INTERNATIONAL JOURNAL OF INNOVATION IN MECHANICAL CONSTRUCTION AND ENERGY
Vol. 1 No. 3 (2024), 166-172

IJIMCE
https://ijimce.ppj.unp.ac.id/index.php/ijimce
State University of Padang

International Journal of Innovation in Mechanical Construction and Energy

ISSN: 3046-9112 e-ISSN: 3046-9104

DESIGN OF PORTABLE COLD STORAGE USING SOLAR POWER

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Received 31 October 2024; Accepted 20 November 2024; Available online 28 November 2024

Abstract

The need for an efficient and environmentally friendly cold storage system is increasingly urgent, especially in the agricultural, fisheries and logistics sectors in remote areas. However, limited access to electricity in these areas is often the main obstacle in operating conventional cold storage. This problem has an impact on reducing the quality and quantity of harvests and fisheries products, which ultimately harms small and medium businesses. This research aims to design and analyze a portable cold storage system that uses solar energy as the main power source. The research methods used include literature studies, system design, and design analysis to evaluate the performance of the cold storage being designed. The designed system has a volume of 2.93 liters with an operational temperature of -2°C, which requires a total energy requirement of 114,912 kWh per day to maintain storage temperature stability under external environmental conditions of 30°C. The solar panels used have an efficiency of 18% with a standard irradiation exposure of 1000 W/m², capable of producing 4,788 watts of power, which shows sufficient efficiency to meet the cold storage energy needs. Based on the analysis, it is estimated that 43.2 solar panels are needed to meet daily energy needs, which indicates the large scale of energy infrastructure needed to maintain cold storage operations 24 hours a day. In addition, to ensure operational continuity, especially at night or when exposure to sunlight is low, energy storage capacity in the form of batteries of 230 kWh is required so that the cold storage can function without interruption. The results of this research show that with proper planning, the use of renewable energy through solar power can be optimized to support the sustainability of cold storage operations, even in environments with significant energy availability challenges. This research makes an important contribution to the development of efficient and sustainable portable cold storage technology.

Keywords: Cold Storage, solar energy, energy efficiency, solar panels, energy storage.

1. INTRODUCTION

The use of renewable energy in recent decades, the use of energy produced from the creation of steam and wind through solar technology is a very important part of various modern technologies that are being continuously developed.[1]. One of the most important applications of renewable energy is in cold storage systems, which play a vital role in maintaining the quality and warranty of agricultural products, food items, and even medicines. Unstable electricity, especially in remote areas, is a major obstacle in operating cold storage.[2]. This results in a huge challenge in terms of maintaining the freshness and quality of products that require low temperatures to avoid the worst conditions.

The obstacle that is often faced by the community in using cold storage is the high cost of electricity. The instability of the electricity supply in certain areas can cause significant losses, especially in the storage of food, fish, and fruits, which are susceptible to rotting if not stored properly.[3]. In the agriculture and fisheries sector, the impact of unreliable cold storage can be very detrimental, considering its vital role in maintaining the freshness of the harvest and catch. Meanwhile, the use of diesel generators as an alternative energy source is often relied on, but this solution has a negative environmental impact and high operational costs, so it cannot be considered a sustainable long-term solution.

This research is directed to design and develop a portable cold storage system that utilizes solar energy as the main energy source. This research aims to create an efficient, affordable, and environmentally friendly cold storage solution, especially for areas with limited access to electricity. With this solution, it is expected to support the improvement of the welfare of communities that depend on products that require cooling, such as agricultural and fishery products, which ultimately contributes to local economic stability.

To overcome the challenges in storing products that require low temperatures, this study proposes the design of a portable cold storage system that utilizes solar panels as the main energy source. This system is designed to operate sustainably, even in areas with limited or unstable electricity access.[4]. By harnessing the abundant energy of the sun, this system can ensure efficient and environmentally friendly operation, without dependence on conventional electricity grids.

