

IoT-Enabled Solar-Powered Cold Storage Solutions for Street Vendors: Enhancing Food Preservation and Business Sustainability

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Abstract—This paper presents the development of cutting-edge solar-powered cold storage units designed specifically for street vendors. This innovative technology addresses the critical need for reliable and mobile cold storage solutions in off-grid areas by integrating portability, flexibility, and efficiency through solar energy. Historically, street vendors have heavily relied on non-renewable energy sources and faced limited access to cold storage facilities. Our system aims to provide a user-friendly interface, efficient cooling mechanisms, and real-time monitoring and management through IoT connectivity. By offering dependable cold storage for perishable items in a portable and user-friendly design, the Solar Powered Cold Storage system for street vendors has the potential to revolutionize their business practices. The system's key features include its portability, which allows street vendors to transport and set up the cold storage unit wherever needed, and its reliance on solar energy, making it a sustainable and cost-effective solution. Additionally, the integration of IoT technology enables remote monitoring and management of the cold storage unit, ensuring optimal performance and energy efficiency. Overall, this technology offers street vendors a reliable and efficient cold storage solution that can significantly enhance the quality and shelf life of their products, ultimately improving their business operations and profitability.

Index Terms— IoT systems, food quality monitoring, sensors, safety, adaptive technology, food engineering.

I. INTRODUCTION

In today's bustling urban environments, street vendors play a crucial role in providing accessible goods to communities. However, one of their key challenges is the lack of efficient and reliable cold storage options for their perishable products. To tackle this issue, the integration of cutting-edge technology has led to a groundbreaking solution: IoT-Based Solar-Powered Cold Storage designed specifically for street vendors. This innovative cold storage system combines IoT (Internet of Things) and solar energy to revolutionize how street vendors store and preserve their perishable goods. The system utilizes IoT technology for real-time monitoring, precise temperature control, and a user-friendly interface, ensuring optimal storage conditions for a variety of

perishable items [1][2]. This concept holds promise for sustainable preservation of perishable commodities, potentially influencing the street vendor industry significantly. Our technology reduces operating costs and carbon footprints while improving cold storage accessibility for street vendors operating in underdeveloped regions through the use of solar power. It underscores a comprehensive exploration of the economic, environmental, and technological implications of solar-powered cold storage for street sellers, highlighting how portable and sustainable cold storage technologies have the potential to fundamentally change how street merchants perceive and utilize them [3][4].

II. MODEL OF THE COLD STORAGE SYSTEM

Firstly, ethylene is a major contributor to the deterioration of fruits and vegetables. In lower temperatures, the ethylene reaction slows down, effectively extending the shelf life of perishable items. It is crucial to monitor the storage environment's humidity, oxygen (O₂), carbon dioxide (CO₂), and nitrogen (N₂) content. A system designed to manage these factors, including ethylene concentrations and gas levels, can significantly improve the preservation of products stored within the facility. Additionally, maintaining food preservation in a healthy state is vital for prolonging the shelf life of perishables. This involves controlling heat transmission within the storage facility and optimizing the architecture of the surrounding system to ensure optimal storage conditions [5][6].

Secondly, temperature control and dynamics play a crucial role in the efficient operation of cold storage units. Differential equations or mathematical models can describe the thermal dynamics within the unit based on heat transfer principles. Factors such as outside ambient temperature, solar radiation, insulation properties, and cooling mechanisms (such as compressors and fans) must be considered. Solar energy utilization is another important aspect, with mathematical equations used to represent the conversion of solar radiation into electrical energy through photovoltaic panels. Energy balance equations are essential to account for solar energy generation, storage, and utilization within the cold storage system. Furthermore, energy consumption and efficiency can be quantified using mathematical models to evaluate the energy consumption of system components like compressors, IoT sensors, control systems, and auxiliary equipment. Formulas can calculate the overall system efficiency, considering energy inputs, losses, and output required to maintain desired storage temperatures [7][8].

