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Prototype Development and Fabrication of a Solar Powered Smart Dual Chamber Thermal Preservation System

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ABSTRACT—

Conventional portable coolers rely on ice packs or grid electricity, and portable warmers are bulky and rarely use renewable energy. This paper presents the development and fabrication of a portable, solar-powered dual-chamber thermal preservation system that provides a cooling chamber and a heating chamber from a single thermoelectric (Peltier) module. A 10 W solar panel charges a 12 V, 7 Ah lead-acid battery through a charge controller. An ESP32 microcontroller reads two DS18B20 temperature sensors, shows the readings and setpoints on an OLED display, and switches the module through a MOSFET driver according to user-selected setpoints. In a 3-hour test at a room temperature of 32 °C, the cooling chamber fell to 27 °C and the heating chamber rose to 37 °C (average 1.67 °C/h in each chamber), while the battery voltage fell from 12.8 V to 12.1 V. The cooling setpoint of 20 °C was not reached, and the limitations of the prototype are discussed together with improvements required.

Keywords— *Solar energy, thermoelectric cooling, Peltier effect, dual-chamber system, thermal preservation, ESP32, portable thermal storage.*

1. INTRODUCTION

Many everyday and professional activities require items to be kept colder or warmer than the surrounding air. Food and beverages are stored cool to slow spoilage, cooked food is kept warm until served, and some medicines and biological materials must be held within a narrow temperature band during storage and transport. In urban areas this need is met by compressor-based refrigerators and mains-powered warmers, but these devices are bulky, depend on continuous electricity, and are inconvenient for short journeys, field work, or places with unreliable supply.

Thermoelectric (Peltier) modules offer a different approach. A Peltier module is a solid-state device with no compressor, refrigerant, or moving parts; when a direct current passes through it, one face absorbs heat and becomes cold while the opposite face releases heat and becomes hot [3], [4]. One module can therefore provide cooling and heating at the same time, and its low-voltage DC supply suits battery and solar-powered systems. Its main disadvantage is a low coefficient of performance (COP) compared with vapour-compression systems [5].

This work proposes a portable solar-assisted unit that uses the cold face of one module for a cooling chamber and the hot face for a separate heating chamber, with ESP32-based temperature display and thermostatic control. The aim is to design and fabricate this system and to evaluate its performance honestly through a measured test, reporting what the prototype achieved and what it did not.

2. LITERATURE REVIEW

Zhao and Tan [3] reviewed thermoelectric cooling and highlighted its small size, reliability, absence of working fluids, and easy switching between cooling and heating, while Riffat and Ma [4] surveyed present and potential applications. Min and Rowe [5] tested prototype thermoelectric refrigerators and reported a COP of roughly 0.3–0.5 at a 5 °C cold side with 25 °C ambient, noting that lower contact resistance and better heat exchangers improve performance. This supports the use of thermal paste, aluminium plates, and fan-cooled heat sinks on both module faces in the present design.

Dai et al. [1] built a solar-cell-driven thermoelectric refrigerator with battery storage that held 5–10 °C inside with a COP of about 0.3, and Abdul-Wahab et al. [2] developed a low-cost portable solar thermoelectric refrigerator in which the interior fell from 27 °C to 5 °C in about 44 minutes (COP about 0.16). Low-cost controllers are widely used for monitoring: Talamayan et al. [7] used DS18B20 sensors with on–off control in a Peltier cooling vest, and Gofur et al. [8] built an ESP32-based thermoelectric cool box with Wi-Fi monitoring. Al-Homoud [6] showed that insulation reduces heat leakage, and hence the load on the module and battery.

Research gap. Reported solar thermoelectric systems are mainly refrigerators in which the heat released at the hot face is rejected, and many portable boxes provide a single function with little information on the actual internal temperature. A compact, low-cost, solar-assisted unit that uses both faces of one module for two separate insulated chambers, and reports its limitations, is therefore of interest.

3. SYSTEM DEVELOPMENT AND FABRICATION

3.1 System Overview

The system is a dual-chamber thermoelectric unit powered by a solar-charged battery (Fig. 1). The panel charges the battery through the charge controller; after a fuse and main switch, the 12 V supply feeds a thermal branch (Peltier module via MOSFET, and two fans via a relay module) and a control branch (buck converter supplying the ESP32 and peripherals). The functions of the components are summarised in Table 1.