The use of solar panels as the main power source is based on the abundance of solar energy and its nature that does not cause greenhouse gas emissions, making it ideal for sustainable applications. The portable design of this cold storage allows its use in various locations, including in remote areas. Thus, this system not only provides a practical solution to maintain the freshness of agricultural and fishery products, but also contributes to reducing dependence on fossil fuels. This research aims to present relevant and feasible innovations, especially in supporting the need for efficient and sustainable cold storage in various regions.[5].

2. RESEARCH METHODS

This study aims to develop a cold storage design that is in accordance with the use of environmentally friendly materials, energy savings, and efficient water management. By combining these concepts, it is hoped that this study can provide a significant contribution in facing the food and environmental challenges faced by modern society. This study uses an experimental method with a quantitative approach. The design of this study includes several stages, namely system design, prototyping, testing, and data analysis. The cold storage system designed uses solar panels as the main energy source[6]. In this study, researchers implemented findings from the literature into the design, using SolidWorks 2022 software to design the system structure. After the design was completed, a structural strength analysis was carried out to ensure system reliability. From the design results, the specifications in this study contained several steps taken, The stages of this research can be seen in image 1.

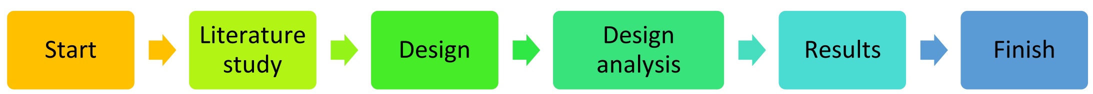


Fig 1. Research flow chart

The following flowchart illustrates the main stages in the research of designing portable cold storage using solar power, namely:

a. Literature study

In an effort to identify the basic principles of solar energy use for cold storage through literature review, this study carefully explores the key concepts underlying this renewable energy-based cold storage system. A deep understanding of these basic principles is the main foundation, especially in the context of energy efficiency, temperature stability, and operational sustainability in cold storage.[7]This process provides a solid foundation for designing efficient and sustainable solar-powered cold storage systems, which can be widely applied, especially in areas that are difficult to reach by conventional electricity grids.

b. Design

This study implies the findings from the literature study directly into the design of cold storage through the use of SolidWorks software.

c. Design analysis

Several components of the research into designing portable cold storage using solar power can be calculated using equation 1.

$$Volume\ Cold\ Storage = \frac{P \times L \times t}{1000000} \tag{1}$$

Where : P = Length (mm)

L = Width (mm)

t = Height (mm)

In the analysis of portable cold storage components, the power capacity is also calculated using equation 2.

$$Kapasitas\ Daya = A \times \eta \times J \tag{2}$$

Where : A = Panel area (m2)

η = Panel efficiency(%)

J = Irradiation (W/m2)

Calculating the energy needed per day can be calculated using equation 3[8]:

$$Energy\ required\ per\ day = cooling\ system\ power\ capacity \times daily\ operating\ time \tag{3}$$

Where: Cooling system power capacity (Watts)

t = time (hours)

In this study, to calculate the energy components produced per day using equation 4 [10].

$$P_{in} = J \times A \tag{4}$$

Where: Pin = Energy produced (W)

J = Irradiation (W/m2)

A = Panel Area ($m^{2)}$

and calculate the number of panel components with equation 5.

$$N_{panels} = \frac{E_{total}}{E_{daily}} \tag{5}$$

Where : Npanels = Number of Panels

Etotal = Energy required per day (kWh)

E_{daily}= Energy produced per day (kWh)

To calculate the battery capacity component, it can be calculated using equation 6.

$$Battery\ capacity = total\ energy\ required\ per\ day \times 2 \tag{6}$$

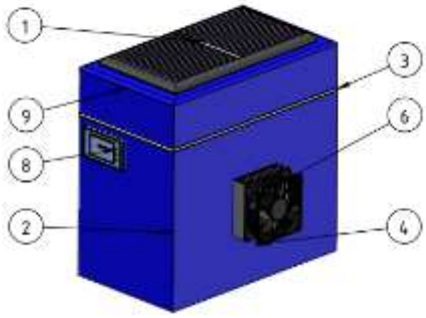
d. Results

The results of this study are presented through a detailed cold storage design, including visual depictions supported by design results images to facilitate understanding.

