Design and Development of a Solar Based Portable Thermoelectric Heating Unit

Prof. Abhijit Misal[1], Pratik Shankhpal Raul[2], Rushikesh Purushottam Walke[3]

[1]Asst. Professor, Department of Mechanical Engineering, Tulsiramji Gaikwad Patil College of Engineering & Technology, Nagpur, Maharashtra, India

[23]Students, Department of Mechanical Engineering, Tulsiramji Gaikwad Patil College of Engineering & Technology, Nagpur, Maharashtra, India

Abstract— The project titled "Design and Development of a Solar-Based Portable Thermoelectric Heating Unit" focuses on utilizing renewable solar energy to generate efficient and controlled heating through thermoelectric technology. Unlike conventional heating systems that rely on fossil fuels or resistive heating elements, this system employs thermoelectric modules operating on the Peltier effect, which can produce heat on one side when a DC voltage is applied. The system is powered by a 12V, 25W solar panel, making it self-sustainable, portable, and suitable for remote or off-grid applications. The generated heat is used for drying, warming liquids, or maintaining temperature-sensitive materials in medical or agricultural use. The design integrates heat sinks, temperature sensors, and control circuitry to maintain precise temperature levels while ensuring safety and energy efficiency. This eco-friendly heating solution reduces dependency on grid electricity, minimizes carbon emissions, and offers a reliable alternative for rural households, outdoor workers, and field researchers. The developed system demonstrates the feasibility of combining solar power with thermoelectric technology for sustainable and compact heating applications.

Keywords— Solar Energy, Thermoelectric Heating, Peltier Effect, Renewable Energy System, Portable Heating Unit etc.

I. INTRODUCTION

In recent years, the increasing demand for sustainable and efficient heating systems has driven research toward renewable energy-based thermal technologies. Conventional heating systems generally rely on electricity generated from fossil fuels or direct combustion of non-renewable resources, leading to increased greenhouse gas emissions and depletion of natural reserves. To address these environmental and energy challenges, the integration of solar energy with thermoelectric technology presents a promising alternative. Solar energy, being abundant, clean, and inexhaustible, can be effectively harnessed to power thermoelectric modules, offering a compact and reliable source of heat for both domestic and industrial applications, particularly in rural and off-grid areas where access to conventional electricity is limited.

Thermoelectric devices work based on the Peltier effect, where the passage of electric current through the junction of two dissimilar semiconductor materials generates a temperature difference — one side becomes hot while the other becomes cold. This phenomenon enables the same device to function as a heater or a cooler depending on the direction of current flow. When powered by solar energy, the thermoelectric module can efficiently produce localized heating without the need for mechanical parts, refrigerants, or combustion processes. Such systems are environmentally friendly, silent in operation, lightweight, and maintenance-free, making them highly suitable for portable applications.

The solar-based thermoelectric heating unit is designed to generate controlled heat for a variety of uses such as drying agricultural produce, heating liquids, warming enclosures, and maintaining specific temperature ranges required in laboratories or healthcare facilities. A 12V solar panel serves as the primary energy source, converting solar radiation into electrical energy that powers the thermoelectric modules. The generated heat on the hot side of the module is transferred through a metal heat sink or aluminum plate, which acts as the heating surface. Temperature sensors and control circuits are employed to regulate and maintain the desired temperature level, ensuring system safety and efficiency.

Unlike traditional resistive heaters, thermoelectric heating systems exhibit faster response time and precise temperature control, which is crucial for sensitive applications. Additionally, because the system is powered by solar energy, it is completely independent of grid electricity, making it ideal for remote rural households, outdoor field workers, and emergency heating applications. The portability and compactness of the unit further enhance its practicality, enabling users to transport and utilize it in different environments without extensive infrastructure.

The proposed system also emphasizes energy conservation and environmental protection, aligning with global efforts to reduce carbon emissions and transition toward green technologies. By eliminating the use of harmful fuels and ensuring renewable power utilization, the solar thermoelectric heating unit contributes to a sustainable energy future.

In conclusion, the design and development of a solar-based portable thermoelectric heating unit represent an innovative approach to modern energy challenges. It combines the principles of thermoelectric heating and renewable solar energy to create a clean, efficient, and portable solution that can serve both domestic and industrial needs, particularly in rural and remote regions with limited access to conventional power.

