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Research Article

Design and calculation of cold storage capacity of 10 tons for tuna commodity

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Abstract

The Ministry of Maritime Affairs and Fisheries, Republic of Indonesia, urges economic stakeholders to maximize increasingly open export opportunities. With an abundance of fishery products in Indonesian waters, it must be supported by adequate facilities, one of which is the availability of cold storage, which maintains the quality of fishery products. In this study, the design of the cold storage was carried out by measuring the size of the cold storage and using the calculation of the cooling load, the calculation of cooling capacity, the calculation of the P-h diagram, and the cost estimate. The results of this study include cold storage design dimensions of 420 m^3 with a long length and tall of 15×7×4 m^3 made from insulation materials of polyurethane, stainless steel, and plaster. The cooling load data for the cold storage, when the product (tuna) is cooled and filled, is 3,707,444.3 kJ every 24 hours. A ton of refrigeration absorbs 12,660 kJ per 24 hours, equaling 16.3 tons of required refrigeration capacity. Meanwhile, under normal operating conditions, the total cooling load is 759,427.588 kJ per 24 hours. After calculating the cooling load, it was discovered that the initial design, which only had a capacity of 10 tons during the refrigeration process, could accommodate a cooling capacity of up to 16.3 tons. The cooling capacity of cold storage is 23.9 kW or 81.400 Btu/h. P-h diagram calculation of compressor cooling load is 0.7 kW, and the cooling load total from the evaporator to keep air room temperature of cold storage 0 °C is 0.43 kW. Estimated cost total for materials of cold storage design is USD 128,655.

1. Introduction

The Ministry of Maritime Affairs and Fisheries encourages economic stakeholders to take advantage of expanding export opportunities. Production fishery total in the first quarter of 2022 was 5.9 million tons, consisting of capture fisheries production of 1.9 million tons and aquaculture production of 3.9 million tons. The total value of fishery production in the first quarter of 2022 reached IDR 120.7 trillion, a decrease of 0.7 percent compared to the same quarter in 2021, which was IDR 121.6 trillion. Totally, the production value was contributed to by capture fisheries to the amount of IDR 62.1 trillion, and by aquaculture fisheries to the amount of IDR 58.6 trillion (The Ministry of Maritime Affairs and Fisheries, 2022). The catch fisheries commodity with the highest production in the first quarter of 2022 was cob in sea waters, with 147 thousand tons, which experienced a decrease in growth of 2.4 percent, and which followed by skipjack tuna, amounting to

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129 thousand tons, which experienced a decrease in growth of 2.1 percent (The Ministry of Maritime Affairs and Fisheries, 2022).

The carbon dioxide mitigation potential of the proposed power system is estimated to be about 350 tons, which can save an annual carbon tax of USD 5,067 (De & Ganguly, 2021). At present, about 40 % of the worldwide annual food production needs to be preserved through the various modes of refrigeration (Gao, 2019). The most popular and conventional modes for the storage of perishables are drying and cooling (Raza et al., 2020).

However, inadequate cold storage facilities in agricultural-based countries cause huge food loss (Sadi & Arabkoohsar, 2020), increasing the market price of the products significantly (Gardas et al., 2018). The need for cold storage is also increasing progressively, with growing food production and consumption worldwide (De & Ganguly, 2019a, 2019b). In developing nations like India, there are more than six thousand cold storage facilities operating presently to preserve agricultural products (Ganguly & De, 2018). These cold storage facilities are highly energy dependent and operate mostly on fossil fuel-based electricity (Ganguly & De, 2018). Overall, cold storage unit efficiently controlled total weight loss (7.64 %) and preserved quality attributes (3.6 °Brix Total soluble solids, 0.83 % Titratable acidity, 6.32 PH) of the product during storage time (Anjum et al., 2021). The process of drying removes moisture from perishables; thus, the microbial activity decreases, and spoilage of food is prevented (Hasan et al., 2019).

The cooling technology gap includes using less environmentally friendly refrigerants in several countries worldwide, limited refrigerator facilities that reach remote coastal areas, and a need to use renewable energy in cooling systems. In this study, the purpose of designing cold storage includes determining the cooling load of the cold storage, calculating capacity from the cold storage, and determining the estimated storage cost. The advantages of cold storage include serving as cold storage for the storage of fishery products in order to maintain the quality of those fishery products, knowing the total cooling load when the cold storage is working, knowing the total cooling capacity of the cold storage when it is used as a fish storage refrigerator, and knowing the total estimated operational costs of the cold storage.

2. Materials and methods

2.1 Flowchart of cold storage design

A cold storage design flowchart can be used to describe or visualize the process from the first step to the final step of cold storage design. The flowchart is crucial in cold storage design research steps (**Figure 1**).

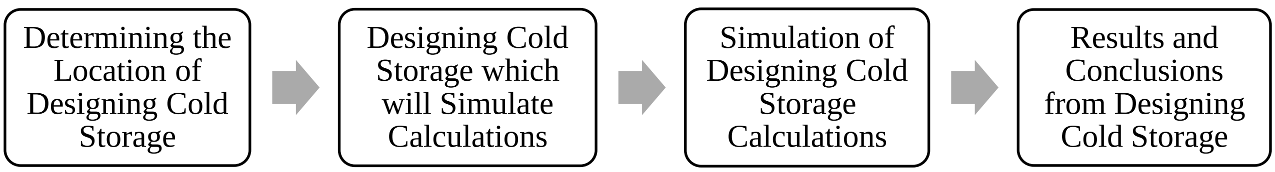

Figure 1 Flowchart of cold storage design.

The first step involves determining the placement of the cold storage to be designed by determining the initial size of the cold storage design. The initial size of cold storage is determined which supports the simulation calculation to be carried out using the appropriate calculation formula, such as the cooling load of cold storage calculation simulations, cold storage capacity calculation simulations, and cost estimation from cold storage design. Then, the calculation simulation results are obtained from the cold storage design as the research output.

2.2 Initial design of cold storage

Tuna is stored in cold storage (freezer room) with a capacity of 10 tons. The cold storage is 420 m^3, with dimensions of 15×7×4 m^3, and insulation materials made of polyurethane, stainless steel, and plaster. The thermal conductivity of each material is 0.01 W/mK for polyurethan, 13 W/mK for stainless steel, and 0.05 W/mK for plaster with thicknesses of 0.03 m for polyurethan, 0.03 m for stainless steel, and 0.03 m for plaster.

Table 1 Initial data of cold storage.

Design Cold Storage		
Properties	**Total**	**Unit**
Product Volume	110	m^3
Box Volume	45	m^3
Total Volume	155	m^3
Internal Dimension		
Length	15	m
Width	7	m
Height	4	m
Space Volume	265	m^3
Internal Total Volume	420	m^3
External Dimension		
Wall Width	0.5	m
Floor and Ceiling Width	0.5	m
Length	16	m
Width	8	m
Height	4.5	m
Building Total Volume	576.25	m^3

The total volume of the product is obtained by adding the calculation product volume of 110 m^3 and tuna box volume of 45 m^3; the total volume of the product is 155 m^3. Internal dimension data cold storage design calculation is used for obtaining the total internal volume using rectangular building volume formula, applied as a cold storage design; then, internal volume total is 420 m^3. External dimension data of cold storage design to obtain building volume total, length, width, height, wall thickness, and floor thickness are calculated. Calculation results are obtained, with building volume total of 576.3 m^3 (**Table 1**).