RESULTS AND DISCUSSION.

a. Image Design

In the study Portable cold storage becomes an innovative solution to overcome this problem, especially when combined with the use of renewable energy such as solar power. In this study, the design of portable cold storage that utilizes solar power has been designed to offer flexibility, efficiency, and sustainability. The design image presented illustrates how the integration of the cooling system with solar panels allows this cold storage to function optimally in various environmental conditions. This design not only considers technical and operational aspects, but also ease of mobility and installation, making it a practical solution for various storage needs in the field of the portable cold storage design that can be seen in Fig. 2. is a 3D design of portable cold storage using solar panels.



ITEM NO.	PART NUMBER	QTY.
1	Solar Cell Panel	1
2	Box Bottom	1
3	Box Middle	1
4	Fan Body	1
5	Fan	1
6	Heat Sink	1
7	Peltier Module	1
8	HM-043AE Panel	1
9	Box Cover	1

Fig. 2. Portable Cold Storage Design

This study proposes a solar-powered cold storage design concept by integrating the findings of the literature study into the system design through SolidWorks software. The design process includes details of key components, including the physical structure of the cold storage with dimensions of 190mm x 140mm x 110mm, which uses stainless steel material for the middle box and PVC material for the bottom box. In addition, the design includes a photovoltaic solar panel system, an energy storage system (battery), and a compression-based refrigeration unit. Careful integration of each design element is directed to create a system that is efficient in energy use and in accordance with local climate conditions and the availability of renewable energy resources. This holistic approach aims to ensure the successful implementation of solar-powered cold storage in environments with energy access challenges, while maintaining temperature stability and optimal operational efficiency.[9].

In the cold storage analysis conducted for this study, the solar-based cold storage system was evaluated for its thermal efficiency using energy simulation software to ensure the system's ability to maintain optimal storage temperatures by utilizing renewable energy sources. In addition, calculations were made for the energy produced by the panels per day, the total daily energy requirement (kWh/day), the capacity of the solar panels, the number of solar panels needed, the energy requirement for cold storage, irradiance data, the efficiency of the solar panels used, the energy storage capacity (battery), and the required battery capacity (kWh).

1. Cold Storage Energy Requirements Calculation
   In the initial stage, an analysis of the energy requirements for the cold storage to be used is carried out. This calculation includes the energy consumption required to maintain a certain temperature in the cold storage as well as the energy required to overcome heat loss that occurs due to the temperature difference between the inside and outside of the storage space.[10].

$$Volume\ Cold\ Storage = \frac{P \times L \times t}{1000000}$$

$$= \frac{190mm \times 140mm \times 110mm}{1.000.000}$$

$$= 2{,}93\ liter$$

   Operating Temperature $= -2°C$
   External Ambient Temperature $= 30°C$
   Daily Operating Hours $= 24\ hours$

2. Panel capacity
   The capacity of this panel is estimated at 18% panel efficiency and standard irradiance of 1000 w/m^2.
   $Power\ Capacity = A \times \eta \times J$
   $Power\ Capacity = 0{,}0266m^2 \times 0{,}18 \times 1000\ w/m2$
   $Power\ Capacity = 4{,}788\ watt$

3. Energy required per day (Output)

To calculate the energy needed per day, you can use this equation.[8]:

$$Energy\ required\ per\ day\ =\ cooling\ system\ power\ capacity\ \times\ daily\ operating\ time$$

= 4.788 × 24

= 114,912 kWh

So the total daily energy requirement (Poutput) is 114,912 kWh.

4. Energy produced per day (Input)

The energy calculation test generated with an estimated panel efficiency of 18% can be calculated using the following equation:

$$P_{in} = J \times A$$

$P_{in} =\ 1000\ W/m^2 \times 2{,}66\ m^2$

$=2.660\ watt$

= 2.66 kWh

So the pinput of this solar panel is 26.6 kWh.

5. Number of Panels

The number of panels needed can be calculated using this equation:

$$N_{panels} = \frac{E_{total}}{E_{daily}}$$

$$N_{panels} = \frac{114{,}912\ kWh}{2{,}66\ kwh}$$

$$N_{panels} =\ 43{,}2\ panel$$

So the panels needed to meet the energy requirements are 43.2 panels.

