cooling in remote, off-grid locations. Unlike conventional designs, the system emphasizes smart energy management and sustainability, enabling better utilization of solar energy while maintaining eco-friendly operation without refrigerants. This approach significantly improves usability in areas with unreliable electricity by combining thermoelectric cooling with digital monitoring for efficient and controlled operation.[8]

The study reports a key new finding in achieving an improved coefficient of performance (COP) of approximately 0.61, which is relatively higher than typical solar Peltier refrigeration systems, indicating enhanced efficiency. It also demonstrates that with optimized operating conditions and better heat dissipation, thermoelectric cooling can produce stable and significant temperature reduction suitable for medicine and food storage. Additionally, the research highlights that solar-powered thermoelectric refrigeration can deliver reliable performance under real environmental conditions, making it a more practical solution for off-grid applications compared to earlier low-efficiency designs.[9]

The study presents a contribution through the integration of performance analysis with life cycle assessment of a portable solar thermoelectric refrigerator, going beyond conventional experimental studies. A key finding is the system's ability to achieve a significant internal temperature reduction while maintaining good agreement between experimental and simulation results, validating the design approach. Additionally, the research demonstrates economic feasibility and long-term sustainability, highlighting that portable solar TEC systems can be both technically reliable and cost-effective. This combined evaluation of thermal performance, simulation validation, and life cycle viability represents an important advancement toward practical deployment in real-world applications.[10]

This research investigates enhanced heat sink designs to improve thermoelectric refrigerator performance, showing that thermal management improvements can boost cooling efficiency while addressing space and power constraints.[11]

It presents a comprehensive analysis of solar photovoltaic-powered thermoelectric cooling systems, highlighting key advancements in performance enhancement. The study identifies that system efficiency is primarily limited by low COP (~0.5 for a 20°C temperature difference) and emphasizes that improved heat dissipation and advanced thermoelectric materials (higher figure of merit, ZT) are critical for performance improvement. A significant finding is that overall system efficiency depends on both PV efficiency and thermoelectric performance, making optimization of both essential. The paper also highlights recent progress in nanostructured materials and system design, indicating potential for future efficiency improvements and wider application of solar thermoelectric refrigeration systems.[12]

The study demonstrates that a solar-powered thermoelectric system based on the Peltier effect can effectively perform both cooling and heating by reversing current flow. It achieved a temperature drop from 32°C to 15.5°C in 35 minutes and heating up to 60°C in 20 minutes, validating the concept of solid-state heat transfer using semiconductor junctions. The key finding confirms that such systems are feasible, eco-friendly, and suitable for off-grid applications, with further performance improvement possible through better heat dissipation and module optimization.[13].

This study develops and experimentally evaluates a compact thermoelectric cold storage unit using Peltier modules, demonstrating measurable temperature reduction under real operating conditions. The system's performance is quantified through Coefficient of Performance (COP) analysis, highlighting the impact of input power, heat dissipation, and insulation on efficiency. Results indicate that proper thermal management and optimized electrical input significantly improve cooling effectiveness, making thermoelectric refrigeration a viable low-power solution for small-scale and portable cold storage applications.[14]

The study experimentally demonstrates a solar-powered thermoelectric refrigerator based on the Peltier effect, where heat is absorbed at one junction and rejected at another using semiconductor modules. With two Peltier modules powered by a PV-battery system, the setup achieved a 14°C temperature drop (30.9°C to 16.9°C) in 22 minutes, operating at ~26.4 W with a runtime of 3.18 hours. The system shows moderate cooling performance but low coefficient of performance (COP), highlighting limitations in efficiency and suitability mainly for small-scale applications.[15]

It presents significant advancements in solar-powered thermoelectric refrigeration for rural applications. The system demonstrates effective integration of photovoltaic (PV) panels with thermoelectric (Peltier) modules, achieving a reliable temperature drop suitable for small-scale cooling

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needs such as food and medicine storage. A key finding is the improvement in system efficiency through optimized heat sink design and enhanced heat dissipation, which directly increases the coefficient of performance (COP). The research also highlights that direct DC operation from solar panels reduces energy conversion losses, making the system more viable in off-grid regions. Additionally, the system proves to be low-maintenance, environmentally friendly, and economically feasible, making it a sustainable alternative to conventional refrigeration in rural areas with limited electricity access.[16]