2.3 Location of cold storage

The Kutaraja ocean fisheries port is the largest fishing port in Aceh Province and has been designated as a type A port (Salmarika & Wisudo, 2019; Sari et al., 2019). According to the Kutaraja ocean fisheries port's Technical Implementing Unit (2020), the production of marine catches at Kutaraja Ocean fisheries port has increased yearly, reaching 12.6 ton in 2016 and 18.6 ton in 2020. This potential is expected to enhance the global competitiveness of fishery products by increasing the availability of high-quality export raw materials and handling catches following environmental quality standards such as clean water and sanitation.

The Kutaraja Ocean Fisheries Port is strategically located as a fisheries port or as storage facilities for fisherman to load and unload their catches. The Kutaraja Ocean Fisheries Port is adjacent to the pier and is alongside the Lampulo market. Based on latitude, the Kutaraja Ocean Fisheries Port is located at 96.75, DMS latitude 5.57° N, DMS longitude 95.32° E, and latitude 4.7 (**Figure 2**).

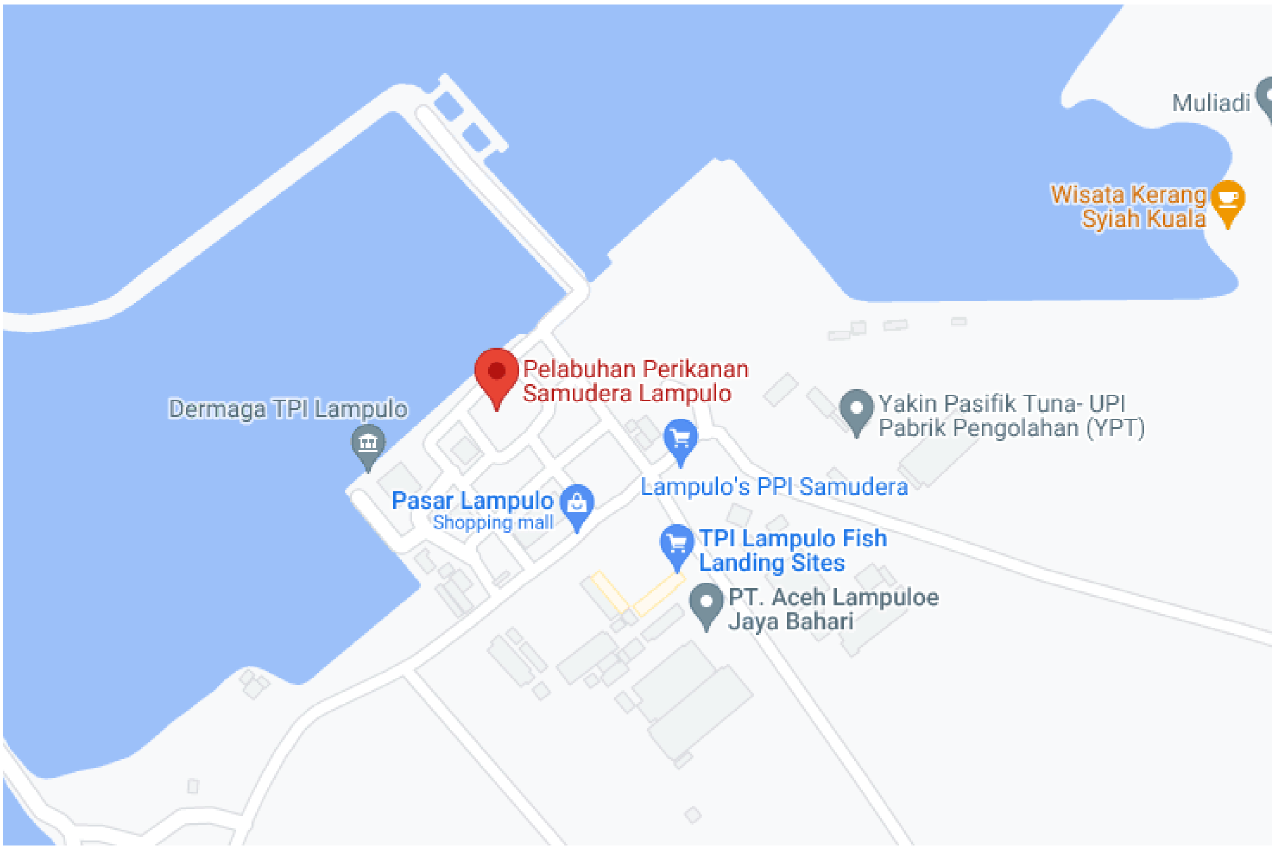

Figure 2 Kutaraja Ocean Fisheries Port, Aceh.

Figure 3 Current fisheries environment at the Kutaraja Ocean Fisheries Port, Aceh.

Figure 3 depicts the location of the Kutaraja Ocean Fisheries Port across from Kutaraja Lampulo. The Kutaraja Ocean Fisheries Port Lampulo, Banda Aceh, is situated on the coast, so it is a hub for the loading and unloading of fish by numerous fishing vessels.

2.4 Design of a cooling scheme for cold storage

The cooling scheme for cold storage in this study is divided into two stages: Pre-Cooling is the first step in the cooling scheme. Tuna is washed and sorted before being placed in a storage box based on size and quality. Tuna is placed in an air blast freezer at −30 °C for 6 hours. Tuna is then packaged according to the specifications. Main Cooling is a follow-up process from Pre-Cooling, in which tuna goes into cold storage at −25 °C after being packed into boxes; then, it is ready to be shipped to consumers (Dewayani, 2016).

