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Portable Solar Colling Box

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Abstract

As the demand for efficient, sustainable and revolutionary cooling solution designed for various applications. This innovative device utilizes solar energy to cool, eliminating the need for fuel or electricity, and reducing carbon emissions. Its compact and lightweight design makes it ideal for remote or off-grid areas, outdoor events, military operations, and emergency response situations. The portable solar cooling box features a advanced insulation system, high-efficiency solar panels, and a robust cooling system, enabling it to maintain a consistent temperature range of 2-8°C (36-46°F) for extended periods. Its user-friendly interface and automated temperature control system ensure easy operation and optimal performance. The portable solar cooling box has far-reaching potential to transform various industries, including healthcare, food and beverage, and logistics, by providing a reliable and sustainable cooling solution. Its impact on the environment and communities is significant, offering a cleaner, more efficient, and cost-effective alternative to traditional cooling methods.

Introduction

In modern society, vehicles are crucial for transportation, but their reliance on fossil fuels leads to smog, emissions, and global warming, prompting interest in alternative energy sources like electric vehicles (EVs) and energy harvesting. High temperatures in parked cars exacerbate issues like plastic aging and increased fuel consumption for air conditioning. Solar energy, particularly through photovoltaic (PV) and photothermal systems, has emerged as a solution for powering air conditioners, with various studies showcasing their effectiveness. While solar-powered cooling systems have been extensively researched for buildings, there's limited exploration of their application in vehicle cabins. To address this gap, this paper introduces a novel portable solar-powered cooling system for vehicle cabins, leveraging wireless power transfer technology for easy installation. The paper outlines the system's design, modeling, experimentation, and discusses the implications of the results. The global demand for refrigeration is on the rise, driven primarily by needs in food preservation, medical services, automotive and household air conditioning, as well as cooling for electronic and scientific devices. While vapor compression and absorption refrigeration systems are commonly employed for both domestic and industrial applications due to their high coefficient-of-performance (COP), they present drawbacks such as high energy consumption, use of environmentally harmful liquid refrigerants, and challenges in developing portable and lightweight devices for outdoor use. The bulky nature of vapor compression refrigerators further restricts their usage in small or temporary spaces. In contrast, thermoelectric cooling systems (TECS) offer numerous advantages, including minimal environmental impact, rapid thermal res maintenance, and long lifespan.

When combined with solar photovoltaic cells, TECS become particularly attractive for use as mini-refrigerators in small spaces for preserving food and drugs. TECS find wide application in cooling laboratory equipment, thermal sensors, computer devices, water cooling systems, and low-capacity cooling devices for various purposes. However, one limitation of TECS is their relatively low COP, sometimes falling below one. Meeting the demand for refrigeration poses significant challenges, especially in areas with unreliable electricity supply and limited access to conventional fuels. Solar energy emerges as a viable solution to address both current and long-term energy crises due to its abundance, environmental friendliness, and versatility. Solar refrigeration presents an alternative to traditional refrigeration methods by harnessing solar energy through photovoltaic (PV) technology to power refrigeration systems. Despite fluctuations in solar radiation, solar refrigeration systems are most effective during periods of ample sunlight, making them particularly suitable for regions with inconsistent electricity supply and abundant solar energy resources. Thermoelectric cooling systems (TECS) operate on the principles of the Peltier effect, utilizing pairs of semiconductor thermoelements to create a temperature gradient without the need for refrigerants. TECS offer numerous advantages, including environmental friendliness, rapid thermal response, silent operation, compactness, portability, and reliability. Research has focused on enhancing the performance and efficiency of TECS, particularly when combined with solar energy. Various studies have demonstrated the effectiveness of solar-driven thermoelectric refrigeration systems in maintaining low temperatures, with coefficients of performance (COP) ranging from 0.1 6 to 0.74. Despite advancements, there's a need for further research to improve the COP of solar thermoelectric cooling systems, particularly for applications like foThe escalating use of fossil fuels such as oil, coal, and natural gas has exacerbated the energy crisis in the 21 st century. Consequently, there has been a growing emphasis on the development of renewable energy sources in current research. Renewable energy research spans various domains, including wind energy, tidal energy, nuclear energy, mechanical energy, acoustic energy, and notably, solar energy. Solar energy, in particular, has garnered significant attention due to its abundant supply and sustainability. As the primary source of energy for humans, solar energy represents an inexhaustible resource. In the context of diminishing fossil fuel reserves, the comprehensive utilization of solar energy holds dual significance for sustainable development and environmental protection. Solar energy is extensively explored as a power source for air-conditioning systems, primarily through photovoltaic (PV) and photothermal technologies. The advancement of the photovoltaic industry and technology has led to improvements in photovoltaic airconditioning systems. Additionally, research has focused on photovoltaic and photothermal cooling systems, which have shown promising results in reducing power consumption and enhancing energy efficiency. Moreover, solar-powered airconditioning systems for vehicles have also been investigated, demonstrating the feasibility of utilizing solar energy for cooling purposes on the go. Another avenue for powering air-conditioning systems is through photothermal conversion, an area of interest for many researchers. Studies have examined various methods, such as silica-water adsorption cooling systems, multi-stage thermoelectric cooling systems, and solar-driven injector cooling systems, to harness solar energy for cooling applications. These efforts have yielded valuable insights into optimizing system performance and enhancing efficiency.

Despite the progress made in solar air conditioning, challenges persist, particularly regarding portability and power transfer methods for vehicle applications. To address these challenges, this paper proposes a novel portable solar-powered cooling system for vehicles, incorporating a supercapacitor for power storage. Additionally, therof solar air conditioning systems into vehicles without the need for extensive modifications. The subsequent sections of this paper delve into the design, modeling, and experimental analysis of the proposed solar-powered cooling system. Experimental details and results, along with simulations, are provided, followed by a discussion of the findings. Finally, conclusions drawn from this study are presented. The detrimental environmental effects of burning fossil fuels have prompted the energy research community to explore renewable alternatives seriously. Solar panels offer a costeffective and environmentally friendly means of power generation, mitigating the harmful impact of traditional fuels. However, many individuals in remote or underserved areas lack reliable power sources, hindering their ability to store essential items at optimal temperatures, such as medications, vaccines, and perishable goods. Failure to maintain proper storage conditions can lead to economic losses or compromised therapeutic efficacy.

