

Estimation of R404A Refrigerant Cooling Load and System Efficiency of a Small-Scale Cold Box for Strengthen The Fisheries Cold Chain in Timbolsloko, Demak

Hanityo Adi Nugroho^{1*}, Samsudi R², Rubijanto JP³, M. Ahnaf F⁴, Aulia SS⁵, Aditano YR⁶

^{1,5,6}Department of Marine Science, Faculty of Science and Agroculture Technology, Universitas Muhammadiyah Semarang
^{2,3,4}Department of Mechanical Engineering, Faculty of Engineering and Computer Science, Universitas Muhammadiyah Semarang

Article Info

Article history:

Received May 25, 2025
Revised November 23, 2025
Accepted January 19, 2026

Keywords:

Cooling Load
Refrigeration System
Energy Efficiency
R404A Refrigerant
Fishing Vessel

ABSTRACT

The cooling system of the fishing boat is extremely crucial in maintaining the quality of the catch during storage. In this study, the system performance and cooling load are analyzed in a box of dimensions 1.8 m × 2.4 m × 1.2 m with R404A refrigerant at an evaporation temperature of -21.8°C and a condensation temperature of 37.6°C. Total daily cooling load is 15.504 kWh, which includes heat transmission load of 5.653 kWh, product load of 6.656 kWh, internal load of 0.542 kWh, equipment load of 1.61 kWh, and infiltration load of 1.043 kWh. System performance by pressure-enthalpy (P-h) analysis provides actual Coefficient of Performance (COP) as 4 with 94% refrigeration efficiency. The 100 mm polyurethane insulation utilized are enhance energy efficiency and environmental sustainability. This cooling system design was found to be optimal for maintaining the box temperature at -20°C with high efficiency, serving to benefit the small-scale fisheries sector under tropical conditions.

This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



1. INTRODUCTION

In the fishing industry, refrigeration systems are a key factor in maintaining product quality and freshness in storage and sea transportation. Fish and seafood catches are most susceptible to quality loss from exposure to high ambient temperatures. Cooling facilities such as cold storage and freezers are designed to provide optimal temperatures that inhibit the growth of microorganisms, prevent spoilage, and maintain the texture, flavour, and nutritional value of stored products. Their misuse will result in reduced product quality or increased energy losses [2]. The effectiveness of the cooling system has been a significant challenge to fishermen, particularly in the aftermath of high energy prices and small storage capacity on fishing boats.

R404A refrigerant meets the standards set by the U.S. Environmental Protection Agency (EPA) and belongs to the A1 safety level category (the highest level, harmless to the human body) according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). While R404A is still widely used and recognized as a mainstream low-temperature refrigerant [6], its high Global Warming Potential (GWP) means that many countries are now phasing it down in favor of lower-GWP alternatives to enhance environmental sustainability. Rather than replacing the system outright, retrofitting is the suggested method utilized to improve the energy performance of R404A systems to suit hot climate regions and achieve low Global Warming Potential (GWP) [26][15][19][33].

Regardless of the refrigerant used, the efficiency and long-term sustainability of fishing operations heavily rely on accurate thermal analysis. Erroneous cooling load calculations—including errors in determining the volume of stored commodities, the catch's initial temperature, and the ambient sea temperature—can significantly compromise the overall sustainability of these activities. Therefore, it is essential to adopt a cooling load calculation method that accurately considers these parameters to ensure the cooling system operates efficiently without negatively affecting product quality [17]. The R404A refrigerant is also worth

*Corresponding Author
Email: hanityoadi@unimus.ac.id

considering due to its high safety level; under normal temperature and pressure, R404A does not easily explode in the air, with its minimum oxygen content for explosion being 23.84% or mildly flammable [31][45].

In fisheries, cooling systems are essential for transporting catches to port or to a fish auction. The issues at this point are the fluctuations in ambient temperature along the journey, extended transportation hours, and the vessel's thermal insulation. [20] proposed that applying suitable cooling technology to vessels can reduce fish quality loss by up to 30% and carbon emissions by 20%. This support for low-emission systems is reinforced by the study of [28], Based on a fuzzy inference system that considers traffic density, the weight of approaching vehicles, and the carbon dioxide emission rate, indicate that these cold chain systems have a low emission rate [28].

Advances in modern technology have opened up opportunities to improve the efficiency of cooling systems on fishing boats. The use of environmentally friendly refrigerants, such as R404A, coupled with innovations like variable refrigerant flow (VRF) technology, has been shown to maximize cooling system performance while reducing energy consumption. Through these innovations, fishermen can balance operational effectiveness with environmental friendliness [8].

This study aims to develop the cooling load application on fishing vessels. It conducts analyses to determine the key variables that govern the cooling system's performance, including the marine environment temperature, the quantity of preserved catch stored, and the length of the sea trip. The objective of this study is to provide recommendations on appropriate cooling equipment specifications to ensure energy efficiency without compromising integrity in the catch [39]. Following a systematic design, this study is anticipated to significantly help fishermen maximize yield by optimizing their vessel's cooling systems.

2. METHOD

2.1. Research Tools and Materials

The tools used include a meter roll, thermometer, and anemometer. The materials or objects of research in this study have the following specifications.