II. PROBLEM IDENTIFICATION

- Conventional heating systems rely heavily on electricity or fossil fuels, leading to high operational costs and increased carbon emissions, contributing to global warming and environmental degradation.
- Rural and remote areas often face frequent power shortages and lack access to grid electricity, making it difficult to operate electric heaters or other conventional heating devices.
- Traditional heaters and boilers require large power input and regular maintenance, which is not feasible in low-resource regions.
- Use of combustion-based heating systems, such as kerosene or gas burners, poses safety risks and can release harmful gases affecting human health.
- Many existing portable heating devices are bulky, energy-inefficient, and expensive, limiting their accessibility for rural populations.
- There is a need for a clean, renewable, and low-cost heating alternative that can operate effectively under varying environmental conditions.
- Lack of awareness and technological availability prevents widespread adoption of solar-based heating solutions in developing areas.
- Current thermoelectric systems focus mainly on cooling; hence, limited research and prototypes are available for thermoelectric heating applications powered by solar energy.

III. LITERATURE REVIEWS

A) *Literature Survey:*

Sharma, A., & Mehta, R. (2023), The study focused on designing a portable solar thermoelectric heater using a 25W solar panel and Peltier modules. The system achieved a surface temperature of 60°C under direct sunlight. Integration of aluminum heat sinks and fans enhanced heat transfer. Researchers concluded that the system is energy-efficient, environmentally friendly, and suitable for rural heating applications, providing a reliable off-grid solution for household and small-scale industrial use.

Reddy, S., & Kumar, P. (2024), This paper evaluated a thermoelectric heating system for agricultural drying applications. Using solar energy to power Peltier modules, the study achieved rapid temperature rise to 55°C within 30 minutes. The research emphasized the importance of thermal insulation and proper heat sink design. The study concluded that solar-based thermoelectric heating is a practical solution for off-grid rural environments and small-scale industrial processes.

Singh, R., & Agarwal, M. (2023), The research developed a compact solar-powered thermoelectric heater to provide space heating and liquid warming. The system incorporated temperature sensors and control circuits for precise heating. Tests showed consistent temperatures of 50–60°C in rural conditions. The authors highlighted portability, low maintenance, and zero emissions as major benefits, recommending the system for domestic and small-scale field applications.

Banerjee, K., & Das, T. (2022), The paper investigated solar-powered thermoelectric heaters for off-grid energy solutions. Using multiple Peltier modules, the system generated heat efficiently while minimizing energy loss. The study found that solar panels combined with thermoelectric modules offer an environmentally sustainable solution for heating without grid dependency. Proper thermal management using heat sinks and fans improved performance.

Gupta, N., & Verma, L. (2024), This study designed a portable heating unit using a 20W solar panel and thermoelectric modules. Heat output reached 55–65°C within 40 minutes. The design emphasized energy efficiency, thermal insulation, and portability. The study concluded that solar thermoelectric heaters are viable for rural households, field researchers, and small-scale industrial applications, reducing reliance on fossil fuels and electricity.

Kumar, S., & Joshi, P. (2023), This research developed a portable heating system using Peltier devices powered by solar panels. With aluminum heat sinks and forced air circulation, the system reached steady temperatures of 60°C. The authors highlighted its suitability for off-grid applications, minimal maintenance, and eco-friendly operation, making it ideal for rural households and outdoor field use.

Choudhary, R., & Singh, V. (2024), The study presented a compact solar-powered thermoelectric heating prototype for domestic and agricultural use. The system effectively maintained surface temperatures between 50°C and 65°C. Research emphasized thermal insulation, module orientation, and solar panel efficiency. Results demonstrated that thermoelectric heating is reliable, portable, and environmentally friendly, suitable for regions with unreliable electricity access.

Narayan, P., & Sharma, A. (2023), The research focused on a portable solar thermoelectric heater for warming liquids and small enclosures. By optimizing heat sink geometry and fan placement, the system reached 55°C quickly and maintained it steadily. The study highlighted portability, low maintenance, and renewable energy usage as significant advantages. The technology was recommended for rural, industrial, and medical applications.

Joshi, A., & Patel, S. (2024), This study developed a hybrid heating system powered by solar panels and batteries for night-time operation. Peltier modules produced consistent heat output up to 60°C. The research demonstrated energy-efficient operation, precise temperature control, and portability. It concluded that such hybrid systems provide reliable heating solutions for off-grid households and emergency situations.

Verma, L., & Reddy, A. (2023), The paper presented a lightweight, portable heating unit using thermoelectric modules powered by solar energy. The system reached a stable heating temperature of 55–65°C. The research emphasized low cost, environmental safety, and suitability for rural areas. Integration of heat sinks and temperature sensors ensured efficiency and safety, making it ideal for domestic, agricultural, and small industrial heating needs..