III. GAP IDENTIFICATION

Although Peltier modules are widely used for compact and eco-friendly refrigeration, a major limitation identified in existing literature and prototypes is the excessive heat generated on the hot side of the module, which, if not effectively dissipated, significantly reduces cooling performance and can even damage the module. Most low-cost solar thermoelectric refrigerator designs rely only on Air cooling using aluminum heat sinks and small DC fans; however, this approach is often inadequate because the heat flux produced by high-power modules exceeds the dissipation capacity of air convection alone. As a result, the cold-side temperature drops only marginally, the coefficient of performance decreases, and long-term operational reliability is compromised due to thermal stress. This performance gap indicates the need for a more efficient heat-rejection mechanism. To overcome this challenge, the proposed system incorporates a water-cooling arrangement, which offers superior thermal conductivity and higher heat-transfer rates compared to air. By integrating a water block, pump, and radiator, the system ensures faster removal of heat from the hot side, enabling the Peltier module to maintain lower temperatures, deliver improved cooling efficiency, and operate safely over extended periods. This modification directly addresses the identified gap and enhances the overall performance of the solar Peltier refrigerator. The results and discussion may be combined into a common section or obtainable separately. They may also be broken into subsets with short, revealing captions. This section should be typed in character size 10pt Times New Roman, Justified.

IV. METHODOLOGY

Literature Survey: Review of research paper, journals and finding the new key points from it. Clearing basic concept from it.

Gap Identification: Finding what is missing, insufficient, or needs improvement in the existing projects which our projects will address.

Define Requirements: Define its function, performance, hardware, electrical, mechanical requirements.

Designing Calculator: Find temperature difference, conduction head load, power system analysis and all other needed data.

Select the Component: According to the requirements select the appropriate component.

Design the System: Study the block diagram, make model using anyone software (CAD Model).

Assemble the System: All components are been assemble.

Test the System: Testing.

Performance Evaluation.

V. FABRICATION AND IMPLEMENTATION

1. TEC1-12704 Peltier Module: The TEC1-12704 is a solid-state thermoelectric module as shown in figure 1. used for cooling applications. The TEC1-12704 Peltier module is made from thermoelectric semiconductor materials, mainly bismuth telluride (Bi_2Te_3), which forms p-type and n-type elements. These semiconductor pellets are connected using thin copper conductors and are sandwiched between two ceramic plates made by alumina that provide insulation and support. This structure allows the module to create a temperature difference when electric current passes through it. It operates on the Peltier effect, where an electric current passing through the junction of two different semiconductors creates a temperature difference, causing one side to absorb heat (cold side) and the other to release heat (hot side). Each module operates at 12 V DC and draws 5.5 A of current. The cooling power of a single module is approximately 25 W, and the input power is 66 W, providing a coefficient of performance (COP) of around 0.38. In the project, two modules are used in parallel to achieve sufficient cooling for the 40 × 30 × 25 cm insulated box. The cold side of each module is attached to an Aluminium cooling block to transfer heat from the refrigerator chamber, while the hot side is mounted on a heat sink with water cooling to dissipate heat efficiently. Proper thermal management ensures maximum temperature difference and efficient operation. Peltier modules are compact, silent, vibration-free, and require low maintenance, making them suitable for portable and off-grid refrigeration applications.

2. Aluminium Cooling Block (40 × 80 mm): Aluminium cooling blocks are used to improve heat transfer between the Peltier module and the interior of the cooling box. Aluminium is chosen due to its high thermal conductivity

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(approximately 205 W/m·K), low density, and resistance to corrosion. The block dimensions of 40 mm × 80 mm are designed to provide sufficient surface area for heat absorption from the cold side of the Peltier module. The aluminium block ensures uniform distribution of cooling across the module surface and reduces thermal resistance, which is critical for achieving the target temperature of 15°C inside the insulated box. The block also provides mechanical support to the Peltier module and allows for easy mounting of thermal paste to improve heat conduction. Proper sizing and material selection of the cooling block directly influence the efficiency of the thermoelectric cooling system and prevent hotspots that could reduce the module's performance.

