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Peltier module-based solar refrigeration system

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Abstract

A massive interest in solar-powered refrigeration systems comes from a growing demand for ecologically sound and energy-efficient choices. The inclusion of a Peltier module in a solar refrigeration system is looked into in this work as a potential off-grid cooling solution. A photovoltaic (PV) solar panel links to the Peltier module, an electronic component that relies on the Peltier effect to create a temperature differential, to use solar energy for cooling objectives. A system including of heat sinks, batteries, Peltier modules, solar panels, and a charge controller is being constructed and put into operation as part of this project. The performance of the system is assessed on the basis of how well it cools, its energy usage, and its ability to lower temperatures. Experimental results demonstrate the potential of the Peltier-based solar refrigeration system to achieve significant cooling with renewable energy where the findings showed that the system successfully lowered the internal temperature to as much as 15°C lower than the surrounding conditions, and the Peltier modules had an average efficiency of 80%. The project addresses issues like efficiency losses and proper choice of solar input while illustrating the suitability of combining solar power and thermoelectric cooling technology to provide a sustainable refrigeration solution. Future research will concentrate on improving overall performance and reliability by investigating hybrid approaches and optimizing system components.

Keywords: Peltier module, off-grid cooling, thermoelectric cooling

1. Introduction

Pursuing environmentally friendly and energy-efficient refrigeration solutions has led to exploring innovative technologies that integrate renewable energy sources. Among these, solar refrigeration systems using Peltier modules have gained attention for their potential to provide sustainable cooling with minimal environmental impact. This introduction delves into the principles and benefits of combining solar energy with Peltier thermoelectric modules to create an effective refrigeration system. Solar refrigeration systems harness the power of the sun through photovoltaic panels to generate electricity. This renewable energy source is then utilized to power Peltier modules, which are based on the thermoelectric effect—a phenomenon first discovered by Jean Charles Athanase Peltier in 1834. Peltier modules operate by creating a temperature gradient when an electric current flows through them, thereby transferring heat from one side of the module to the other. This results in a cooling effect on one side of the module and heating on the opposite side, allowing for refrigeration without the use of traditional refrigerants or mechanical compressors. The integration of solar energy with Peltier-based refrigeration systems offers several advantages. It significantly reduces the reliance on fossil fuels and grid electricity, making it particularly advantageous for remote or off-grid locations. Furthermore, it eliminates the need for chemical refrigerants, which are often associated with environmental harm. Studies have shown that solar-Peltier systems can effectively provide cooling while contributing to reduced carbon emissions and energy consumption. Despite these benefits, there are challenges associated with solar refrigeration using Peltier modules. The efficiency of Peltier devices can be relatively low compared to conventional refrigeration methods, and the performance of the system is highly dependent on the availability and intensity of solar radiation (Dincer & Rosen, 2011). However, ongoing advancements in thermoelectric materials and solar panel technology are addressing these limitations and enhancing the feasibility of such systems. This introduction provides a foundational understanding of solar refrigeration systems utilizing Peltier modules, highlighting their potential to revolutionize cooling technology in an eco-friendly manner. Further exploration into the design, efficiency, and practical applications of these systems will shed light on their role in sustainable development and energy management

2. Peltier Structure

. A typical thermoelectric module consists of an array of Bismuth Telluride semiconductor pellets that have been carried either positive or negative for the majority of current. The pairs of P/N pellets are configured so that they are connected electrically in series, but thermally in parallel. Metalized ceramic substrates provide the platform for the pellets and the small conductive tabs that connect them. When DC voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side. The surface where heat energy is absorbed becomes cold; the opposite surface where heat energy is released becomes hot. Reversing the polarity will result in Reversed hot and cold sides.

3. Basic Principles

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. The Peltier module-based solar refrigeration system operates on the thermoelectric effect, specifically utilizing the Peltier effect. Here's how it works:

3.1.a.Thermoelectric Effect: When an electric current passes through two different conductors or semiconductors, a temperature difference is created. One side of the Peltier module becomes hot, while the other side cools down.

3.1.b Peltier Module: This module consists of multiple thermoelectric couples made from semiconductor materials. By applying a voltage, heat is absorbed on one side (the cold side) and released on the other (the hot side).

