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Cooling Capacity Estimation of Cold Storage Plant: A Case Study

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ABSTRACT

This research paper delves into an extensive examination of the complex mechanisms governing the cooling capacity and load calculations for a cold storage plant with a significant capacity of 5000 metric tons (MT). The investigation is driven by the urgent need to enhance resource efficiency and promote sustainability in cold storage operations. By emphasizing the importance of thorough planning and analysis, various factors influencing cooling load dynamics are comprehensively explored. Moreover, this investigation extends beyond theoretical analysis to address practical considerations related to refrigeration system selection. Factors like compressor capacity, evaporator design, condenser type, and refrigerant selection are carefully evaluated to optimize energy efficiency, reliability, and environmental sustainability. To validate the methodologies, a detailed case study of Ashoka Cold Storage–II, Jagdalpur, utilizing empirical data from a comparable operational cold storage plant is presented. Through thorough comparison and analysis, the alignment between theoretical predictions and real-world observations is demonstrated, confirming the practical utility and relevance of the findings.

KEYWORDS: Cold storage, Cooling capacity, Refrigeration systems, Energy efficiency, Load calculation.

1. INTRODUCTION

Cold storage is a widely adopted approach for managing perishable goods between production and marketing processing. It involves preserving perishable commodities in a fresh and wholesome state for extended periods by regulating temperature and humidity within the storage system. Maintaining sufficiently low temperatures is crucial to prevent chilling injury to the produce. Additionally, maintaining a relative humidity of 80-90% within the storeroom is essential for most perishables, as deviations from this range can adversely affect the quality and shelf life of the produce [1].

Substantial opportunities for energy conservation exist in cold storage, particularly through the procurement of appropriate refrigeration equipment compared to retrofitting efforts during the facility's lifespan. Inadequate storage design and a difference between the expected cooling load and the actual operational requirements matched with the refrigeration capacity selected during the planning phase are two major sources of potential energy waste. The cooling load represents the aggregate heat energy that must be extracted from the cold storage to achieve the desired temperature, necessitating consideration of all potential sources of heat influx into the space. The total heat load corresponds to the cooling demand that the refrigeration system must fulfill for a specific storage area [2]. The cooling load determined the appropriate capacity for the cold storage equipment and distribution system. If the chosen capacity fell short of the required cooling load, the system would operate continuously, potentially failing to reach the necessary temperature and resulting in inadequate refrigeration, leading to food spoilage and waste [5]. Conversely, if the capacity exceeded requirements, the refrigeration equipment would be needlessly costly. Rapid achievement of the temperature regime would lead to frequent system stops and temperature fluctuations, rendering the operation inefficient [2].

Considering this context, this study examined the heat load generated by various sources and how it affected the desired cooling capacity for the Ashoka Cold Storage. Despite an increasing market trend, no research has been conducted on cold warehouses specifically suited for horticultural products and the climate of Chhattisgarh. Figure.1. shows the arrangemts of the equipemnts according to the refrigeration cycles.

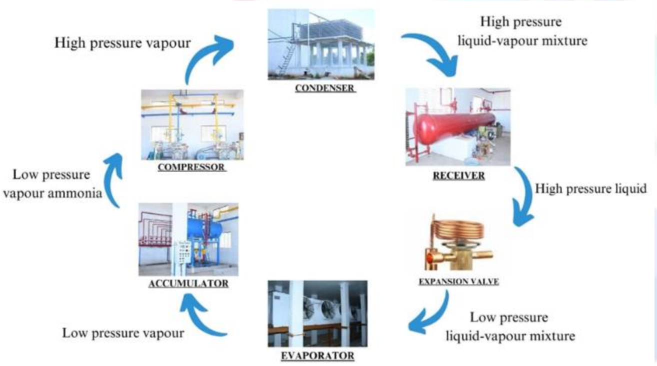

Figure 1. Refrigeration Cycle of Cold Storage Plant

The present research sought to address several key aspects in order to mitigate the burden of excessive energy consumption in cold room facilities. Firstly, it focused on demonstrating the proper design of cold storage units of Ashoka Cold Storage. These requirements include dimensions, architecture, lighting standards, ease of cleaning structures, and cleanliness practice adherence, all of which have not been specifically addressed in previous research. The study then calculated the heat load originating from different factors in accordance with the proposed cold warehouse architecture, resulting in the estimation of the necessary cooling load. The corresponding cooling load served as the foundation for determining the proper refrigeration capacity, resulting in an efficient refrigeration process within the cold room facility.

