Design of 4000 MT Hybrid Solar Powered Potato Cold Storage Plant

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Abstract

This paper presents a case study of designing a 4000 MT Hybrid solar powered cold storage system for storing potatoes. Cold storage can restrict the wastage of perishable foods produced in the country . For this design, the building plan calculation , cooling load calculation, design and selection of refrigeration system elements, and hybrid solar plant design have been done. For this project, a hybrid solar plant is chosen, where the plant is powered both by the grid and a battery backup system in case of an emergency grid outage. As the cold storage units are commonly situated in remote areas, electric cut-off is a regular issue, which is why we're using hybrid solar plant construction. Different designs of the same capacity cold storage plant are also compared to get the best result.

Keywords: *cold storage, cooling load, refrigeration, hybrid solar plant.*

1. Introduction

In this article, a case study involving the development of a 4000 MT hybrid solar-powered cold storage system specifically designed for the preservation of potatoes is discussed. The primary goal is to reduce perishable food losses in the nation by using cutting-edge cold storage technologies. This study goes into a number of crucial components, such as rigorous architectural planning, accurate cooling demand estimation, precise component selection and design, and the incorporation of a hybrid solar power plant.
The hybrid solar power plant arrangement that was chosen offers a dual power source strategy, using the grid while also adding a battery backup system to assure continuous operation during grid interruptions. This tactical decision is especially critical to outlying cold storage facilities susceptible to power outages. This research has a strong emphasis on decarbonization, which is both different and important. The cold storage facility greatly reduces its dependency on conventional energy by utilizing renewable solar energy, which helps to reduce carbon emissions. This adherence to sustainable practices shows a conscious attempt to solve environmental issues brought on by cold storage operations that use a lot of energy.

The research also attempts to optimize design variations for cold storage units with equivalent capacities. The study aims to find the most effective and financially viable option through careful comparison. This comprehensive assessment takes into account not only technical and operational factors but also financial ones to make sure the chosen design is in line with long-term sustainability goals.
Sadi et al. (2020) [1] conducted a techno-economic analysis of solar-driven cold storage systems that do not rely on the electrical grid. The study found that these systems are a viable way to reduce food waste in hot and humid climates. Munir et al. (2021) [2] developed a solar-hybrid cold energy storage system that uses cooling pads backup. The system was tested in three modes: grid utility, solar, and hybrid. The results showed that the system is a feasible and efficient solution for decentralized cold storage. Dash et al. (2022) [3] investigated the economic feasibility of solar-powered cold storage systems for farmers in India. The study found that these systems are a viable option for farmers, as they can save them money on electricity costs. Sharma et al. (2022) [4] developed a solar-powered potato cold storage system that is efficient, cost-

effective, and scalable. The system uses solar panels to generate electricity, which is then used to power a compressor that cools the storage space. The system can be used by farmers of all sizes, and it can help to reduce food waste. Rathore (2021) [5] provides an overview of cold chain logistics in India. The cold chain is the system that ensures that food is kept at a safe temperature from the farm to the consumer. The paper discusses the challenges of cold chain logistics in India, such as the lack of infrastructure and the high cost of electricity. Takeshima et al. (2020) [6] examine the economic viability of providing cooling technologies in poor regions. The book argues that the declining cost of off-grid solar electricity has made it more feasible to provide such technologies in these regions.

Optimization of the building plan for potato cold storage using hybrid solar plants has not been studied much by the researchers. This study is important as the power consumption can be minimized by suitable selection of building plan and other system requirements according to that. In this research paper we have designed a potato cold storage plant of capacity 4000 MT. Two different building plans are studied and compared from the aspect of cooling load, refrigeration system and hybrid solar plant design.

A significant staple crop with a wide range of seasonal flexibility is the potato. It is a cool-season crop that can tolerate some frost. One of the key elements affecting yield that has long been acknowledged is temperature during the growing season. At a temperature of 24°C, young plants develop the best; at 18°C, later growth is preferred. As the temperature rises, tuber production falls until it completely stops at about 30^oC, when it reaches its maximum level at 20^oC. Short days are advantageous for the growth of tubers. Table 1 lists the required temperature, relative humidity, and storage time for early crop, seed potato, and table potato [7,8].

2. Methodology

The research methodology of this paper is shown in FIG. 1.

