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Design and Thermal Performance Analysis of a Multilayer Coolbox with Polyurethane as the Primary Insulation for Portable Fish-Hold Applications

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ABSTRACT: Post-harvest handling of fresh fish by small-scale fishermen is highly dependent on effective temperature control to minimize quality deterioration during storage and transportation. This study aimed to design, fabricate, and evaluate the thermal performance of a 70-L portable coolbox using rigid polyurethane foam as the primary thermal insulation material. The coolbox was constructed using a 3-cm-thick multilayer composite wall consisting of fiberglass (1.0 cm), meranti plywood (0.5 cm), aluminum foil (0.5 cm), and rigid polyurethane foam (1.0 cm). A rubber sealing strip and clamp locks were incorporated to reduce heat infiltration through the lid interface. Thermal performance was evaluated experimentally over 168 h under two loading conditions: 30 kg of block ice and a combination of 30 kg of block ice and 20 kg of fresh fish. A one-dimensional steady-state heat conduction model was also applied to estimate the thermal resistance and equivalent thermal conductivity of the composite wall. The results yielded a total thermal resistance of 0.4291 K/W and an equivalent thermal conductivity of 0.0606 W/(m·K). Polyurethane contributed approximately 84.15% of the total thermal resistance, indicating that it was the dominant insulating layer in the composite structure. During the first 72 h, the internal temperature remained within approximately 0–4 °C under both loading conditions. After 72 h, the internal temperature gradually increased as the ice load decreased, reaching 18–19 °C by the seventh day. The total material cost for fabricating one prototype was IDR 1,445,000. These findings indicate that the multilayer polyurethane-based coolbox can provide effective passive thermal insulation for short-term chilled fish storage in small-scale fishing operations.

KEYWORDS: Coolbox; Polyurethane Foam; Thermal Insulation; Post-Harvest Handling; Fish Storage.

I. INTRODUCTION

Fish is a highly perishable food commodity that undergoes quality deterioration after capture as a result of enzymatic, oxidative, and microbiological processes. Consequently, temperature control from the initial handling stage on board fishing vessels through distribution is an essential component of the fishery cold chain. Cold-chain management is not only important for maintaining product quality and safety but also affects supply-chain efficiency, economic value, and the reduction of post-harvest losses[1],[2]. Studies of fishery supply chains have shown that inadequate temperature control can accelerate quality deterioration and increase the risk of product losses, particularly in supply chains with limited refrigeration infrastructure[2],[3].

Ice-based cooling remains one of the most widely applied methods for handling fresh fish because it is relatively simple, inexpensive, and suitable for fishing vessels with limited access to electrical energy. Previous studies have demonstrated that storage temperature, storage duration, ice quantity, and product characteristics are important factors governing the rate of quality deterioration during storage [4],[5]. The Codex Code of Practice for Fish and Fishery Products also identifies temperature control as a fundamental principle in fish handling and preservation [6]. In Indonesia, the quality requirements for fresh fish are specified in SNI 2729:2021 [5]. Therefore, the ability of a storage container to maintain a sufficiently low temperature is an important design parameter for fish-handling systems.

In small-scale fisheries, coolboxes are commonly used to store ice and catch because their relatively simple construction can be adapted to the limited space available on fishing vessels. Various approaches have been developed to improve portable coolboxes for supporting the cold chain in small-scale fisheries, including active cooling systems and combinations of different insulation materials [7],[8]. Recent research on coolboxes incorporating combinations of aluminum, aluminum foil, EVA, and fiberglass has demonstrated that wall-material configurations can affect cooling rates and temperature stability during storage

[9]. Other studies in small-scale fisheries have also indicated that insulation-material selection is an important factor influencing coolbox thermal performance [8].

From a thermal perspective, the ability of an insulated container to maintain a low internal temperature is governed by its resistance to heat transfer through the walls, base, lid, and structural joints. Thermal models of multilayer boxes indicate that conduction and radiation can contribute substantially to product temperature changes, while reflective layers can reduce radiative heat transfer within the storage system [10]. Experimental and numerical investigations of insulated boxes have also demonstrated that one-dimensional models can be used to estimate key parameters such as product temperature changes and ice-melting duration, although actual operating conditions may deviate from the model because of three-dimensional heat transfer and uncontrolled environmental conditions [11]. These findings highlight the importance of combining theoretical thermal analysis with experimental prototype testing.