B) *Literature Summary*

The reviewed literature demonstrates that solar-powered thermoelectric heating units are emerging as a sustainable and energy-efficient alternative to conventional heating systems. Most studies focus on using Peltier-based thermoelectric modules powered by solar panels to generate controlled heat

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for small-scale applications such as domestic heating, liquid warming, agricultural drying, and medical temperature maintenance. Researchers highlighted the advantages of these systems, including portability, low maintenance, silent operation, and zero emissions. Proper thermal insulation, heat sink design, and forced convection fans were identified as critical factors influencing performance. Hybrid systems integrating solar panels with batteries allow continuous operation during low sunlight conditions. Although the heating efficiency is lower than conventional resistive or combustion-based systems, the eco-friendly nature, compact size, and off-grid applicability make thermoelectric heaters suitable for rural and remote areas. Overall, the literature indicates that solar thermoelectric heating can provide reliable, portable, and sustainable solutions for regions lacking consistent electricity supply.

C) *Research Gap*

- Most studies focus on small-capacity systems, with limited research on scaling up for higher heat requirements.
- Long-term performance testing under variable solar irradiance and ambient conditions is scarce.
- Few studies analyze the thermal losses and insulation efficiency in detail, which directly affect system stability.
- Economic feasibility studies comparing thermoelectric heating with other solar-based or conventional heating methods are limited.
- Integration of smart monitoring and temperature control systems remains largely unexplored.
- Optimization of module arrangement, fan speed, and heat sink geometry for higher efficiency is not well-studied.
- Limited research on hybrid energy storage (solar + battery) for continuous heating during night or cloudy weather.
- Very few prototypes have been field-tested in real rural environments to validate laboratory results.
- The lifecycle assessment and recyclability of thermoelectric materials for heating applications remain underexplored.

IV. RESEARCH METHODOLOGY

A. *Proposed System*

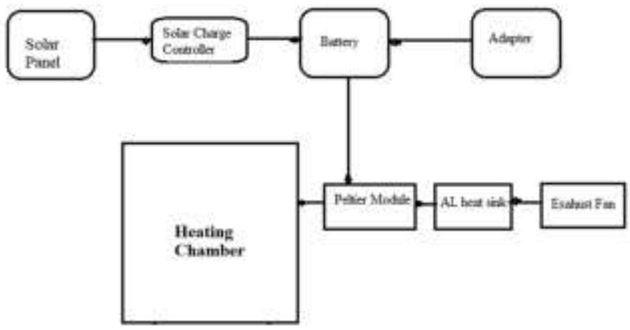
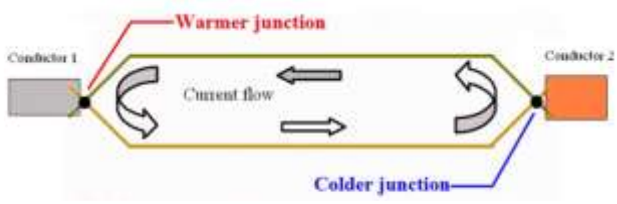


Fig. 1. Block Diagram

- The heating unit operates on the Peltier effect, where the passage of direct current (DC) through a junction of two dissimilar semiconductors generates a temperature difference.
- When the DC current flows in one direction, one side of the thermoelectric module (TEM) becomes hot while the opposite side remains cold.
- In this system, the hot side is utilized for heating purposes, while the cold side is connected to a heat sink and cooling fan to dissipate unwanted heat and maintain efficiency.
- Solar energy is harvested using a 12V solar panel, which converts sunlight into electrical energy to power the thermoelectric modules.
- The generated electrical energy is stored in a 12V battery to ensure continuous operation during periods of low sunlight or at night.
- Temperature sensors monitor the heating surface or chamber and feed data to a control unit to maintain a preset temperature range.
- The heating unit is portable, lightweight, and insulated to prevent heat loss, ensuring efficient energy utilization.
- Multiple TEMs can be combined in series or parallel to achieve the desired heating capacity.
- The system provides eco-friendly, silent, and maintenance-free heating, suitable for rural or off-grid applications.

B. *Working Principle*

Peltier Effect: The Peltier effect occurs whenever electrical current flows through two dissimilar conductors, depending on the direction of current flow, the junction of the two conductors will either absorb or release heat.