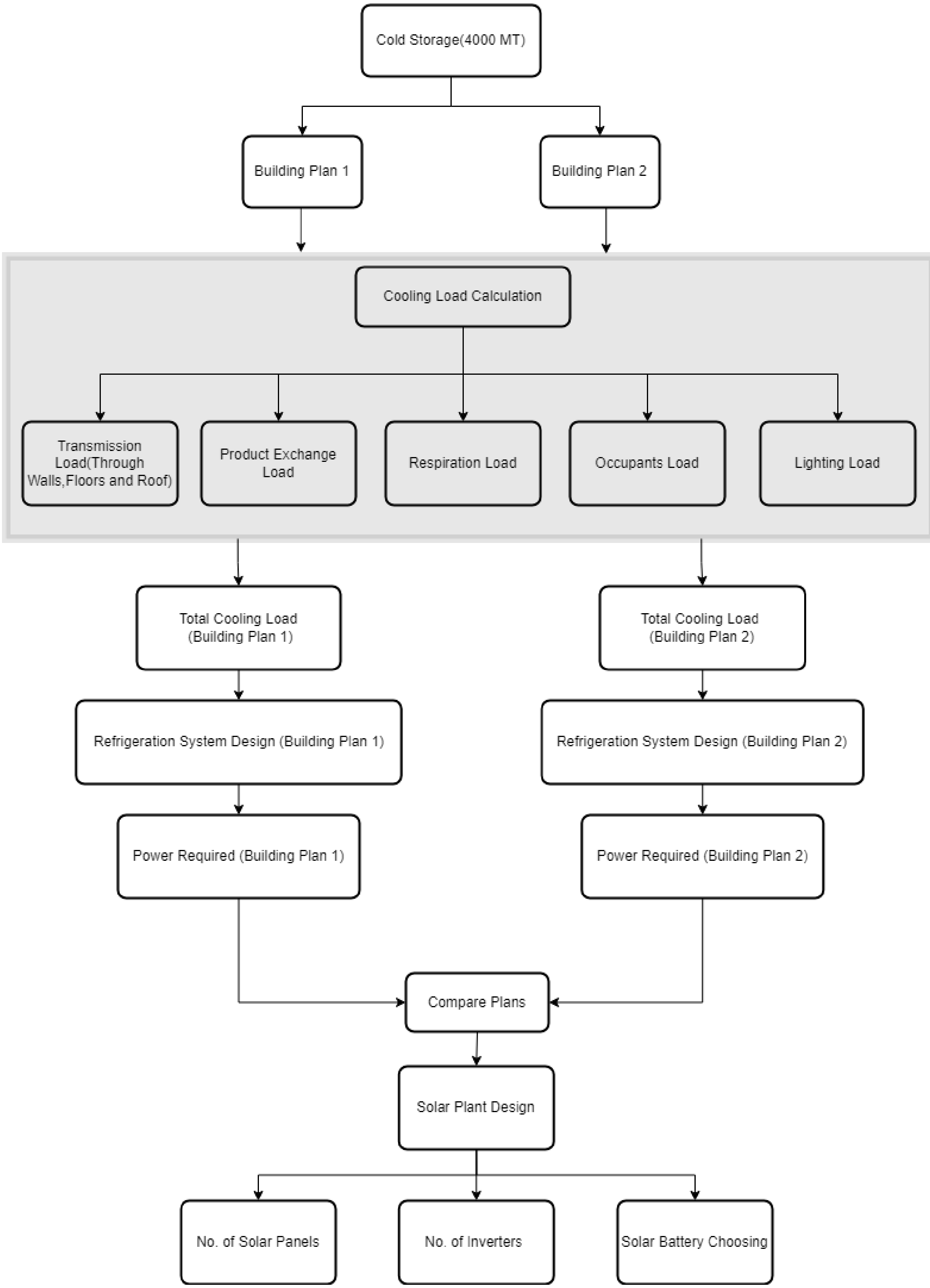

FIG. 1. Flowchart of the research methodology

2.1 Potato Storage Condition

A significant staple crop with a wide range of seasonal flexibility is the potato. It is a cool-season crop that can tolerate some frost. One of the key elements affecting yield that has long been acknowledged is temperature during the growing season. At a temperature of 24°C, young plants develop the best; at 18°C, later growth is preferred. As the temperature rises, tuber production falls until it completely stops at about 30°C, when it reaches its maximum level at 20°C. Short days are advantageous for the growth of tubers. Table 1 lists the required temperature, relative humidity, and storage time for early crop, seed potato, and table potato [7,8].