Polyurethane foam is widely used as a thermal insulation material because of its cellular structure and relatively low thermal conductivity. The thermal properties of polyurethane are affected by cell structure, cell size, density, blowing-agent characteristics, temperature, moisture content, and aging conditions [12],[13]. Experimental investigations have demonstrated that the thermal conductivity of polyurethane can vary with temperature and moisture; therefore, the use of a single thermal-conductivity value in a thermal model should be regarded as an approximation under specific operating conditions [14]. Studies of rigid polyurethane cellular structures have also reported relationships between cell characteristics, density, and thermal insulation performance [15]. Therefore, the design of polyurethane-based coolboxes should consider not only the material type but also its thickness and configuration within the composite wall structure.

Multilayer configurations may provide additional advantages because each layer can perform a different function, including insulation, structural reinforcement, mechanical protection, and radiation control. In multilayer boxes, reflective layers can reduce radiative heat transfer within the storage space [10]. Polyurethane, meanwhile, functions primarily as the layer providing dominant resistance to conductive heat transfer. Research on polymeric insulation materials has demonstrated the potential of polymer foams as thermal insulators [16], while recent studies have confirmed the continuing importance of polyurethane for thermal insulation applications [14][17],[15]. Nevertheless, the overall performance of an insulated system remains dependent on its structural configuration and environmental operating conditions.

In addition to its initial thermal properties, the environmental durability of polyurethane should also be considered. Exposure to water and aging processes can alter the cellular structure and physical properties of polyurethane [18]. Water absorption and freeze–thaw cycling may increase the effective thermal conductivity of polyurethane insulation materials [19]. More recent research has also shown that changes in the gas composition within polyurethane cells during aging can increase thermal conductivity and consequently reduce insulation performance [20]. These factors are particularly relevant to fisheries applications because coolboxes may be exposed to high humidity and marine environments during operation.

Research on polyurethane for cold-storage applications has also expanded through its integration with thermal energy storage materials, particularly phase change materials (PCMs). Previous studies have indicated that combining insulation with thermal energy storage can reduce heat loads and extend the duration of temperature control [21],[22]. However, such approaches generally require additional materials and more complex configurations. For small-scale fisheries, passive systems with simple construction remain practically attractive because they do not require continuous electrical power and can be relatively easy to maintain.

From the perspective of fish quality, temperature control is particularly important because temperature fluctuations can accelerate microbiological and chemical deterioration during storage. Previous studies have shown that temperature and storage duration influence fish quality changes and shelf life [23],[24],[25],[26]. Recent research on grouper has demonstrated that temperature variations during chilled storage can accelerate deterioration and affect microbial communities [26]. Other studies have shown that ice storage can delay post-harvest quality deterioration compared with storage at higher temperatures [27]. Consequently, evaluating the ability of a coolbox to maintain temperatures around 4 °C for a defined period is directly relevant to fresh-fish handling.

Although research on coolboxes, insulation materials, and fish-cooling systems has continued to develop, studies integrating polyurethane as the primary insulation layer within a multilayer wall configuration for portable fishing-vessel coolboxes, combined with composite thermal-resistance analysis and multi-day experimental testing, remain limited. Previous studies have primarily focused on the development of coolboxes using specific materials, heat-transfer modeling of insulated boxes, or characterization of the thermal properties of individual materials [7],[11]. Recent studies have also investigated alternative insulation materials, such as nipa palm fiber and EPS, as well as aluminum–EVA coolbox configurations [8],[9]. However, there remains a need to

evaluate multilayer polyurethane-based coolboxes designed specifically for the operational requirements of small-scale fishermen and analyzed using a composite thermal-resistance approach.

