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Design and Development of a Thermoelectric Water Cooler Using Semiconductor Technology,"THERMOELECTRIC COOLER"

[1]Ms. Anjali Gaikwad, [2]Ms. Rutuja Bansode, [3]Mr. Niranjan Bargaje, [4]Mr. Rushikesh Kadam, [5]Prof. Sachin V Tayade, [6]Prof. Punam M Chabukswar

[1234] Department of electrical engineering, TCOER, Pune.

[56] Assistance Professor Department of electrical engineering, TCOER, Pune.

A B S T R A C T:

This research focuses on the design, development, and testing of a thermoelectric water cooler that uses Peltier modules as its main cooling element. Thermoelectric cooling provides a compact, eco-friendly, and solid-state alternative to traditional vapor compression systems, making it especially appealing for small-scale or portable applications. In this study, a working prototype was built using a TEC1-12706 thermoelectric module, an aluminium heat sink with a fan, a copper cold plate, and an insulated water container. A series of experiments were carried out to measure the cooler's performance, looking at factors like cooling capacity, temperature reduction, and power consumption under different operating conditions. The collected data were analysed to calculate the system's cooling power, coefficient of performance (COP), and temperature-time behaviour, offering useful insights into its efficiency and performance limitations. The results demonstrate that the thermoelectric water cooler is capable of achieving meaningful temperature drops over time, although its overall efficiency is affected by elements such as heat sink design, input power, and the quality of thermal connections. This study not only shows the practical potential of using thermoelectric technology for water cooling but also highlights areas for improvement, particularly in optimizing thermal management. Overall, the research adds to the development of sustainable cooling solutions and lays the groundwork for future innovations in applications like electronics cooling, beverage chilling, and portable refrigeration.

Keywords: Materials and Components, Block diagram , Improving Thermoelectric Cooler Efficiency.

1. Introduction

In today's world, the demand for cooling technologies that are efficient, compact, and environmentally friendly is steadily increasing. Conventional cooling systems, like vapor compression refrigerators, often depend on refrigerants that can harm the environment by contributing to ozone layer depletion and global warming. As an alternative, thermoelectric cooling systems offer a clean, solid-state solution that avoids the use of harmful gases, operates quietly, and can be designed for small-scale or portable applications.

Thermoelectric cooling works on the principle of the Peltier effect — a process where the flow of direct current (DC) through a thermoelectric module moves heat from one side (the cold side) to the other (the hot side). These solid-state devices, often referred to as Peltier modules, are increasingly used in specialized applications such as electronic component cooling, portable refrigerators, beverage chillers, and temperature-controlled containers. While thermoelectric systems generally have lower energy efficiency compared to large-scale refrigeration units, they offer unique advantages, including compactness, simplicity, reduced noise, and a lower environmental footprint — making them well-suited for certain niche applications.

The specific goals of this research are to: (1) design and build a working prototype of a thermoelectric water cooler, (2) experimentally evaluate its cooling performance under different operating conditions, and (3) analyse key performance indicators such as cooling power, coefficient of performance (COP), and temperature-time behaviour. Through this work, we aim to provide meaningful insights into the potential of thermoelectric cooling technology and identify areas for future improvements and practical applications.

Research Methodology :

This research is focused on the design, development, and experimental evaluation of a thermoelectric water cooler that operates using Peltier modules. The methodology was carefully structured to cover all stages — from system design and material selection to fabrication, experimental testing, and data analysis — to ensure a thorough and reliable assessment of the system's performance.

1.Research Approach:

An experimental research approach was employed in this study, centred on building and testing a prototype thermoelectric water cooling system. The approach is quantitative, involving the systematic collection of data related to temperature variation, cooling capacity, and power consumption under various operating conditions. Both experimental measurements and theoretical calculations were used to assess the system's feasibility, efficiency, and potential limitations, providing a balanced and comprehensive understanding of thermoelectric cooling technology in water-based applications.