Table 1. Potato storage conditions

Fresh Potato	Temperature	Storage Period	Relative Humidity
Early Potato	$4^oC - 9^oC$	0-4 months	96%
Seed Potato	3^oC	4-10 months	91-96%
Table Potato	4^oC	4-10 months	91-96%

2.2 Cold Storage Building Plan

Building plans have to be done according to the capacity of the cold storage. There are many things, like sac dimension and cell dimension, on which building plans depend. We have considered two building plans for our study, a summary of which is shown in Table 2&3

Table 2. Cold storage module parameters

Parameters	Building Plan-1	Building Plan-2
Total No. of Sac Requirements	66667	66667
Volume of Cell(cubic ft.)	1210	1521
Total No. of sacs in a unit cell	48	84
No. of cell required	1389	794
No. of cell in one floor(Approx)	278	190

Table 3. Cold storage building plan parameters

Parameters	Building Plan-1	Building Plan-2
Total Floors	5	4
Length of Building(ft.)	264	154
Width of Building(ft.)	194	180

Floor height(ft.)	11	10
Total Height of Building(ft)	55	40
Volume of Building(cubic ft)	2816880	1108800
Total floor height taken by stacks	8	7

The drawings of the floor plans for two case studies are shown in FIG. 2.

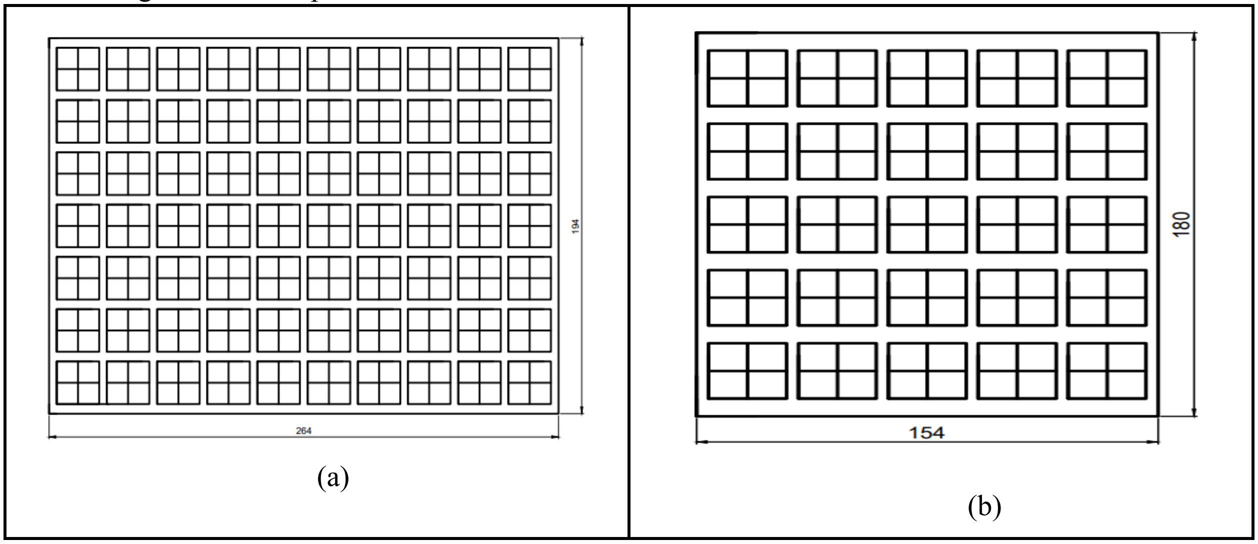

FIG. 2. Building Floor Plan (a) Building Plan-1 (b) Building Plan-2

2.3 Cooling Load Calculation

Transmission Load:

Transmission load means heat transmitted through walls, floors, and the roof. As we're making a cold storage building, the inner temperature of the building is actually lower than the outer temperature, which is why heat transfer happens from the surrounding area to the room. This heat transfer is

$$Q_T = kA(T_o - T_i) \quad \ldots(1)$$

Where, Q_T = heat transmission at flat surface (W), k= total heat transmission coefficient (W/m^2K), A= area of heat transmission (m^2), T_O=outside temperature (K), T_i= inside temperature (K)

Product Load:

Product Exchange Load:

It's the amount of heat to be extracted from the product to maintain it at the desired temperature.

