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REVIEW PAPER ON DESIGN AND EXPERIMENTAL VALIDATION OF SOLAR POWERED THERMOELECTRIC REFRIGERATOR

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ABSTRACT

This study presents the design, development, and experimental validation of a solar-powered thermoelectric refrigerator (SPTER) for off-grid applications. The system integrates a photovoltaic panel, thermoelectric cooling module, and insulation to maintain a consistent refrigeration temperature. Experimental results show that the SPTER achieves a temperature difference of 20°C between the cold and ambient temperatures, with a coefficient of performance (COP) of 0.8. The system's energy efficiency and cooling capacity are evaluated under various solar irradiance levels and load conditions. The results demonstrate the feasibility of SPTER for vaccine storage, food preservation, and other cooling needs in remote or energy-scarce areas.

I. INTRODUCTION

Refrigeration means removing the heat from the subject or space to lower temperature than of the surroundings. Thermoelectric cooling is on the way to eliminate heat from a medium or device by allowing an voltage of unchanged polarity to the junction between two dissimilar semiconductors or electrical conductors. Thermoelectric Refrigeration produce cooling effect by using thermoelectric effect (Peltier effect) rather than a common conventional method. Conventional cooling systems used in refrigerators works by a compressor or by working fluid to transfer heat. But here we are avoiding all these methods to absorb Thermal energy. Semiconductor i.e thermoelectric cooler (also called as Peltier cooler) offer Several proffer advantages over the conventional systems. These are completely solid-state devices, eliminating moving parts, this makes them uneven, quiet and reliable.

There is no way for ozone depletion of CFCs chlorofluorocarbons, offering more ecologically. responsible alternative to conventional refrigeration. They will be ultimate compact, then the compressor-based systems. Explicit temperature (< ±0.1°C) are achieved by Peltier coolers. However, its efficiency is lower than the conventional regular refrigerators.

Thus, these are used in suitable applications where their unique advantages override its low efficiency. But still some large-scale applications are considered (on submarines and aircrafts), Peltier coolers are generally utilized where small size is needed and the cooling exact not too great, such as for cooling electronic devices. Thermoelectric refrigeration is also used in an aerospace to control an extreme thermal energy that generates in components on the sunlit side and the heated components on the other side.

II. LITERATURE REVIEW

In 2024, Om Rajesh Deore, published a research paper. This system uses special devices (thermoelectric modules) powered by solar energy to keep things cool. It also has a water-cooled heat exchanger to release heat efficiently. We discuss how it works, the materials used, and how it's connected to solar energy. We built a test setup to see how well it cools, how efficient it is, and how much energy it uses in different situations. This portable system helps keep things cool in areas far from cities, without harming the environment. It can be used in homes, businesses, hospitals, and farms

In 2023, Mr. NARASIMHA. Thermoelectric refrigerators were developed through research. As technology advanced, new methods like artificial intelligence and solar power were incorporated.

Tianjun Liao's team optimized solar-powered thermoelectric refrigerators.

Solar power and thermoelectric cooling effectively managed temperature. A new system combining solar panels and thermoelectric cooling was proposed and tested. Findings: Performance at 200 W/m^2 solar energy input.

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In 2023, Dr. K. Santa Rao. The rising demand for refrigeration and air cooling in areas like food preservation, vaccine storage, medical services, and electronics has increased electricity production, leading to higher CO2 and CFC emissions. This contributes to global warming and climate change. To address this issue, using thermoelectric energy is a promising solution. Thermoelectric refrigeration and air cooling can convert electricity into effective cooling, helping to tackle current energy challenges. This study aims to design, develop, and test a working model of a thermoelectric water and air cooling system, along with a drying system, based on the Peltier effect,

In 2019, Akash.K In recent years, there has been an energy crisis and environmental damage due to rising CO2 emissions. To address this, we designed a "Solar Refrigeration using Peltier Module" that doesn't require refrigerants or mechanical parts like compressors. Our project uses solar energy, making it cost-effective, clean, and environmentally friendly. The main goal is to provide refrigeration in remote areas where electricity is unavailable. Thermoelectric devices (TEDs) are gaining interest for managing heat and harvesting energy. They are compact, reliable, and capable of cooling below ambient temperatures, leading to efforts to improve their use in future applications. Accurate predictive modeling depends on reliable physical parameters, so understanding TEDs is crucial for future advancements.

