Development of an Energy-Conversion Fish Cooling Unit for Small-Scale Fishing Vessels

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Abstract

Small-scale fishing vessels frequently operate without reliable onboard cooling, exposing the catch to rapid quality deterioration before landing. This study developed UNIBOX, a compact fish-cooling unit that converts fishing-vessel engine rotation into electrical energy for refrigeration and auxiliary monitoring. The development adopted an industry-university co-design process comprising needs mapping, mechanical and thermal design, material selection, fabrication, subsystem integration, functional verification, and field implementation. The prototype has a 100 L cooling capacity, overall dimensions of 97 cm × 62 cm × 80 cm, a mass of 55 kg, and a specified operating temperature range of -7 °C to 10 °C. Mechanical power is transferred through a 1:2 sprocket-chain system to a 460 W generator, buffered by a 12 V 75 Ah LiFePO4 battery, while the maximum cooling-system consumption is approximately 200 W. Nominal calculations indicate a 260 W generation margin, a generation-to-load ratio of 2.30, a gross battery energy of 900 Wh, and an ideal backup duration of 4.5 h at maximum load before conversion and battery-use losses. Three units were fabricated and implemented on traditional fishing boats. The main contribution is the integration of compact refrigeration, engine-coupled electricity generation, battery buffering, sonar display, and local monitoring in a field-deployable platform for small-scale fishers. Future work must quantify cooling-down time, coefficient of performance, temperature uniformity, vibration durability, and fish-quality retention under controlled operating cycles.

Keywords: *Cold chain; Energy conversion; Fish cooling; Small-scale fisheries; Technology transfer*

1. Introduction

Fresh fish is highly perishable because biochemical, microbial, and physical changes begin immediately after capture. The rate of deterioration is strongly influenced by the delay before chilling, the storage temperature, temperature fluctuation, hygiene, and mechanical handling. Studies of chilled and frozen fish consistently identify temperature management as a central requirement for retaining sensory, chemical, and microbiological quality [1]-[3]. Consequently, the cold chain should ideally begin on board, rather than after the vessel reaches the landing site.

This requirement is difficult to achieve in many small-scale fisheries. Small fishing boats have limited deck area, modest electrical capacity, high exposure to vibration and seawater, and strict constraints on equipment weight and cost. Post-harvest surveys have shown that the absence of accessible cold storage is a major cause of quality loss among artisanal and commercial fishers [4], while value-chain studies identify inadequate cold-chain infrastructure as a recurring barrier to market access and product value [5], [12]. These constraints create a practical engineering gap: conventional fish holds or shore-based cold rooms are too large, while domestic refrigerators are not designed for marine vibration, salt exposure, restricted power, or vessel integration.

Several engineering approaches have been reported. Siahaan et al. developed a 35 L refrigeration machine for small fishing vessels and reported a coefficient of performance of 2.42 with an electrical power requirement of 507 W during load cooling [6]. Budiyanto et al. evaluated a modular fish hold for a 30 GT fishing vessel, demonstrating the importance of air distribution and cooling-time evaluation at a larger vessel scale [7]. Other researchers have integrated cyber-physical monitoring into fishing-vessel refrigeration to improve temperature supervision and control [8]. At the system level, Xu et al. reviewed engine-waste-heat-driven refrigeration and emphasized the energy-saving potential of recovering onboard engine energy, although adsorption, absorption, and ejector systems remain relatively complex for small traditional vessels [9].

The development reported here addresses a different scale and integration problem. UNIBOX was conceived as a portable 100 L unit for traditional fishing boats. Rather than introducing a new refrigeration cycle, the engineering novelty lies in combining four functions in one field-deployable platform: (1) compact refrigerated storage, (2) mechanical-to-electrical energy conversion from the vessel engine, (3) battery buffering and electrical distribution, and (4) local monitoring and auxiliary functions, including sonar, temperature, battery, voltage, and lighting displays. This integration is relevant because a refrigeration unit may be thermally adequate but operationally unusable when the vessel cannot supply stable electrical power.