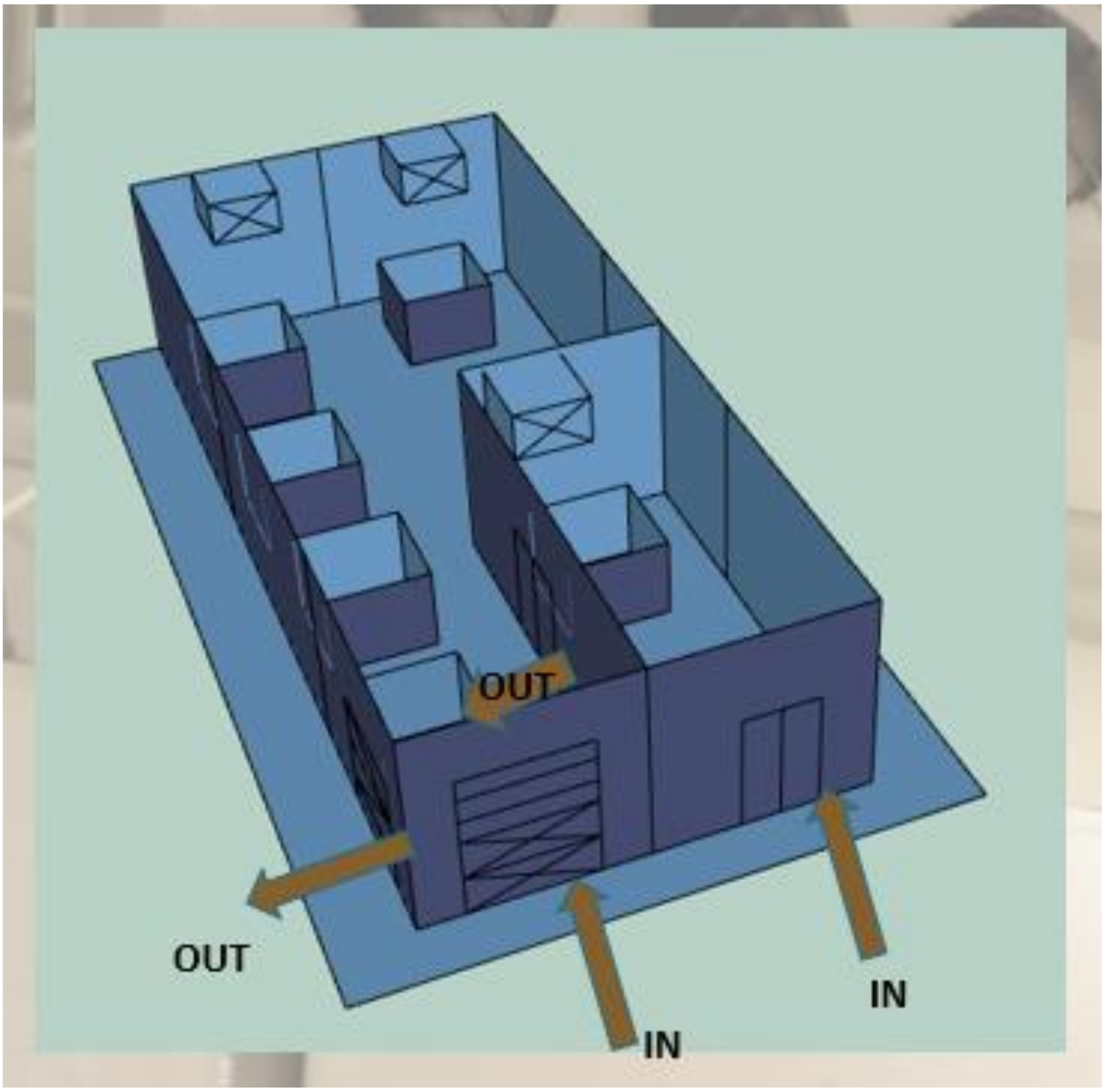

Figure 4 Design of a cooling scheme for cold storage.

Figure 4 shows and describes the cold storage design cooling scheme. Cold storage design has two doors to the pre-cooling and the primary cooling area. The basket for tuna fish and the cooling system for cold storage design are shown in the pre-cooling and main cooling areas.

2.5 Calculation of cooling load

Cooling load calculations under the cooling conditions filled product (tuna) and average temperature conditions is shown here.

Table 2 Initial data for calculating cold storage cooling loads.

Conditions	Example
Storage Size	16×8×4.5 m^3
Outside surface area (including the floor)	472 m^2
Inside dimensions	15×7×4 m^3
Volume	420 m^3
Insulation	0.03 m of polyurethane with a conductivity value (k) = 1.3 kJ per m^2 per m thickness per °C Coefficient of transmission (U) = 1.1 kJ per h per m^2 per °C
Ambient conditions at harvest	31 °C and 65 % RH
Tuna temperature	At harvest, 20 °C; In storage, −23 °C
Storage capacity	16 Box at 600 kg Tuna per Box = 9,600 kg of Fish (Tuna Blue Fin)
Box weight	70 kg; total weight of box = 1,400 kg
Loading weight and time	Four boxes (2,400 kg Tuna per day); 2 days to fill
Cooling rate	1st day, 20 to −15 °C; 2nd day, −15 °C to −25 °C
Air change from door openings during cooling	Six per day
Air change from door openings during storage	1.8 per day
Specific heat	Tuna Blue Fin, 3.43
Heat load to lower air from 31 to −25 °C (65 % RH)	3.095 kJ per m^3
Heat load to lower air from 20 to −25 °C (50 % RH)	2.619 kJ per m^3
Miscellaneous heat loads	Lights, 240 W per h (2.19 kJ per W) Fans at 3.112 kJ per HP Electric forklifts, 36,920 kJ each for 8 hours Workers, 1,000 kJ per h for each person

Data in **Table 2** is used for cooling load calculation from condition and value results. Cold storage design using size or volume is 16×8×4.5 m^3, size or volume inside cold storage design is 15×7×4 m^3, and cold storage design volume total is 420 m^3. Cold storage ambient condition temperature is 31 °C and 65 % RH. Tuna fish temperature is 20 °C before being put in cold storage, and -23 °C after being put in cold storage. Cold storage for tuna fish allows a capacity of 9,600 kg for 16 baskets or boxes, and 660 kg per basket-filled tuna bluefin fish. Cold storage design cooling ratio temperature on the first day starts from 20 °C until −15 °C, and on the second day from −15 °C until −25 °C. When the cold storage is operated, the cooling tuna fish door is opened six times per day, and the cold storage door is opened 1.8 times per day; when tuna fish is put in cold storage, air changes. Bluefin tuna has a specific heat of 3.4. The heat load to cool air from 31 to −25 °C (65 % RH) is 3.1 kJ per m3, while the heat load from 20 to −25 °C (50 %) is 2.6 kJ per m^3. Cold storage lamp heat load is 0.240 kW per hour. The heat load of fans is 3.1 kJ per horsepower, the heat load of electric forklifts operating for eight hours is 36.920 kJ, and the heat load of workers in a cold storage area is 1,000 kJ per person.

2.6 Calculation of cooling capacity

Total air flow calculation is the first step for cooling capacity calculation. After, the cooling capacity of the cold storage design is determined (**Table 3**).

Table 3 Initial data for calculating the cooling capacity of cold storage.

No.	Variables	Value
1	Total Volume and ACH	15×7×4 m^3 and 6 ACH
2	Room Temperature	25 °C and 50 % RH
3	Environment Temperature	31 °C and 65 % RH
4	Air Supply	20 °C
5	Fresh Air Amount	10 % of Total Air Flow
6	SHF	3.43 °C

It was previously known that the volume of cold storage is 420 m^3, in order to calculate the cooling capacity. The room temperature is 25 °C, the ambient temperature is 31 °C, and the air supply accounts for 10 % of the total airflow.

$$\text{Total Air Flow : m = Room Volumes} \times \text{ACH} \quad (1)$$

M is the total air flow (m^3/s), and ACH is air change hours. The above equation is used to find the total airflow in the cold storage design. To obtain the value of the total airflow, the volume of the room is multiplied by the ACH.

$$T_{ma} = \frac{(\text{Tdb OA} \times 15\% \text{ Air Flow}) + (\text{Tdb RA x } 85\% \text{ Air Flow})}{\text{Air Flow}} \quad (2)$$

T_{ma} is the air flow total, T_{db} is dry bulb temperature, OA is the outdoor air conditions line, and RA is the indoor conditions line. The above equation is used to find the mixed air temperature in cold storage by multiplying the ambient temperature and 15 % air flow, then adding the multiplication of room temperature and 85 % air flow, then dividing it by the total airflow previously obtained.

Cooling machine capacity:

$$Q_C = \dot{m} \times (h_2 - h_1) \quad (3)$$

Q_C is cooling capacity in the cold storage, ṁ is air flow total cold storage, h_1 is enthalpy 1 that occurs in compressor cold storage, and h_2 is enthalpy 2 that occurs in condensor cold storage. The above equation determines the cooling capacity in cold storage by calculating the total airflow multiplied by h_2, which has been reduced by h_1.

2.7 Design data- P-h diagram calculation (Qevap – Wcomp – Qcond)

The cooling effect:

$$\Delta h_e = h_1 - h_4 \quad (4)$$

Δh_e is enthalpy change that occurs in the cold storage evaporation process, h_1 is enthalpy 1 that occurs in compressor cold storage, and h_2 is enthalpy 2 that occurs in condensor cold storage. The above equation is used to find the value of the refrigeration effect with enthalpy one minus enthalpy 4.

The mass flow rate of the refrigerant:

$\dot{m}_r = q_{evap} / \Delta h_e$ (5)

$\dot{m}_r$ is mass flow rate of refrigerant, q_{evap} is heat energy that works on the evaporator area, and Δh_e is enthalpy change that occured in the cold storage evaporation process. The above equation is used to find the mass flow rate of the refrigerant with heat in the evaporator, divided by the refrigeration effect that has been obtained previously.