3. Heat Sink with 120 × 120 mm Fan: A heat sink is used to dissipate heat from the hot side of the Peltier module efficiently. The heat sink is made from aluminium due to its high thermal conductivity and lightweight nature. A 120 × 120 mm fan is mounted on the heat sink to actively circulate air and improve convective heat transfer. This forced-air cooling prevents heat accumulation on the hot side, which is critical to maintaining the performance of the Peltier modules. Without proper heat dissipation, the temperature difference across the module would reduce, lowering cooling efficiency. The fan operates at 12 V DC and draws minimal current, adding negligible load to the battery. In addition, the heat sink ensures structural support and stability for the hot side assembly.

4. 12 V Water Pump with 2 L Water Tank: The 12 V DC water pump is used to circulate water through the heat sink attached to the hot side of the Peltier modules. The pump ensures continuous removal of heat, preventing the hot side temperature from rising excessively. The water absorbs heat from the heat sink and carries it to a 2 L water reservoir, from where it is recirculated. The cooling system enhances the overall efficiency of the thermoelectric modules by maintaining a lower hot-side temperature, which increases the temperature difference between the cold and hot sides. The pump operates at 12 V and consumes minimal power, ensuring energy-efficient operation alongside the Peltier modules. Proper sizing of the water tank ensures sufficient heat absorption capacity to avoid temperature spikes during operation. The system uses PVC tubing to direct water flow, and insulation is applied to minimize heat losses from the pipes.

5. Thermocol Cooling Box: The cooling chamber is made from thermocol sheets with an insulation thickness of 25 mm. Thermocol is chosen due to its low thermal conductivity (0.035 W/m·K), light weight, and ease of fabrication. The internal dimensions of the box are 40 cm × 30 cm × 25 cm, providing adequate storage space while minimizing heat gain from the surroundings. Thermocol insulation reduces the conduction of heat from ambient air into the cooling chamber, ensuring the Peltier modules can maintain the target temperature efficiently. The box is designed to accommodate the cold-side aluminium blocks and internal fan, ensuring uniform air circulation. Proper sealing of the box prevents air leakage, which could reduce cooling performance. Thermocol also provides structural support for internal components and can be easily covered with plywood for external protection and aesthetics.

6. 12 V, 5 W Solar Panel: A 12 V, 5 W solar panel is used to recharge the battery, providing renewable energy input for off-grid operation. Although the panel is small, it demonstrates solar energy integration with thermoelectric cooling systems. The solar panel converts sunlight into electrical energy, which charges the battery over several hours of sunlight. This enables sustainable operation without relying on grid electricity. The panel is connected with proper wiring and diodes to prevent reverse current flow, ensuring safe and efficient charging. In combination with the battery, the solar panel supports continuous operation during daytime or in sunny conditions.

7. 12 V, 8 Ah Battery: The system is powered by a 12 V, 8 Ah rechargeable battery, which supplies current to the Peltier modules, fan, and water pump. The battery provides off-grid operation, enabling the refrigerator to function in remote or rural areas. The battery is connected through an on/off switch to control power supply safely. With a total system load of approximately 145 W, the battery can provide a runtime of around 40 minutes for two Peltier modules, ensuring short-term cooling during power outages or limited sunlight conditions. The battery is housed in a separate thermocol enclosure for safety, protection from water spills, and organized placement, allowing clean wiring and easy maintenance.

8. Plywood Base & Component Exposure: The entire system is mounted on a plywood base to provide mechanical stability, ease of handling, and organized component placement. The battery, water pump, and water tank are housed in a separate thermocol enclosure on the plywood plate, which keeps the prototype neat, safe, and aesthetically clean. The plywood provides a strong, lightweight, and easily modifiable platform for assembling all components, ensuring durability and portability of the system.