AC Brand & Type	: Denso type FS 2
Box Size (p, l, t)	: 1.8 m x 2.4 m x 1.2 m
Compressor	: Denso 10 PA17C
Cooling unit	: FS 2 50 Watt
Condensing unit	: Type M 140 Watt
Refrigerant	: R404a
Box insulation	: 100 mm thick PU coated with 2 mm fiberboard outside and inside
Number of lights	: 150 watts
Number of people	: 1 person
Vehicle type	: Mitsubishi L300

The fishing vessels shown in Figure 1 are equipped with power electronic converters to reduce dimensions, mass, maintenance costs, and operational expenses while improving efficiency, safety, and reliability. These systems integrate alternating current (AC) and direct current (DC) loads, often requiring auxiliary systems to operate correctly to keep super-fresh seafood products on board [27].

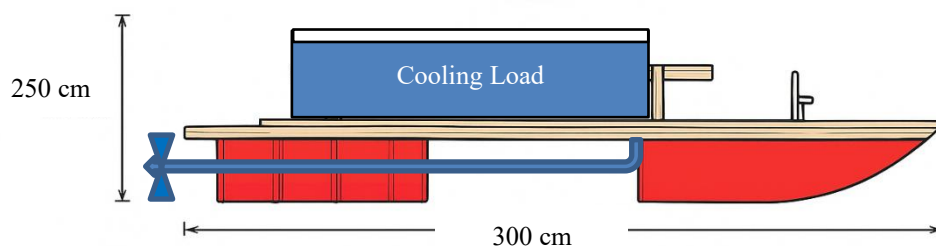


Figure 1. Fishing Vessel Scheme : Small-Scale Cold Box for Strengthen The Fisheries Cold Chain

2.2.1. Method Analysis

This research employed two main quantitative analyses based on primary data gathered through dimensional measurements, material analysis of the main components used, and observation of operational conditions. These analyses utilize fundamental equations, namely: the thermal property equations [10][22] and the generator efficiency equation [37]. After the data is obtained, the cooling load calculation of the cooling box is carried out, including:

- 1) heat load passing through the wall,
- 2) product heat load,

- 3) load when empty,
- 4) load from the use of equipment in the box,
- 5) human load when entering the box,
- 6) infiltration heat load,

The values of each heat load are then summed to obtain the total heat load. From the total heat load, the equivalent size (pk) of the cooling machine is determined to meet the cooling load efficiency requirements. The DC motor has the attribute of a single control system capable of operating in two control modes. The initial mode is the armature control mode, in which the field current remains constant. Alternatively, it is referred to as a field control mode with a constant armature current. The features of a DC motor consist of resistance, inductance, and return electromotive-force voltage, as seen in Figure 2 [3].

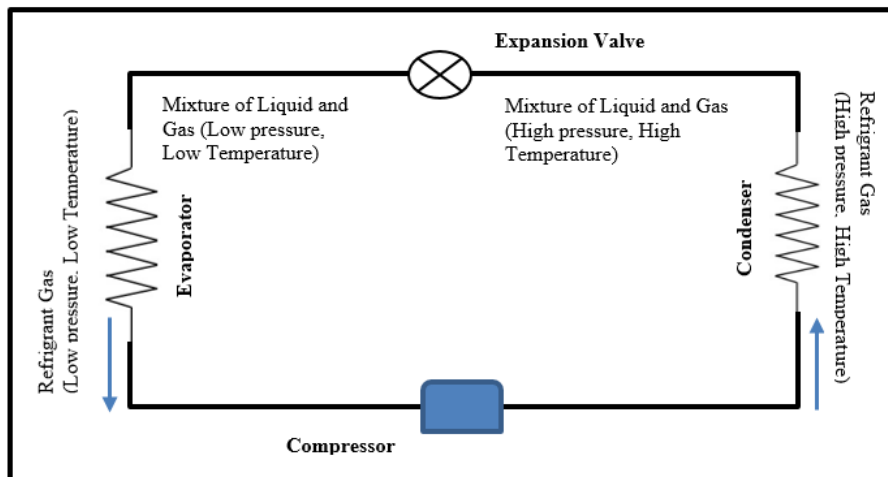


Figure 2. The DC motor schematic

The working principle of the Transport refrigerator is the same as that of the car AC in general. The cooling system consists of a compressor, condenser, cooling unit, control unit, hoses, pipes, and other components. The refrigerant circulates in a closed circuit, transferring heat from a low-temperature source (air in the cargo box) to a high-temperature source (outside air/atmosphere) to cool the cargo box interior. The use of new refrigerants (HFC134a or R404A) aims to reduce environmental damage in small-scale fishing industry cooling systems. HFC-134a refrigerant is used for cooling or chiller types, while R-404A is generally used for frozen or super-frozen types. Utilizing natural gas to meet energy needs for businesses, transportation, and other uses is environmentally friendly and legally accepted. Energy usage in buildings is a crucial factor in global efforts to achieve energy sustainability. This significant share underscores the importance of advancing sustainable energy management practices in the built environment [1].

The main advantage of DC motors in fan applications is their ability to easily regulate speed. This speed regulation can be achieved by adjusting the voltage entering the motor; for example, lowering the voltage from 12 volts to 6 volts can halve the motor's rotation speed, resulting in a softer breeze. In addition, DC motors are highly efficient, with electrical-to-mechanical conversion efficiencies of 85-90%, higher than those of AC motors, which typically range from 70-80%. This high efficiency not only reduces power consumption but also minimizes heat generation, thereby extending the overall life of the motor and fan [40].