2. CASE STUDY: ASHOKA COLD STORAGE-II, JAGDALPUR:

ASHOKA COLD STORAGE UNIT II, situated in TeliSemra, Jagdalpur, Bastar, Chhattisgarh, is a partnership venture led by Mr. Ashok Gondi, Mr. Abhishek Gondi, Mrs. Rita Gondi, and Mrs. Anshu Gondi. The project, categorized as a new endeavor, operates on a rental business model and focuses on handling chill products within a temperature zone of 0-10°C. The facility boasts cold store chambers designed to maintain a temperature of 3°C with a relative humidity of 90-95%, primarily storing potatoes in wooden grating platforms. Each chamber measures 24.20 meters in length, 23.45 meters in width, and 15.00 meters in height, with a storage capacity of 2,500.00 tons per chamber, utilizing bags as the primary storage unit with a total of 50,000 units weighing 50 kg each. The construction of the building features RCC civil construction, steel structure roofing with composite insulation panels, and LED lighting fixtures in the cold chambers. Safety provisions include a machine room ventilation system for self-containing fire-fighting equipment, dry and water-based fire-fighting equipment compliant with state standards, and handling measures for refrigerants and leaks, such as gas cylinders, leak detection sensors, ventilation fans, water sumps, masks, and first aid kits. The details about the construction and the equipment's employed in Ashoka Cold Storage is given below:

2.1 CONSTRUCTION DETAILS:

The construction details highlight the robust infrastructure designed to support the cold storage operations effectively. The building construction primarily consists of RCC civil construction, providing a sturdy and durable framework for the facility. The external and internal walls, as well as partition walls of the cold chambers, are constructed using civil building techniques with insulation slabs integrated into the walls to enhance thermal efficiency. The roof and ceiling feature a steel structure with composite insulation panels, ensuring proper insulation and temperature control within the storage chambers. LED lighting fixtures are installed in the cold chambers, offering energy-efficient illumination for the storage areas. The process, external, and compound areas are constructed using steel structures, further enhancing the durability and functionality of the facility. Additionally, insulated vertical components are incorporated into the construction to improve thermal performance and maintain the desired temperature levels within the cold storage unit.

2.2 INSULATION:

ASHOKA COLD STORAGE UNIT II incorporates insulation and vapor barrier features to ensure optimal storage conditions. The insulation materials used include Expanded Polystyrene (EPS) for the walls, ceiling, and floor, meeting relevant IS Codes such as IS 4671 and IS 661:2000. The composite panels utilized in the construction provide enhanced thermal conductivity, crucial for maintaining the desired temperature within the storage chambers. This insulation strategy helps in regulating the internal climate of the cold storage unit, contributing to efficient energy utilization and preserving the quality of the stored products.

2.3 COOLING SYSTEM:

The mechanical refrigeration system utilizes ammonia as the refrigerant, with a total refrigeration capacity of 452.00 kW. Operating on a liquid overfeed system, the refrigeration setup features reciprocating compressors with automatic capacity control in steps ranging from 25% to 100%. The system includes ceiling-suspended finned type air coolers for efficient heat exchange, with induced draft fans ensuring proper air circulation within the chambers. Defrosting is carried out using air-based methods, and humidifiers are installed to control humidity levels during loading and pull-down periods. Pressure vessels are utilized for refrigerant storage, with separate vessels for low and high-pressure applications, each designed to handle specific temperature and pressure ranges. The design and testing of the pressure vessels comply with ASME Sec VIII Div 1 standards, ensuring safety and reliability in refrigerant handling.

2.4 COMPRESSOR:

The refrigeration equipment includes compressors and racks from Kirloskar, specifically the KCX-4 and KCX-3 models as shown in the Figures. 2(a) & 2(b). These compressors operate at varying capacities and temperatures, with the KCX-4 running at 600 RPM and the KCX-3 at 400 RPM. The refrigeration capacity ranges from 255.10 kW to 300.97 kW, depending on the operating parameters. The power consumption of the compressors is between 55.16 kW and 151.03 kW, with a total connected motor power of 75.00 kW to 85.90 kW. The system is designed to handle peak and holding periods efficiently, ensuring consistent and reliable cooling for the stored products.