Based on this research gap, this study aimed to: (1) design and fabricate a multilayer coolbox using polyurethane as the primary insulation material for portable fish-hold applications; (2) calculate the thermal resistance and equivalent thermal conductivity of the composite wall using a one-dimensional conductive heat-transfer model; (3) evaluate internal temperature changes over 168 h under ice-only and ice–fish loading conditions; and (4) determine the material cost required to fabricate the prototype as an initial assessment of its affordability.

II. MATERIALS AND METHODS

A. Research Design and Study Location

This study employed a quantitative experimental approach consisting of three main stages: prototype design and fabrication, theoretical thermal analysis, and experimental thermal-performance testing. Preliminary observations concerning fish-storage requirements were conducted at Karangsong Fishing Port, Indramayu, West Java, Indonesia. Prototype fabrication was carried out at the PT Waluya Wijaya Workshop, Bogor, West Java. Thermal testing was conducted for 168 h (7 days) under two loading conditions: (i) 30 kg of block ice and (ii) 30 kg of block ice combined with 20 kg of fresh fish. The primary measured responses were internal coolbox temperature and ambient temperature.

B. Material Specifications and Composite Wall Configuration

The prototype was designed with an internal storage volume of approximately 70 L, with internal dimensions of 50 cm × 40 cm × 35 cm and external dimensions of 56 cm × 41 cm × 43 cm. The total wall thickness was approximately 3 cm (0.03 m) and consisted of a multilayer composite sandwich structure. as shown in the following image.

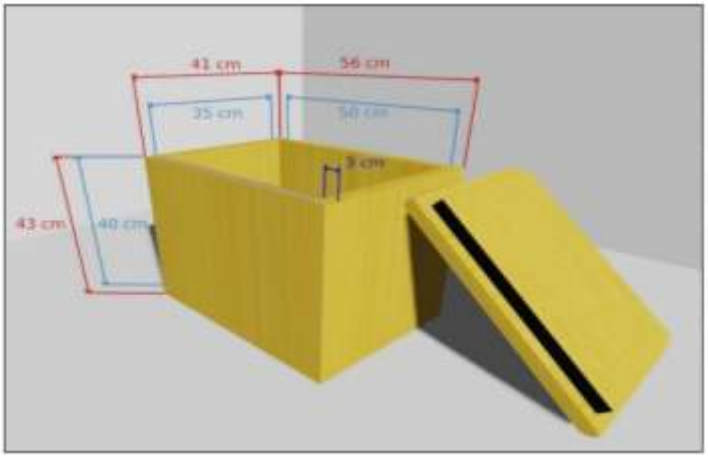


Figure 1. Coolbox prototype

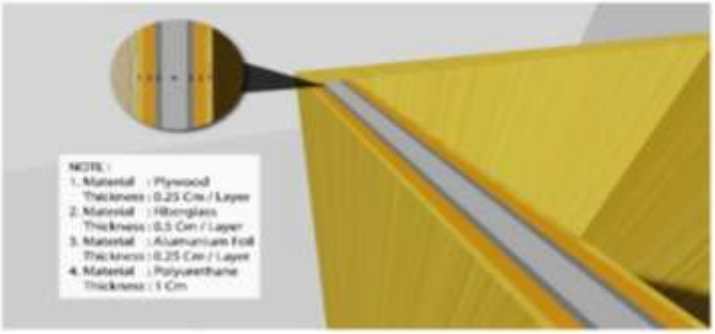


Figure 2. Material Specifications

The wall configuration from the outer to the inner side consisted of four principal material layers:

1. Outer fiberglass shell: A 1.0-cm-thick fiber-reinforced plastic (FRP) layer fabricated using chopped-strand fiberglass mat combined with an unsaturated polyester-resin matrix, talc powder filler, methyl ethyl ketone peroxide (MEKPO) catalyst, and a glossy gelcoat finishing layer.

2. Structural plywood layer: A 0.5-cm-thick meranti plywood layer used to provide mechanical stiffness and dimensional stability to the frame.
3. Aluminum foil layer: An aluminum foil layer with a nominal thickness of 0.5 cm, incorporated as a reflective barrier intended to reduce thermal radiation from solar exposure and the external environment.
4. Primary rigid polyurethane insulation layer: A 1.0-cm-thick rigid polyurethane foam layer produced by mixing Polyol A and Isocyanate D at a 1:1 ratio.