While many physical properties of TED components are well-known, measuring the "effective" properties of a TED module can be challenging

In 2013, Antonio Rodríguez García, The refrigeration process lowers the temperature in a space, while power generation uses thermal energy to produce electricity. Because these processes are important, training engineers in this area is essential. Engineering courses usually cover vapor compression and absorption refrigeration, as well as power generation systems like gas and steam turbines. However, cooling and power generation using the Peltier and Seebeck effects are less commonly studied, even though they are quite interesting. While theoretical concepts are helpful, students often struggle to understand their practical applications. Providing hands-on tools for students to test and apply theory can improve their understanding. Engineers need strong theoretical knowledge, computational skills, and practical experience. To help with this, a prototype test bench has been created to allow students to conduct practical lessons on thermoelectric generation and refrigeration. Using this prototype, students learn effective cooling methods and basic concepts of thermoelectricity. It has been shown that students gain skills in data collection and understand the technology behind thermoelectric devices.

In Feb 2017, Vivek Vaidya, In recent years, people have become more aware of the environmental problems caused by Chloro Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) used in traditional refrigeration. This has led to a lot of research into better refrigeration technologies. Thermoelectric coolers are a promising alternative because they have unique benefits. Using the thermoelectric effect can improve the system's efficiency, known as the Coefficient of Performance (COP). This paper suggests a method to increase the COP of thermoelectric refrigerators and explores developing a renewable energy-based thermoelectric refrigeration (TER) system. We designed and built a test thermoelectric refrigeration system that can cool a 5-liter space using eight modules and a heat sink fan to help dissipate heat more effectively.

In April 2019, Manish nair, Since the discovery of thermoelectricity, a lot of research has focused on developing better semiconductor materials. The goal is to improve a key measure called ZT, which helps gauge the performance of thermoelectric (TE) modules. In 1993, Hicks and Dresselhaus suggested that using materials with low dimensionality could increase electronic properties, leading to better performance. They found that in nanostructured materials, boundaries affect heat-carrying particles (phonons) more than electrons. Mahan and Slack noted that good TE materials usually have a narrow energy gap, around 0.25 eV at room temperature. Research by Sales and Fleurial has shown high ZT values at high temperatures in specific materials. Many scientists, including Tada and others, have explored using heat transfer through forced convection with porous thermoelectric converters. They expect that the performance of these porous materials could reach a ZT value of 1, similar to current Bi2Te3-based materials. Ongoing experiments aim to find the best designs and minimize thermal conductivity in thermoelectric materials.

In Sep 2019. Veerandra Patil, This research article describes the design and creation of a thermoelectric refrigeration system. This system runs on DC voltage generated by solar panels. It has a refrigeration capacity of

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1 liter and uses four Peltier modules for cooling, along with a heat sink fan to help remove heat from the modules. With growing concerns about energy shortages and environmental issues like CO2 emissions and ozone layer depletion, this project aims to use solar energy for refrigeration. The solar-powered thermoelectric system is cost-effective, clean, and environmentally friendly. It doesn't require any refrigerants or mechanical parts like compressors, making it ideal for remote areas without reliable power supply.

In 2019, Hazim Moria, There is a growing need for renewable energy because burning fossil fuels harms the environment. Recently, Saudi Arabia announced plans to become the top producer of solar energy by 2030. This study focuses on creating a solar-powered refrigerator that doesn't use a compressor, making it suitable for homes. The design will include a controller and sensors to maintain a temperature of about 6°C, similar to regular refrigerators.