Figure 2(a). Compressors

Figure 2(b). KCX-4 & KCX-3 models of Compressor

2.5 CONDENSER:

The condenser type is specified as local make atmospheric type with 2” NB Pipe, and the operating parameters include a condensing temperature of 38°C and a water flow rate of 42 LPS. The condenser has a heat rejection capacity of 537.90 kW and is equipped with electric fans/pump motors rated at 3.75 kW each. The total electric power consumption for the condenser is noted to be 7.00 kW. The remarks indicate that the condenser operates both in working and standby modes, highlighting its importance in the refrigeration system of the cold storage unit. Figure. 3. depects the condenser unit of Ashoka cold storage

Figure 3: Condenser

2.6 PRESSURE VESSELS:

The condenser type is specified as local make atmospheric type with 2” NB Pipe, and the operating parameters include a condensing temperature of 38°C and a water flow rate of 42 LPS.

Figure 4(a): Refrigerant Container

Figure 4(b). Pressure Vessel

The condenser has a heat rejection capacity of 537.90 kW and is equipped with electric fans/pump motors rated at 3.75 kW each. The total electric power consumption for the condenser is noted to be 7.00 kW. Pressure vessels used in the ashoka cold storage are shown in the figures 4(a) and 4(b).

2.7 EVAPORATORS/AIR COOLING UNITS:

The ACU type, make, and model are specified, with a total of eight units installed in the facility. These evaporators operate under different temperature conditions, with specific cooling capacities and air flow rates for both peak and holding periods.

Figure 5(a): Evaporators/ACU

Figure 5(b): Air Control Unit

During the peak period, the evaporators have a cooling capacity of 452.00 kW and an air flow rate of 4,25,000 CMH, while during the holding period, the cooling capacity is 255.10 kW with an air flow rate of 2,40,000 CMH. The evaporator coils are constructed with stainless steel tubes and aluminum fins, ensuring efficient heat transfer and durability. The ACUs are designed to maintain the required temperature differences between the evaporator and return air, essential for effective cooling within the cold storage chambers. The evaporator and air control unit of ashoka cold storage are shown in the Figures.5(a) and 5(b).

2.8 ELECTRICAL INSTALLATION:

The electrical system is designed to support the refrigeration and operational needs of the cold storage facility. The total connected load is estimated to be approximately 200 kW, with specific power requirements identified for peak load, holding load, and lean load periods.

Figure 6(a): Electrical Control Room

Figure 6(b): Electrical Control Panel

During peak load periods, the estimated power requirement includes contributions from compressors, water pumps, ACU fans, and ammonia pumps, totaling 117.15 BkW. Similarly, the estimated power requirements for holding and lean load periods are 73.86 BkW each. The capacity of the transformer serving the facility is specified as 315 KVA, with a 200 KVAR capacitor installed for power factor correction. Additionally, standby Diesel Generator Sets with a capacity of 200 HP and 11 KV are designated for backup power supply in case of electrical outages. Figures 6(a) and 6(b) depicts the electrical control units of ashoka cold storage.

2.9 MATERIAL HANDLING PROCEDURE:

The mechanized processes and equipment's are employed for efficient movement and management of goods within the cold storage facility.

Figure 7(a): Material Handling Tools

Figure 7(b): Material Handling Tools

The procedure includes the utilization of a mechanized belt conveyor system with a motor rating of 3.75 kW to facilitate the handling of produce and materials throughout the storage and processing areas. The mechanized belt conveyor system is designed to streamline the transportation of goods, reduce manual labor, and enhance operational efficiency within the facility. By utilizing motorized equipment for material handling, the cold storage unit can optimize workflow, minimize handling time, and ensure the safe and systematic movement of products within the storage chambers and processing areas. Figure. 7(a) and 7(b) shows the material handling unit of ashoka cold storage.