The objective of this study was therefore to design, fabricate, and implement an engine-coupled fish-cooling unit for small-scale fishing vessels and to evaluate its engineering feasibility using technical specifications, nominal power-balance calculations, prototype realization, and field deployment. The study also positions the design against previously reported vessel refrigeration systems and identifies the remaining performance tests required before commercial replication.

2. Method

2.1. Development Framework

The study used a design-and-development method implemented through collaboration between Institut Teknologi Adhi Tama Surabaya and CV Anugerah Teknik. The development sequence is shown in Figure 1. The process began with mapping operational constraints on traditional fishing vessels, including restricted deck space, exposure to seawater, dependence on the main engine, and the need for simple operation and maintenance. The resulting requirements were translated into mechanical, thermal, electrical, and user-interface specifications.

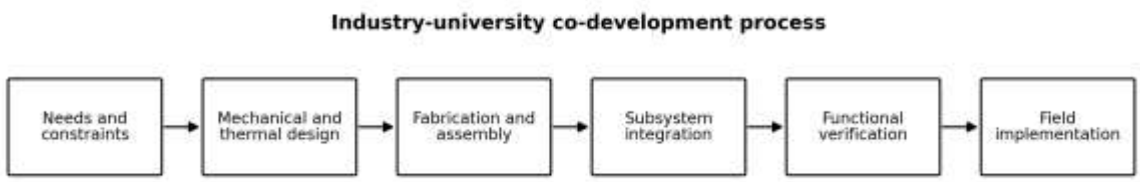

Figure 1. Industry-university development stages for the UNIBOX prototype

The engineering stages consisted of: (1) needs and constraint mapping with the industrial partner and prospective users; (2) design of the frame, enclosure, cooling chamber, transmission, electrical system, and user interface; (3) procurement and fabrication of the body and supporting components; (4) assembly and integration of the cooling, power-generation, battery, monitoring, and lighting subsystems; (5) limited functional verification and design revision; and (6) implementation in an actual small-boat operating environment. Three identical prototype units were produced to verify manufacturability and repeatability.

2.2. Design Requirements and System Architecture

The design requirements were established from the operational problem and the available components. The unit was required to provide approximately 100 L of cooled storage, operate from a power source derived from the vessel engine, include energy buffering for transient operation, remain movable on shore, and provide operators with basic status information. Table 1 summarizes the principal requirements.

Table 1. Principal design requirements

Design aspect	Requirement	Engineering rationale
Storage volume	100 L	Sufficient for temporary onboard storage while retaining portability.
Temperature range	-7 °C to 10 °C	Supports chilled storage and limited sub-zero operation depending on catch and duty cycle.
Electrical demand	≤ 200 W nominal maximum	Compatible with a compact engine-coupled generator and battery buffer.
Power generation	460 W nameplate	Provides nominal capacity above the cooling and auxiliary loads.
Energy buffer	LiFePO4, 12 V, 75 Ah	Improves voltage stability and enables temporary operation when engine-derived power is unavailable.
Marine integration	Compact frame and enclosed body	Reduces deck-space demand and protects components from incidental exposure.
Operator interface	LCD, sonar, and LED lighting	Provides local information on temperature, electrical status, and fishing support.

Figure 2 presents the integrated energy architecture. Mechanical rotation from the fishing-vessel engine is transmitted through a sprocket-and-chain arrangement with a 1:2 ratio to a generator. Generated power is routed through charging and control components to a 12 V LiFePO4 battery. Power conditioning then supplies the cooling system and auxiliary loads. The battery is not treated as an unlimited primary source; it functions as a buffer for startup, transient load, and short periods when the mechanical input is unavailable.