To address this issue, a solar-powered system combined with portable cooling boxes can provide on-demand power generation and temperature control wherever needed. Fuzzy logic, a decision-making mechanism akin to human logic, is utilized to develop control systems for these applications. Fuzzy Logic Control (FLC) systems offer advantages over traditional control systems, such as simplicity, flexibility, and lower costs, making them suitable for monitoring nonlinear systems and handling uncertainties. Efforts to enhance the efficiency of solar panels include material improvements, cooling systems, and power conversion methods. Moreover, research has focused on developing thermoelectric generators to improve healthcare infrastructure, particularly in rural areas with unreliable electricity. This study aims to design a portable solarpowered cooling box capable of maintaining temperatures suitable for storing medications and vaccines in areas lacking reliable power grids. The proposed system utilizes solar energy collected through photovoltaic panels and stored in batteries, enabling operation even in off-grid locations. Additionally, it can store essential implementation details, fuzzy logic controller design, results, and discussion are outlined in subsequent sections of this article, followed by references. Since the 1 990s, there has been a growing interest in the application and study of solar energy systems in buildings. Traditionally, these systems were primarily installed on roofs and used flat collectors to separately generate electricity and heat. However, recent advancements include the development of cogeneration systems, utilizing concentrating solar thermal collectors, often installed on either the façade or roof of buildings. These systems integrate double-effect absorption chillers, resulting in higher overall efficiency and operating temperatures. They can effectively provide both heating and cooling for buildings year-round. Studies have shown that the architectural integration of standard active solar systems, particularly when installed on building façades, may not be as efficient in terms of energy production. However, concentrating systems (CS) applied to solar generation processes offer several advantages over conventional thermal collectors. These advantages include better space utilization, easier recycling of materials, regulation of flux for optimal flow conditions, higher power density leading to increased fluid temperature, reduced heat loss, and improved overall system efficiency. The economic viability of building-integrated concentrating systems depends on cost comparisons with flat plate or evacuated tube collectors, whose prices are decreasing over time. Additionally, the higher operating temperatures enabled by CS make them particularly suitable for cooling applications, as they allow for the use of more energyefficient double-effect absorption chillers.

This paper presents a comparative analysis of existing concentrating systems suitable for solar cooling, heating, and electricity applications. It discusses specific challenges related to the integration of each system into buildings and describes a building-integrated CS composed of a Fresnel reflective solar concentrator directing solar beams to thermal modules. The paper is divided into two main parts: the first part addresses the requirements for building integration of concentrating systems and solar cooling technologies, while the second part describes the proposed concentrating device and presents a comparative study with a conventional evacuated tube collector system. Finally, the paper concludes with the main findings of the research. India, being a tropical nation, experienCancer and the equator. The average annual temperature in India typically ranges from 25°C to 27.5°C. Most regions in India receive between 2300 to 3200 hours of sunshine annually, with approximately 300 clear sunny days per year. The average solar radiation incident over India ranges from 4 kWh/day to 7 kWh/day. With such abundant solar energy availability, India holds great promise for solar energy applications. This paper presents a portable solar refrigerator equipped with an uninterrupted power supply (UPS). Experiments were conducted at the Indira Gandhi Institute of Technology, Sarang (20.95°N 85.23°E), throughout the year 201 8, under varying climatic conditions.

At present, solar cooling and refrigeration technology play a crucial role in enhancing human comfort and preserving temperature-sensitive food items, primarily because solar energy, being the most affordable and widely available renewable energy source, is utilized. Additionally, there is a pressing need to develop and promote environmentally friendly sustainable cooling technologies due to the high energy consumption and negative environmental impacts associated with conventional cooling methods. Concentrated solar power (CSP) plants have garnered recent interest as alternatives for generating renewable electricity on a large scale and for solar cooling purposes. Various studies have reviewed thermal energy storage systems in CSP, categorizing storage concepts, materials, and technologies. Furthermore, research focusing on solar cooling applications has increased in recent years. For instance, studies have explored the feasibility of applying solar cooling in different climatic conditions, such as those in Tokyo and Mediterranean regions, as well as compared different cooling systems for building integration. However, a significant drawback of solar energy is its time-dependent nature, leading to a mismatch between energy supply and demand. Thermal energy storage (TES) systems can address this issue by storing excess energy for later use, thereby reducing load, saving energy, and compensating for intermittent energy supply and demand. Three types of TES systems—sensible heat thermal energy storage, latent heat thermal energy storage, and chemical thermal energy storage—can be applied in solar power generation and solar cooling applications. This paper focuses on analyzing a TES system based on phase change materials (PCM), which absorb or release heat during a and experimental studies on PCM-based TES systems, utilizing various configurations and methods. However, most studies have focused on PCM at low phase change temperatures, mainly for cold applications in the building sector, and involved small-scale PCM storage units. In this study, two pilot plant-scale storage tanks, each containing 1 70 kg of PCM, were designed and constructed for solar cooling applications requiring a heat source of 1 50-200 °C. The selected PCM material, hydroquinone, has a melting temperature range suitable for solar cooling applications.