3.1.c Solar Power Generation: Solar panels convert sunlight into electrical energy. This energy powers the Peltier module, allowing it to create the temperature differential necessary for refrigeration.

3.1.d. Cooling Mechanism: The cold side of the Peltier module is placed inside the refrigeration chamber, where it absorbs heat from the interior, lowering the temperature. The hot side is connected to a heat sink that dissipates heat into the surrounding environment.

3.1.e. Energy Efficiency: While Peltier-based systems are generally less efficient than traditional vapor-compression refrigeration, they offer benefits such as no moving parts, compact design, and the ability to operate in off-grid locations using solar energy.

Overall, this system combines solar energy with thermoelectric cooling technology to provide an eco-friendly refrigeration solution, particularly suited for remote areas or applications where conventional refrigeration is impractical.

4. Method of Heat Transport

There are several methods which can be employed to facilitate the transfer of heat from the surface of the thermoelectric to the surroundings.

Electrons can travel freely in the copper conductors but not so freely in the semiconductor.

As the electrons leave the copper and enter the hot- side of the p-type, they must fill a "hole" in order to move through the p-type. When the electrons fill a hole, they drop down to a lower energy level and release heat in the process. Then, as the electrons move from the p-type into the copper conductor on the cold side, the electrons are bumped back to a higher energy level and absorb heat in the process. Next, the electrons move freely through the copper until they reach the cold side of the n-type semiconductor. When the electrons move into the n-type, they must bump up an energy level in order to move

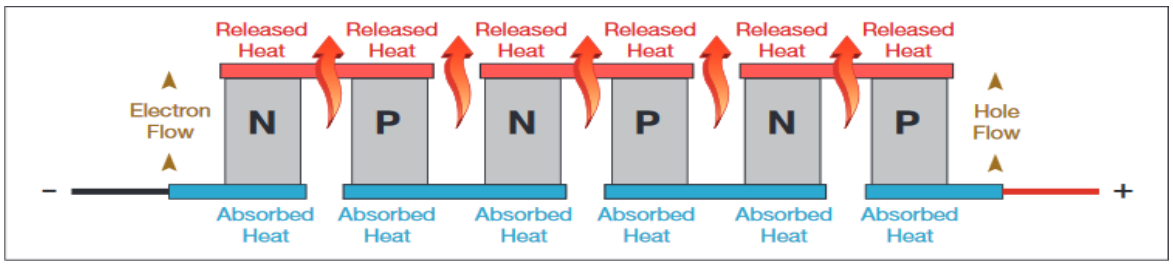


Fig.1.Method of Heat Transport of Peltier[4]

through the semiconductor. Heat is absorbed when this occurs. Finally, when the electrons leave the hot side of the n-type, they can move freely in the copper. They drop down to a lower energy level and release heat in the process. To increase heat transport, several p-type or n-type thermoelectric(TE) components can be hooked up in parallel. However, the device requires low voltage and therefore, a large current which is too great to be commercially practical. The TE components can be put in series but the heat transport abilities are diminished because the interconnecting between the semiconductors creates thermal shorting.

5. Construction & Design

Firstly, a box of Thermocol is made of the given dimensions and then the Thermocol box is made and fixed into it. The Peltier module is mounted between the heatsink using thermal paste. One side of the Box is attached to the cold side of the Peltier and the hot side is attached to a heat sink. A fan is attached parallel to the heat sink to remove the heat. A temperature sensor is connected in such a way that the sensor comes inside and the display comes outside the box. A battery is placed beside the Thermocol Box with proper insulation. Basic Methodology for a solar refrigeration system using Peltier module: Solar energy, Electrical system, Peltier Module, Heat transfer, Cooling chamber, Control System, Circulation System Monitoring and maintenance

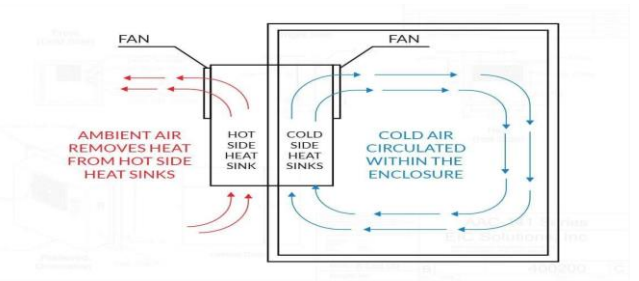


Fig.2. Methodology of Peltier[5]

