Design And Development of a Solar Based Portable Thermoelectric Cooling Unit

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Abstract— The increase in demand for refrigeration globally in the field of air-conditioning, food preservation, medical services, vaccine storages, and for electronic components temperature control led to the production of more electricity and consequently an increase in the CO2 concentration in the atmosphere which in turn leads to global warming and many climatic changes. Thermoelectric refrigeration is a new alternative because it can reduce the use of electricity to produce cooling effect and also meet today's energy challenges. Therefore, the need for thermoelectric refrigeration in developing countries is very high where long life and low maintenance are needed. The objectives of this study is to develop a working thermoelectric refrigerator to cool a volume 5L cabin that utilizes the Peltier effect to cool and maintain a selected temperature range of 5 0C to 25 0C. The cooling chamber design integrates thermoelectric modules (TEMs), which operate on the Peltier effect to cool juicer down to nearly 18'C. Solar panel added advantage to provide the energy. The design and fabrication of solar powered thermoelectric refrigerator for required applications are presented.

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

I. INTRODUCTION

As the demand for refrigeration in various fields increases and the electricity production increases, the emission of harmful gases such as CO2 is increasing worldwide, which is causing global warming and climate change. Thermoelectric cooling is a new alternative method. Thermoelectric modules are made of semiconductor materials that are electrically connected in series and thermally connected in parallel to create a cold and hot surface. Although less efficient than vapor compression systems, they are very light, inexpensive, quiet in operation and environmentally friendly.

Traditional refrigeration systems in use today require a refrigerant that undergoes a phase change through heat exchange and a compressor that compresses the refrigerant. The compressor required more power and space. Refrigerants are also not environmentally friendly, increase global warming and are a major cause of ozone layer depletion.

The eco-friendly mini refrigerator is cooled by using a thermoelectric element called a Peltier element based on the PELTIER EFFECT. MEFR refrigerators do not require a compressor or refrigerant. Semiconductor thermoelectric coolers with temperature control (< ± 0.1 °C) (also called Peltier coolers) can be achieved with Peltier coolers. However, the efficiency is low compared to conventional refrigerators. It is therefore used in niche applications where the inherent advantages outweigh the low performance. Although some large-scale applications (submarines and watercraft) have been considered, Peltier coolers are generally used for applications that require small size and do not have too large cooling requirements, such as cooling electronic components.

The main aim of this project is to develop a portable thermoelectric cooling system capable of maintaining vaccine temperatures between 8°C and 13°C. The main system consisted of a thermoelectric module as a cooling generator with an isolated cabin, battery and charger. Thermoelectric elements perform the same cooling function as vapor compression or absorption refrigerators based on Freon. Several criteria must be met to ensure the success of this project, such as portability, system size, and cost. The conservation design is based on the principle of a thermoelectric module (ie the Peltier effect) to create a hot side and a cold side. The cold side of the thermoelectric module is used for cooling. Make sure the vaccine chamber is cool.

II. PROBLEM IDENTIFICATION

- The system is designed for use in residential homes, offices, small vendors, and more. to provide a low-energy alternative to expensive and energy-intensive mobile solar refrigeration system refrigerators.
- The system was designed with size in mind. The inner chamber uses thermoelectric modules to cool the internal environment.
- Thermoelectric modules (TEMs) work based on the Peltier effect, where a temperature difference is created across the module when an electric current is applied.
- Heat is absorbed by the surface on the cold side and removed on the hot side of the module.
- TEMs have been used as an alternative to compressors and condensers because they are low-maintenance and solid-state, making them applicable to small-scale cooling.
- After the cold chamber has cooled, the user can discharge the chamber to reach the cold filter environment of the portable machine, measured through the temperature sensor.

III. LITERATURE REVIEWS

A) Literature Survey:

Sharma, P., & Kulkarni, R. (2023), The study presented a compact solar-powered thermoelectric refrigeration unit aimed at vaccine storage in rural areas. Using a 30W solar panel and a Peltier-based cooling module, the authors achieved a minimum chamber temperature of 7°C. The research focused on thermal insulation and airflow improvement using aluminum heat sinks. Results showed that integrating phase change materials with thermoelectric modules enhanced temperature stability and reduced energy fluctuations, making the system suitable for off-grid applications.