2.10 SAFETY PROVISIONS:

The safety provisions at Ashoka Cold Storage, are comprehensive and meticulously designed to ensure the well-being of personnel, protect equipment, and safeguard the environment. The facility adheres to stringent fire safety standards by installing dry and water-based firefighting equipment, along with machine room ventilation systems to mitigate fire risks. Refrigerant handling protocols include gas cylinders, leak detection systems, and ventilation mechanisms to maintain air quality and prevent leaks. Emergency response measures encompass emergency lighting, alarm systems, and first aid provisions for swift and effective responses during critical situations. Energy-saving initiatives like LED fixtures, natural lighting, and advanced technologies promote sustainability and efficiency while enhancing safety

3. METHODOLOGY

Storing fresh horticultural products after harvesting poses a significant challenge in tropical countries. Vegetables, being perishable, require immediate post-harvest care to minimize microbial growth and extend shelf life. Time and temperature play crucial roles in preventing product deterioration. This can be achieved by placing them in cold storage facilities, rooms with low temperatures and high relative humidity. Refrigeration is extensively utilized for preserving, storing, and distributing perishable foods [3,6]. Recommended temperature and relative humidity, and approximate transit and storage life for vegetable crops are listed in Table 1.

TABLE 1: Storage Conditions for Some Perishable Goods [4]

Product	Temperature (°C)	Relative Humidity (%)	Approx. storage Life (weeks)
Tamarind	4 to 6	90 to 95	15 to 16
Potato	2 to 4	85 to 90	32 to 36
Ginger	2 to 4	65	14
Lime	8	85 to 90	6
Cabbage	0 to 1.5	90 to 95	10 to 12
Cauliflower	0 to 1.5	90 to 95	8 to 10
Tomatoes	7	85 to 90	4 to 5
Frozen Foods	-18 to -20	95 to 98	24 or more
Eggs	1 to 5	75 to 80	20 to 24

This study focuses on various aspects of designing cold storage facilities for vegetables to preserve their post-harvest quality. It emphasizes accurately determining the storage capacity and total cooling load, crucial for effective operation. If the capacity falls short, the refrigeration system will run continuously, risking failure to attain the required temperature. Conversely, excessive capacity leads to oversized, costly equipment, resulting in frequent starts and stops [3].

- **Cooling Load Temperature Difference (CLTD) Method**

The Cooling Load Temperature Difference (CLTD) methods employed in this study to calculate the total cooling load of the cold storage facility. In a cold storage facility, the air inside absorbs heat from various sources, necessitating its removal to maintain desired temperature and humidity levels. This heat absorption is termed as the cooling load, which originates from two main sources: internal and external. Internal sources include heat from products, electric lights, human presence, and air cooler fans, while external sources encompass heat infiltration and transmission through enclosure surfaces like walls, ceilings, and floors. The CLTD method is employed to calculate the extent of heat gain from these sources. Equations from the literature can be customized to precisely compute the heat load generated by different sources based on the cold storage's specific design requirements and present operating characteristics. This calculation is essential for figuring out how much cooling power the proposed cold storage will need. [3].

Transmission Heat: Transmission heat refers to the heat that is transferred through the walls, roof, and floor of a building or storage facility due to the temperature difference between the interior and exterior environments [2]. This heat transfer occurs through conduction, convection, and radiation. The transmission heat load may be calculated using the formula as follows: [4].

$Q_T = (A \times U \times (T_o - T_i) \times t_d)$

Where, A = Area of component

U = Heat Transfer Coefficient

T_0 = Outside Temperature of Cold storage plant / Ambient air

T_i = Inside Temperature of cold storage plant

t_d = Number of hrs. in day

Change in Air: Air from outside entering the cold room through door openings, adding to the cooling load. In the event of frequent door openings and intense usage, the change in air can be enhanced by 100%. If strip curtains are installed on cold room doors, change in air can be decreased by approximately 50%. The air change load can be estimated using the following formula. [4].

$(Q_V) = (Aq) \times (H_o - H_i) \times (\varrho) \times V$

Where, Aq = Air quantity kg/day

H_o = Outside Enthalpy of Air (loading, pull-down and holding period)

H_i = Inside Enthalpy of Air (loading, pull-down and holding period)

ϱ = Density of product (rho)

V = Volume of each chamber

Product Heat: Product heat refers to the heat generated by the products or goods stored within a cold storage facility. Aside from the product's freezing / cooling load, heat created during respiration must be taken up. However, these values are extremely modest and can be disregarded for all practical applications. The product heat can be calculated by the following formula [4].

- Sensible Load (Q_S) = m_p x Cp x ΔT / tp
- Respiration Load (Q_R) = m x q_r

Where, mp = Mass of product

m = overall mass

Cp = Specific heat of product

ΔT = temperature difference

q_r = heat of respiration product

t_p = pull down time

Lighting heat: Lighting heat refers to the heat generated by lighting fixtures used within a space, such as cold storage facilities. When lighting fixtures, such as fluorescent or LED lights, are turned on, they produce light energy as well as a certain amount of heat energy. The lighting heat can be calculated by the following formula [4].