$Q_{cond} = q_{evap} + W_{comp}$ (6)

Q_{cond} is heat energy on the condensor, q_{evap} is heat energy that works on the evaporator area, and W_{comp} is the power that works on the compressor. The above equation is used to find the heat energy on the condenser, the heat on the evaporator, and the power on the compressor.

Based on all existing load calculations, the total cooling load required by the evaporator to keep the air temperature of the cold storage room at 0 °C is:

$qCS = q_{product} + q_{transmition} + q_{inf} + q_{fan}$ (7)

qCS is the cooling total in the cold storage, q_{produk} is the cooling load that occurs in product storage in the cold storage, $q_{transmition}$ is the cooling load that occurs in transmission of cold storage, $q_{infiltration}$ is the cooling load that occurs in infiltration of cold storage, and q_{fan} is the cooling load that occurs in the fan works of cold storage. The above equation is used to find the total heat in cold storage by adding product heat, transmission heat, infiltration heat, and fan heat.

Generally, refrigeration machines in Indonesia are designed with a safety factor of 30 %, so the refrigeration load required by the evaporator with a safety factor of 30 % is:

$q_{evap} = 1.3qCS$ (8)

q_{evap} is heat energy that works on the evaporator area, and qCS is the cooling total in the cold storage. The above equation is carried out to obtain the heat acting on the evaporator by 1.3 multiplied by the total heat working on the cold storage, as obtained in the previous calculation.

2.8 Determination of component units (P_{evap} - P_{comp} - P_{cond})

The previous calculation determined the refrigeration load for the condenser to be 704 watts. Then, a condenser is selected that is appropriate for this cold storage design. The procedure is the same as when selecting an evaporator, with calculations from the Güntner Product Calculator Customer software being used.

The condenser component uses GVM 037A/1-L with a capacity of 2.9 kW, refrigerant R134a, fans are used 1 - 230 V 50 Hz, and the total energy consumption is 0.06 kW. The casing material used is galvanized steel and RAL 7035. The tube uses copper material, and the fins use aluminum material (**Table 4**).

The electric load for the DC compressor type BD80F is 145 watts, the evaporator is 70 watts, and the condenser is 60 watts. As a result,

$W_{total} = W_{comp} + W_{evap} + W_{cond}$ (9)

W_{total} is power total that occurs in cold storage, W_{comp} is power that occurs in the compressor in cold storage, W_{evap} is power that occurs in the evaporator in cold storage, and W_{cond} is power that occurs in the condenser in cold storage. The above equation is used to find the total load in cold storage by adding the BD80F type DC compressor electrical load, the evaporator electrical load, and the condenser electrical load.

Table 4 Data on the components of cold storage design.

Condenser	**GVM 037A/ 1-L**		
Capacity :	2.9 kW	**Refrigerant :**	**R134a**
Airflow :	1,450 m^3/h	Hot gas temperature :	82 °C
Air inlet :	38 °C	Condensation temperature :	50 °C
Altitude :	0 m	Condensate outlet :	48.4 °C
		Hot gas flow :	0.90 m^2/n
Fans :	One piece (s) 1 - 230 V 50 Hz	Noise pressure level :	33 dB(A)
Data per motor (nominal data) :		At a distance of :	10 m
Speed :	890 min^{-1}	Noise power level :	64 dB(A)
Capacity :			
Current :	0.28 A		
Total power consumption: 0.06 kW		Energy efficiency class :	C
Casing :	Galv, Steel, RAL 7035	Tubes :	Copper
Surface :	8.1 m^2	Fins :	Aluminum
Tube volume :	2 l	Connection per unit :	
Fin pitch :	2.20 mm	Inlet :	9.5×1.00 mm^2
Passes :	36	Outlet :	9.5×1.00 mm^2
Dry weight :	13 kg	Distributions :	1×1
Dimensions : L = 610 mm; B = 310 mm; H = 460 mm; L1 = 530 mm			

2.9 Design of cold storage (Embodiment design)

The design of cold storage depicts the components contained in cold storage.

Figure 5 displays a 3D top view of a cold storage design with an open and closed cover. Previously described cold storage design components include the cooling system, tuna fish basket, and operational doors.

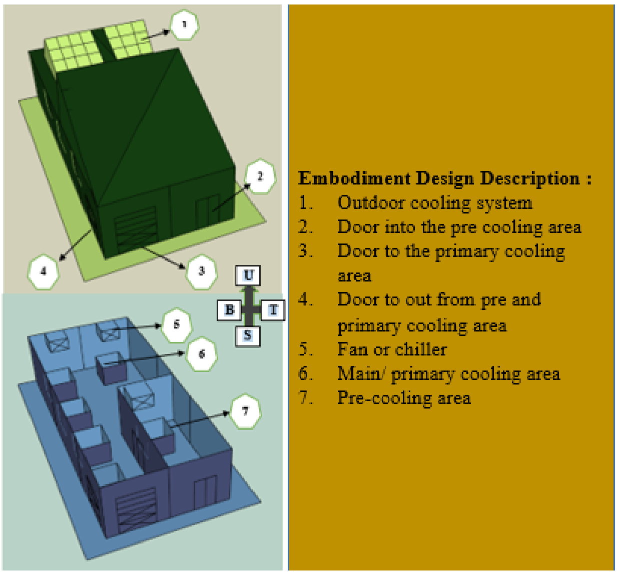

Figure 5 Embodiment design.

2.10 Cost estimation Capex-Opex

Operational cost predicts operational costs from cold storage designs and shows the cost of the types of equipment to be used.

Table 5 Equipment data in cold storage.

Equipment Item	Qty	Unit	Unit Price ($)	Total Price ($)	References
Polyurethane Wall (CS)	1	Set	30,357	30,357	(Arif, 2022)
Condensing Unit 20 HP	3	Unit	22,448.30	67,344.9	(Nazaruddin, 2019)
Control Panel	1	Set	2,758.6	2,758.6	
Polyurethane Wall (Room)	1	Set	12,500	12,500	
Chiller 7 HP	3	Unit	9,643	28,929	
Other Materials	1	Set	827.6	827.6	
Accommodation	1	Lot	1,786	1,786	(Arif, 2022)
Commissioning Test	1	Lot	2,500	2,500	
Total				128,655	

The cost of cold storage elements is divided into two categories: standard atmosphere and controlled atmosphere. Condensing unit 20 HP is the most expensive equipment, at USD 51,402, and other materials are the cheapest equipment, at USD 1,000, from equipment used in cold storage design. The total cost for types of equipment is USD 128,655 (**Table 5**).

Table 6 Cold storage equipment capacity data.

Equipment	Capacity (kW)	Quantity	Total (kW)
Condensing Unit 20 HP	15.3	4	61.2
Condensing Unit 9 HP	7	1	7
Lighting	0.3	4	1.2
Total			69.4

The largest capacity needed in a 20 HP condensing unit is 15.3 kW, and a total capacity is 61.2 kW from the use of 4 to 20 HP condensing units. The lowest capacity required for lighting equipment is 0.3 kW, and the total capacity used for lighting is 1.2 kW (**Table 6**).

Table 7 Energy system used in cold storage design.

Energy System	PV (kW)	Inverter (kW)	Battery (Unit)	Generator (kW)	Investment Cost ($)
Grid (83 kVA)	PLN				5,720
Generator				73	14,300
PV Hybrid	100	63	50	73	322.1
PV Off-grid	478	72	577		955
PV On-grid	100	70			260

The system energy used in off-grid PV cold storage requires the largest PV capacity with 478 kW; this result is consistent with energy and production analysis of a dairy milk factory (Taner, 2023a). For grid (83 kVA), using power from the State Electricity Company (PLN), there is an investment cost of 5,720 USD. The most significant investment cost required for a generator is 14,300 USD, and the lowest is for an on-grid PV energy system of 260 USD (**Table 7**).