9. 12MM Water hose: A 12mm water hose refers to a water hose with an inner diameter of 12 millimeters. These hoses are commonly used to transport water for various purposes, including gardening, irrigation, automotive cooling systems,

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and general water transfer applications. The 12mm inner diameter of the hose determines the flow rate and capacity of water it can handle. Generally, a larger inner diameter allows for a higher flow rate, which is advantageous when you need to move a substantial amount of water quickly. 12mm water hoses are available in various lengths and materials, such as rubber, PVC, or reinforced hoses. The choice of material depends on the specific application and the durability required for the hose. These hoses often come with connectors or fittings to facilitate easy attachment to faucets, nozzles, or other water sources. In gardening and landscaping, a 12mm water hose is suitable for watering plants, lawns, and gardens. Its size allows for efficient water distribution while maintaining flexibility and ease of use. It can also be used in automotive applications to transport coolant or as a general-purpose water transfer hose for tasks like washing cars, boats, or outdoor surfaces. The 12mm water hose is just one of many hose sizes available, each catering to different flow and pressure requirements. When selecting a water hose, it's important to consider the specific needs of your application and ensure compatibility with connectors and accessories for a seamless water transport solution.

10. Water Tank: Polypropylene (PP): Polypropylene is a versatile thermoplastic known for its resistance to chemical corrosion, impact strength, and durability. In this project a plastic container is used as the water tank for cooling purposes. It acts as a low-cost and easily available reservoir to store water, which helps in absorbing and dissipating heat from the hot side of the Peltier module. The plastic container is lightweight, non-corrosive, and provides basic thermal insulation. It is suitable for small-scale experimental setups and helps maintain a stable cooling environment.

11. Electrical Wires: A 0.25mm wire, often referred to as a 0.25mm electrical wire or simply a 0.25mm wire, denotes a wire with a diameter of 0.25 millimeters. These wires are used in a variety of electrical and electronic projects for conducting electricity and transmitting signals. Here's an overview:

Diameter: The primary characteristic of a 0.25mm wire is its diameter, which is 0.25 millimeters or approximately 0.00984 inches. This dimension determines the wire's electrical properties, including its resistance and current-carrying capacity.

12. Application: Signal Wiring: Thin wires like the 0.25mm variety are often used for signal transmission within electronic circuits, connecting components, sensors, or devices.

Interconnecting Components: In circuit board design and electronics, these wires are used to connect various components, such as resistors, capacitors, and integrated circuits.

Prototyping: In electronics prototyping, these wires can be used to create temporary connections or to establish links between different parts of a circuit.

Repair and Maintenance: Thin wires are valuable in repairing or modifying electronic devices, where fine soldering and delicate connections are necessary.

Jumper Wires: They are used as jumper wires on breadboards to create specific connections during the testing and development of electronic circuits.

VI. EXPERIMENTAL SETUP

The experimental setup of the solar Peltier refrigeration system was developed based on the CAD model designed using CATIA V5 R21 as shown in following figure 10. The CAD model was designed to define the dimensions and arrangement of components such as the insulation box, Peltier module placement, heat sink, cooling fan, and internal space for storage. Proper positioning of all components was ensured in the model to achieve efficient heat transfer and compact design. Based on the CAD model dimensions, a suitable insulated box was selected directly (ready-made) instead of fabricating a new one, to reduce complexity and cost. The box acts as the refrigeration chamber. A thermoelectric module (TEC1-12704) was then installed on one side wall of the box such that its cold side faces the interior of the chamber while the hot side is exposed to the outer environment.

To improve thermal contact and reduce interfacial resistance, a thin layer of thermal paste was applied between the contacting surfaces. A finned heat sink was attached to the hot side of the Peltier module to facilitate heat dissipation. Additionally, a DC fan was installed to provide forced convection, thereby enhancing the rate of heat removal and preventing thermal accumulation at the hot junction. On the cold side, an aluminum cooling plate was installed to increase the effective heat absorption area within the chamber. The solar energy subsystem comprised a photovoltaic panel, charge controller, and rechargeable battery.

The solar panel was mounted at an appropriate tilt angle to maximize solar irradiance capture. The generated electrical energy was regulated using the charge controller and stored in the battery to ensure continuous and stable DC supply to the thermoelectric module and auxiliary components. The electrical circuit was configured such that the power flows from the solar panel to the charge controller, then to the battery, and finally to the Peltier

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module and cooling fan. A control switch was incorporated for system operation. Measurement instruments including a digital thermometer, voltmeter, and ammeter were integrated into the setup to monitor temperature variation and electrical input parameters. The complete system was assembled and sealed as per the CAD layout to minimize thermal losses and air leakage. Initial testing was conducted to verify proper functioning of all components. Subsequently, the setup was used for experimental analysis under varying environmental conditions to evaluate cooling performance and system efficiency.