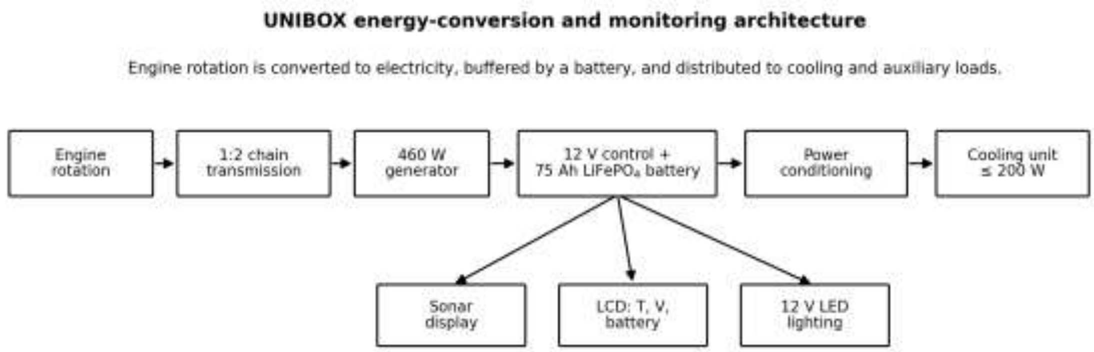

Figure 2. Energy-conversion, storage, cooling, and monitoring architecture.

2.3. Nominal Power and Battery Calculations

Because detailed time-series measurements were not available in the final implementation report, the present evaluation uses conservative nameplate calculations. The nominal power margin, generation-to-load ratio, gross battery energy, and ideal backup duration were calculated using Equations (1)-(4). These equations indicate basic feasibility but do not replace measurements of generator efficiency, inverter efficiency, battery depth of discharge, compressor cycling, starting current, and thermal load.

$$P_m = P_g - P_L \quad (1)$$

$$R_p = P_g / P_L \quad (2)$$

$$E_b = V_b \, C_b \tag{3}$$

$$t_{ideal} = E_b / P_L \tag{4}$$

In these equations, P_m is the nominal power margin, P_g is generator nameplate power, P_L is the maximum specified electrical load, R_p is the power-capacity ratio, E_b is gross battery energy, V_b is battery voltage, C_b is battery capacity, and t_{ideal} is the ideal backup duration. All calculated results are interpreted as design estimates rather than measured operating performance.

2.4. Fabrication and Functional Verification

The enclosure was manufactured from stainless-steel plate and acrylic components, supported by a 30 mm × 30 mm × 1.2 mm hollow-section frame. Fabrication included cutting, welding, acrylic forming, finishing, mounting of the cooling components, installation of the generator and transmission, electrical wiring, and integration of the display and auxiliary systems. Functional verification checked physical assembly, subsystem activation, temperature indication, battery and voltage display, lighting, generator coupling, and operation in the intended boat environment. The verification was limited to confirming integrated function and field deployability; it did not include a standardized thermal pull-down test, calorimetric load test, coefficient-of-performance measurement, or controlled fish shelf-life experiment.

3. Results and Discussion

3.1. Prototype Configuration and Technical Specifications

The completed UNIBOX is a compact, wheeled enclosure with an integrated cooling chamber, engine-coupled generator, battery, control components, and operator displays. The finished unit measures 97 cm × 62 cm × 80 cm and has an empty mass of approximately 55 kg. Its 100 L capacity is substantially larger than the 35 L prototype reported for a small fishing-vessel refrigeration machine in [6], while its specified maximum consumption of approximately 200 W is lower than the 507 W reported during the earlier system test. This comparison should be interpreted cautiously because the two systems have different cooling loads, component arrangements, test procedures, and reported performance metrics.

Table 2. Technical specification of the UNIBOX prototype

No.	Parameter	Specification
1	Overall dimensions	97 cm × 62 cm × 80 cm
2	Empty mass	55 kg
3	Cooling volume	100 L
4	Body material	Stainless-steel plate and acrylic
5	Frame material	30 mm × 30 mm × 1.2 mm hollow section
6	Finishing	Paint and clear coating; white frost color
7	Specified cooling temperature	-7 °C to 10 °C
8	Operating supply	220 V AC, 50 Hz
9	Maximum specified consumption	Approximately 200 W
10	Mechanical power conversion	Vessel-engine rotation to generator
11	Transmission	Sprocket and chain, 1:2 ratio
12	Generator nameplate output	460 W
13	Battery	LiFePO4, 12 V, 75 Ah
14	Electrical output	12 V DC and conditioned 220 V AC
15	Sonar display	Digital display for fish-position distribution
16	Status display	3.2 in LCD for temperature, battery, and voltage
17	Lighting	12 V, 12 W LED strip

