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# Green Energy as an Alternative for the Preservation of Muscle Foods

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***Abstract:*** Solar thermoelectric coolers (STCs) present a promising solution for preserving muscle foods (meat and fish) in an environment lacking reliable electricity or traditional refrigeration infrastructure. This article explores the feasibility and potential benefits of using STCs for muscle food preservation, focusing on their ability to harness solar energy efficiently and convert it into cooling power through thermoelectric principles. Key advantages include their off-grid operation, making them suitable for remote areas; their environmentally friendly nature, reducing carbon footprint compared to conventional methods; and their reliability with minimal maintenance requirements. Despite initial investments and cooling capacity limitations, opportunities for enhancement and scalability exist. Overall, STCs offer a sustainable and effective means to ensure the freshness and safety of muscle food, crucial for both economic viability and public health in underserved regions.

***Keywords:*** Muscle food preservation, thermoelectric module, photovoltaic cells, sustainability.

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## 1. Introduction

Muscle food (fish and meat) are a rich source of essential amino acids and vital nutrients. They are well suited to meet human nutritional requirements even though they are not easily obtained with meat-free diets. However, they are highly perishable due to microbial attack, enzymatic activities, and lipid oxidation leading to deterioration of their quality (Leroy *et al.*, 2023). Given the temperature-sensitive nature of muscle food spoilage, maintaining a consistently low temperature is crucial for optimal preservation. In this era of modern food safety and preservation, refrigeration serves as a staunch pillar against the delirious activities of spoilage and contamination. There is increasing demand worldwide for food preservation, medical services, cooling of electric and scientific instruments, and automobile and household conditioning (Jugsujinda *et al*., 2011). Owing to their high coefficient-of-performance (COP), the vapour absorption and vapour compression refrigeration systems are widely utilized for domestic and industrial purposes. However, the big build size of the vapour compression refrigerator hinders its placement in small and temporary places. Also, they utilize high electric power, use liquid refrigerants that are detrimental to the environment and are challenging to develop as portable and lightweight devices for outdoor use (Qi *et al*., 2017). Solar Thermo-electric Cooler (STC) is gaining momentum in recent times to counteract these growing concerns. As a matter of fact, this has no irreversible threat to the environment, provides accelerated thermal action, is devoid of noise, compact in size, portable and lightweight, reliable, highly efficient, cost-effective production, maintenance-free, high durability, feasible for outdoor use combined with solar photovoltaic cells, and convenient to use as mini-refrigerator for preserving foods and drugs in confined areas (Afshari, 2020).

## 2. Need for Renewable Energy

Due to the inconsistent power supply and the difficulties in accessing conventional fuels, refrigeration energy has faced a huge time constraint. Solar energy presents a dependable solution to mitigate these challenges, addressing both current and future energy concerns. In comparison to the conventional refrigeration systems which have high electricity consumption and high cost, this 'green energy' initial capital investment is inexpensive and the ongoing costs will be practically zero (Biswas and Nanda, 2023). Solar energy is a great resource for providing renewable power, and it has been employed in multiple domestic and engineering applications (Zeyghami *et al*., 2015). Thermo-electric solar coolers could be the promising alternative to conventional cooling systems. In TEC systems, Photovoltaic (PV) technology converts solar energy into electricity, which is then used to power refrigeration systems. Nevertheless, the intensity of solar radiation varies over time, and the cooling capacity of the solar refrigeration system reaches its peak during periods of sunshine supply (Colak *et al*., 2021). Thus, it has been proposed as a sustainable cooling technology, especially in hot areas with an inconsistent electricity supply and a good deal of solar energy available.

## 3. Working Principle of STC

Solar thermoelectric Coolers (STC) operate based on the Peltier effect principle. This occurs when a direct current flows between two electrically different materials, and heat is absorbed or released at the junction. Heat flow direction is governed by the electric current's direction and the materials relative Seebeck coefficients. The device has two distinct sides, therefore when a DC electric current passes through it, it transfers heat from one side to the other, resulting in cooling on one side while the other becomes hotter. The "hot" side is connected to a heat sink and remains at ambient temperature, meanwhile, the cool side drops below room temperature. In certain situations, several coolers can be cascaded together to achieve lower temperatures. This device also works on the principle of the Seebeck effect, in which the voltage is applied between two distinct combinations of metal, and the effect of Seebeck causes cooling and heating phenomena which can be used for different purposes accordingly (Patil *et al*., 2019).