3. Results and discussion

3.1 Initial design of cold storage

The cold storage design dimensions are 420 m^3 with dimensions of 15×7×4 m^3 and polyurethane, stainless steel, and plaster insulation materials. Each material has a thickness of 0.03 m polyurethane, 0.03 m stainless steel, and 0.3 m plaster, and a thermal conductivity of 0.01 W/mK polyurethane, 13 W/mK stainless steel, and 0.5 W/mK plaster mK. The insulation material is considered safe for food and protecting the environment (Taner, 2023b). The cold storage design has a total building volume of 576.25 m^3.

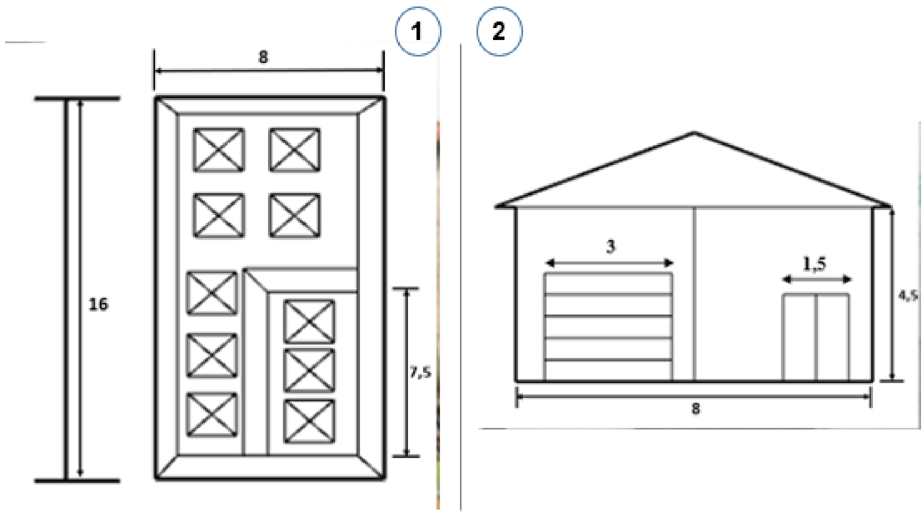

Figure 6 Top view of cold storage design, with measurements for length and width (1); Front view of a cold storage design (2).

The two-dimensional image above is the top view of the cold storage design. Fish storage basins have been arranged in the primary and pre-cooling areas. The total length of the cold storage design is 16 m, width is 8 m, and height is 4 m. The length of the pre-cooling area is 7.5 m and the width of the pre-cooling area is 5 m (**Figure 6**).

3.2 Calculation of cooling load

Temperature difference (TD) from 31 °C to −23 °C is 54 °C, assuming 54 °C TD on all cold storage surfaces. **Table 8** shows the results of the cooling load calculation.

Table 8 Results of the cooling load calculation.

No.	Calculation	kJ per 24 hour
1	**Building-transmission load**: area (472 m^2) × U (1.1 kJ) × TD (54 °C) × h (24)	672,883.2
2	**Air change load from door opening**: volume (420 m^3) × heat load (3,095 kJ) × air changes (6)	7,799.40
3	**Product cooling (field heat removal)**	
	First Day	
	Tuna (2,400 kg) × specific heat (3.43) × TD (20 to −15 °C) × kJ factor (4,186)	1,206,070.32
	Box weight (1400 kg) × specific heat (3.43) × TD (35 °C) × kJ factor (4,186)	703,541.02
	Second Day	
	Tuna (2,400 kg) × specific heat (3.43) × TD (−15 to −25 °C) × kJ factor (4,186)	344,591.52
	Box weight (1,400 kg) × specific heat (3.43) × TD (10°C) × kJ factor (4,186)	201,011.72
4	The heat of respiration during cooling (vital heat)	
	First Day	
	The average temperature of 17.5 °C; the respiration rate is 12,206 kJ per ton per 24 h ;	
	Ton of tuna (10) × rate (12,206)	122,060
	Second Day	
	The average temperature of −20 °C; the respiration rate is 1,741 kJ per ton per 24 h ;	
	Ton of tuna (10) × rate (1,741)	17,410
	Max heat accumulated in storage before cooling completely:	
	Total tuna weight (9,600 kg) - 2-day loading weight (4,800); respiration rate at −25 °C is 227 kJ per ton per 24 h; a ton of tuna (10) × respiration rate (227)	2,270
5	Miscellaneous heat loads :	
	Lights ; 240 W × 2,19 kJ per W × 5 h	2,628
	Fans ; 4 HP × 3,112 kJ per HP × 24 h	298.752
	Forklifts; 2 × 36,920 kJ per forklift for five h	73,840
	Labor ; 4 workers × 1,000 kJ per h × 4 h	16,000
No.	**Total heat load during cooling**	**kJ per 24 hour**
1	**Building transmission**	672,883.2
2	**Air change**	7,799.4
3	**Product cooling**	2,455,214.58
4	**Product respiration**	141,740
5	**Miscellaneous**	92,766.752
	Subtotal	3,370,403.932
	Add 10 % to be caution	337,040.3932
	Total required refrigeration	3,707,444.325

The cooling load data for the cold storage, when the product (tuna) is cooled and filled, is 3,707,444.3 kJ every 24 hours. If cold storage is accessible for 18 hours a day, 3,707,404.325 kJ divided by 18 hours equals 205,969.13 kJ per hour. A ton of refrigeration absorbs 12,660 kJ per 24 hours; therefore, 20,969.13 kJ per 12,660 equals 16.3 tons of required refrigeration capacity.

Normal cooling load when cold storage operates (average outdoor environmental conditions) is TD = 20 + 25 = 45 °C, as calculated in **Table 9**.

Table 9 Average cooling load in cold storage.

No.	Calculation	kJ per 24 hour
1	**Building-transmission load** : area (472 m^2) × U (1.1 kJ) × TD (45 °C) × h (24)	560,736
2	**Air change load from door opening**: volume (420 m^3) × heat load (2,619 kJ) × air changes (1.8)	1,979.964
	Product load (Respiration, no cooling)	
3	Respiration rate at –25 °C is 12,206 kJ per ton per 24 h; ton of tuna (10) × rate (12,206)	122,060
4	Miscellaneous heat loads :	
	Lights ; 240 W × 2,19 kJ per W × 2,5 h	1,314
	Fans ; 4 HP × 3,112 kJ per HP × 24 h	298.752
No.	**Total heat load during cooling**	**kJ per 24 hour**
1	**Building transmission**	560,736
2	**Air change**	1,979.964
3	**Product respiration**	122,060
4	**Miscellaneous**	5,612.752
	Subtotal	690,388.716
	Add 10% to be cautious	69,038.8716
	Total required refrigeration	759,427.5876

Meanwhile, under normal operating conditions (average outdoor environmental conditions), the total cooling load is 759,427.588 kJ/24 h. If cold storage is accessible for 18 hours a day, 759,427.59 kJ divided by 18 hours equals 42,190.42 kJ per hour. One ton of refrigeration absorbs 12,660 kJ per 24 hours, so the required refrigeration capacity is 3.33 tons (42,190.42 kJ per 12,660 kJ).

3.3 Calculation of cooling capacity

First, to calculate the cooling capacity, determine the total airflow from the cold storage, which is 0.7 m^3/s or 1,483.216 cfm. A T_{ma} of 25.9 °C is produced for total mixing water, resulting in a cooling capacity of 23.856 kW or 81,400.012 Btu/h.