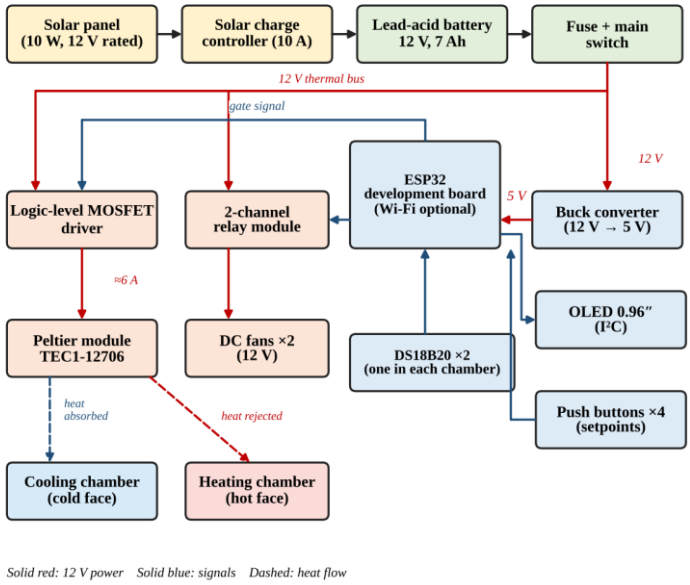


Fig. 1. Block diagram of the solar-powered smart portable thermal preservation system

Table 1. Major components of the proposed system

Component	Specification	Function
Solar panel	10 W, 12 V rated	Converts sunlight to DC energy
Charge controller	10 A	Regulates battery charging
Battery	12 V, 7 Ah lead-acid	Stores energy, supplies loads
Peltier module	TEC1-12706	Moves heat from cold to hot face
Heat sinks and fans	2 aluminium sinks, 12 V DC fans	Exchange heat with chamber air
ESP32 board	1 unit	Reads sensors, controls loads
Temperature sensors	2 × DS18B20	Digital chamber temperatures
OLED display, buttons	0.96-inch I²C, 4 push buttons	Show readings; set setpoints
Relay module, MOSFET	2-channel relay; logic-level N-MOSFET	Switch fans; switch Peltier current (up to ~6 A)
Buck converter	12 V to 5 V	Supplies the control circuit

3.2 Mechanical and Thermal Design

The enclosure is made of plywood, approximately 30 × 60 cm in plan, divided by a central partition so that each chamber occupies about 30 × 30 cm. The Peltier module is mounted in a cut-out in the partition between aluminium thermal plates with thermal paste on both faces to reduce contact resistance. The cold face, with its heat sink and 12 V fan, faces the cooling chamber, and the hot face, with its heat sink and fan, faces the heating chamber. The chamber walls and lids are lined with thermal insulation, and the gap around the module is filled to limit heat leakage from the hot side to the cold side. One DS18B20 sensor is placed in each chamber, away from the heat-sink air stream, so that it represents chamber air temperature. The fabricated prototype is shown in Fig. 2.