3. RESULTS AND DISCUSSION

Based on direct observation, measurement data were obtained. These data will subsequently be used to calculate the cooling load on the object under study, by referring to relevant thermal property equations 1-9 [10].

Calculating the total cooling load

The overall heat transfer resistance in the plate heat exchanger was evaluated by summing the thermal resistances of the ambient, water, and refrigerant sides, along with the conduction resistance through the plate material [41]. These resistances are typically categorized into four main groups:

1. Transmission Load From Walls

a. Wall material data

Fiberboard with a thickness of 2 mm, each layer (inner and outer), with a thermal conductivity value of 0.23 W / (m2K). Polyurethane thickness with a thickness of 100 mm, with a thermal conductivity of 0.0224 (m2K). The ambient temperature is 34 °C with a relative humidity of 40%, and the desired air in the box is - 20 °C. Walls, roofs, and floors are insulated with 100 mm using Polyurethane coated with outer and inner fiberboard. It is known that the fiberboard thickness is 4 mm, and the polyurethane thickness is 100 mm. The thermal resistance value of the fiberboard is 0.23 W/m2K, and that of polyurethane is 0.0224 W/m2K.

$$R_{total} = (0.004/0.23) + \left(\frac{0.1}{0.0224}\right) = 4.481 \text{ W/m}^2\text{K} \quad (1)$$

Calculation of transmission load :

$$Q = U \times A \times \Delta T(\text{Inner air Temp.} - \text{Outside temperature}) \times 24 \div 1000 \quad (2)$$

Q = kWh / heat load per day

U = U insulation value 1/ 4.481 W / m².K

A = Surface area of ceiling, walls, and floor (m²)

Indoor Temp. = Inner air temperature (°C)

Outdoor Temp. = Ambient outside temperature (°C)

24 = Hours in a day

1000 = Watt to kW conversion

Calculating A (Surface area of walls, roofs, and floors):

1. Right side wall = 1.8 m × 2.4 m = 4.32 m²

2. Left side wall = 1.8 m × 2.4 m = 4.32 m²

3. Front wall = 1.2 m × 2.4 m = 2.88 m²

4. Back wall = 1.2 m × 2.4 m = 2.88 m²

5. Ceiling = 1.8 m × 1.2 m = 2.16 m²

6. Floor = 1.8 m × 1.2 m = 2.16 m²

Calculation of the floor, front wall, and ceiling separately due to different temperature differences, so heat transfer will also differ.

Right, left, back walls:

$$Q = U \times A \times (\text{Outdoor temp} - \text{Indoor temp}) \times 24 \div 1000$$

$$Q = 0.223 \frac{\text{W}}{\text{m}^2} \cdot \text{K} \times 11.52 \text{ m}^2 \times (34^\circ\text{C} - (-20^\circ\text{C})) \times 24 \div 1000$$

$$Q = 3.329 \frac{\text{kWh}}{\text{day}}$$

Front wall:

$$Q = U \times A \times (\text{Outdoor temp} - \text{Indoor temp}) \times 24 \div 1000$$

$$Q = 0.223 \frac{\text{W}}{\text{m}^2} \cdot \text{K} \times 2.88 \text{ m}^2 \times (34^\circ\text{C} - (-20^\circ\text{C})) \times 24 \div 1000$$

$$Q = 0.832 \frac{\text{kWh}}{\text{day}}$$

Ceiling:

$$Q = U \times A \times (\text{Outdoor temp} - \text{Indoor temp}) \times 24 \div 1000$$

$$Q = 0.223 \frac{\text{W}}{\text{m}^2} \cdot \text{K} \times 2.16 \text{ m}^2 \times (34^\circ\text{C} - (-20^\circ\text{C})) \times 24 \div 1000$$

$$Q = 0.624 \frac{\text{kWh}}{\text{day}}$$

Floor:

$$Q = U \times A \times (\text{Outdoor temp} - \text{Indoor temp}) \times 24 \div 1000$$

$$Q = 0.223 \frac{\text{W}}{\text{m}^2} \cdot \text{K} \times 2.16 \text{ m}^2 \times (55^\circ\text{C} - (-20^\circ\text{C})) \times 24 \div 1000$$

$$Q = 0.867 \frac{\text{kWh}}{\text{day}}$$

Total daily transmission load (Q_{total}):

$$Q_{total} = 3.329 + 0.832 + 0.624 + 0.867 = 5.653 \frac{\text{kWh}}{\text{day}}$$

2. Product Loading Load

a. Product Cooling Load

- Volume 1 : 70 ml takes up space ($20 \times 8 \times 2 = 320 \text{ cm}^3 = 0.00032 \text{ m}^3$)
- BOX Volume : $1.70 \times 1.70 \times 2.50 = 7.225 \text{ m}^3$
- Internal volume
Maximum quantity that : $5,175 \text{ m}^3$
- can be loaded : $5,175 \div 0.00032 \text{ m}^3 = 16,171 \text{ pcs}$
- Total weight : $16,171 \times 70 \text{ ml} = 1,131,970 \text{ ml} \times 0.92 \text{ gr/ml (ice density)} = 1,041 \text{ kg}$