Formula for product exchange load calculation:

$$Q_{PE} = (m * S * (T_0 - T_i) * 24)/T \quad \ldots..(2(a))$$

Q_{PE} = Product exchange load, T_0= Product entering temperature, T_i= Cold-room Temperature, T= Effective operating time of the total cooling unit, m=Amount of the product (kg) stored per day, S= Specific heat up to product freezing (KJ/kgK)

Product Respiration Load:

The potato is a living entity, so it has respiration. Due to that, some heat is also generated. When we're designing the cold storage, we've also got to take care of the respiration heat.

$Q_{PR} = m * R$ …(2(b))

Q_{PR} = Amount of product (kg), R = rate of respiration heat per kg

Therefore, the total product load is calculated as

$Q_P = Q_{PE} + Q_{PR}$…..(3)

Occupants Heat Load:

In cold storage, some people are there to store the potatoes daily or to take them out daily from the store. Some heat is also coming from the human body. First of all, workers are entering the building from outside, so their body temperature is higher than the cold storage temperature. Also, they are releasing respiration heat. So, we have to consider the occupant's heat. Our cooling system has to bear that load as well.

Formula for calculating the occupant's heat:

$Q_0 = N * F$ …(4)

where N= number of people, F= factor (Kw/person),

Lighting Load:

The heat emitted by the light sources is called the lighting load. We have considered that the lighting generates 1 watt of heat for every square foot of floor space.

$Q_L = L \times A_f \times f$ …(5)

Q_L=Total Lighting Load, L= Lighting Load per sq. feet, A_f= floor area in each floor (in sq. feet), f= No. of Floor

Ventilation Load:

As we establish a cold storage unit for potatoes, the natural process of respiration causes an accumulation CO_2 over time. To counter this, it becomes necessary to periodically replace the air within the storage. Unfortunately, this air exchange also leads to the intrusion of heat into the cold storage environment. That's why we have to consider the ventilation load as well.

$Q_V = m_f \times (h_0 - h_i)$ …(6)

Q_V=ventilation load, m_f= mass flow rate of air, h_0= outdoor enthalpy of air, h_i=indoor enthalpy of air.

The total cooling load is calculated as

$Q_C = Q_T + Q_P + Q_O + Q_L + Q_V$ …(7)

Q_C=Total Cooling Load (kW)

2.4 Refrigeration System Design Calculation

We know the temperature of the cold storage and the surrounding temperature. Based on that, we've got to choose the evaporator and condenser temperatures. For effective heat transfer, there should be at least a 10°C temperature difference. Now, from the refrigerant table, we've got to choose those suitable temperatures based on the available data. For a vapour compression refrigeration cycle (VCRC) as shown in FIG. 3. The compression process from 1 to 2 occurs in the compressor, the condensation process from 2 to 3 takes place in the condenser, the expansion process from 3 to 4 in the capillary tube, and the evaporation process from 4 to 1 at the evaporator.

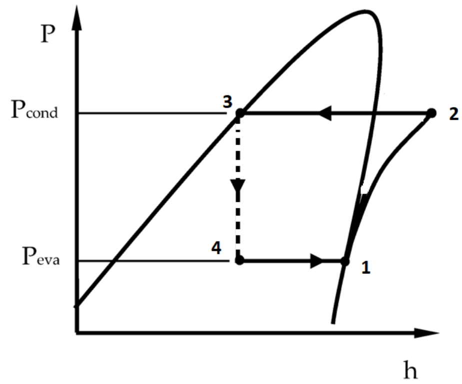

FIG. 3. Refrigeration Cycle.

Now we'll be finding the enthalpy values of the refrigerant at the inlet and outlet points of different parts of the refrigeration unit.

After that,we've got to calculate the mass flow rate of refrigerant using the following equation:

m_R=Total cooling Load/$(h_1 - h_4)$ …(8)

Where, h_1= Enthalpy at evaporator outlet

& h_4 = Enthalpy at evaporator inlet

These $h_4$is equal to $h_3$because in an expansive valve, refrigerant goes through an iso-enthalpic process.

h_3= Enthalpy at condenser outlet

Now, compressor power has to be calculated.