Materials and Components:

The main materials and components used in the system included:

- Peltier Module (TEC1-12706): A widely used thermoelectric cooler with a maximum operating voltage of 12 V, current of 6 A, and a theoretical temperature differential of approximately 65°C.
- Heat Sink and Cooling Fan: An aluminium fin-type heat sink combined with a DC fan, enhancing heat dissipation from the hot side of the module.
- Cold Plate (Copper or Aluminium): A highly conductive plate ensuring efficient thermal transfer from the cold side of the module to the water container.
- Insulated Water Container: Designed to reduce external heat exchange, maintaining the focus on the cooling performance provided by the system.
- Thermal Interface Material (TIM): High-conductivity thermal paste applied to reduce thermal resistance at the contact points between components.
- DC Power Supply: An adjustable power source enabling controlled delivery of electrical energy to the Peltier module.
- Digital Thermometers/Thermocouples: Providing precise temperature readings (with a resolution of ±0.1°C).

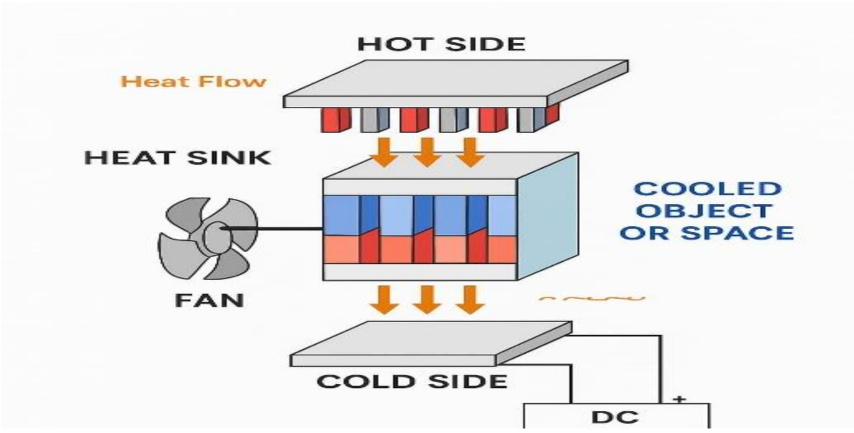

Figure.1: working of Peltier module

3. How Thermoelectric coolers work

- TECs use a phenomenon called the Peltier effect to transfer heat. When electricity flows through a thermoelectric module, one side becomes cold while the other heats up. This heat transfer allows for cooling without moving parts, making TECs silent and reliable.
- To measure how well a TEC works, we use a term called the Coefficient of Performance (COP), which is simply:
- COP = Cooling Power/Input Power
- This tells us how efficiently a TEC can cool something compared to the electricity it consumes.

4. Block diagram

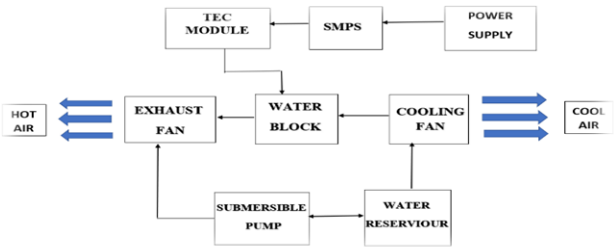

Figure.2: Block diagram of System

Improving Thermoelectric Cooler Efficiency :

Choosing the Right Materials:

The performance of a TEC depends on the material used in the thermoelectric module. The ideal material should conduct electricity well but not heat. A common choice is Bismuth Telluride (Bi_2Te_3) because it has a good balance of these properties. Scientists are also working on new materials, like nanostructured compounds, to improve efficiency.

Better Heat Management:

- For a TEC to work effectively, the heat from the hot side
- needs to be removed quickly. This is usually done using heat sinks, which come in two types:
- Air-cooled heat sinks, which use fans to remove heat.
- Liquid-cooled heat sinks, which use water or special fluids to absorb heat more efficiently.

Some researchers are also testing phase-change materials (PCMs) and nanofluids to boost cooling performance.

- Multi-Stage TECs for More Cooling Power: A single TEC module can only lower the temperature by a limited amount. To achieve lower temperatures, multiple TECs can be stacked together in multi-stage TEC systems. These are useful for applications like medical storage or infrared cameras, where extreme cooling is needed.