We can use the following formula for this calculation:

$$Q = m \times C_p \times \Delta T (\text{Product inlet temperature} - \text{Cold room internal temperature}) \div 860 \quad (3)$$

where:

Q	= kWh/day
C_p	= Product Specific Heat Capacity (kJ/kg.°C)
m	= Mass of added product (kg)
Product inlet temperature	= Product inlet temperature (°C)
Cold room internal temperature	= Cold room internal temperature (°C)
860	= Kcal to kWh conversion rate

Cooling load calculation assumes ice cream (milk-based) has a similar specific heat to fish products, with an average of 0.50 kcal/kg.°C, cooled from -10°C to -20°C for a storage capacity of 1,041 kg [38]:

$$Q = \frac{m \times C_p \times \Delta T (\text{Product inlet temperature} - \text{Cold room internal temperature})}{860}$$

$$Q = \frac{1041 \text{ kg} \times 0.50 \text{ kcal/kg}^\circ\text{C} \times \Delta T (-10^\circ\text{C} - (-20^\circ\text{C}))}{860}$$

$$Q = 6.052 \frac{\text{kWh}}{\text{day}}$$

b. Calculating Cooling Load from Product Respiration

$$Q = \frac{m \times \text{respiration}}{3600} \quad (4)$$

where:

Q	= kWh/day
m	= amount of product in storage (kg)
Resp.	= product respiration heat (kJ/kg)
3600	= Converting kJ to kWh

$$Q = \frac{m \times \text{respiration}}{3600}$$

$$Q = \frac{1041 \times 2.09}{3600}$$

$$Q = 0.604 \frac{\text{kWh}}{\text{day}}$$

$$Q_{Total} = 6.052 + 0.604 = 6.656 \frac{\text{kWh}}{\text{day}}$$

3. Internal Heat Load

Calculation of Cooling Load from Humans (1 person in the box for 30 minutes).

$$Q = \frac{\text{number of workers} \times \text{time} \times \text{heat}}{1000} \quad (5)$$

Where:

Q	= kWh
Number of people	= Number of people entering
Time	= Duration spent in the box per person (Hours)
Heat	= Heat loss per person per hour (Watt)
1000	= Converting watts to kW

Calculation:

$$Q = \frac{\text{number of workers} \times \text{time} \times \text{heat}}{1000}$$

$$Q = \frac{1 \times 2 \text{ hours} \times 271}{1000}$$

$$Q = 0.542 \frac{\text{kWh}}{\text{day}}$$

4. Heat Load from Equipment

a. Calculation of cooling load from lighting

Heat generated by lighting is calculated using the following calculation:

$$Q = \frac{\text{lamps} \times \text{time} \times \text{watts}}{1000} \quad (6)$$

where:

Q	= kWh
Lamps	= number of lamps in the cold room
Hours	= daily usage hours for cold room lighting
Watts	= lighting power rating
1000	= Watts to kW

If there is 1 lamp with 50 W power operating for 2 hours per day:

$$Q = \frac{\text{lamps} \times \text{time} \times \text{watts}}{1000}$$

$$Q = \frac{1 \times 2 \text{ hours} \times 50 \text{ Watts}}{1000}$$

$$Q = 0.1 \frac{\text{kWh}}{\text{day}}$$

b. Calculation of cooling load from fan motor

Heat load conversion from evaporator fan motor.

$$Q = \frac{\text{Fans} \times \text{time} \times \text{watts}}{1000} \quad (7)$$

where:

Q	= kWh/day
Time	= Fan operating time per day (hours)
Watts	= Fan motor nominal power (Watts)
1000	= Watts to kW

This cold room evaporator uses 2 fans, each rated at 96 Watts, with a working load of 8 hours per day.

$$Q = \frac{\text{Fans} \times \text{time} \times \text{watts}}{1000}$$

$$Q = \frac{2 \times 8 \text{ hours} \times 96 \text{ Watts}}{1000}$$

$$Q = 1.5 \frac{\text{kWh}}{\text{day}}$$

c. Calculation of cooling load from defrost

Calculating heat load from evaporator defrosting. To calculate this load, we will use the following formula:

$$Q = \text{Time} \times \text{Power} \times \text{defrost cycles} \times \text{efficiency} \quad (8)$$

where:

Q	= kWh/day
Power	= Heating element power (kW)
Time	= Defrost operation time (Hours)
Defrost cycles	= How many times per day defrost cycles occur
Efficiency	= what % of heat will be transferred to the environment

Defrost runs for 10 minutes 4 times a day, and 30% of the energy consumed is transferred to the cold room. During defrost, heating is provided by the refrigeration system itself. When defrost occurs, the condenser fan stops, preventing heat transfer, and the hot temperature is released to the evaporator through the bypass valve, raising the evaporator temperature and melting the ice. It is known that defrost occurs for 10 minutes changing temperature from -12°C to 5°C where it experiences a temperature change of 17°C, if converted to power of 32,284 joules if converted to watts becomes 53.81 watts = 0.05381.