Today, the growing interest and expanding market for refrigeration and cooling have led to increased consumption of primary energy, resulting in negative environmental impacts and contributing to the rise in electricity peak loads. The widespread use of conventional vapor compression cooling machines, with over 1 00 million units sold in 201 4, further exacerbates the situation. Refrigeration and air conditioning systems alone account for approximately 30% of total global energy consumption. Solar cooling technology offers significant advantages due to its ability to align with both cooling demand and solar irradiation patterns consistently. According to the International Institute of Refrigeration in Paris (IIF/IIR), cooling purposes consume 1 5% of the world's total electricity production and account for 45% of energy consumption by air-conditioning systems in residential and commercial buildings. In various regions, such as Canada, Greece, and Jordan, the demand for air conditioning has soared, leading to a substantial increase in carbon dioxide emissions, exacerbating climate change concerns. Replacing conventional cooling systems with energy-efficient solar cooling chillers could substantially reduce emissions, with a potential reduction of 3.74 Mt CO2 eq/year with a 25% penetration rate. Solar cooling technologies offer a promising alternative, particularly in areas without reliable electricity access and regions where peak cooling demands coincide with available solar power. This manuscript comprehensively outlines the current strategies, techniques, and applications of solar cooling technologies, including system designs, developments, challenges, optimizations, and case studies. It also discusses optimization methods to maximize specific cooling power (SCP) and system performance while minimizing costs. Additionally, it highlights research areas and emerging trends in solar cooling solar cooling systems for residential and commercial use. The demand for fresh vegetables and fruits has increased significantly in recent years. Cold chain systems are known to extend storage time, maintain freshness and functionality of perishable foods and medicines, and reduce the risk of quality degradation. Unfortunately, improper temperature storage during transport contributes to significant food wastage, with about a third of the world's fresh foods being discarded due to this issue. Proper utilization of cold chain, especially during transport, is crucial to ensure food safety and quality.

Figure 1.1: General view of solar cooling technologies and applications.

Currently, cold chain systems primarily rely on mechanical vapor-compression refrigeration driven by diesel engines. However, this technology faces various challenges including poor energy efficiency, high particulate emissions, and high operation and maintenance costs. Several approaches have been developed to address these challenges and improve the performance of on-board refrigeration systems. One proposed solution is the integration of solid oxide fuel cell auxiliary power units with vapor-absorption refrigeration systems, which has shown efficiency improvements of up to 80%. Additionally, optimizing airflow distribution within refrigerated vehicles through the use of air duct systems has been found to improve teprevent stagnant zones. Conventional diesel-powered refrigeration systems typically have a thermal efficiency of 40% and high greenhouse gas emissions. Moreover, they are prone to refrigerant leakage risks and have a high failure rate. To address these issues, we propose the use of cold thermal energy storage methods with phase change materials (PCMs) for cold storage.

Thermal energy storage with PCMs offers several advantages, including large energy density and constant temperature during phase transition. This approach has been extensively studied for improving the performance of stationary refrigeration systems. Research has demonstrated that incorporating PCMs into refrigeration systems can lead to energy savings and improved system performance under various climate conditions. Studies have also explored the use of PCM slabs on the evaporator surfaces of household freezers, resulting in enhanced heat transfer and increased energy efficiency. Additionally, experiments with PCM-based condensers have shown improvements in overall heat transfer performance and energy efficiency. However, there is limited research on the design optimization of portable cold storage boxes with PCMs, and few published reports exist on the discharging depth of PCM-based TES boxes. Therefore, further research is needed in these areas to optimize the design and performance of PCM-based cold storage solutions.

In today's world, various issues demand attention, with the greenhouse effect or global warming standing out as one of the most pressing concerns. Concurrently, there has been a significant rise in the number of conventional vapor compression cooling and air conditioning systems, with approximately 2 billion air conditioning units in operation worldwide as reported by the International Energy Agency (IEA). This surge in usage contributes to higher greenhouse gas emissions. While the exact number of installed solar cooling systems (SCSs) is uncertain, it was estimated that there were around 1 800 small units in 201 8. These smaller units, with capacities below 20 kW, are becoming more compact, cost-effective, and targeted toward the mass market globally. SCSs offer potential alternative technologies, particularly in hot and sunny advantage in aligning solar radiation with cooling demand, especially during peak demand times. This alignment allows for the immediate use of solar energy to initiate a cooling effect with minimal reliance on energy storage. Despite the higher initial investment required compared to equivalent conventional systems, SCSs boast lower operating costs and have demonstrated feasibility, especially in areas with medium to high solar irradiation levels. Recent research has focused on the principles, development, and applications of solar cooling and air conditioning systems. Solar energy can be integrated into SCSs through two main approaches. The first approach utilizes the solar photovoltaic (PV) principle, where solar PV panels generate electricity to power either a conventional cooling machine or a thermoelectric element to produce cooling effects. The second approach involves harnessing solar thermal energy to achieve cooling effects in thermal SCSs. Thermal solar cooling systems (TSCSs) can be categorized into thermo-mechanical systems and thermal sorption systems.