From the graph above, the air supply temperature is 20 °C, room temperature is 25 °C/65 %, and room temperature is 31 °C. The h1 enthalpy is known to be 54.1 kJ/kga, and the h2 enthalpy is 82.5 kJ/ kga (**Figure 7**).

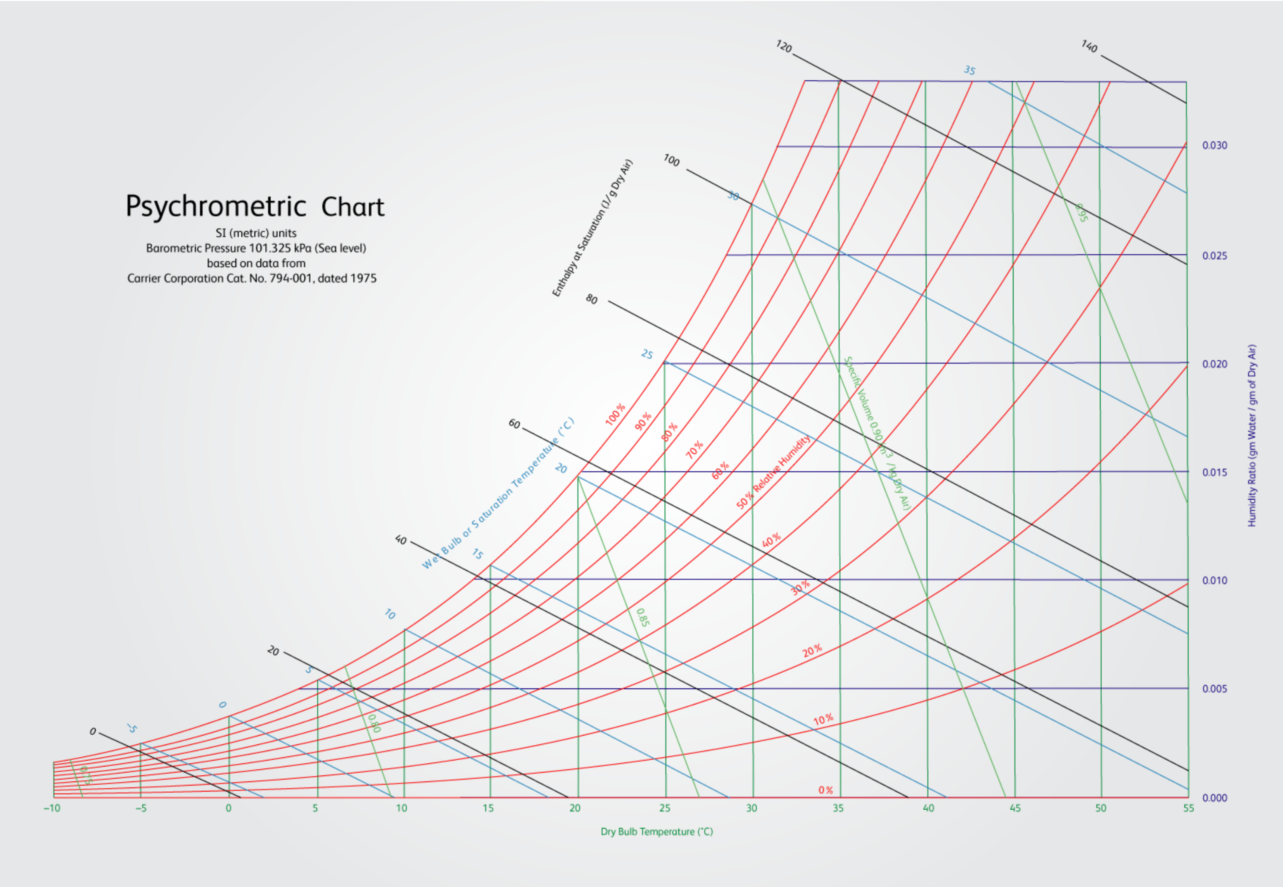

Figure 7 Psychometric graph of total airflow and air mixture calculations.

3.4 Design data - P-h diagram calculation (Qevap – Wcomp – Qcond)

The refrigeration effect obtained from the P-h diagram calculation is (Δh_e) 125 kJ/ kg, and the refrigerant mass flow rate ($\dot{m}_r$) is 0.00452 kg/s. If the compressor cooling load (Q_{cond}) is 0.704 kW, the evaporator's overall cooling load (q_{CS}) that must be provided to keep the cold storage room's air temperature at 0 °C is 0.43 kW.

The refrigeration effect is obtained by adding enthalpy 1 of 385 kJ/kg minus enthalpy 4 of 260 kJ/kg. The refrigerant mass flow rate is found by dividing the evaporator heat and the known refrigeration effect. The condenser cooling load is obtained by adding the evaporator heat of 0.56 kW and the compressor power of 0.139 kW.

Figure 8 is a psychometric graph of R134a refrigerant in cold storage design. Temperature 1 is known to be –25 °C, temperature 2 is 29 °C, and temperature 3 is 40 °C. Pressure one is known to be 2.2 kPa, and pressure 2 to be 11.5 kPa.

Table 10 Data from calculations and the design of a P-h diagram.

Point	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ.kg)	Classification Mass (kg/m^2)
1	–25	2.26	385	0.09
2	29	11.6	430	0.019
3	40	11.6	260	0.019
4	–25	2.26	260	0.09