Integration of the Internet of Things (IoT) allows for advanced monitoring and control functionalities. Algorithms can collect data from sensors, use communication protocols, and adjust system parameters based on real-time data to maintain stable and efficient cold storage conditions. Additionally, optimization and control algorithms can be developed to minimize energy consumption while ensuring optimal temperature conditions for stored goods. These algorithms can dynamically adjust system parameters based on real-time IoT data. Finally, financial and environmental analyses can be conducted to evaluate the financial aspects and environmental impact of using solar-powered cold storage for street vendors. Formulas can assess initial investment costs, operational expenses, and potential savings or revenue generated by using renewable energy-based systems, along with reductions in carbon footprint compared to conventional systems [9][10].

III. CALCULATION REGARDING COOLING POINTS & HEAT POINT TRANSFER INTERIOR TO THE COLD STORING POINTS

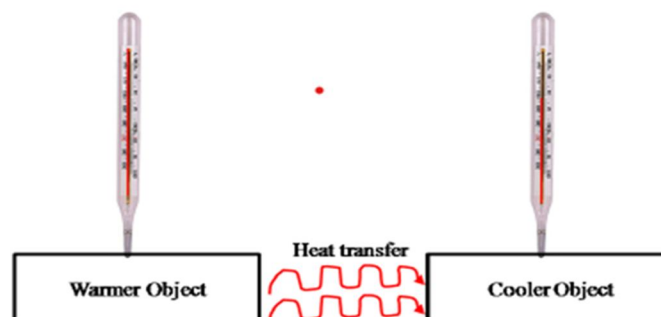


Fig. 1: The principle of transferring heat from one object to another

The heat transfer rate in a specific material is measured as the amount of heat passing through a unit area per unit time, with a temperature gradient of one degree per unit distance as shown in the Fig. 1[11].

$$k = \frac{Q \times \Delta x}{A(\Delta T)} \text{ W/m}^\circ\text{C}$$

Here, Q will be the heat transferring rates, thick-ness of the heat passings & the parameter A will be the area of different objects [12].

Thermal Conductances [C]

It quantifies a material's capacity to conduct heat over time, considering a unit area and a temperature gradient across its thickness. The thermal conductivity (C) is obtained by dividing the material's thermal conductivity (k) by its thickness (d), allowing for the application of relevant equations [13][4].

$$C = \frac{k}{d} \text{ W/m}^2\text{.}^\circ\text{C}$$

Thermal based Resistances [R]

$$R = \frac{1}{C} \text{ m}^2\text{.}^\circ\text{C/W}$$

It is the opposite of thermal conductance [15].

IV. METHODOLOGY ON THE COLD-STORAGES CONSTRUCTION

The IoT sensing system integrates intelligent sensors, wireless communication, and radio frequency identification (RFID) technology, making it suitable for implementing a visibility and traceability system for managing perishable food. By using fundamental sensors like temperature, humidity, and light sensors, the system monitors various parameters contributing to food spoilage [16][17]. The gathered data is then transmitted to the cloud, enabling users to receive notifications about quality changes and exercise manual or automatic control over food spoilage. The data is processed by an Arduino processor via a Wi-Fi module, leading to decisions based on the data received. Designing an IoT-based solar-powered cold storage system for street vendors involves a structured methodology that includes various stages, from conceptualization to implementation [18][19]. The proposed methodology outlines the following steps: Needs Assessment and Requirement Analysis, Conceptualization and System Design, Technology Selection and Integration, Mathematical Modeling and Simulation, Prototype Development and Testing, IoT Integration and User Interface Development, Field Trials and Validation, Performance Evaluation, Documentation, and Scaling Up. This approach ensures the final product meets the specific needs of street vendors while effectively utilizing IoT and solar energy technologies as shown in the Fig. 2 [20][21].