Thermal sorption systems, the focus of this review paper, typically consist of multiple subsystems working together to produce cooling effects. These systems include solar collectors, heat rejection modules, energy auxiliary units, and the sorption system itself. Solar collectors absorb thermal solar energy and deliver it to the sorption machine at specific temperatures. Depending on the type of sorption machine and the required temperature level, different types of solar collectors can be selected. Heat rejection modules are essential components in TSCSs to remove excess heat generated in the system's thermodynamic cycle. Energy auxiliary units enhance the reliability and effectiveness of TSCSs, especially when solar energy is unavailable or insufficient to meet operational needs. These units may include auxiliary heaters, additional heat exchangers, and energy storage components. Sorption machines in TSCSs employ various technologies, including absorption, adsorption, and dissociative evaporative cooling (DEC). Absorption technology dominates the solar sorption cooling landscape, followed by adsorption and DEC systems. The main difference between absorption and adsorption lies in their sorption approaches: absorption involves volumetric sorption using an absorbent material, while adsorption utilizes a solid other hand, operate in either an absorption or adsorption mode. Common absorbents used in sorption systems include LiBr, LiCl, water, and silica gel. The choice of technology depends on factors such as cooling application, refrigerant conditions, available capacity, peak load conditions, required equipment, and control system strategies. Researchers have explored various optimization methods to enhance the efficiency and economy of solar-powered cooling systems. Additionally, there is ongoing research and development in vapor compression-sorption refrigeration hybrid systems, with potential for significant advancements in the future. Comparisons between sorption systems and conventional systems reveal differences in operating temperature, coefficient of performance (COP), and energy savings, underscoring the potential benefits of sorption technologies. Vehicles play a crucial role in modern transportation, but the use of fossil fuels has led to issues like smog, harmful emissions, and global warming. This has spurred interest in exploring new energy sources. Electric vehicles (EVs) have been extensively researched to reduce emissions. Another solution gaining attention is energy harvesting, particularly vibration energy, from the environment. Various energy harvesting systems exist, including mechanical, piezoelectric, thermoelectric, wind, and solar. During summer, drivers often rely on vehicle air conditioners to maintain comfort. However, parked vehicles can quickly become hot, accelerating plastic degradation, emitting harmful gases, and increasing fuel consumption for air conditioning. Solar energy, being renewable and clean, has been widely adopted for heating and electricity generation. Utilizing solar energy to power air conditioners offers a promising way to reduce greenhouse gas emissions and energy consumption. Researchers have proposed solar-powered air conditioning systems, categorized into photovoltaic (PV) conversion and photothermal conversion. PV collectors are increasingly used to power solar air conditioning cooling systems due to their cost-effectiveness. Several studies have explored PV-powered air conditioning systems, optimizing their design and performance. Additionally, solar energy has been used for air conditioning via photothermal conversion, with various studies analyzing the technology and economics of solar-powered cooling systems for industrial applications.

Literature Review

As the severity of the greenhouse effect escalates, there is a growing focus on cooling vehicle cabins parked in the scorching sun without relying on the engine or the power of an electric vehicle. In this study, we introduce an innovative portable cooling system powered by renewable solar energy, incorporating wireless power transfer (WPT) and supercapacitors to effectively cool the vehicle cabin. The system comprises a solar collector mechanism, an energy conduit, and a temperature control and cooling module. The portable nature of the system is enabled by folding solar photovoltaic (PV) panels within the collector mechanism. Solar energy is harvested and stored in the supercapacitors via wireless power transfer without the need to penetrate the vehicle body. Automatic temperature regulation is achieved through the cooling device integrated with the temperature control and cooling module. Experimental results demonstrate a maximum output power of 2.1 81 W and a maximum WPT efficiency of 60.3% when the prototype is loaded with 3X and 5X respectively. Simulation results reveal an average reduction of cabin temperature by up to 4.2 °C, indicating the effectiveness and feasibility of the proposed solar energy-powered cooling system in cooling a hot vehicle cabin. Preserving perishable foods presents a significant challenge, particularly in regions with unreliable electricity supply. This study focuses on the development and evaluation of a solar thermoelectric cooler (STEC) designed to leverage solar energy for cooling purposes. The STEC system consists of a thermoelectric module (TEM), inner and outer heat sink-fan units integrated into the cooler box wall, and a photovoltaic (PV) panel connected to the device via a battery and PV charge controller. During daylight hours, the PV panel powers the device while simultaneously charging the battery, which stores excess electricity for nighttime cold side temperature of the TEM, cooling capacity, power consumption, and coefficient -of-performance (COP). Results indicate that the cold side temperature decreased to 5±0.2ºC within 1 20 and 1 80 minutes for trials conducted without and with a product load (0.5 kg fish fillets), respectively. At an input electric current of 3.5 A, the STEC exhibited a cooling capacity of 23.8 W, power consumption of 53.5 W, and a COP of 0.44. The battery power sustained the operation of the STEC for 5-6 hours after sunset, positioning it as a viable "green" alternative to traditional domestic refrigeration systems in areas where electricity access is limited. During summer, the issue of high temperatures inside parked vehicles poses a challenge, as cooling them consumes both time and energy. This paper introduces a portable solar-powered cooling system (SPCS) utilizing a foldable-flower mechanism and wireless power transfer (WPT) technology. The system comprises three main components: a solar foldable-flower module (SFFM), an energy transfer module, and a temperature control module. The SFFM employs a unique foldable mechanism resembling a flower opening its petals, enabling efficient space utilization through rotational and folding processes. Equipped with photovoltaic (PV) cells, the SFFM collects solar energy and converts it into electricity. The energy transfer module stores this electricity from the SFFM in a supercapacitor via a WPT unit. Meanwhile, the temperature control module ensures

automatic temperature regulation using a cooling device. Experimental findings indicate an output power potential of up to 7.571 W with a load resistor of 5 Ω, alongside a WPT efficiency reaching 73.6% with a load resistor of 1 5 Ω. Furthermore, thermal simulation demonstrates that the proposed system can effectively lower the average temperature by 27.45 ℃, showcasing its feasibility and effectiveness in cooling a hot vehicle cabin.
Some regions of the country still face challenges in maintaining consistent electricity supply, particularly for critical medical supplies such as vaccines or insulin, which require specific temperature conditions. Combining renewable energy sources for electricity generation with portable cooling solutions for medical supplies could offer a significant remedy to this issue. In this study, a portable cooling box is designed to maintain temperatures between 2–1 6 °C using Peltier units powered by solar energy. Temperature sensors monitor the internal temperature of the box, while current sensors gauge the power genesolar and battery power based on variations in solar radiation.