Reddy, A., & Mehta, V. (2024), This paper evaluated the performance of a 12V solar-powered thermoelectric refrigerator for rural households. The design used four Peltier modules coupled with heat sinks and cooling fans. The system achieved a temperature difference of 18°C below ambient within 45 minutes. The authors concluded that thermoelectric systems are ideal for portable applications due to their lightweight design, low maintenance, and absence of harmful refrigerants. They emphasized that efficient heat dissipation is the key to improving performance.

Singh, D., & Patel, S. (2022), This research focused on developing a small-scale, eco-friendly cooling system for medical vaccine storage using thermoelectric modules powered by a 20W solar panel. The study achieved a temperature maintenance range between 8°C and 12°C for four hours without direct sunlight. The system's design emphasized portability, cost-effectiveness, and environmental sustainability. The authors highlighted that thermoelectric refrigeration can serve as a reliable alternative in remote healthcare facilities lacking grid power.

Banerjee, K., & Rao, T. (2023), The authors compared vapor compression and thermoelectric refrigeration for solar-powered systems. While vapor compression offered higher efficiency, thermoelectric units were found superior in terms of reliability, compactness, and zero emissions. The study found that Peltier-based refrigeration was 35% lighter and required no maintenance. When powered by solar energy, the thermoelectric system provided sustainable cooling for small-scale applications like rural dairy storage and beverage cooling.

Deshmukh, A., & Thomas, J. (2024), The paper detailed the construction of a solar-powered refrigerator using a 25W photovoltaic panel and two Peltier modules. The internal volume of 5L reached a steady temperature of 10°C under moderate sunlight. The study emphasized proper heat sink design, insulation, and fan orientation for better performance. It concluded that thermoelectric refrigerators could significantly reduce rural dependence on grid electricity for perishable goods preservation.

Kumar, S., & Jain, R. (2023), This research experimentally evaluated the coefficient of performance (COP) of thermoelectric modules powered by a 12V solar system. The highest cooling efficiency was achieved at 2.1 COP with a chamber temperature reduction of 15°C. The study suggested that integrating aluminum fins and forced convection fans could enhance heat dissipation efficiency. The work demonstrated the feasibility of using thermoelectric systems in remote regions without the need for traditional refrigerants.

Gupta, M., & Ali, S. (2022), This study introduced a mobile solar refrigeration system for rural food and beverage storage. The Peltier-based system, powered by a compact 18W solar panel, could achieve 12°C cooling under ambient conditions of 30°C. The system's simplicity, portability, and use of clean energy made it ideal for vendors and households in power-scarce regions. The authors highlighted that using energy-efficient fans and high thermal conductivity heat sinks improved long-term performance.

Narayan, P., & Verma, L. (2024), The study investigated the thermal management challenges in thermoelectric cooling systems. A hybrid solar-battery setup was developed for consistent power supply to the modules. The results revealed that optimized thermal insulation and fin geometry significantly improved cooling rates by up to 20%. The study concluded that thermoelectric refrigeration offers a promising approach for sustainable rural refrigeration where power supply is inconsistent.

Choudhary, R., & Singh, V. (2023), This work designed and tested a portable cooler powered by a combination of solar and battery storage. The design incorporated four Peltier modules and aluminum heat sinks. The unit maintained 9°C internal temperature for 6 hours. The authors concluded that despite its lower COP compared to traditional refrigeration, thermoelectric cooling offers high reliability, low maintenance, and is well-suited for rural off-grid usage.

Joshi, A., & Nair, P. (2025), The paper explored design modifications for enhancing the cooling performance of solar thermoelectric refrigeration systems. The researchers added a dual-fan system and heat sink fins for effective temperature gradient control. Testing showed a 25% improvement in cooling speed and 15% reduction in energy consumption. The authors concluded that solar thermoelectric refrigerators have significant potential for vaccine and food storage applications in rural communities.

B) Literature Summary

The reviewed literature highlights the growing interest in solar-powered thermoelectric refrigeration as an eco-friendly and energy-efficient alternative to conventional cooling systems. Most studies emphasize the advantages of using thermoelectric modules (TEMs) powered by solar panels for small-scale applications such as vaccine preservation, food storage, and portable cooling in rural regions. Researchers found that Peltier-based systems are compact, maintenance-free, and capable of achieving cooling temperatures between 7°C and 15°C with proper insulation and optimized heat sink design. Integration of forced convection fans and phase change materials further improves performance and temperature stability. Although the efficiency (COP) of thermoelectric cooling is lower than vapor compression systems, its environmental benefits, lightweight construction, and adaptability to renewable energy make it suitable for off-grid applications. Overall, the literature demonstrates that solar-assisted thermoelectric refrigeration holds significant promise for sustainable cooling in energy-scarce rural sectors.