A rubber sealing strip with a total length of 6 m was installed around the lid interface and secured using two clamp locks to minimize potential air leakage through the lid joints.

Table 1. Multilayer Composite Coolbox Wall Configuration

Layer	Material	Thickness (cm)	Thermal Conductivity (W/m.K)
Outer Side	Fiberglass (FRP)	1.0	K1 = 0.250
	Plywood	0.5	K2 = 0.130
	Alumunium Foil	0.5	K3 = 205.0
Inner Side	Polyurethane Foam	1.0	K4 = 0.024

The thermal-conductivity values listed in Table 1 were used as parameters in the theoretical model. The polyurethane thermal-conductivity value was adopted from reported experimental characteristics of polyurethane foams [15],[16]. Because the actual thermal conductivity of polyurethane can be affected by density, cellular structure, temperature, and moisture content, the value used in the model should be regarded as an estimated parameter rather than a direct measurement of the fabricated prototype.

C. Prototype Fabrication Materials and Procedure

The principal fabrication materials consisted of polyurethane, meranti plywood, aluminum foil, fiberglass, polyester resin, MEKPO catalyst, talc powder, pigment/gelcoat, rubber sealing material, and clamp locks. The fabrication process was conducted through the following stages.

1. Frame Cutting and Assembly. The plywood sheets were cut according to the specified dimensions and assembled using nails and structural adhesive to form the outer and inner wall cavities.
2. Installation of the Reflective Barrier and Polyurethane Foam. The external surfaces of the wooden frame were covered with aluminum foil. Polyurethane components consisting of Polyol A and Isocyanate D were mechanically mixed for approximately 2 min until homogeneous. The mixture was then poured into the wall cavity and allowed to expand and cure for approximately 3–6 h.
3. Joint Filling and FRP Lamination. All wall joints and gaps were filled using polyester putty (Sanpolac). The external surfaces were subsequently covered with two layers of fiberglass mat impregnated with polyester resin and MEKPO catalyst.
4. Finishing and Sealing. The external surface was coated with yellow gelcoat to provide UV protection and improve the surface finish. The final stage involved installing the rubber sealing strip along the lid-contact line and attaching the clamp locks.

The rubber sealing strip and clamp locks were treated as components intended to reduce air leakage at the lid interface. Their individual effectiveness was not quantified because air-infiltration rates were not measured experimentally.

D. Mathematical Formulation of Multilayer Heat Conduction

Heat transfer through the composite coolbox wall was analyzed using the one-dimensional steady-state form of Fourier's law. Heat flow was assumed to occur perpendicular to the plane of the composite wall.

1. Total Thermal Resistance (R_{Total})

A composite wall acts as an arrangement of thermal resistances in series. The total conductive thermal resistance (R_{Total}, K/W) is calculated using Equation (1):

$$R_{total} = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} \frac{x_i}{k_i \cdot A} = \frac{1}{A}\left(\frac{x_{FRP}}{k_{FRP}} + \frac{x_{ply}}{k_{ply}} + \frac{x_{Al}}{k_{Al}} + \frac{x_{PU}}{k_{PU}}\right)$$

Where:

- x_i = Thickness of layer (i)
- k_i= Thermal conductivity of layer (i) *(W/m.K)*
- A = Effective heat-transfer area of the coolbox wall *(m^2)*

2. Equivalent Thermal Conductivity *(k_{eq})*

The equivalent average thermal conductivity value $(k_{eq}, \frac{W}{m}.K)$ of the entire multilayer composite wall structure is calculated using Equation (2):

$$k_{eq} = \frac{x_{total}}{\sum_{i=1}^{n} \frac{x_i}{k_i}} = \frac{x_{FRP} + x_{ply} + x_{Al} + x_{PU}}{\frac{x_{FRP}}{k_{FRP}} + \frac{x_{ply}}{k_{ply}} + \frac{x_{Al}}{k_{Al}} + \frac{x_{PU}}{k_{PU}}}$$