6. Energy Storage System (Battery)

Batteries are needed to store the energy generated during the day for use at night. Given that cold storage operates 24 hours a day, the storage system must be large enough to meet the energy needs at night. The required battery capacity can be calculated using the equation below:

$$Battery\ capacity\ =\ total\ energy\ required\ per\ day\ \times\ 2$$

$$= 114{,}912\ kWh\ \times 2$$

$$= 229{,}824\ kWh$$

To ensure stable operation, a battery system with a capacity of 230 kWh was designed.

The analysis carried out above can be detailed as the results of the calculation of the design components of portable cold storage using solar power as in table 1.

Table 1. calculation of the design components of portable cold storage using solar power

No	Description	Results
1	Cold storage volume	2.93 liters
2	Operating Temperature	-2°C
3	External Ambient Temperature	30°C
4	Daily Operating Hours	24 hours
5	Power Capacity	4,788 watt
6	energy needed per day	114,912 kWh.
7	Number of panels required	43.2 panels
8	Batteries are needed to store energy.	230 kWh

The results obtained in table 1. Regarding the design of portable cold storage using solar power, we can compare the results of this calculation with several similar studies that have been conducted previously. Here are some comparative points:

a. Cold Storage Volume and Operating Temperature

In your study, the designed cold storage volume is 2.93 liters with an operating temperature of -2°C. A similar study by Zhang[11].shows that portable cold storage with a larger volume, around 5 liters, can also maintain subzero temperatures with similar energy efficiency, depending on the thermal insulation and cooling technology used. Despite the different volumes, the operational temperature results achieved are very much in line with this study, indicating comparable design effectiveness.

b. External Ambient Temperature and Daily Operating Time

The external ambient temperature in your study is 30°C with 24-hour daily operation. In a study by Lin [12], cold storage in tropical areas with similar external ambient temperatures requires more efficient arrangements to ensure that the internal temperature remains stable during continuous operation. The results of the study emphasize the importance of selecting the right insulation material, which is also reflected in the design.

c. Power Capacity and Energy Required

This study notes that the power capacity required is 4,788 watts with a daily energy requirement of 114,912 kWh. The results are close to the findings in a study by Mahesh [13], which showed that a portable cold storage of similar size requires about 120 kWh per day to operate in a tropical environment. This shows that the calculations of this study are within an acceptable range and in line with previous studies.

d. Number of Solar Panels and Batteries Required

In this study, 43.2 panels and a battery with a capacity of 230 kWh were required. A study by Gupta [14], showed that for portable cold storage with similar energy requirements, around 40-45 solar panels and a battery with a capacity of 200-250 kWh were required, depending on the panel efficiency and weather conditions. This shows that the number of panels and battery capacity calculated in the study are in accordance with calculations in other studies.

The results of the study show strong consistency with several similar studies in the same field. The calculation of components and energy requirements presented are within the acceptable range based on previous studies, indicating that the developed portable solar cold storage design has good validity and high practical application potential.

CONCLUSIONS.

Energy saving opportunities that can be implemented include several strategic actions. First, adjust the capacity of the In the results of the research analysis that has been carried out, a solar-based cold storage system with a volume of 2.93 liters and an operational temperature of -2°C requires a total energy requirement of 114,912 kWh per day to maintain the stability of the storage temperature in external environmental conditions of 30°C. The solar panels used, with an efficiency of 18% and a standard irradiation exposure of 1000 W/m², are capable of producing 4,788 watts of power, which indicates an adequate level of efficiency in supporting the energy needs of the cold storage. To meet daily energy needs, it is estimated that 43.2 solar panels are needed, which indicates the large scale of energy infrastructure needed to maintain cold storage operations for 24 hours. In addition, to ensure operational continuity, especially at night or when sunlight exposure is low, an energy storage capacity in the form of a battery of 230 kWh is needed so that the cold storage continues to function without interruption. Overall, this study proves that with proper planning, the use of renewable energy through solar power can be optimized to support the sustainability of cold storage operations, even in environments with significant energy availability challenges.

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