Methodology

The cooling efficiency of the solar thermoelectric cooler (STEC) was assessed in hot weather conditions (April-May 201 9) in Santiniketan, West Bengal, India, where the average outside temperature ranged from 30-34°C. Fish fillets, weighing approximately 0.5 kg each, were stored in the STEC to evaluate their freshness. The fillets were prepared by purchasing freshly harvested base fish from a local farm, stunning them with a hammer blow to the skull, and then slaughtering and bleeding them by cutting the gill arches and main blood vessels. The portable STEC primarily consists of a cooler box made of food-grade double density polyethylene (HDPE) with a refrigeration-grade polyurethane insulation foam layer, along with a power storage battery, thermoelectric module, heat sinks, and fans. The insulation materials, HDPE and polyurethane foam, have thermal conductivities of 0.44. The cooler box dimensions are 0.36×0.28×0.25 m (length × wiloops for lid closure. The insulation prevents heat backflow and loss, with an estimated total heat energy of 41 .52 W. The TEM (model: TEC1 -1 2705S, make: Hebei) generates hot and cold sides when electric current flows through it, converting solar direct current (DC) to alternate current power. Two heat sinks are placed on either side of the TEM to dispel heat and maintain an ambient environment, with one at the hot side (cm) and the other at the cold side. Cooling fans are employed to reject excess heat from the hot side of the TEM to the surroundings, ensuring effective ventilation and TEM operation.
The solar photovoltaic (PV) module was positioned at the optimal angle (40º) to maximize solar radiation absorption. It was then linked to the solar charge controller, which in turn connected to the battery terminals using appropriate cables. The thermoelectric module (TEM) was attached to the storage battery, with the red wire connecting to the positive power supply and the black wire to the negative power supply. As heat was absorbed, the TEM's positive side converted into the cold side, transferring heat to the opposite side, which became the hot side. The cold side of the TEM was situated inside the cooler box, while the hot side was positioned externally. To assess the cooling effectiveness of the solar thermoelectric cooler (STEC), various parameters such as power generation of the PV module, temperatures of the hot and cold sides of the TEM, power consumption, cooling capacity, and coefficient of performance (COP) were determined. Measurements included the PV module's power output, current, and voltage using a digital multimeter, while temperatures of the TEM's hot and cold sides were recorded using T-type thermocouples connected to a digital temperature indicator. Additionally, room temperature was monitored, and the STEC's voltage, electric current, and power consumption were measured using a digital energy meter. Experimental data were logged using a data logger.

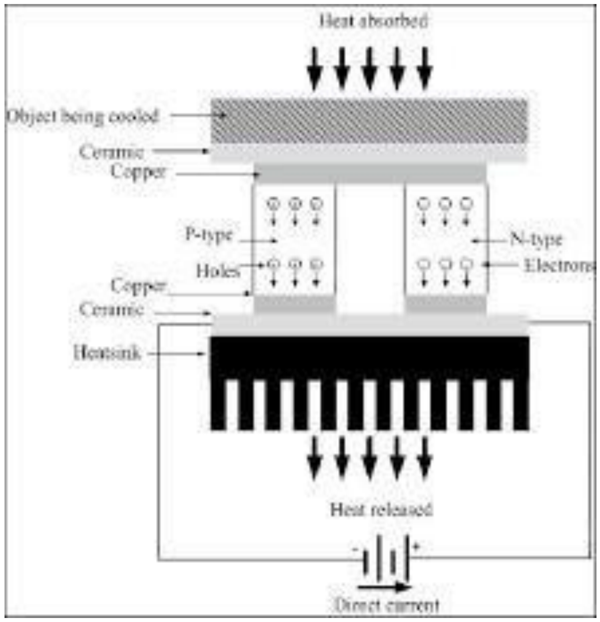

Figure 1.2: Schematic arrangement of basic components of the thermoelectric cooling system.

In scientific investigations of solar-powered thermoelectric cooling systems, key factors include determining the total heat gain of the cooler box, the coefficient of performance (COP) of the thermoelectric module, and sizing the solar photovoltaic (PV) module. The cooling process relies on heat transfer through the cooler box walls, product heat, heat dissipated by fans, and heat resulting from air infiltration into the cooler. Calculations incorporated the average outside temperature over the study duration to account for temporal temperature variations. Wall heat loss (Qwan) of the cooler box was estimated using a formula, while conduction heat loss (Qm) within the thermoelectric module was determined separately. Product heat (Qp) within the cooler, emitted by the stored items, such as the 0.5 kg of fish fillets used in this study, was calculated based on the specific heat capacity of the fillets. Additionally, the rated power consumption of the fan (Fl) was employed to calculate the heat dissipation at the cold side of the thermoelectric module.

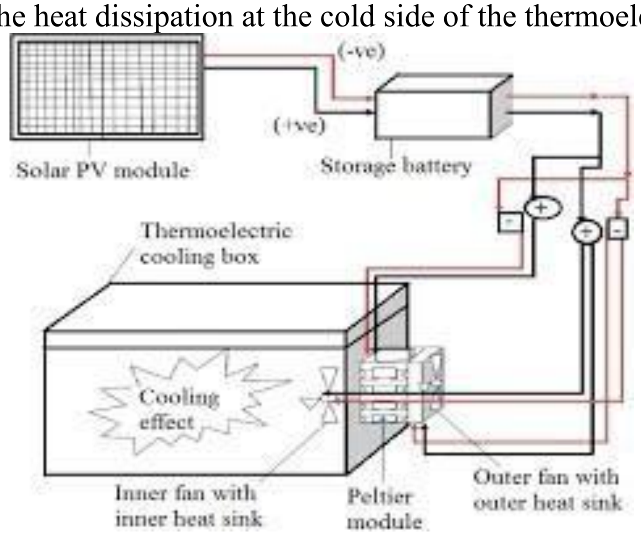

Figure 3.1: Schematic diagram of the experimental portable solar thermoelectric cooler.