(Q_L)= (W_t) x (t_o) / 1000

Where, W_t = Total Watt

t_o = Number of hours during operation per day

Occupancy heat: Occupancy heat refers to the heat generated by the presence and activities of people within a space, such as a room or a building. People working in cold facilities dissipate heat at a pace that varies with the temperature of the room, but only for a brief period of time each day. The occupancy (workmen) heat can be calculated using the following formula [4].

(Q_O) = (n_p) x (t_o) x (q_p)

Where, q_p = Heat generated per person

n_p = Total number of Workmen

t_o = Total hours during operation per day

4. CALCULATION OF COOLING LOAD

To calculate the total heat generated in a cold storage plant, we have done a case study of Ashoka Cold Storage-II. In this case study we have taken the design conditions of Ashoka Cold Storage-II and have calculated the cooling load for it. The design conditions are given below in the table-2.

TABLE 2: Design Conditions for Ashoka Cold Storage-II

Cold Storage Chambers	24.20 M x 23.45 M x 15.00 M ht x 2 Nos.
Cold Storage Capacity	5,000 MT
Product Stored	Horticulture Crops (Potato)
Insulation Details:	
Ceiling	150 mm EPS
Walls	150 mm EPS
Floor	125 mm EPS
Outside Conditions:	
Altitude	552 Mtr
(During Loading Period)	0.4% of March
Temperature	39.6°C DB & 20.4°C WB
Temp above ceiling	44.6°C
Temp. below floor	30.0°C
Density	1.051 Kg/Mtr3
Enthalpy	60.90 KJ/Kg
(During Pull Down & Holding Period)	0.4% Annual
Temperature	43.2°C DB & 22.5°C WB
Temp above ceiling	47.2°C
Temp. below floor	30.0°C
Density	1.038 Kg/Mtr3
Enthalpy	68.70 KJ/Kg
Inside Conditions	
(During Loading Period)	9°C DB & 90% RH, Enthalpy: 26.40 KJ/K
(During Pull Down & Holding Period)	3°C DB & 90% RH, Enthalpy: 14.40 KJ/Kg
Other Details:	
Loading Period	25 days
Load per day	200 MT
Product Incoming Temperature	30°C
Lighting Load	1.85 kW for 12 hrs.
Ventilation Air	4 air changes/day
Occupancy	16 people working for 12 hrs. during loading
Heat Recovery Unit for Ventilation	70% energy recovery
Specific Heat of F&V (Potato)	3.433 KJ/Kg K
Heat of Respiration at 3°C	0.018 watt/Kg
Heat of Respiration at 15°C	0.027 watt/Kg
Heat Transfer Coefficient:	
External Walls	0.27 watt/m² K
Ceiling	0.24 watt/m² K
Floor	0.29 watt/m² K

1. Transmission Load:

Q_T = (A x U x (T_o - T_i) x t_d)

TABLE 3: Transmission load calculation for Cold Storage Chambers (CSC 1 & CSC 2)

Components	Loading Period (kW)		Pull Down & Holding Period (kW)	
	CSC 1	CSC 2	CSC 1	CSC 2
Ceiling	4.85	9.7	6.02	12.04
Floor	3.46	6.92	4.44	8.88
Walls	11.81	23.62	15.52	31.04
Subtotal (Q_T)	**20.12**	**40.24**	**25.98**	**51.96**

2. Product Load:

- Sensible Load (Q_S) = $m_p \times Cp \times \Delta T / tp$
- Respiration Load (Q_R) = $m \times q_r$

TABLE 4: Product load calculation for Cold Storage Chambers (CSC 1 & CSC 2)

Components	Loading Period (kW)		Pull Down Period (kW)		Holding Period (kW)	
	CSC 1	CSC 2	CSC 1	CSC 2	CSC 1	CSC 2
Sensible	60.79	121.58	79.86	159.72	00	00
Respiration	67.50	135	67.50	135	45	90
Subtotal (Q_P)	**128.29**	**256.58**	**147.36**	**294.72**	**45**	**90**

3. Lighting Load:

(Q_L)= (W_t) x (t_o) / 1000

TABLE 5: Lighting load calculation for Cold Storage Chambers (CSC 1 & CSC 2)