$$Q = 0.05381 \text{ kW} \times 0.16 \text{ hours} \times 4 \times 0.3$$

$$Q = 1.61 \frac{\text{kWh}}{\text{day}}$$

Total heat load from equipment: $0.1 + 1.5 + 0.01 = 1.61 \text{ kWh/day}$

d. Calculation of Cooling Load from Infiltration

At this stage, the heat load from air infiltration needs to be calculated. Using the formula below:

$$Q = \frac{\text{volume} \times \text{energy} \times \text{changes} \times (\text{Outdoor Temp} - \text{Indoor Temp})}{3600} \quad (9)$$

where:

Q	= kWh/day
Changes	= Number of volume changes per day
Volume	= Cold storage volume
Energy	= energy per cubic meter in degrees Celsius
Outdoor Temperature	= Outdoor air temperature
Indoor Temperature	= Cold room temperature
3600	= kJ to kWh

$$Q = \frac{\text{volume} \times \text{energy} \times \text{changes} \times (\text{Outdoor Temp} - \text{Indoor Temp})}{3600}$$

$$Q = \frac{7.225 \text{ m}^3 \times 2 \text{ kJ}/^\circ\text{C} \times 5 \times (34^\circ\text{C} - (-18^\circ\text{C}))}{3600}$$

$$Q = 1.043 \frac{\text{kWh}}{\text{day}}$$

Table 1. Total cooling load

No	Type of Cooling Load	Cooling Load Amount (kWh/day)
1	Load through walls	5.653
2	Product load	6.656
3	Internal load	0.542
4	Equipment load	1.61
5	Infiltration load	1.043
Total		15.504

The total cooling load of ice cream box is 15.504 kWh/day

e. Calculating Cooling Efficiency in Cooling System

To simplify the analysis, the determined measurement data were illustrated using a pressure-enthalpy (P-h) diagram, which is derived from energy and exergy analyses [12][37][44][5]. The enthalpies at the evaporator outlet ($h_{e,out}$) and inlet ($h_{e,in}$), expressed in kJ/kg, were obtained from the measured pressure and temperature values. Subsequently, the cooling capacity (Q_c) through the evaporator can be determined in kW. Based on the existing operational data, system performance is analyzed and compared with the original design conditions.

Table 2. Data from Transport Refrigerator

No	Parameter	Value
1	Discharge Pressure	330 Psi (22.4 Bar)
2	Suction Pressure	25 Psi (1.7 Bar)
3	Discharge Temperature	100.7°C
4	Evaporator Inlet Temperature	-28.4°C
6	Condenser Outlet Temperature	46°C
7	Suction Temperature	36°C
8	Room Temperature	-22°C

When plotted on the R404 P-h diagram, the following enthalpy values can be obtained:

- h_1 (Evaporator Outlet) = 400 kJ/kg
- h_2 (Compressor Outlet) = 420 kJ/kg
- h_3 (Condenser Outlet/Expansion Valve Inlet) = 320 kJ/kg
- h_4 (Evaporator Inlet) = h_3

Calculated Mass Flow Rate (m):

Given the compressor power input (P comp), P comp = 11.3 HP = 8.4 kW

The mass flow rate (m) can be calculated using the work done by the compressor:

$$m = P_{\text{comp}} / (h_2 - h_1) = 8.4 / (420 - 400) = 0.42 \text{ kg/s}$$

The exergy concept can be referred to as the knowledge of the total irreversibility of the refrigeration cycle. The second law of thermodynamics defines exergy destruction (irreversibility) as the reduction in a system's ability to operate due to losses. Hence, the exergy efficiency of the system (η_{ex}), which is also known as second law efficiency (cooling capacity at evaporator Q_c), can be calculated as follows:

$$Q_c = m(h_1 - h_4) = 0.42 \text{ kg/s} \times (400 - 320) \text{ kJ/kg} = 33.6 \text{ kW}$$

$$COP_{\text{actual}} = \frac{Q_c}{P_{\text{comp}}} = 33.6/8.4 = 4$$

$$COP_{\text{carnot}} = \frac{T_{\text{evaporation}}}{T_{\text{condensation}} - T_{\text{evaporation}}} = ((-21.8 + 273))/(37.6 - (-21.8)) = 4.22$$

$$\eta_{\text{refrigeration}} = \frac{(COP_{\text{actual}})}{(COP_{\text{carnot}})} \times 100\% = \frac{4}{4.22} \times 100\% = 94\%$$

4. CONCLUSION AND LIMITATION

This research analyzes cooling load and system efficiency in a box measuring 1.8 m × 2.4 m × 1.2 m using R404A refrigerant with an evaporation temperature of -21.8°C and a condensation temperature of 37.6°C. The total daily cooling load is 15.5 kWh, consisting of heat transmission (5.653 kWh), product (6.656 kWh), internal (0.542 kWh), equipment (1.61 kWh), and infiltration (1.043 kWh). System efficiency, based on a pressure-enthalpy (P-h) analysis, yields an actual Coefficient of Performance (COP) of 4 and a refrigeration efficiency of 94%. The use of 100 mm polyurethane insulation and environmentally friendly refrigerants supports energy efficiency and environmental sustainability. This cooling system design proves optimal for maintaining box temperature at -20°C with high efficiency, supporting the small-scale fisheries sector in tropical regions.

However, the use of R404A refrigerant, which has a high Global Warming Potential (GWP), poses environmental challenges. Additionally, the calculations were conducted through simulation rather than field testing, so technical and operational validation is still required. This research provides a preliminary technical foundation that can be further developed to support the cold chain of small-scale fisheries in tropical regions.