No.	Parameter	Specification
18	Mobility	3.5 in caster wheels

The design temperature range extends from sub-zero operation to chilled storage. However, a specified set point is not equivalent to a verified product-core temperature or uniform chamber temperature. For fish-preservation claims, future testing should record air temperature at multiple locations, product-core temperature, pull-down time, compressor duty cycle, door-opening recovery, ambient temperature, and catch mass. Fish freshness should then be evaluated using sensory, chemical, microbial, or sensor-based indicators as discussed in [1]-[3].

3.2. Nominal Energy Adequacy

The nominal calculations are summarized in Table 3. A 460 W generator supplying a maximum specified load of 200 W provides a nameplate margin of 260 W and a generation-to-load ratio of 2.30. This ratio is encouraging because it allows capacity for charging and auxiliary loads. Nevertheless, it must not be interpreted as a measured net surplus. Mechanical transmission losses, generator efficiency, charge-controller losses, power-conditioning losses, battery charging current, compressor starting current, and environmental derating reduce the usable margin.

Table 3. Nominal power-balance and battery estimates

Indicator	Calculation	Result	Interpretation
Nominal power margin	460 - 200	260 W	Nameplate capacity remaining before losses and auxiliary demand.
Generation-to-load ratio	460 / 200	2.30	Generator rating is 2.3 times the specified maximum cooling load.
Gross battery energy	12 × 75	900 Wh	Theoretical stored energy based on nominal voltage and capacity.
Ideal backup duration	900 / 200	4.5 h	Upper-bound estimate before conversion loss, depth-of-discharge limit, and cycling.

The gross battery energy is 900 Wh, producing an ideal 4.5 h duration at a continuous 200 W load. In actual marine operation, the usable duration will be lower because LiFePO4 batteries should be operated within defined state-of-charge limits and the power path includes conversion losses. Conversely, compressor cycling may reduce the time-averaged demand after the chamber reaches its set point. A realistic endurance test should therefore log voltage, current, state of charge, compressor state, generator speed, and chamber temperature throughout a complete fishing cycle.

The engine-coupled approach offers a practical middle ground between direct dependence on shore charging and thermally driven refrigeration systems. Waste-heat-driven adsorption or absorption systems can recover low-grade heat and reduce electrical demand [9], but their component count, heat exchangers, working-fluid management, and marine stability requirements can be difficult to accommodate on traditional boats. UNIBOX instead converts available mechanical rotation into electricity using familiar transmission and electrical components. The trade-off is that electrical conversion introduces several efficiency stages and requires protection against belt or chain misalignment, overspeed, corrosion, and electrical short circuits.

3.3. Prototype Realization and Field Implementation

Three UNIBOX units were fabricated, assembled, and implemented in the intended operating environment. Figure 3 documents installation and handling on traditional fishing boats. The field photographs confirm that the prototype can be positioned within the limited space of small wooden vessels and that the integrated enclosure can be transported and accessed by operators. This is an important result because laboratory-only refrigeration prototypes may fail when confronted with real deck geometry, vessel motion, splash exposure, engine placement, and fishing-gear interference.

Figure 3. Field implementation of UNIBOX on traditional fishing boats

The prototype also incorporates a sonar display and a 3.2 in LCD for temperature, battery, and voltage information. Monitoring is increasingly relevant in vessel refrigeration because temperature data can reveal equipment malfunction and support corrective action [8]. However, the current implementation should be considered a local indication system rather than a validated cyber-physical monitoring platform. Future versions should store time-stamped data, include alarm limits, provide sensor calibration records, and protect electronics against moisture and electromagnetic interference.