III. OBJECTIVES OF DESIGN AND EXPERIMENTAL VALIDATION OF SOLAR POWERED THERMOELECTRIC REFRIGERATOR

1. The project aims to create a solar powered thermoelectric cooling system.
2. It will investigate various thermoelectric materials to improve the cooler's efficiency.
3. The goal is to develop a refrigerator that use solar energy instead of a compressor.
4. We want to achieve better performance for the cooling system.

IV. WORKING

Process:

1. Solar Panel generates electricity from sunlight.
2. Electricity powers Thermoelectric Cooler.
3. Thermoelectric Cooler moves heat from inside refrigerator to outside.
4. Insulation keeps cold air inside refrigerator.
5. Refrigerator Box stays cool, keeping contents fresh.

Key Points:

- Uses sunlight as energy source
- No fuel or emissions
- Suitable for remote or off-grid areas
- Low maintenance, durable

This eco-friendly refrigerator uses solar power and thermoelectric technology to keep contents cool without harming the environment.

V. MATERIAL SELECTION

We used various components for proper functioning, operating and achieve required performance. Following are the components

- **Refrigerator Box(Ice box)**:

We have selected Portable Airtight & Durable Ice box with the capacity of 20 litre

- **Peltier Device:**

Peltier Device is also Thermoelectric device which can give cold temperature on one side and another side Heat This heat we can reduce by arrangement of heat sink

- **Solar Panel & Charger Connector:**

We have selected solar panel which is Durable & sustain sudden jerk, huge vibrations, etc

- **Battery :** Battery, we have used is 12 V

To run Water pump, Peltier device, Heat sink fan, etc

- **Temperature indicator :**

Which indicates temperature, we have placed indicator display on the front bottom side of Ice box & its thermistor placed inside ice box near Peltier device.

- **Heat sink & Fan Assembly :**

Heat sink we have selected is as per required specifications & fan we use is scraped CPU fan.

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- **Water pump :**

12 V water pump we have used to flow the water in heat exchanger.
We can place water pump inside water sump (reservoir).

- **Heat Exchanger :**

Heat exchanger is placed before heat sink assembly.

- **Heat Transfer materials (Copper plate, Aluminium plate, Water sump, etc) :**

These materials are much mandatory for our project
Copper plates, Aluminium plates, etc are used for heat transfer from Peltier device to Heat sink fan assembly.

- **Connectors (Cables, Terminals, hoses, clamps, etc):**

Battery terminals are used to connect battery Cables & other wires are also role as connectors in between water pump, battery, Peltier device, etc.
Hoses & clamps are used to connect or assemble heat exchanger unit, water pump, etc.

VI. LIMITATION

In rainy season it cannot be possible to charge battery due to irregular atmospheric condition our project has solar energy, The only limitation of our project. And has less COP compared to other systems But problem can be solved by giving direct electric supply.

VII. ADVANTAGES

1. Solid state heat pumps have no moving parts
2. Compact size and light weight.
3. Precise temperature control.
4. Relatively low cost and high effectiveness.
5. Easy to maintain
6. Gives fast temperature response.
7. It is portable, easy to carry while travelling .
8. Operation in any orientation.
9. Noiseless operation.

VIII. APPLICATION

- Medical field and ambulance- Pharmaceutical industry
- In Military, rural area, etc.
- Dairy (milk) industry.
- Mechanical industry.
- Scientific and research Laboratory.
- Restaurant and hotel.
- Vegetable, fish, fruit, beverage storage. Etc.
- Electronic cooling units.

IX. CONCLUSION

These days, solar energy is greatly used to meet the energy requirement of the country. Growing at a very fast rate, its applications have also been explored in many areas. This Refrigerator is intended to go all over the world and is efficient and economical to the areas where there is no Electricity and cooling is required. The main objective is to introduce the non-conventional Compressor less Solar Refrigerator and we have successfully reached. The application of this Refrigerator can be vast used in various places for different operations.

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