REFERENCES





- [1] M. Ajuji, M. Dawaki, A. Mohammed, and A. Ahmad4, "Estimating Residential Natural Gas Demand and Consumption: A Hybrid Ensemble Machine Learning Approach," *Vokasi UNESA Bull. Eng. Technol. Appl. Sci.*, vol. 2, no. 3, pp. 549–557, 2025. <https://doi.org/10.26740/vubeta.v2i3.40135>.
- [2] Anderson J., Smith R., & Taylor M., "Optimizing Refrigeration Systems for Food Quality and Cost Efficiency," *Journal of Food Engineering*, vol. 320, 104756, 2023.
- [3] W. Aribowo, L. Abualigah, D. Oliva, T. Mzili, S. Aliyu, and H. A. Shehadeh, "Frilled Lizard Optimization to Optimize Parameters Proportional Integral Derivative of DC Motor," *Vokasi UNESA Bull. Eng. Technol. Appl. Sci.*, vol. 1, no. 1, pp. 14–21, Aug. 2024. <https://doi.org/10.26740/vubeta.v1i1.33973>.
- [4] Atici Ö. A. and Özkan D. B., "Experimental and Theoretical Investigation of Thermal Parameters Influencing the Freezing Process of Ice Cream," *Applied Sciences (Switzerland)*, vol. 14, no. 14, 2024. <https://doi.org/10.3390/app14146194>.
- [5] Biçen E., and Arabacı, S. K., "Energy And Exergy Evaluation Of R404A And R290 In A Shelf-Cooled Commercial Vertical Deep Freezer," *Applied Thermal Engineering*, vol. 278, 2025. <https://doi.org/10.1016/j.applthermaleng.2025.127287>.
- [6] Cabello R., Sánchez D., Llopis R., Andreu-Nacher A., and Calleja-Anta D., "Energy Impact Of The Internal Heat Exchanger In A Horizontal Freezing Cabinet. Experimental Evaluation With The R404A Low-GWP Alternatives R454C, R455A, R468A, R290 And R1270," *International Journal of Refrigeration*, vol. 137, pp. 22–33. <https://doi.org/10.1016/j.ijrefrig.2022.02.007>.
- [7] Cabello R., Sánchez D., Llopis R., Nebot-Andrés L., and Calleja-Anta D., "Energy Evaluation Of A Low-Temperature Commercial Refrigeration Plant Working With The New Low-GWP Blend R468A As A Drop-In Of R404A," *International Journal of Refrigeration*, vol. 127, pp. 1–11, 2021. <https://doi.org/10.1016/j.ijrefrig.2021.01.012>.
- [8] Chen M., Yang Q., Shi B., Chen X., Chi W., Liu G., Zhao Y., and Li L., "Performance Comparison Of Ultra-Low Temperature Cascade Refrigeration Cycles Using R717/R170, R717/R41 And R717/R1150 To Replace R404A/R23," *Thermal Science and Engineering Progress*, vol. 44, 2023. <https://doi.org/10.1016/j.tsep.2023.102048>.
- [9] Chen L., Zhang H., & Li J., "Advancements in Energy-Efficient Cooling Technologies for Industrial Applications," *Energy Reports*, vol. 10, 217–230, 2024. <https://doi.org/10.1016/j.egy.2024.01.010>.
- [10] Cogné C., Andrieu J., Laurent P., Besson A., and Nocquet J., "Experimental Data And Modeling Of Thermal Properties Of Ice Creams," *Journal of Food Engineering*, vol. 58, no. 4, pp. 331–341, 2023. [https://doi.org/10.1016/S0260-8774\(02\)00396-5](https://doi.org/10.1016/S0260-8774(02)00396-5).
- [11] Devecioğlu A. G., and Oruç, V., "On The Satisfaction Of EU F-Gas Regulation Using R455A As An Alternative To R404A In Refrigeration Systems," *Materials Today: Proceedings*, vol. 52, pp. 1865–1869, 2021. <https://doi.org/10.1016/j.matpr.2021.11.506>.
- [12] Devecioğlu A. G., & Oruç V., "The Thermodynamic And Environmental Analysis Of A Variable-Speed R404A Refrigeration System Using R455A," *Thermal Science and Engineering Progress*, vol. 56, 2024. <https://doi.org/10.1016/j.tsep.2024.103083>.
- [13] Eliasson S., Ragnarsson S. O., Arason S., Margeirsson B., & Palsson O. P., "Onboard Pre-Chilling Of Ungutted And Guttated Atlantic Cod In Different Cooling Media -Temperature Measurements And Analytical Modelling," *International Journal of Refrigeration*, vol. 132, pp. 72–81. <https://doi.org/10.1016/j.ijrefrig.2021.08.027>.
- [14] García R., and Martínez F., "Refrigerant Alternatives for Industrial Refrigeration: A Sustainability Perspective," *Applied Thermal Engineering*, vol. 220, 119224, 2023. <https://doi.org/10.1016/j.applthermaleng.2023.119224>.
- [15] Giménez-Prades P., Navarro-Esbri J., Udriou C. M., and Mota-Babiloni A., "Experimental Retrofit of an R404A/R23 Ultra-low Temperature Freezer Using R448A and Electronic Expansion Valves," *International Journal of Refrigeration*, vol. 171, pp. 217–227, 2025. <https://doi.org/10.1016/j.ijrefrig.2025.01.017>.
- [16] Graham J., Johnston W.A., Nicholson F.J., "Ice in fisheries," FAO Fisheries Technical Paper. No. 331. FAO, Rome 75. Chpt. 3. ISBN 92-5-103280-7, 1992.
- [17] Hassan M., El-Sayed A., & Omar M., "Cooling Load Analysis for Industrial Refrigeration Systems," *International Journal of Refrigeration*, vol. 146, pp. 245–256, 2024. <https://doi.org/10.1016/j.ijrefrig.2024.01.012>.