## 4. Fabrication of STC

Fabricating solar thermoelectric coolers involves integrating thermoelectric modules (TEMs) with solar energy collection and heat dissipation components (Biswas and Kandasamy, 2021). Here's a general overview of the fabrication process:

- Thermoelectric Modules (TEMs): These modules are the core components that generate cooling/heating through the Peltier effect. They consist of semiconductor materials.
- Heat Sink and Cold Sink:

  Heat Sink: A component that absorbs heat from the hot side of the TEMs.

  Cold Sink: A component that dissipates heat from the cold side of the TEMs.
- Solar Cells: These convert sunlight into electricity to power the thermoelectric modules.
- Insulation: Materials to minimize heat loss and maximize efficiency.
- Support Structure: To hold the components together securely and facilitate efficient heat transfer efficiency (Biswas, 2022)

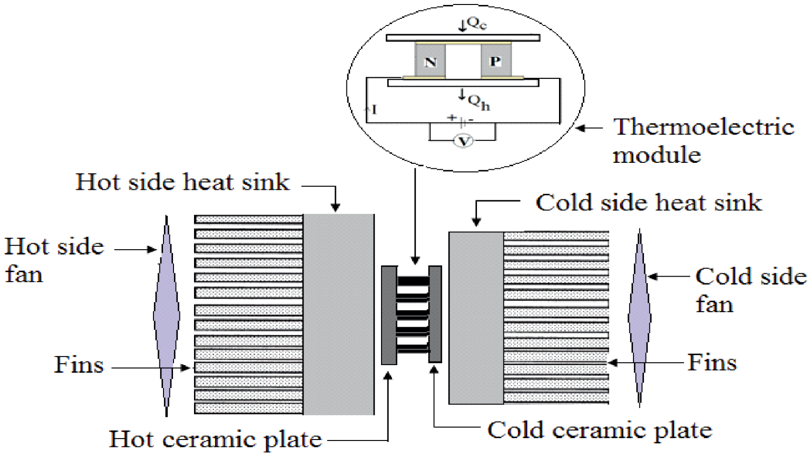


**Figure 1: A schematic diagram of thermoelectric assembly**

## 4.1. Fabrication Steps

### 4.1.1. Design and Planning

- Define thermoelectric cooler specifications based on required cooling/ heating capacity.
- Design the configuration of the solar cells, thermoelectric modules, and heat sinks.

### 4.1.2. Assembly

- Mounting TEMs: Position thermoelectric modules between heat and cold sinks, ensuring optimal thermal interface
- Connecting Solar Cells: Wire the solar cells to generate electricity. The generated power will drive the TEMs.

### 4.1.3. Heat Management

- Heat Sink: Attach a heat sink to the hot side of the TEMs. This will absorb heat from the hot side.
- Cold Sink: Attach a heatsink or a finned structure to the cold side of the TEMs. This dissipates heat from the cold side.

### 4.1.4. Insulation

- Encase the assembly in insulation material to reduce cold-side heat leakage"

### *4.1.5. Testing and Optimization*

- Test the solar thermoelectric cooler under various conditions to ensure it meets cooling/heating requirements.
- Optimize the arrangement of components for maximum efficiency (Biswas, 2022)

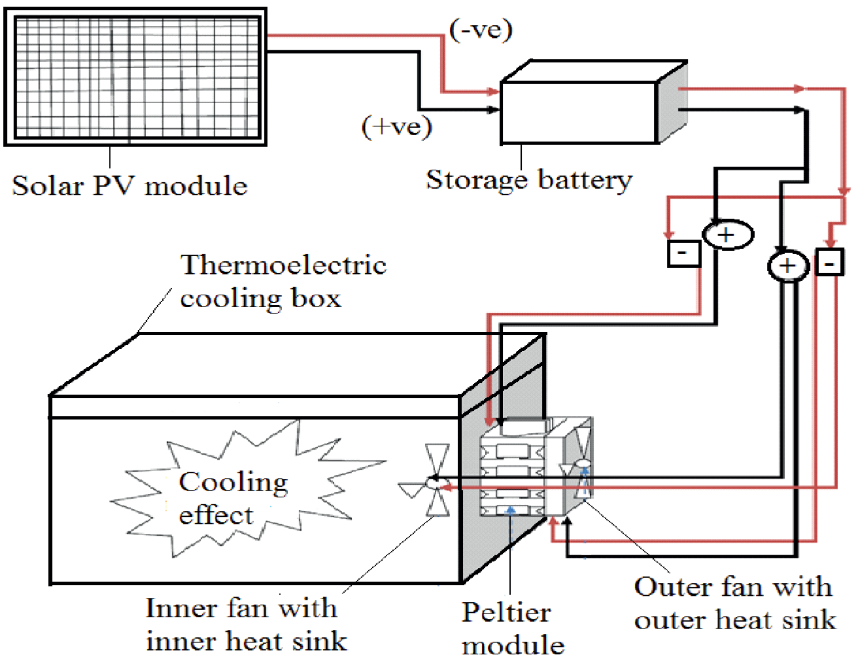


**Figure 2: Schematic diagram of solar thermoelectric cooling system**

## 5. Advantages

Solar thermoelectric coolers offer several advantages compared to traditional cooling technologies:

### *5.1. Environmentally Friendly*

Solar thermoelectric coolers boast environmental sustainability through reliance on solar energy, a clean and renewable power source.