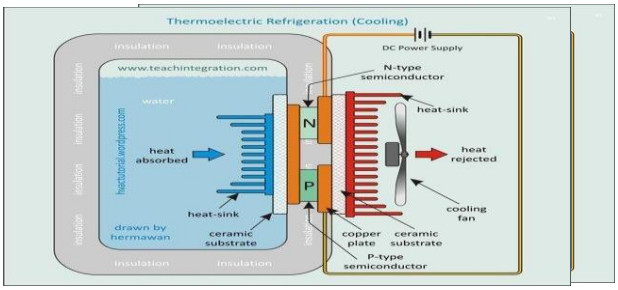


Fig.3.Construction design[4]

6. Program Flow Chart

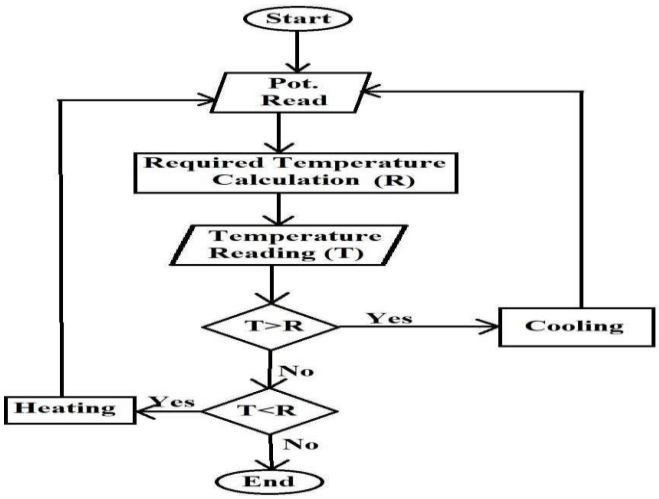
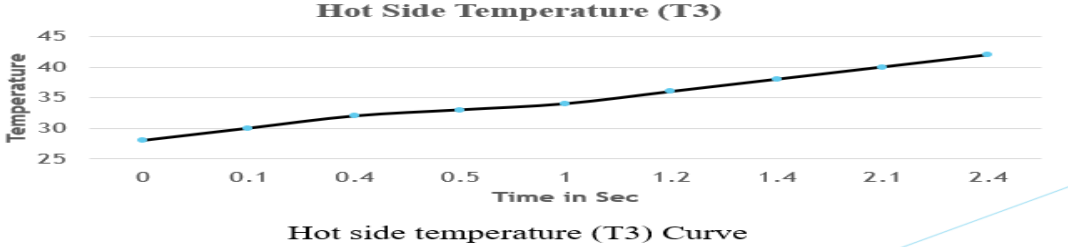


Fig.4. Flow Chart[8]

7. Result and Discussion

❑ **Hot Side Temperature (T3) :**

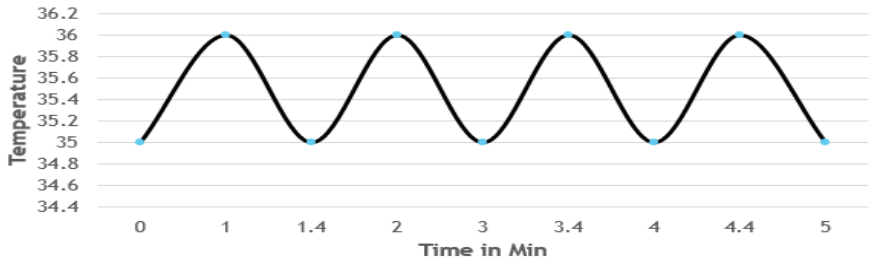
Hot Side Temperature T_3	
Temperature in $^0C(T_3)$	Time in Min
28	0
30	0.10
32	0.40
33	0.50
34	1
36	1.2
38	1.4
40	2.1
42	2.4