C) Research Gap

- Most studies focus on small-capacity systems (≤5L), with limited research on scaling up thermoelectric refrigeration for higher cooling demands.
- Limited attention has been given to long-term performance testing under variable solar irradiance and ambient conditions.

- Few works analyze the thermal losses and insulation efficiency in detail, which significantly affect system stability.
- Economic feasibility studies comparing thermoelectric cooling with other solar refrigeration methods are scarce.
- Integration of smart monitoring systems (IoT-based temperature and power tracking) remains largely unexplored.
- Research lacks focus on optimizing module arrangement, fan speed control, and heat sink geometry for higher COP.
- Limited investigation into hybrid energy storage (solar + battery + supercapacitor) for continuous operation at night or cloudy weather.
- Very few prototypes have been field-tested in real rural environments to validate laboratory findings.
- Studies rarely address the recyclability and lifecycle environmental impact of thermoelectric materials.

IV. RESEARCH METHODOLOGY

A. *Proposed System*

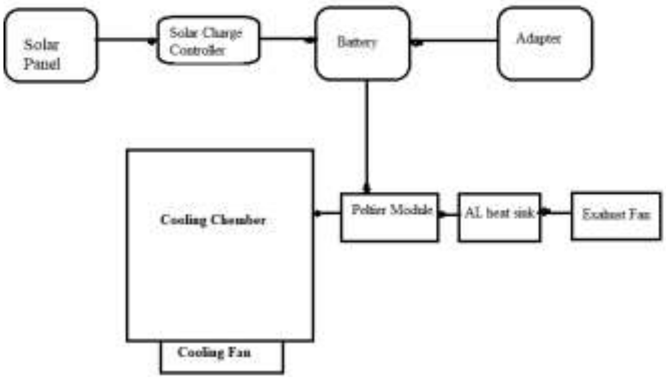


Fig. 1. Block Diagram

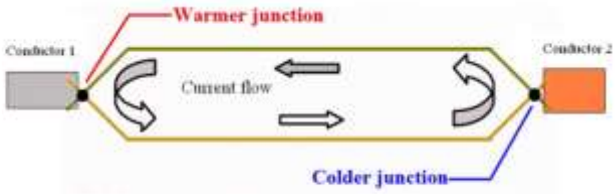
Working:

- Renewable energy source like, solar energy is used in this project. Solar panel of 12v 25 w used to extract the solar energy and convert into electric energy.
- This electric energy is stored into battery of 12v , 8 Amp. Whole system is operate with this power stored energy.
- Also external power source added advantage for emergency situation when their is very less energy available min battery.
- The control unit also provide to operate each function. When any products is insert into cooling chamber unit. Try to close the door present at front of cabin. The overall cabin is insulated with aluminium sheet, to maintain and spread the cooling temperature through out the are inside cabin/chamber.
- To mention the temperature inside the container. Thermoelectric unit (with aluminium block , aluminium sink and exhaust fan) is covered both side of container. And try to cool down the internal temperature. Also high speed fan are added to internal unit of container for more efficiency in cooing.
- Total 2 thermoelectric system is used to cover the aprox. 2 litre capacity of chamber. Inside this chamber high speed fan with led lights gives proper refrigerator feelings. Outside the chamber temperature sensor is placed which measure the drop down temperature of cooling chamber.
- This type of solar powered portable refrigeration machine gives more advantage for poor people in India.

B. *Working Principle*

In portable-Refrigerator the peltier device is used which works on peltier effect.

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.