### *5.2. No Moving Parts*

Unlike traditional refrigeration systems that rely on compressors and other mechanical components, thermoelectric coolers have no moving parts. This results in silent operation, reduced maintenance, and longer operational lifetimes.

### 5.3. *Compact and Lightweight*

Thermoelectric modules are relatively compact and lightweight compared to compressor-based refrigeration systems, making them suitable for applications where space and weight are limited.

### 5.4. *Reliability in Remote Areas*

They provide a reliable cooling solution in off-grid and rural settings where traditional refrigeration infrastructure is limited or nonexistent. This ensures that perishable meat can be stored safely for longer periods.

### 5.5. *Temperature Control Precision*

They offer precise temperature control, crucial for maintaining the freshness and quality of meat. This is achieved through direct electrical-to-thermal conversion, allowing for rapid cooling or heating responses as needed.

### 5.6. *Emergency Preparedness*

In disaster-prone areas or during emergencies, solar thermoelectric coolers efficiently protect drugs and vaccines in emergency response scenarios.

### 5.7. *Suitability for Mobile Applications*

They are suitable for mobile meat transport or temporary storage solutions, such as during outdoor events or in mobile food service operations, where access to conventional cooling infrastructure may be limited.

### 5.8. *Enhanced product quality*

Retail fish sellers used ice to preserve their catch, and retailers in rural and remote areas found it difficult to obtain ice. Furthermore, these ices do not always meet food safety standards and can be significant sources of contamination (Biswas *et al.*, 2021). The preservation of fish in a portable solar cooler system is thus economically suitable, feasible and acceptable for up to 7 days compared to the domestic refrigeration method at controlled temperature (Biswas, 2023).

## 6. Challenges and future perspectives

While solar thermoelectric coolers offer several advantages, they also face some challenges that need to be addressed for wider adoption and improved efficiency:

## *6.1. Efficiency and Performance*

The efficiency of thermoelectric modules (TEMs) in converting solar energy into cooling or heating is relatively low compared to compressor-based refrigeration systems. This limits their cooling capacity and effectiveness, especially in hotter climates or when larger cooling loads are required.

## *6.2. Cost Considerations*

The initial cost of solar thermoelectric coolers can be higher compared to traditional refrigeration systems. This includes the cost of high-efficiency thermoelectric modules, solar panels, and other components required for reliable operation. However, over the long term, they may offer cost savings in terms of reduced operational and maintenance costs.

## *6.3. Limited Cooling Capacity*

Thermoelectric coolers have limitations in terms of the amount of heat they can effectively transfer, which affects their cooling capacity. This makes them less suitable for applications requiring very low temperatures or high cooling loads.

## *6.4. Temperature Control Challenges*

Maintaining precise temperature control, especially over a wide range of ambient temperatures, can be challenging for thermoelectric coolers. Variations in solar radiation and ambient temperature can affect their performance and reliability.

## *6.5. Solar Energy Availability*

Dependence on solar energy means that the cooling performance of these systems can fluctuate depending on weather conditions, time of day, and geographic location. Cloudy days or reduced sunlight can impact their effectiveness.

Continued research and development are needed to optimize the efficiency and performance of thermoelectric materials and modules. Innovations in materials science and manufacturing techniques could lead to more efficient and cost-effective solutions. Addressing these challenges through technological advancements, improved design, and integration with energy storage solutions could further enhance the viability and adoption of solar thermoelectric coolers in various applications, including refrigeration for perishable goods in remote areas.

## 7. Conclusion

Thermoelectric devices offer versatile applications such as coolers, heat pumps, power generators, and thermal energy sensors. They are widely used in various fields, including military, aerospace, instrumentation, medicine, and commercial industry. Rising energy costs and stricter CFC regulations have revived interest in the TEC effect, particularly in developing countries with limited energy resources. At the farm level, TEC chilling can prevent enzymatic or microbial degradation of muscle food quality (fish and meat). Furthermore, thermoelectricity research and material experimentation are needed to enhance the coefficient of performance of the TEC. Thermoelectricity holds significant promise for energy-efficient solutions in the coming years and provides effective solutions in both industrial and commercial setup.

## Conflict of Interest

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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