From a manufacturability perspective, producing three units demonstrates that the design can be repeated beyond a single proof-of-concept assembly. The collaboration with an industrial partner also enabled the design to be translated into workshop operations, tooling, procurement, assembly, and documentation. The program produced a user manual, trademark registration, a submitted simple-patent application, and a product-certification submission. These outcomes strengthen technology-transfer readiness, but they do not substitute for technical certification, safety testing, reliability testing, and market validation.

3.4. Comparative Positioning and Engineering Contribution

Table 4 positions UNIBOX against representative previous work. The comparison shows that the principal contribution is system integration for the small traditional-vessel context. The unit is not intended to outperform a large modular fish hold in absolute cooling capacity, nor does the present study claim a new refrigeration thermodynamic cycle. Its contribution is to package storage, cooling, mechanical-to-electrical generation, battery buffering, local monitoring, sonar, and lighting into one compact prototype that has been fabricated in multiple units and placed on operating boats.

Table 4. Positioning against representative fishing-vessel refrigeration studies

Study/system	Application scale	Reported focus	Position relative to UNIBOX
Siahaan et al. [6]	Small vessel; 35 L	Load-cooling test, COP 2.42, 507 W	Provides measured refrigeration performance; smaller storage volume and higher reported test power.
Budiyanto et al. [7]	30 GT vessel fish hold	Cooling performance and modular fish-hold arrangement	Addresses a larger vessel and hold-scale system rather than a portable traditional-boat unit.
Suhengki et al. [8]	Fishing-vessel refrigeration	IoT/CPS monitoring and temperature-sensor comparison	Stronger data-monitoring focus; UNIBOX currently uses local display without validated remote monitoring.
Xu et al. [9]	Fishing vessels; system review	Exhaust-heat-driven adsorption, absorption, and ejector refrigeration	Higher thermodynamic integration potential but greater complexity for very small vessels.

Study/system	Application scale	Reported focus	Position relative to UNIBOX
UNIBOX	Traditional small fishing boat; 100 L	Integrated cooling, engine-coupled generator, battery, sonar, display, and field deployment	Integration-oriented prototype; detailed thermal and durability testing remains necessary.

A key limitation is the absence of standardized quantitative performance data. The report confirms successful fabrication, integration, and field implementation, but it does not provide temperature-time curves, product loads, ambient conditions, electrical measurements, COP, noise, vibration, corrosion exposure, or fish-quality indicators. Therefore, the present paper deliberately limits its conclusions to engineering development and nominal feasibility.

The future work will be using a factorial or response-surface test program covering catch mass, initial fish temperature, ambient temperature, engine speed, battery state of charge, and set point. Primary responses should include pull-down time, spatial temperature variation, average electrical demand, generator output, energy consumption per kilogram of fish, and COP. A parallel fish-quality study will also be conducted to measure sensory score, pH, total volatile basic nitrogen, microbial count, texture, and mass loss over storage time. Vibration and salt-spray tests are also necessary because the practical value of a small-vessel refrigeration unit depends as much on reliability and maintainability as on initial cooling performance.

4. Conclusion

UNIBOX was developed as a compact, engine-coupled fish-cooling platform for small-scale fishing vessels. The 100 L unit integrates a -7 °C to 10 °C specified cooling range, a 460 W generator driven through a 1:2 sprocket-chain transmission, a 12 V 75 Ah $LiFePO_4$ battery, an approximately 200 W maximum specified load, local electrical and temperature display, sonar, and lighting. Nominal calculations yield a 260 W nameplate margin, a generation-to-load ratio of 2.30, 900 Wh of gross battery energy, and an ideal 4.5 h backup duration at maximum load. Three prototypes were manufactured and implemented on traditional boats, demonstrating physical integration and repeatable production. The study contribution is the integration of cooling, power conversion, buffering, and monitoring for a small-vessel environment. The prototype should not yet be treated as a fully validated commercial refrigeration product because standardized thermal, electrical, reliability, safety, and fish-quality tests remain outstanding. These will be done for the future works.

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