3. Heat Transfer Rate and Heat Flux

The rate of conductive heat flow (Q, Watt atau J/s) rom the external environment into the cold storage space is determined based on the temperature difference between the external environment (T_{out}) and the internal temperature (T_{in}) in accordance with Equation (3):

$$Q = \frac{T_{out} - T_{in}}{R_{total}} = \frac{A \cdot (T_{out} - T_{in})}{\sum_{i=1}^{n} \frac{x_i}{k_i}}$$

Heat flux (q,W/m^2) or the rate of heat transfer per unit area is calculated using Equation (4):

$$q = \frac{Q}{A} = \frac{T_{out} - T_{in}}{\sum_{i=1}^{n} \frac{x_i}{k_i}}$$

4. Theoretical Ice-Melting Rate (m_{ice})

The heat entering the coolbox was assumed to be consumed by the melting of ice at approximately (0°C). The theoretical ice melting rate (m_{ice} , kg/s) was formulated using the latent heat of fusion of ice ($h_{sf} \approx 334.000$ J/kg) through Equation (5):

$$m_{ice} = \frac{Q}{h_{sf}} = \frac{A \cdot (T_{out} - T_{in})}{h_{sf} \cdot \sum_{i=1}^{n} \frac{x_i}{k_i}}$$

The total mass of melted ice (M_{melt},,kg) over a specific time period (Δt hour, second) is obtained by integrating the conductive heat flow rate with respect to time:

$$M_{melt} = \frac{1}{h_{sf}} \int_0^t Q\,(t)\,s$$

E. Thermal Testing and Data Collection

Thermal insulation performance was experimentally evaluated over 168 h (7 days). Internal coolbox temperature (T_{in}) and ambient external temperature (T_{out}) were recorded at 24-h intervals. Therefore, the experiment should be interpreted as a periodic temperature-monitoring procedure rather than continuous temperature logging. Temperature measurements were obtained using an HTC-2 digital thermometer equipped with a wired temperature probe. Two operational loading conditions were investigated:

1. Condition I – Ice-only loading: The coolbox was loaded with 30 kg of block ice to evaluate its ability to maintain a low internal temperature under ice-only conditions.
2. Condition II – Ice and fresh-fish loading: The coolbox was loaded with 30 kg of block ice and 20 kg of fresh fish, corresponding to an ice-to-fish mass ratio of 1.5:1, to simulate a practical post-harvest fish-handling condition.

The thermal-performance criterion was defined as the ability of the coolbox to maintain an internal temperature within the 0–4 °C range during the relevant storage period.

III. RESULTS AND DISCUSSION

A. Numerical Analysis of Heat Transfer through the Multilayer Composite Wall

The wall structure of a 70-liter capacity coolbox—with interior dimensions of 50 cm x 40 cm x 35 cm and exterior dimensions of 56 cm x 41 cm x 43 cm—was analyzed using a one-dimensional (1D) steady-state heat conduction approach. The composite wall has a total thickness of x_{total} =0.03 m (3 cm) and is composed of four materials: Fiberglass (x_{FRP} = 0.010 m), Plywood (x_{ply} = 0.005 m), Aluminum Foil (x_{Al} = 0.005 m), and Rigid Polyurethane Foam (x_{PU} = 0.010 m). The average heat transfer surface area of the composite wall was calculated to be A ≈ 1.154 m².

1. Specific Thermal Resistance and Total Resistance (R_{Total})

The thermal conductivity value of each material is determined based on technical literature standards: $k_{FRP} = 0.250$ W/m · K, $k_{ply} = 0.130$ W/m · K, $k_{Al} = 205.0$ W/m · K, and $k_{PU} = 0.024$ W/m · K. Specific thermal resistance per unit area ($R_i' = \frac{x_i}{k_i}$) for each layer is calculated as follows:

- **Fiberglass Layer (FRP):**

$$R_{FRP}{}' = \frac{0{,}010 \text{ m}}{0{,}250 \text{ W/m} \cdot \text{K}} = 0{,}0400 \text{ m}^2 \cdot \text{K/W} \quad (8{,}08\%)$$