The heat dissipated by the fan (Qf) based on the number of fans (Nf) and their rated power consumption (Fr). Air infiltration into the cooler box through the top lid contributes to heat generation. The total heat energy (QT) is determined by summing the heat flux entering the cooler box, conduction heat loss within the thermoelectric module, product heat, heat dissipated by the fan, and air infiltration heat, all measured in watts. The thermoelectric heat balance analysis considers Peltier heating, Peltier cooling, Joule heat, and Fourier heat. The heat transfer at the cold and hot sides of the thermoelectric module, respectively. Joule heating at either side of the module, quantifies heat conduction through the thermoelectric material. The cooling capacity (Qc) of the thermoelectric module, representing the heat pumped or absorbed at the cold side. Similarly, the heat transferred at the hot side (Qh). The electrical power consumption of the thermoelectric module (Pym) is determined by the difference in heat absorption and rejection at the cold and hot sides. The total electric calculated by adding the power consumption of the thermoelectric module fans. The coefficient of performance (COP) of the thermoelectric cooler in cooling mode estimated using either the total heat energy (QT) or the cooling capacity (Qc). The optimum electric current input to the thermoelectric module for maximum COP is determined when the hot and cold side temperatures are in a steady-state condition.

Table 1.1: Specifications of the solar PV module and thermoelectric module (Hebei, China)

Solar PV Module		**Thermoelectric module**		**Battery Parameters**	
PV module VE1 21 00	type	TEM Type	TEC1 -1 2705S	PcW	53.2
Maximum rated power Wp	1 00	Imax	5.3 A	Φb	0.85 W
Maximum power voltage V	1 8.58	Umax	15.4 V	Hb	0.90 W
Maximum power current A	5.98	Q max. @ΔT=0	57 W	Δ	0.90 W
Open circuit voltage V	22.58	ΔT max	67 ºC	χb W	0.05
Short circuit current A	5.96	Th	40 ºC	Ds	1 Day
Module efficiency	1 3.2%	N-P junction couples	1 27		
Output tolerance	5 %	Max. temperature	1 38ºC		
Maximum series fuse rating A	1 0	Dimension mm	40×40×3.8		
Operating temperature ºC	- 40 to 85	Design	Silicone sealed		
Module dimension Mm	1 032×672	Material telluride	Bismuth		
Weight	8 kg	Weight	29 g		

PV module at standard test condition: solar irradiance 1 .0 kW/m2; module temperature 25°C; wind speed 1 .0 m/s. In this, solar energy from the solar plate was stored in the battery through the solar charge controller, which is an ACS 71 2 current sensor module used for battery level indicators that went to the Arduino along with DHT1 1 temperature sensor input. Those values were then processed and shown on the display. From the temperature sensor value, the Arduino processed those values and gave a command to the relay controlling the Peltier and cooler fan to be triggered. This section presents the detailed methodology of the proposed project. Initially, an airtight enclosure is constructed to prevent the ingress of outside temperature and the escape of inside temperature. Subsequently, internal temperature control is achieved through the use of a

Peltier device. Key hardware components, such as the solar panel, are positioned on top of the enclosure, while others, including the charge controller, battery, and sensors, are placed inside. The display and buzzer are located externally to allow users to monitor internal temperature and promptly respond to buzzer alerts. Additionally, the software of the proposed prototype integrates a Fuzzy Inference System (FIS) for its simplicity in rule configuration. This FIS, operating on a basic artificial language, streamlines task execution without consists of four primary components: fuzzification, a knowledge base comprising IF-THEN rules, inference engines for fuzzy reasoning, and defuzzification to convert fuzzy set outputs into precise values.

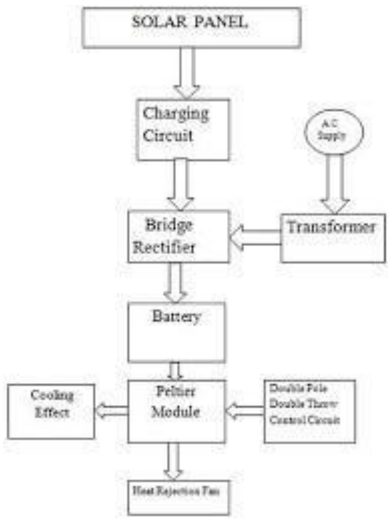

Figure 3.2: Block diagram of the proposed model

The system first started and initialized the circuit, then read the temperature sensor value along with the current sensor value. The system would trigger the Peltier to rely upon the temperature sensor value exceeding the threshold value; otherwise, it would again check for the value. The system, on the other hand, would read the current sensor value; if the value fell below the threshold, the system would notify via a buzzer; the buzzer would also be activated when the relay was triggered. The value of battery life, which denotes the current sensor value and the temperature value, would be shown on the display attached to the system.

Table 1.2: Main characteristics of the building with the SCCS.

Building Parameter	**Value**
Floor dimensions (m)	60x20
Height (m)	12
Height (m)	3
Number of story's	30
Windows surface on the walls (%)	0.5
Ventilation rate (h-3) Annual Specific demand for cooling (kWh m-2 year)	54
Building Element	**Heat Transfer Coefficient (Wm-2 K-1)**
Outdoor wall	0.6
Roof	0.3
Ground	0.5
Windows	1.3

It is presumed that the Solar Cooling Concentrating Systems (SCCS) are installed within an office building situated in Barcelona, Spain. We explored two design alternatives based on the solar azimuth constraints of the mirrors' orientation, ranging from ±45 degrees (SCCS 45) to ±70 degrees (SCCS 70). The key attributes of the building considered are outlined in Table 2. Utilizing the data from Table 2, one can estimate the hourly cooling requirements employing the degree-day normalization method with a variable base temperature. The TRNSYS software is utilized to simulate and subsequently assess the energy efficiency of the SCCS options for August 3rd. This simulation period is selected due to the fixed solar height value in the non-illuminated fraction, employed to compute the corresponding concentration ratio in the TRNSYS Simulation Studio environment, volumes of the hot and cold storages are optimized. This optimization is executed with the TRNOPT application within TRNSYS, employing the program to maximize the fraction of the daily cooling demand.
The attained results are juxtaposed with those of the TRNSYS optimization of a benchmark low-temperature solar cooling system, RSCS 45 and RSCS 70, capable of generating equivalent cooling output to SCCS 45 and SCCS 70, respectively, over the same timeframe. The configuration of the Reference Solar Cooling Systems (RSCSs) mirrors that illustrate, featuring a single-effect absorption chiller and ETC solar collectors with a tilt angle of 35 degrees relative to the horizontal position (roof mounted). The rooftop installation for the reference solar cooling system is selected due to its prevalence, ensuring a more realistic comparison. However, it's noteworthy that the RSCS receives a higher percentage of radiation on the aperture area compared to the vertically positioned SCCS. Both SCCS and RSCS systems model the solar collector using a modified ETC solar collector to account for thermal capacitance, while the thermal chillers are modeled using the characteristic equation approach.