Components	Loading Period (kW)		Pull Down Period (kW)		Holding Period (kW)	
Lighting Load	CSC 1	CSC 2	CSC 1	CSC 2	CSC 1	CS C 2
	0.46	0.92	0	0	0	0

4. Occupancy Load:

(Q_O) = (n_P) x (t_o) x (q_P)

TABLE 6: Occupancy load calculation for Cold Storage Chamber (CSC 1 & CSC 2)

Components	Loading Period (kW)		Pull Down Period (kW)		Holding Period (kW)	
Occupancy Load	CSC 1	CSC 2	CSC 1	CSC 2	CSC 1	CS C 2
	1.075	2.15	0	0	0	0

5. Ventilation Load:

(Q_V) = (Aq) x (H_o – H_i) x (ϱ) x V

TABLE 7: Ventilation load calculation for Cold Storage Chambers (CSC 1 & CSC 2)

Components	Loading Period (kW)		Pull Down Period (kW)		Holding Period (kW)	
	CSC 1	CSC 2	CSC 1	CSC 2	CSC 1	CSC 2
Ventilation Load	4.85	9.7	6.16	12.32	00	00
Net Ventilation Load after 70% recovery	**4.29**	**8.58**	**6.66**	**13.32**	**6.36**	**13.32**

Sub Total Load:

Q_{Total}= (Q_T) + (Q_P) + (Q_L) + (Q_O) + (Q_V)

Q_{Total}= 20.12 + 128.29 + 0.46 + 1.075 + 4.29

Q_{Total}= 154.235 kW (For each Chamber)

- Fan motor load @10%= 10% of 154.235 + 154.235

= 15.42 + 154.235

= 169.655 kW

- Safety Factor @10% = 10% of 169.655 + 169.65

= 186.615kW

Total Heat Load Based on 24 hrs. = 53.318 TR

5. OPTIMIZATION STRATEGIES:

Optimization strategies for cold storage plants are crucial for enhancing efficiency, reducing costs, and minimizing environmental impact. Here are some strategies based on recent research and industry practices:

1. Distribution Path Optimization: By constructing a model that considers green costs, such as carbon emissions and energy use, and using algorithms like the ant colony algorithm, companies can reduce transportation and refrigeration costs, as well as cargo damage costs.

2. Energy Consumption Simulation and Optimization: Improving constructive and operating parameters, such as external temperature, enclosure insulation, and door opening time, can lead to significant energy savings. For example, a study showed potential energy savings of up to 40% with an initial investment that has a payback time of 2 to 5 years.

3. Supply Chain Management: Implementing better tracking and control systems, optimizing shipping and delivery processes, and consulting with logistics experts can improve cold storage supply chain management.

4. Automating Monitoring and Control Systems: Automation can enhance quality assurance practices, reduce human error, and provide real-time data analysis for better decision-making. These strategies aim to balance economic and environmental benefits, promoting sustainable development in the cold storage industry.

6. FUTURE SCOPE AND CONCLUSION

This research presented the operational strategy for setting up a cold chamber with a capacity for storing of 200 MT potatoes while taking into account all of the relevant design factors. The cooling load for the selected cold storage was then calculated by taking into account all potential sources of heat during the functioning in order to determine the appropriate and matched refrigeration capacity. The heat load gained by transmission through enclosed structures accounted for approximately 13% of the total load, followed by the goods (potatoes) at 83% and other heat loads such as lighting, ventilation, and humans at 4%. The maximum percentage is accounted for by the heat load originating from the products themselves. A substantial percentage of the overall cooling load is also made up of heat load acquired by the transmission through structures. After accounting for fan motor load at 10% and safety factor at 10%, the total cooling load for Ashoka Cold Storage-II was determined to be 154.235 kW for each chamber. This meant that the cooling load that the refrigeration system needed to supply was 186.615 kW, or 53.318 TR. This is a crucial factor to take into account because the food industry's demand was erratic and subjected to change, often requiring manufacturers to increase output to meet demand. Furthermore, the safety factor is required since, on certain warmer days, the product's entering temperature exceeds its average temperature. The capacity of the refrigeration system used in Ashoka Cold Storage-II is 452 kW or about 130 TR, which is more than the calculated cooling load even after considering safety factor and all other factors. Hence the refrigeration system used in Ashoka Cold Storage-II is justifiable.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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