- **Layer Plywood:**

$$R_{ply}{}' = \frac{0{,}005 \text{ m}}{0{,}130 \text{ W/m} \cdot \text{K}} = 0{,}0385 \text{ m}^2 \cdot \text{K/W} \quad (7{,}77\%)$$

- **Layer Alumunium Foil:**

$$R_{Al}{}' = \frac{0{,}005 \text{ m}}{205{,}0 \text{ W/m} \cdot \text{K}} = 0{,}000024 \text{ m}^2 \cdot \text{K/W} \quad (0{,}005\%)$$

- **Layer Polyurethane (PU):**

$$R_{PU}{}' = \frac{0{,}010 \text{ m}}{0{,}024 \text{ W/m} \cdot \text{K}} = 0{,}4167 \text{ m}^2 \cdot \text{K/W} \quad (84{,}15\%)$$

The total specific thermal resistance of the composite is:

$$\sum_{i=1}^{4} \frac{x_i}{k_i} = 0.0400 + 0.0385 + 0.000024 + 0.4167 = 0.4952 \text{ m}^2 \cdot \text{K/W}$$

Calculation results indicate that the polyurethane foam layer contributes 84.15% of the wall's total thermal resistance, demonstrating its crucial role as the primary insulator in retarding heat transfer.

Total conductive thermal resistance of the coolbox wall. (R_{total}) with extensive $A = 1.154$ m^2 amounting to:

$$R_{total} = \frac{\sum \frac{x_i}{k_i}}{A} = \frac{0{,}4952 \text{ m}^2 \cdot \text{K/W}}{1{,}154 \text{ m}^2} = 0{,}4291 \text{ K/W}$$

2. Equivalent Thermal Conductivity (k_{eq})

Equivalent thermal conductivity (k_{eq}) of the entire 3 cm-thick multilayer composite wall structure is formulated as:

$$k_{eq} = \frac{x_{total}}{\sum_{i=1}^{4} \frac{x_i}{k_i}} = \frac{0{,}030 \text{ m}}{0{,}4952 \text{ m}^2 \cdot \text{K/W}} = 0{,}0606 \text{ W/m} \cdot \text{K}$$

This $k_{eq} = 0{,}0606$ W/m · K is significantly lower than the thermal conductivity of single-material walls such as plywood ($0{,}130$ W/m · K) or *fiberglass* $0{,}250$ W/m · K), thereby confirming the effectiveness of combining highly insulating materials.

3. Heat Flux (q), Heat penetration rate (Q), and Ice Melting Rate (m_{ice})

Under initial operating conditions with an external ambient temperature of T_{out} = 26,5°C and an internal temperature of T_{in} = 0,15°C (ΔT = 26,35 K the conductive heat flow rate (Q) and heat flux (q) passing through the wall are calculated as follows:

$$Q = \frac{\Delta T}{R_{total}} = \frac{26{,}35 \text{ K}}{0{,}4291 \text{ K/W}} = 61{,}41 \text{ Watt} \quad \text{(Joule/second)}$$

$$q = \frac{Q}{A} = \frac{61{,}41 \text{ W}}{1{,}154 \text{ m}^2} = 53{,}22 \text{ W/m}^2$$

The theoretical ice melting rate (m_{ice}) resulting from that conductive heat penetration, given the latent heat of fusion of ice $h_{sf} = 334.000$ J/kg is:

$$m_{ice} = \frac{Q}{h_{sf}} = \frac{61{,}41 \text{ J/s}}{334.000 \text{ J/kg}} = 1{,}838 \times 10^{-4} \text{ kg/second} = 0{,}662 \text{ kg/hour} \approx 15{,}89 \text{ kg/day}$$

B. Results of 7-Day (168-Hour) Empirical Thermal Testing)

Thermal insulation performance testing was conducted over a period of 7 days (168 hours), with daily temperature data recorded for two loading variations: Variation 1 (30 kg of ice) and Variation 2 (30 kg of ice + 20 kg of fish). A summary of the test results is presented in Table 2.

Table 2. Summary of Coolbox Internal Temperature T_{in} and Ambient TemperatureT_{out} Testing Over 7 Days.