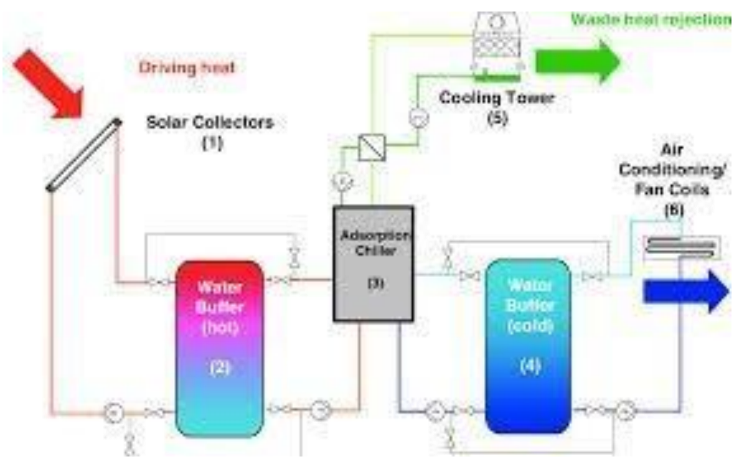

Figure 3.3: Simplified diagram of the solar concentrating cooling system (SCCS).

First, the verification of grid independence is performed. Illustrates the finite element mesh generated in COMSOL Multiphysics. A sensitivity analysis of grid numbers is then conducted, where the contour of elements represents skewness, indicating higher grid quality when closer to a value of 1 . Default settings in COMSOL for predefined mesh sizes—finer, extra finer, and extreme finer—are utilized. A comparison of internal box temperatures with varying grid sizes. As the grid size decreases, the discrepancy in internal box temperature remains within 5%. These minor variations demonstrate the grid's strong independence. Consequently, a finer grid with 1 98,41 2 elements is chosen for simulation, balancing reliability and computational efficiency.

Figure 3.4: Portable Solar cooling box

In the context of a conventional cold chain box, maintaining a central temperature below 8°C is essential. Consequently, the cooling time, denoted as 't', signifies the duration required for the central temperature to reach 8°C. Given that cooling is the primary objective of the box, we introduce the concept of cooling efficiency, also referred to as discharging efficiency, to assess its performance. In this evaluation, all the cold energy stored in Phase Change Materials (PCMs) is utilized to sustain the cooling of the box. Ideally, upon completion of the discharging process, the PCM should release both its latent and sensible energies entirely. For achieving maximum latent energy, the PCM sensible energy is attained when the temperature aligns with the ambient temperature Equation (7) is thus formulated to define the discharging efficiency, encompassing both latent and sensible energy considerations.

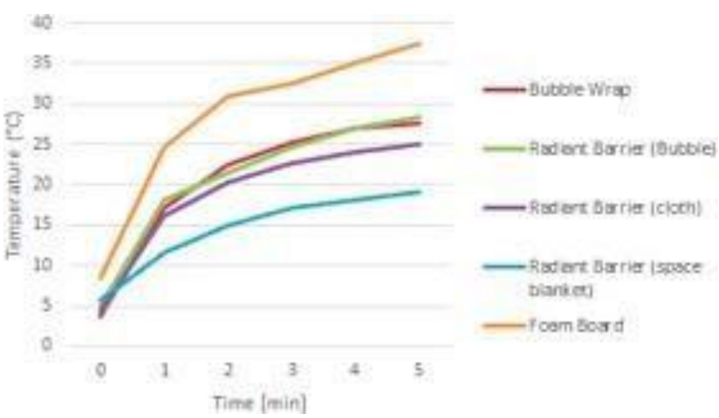

Figure 4.1:

View on Sorption Cooling System:

Internal temperature of the box with different grid sizes. In this segment, an overview of sorption cooling systems and associated technologies is provided and analyzed. Baniyounes et al. (reference [8]) investigated the potential markets for Sorption Cooling Systems (SCSs) and their implications for architecture and management. They also examined the growth of the SCSs industry market and the application of solar cooling technologies across various sectors. Zhai and Wang (reference [9]) discussed five representative cooling system projects, highlighting the suitability of solar absorption cooling (ABSC) systems for large building air conditioners and solar adsorption cooling (ADSC) systems for relatively smaller units. They underscored the significant role of solar cooling technologies in future applications.

Baldwin and Cruickshank (reference [1 0]) analyzed solar cooling techniques, particularly focusing on systems at lower levels and their feasibility and application in residential areas of

Canada. They noted a dearth of research on lower-level SCSs, despite their potential to reduce energy consumption and carbon dioxide emissions in residesolar systems, including heating, cooling, and household hot water. They introduced performance indicators for these systems and calculated them for 1 1 real systems, providing specific values for each indicator. Mugnier et al. (reference [1 2]) provided an overview of solar cooling and heating origin systems within the framework of IEA Solar Heating and Cooling (SHC) task 53. Kojok et al. (reference [1 3]) evaluated the energy efficiency of hybrid cooling systems (HCS) for air conditioner production, proposing techniques with distinct processes or machines for cooling. They emphasized the role of a well-chosen HCS in reducing energy usage and improving the coefficient of performance (COP) under varying weather conditions and system designs.