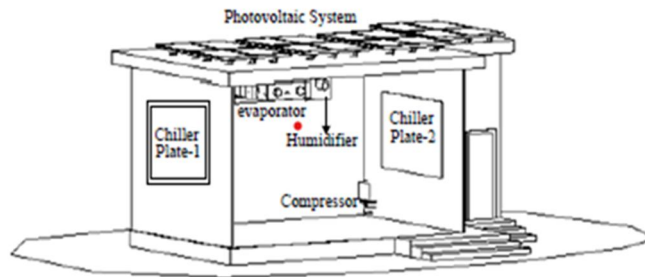


Fig. 2: Block-diagram

TABLE I. PROPERTY OF THE MATERIALS OF THE STORAGES IN THE COMPOSITE STRUCTURES

Property	Galvanize iron sheet	Polycarbonate sheet	Plywood sheet	Glass wool
Thickness (mm)	3	3	5	50
Thermal Conductivity (W/m K)	18	0.7	0.13	0.036

V. PROPOSED COLD STORAGE DESIGNING

The increasing need for reliable and efficient cold storage systems is evident in a time where street vendors play a crucial role in providing perishable items to urban and off-grid communities. Traditional limitations, such as inaccessibility, dependence on non-renewable energy sources, and immobility, have underscored the necessity for a sustainable and innovative solution [22][23]. The proposed cold storage architecture aims to address these challenges and revolutionize the way street vendors offer and preserve perishable items by integrating solar energy and IoT technologies. Street vendors often struggle to preserve their goods due to unpredictable environments and limited access to reliable refrigeration. By combining solar energy with IoT technology, this proposed design presents an opportunity to develop a game-changing solution, reinventing cold storage accessibility and sustainability for street vendors. Solar power offers energy independence, while IoT integration provides real-time monitoring, precise temperature control, and data-driven administration [24][25].

The primary objective of this design is to provide street vendors with a portable, user-friendly, and energy-efficient cold storage system, freeing them from the constraints of stationary refrigeration units and fossil fuel dependence. This solution aligns with vendor demands and sustainability goals by incorporating solar power and IoT integration, aiming for efficient cold storage, reduced operational costs, and minimized environmental impact [26][27]. The insulation of the storage is critical for the system's efficiency, requiring examination of insulation in pipes, walls, and connecting cables. The strategic placement of components such as the evaporator, chiller plates, and humidifier ensures optimal airflow and temperature control, extending the shelf life of perishables. Additionally, the electric system and source size estimation, involving PV power plants and battery banks, provide the cold storage with reliable power throughout the day, optimizing energy generation and storage for efficient operation as shown in the Fig. 3 [28][29].

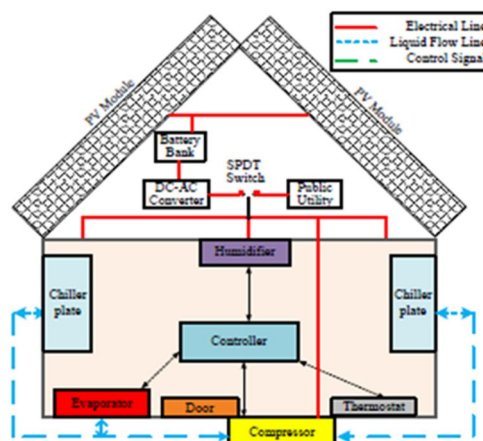


Fig. 3: A 3D depiction of the interior of the Cold Storage and a conceptual layout of the suggested hybrid cold storage

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VI. SPECIFICATIONS

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Fig. 4: A mobile cold storage facility powered by solar energy, equipped with a 0.8-tonne air

TABLE II. FINANCIAL EVALUATION OF A SOLAR-POWERED COLD STORAGE SYSTEM

Item	Cost (Rs)	Useful life(years)	Cost (Rs)/year
AC	20,000	10	2,000
Solar Panels	72,000	20	3,600
Battery	65,000	5	13,000
Inverter	15,000	10	1,500
Total Cost			20,100
Power cost savings	49/day		17,885
Net cost/year			2,215
Net cost/day			6.07
Cost/day/kg produce			0.006

Furthermore, the table 2 gives, the analysis underscores the significant obstacles that street sellers encounter in obtaining dependable cold storage facilities and suggests creative technical strategies as workable remedies. The convergence of IoT applications in the food and agriculture sectors demonstrates a significant change in the direction of assuring perishable commodities quality preservation and minimising spoiling. The review prompts reflection on the path of these innovations by examining new trends and directions in IoT and solar energy applications. It also offers a hopeful vision of the future, wherein solar-powered IoT-driven cold storage could revolutionise street vendors' sustainability and operational efficiency. This collection of work highlights the potentially revolutionary effects of Internet of Things (IoT)-based solar-powered cold storage systems, opening doors for street sellers and small companies to operate in a more sustainable, efficient, and accessible manner in the future which can be seen in Fig. 5.