Days	Duration (hour)	Variation 1		Variation 2		Freshness Quality Criteria (Ideal Temperature: 0–4°C)
		T_{in} (°C)	T_{out}(°C)	T_{in}(°C)	T_{out}(°C)	
1	24	0,2	26,0	0,1	26,9	Compliant with Standards
2	48	2,3	26,0	2,5	28,0	Compliant with Standards
3	72	3,7	27,0	4,0	27,0	Compliant with Standards (Maximum Limit)
4	96	4,5	26,0	6,2	25,0	Exceeding the Limit of Tolerance

5	120	7,7	27,0	7,9	27,0	Experiencing a Decline in Quality
6	144	12,0	26,0	11,0	26,0	Accelerated Decay
7	168	19,0	27,0	18,0	27,5	Ice Melts Perfectly

Visualization of the trend of changes in internal temperature against external environmental temperature is presented in Figure 1.

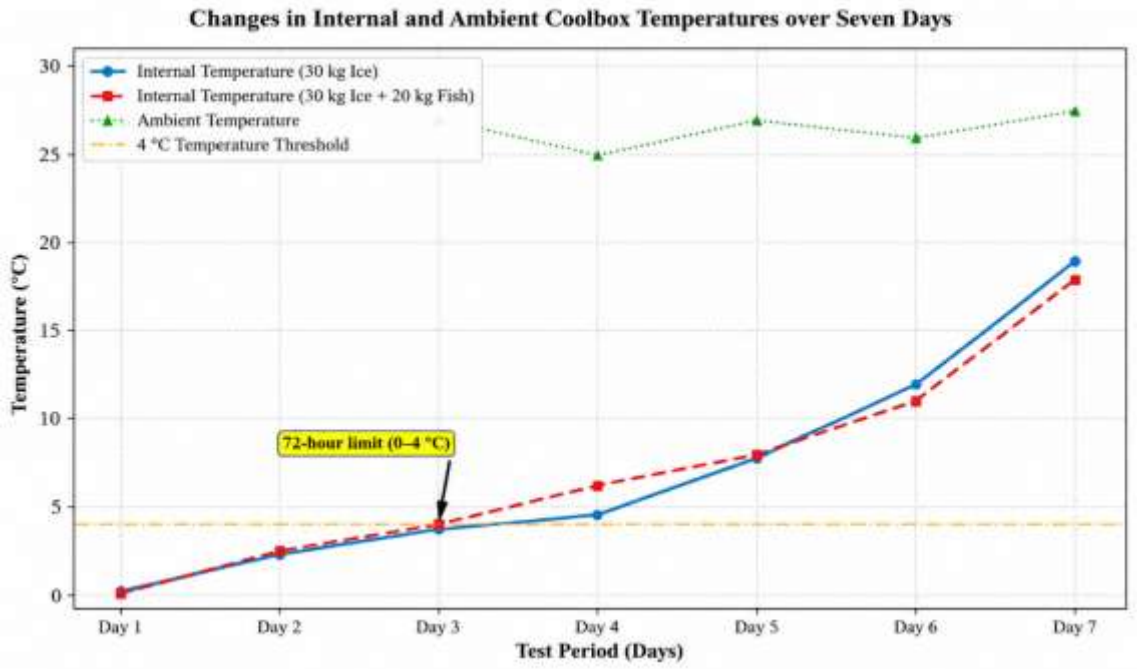


Figure 1. Graph of Coolbox Internal and Ambient Temperature Changes (7 Days)

It can be observed from Figure 1 and Table 1 that during the first 72 hours (Day 1 to Day 3), the polyurethane-based composite coolbox was able to maintain the internal storage temperature within the 0.1°C to 4°C range with great stability. This temperature range represents the ideal critical zone for inhibiting the growth rate of spoilage bacteria and preserving the biochemical freshness of the fish tissue. By Day 4 (96 hours), the internal temperature began to exceed 4°C (4.5°C for Variation 1 and 6.2°C for Variation 2) due to the reduction in the remaining ice mass. By Day 7 (168 hours), the ice had completely melted, causing the internal temperature to approach the ambient temperature (18–19°C).