Beccali et al. (reference [1 4]) examined the usage of a life-cycle assessment tool established in the model of the IEA SHC Task 48 to compare different categories of solar-assisted systems for cooling and heating. They identified the most efficient design in Palermo as a traditional system aided by a photovoltaic plant connected through a grid, significantly reducing the global energy requirement. Husain et al. (reference [1 5]) comprehensively discussed developments in transparent solar cells (TSCs) from 2007 onwards, emphasizing the need for sustainable electricity generation methods. They highlighted TSCs as a solution to space constraints for solar panel installation in larger buildings, absorbing extra energy from building glass such as windows. Al-Ugla et al. (reference [1 6]) compared various AC systems, including solar LiBr–H2 O absorption, solar PV vapor-compression, and conventional vapor-compression, based on a techno-economic examination for large building cooling loads. Their analysis, conducted in Khobar City, Saudi Arabia, aimed to reduce electrical peak power claims by using solar cooling technology (SCT) in commercial places, resulting in substantial economic gains. They found that solar absorption systems are more economically rational than solar PV-vapor-compression systems, especially as building size increases and electricity rates rise. Lastly, Allouhi et al. (reference [3]) presented an overview of available thermal and pmulti-criteria performance indicators from previous studies and evaluated the benefits and drawbacks of distinguishing solar thermal cooling systems. Market research findings were also discussed, along with brief descriptions of cooling installations in Europe, Egypt, and China.

Solar absorption cooling technology

This section presented and discussed the principle of solar absorption cooling systems and technologies. Absorption generally refers to two broad distinct phenomena. In one instance, it relates to when atoms, molecules, or ions get into some volume–gas, liquid, or solid material. For example, a sponge soaks up water when it is dry. Absorption also deals with the process by which the energy of a photon is taken up by another structure, for instance, by an atom whose valence electrons move between two electronic energy levels. The photon is eliminated in the process. The absorbed energy may be diffused as radiant energy or converted into heat energy. The absorption of light when waves disseminate, usually known as attenuation. In chemistry, the measures of spectroscopy depend on the absorption of photons by atoms and molecules. A simple ABSC system mainly consists of an absorber, generator, condenser, evaporator, expansion valves, solar heating module, and water cooling module.

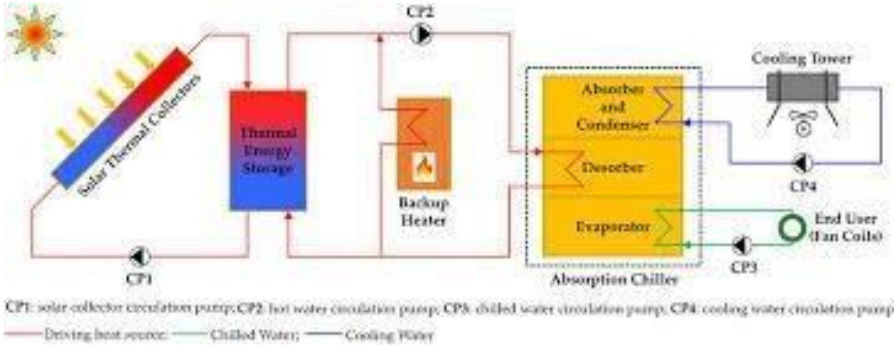

Figure 4.2: Generic layout of a solar adsorption cooling system

It is observed that the parameters studied above play an essential part in the selection of commercially available chillers. The COP of the EAW [42,43] is better than the other chillers. Also, the chiller's capacity even nominal 1 5–50 kW to produce the chilling effect for the particular application. The particulars provided are as per the literature survey carried out. But it is not sure that all the available studies are covered. Ajib and Gunther (reference [38]) conducted experimental research aimed at optimizing heat and mass exchange processes in a shell tube heat exchanger within a 5 kW capacity H2O/LiBr solar absorption chiller. One heat exchanger featured an even outer surface, while the other had an uneven outer surface. Results indicated superior heat and mass exchange characteristics in the heat exchanger with uneven tubes compared to those with even tubes. They observed that the heat exchange coefficient increased with both even and uneven tubes as the flow rate of the working fluid increased and decreased with the cooling water temperature. Notably, the heat exchange coefficient of the uneven tubes heat exchanger outperformed that of the even tubes in both scenarios. Soussi et al. (reference [39]) evaluated a 1 6 kW double effect H2O/LiBr absorption chiller theoretically and experimentally for a 1 26 m2 laboratory building in Tunisia, incorporating a solar field consisting of PTC (3*1 3.1 m2). Collector efficiency ranged between 26% and 35%, with COP values between 0.65 and 1 .29. They highlighted the enhancement in functioning, running time, and cooling potential of the absorption chiller with the incorporation of an auxiliary heater. Gao et al. (reference [40]) assessed theoretical and experimental single-stage and double-stage cooling absorption solar thermal systems utilizing H2O/LiBr working pairs. Illustrates various parameters studied in ABSC systems, including the technology used, working material, chiller power, collector type and area, and applications. ABSC technology is widely adopted due to its efficiency, cost-effectiveness, and environmental friendliness in cooling systems.

Conclusion

In conclusion, the portable solar cooling box is a game-changer in the quest for sustainable and efficient cooling solutions. This innovative device has the potential to transform the way we access cooling, particularly in off-grid and remote areas where traditional cooling methods are scarce. By harnessing the power of the sun, the portable solar cooling box provides a reliable and eco-friendly alternative for storing and transporting perishable goods, medications, and even food and drinks. Its compact design, ease of use, and ability to operate for extended periods make it an ideal solution for various applications, including outdoor events, military operations, and emergency response situations. Moreover, the portable solar cooling box is a cost-effective solution, eliminating the need for fuel or electricity, and reducing the carbon footprint associated with traditional cooling methods. As the world continues to grapple with climate change and energy security, the portable solar cooling box is a shining example of innovation and sustainability. Its potential to improve lives, particularly in underserved communities, is vast, and its impact on the environment is negligible. As we look to the future, the portable solar cooling box is an exciting development that holds great promise for a cooler, more sustainable tomorrow.

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