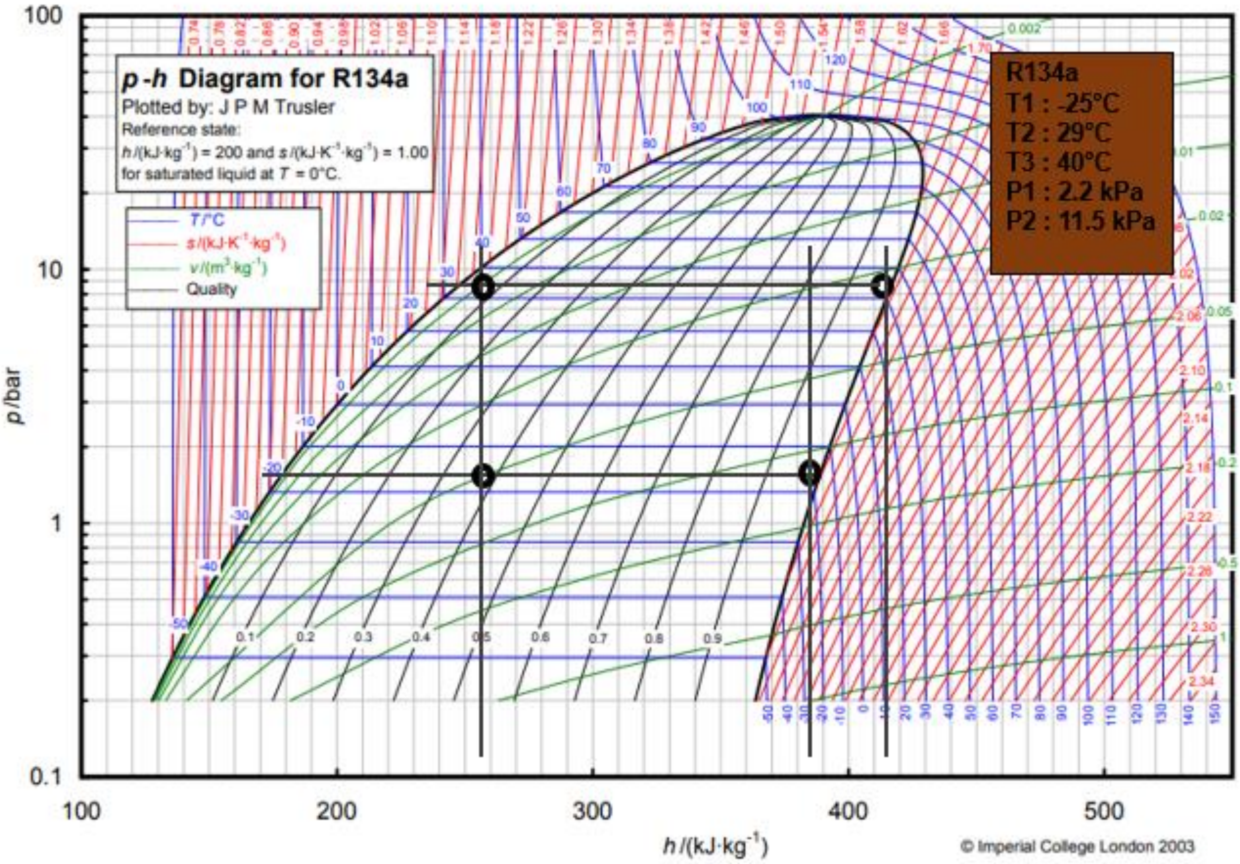

Figure 8 Psychometric graph of cold storage design.

From the calculations and design of the P-h diagram, the lowest temperature of –25 °C occurs at points 1 and 4, while the highest temperature is at point 3 at 40 °C. The lowest pressure occurs at points 1 and 4 with 2.26 kPa, while the highest pressure occurs at points 2 and 3 with 11.6 kPa. The lowest enthalpy occurs at points 3 and 4 with 260 kJ.kg, while the highest enthalpy occurs at point 2 with 430 kJ.kg. The lightest density occurs at points 2 and 3 with 0.019 kg/m2, while the heaviest density occurs at points 1 and 4 with 0.09 kg/m^2 (**Table 10**).

3.5 Determination of component units (P_{evap} - P_{comp} - P_{cond})

The refrigeration load for the condenser was calculated to be 704 watts using the previous calculation. Then, a condenser is selected that is appropriate for this cold storage design. The procedure is the same as when selecting an evaporator, with calculations from the Güntner Product Calculator Customer software. The electric load for the DC compressor type BD80F is 145 watts, the evaporator is 70 watts, and the condenser is 60 watts. As a result, the total power (W (total)) of the components used is 275 watts.

3.6 Design of cold storage (Embodiment design)

The embodiment design that has been created can still be modified in terms of material, refrigerant, capacity, and so on to achieve the desired specifications (**Figure 9**).

The cold storage design above is equipped with two entrances, divided into one entrance to the pre-cooling area and one entrance to the primary cooling area. The cooling system outside the cold storage cooling area (compressor, condenser, and evaporator), including the electrical system of the cold storage design, has been adjusted based on the efficiency of the location and maintenance of the cooling system as the electricity of the cold storage design.

Table 11 Material specifications and weight of materials used in cold storage design.

Materials	Weight (Kg)
Carbon Steel	
Outer wall	420
Inner wall	400
Inside cover	80
Outer cover	93
Sub Total	993
Polystyrene	
Wall	20
Cover	5
Sub Total	25
Wood	
Cover mat	265
Cover	15
Sub Total	280
CS Total	1,033
Stainless Steel	
Mat Solar Module	92
CU wall	33
CU cover	41
CS cover	132
Sub Total	298
Photovoltaic module	75
Sub Total	75
Refrigeration Machine	
Evaporator	13
Condenser	14
Battery	11
Sub Total	38
Total	**1,709**

The materials used in the cold storage design are carbon steel with a total weight of 993 kg, polystyrene with a total weight of 25 kg, wood with a total weight of 280 kg, stainless steel with a total weight of 298 kg, photovoltaic modules with a total weight of 75 kg, and refrigeration machines with a total weight of weight 38 kg. The total weight of the materials used in the cold storage design is 1,709 kg (**Table 11**).

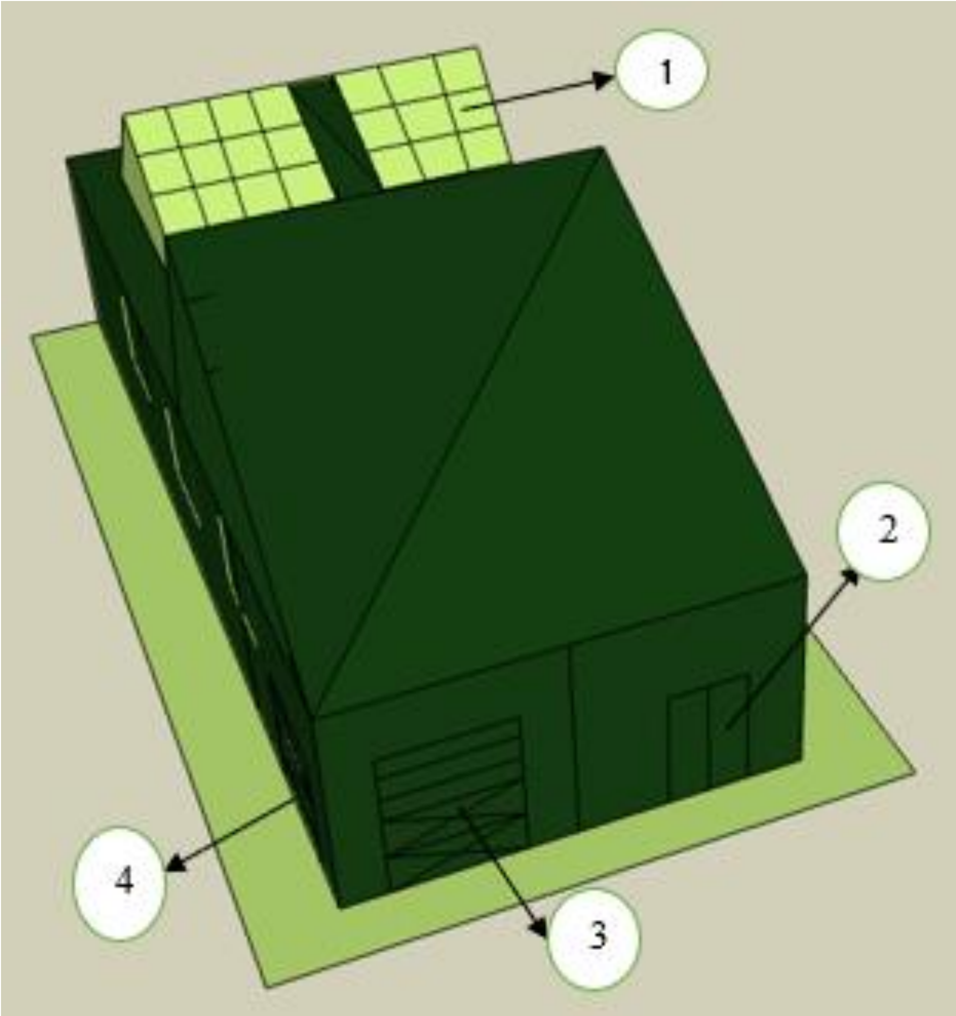

Figure 9 Design of cold storage (embodiment design), outdoor cooling system (1), entrance to the pre-cooling area (2), entrance to the primary cooling area (3), and exit from the main cooling area (4).

3.7 Cost estimation Capex-Opex

The total cost of the equipment used in the cold storage design is USD 128,655. Each company's estimated cost for the cost elements used in cold storage with a standard atmosphere is USD 245,540.57/ enterprise, while the estimated cost for a controlled atmosphere is USD 303,580.11/ enterprise. The most significant investment in the energy system is the generator, which costs USD 14,300, while the smallest is the on-grid PV system, which costs USD 260.