C. Discussion on Thermal Insulation Performance and Heat Leakage (Thermal Bridging)

Experimental results demonstrate that using a 1 cm thick layer of polyurethane foam (70% density) combined with a multi-layered structure provides superior thermal insulation compared to commercial coolers made of synthetic foam (Styrofoam/EPS). Installing a 6-meter rubber seal along the contact line between the lid and the body, along with two locking clamps, proved effective in minimizing the influx of hot air (thermal leakage).

However, a comparison between the theoretical estimated ice melting rate (15.89 kg/day) and the empirical experimental results reveals a discrepancy. This is attributed to several real-world thermal phenomena:

1. Thermal Bridging: Cold energy still transfers to the outer walls, particularly at corners and panel joints that are not perfectly insulated by the polyurethane.
2. External Convective and Radiative Heat Transfer: The Fourier-based theoretical model accounts only for pure steady-state conduction, whereas actual conditions involve the external air convection heat transfer coefficient (h_{outrp}) and ambient thermal radiation, both of which increase the inward heat flux.
3. Ice Shrinkage and Internal Air Voids: As the ice melts, internal air gaps form within the cooler; these increase internal convective resistance but reduce the direct contact area between the ice and the contents.

D. Material Cost Analysis and Economic Feasibility

The total material cost required to fabricate one unit of the 70-liter capacity polyurethane composite coolbox prototype is Rp1,445,000. The production cost breakdown is presented in Table 2.

Table 3. Coolbox Fabrication Material Cost Budget Details.

No	Material	Quantity	Unit Price (IDR)	Total Cost (IDR)	Percentage (%)
1	Polyurethane (Polyol A + Isocyanate D)1213	6 Liter	95.000	570.000	39,45
2	Rubber Shield212	6 Meter	35.000	210.000	14,53
3	Resin Polyester1214	6 Liter	30.000	180.000	12,46
4	Chopped Strand Mat1215	4 kg	40.000	160.000	11,07
5	Gelcoat Yellow1216	1 Paket	20.000	100.000	6,92
6	MEKPO1217	1 Liter	65.000	65.000	4,50
7	Clamp Lock212	2 Buah	50.000	50.000	3,46
8	Meranti Plywood Board1218	1 Lembar	40.000	40.000	2,77
9	Aluminium Foil1219	1 Roll	35.000	35.000	2,42
10	Talc Powder (Filler)1220	5 kg	7.000	35.000	2,42
TOTAL				**1.445.000**	**100%**

As shown in Table 3, the polyurethane component represents the largest share of material investment (39.45%). Although the initial cost appears higher than that of standard Styrofoam coolboxes, the ability to extend ice retention up to 72 hours (3 days) results in a 50–60% saving on daily block ice purchases for one-day fishing operations. Consequently, the investment in manufacturing these portable polyurethane composite fish holds demonstrates high economic viability and operational durability for adoption by small-scale fishing communities.

IV. CONCLUSIONS

Based on the design, thermal modeling, and experimental testing of the portable hold-style coolbox prototype, several conclusions were drawn. A 70-liter capacity multi-layer composite coolbox prototype (with internal dimensions of 50 cm x 40 cm x 35 cm) was successfully designed and fabricated using 1 cm thick rigid polyurethane foam (70% density) as the primary insulation core. The 3 cm thick multi-layer wall configuration—integrating fiberglass (FRP), plywood, aluminum foil, and polyurethane, and equipped with a rubber seal and clamp lock—produced a robust, airtight thermal insulation system.

Numerical analysis indicated a total wall thermal resistance (R-total) of 0.4291 K/W and an equivalent thermal conductivity (keq) of 0.0606 W/m.K, with polyurethane contributing the largest share of resistance at 84.15%. Empirically, the coolbox proved highly effective at maintaining cold storage temperatures within the critical 0°C to 4°C range for 72 hours (3 days), whether tested with pure ice cubes or a mixture of ice cubes (30 kg) and fresh fish (20 kg).

The total raw material cost for manufacturing a single prototype unit was Rp1,445,000. This three-day thermal insulation performance effectively slows the rate of ice melting, thereby improving cost-efficiency regarding ice purchases for daily fishing operations.

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