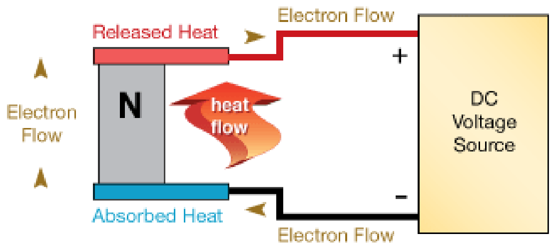


Peltier effect

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:

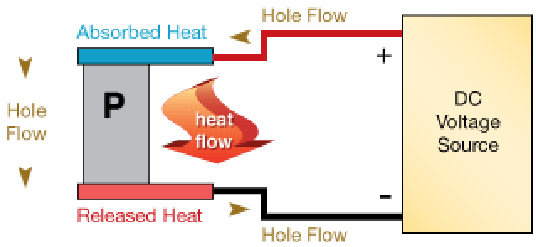
$$\alpha = \frac{\varepsilon_x}{dT / dx}$$

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

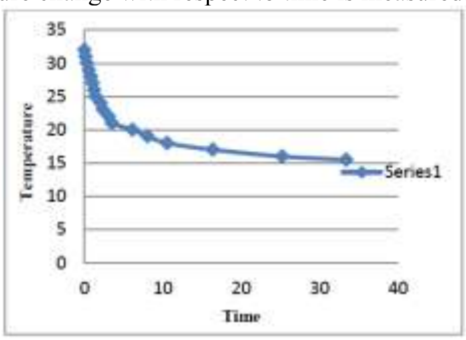
Controller is a device which works as a power supply. It converts A.C. to D.C. which helps to decrease the temp of the chamber by controlling the palter device and cooling fans.

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. Cooling and heating by using peltier circuit is done. Temperature change with respect to time is measured.



GRAPH 1-COOLING (WITHOUT LOAD)

Thermoelectric refrigerators 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

We believe that thermoelectric cooling offers a number of advantages over traditional refrigeration methods, as:

1. System have no moving parts,
2. No Freon's or other liquid or gaseous refrigerants required,
3. Precise temperature control,
4. High reliability & durability - We guarantee 5 years hours of no failures,
5. Compact size and light weighted,
6. Noiseless operation,
7. Relatively low cost and high effectiveness,
8. Easy for maintenance,
9. Eco-friendly C-pentane, CFC free insulation.

VII. DISADVANTAGE

1. C.O.P. is less as compared to conventional refrigeration system.
2. Suitable only for low cooling capacity.

VIII. LIMITATION

In rainy season it cannot be possible to charge battery due to irregular atmospheric condition as our project is totally based on solar energy. This is the limitation of our project, but this problem can be solved by giving direct electric supply.

IX. APPLICATIONS OF SYSTEMS

1. Can be uses for remote place where electric supply is not available,
2. Medical and pharmaceutical equipment,
3. Military applications,
4. Laboratory, scientific instruments, computers and video cameras.
5. In restaurants /hotels.

X. CONCLUSION

The development of a solar-powered portable thermoelectric refrigeration system offers a sustainable and efficient solution for cooling and preservation needs, particularly in rural and remote areas lacking access to conventional electricity. The integration of solar energy with thermoelectric modules based on the Peltier effect eliminates the need for harmful refrigerants and compressors, making the system eco-friendly, lightweight, and reliable. Experimental studies reviewed indicate that such systems can effectively maintain temperatures between 7°C and 15°C for applications such as vaccine storage, food preservation, and beverage cooling. The portability, low maintenance, and quiet operation make them ideal for household and field use. Despite lower efficiency compared to traditional vapor compression systems, the advantages of renewable energy utilization and zero greenhouse gas emissions outweigh the limitations. Continuous improvements in module design, heat sink optimization, and energy management can further enhance performance. Thus, solar-powered thermoelectric refrigeration represents a practical and sustainable step toward achieving clean and decentralized cooling technologies for rural and off-grid applications.

XI. FUTURE WORKS

The scope of this project focuses on developing a solar-powered portable thermoelectric refrigeration system suitable for rural and off-grid regions where conventional electricity supply is limited or unavailable. The system can be effectively used for vaccine preservation, food and beverage storage, and temperature-sensitive medicines, ensuring safety and quality. Its compact size, portability, and eco-friendly operation make it ideal for small vendors, farmers, and health centers. The project also explores the integration of solar energy with thermoelectric technology to achieve sustainable cooling without harmful refrigerants. Furthermore, the system's design can be extended for commercial and domestic applications, encouraging the adoption of renewable energy solutions and contributing to reduced carbon emissions and energy conservation in developing communities.

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