Compressor power = $m_R \times (h_2 - h_1)$ …(9)

Here, h_2= Enthalpy at compressor outlet

Then we'll be dividing the total cooling load by compressor power to get the COP of the cooling unit. Refrigeration system components are selected according to the above calculation.

2.5 Hybrid Solar Plant Design

FIG. 4. Hybrid solar power plant

It's important to find out the most appropriate combination of modules and inverters by considering the local operating conditions. The voltage, current, and power rating, of the module and inverter are the three criteria that ensure the proper matching of the system in terms of performance and safety. The important steps related to the matching of inverters and PV modules are:

1. Number of modules in a string
2. Maximum number of strings (to match with inverter input)
3. Matching the power rating

Number of Modules in a String: The first is to determine the lower and upper limits of a string, i.e., the minimum and maximum number of modules that can be connected in series. Here, two factors are important:

1. max. and min. Operating temperatures
2. Maximum and minimum effective voltages of the module

Max. and Min. Operating temperatures:

By knowing, the ambient temperature of a particular location, the NOCT of the PV module, and the incident solar radiation at the location, the module operating temperature can be calculated as:

$T_{OP} = T_{amb} + \frac{NOCT-20}{800} \times G$ Where, G is Solar intensity

The maximum and minimum operating temperatures can be calculated using this equation by considering the recorded highest and lowest ambient temperatures of a particular location.

Minimum and maximum effective voltages of the module:

The minimum and maximum effective voltages of PV arrays can be calculated using the following equations:

$$V_{Min-eff} = V_{MP-STC} - [\gamma_P \times \{(T_{OP})_{max} - T_{STC}\}]$$

$$V_{Max-eff} = V_{OC-STC} - [\gamma_{V_{OC}} \times \{(T_{OP})_{min} - T_{STC}\}]$$

The minimum number of modules in a string can be calculated using the equation:

$(M_{String})_{min} = \frac{(V_{INV-DC})_{min}}{V_{Min-eff}}$

The maximum number of modules in a string can be calculated using the equation:

$$(M_{String})_{max} = \frac{(V_{INV-DC})_{max}}{V_{Max-eff}}$$

Maximum number of strings (to match inverter input): The current rating of the module has to be matched with the inverter's input current rating in order to determine the maximum and minimum possible strings to be connected in parallel with the inverter. Due to the variation in operating temperature, the value of short-circuit current of the module also differs from it's STC value, which can be determined as:

$$I_{Sc-Eff} = I_{SC-STC} - [\gamma_{I_{SC}} \times \{(T_{OP})_{max} - T_{STC}\}]$$

The maximum number of strings to be connected in parallel with the inverter can be determined using the following equation:

$(S)_{max} = \frac{I_{Inv-DC}}{I_{SC\,Eff}}$

$\gamma_{I_{SC}}$ = Short-circuit temperature coefficient(%/^{0}C)

γ_P = Maximum power temperature(%/^{0}C)

$\gamma_{V_{OC}}$ = Open circuit voltage temperature coefficient(%/^{0}C)

Match the best combination of strings and arrays to get the maximum DC power output. The maximum DC power output should always ≤ to the input DC power of the inverter.

Selection of Cable:

For DC cables: $A_{DC\ cable} = \frac{2 \times L_{DC\ Cable} \times I_{DC} \times \rho}{Loss \times V_{MP\ string}}$

For AC cables: $A_{DC\ cable} = \frac{2 \times L_{AC\ Cable} \times I_{AC} \times \rho \times \cos\varphi}{Loss \times V_{MP\ string}}$

3. Results and Discussion

3.1 Comparison of cooling load components

It is clear from FIG. 4. that ventilation load is a major contributor to cooling load. Though the other cooling load components (transmission, product, lighting, occupants, and respiration load) are comparable for the BP-1 and BP-2, the ventilation load makes the BP-2 design more suitable in terms of the cooling load required.