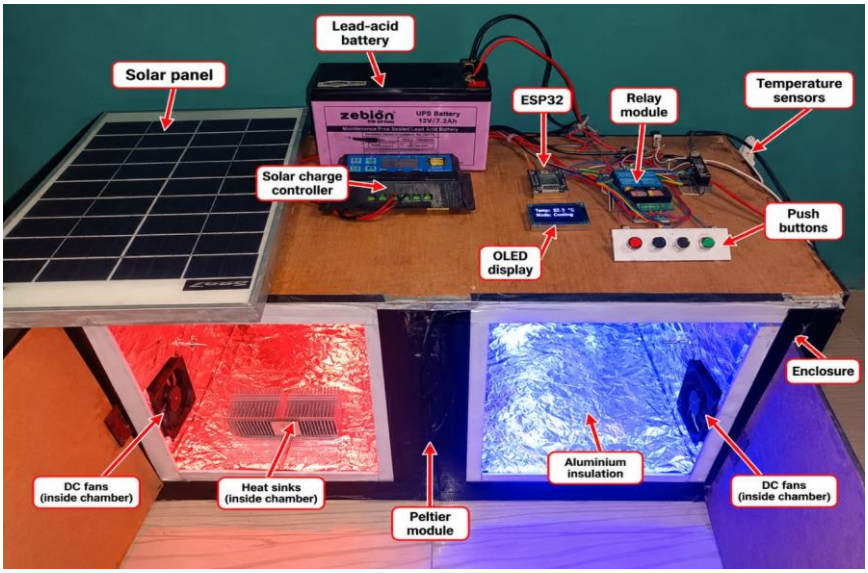


Fig. 2. Fabricated prototype with the major components labelled

3.3 Power and Electronic System

The 10 W panel charges the 12 V, 7 Ah battery (nominal energy 12 V × 7 Ah = 84 Wh) through the charge controller. The Peltier module is supplied through a logic-level N-channel MOSFET with a gate resistor and pull-down, because its current cannot be supplied from an ESP32 pin. The two fans are switched by the relay module. A buck converter reduces the battery voltage to 5.0 V for the ESP32 and relay module, and the thermal and control grounds meet at a single star point. The two DS18B20 sensors share one 1-Wire line with a 4.7 kΩ pull-up and are identified by their unique 64-bit addresses, so the two chambers are not interchanged. The OLED is on the I²C bus and four push buttons (internal pull-ups) raise and lower the cooling and heating setpoints.

3.4 Control Strategy

The ESP32 is programmed in the Arduino IDE. In a loop of about one second it reads both temperatures, validates them, reads the buttons, decides the state of the module and fans, and refreshes the OLED. Because one module serves both chambers, the module is switched on when either chamber needs correction (cooling chamber above its setpoint plus the hysteresis band, or heating chamber below its setpoint minus the band) and is blocked when either chamber has passed its setpoint in the wrong direction, so both setpoints act as limits. A minimum on-time and off-time protect the module and MOSFET from rapid cycling, the fans run on briefly after the module is switched off, and a sensor fault switches the module off.

3.5 Working Principle

The solar panel converts sunlight into DC electricity by the photovoltaic effect and stores it in the battery. When the module is energised, the Peltier effect pumps heat from the cold face to the hot face. The heat released at the hot face equals the heat absorbed at the cold face plus the electrical input power, so the heating chamber is expected to gain heat faster than the cooling chamber loses it. Temperature feedback from the DS18B20 sensors lets the ESP32 hold each chamber near its setpoint.

4. EXPERIMENTAL PROCEDURE

The prototype was tested for 3 hours with the solar panel and battery supplying the system together. The initial room temperature was 32 °C, both chambers started at 32 °C, and the cooling setpoint was 20 °C. Chamber temperatures were read from the OLED display and recorded at the start and at 30 minutes, 1 hour, 2 hours and 3 hours; battery voltage was measured before and after the test. The cooling and heating rates are computed as

$$\text{Cooling rate} = (T_i - T_f) / t, \quad \text{Heating rate} = (T_f - T_i) / t \qquad (1)$$

where T_i and T_f are the initial and final chamber temperatures and t is the elapsed time. Electrical power is P = V × I and energy is the sum of V × I × Δt over the readings. Current and watt-hour readings were not recorded in this test, so power consumption and COP are not reported.

5. DISCUSSION

The results show that the arrangement works as intended but with modest performance. The 5 °C cooling in 3 hours is smaller than that reported in earlier solar thermoelectric refrigerators [1], [2], which is not surprising for a single module serving two chambers of about 30 × 30 cm each. Likely contributing factors, which should be investigated, are heat leakage through the insulation, thermal coupling between the two sides, limited heat-sink capacity on the hot face and the unrecorded chamber loads. The two chambers changed by equal amounts, whereas the hot face is expected to deliver more heat than the cold face absorbs; five readings recorded to whole degrees are too few to resolve this. Condensation in the cooling chamber and overheating of the hot side are practical concerns, so the module must never be energised without both fans running.

6. CONCLUSION AND FUTURE SCOPE

A solar-powered portable dual-chamber thermal preservation system was fabricated using a single Peltier module, a 10 W panel with a 12 V, 7 Ah battery, and ESP32-based monitoring with DS18B20 sensors and an OLED display. In a 3-hour test at 32 °C ambient the cooling chamber fell to 27 °C and the heating chamber rose to 37 °C, demonstrating simultaneous cooling and heating, while the cooling setpoint of 20 °C was not achieved and the battery voltage fell from 12.8 V to 12.1 V. The work shows the feasibility of combining solar energy, thermoelectric technology and microcontroller-based monitoring in one portable unit.

Future work includes:

- measuring module voltage and current, solar charging and battery backup time so that power and COP can be calculated;
- improving insulation, heat-sink size and airflow, and testing with known water loads for repeatable results;
- adding battery-voltage monitoring with low-voltage protection, sensor-fault protection and humidity/condensation control;
- using thermal-storage materials to hold chamber temperatures, and completing the Wi-Fi/IoT remote monitoring function.

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