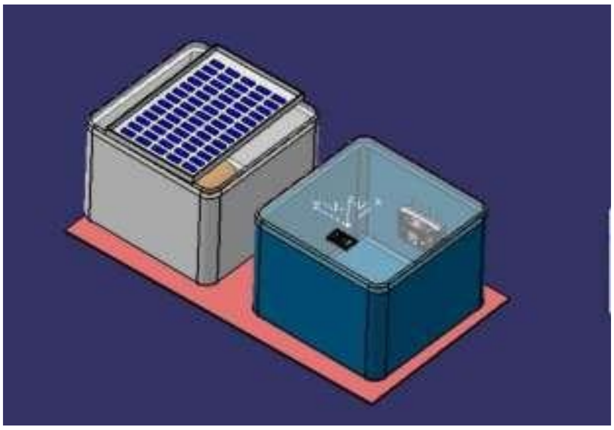

Figure 1: CAD Model

VII. WORKING OF MODEL

The solar thermoelectric refrigerator operates on the principle of the Peltier effect, where a temperature difference is created across a thermoelectric module when an electric current passes through it. In this project, two TEC1-12704 modules are used to provide the required cooling. When the modules are powered by the 12 V battery, electrons move from one side of the module to the other, absorbing heat from the cold side and transferring it to the hot side. The cold side of the modules is attached to aluminium cooling blocks, which help in efficiently transferring heat from the interior of the insulated cooling box to the module surface. A 120 × 120 mm fan inside the cooling chamber circulates the cooled air, ensuring uniform temperature distribution and preventing hot spots inside the box.

The hot side of the Peltier modules is mounted on a heat sink and coupled with a 12 V water circulation pump. Water from a 2 L reservoir is circulated through the heat sink to remove heat from the hot side efficiently, thereby improving the temperature difference across the module and enhancing overall cooling performance. The water absorbs the heat and carries it away to the reservoir, preventing heat accumulation and ensuring continuous operation of the modules.

The entire system is powered by a 12 V, 8 A battery, which can be charged by a 12 V, 5 W solar panel, allowing the refrigerator to operate in off-grid and remote locations. An on/off switch controls the flow of current to the modules, fan, and pump. All electrical and hydraulic components, including the battery, pump, and water tank, are housed in a separate thermocol enclosure mounted on a plywood base to provide safety, stability, and a clean appearance. When the system is switched on, the Peltier modules start cooling the interior, the fan circulates cold air, and the water pump removes heat from the hot side. This coordinated operation reduces the internal temperature of the cooling box to the target of 15The thermocol insulation minimizes heat gain from the surroundings, ensuring efficient cooling with minimal energy consumption. The combination of thermoelectric cooling, water-assisted heat dissipation, and fan circulation provides a compact, silent, and portable refrigeration solution suitable for small-scale applications such as food preservation, medical storage, and off-grid use.

VIII. EXPERIMENTAL VALIDATION

Table 1

S.R	Time (Min)	Temp (°C)	Voltage (V)
1	1	24	14
2	2	23.5	13.9
3	4	22	13.5
4	6	21.7	13
5	8	18	13
6	10	16.5	12.9
7	12	15	12.4
8	14	14.2	12.2
9	16	12	12.1
10	20	11	12

IX. DESIGN AND CALCULATOIN

- Ambient Temperature = 35°C
- Target Cooling Temperature = 15°C
- Temperature Difference (ΔT) = 20°C
- Box Dimensions = 0.40 m × 0.30 m × 0.25 m
- Box Surface Area (A) = 0.40×0.30×2 + 0.40×0.25×2 + 0.30×0.25×2 = 0.24 + 0.20 + 0.15 = 0.59 m²
- Insulation Thickness (t) = 25 mm = 0.025 m
- Thermocol Thermal Conductivity (k) = 0.035 W/m·K
- Mass of items inside box = 0.5 kg
- Specific Heat of items (c) = 4186 J/kg·K
- Peltier Modules = 2 × TEC1-12704
- Peltier Module Cooling Power = 25 W each
- Peltier Module Input Power = 12V × 5.5A = 66 W each
- Water Flow ΔT = 5°C

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- Water Specific Heat = 4186 J/kg·K.