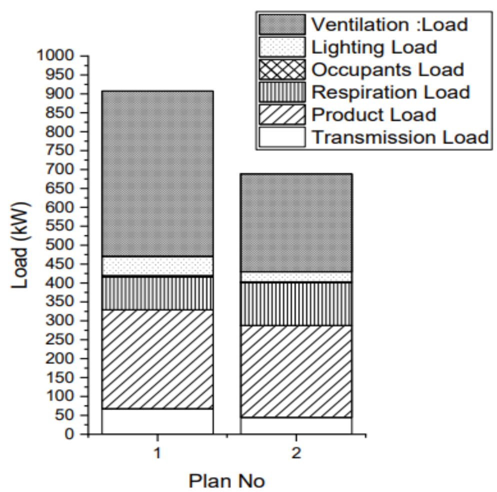

FIG.5. Comparison of cooling Load components for BP-1 and BP-2

3.2 Compare the cooling load and power input of the refrigeration system

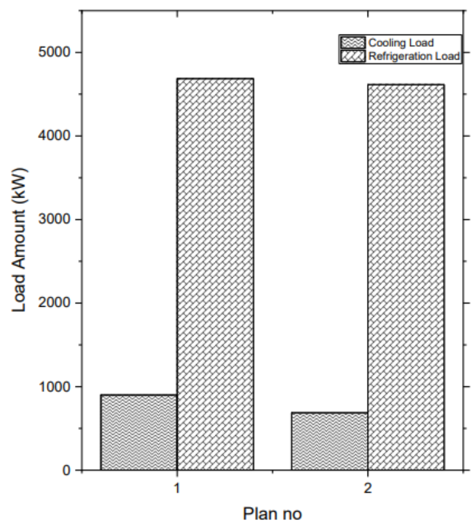

FIG.6. Comparison of power consumption and cooling load (kW) for BP-1 and BP-2

By comparing the power consumption of these two building plans, we can observe that the 2nd building is more appropriate because it consumes less energy and has the same storage capacity (4000 MT). That's why we're choosing the BP-2 for the hybrid solar plant design. The findings suggest that Building Plan 2 possesses notable advantages due to its architectural layout.

3.3 Hybrid solar plant selection

For Building Plan 2, a hybrid solar plant with both grid and battery storage components was created. With the grid acting as a backup power source and batteries serving as energy storage, this design most likely intends to efficiently utilize solar energy. This will allow it to run continuously even when there is little sunlight available.
Specification of a 300Wp solar module:

Electrical parameters at Standard test conditions (STC):

Power output (W)	Module efficiency (η%)	Voltage at $P_{max}I_{MPP}$(V)	Current at $P_{max}I_{MPP}$ (A)	Open-circuit Voltage V_{oc} (V)	Short Circuit Current I_{sc}(A)	power tolerance (W)
300	15.10	36.6	8.20	44.8	8.71	0+-5

Temperature coefficient characteristics:

NOCT (^{0}C)	Module Efficiency (%/^{0}C)	Temperature Coefficient of P_{max} (%/^{0}C)	Temperature Coefficient of V_{OC} (%/^{0}C)	Temperature Coefficient of I_{SC} (%/^{0}C)

47+-2	0.06+-0.01	0.4048	0.2931	0.0442

Inverter Specification:

Input Data (DC):

Max DC Power	Max DC Voltage	Max DC Current	MPP (T) Voltage Range
280 kW	900V	600A	425-975 V

Output Data (AC):

Max Ac Power	Output AC Voltage Range	Max. AC Current	Max. Efficiency
250kW	270-330V	540A	98.3%

PV-Modules: A total of 6050 PV-modules are required to power the cold storage. The configuration of these modules is 22 in series and 55 in parallel. With this setup, the device can effectively produce the necessary electrical energy from sunlight.

Inverters: To change the direct current (DC) output from the PV modules into alternating current (AC), the system depends on at least five inverters. For compatibility with the electrical systems frequently used in cold storage facilities and other commercial applications, this conversion is crucial.

Batteries: When developing a hybrid solar power plant, batteries are essential for storing excess solar energy for later use, especially during times of insufficient sunlight. 221 batteries are linked in parallel in this configuration. The nominal current rating of each battery is 100 A, and its nominal voltage value is 48 V. With this setup, the system is guaranteed to have the necessary energy storage capacity to maintain continuous cold storage operation for 5 days.

4. Conclusion

According to the research, Building Plan 2 provides a stronger framework for the implementation of a hybrid solar-powered cold storage system, boasting higher power efficiency, better cooling load control, and greater cost effectiveness. The planned hybrid solar plant adds to the profitability of this strategy by offering dependable and environmentally friendly energy options and a non stop 5 days battery backup in case of grid failure.

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