Fig. 5: A solar photovoltaic system with a power control unit designed for cold storage



Fig. 6: Node MCU / Programming tools like the / Peltier Module / H-Bridge / Relay / Arduino / RFID / Humidity Sensor

VII. TOOLS & EQUIPMENTS

A variety of advanced yet approachable technologies are used in the street sellers' IoT-Based Solar Powered Cold Storage tools and equipment, which is shown below in Figs. 6.

VIII. RESULTS & DISCUSSIONS

Meteorological conditions significantly impacted the overall performance of the P-V panel. The PV panels demonstrated better efficiency during afternoon periods when rain and clouds were absent, as these conditions rendered the system less effective. This section also includes a comparison of system performance between loaded and empty compartments. Additionally, metrics such as temperature and refrigeration compartment duration set points were considered in evaluating system performance. The system operated with empty compartments for three days and with full compartments for four days. The cost of the cold storage system is primarily attributed to components such as the evaporator, cold plates, solar power plant, and batteries. Apart from these components, most of the storage compartments are constructed from stone and cement to provide the necessary cooling and long-lasting durability for perishable items stored inside. The results are shown in the Figs. 7 to 9 respectively.

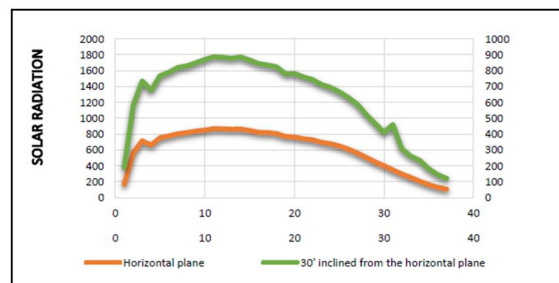


Fig. 7 : Horizontal type of P-V panel vs 40 tilting type of P-V panel

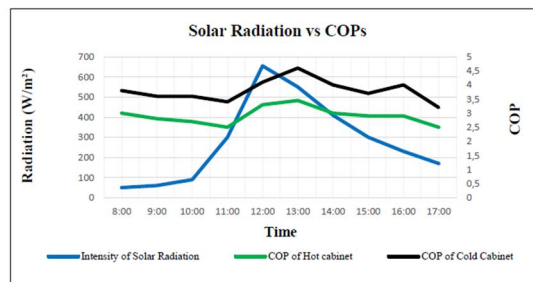


Fig. 8 : Impact of solar radiation on the Coefficient of Performance (COP) of the systems

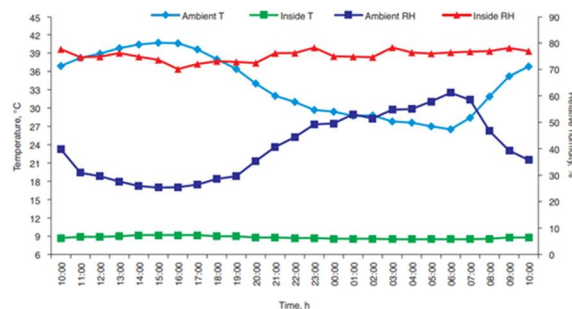


Fig. 9 : Hourly fluctuations in the internal environment of the cold storage structure under unloaded conditions at 10°C

IX. CONCLUSIONS

The adoption of IoT-Based Solar Power Cold Storage has the potential to revolutionize the preservation of perishable items, particularly for street sellers. This innovative device offers portable, energy-efficient, and

sustainable cold storage solutions by combining solar energy with IoT technology. Beyond solving the persistent challenges faced by street vendors in maintaining the freshness of their goods, it also promotes environmental sustainability and economic viability. This technology marks a significant advancement by enhancing the accessibility and longevity of perishable goods, providing street vendors with modern, environmentally friendly options for distribution and storage.

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