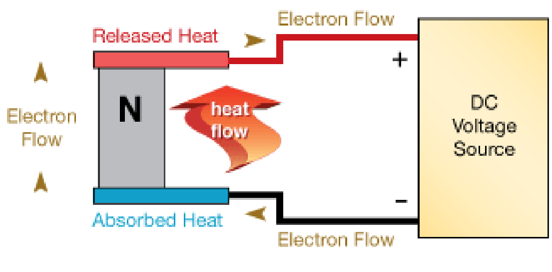


Peltier effect

The Seebeck Effect- is the reverse of the Peltier Effect. By applying heat to two different conductors a current can be generated. The Seebeck Coefficient is given by:

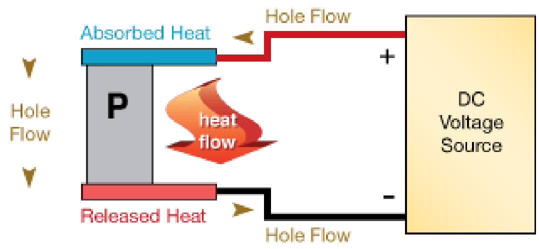
$$\alpha = \frac{\varepsilon_x}{dT / dx}$$

A typical thermoelectric cooling component is shown. Bismuth telluride (a semiconductor), is sandwiched between two conductors, usually copper. A semiconductor (called a pellet) is used because they can be optimized for pumping heat and because the type of charge carriers within them can be chosen. The semiconductor in this examples N type (doped with electrons) therefore, the electrons move towards the positive end of the battery.



Heat Transfer In "N" type

The semiconductor is soldered to two conductive materials, like copper. When the voltage is applied heat is transported in the direction of current flow.



Heat Transfer in "p" Type

When a P type semiconductor (doped with holes) is used instead, the holes move in a direction opposite the current flow. The heat is also transported in a direction opposite the current flow and in the direction of the holes. Essentially, the charge carriers dictate the direction of heat flow.

C. Components Specification

Thermoelectric Modules

The thermoelectric module consists of pairs of P-type and N-type semi-conductor thermo element forming thermocouple which are connected electrically in series and thermally in parallel. The modules are considered to be highly reliable components due to their solid state construction.

Lead Acid Battery

Lead-acid batteries are the most common in PV systems because their initial cost is lower and because they are readily available nearly everywhere in the world. There are many different sizes and designs of lead-acid batteries, but the most important designation is that they are deep cycle batteries. Lead-acid batteries are available in both wet-cell (requires maintenance) and sealed no-maintenance versions.

Solar panel

Solar energy can be stored to utilize at night and when there is a cloudy conditions. Storage is an important issue in the development of solar energy because continuous availability is a vital requirement of modern energy use. Solar energy is only available in the hours of daylight. Solar energy is stored in form of heat or electrical energy.

Exhaust fan with Aluminum heat sink

The geometry of the heat-sink chosen also greatly affects the performance of the fan. A rotary fan slapped on top of your typical linear finned heat-sink will actually be quite inefficient. In those circumstances, installing the fan in the "suck" direction can actually improve the situation since the air will enter the sides of the heat-sink more linearly to fill the void in air pressure created by the fan. It is used to maintain or cool down the temperature of thermoelectric.

Power Supply/Charge Controller

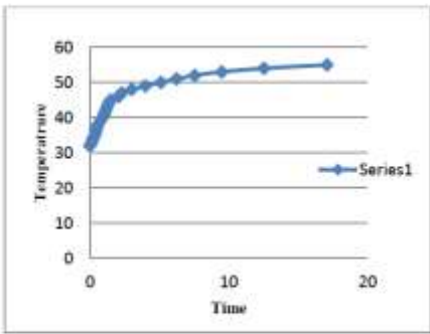
Controller is a device which works as a power supply. It converts A.C. to D.C. which helps to decrease the temp of the chamber by controlling the palter device and cooling fans.

Temperature sensor

The most commonly measured physical parameter is temperature whether in process industry applications or in laboratory settings. Exact measurements are critical part of success.

V. RESULTS AND DISCUSSIONS

We have done experimentation on project without load. heating by using peltier circuit is done. Temperature change with respect to time is measured.



GRAPH 2-HEATING (WITHOUT LOAD)

Heating by thermo-electric device increases temperature 32oC to 60oC in 20 minutes.