1. Conduction Heat load:

Q_cond = (k × A × ΔT) ÷ t

Q_cond = (0.035 × 0.59 × 20) ÷ 0.025

Q_cond = 0.413 ÷ 0.025 = 16.52 W

2. Cooling Loads of Stored Item:

Q_items = m × c × ΔT

Q_items = 0.5 × 4186 × 20

Q_items = 41,860 J

Q_items_avg = 41,860 ÷ 3600 = 11.63 W

3. Internal Heat Load (Fan + pump):

Q_internal = 12V pump + fan = 10 + 3 = 13 W

4. Total Cooling Requirement:

Q_total = Q_cond + Q_items_avg + Q_internal

Q_total = 16.52 + 11.63 + 13 = 41.15 W

5. Peltier Module Performance:

Single Module:

- Cooling Power = 25 W
- Input Power = 66 W
- COP = Cooling ÷ Input Power = 25 ÷ 66 = 0.38

Two Module:

- Total Cooling Power = 25 × 2 = 50 W
- Total Input Power = 66 × 2 = 132 W
- Heat to Reject (Hot Side) = Cooling + Input = 50 + 132 = 182 W

6. Water Colling Requirement:

Heat to remove by water = Q_hot = 182 W Water flow required:

m_dot = Q_hot ÷ (c × ΔT_water)

m_dot = 182 ÷ (4186× 5)= 0.00869 kg/s = 0.52 L/min

7. Battery Run Time Calculator:

Battery = 12V × 8Ah = 96 Wh

Total Power Load = Peltier + Pump + Fan = 132 + 13 = 145 W

Runtime = Battery ÷ Load = 96 ÷ 145 = 0.66 hours ≈ 40 minutes.

X. RESULT AND DISCUSSION

It is observed that the temperature of the cold side decreases progressively from 24°C at 1 minute to 11°C at 20 minutes, demonstrating the effective cooling capability of the Peltier module. The rate of cooling is initially higher, as seen from the rapid drop in temperature during the first 10 minutes (24°C to 16.5°C). However, beyond this period, the cooling rate slows down, indicating that the system is approaching steady -state condition. The voltage supplied to the system shows a slight decrease from 14 V to 12 V over time. This variation can be attributed to fluctuations in solar radiation and possible losses in the power conditioning components such as the charge controller and wiring. The reduction in voltage directly affects the input power to the Peltier module, thereby influencing the cooling performance.

From the analysis, it is evident that the coefficient of performance (COP) of the system decreases with time. Initially, a higher COP is achieved due to a smaller temperature difference between the hot and cold sides of the Peltier module. As the temperature difference increases, the heat pumping capability of the module reduces, leading to a decline in COP. This behavior is consistent with the inherent characteristics of thermoelectric refrigeration systems, where efficiency decreases with increasing temperature gradient. Additionally the performance of the system is influenced by external factors such as ambient temperature, heat dissipation efficiency of the heat sink, and airflow provided by the cooling fan. Inefficient heat rejection at the hot side can further reduce the overall system performance.

XI. CONCLUSION

The solar Peltier refrigerator achieved cooling from 24°C to 11°C in 20 minutes. Cooling rate is higher initially and decreases with time due to increasing temperature difference. the COP decreases with increase in ΔT, indicating reduced efficiency at lower temperatures. System performance is affected by solar voltage fluctuations and heat dissipation efficiency. The system is suitable for small-scale, portable, and eco-friendly cooling, but has lower efficiency compared to conventional refrigeration.

ACKNOWLEDGEMENT

The authors would like to express sincere gratitude to the project guide, faculty members, and institution for their continuous support and guidance throughout the development of this project. Special thanks are extended to the laboratory staff for providing the necessary resources and technical assistance required for successful completion of this research work.

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International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 10, Issue 6, pp 140-149, June-2026

https://doi.org/10.47001/IRJIET/2026.106016

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International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 10, Issue 6, pp 140-149, June-2026

https://doi.org/10.47001/IRJIET/2026.106016

Citation of this Article:

Suraj Ghuge, Sakshi Daphal, Aishwarya Dhumal, Mayur Gaul, & V. R. Patil. (2026). Design & Development of Solar Peltier Plate Refrigerator. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 10(6), 140-149. Article DOI https://doi.org/10.47001/IRJIET/2026.106016

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