Estimating the cost of the elements used in the cold storage design is divided into cost elements in standard and controlled atmospheres. In the standard atmosphere, the estimated cost for the tuna basket element is 2,000 USD/ enterprise; the estimated maintenance and renovation costs are 6,145 USD/ enterprise; the estimated cost for the energy element is 70,000 USD/ enterprise, the estimated cost for the labor element is 54,215 USD/ enterprise, and the estimated cost for the depreciation element is 77,333.57 USD/ enterprise. The estimated cost of the overhead element is 35,847 USD/ enterprise. In a controlled atmosphere, estimated cost for the tuna basket element is 6,600 USD/ enterprise, the estimated cost of maintenance and renovation is 10,105 USD/ enterprise, the estimated cost for the energy element is 74,103 USD/ enterprise, the estimated cost for the labor element is 65,411 USD/ enterprise, estimated the cost for the depreciation element is 92,361.11 USD/ enterprise, and the estimated cost for the overhead element is 55,000 USD/ enterprise (**Table 12**).

Table 12 Data for element cost estimation in cold storage.

Cost Elements	Normal Atmosphere		Controlled Atmosphere		References
	USD/ Enterprise	%	USD/ Enterprise	%	
Fish Box	1,958.4	0.8	6,586.8	2.2	(Arif, 2022)
Maintenance and Renovation	6,144.2	2.5	10,104.8	3.3	
Energy	69,766.4	28.5	74,101.8	24.3	
Labor	53,419.6	21.8	65,405.2	21.5	
Seasonal Labor	2,111.5	0.9	1,729	0.6	
Fixed Labor	51,308.1	20.9	63,676.2	20.9	
Depreciation	77,121.7	31.56	92,354.2	30.29	
Building (5 %)	29,656.1	12.1	33,757.5	11.1	
Cooling System (4 %)	28,615.9	11.7	40,627.9	13.3	
Generator (7 %)	124.3	0.05	10	0	
Fish Box for Rent (25 %)	1,958.4	0.8	65,86.8	2.2	
Minor Equipment (16 %)	176.9	0.07	113.2	0.04	
Forklift (30 %)	11,168.8	4.6	5,192.7	1.7	
Office Supplies (23 %)	1,376.1	0.6	164.7	0.05	
Pickup Truck (20 %)	2,165.1	0.9	3,892.2	1.28	
Battery Powered Forklift (9 %)	723.8	0.3	374.1	0.12	
Truck Weighbridge (7 %)	1,068.2	0.4	1,635.1	0.5	
Truck (25 %)	88.1	0.04	0	0	
Overhead	35,830.7	14.58	54,999.6	18	
Transport	4,860.9	1.9	8,757.5	2.9	
Water	1,583.9	0.7	1,642.9	0.5	
Cleaning	2,794.4	1.14	973.1	0.3	
Stationary	3,003.9	1.23	3,937.1	1.3	
Communication	2,973.2	1.21	2,073.4	0.7	
Heating	2,018.3	0.8	1,609.3	0.5	
Insurance	7,468.6	3.1	13,697.6	4.5	
Taxes	10,640.2	4.3	19,838.6	6.5	
Other	487.3	0.2	2,470.1	0.8	
Total Operating Costs	244,241		303,552.4		

3.8 Levelized Cost of Electricity (LCOE)

According to previous calculations, the energy system produced the highest LCOE of USD 30.031/kWh, while the lowest LCOE generator produced USD 0.306/kWh. Within one year of operation, the highest off-grid PV energy system consumes 78.575 kWh/year, while the lowest grid energy system (83 kVA) consumes 11.408 kWh/year. The generator has the highest estimated maintenance cost of USD 171,600/year, while PV on-grid 1-6 has the lowest maintenance cost of USD 3,120/year.

Table 13 Results of the LCOE calculation.

Energy System	LCOE ($/kWh)	Energy Served (kWh/Year)	PV On-Grid Production (kWh/Year)	Net Electricity ($/Year)	Fuel Cost ($/Year)	Maintenance Cost ($/Year)
Grid (83 kVA)	0.728	11.408		8.305		
Generator	0.306	12			245	171,600
PV Hybrid	13.598	12			3,865.2	3,865.2
PV Off-grid	30.031	78.575				11,460
PV On-grid 1	23.0769	16.438	15.616	379.347		3,120
PV On-grid 2	21.923	16.438	15.616	360.379		3,120
PV On-grid 3	20.769	16.438	15.616	341.412		3,120
PV On-grid 4	16.154	11.507	14.795	185.8799		3,120
PV On-grid 5	15	11.507	14.795	172.603		3,120
PV On-grid 6	13.846	11.507	14.795	159.326		3,120

From the LCOE table data above, the system energy used consists of an off-grid PV with maximal LCOE 30.031 USD/ kWh and a generator with minimal LCOE 0.306 $/kWh. From this result, designed cold storage facilities are feasible to be built in the fisheries area. The cold storage has more advantages compared with traditional ice cube storage. Cold storage allows very precise temperature settings. The temperature can be maintained at the right level as required, which is important for maintaining the quality and freshness of stored products, especially in the case of products that require low temperatures. Cold storage can be used for long-term storage without losing product quality. This is in contrast to ice cubes which, although they can provide temporary cooling, cannot maintain a consistent temperature for long periods of time. In some cases, cold storage can be more energy efficient than traditional cooling methods using ice cubes. Modern cooling systems are often designed to be more energy efficient and efficient (**Table 13**).

4. Conclusions

The initial design of cold storage produces cold storage design measurements and complete specifications; the next step is calculating the cooling load of cold storage design, cooling capacity, components choice, and operational cost estimation of cold storage. When the cold storage operates, it cools and fills product (tuna), resulting in a total cooling load of 3,707,444.325 kJ/24 h or 205,969.13 kJ per hour. A ton of refrigeration absorbs 12,660 kJ per 24 hours; therefore, 20,969.13 kJ per 12,660 equals 16.269 tons of required refrigeration capacity. Meanwhile, under normal operating conditions (average outdoor environmental conditions), the total cooling load is 759,427.588 kJ/24 h, or 42,190.42 kJ per hour. One ton of refrigeration absorbs 12,660 kJ per 24 hours, so the required refrigeration capacity is 3.33 tons. After calculating the cooling load, it was discovered that the initial design, which only had a capacity of 10 tons during the refrigeration process, could accommodate a cooling capacity of up to 16,269 tons. The cold storage design cooling capacity the evaporator must provide to keep the cold storage room’s air temperature at 0 °C is 434.85 W.

The components’ total power (W (total)) is 275 watts. The total cost of the equipment used in the cold storage design is USD 128,655. Each company’s estimated cost for the cost elements used in cold storage with a standard atmosphere is USD 245,540.57/ enterprise, while the estimated cost for a controlled atmosphere is USD 303,580.11/ enterprise. The most significant investment in the energy system is the generator, which costs USD 14,300, while the smallest is the on-grid PV system, which costs USD 260. According to previous calculations, the energy system PV off-grid produced the highest LCOE of USD 30.031/kWh, while the lowest LCOE generator produced USD 0.306/kWh. The generator has the highest estimated maintenance cost of USD 171,600/year, while PV on-grid 1-

6 has the lowest maintenance cost of USD 3120/year. The operational costs of cold storage remain high after calculating the estimated operating costs of cold storage design. Components, materials, cost elements, and energy systems that are more efficient and achieve the desired specifications can be re-selected in the future.

Further research could use renewable energy in cold storage designs as an electrical energy source, like solar panels, green energy, and renewable energy from fossil sources. Cold storage design with the correct choice and eco-friendly refrigerant can be used for research development.

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