

DEVELOPMENT OF AN EFFICIENT SOLAR ENABLED BATTERY POWERED COOLER FOR MEDICAL APPLICATIONS

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ABSTRACT

This paper presents a solar-powered thermoelectric cooling system tailored for medical storage applications, especially for vaccines and biological materials sensitive to temperature variations. The system leverages renewable solar energy, which charges a lead-acid battery that powers thermoelectric Peltier modules. A hysteresis-based control mechanism is implemented using an Arduino Uno to enhance energy efficiency for maintaining its temperature between 10°C and 4°C. The DHT22 uses real-time temperature monitoring, while heat sinks, fans, and ice packs provide auxiliary cooling. Through experimentation and analysis, the results demonstrate power consumption of 2.814 Wh, minimum temperature maintained at 5°C. **Keywords**— Thermoelectric Cooling, Peltier Module, Solar Energy, Hysteresis Control, Vaccine Storage, Arduino Uno, IoT Monitoring

Keywords: *TEC – Thermoelectric Cooler; PWM – Pulse Width Modulation; CE – Cooling Effect; dT/dt – Rate of temperature change; PV – Photovoltaic panel.*

1. INTRODUCTION

Medical facilities in remote regions often lack stable electricity, making it difficult to store vaccines and other temperature-sensitive materials safely. The World Health Organization stresses the importance of reliable cold chain systems in such areas. Thermoelectric cooling (TEC), based on the Peltier effect, offers a viable alternative to vapor-compression systems (Rajasekaran and Rajarajan [1]). TEC modules create a temperature gradient using electric current, allowing precise temperature control without moving parts (Chien [2]; Gonçalves et al. [3]). This makes them compact, silent, and maintenance-free (Dubey et al. [4]).

TEC systems are environmentally friendly, as they avoid harmful refrigerants like CFCs and HFCs (Christopher [5]). When combined with solar power, they can operate independently of the grid, making them ideal for off-grid healthcare (Islamoglu [6]; Zhang et al. [7]). A solar setup with battery backup ensures 24/7 operation, even during poor weather (Kalman et al. [8]). Passive cooling methods like insulation and ice packs further extend their efficiency (Lin et al. [9]).

Smart control systems using hysteresis and PWM help reduce power use by activating cooling only when needed (Kharbanda et al. [10]). Ongoing research into materials and design is making TEC systems increasingly efficient for medical use (Abdel-Hady et al. [11]).

This paper aims to design, develop, and evaluate a hybrid solar-powered thermoelectric cooler that combines active and passive cooling strategies with intelligent energy management. The proposed solution addresses the dual challenge of maintaining medical-grade cooling while minimizing energy usage in off-grid environments. By leveraging low-cost components and smart control algorithms using Arduino Uno, the system offers a scalable and sustainable approach to rural healthcare refrigeration.