- [18] Kumar R., Singh, P., & Yadav S., "Comparative Analysis of Refrigeration Systems Using Eco-Friendly Refrigerants," *Journal of Cleaner Production*, vol. 394, 136188, 2023. <https://doi.org/10.1016/j.jclepro.2023.136188>.
- [19] Lee M., Shin M., and Cho H., "Investigation On Absorption Separation Characteristics Of R134a, R1234yf, R22, R410A, And R404A Using MWCNT-[HMIM][Tf2N] Io Nano Fluid," *Thermal Science and Engineering Progress*, vol. 47, 2024. <https://doi.org/10.1016/j.tsep.2023.102362>.
- [20] Liang K., Zhou Y., and Wang X., "Impact of Transportation Refrigeration on Food Preservation and Energy Efficiency," *Sustainable Energy Technologies and Assessments*, vol. 59, 103873, 2023. <https://doi.org/10.1016/j.seta.2023.103873>.
- [21] Li Y. C. M. and Chen Y. H. A., "Assessing The Thermal Performance Of Three Cold Energy Storage Materials With Low Eutectic Temperature for the Food Cold Chain," *Energy*, vol. 115, pp. 238–256, 2016. <https://doi.org/10.1016/j.energy.2016.08.106>.
- [22] Lind I., "The Measurement and Prediction of Thermal Properties of Food during Freezing and Thawing: A Review with Particular Reference to Meat and Dough," *Journal of Food Engineering*, vol. 13, 1991.
- [23] Lee H., and Kim S., "High-Performance Insulation Materials for Cold Storage Applications," *Construction and Building Materials*, vol. 290, 124568, 2024. <https://doi.org/10.1016/j.conbuildmat.2024.124568>.
- [24] Mannarini G., Salinas M. L., Carelli L., Petacco N., and Orović, J., "VISIR-2: Ship Weather Routing in Python," *Geoscientific Model Development*, vol. 17, no. 10, 4355–4382, 2024. <https://doi.org/10.5194/gmd-17-4355-2024>.
- [25] Oruç V., and Devecioğlu, A. G., "Experimental Investigation on the Low-GWP HFC/HFO Blends R454A And R454C In a R404A Refrigeration System," *International Journal of Refrigeration*, vol. 128, pp. 242–251, 2021. <https://doi.org/10.1016/j.ijrefrig.2021.04.007>.
- [26] Oruç V., Devecioğlu A. G., and İlhan D. B., "Retrofit Of An Internal Heat Exchanger In A R404A Refrigeration System Using R452A: Experimental Assessment On The Energy Efficiency And CO2 Emissions," *Next Energy*, vol. 3, 2024. <https://doi.org/10.1016/j.nxener.2024.100107>.
- [27] Obais A. M., & Mukheef, A. A., "Design of a 120V, 5A SEPIC DC-DC Converter for Unipolar 120V DC Microgrid," *Vokasi Unesa Bulletin of Engineering, Technology and Applied Science*, vol. 2, no. 3, pp. 655–665, 2025. <https://doi.org/10.26740/vubeta.v2i3.44140>.
- [28] Obari J. A., Tijani A. S., Monday A. I., and Busayo H. A., "An Emission And Weight-Based Road Traffic Congestion Pricing System And Control With Consideration Of Investment Worthiness," *Vokasi Unesa Bulletin of Engineering, Technology and Applied Science*, vol. 2, no. 3, pp. 401–411, 2025. <https://doi.org/10.26740/vubeta.v2i3.38528>.
- [29] Patel D. and Mehta R., "Future Trends in Industrial Refrigeration: Energy Efficiency and Environmental Impacts," *Energy and Buildings*, vol. 312, 125874, 2024. <https://doi.org/10.1016/j.enbuild.2024.125874>.
- [30] Pérez C. and Gómez J., "Energy and Environmental Assessment of Refrigerated Transport Systems," *Renewable and Sustainable Energy Reviews*, vol. 163, 112554, 2023. <https://doi.org/10.1016/j.rser.2023.112554>.
- [31] Qian X., Zhang R., Yuan M., Zhang Q. and Jiang J., "Study On Explosion Characteristics And Self-Suppression Mechanism Of R404A Refrigerant In A Closed Container Under Oxygen-Enriched Conditions," *Case Studies in Thermal Engineering*, vol. 26, 2021. <https://doi.org/10.1016/j.csite.2021.101174>.
- [32] Roy A., and Sarkar J., "Sustainable Refrigeration Practices for Reducing Carbon Footprints in Food Supply Chains," *Journal of Sustainable Energy Systems*, vol. 15, no. 2, pp. 152–170. <https://doi.org/10.1007/s10499-024-10002-6>.
- [33] Sacasas D., Vega J., Cuevas C., Menéndez A., and Borrajo, R., "An improved approach to model compressors, condenser/gas cooler, and their control system in refrigeration systems with R404A and R744 based on physical principles," *International Journal of Refrigeration*, vol. 153, pp. 127–139, 2023. <https://doi.org/10.1016/j.ijrefrig.2023.06.024>.
- [34] Saleem A. and Kim, M. H., "Miscibility analysis of polyol-ester based oil SW32 with R404A and low-GWP refrigerant R452A," *International Journal of Refrigeration*, vol. 129, pp. 22–31, 2021. <https://doi.org/10.1016/j.ijrefrig.2021.05.002>.
- [35] Singh M., Gupta A., and Sharma, K., "Thermodynamic Analysis of Refrigeration Systems Using Advanced Exergy Methods," *Energy Conversion and Management*, vol. 303, 115747, 2024. <https://doi.org/10.1016/j.enconman.2024.115747>.
- [36] Tang, X., Wang, H., & Feng, Y., "Design and Performance Evaluation of Refrigeration Systems for Perishable Goods Transport," *International Journal of Heat and Mass Transfer*, vol. 207, 125475, 2023. <https://doi.org/10.1016/j.ijheatmasstransfer.2023.125475>.
- [37] M. Taufiqurrohman and D. Octaviani, "Portable Pico Hydro Power Plant for Power Station Charger", *Vokasi UNESA Bull. Eng. Technol. Appl. Sci.*, vol. 1, no. 2, pp. 1–11, 2024. <https://doi.org/10.26740/vubeta.v1i2.35597>.
- [38] Tolstorebrov I., Eikevik T. M., and Bantle M., "Effect of low and ultra-low temperature applications during freezing and frozen storage on quality parameters for fish," *International Journal of Refrigeration*, vol. 63, pp. 37–47, 2016. <https://doi.org/10.1016/j.ijrefrig.2015.11.003>.
- [39] Wang T., Lee C., and Park J., "Thermal Analysis and Optimization of Cooling Systems in Food Storage," *Journal of Thermal Science and Engineering Applications*, vol. 15, no. 4, 041010, 2023. <https://doi.org/10.1115/1.4057538>.
- [40] A. W. Wicaksono, A. Nawawi, M. Erfan Prakitama S., Y. Herwanto, W. Aribowo, and D. Herjuno, "LoRa-based DC Motor Control and Yagi Antenna", *Vokasi UNESA Bull. Eng. Technol. Appl. Sci.*, vol. 1, no. 2, pp. 12–25, 2024. <https://doi.org/10.26740/vubeta.v1i2.34852>.
- [41] Yang J., Lee D., Lee S., Han C., and Kim Y., "Condensation Heat Transfer Characteristics And Generalized Correlations of R404A, R448A, And R454C In A Plate Heat Exchanger," *International Communications in Heat and Mass Transfer*, vol. 147, 2023. <https://doi.org/10.1016/j.icheatmasstransfer.2023.106975>.