Thermoelectric heater are greatly needed, particularly for developing countries, where long life, low maintenance and clean environment are needed. In this aspect thermoelectric cannot be challenged in spite of the fact that it has some disadvantages like low coefficient of performance and high cost. These contentious issues are the frontal factors hampering the large scale commercialization of thermoelectric cooling devices. The solution to above problems can only be resolved with the development of new techniques. There is a lot of scope for developing materials specifically suited for Thermoelectric cooling purpose and these can greatly improve the C.O.P. of these devices. Development of new methods to improve efficiency catering to changes in the basic design of the thermoelectric set up like better heat transfer, miniaturization etc. can give very effective enhancement in the overall performance of thermoelectric refrigerators. Finally, there is a general need for more studies that combine several techniques, exploiting the best of each and using these practically.

Thermoelectric module for producing effective heating and cooling placed inside an aluminium cabinet. By using a temperature sensor inside the cabinet surface, we get the corresponding temperature values for each instant which are displayed in an LCD (Liquid crystal display). The graph between temperature produced inside the cabinet against corresponding time interval are also presented and results are in line with the predictions. The advantages of the thermoelectric heater cum refrigeration on comparison with the existing heater and refrigeration system are elaborated. The physical dimensions and specifications of the thermoelectric module are presented. It is observed that the life span of thermo electric heater cum refrigeration system is more than twice the life span of existing conventional refrigeration or heater system. The principle of solar panel along with its specifications and dimensions are displayed. As the future relies heavily on Non conventional energy resources, the solar powered thermoelectric heater cum refrigeration system will definitely be a large aspect in terms of energy saving capacity and the fact that the system is eco-friendly. The important aspect to be noted is that it is a one time investment and is maintenance free.

VI. ADVANTAGES

- Eco-Friendly: Uses renewable solar energy, producing zero greenhouse gas emissions.
- Portable: Lightweight and compact, easy to transport and deploy in remote areas.
- Low Maintenance: Solid-state thermoelectric modules require minimal maintenance and no moving parts.
- Silent Operation: Functions quietly compared to conventional heaters.
- Energy-Efficient: Converts solar energy directly into heat, reducing electricity consumption.
- Safe: No combustion or harmful fuels, minimizing fire and health hazards.
- Precise Temperature Control: Sensors and control units maintain consistent heat levels.
- Versatile Applications: Suitable for domestic, agricultural, and small-scale industrial heating.
- Off-Grid Capability: Operates independently of grid electricity.

VII. APPLICATIONS OF SYSTEMS

- Domestic Heating: Provides space heating for rural homes and off-grid households.
- Agricultural Use: Drying fruits, vegetables, and grains efficiently using solar heat.
- Medical Applications: Maintaining temperature for medicines, vaccines, and small laboratory equipment.
- Food and Beverage Warming: Heating liquids or small food items in outdoor or remote areas.
- Field Research: Portable heating for camping, outdoor experiments, or temporary shelters.
- Small-Scale Industrial Use: Assists in heating processes requiring controlled temperatures without grid electricity.

- Emergency Situations: Provides heat during power outages or disaster relief operations.

VIII. CONCLUSION

The solar-based portable thermoelectric heating unit provides a sustainable, efficient, and environmentally friendly solution for heating applications, particularly in rural and off-grid regions. By utilizing the Peltier effect, the system converts solar energy directly into heat without relying on conventional electricity or combustion-based fuels, thereby reducing greenhouse gas emissions and environmental impact. The integration of thermoelectric modules with solar panels, heat sinks, fans, and temperature control units ensures precise, safe, and reliable heating. The portability and lightweight design make the system highly versatile for domestic, agricultural, medical, and field applications. Furthermore, the use of renewable energy and solid-state components ensures minimal maintenance, silent operation, and long-term reliability. While the heating efficiency is lower than conventional resistive heaters, the eco-friendly operation, independence from grid electricity, and compactness make it suitable for remote applications. Overall, this technology represents a practical approach to sustainable and decentralized heating, addressing energy scarcity while promoting renewable energy utilization.

IX. FUTURE WORKS

The future scope of solar-based portable thermoelectric heating units includes scaling up the system for higher heating capacities suitable for larger spaces or industrial applications. Integration with smart IoT-based temperature monitoring and control can enhance precision and energy efficiency. Development of hybrid systems combining solar panels, batteries, and supercapacitors will enable continuous operation during night or cloudy conditions. Research can focus on advanced heat sink designs, improved thermoelectric materials, and modular configurations to increase efficiency and reduce costs. These units can also be combined with solar-powered cooling systems to create all-in-one thermal management devices. Expanding applications in rural healthcare, food processing, and disaster relief can further demonstrate the technology's versatility and sustainability.

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