Hot side temperature (T3) Curve

❑ **Ambient Temperature of Air (T2)**

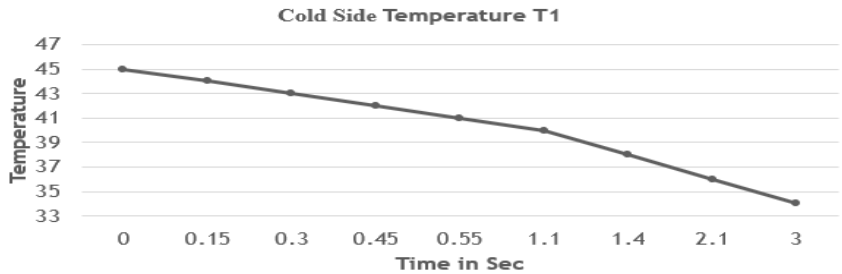
Ambient Temperature of Air T_2	
Temperature in $^0C(T_2)$	Time in min
35	0
36	1
35	1.4
36	2
35	3
36	3.4
35	4
36	4.4
35	5



Ambient Temperature of Air (T2) Curve

❑ **Cold Side Temperature :**

Cold Side Temperature T_1	
Temperature in $^0C(T_1)$	Time in Min
45	0
44	0.15
43	0.30
42	0.45
41	0.55
40	1.10
38	1.40
36	2.10
34	3



Cold Side Temperature (T1) Curve

7.1 Temperature Control and System Stability

- To control the cooling, the system uses a temperature controller. By keeping an eye on the Peltier module's cold side temperature, this controller alters the power supply to the solar panels or Peltier module as necessary. Systems may find it difficult to sustain a steady cooling performance if they lack adequate thermal management (such as heatsinks or fans on the hot side).
- For the Peltier module to remain efficient by preventing hot side overheating, which can restrict its performance, passive or active heat dissipation systems—such as heatsinks, fans, or water cooling systems—are required.

7.2Challenges

- **Limited Cooling Capacity:** Peltier modules might not be enough for systems that need lower temperatures or for larger-scale refrigeration. In such instances, the Peltier effect frequently has to be augmented with additional cooling techniques (such as vapour compression systems).

- **Power Efficiency:** Compared to traditional refrigeration technologies, Peltier modules often have lower power efficiency. In comparison to compressor-based systems, they use more electricity for a given cooling output because of their comparatively low coefficient of performance

8. Recommendations

- **Optimize System Design**: Modular Design: Develop modular systems that can be scaled according to specific cooling needs, allowing for flexibility in various applications. Improved Heat Sinks: Invest in high-performance heat sink materials and designs to enhance heat dissipation, maximizing the efficiency of Peltier modules.
- **Advanced Materials**: Thermoelectric Materials: Research and utilize advanced thermoelectric materials that offer higher efficiency and better performance in varying temperature conditions.
- **Hybrid Systems**: Integration with Traditional Cooling: Consider hybrid systems that combine Peltier modules with traditional refrigeration technologies for enhanced performance, particularly in larger applications.
- **Energy Management Systems**: Smart Controllers: Implement advanced energy management systems that can optimize power distribution from solar panels, ensuring efficient operation under varying sunlight conditions.

9. Challenges and Solutions

While promising, Peltier-based solar refrigeration systems face challenges such as lower cooling efficiency compared to compressor systems and initial cost considerations. Ongoing research aims to improve the thermoelectric materials used in Peltier modules, enhance system integration, and explore hybrid solutions that combine multiple cooling technologies.

10. Conclusion

The Peltier module-based solar refrigeration system represents a promising solution for sustainable and energy-efficient cooling. By harnessing the thermoelectric effect, this system offers several key advantages: Utilizing solar energy reduces reliance on fossil fuels and minimizes greenhouse gas emissions, making it an environmentally friendly alternative to conventional refrigeration methods. This system can be used in various applications, including remote locations, camping, or emergency situations, where traditional power sources may be unavailable. With no moving parts, Peltier modules require minimal maintenance, enhancing their reliability and lifespan. The small size of Peltier modules allows for flexible integration into different systems, making them suitable for various refrigeration needs. By relying on solar power, users can achieve greater energy independence, particularly in off-grid scenarios. While there are challenges regarding efficiency compared to traditional refrigeration systems, ongoing advancements in thermoelectric materials and solar technology hold promise for improving performance. Overall, the Peltier module-based solar refrigeration system offers a viable pathway toward sustainable cooling solutions that align with growing environmental concerns and the need for innovative energy management**.**

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