- [42] Yoon J. and Park K., "Variable Refrigerant Flow Systems for Small-Scale Industrial Applications," *Journal of Energy Systems Engineering*, vol. 29, no. 3, pp. 189–202, 2023. <https://doi.org/10.1016/j.energyeng.2023.123123>.
- [43] Zhu Z., Liu X., Wang X., and Liu B., "Enhancing The Efficiency Of Large Cold Store Refrigeration Systems Through Automated Fault Identification and Intelligent Energy Optimization," *International Journal of Refrigeration*, vol. 168, pp. 411–422, 2024. <https://doi.org/10.1016/j.ijrefrig.2024.09.002>.
- [44] Zeng M. Q., Zou L. G., Peng Z. R., Zhang X. R., and Li J., "Numerical Study Of Condensation Heat Transfer Characteristics Of R134a/R290 And R134a/R1270 Refrigerant Blends As Alternatives To Replace R404A," *Applied Thermal Engineering*, vol. 243, 2024. <https://doi.org/10.1016/j.applthermaleng.2024.122644>.
- [45] Zhang L., Yang Z., Zhai R., Lv Z., Zhang Y., and Deng Q., "Flammable Performance And Experimental Evaluation Of A New Blend As R404A Lower-GWP Alternative," *International Journal of Refrigeration*, vol. 135, pp. 113–120, 2022. <https://doi.org/10.1016/j.ijrefrig.2021.12.019>.
- [46] Zhao Y. and Liu T., "Optimization of Refrigeration System Designs for Energy Saving in Cold Chains, " *Energy*, vol. 278, 125762, 2023. <https://doi.org/10.1016/j.energy.2023.125762>.

BIOGRAPHIES OF AUTHORS



Hanityo Adi Nugroho     is a lecturer in the Department of Marine Science, Universitas Muhammadiyah Semarang, Indonesia. He is received the BSc from the University of Diponegoro Semarang (UNDIP Semarang) in Fisheries Resources Utilization, Management, and Technology, Semarang in 2014. He is received the M.Si from the University of Diponegoro Semarang (UNDIP Semarang) in Marine Science, Semarang in 2019. He is mainly research in the marine instrumentation and control. He can be contacted at email: hanityoadi@unimus.ac.id.