Result:

Sr. No.	Time	Initial Room Temp. (°C)	Temp. With Air Cooler (°C)	Temp. with Water + Cooler (°C)	Temp. With Water Cooler + Peltier module (°C)
1.	10:00 Am	28.2	27.8	26.2	27.5
2.	10:30 Am	27.5	26.7	25.9	26.4
3.	11:00 Am	27.6	26.6	25.8	25.6
4.	11:30 Am	27.7	26.5	24.6	24.5
5.	12:00 Pm	27.8	26.4	24.4	23.7
6.	12:30 Pm	27.8	26.3	23.5	22.4
7.	01:00 Pm	28.0	26.2	23.3	21.4
8.	01:30 Pm	28.1	26.1	23.2	20.3

In Table, it can be seen the comparison of room temperature before and after using a TEC Based water cooler, where the temperature produced by TEC using a water cooler system and an air cooler in a room measuring 10x10 meter at a room temperature of 28.2 °C. It can be described by the graph in Figure 5. below. In the graph in Figure 3. below, it can be seen the comparison between TEC using the water cooler and air cooler method in a 10x10 meter room at a room temperature of 28.2 °C.

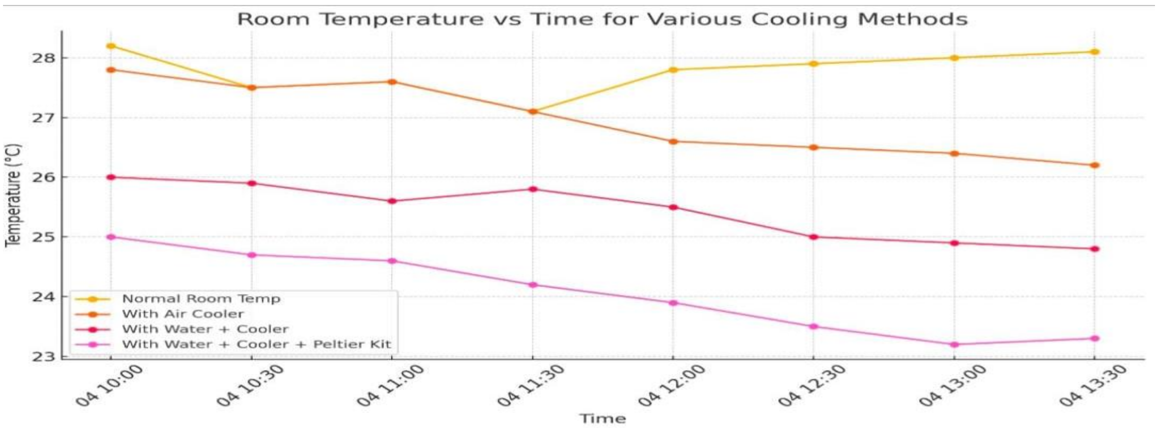

Figure.3: Comparison Chart of Peltier Temperature with Water Cooler and Air Cooler Methods.

Observations:

- Temperature consistently decreases from normal room conditions to the Peltier-assisted setup.
- Peltier system shows the lowest temperatures, confirming its effectiveness.
- Cooling becomes progressively more efficient with each added component.

Challenges and Future Improvements:

- Despite their advantages, TECs have some drawbacks:
- Lower efficiency compared to traditional refrigeration.
- High power consumption when used for large-scale cooling.
- Limited temperature reduction, making them unsuitable for extremely high heat loads.

Conclusion

In this project, we built a thermoelectric cooler that gives us a new and simple way to cool down small spaces using Peltier modules. By using a normal air cooler, adding water, and then attaching a Peltier-based cooling kit, we were able to improve the cooling effect. Our readings showed that the temperature dropped more with each added feature, especially with the Peltier kit. Even though this system isn't as efficient as regular fridges or ACs, it has some great advantages — it's small, doesn't use harmful gases, has no moving parts, and works quietly. It's best for small, closed rooms or for personal cooling. With future upgrades like a better heat sink, solar power support, and automatic temperature control, this cooler can become even more efficient and eco-friendly. Overall, our project shows that thermoelectric cooling is a useful and environment-friendly option for specific cooling needs where portability and simplicity are important.

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