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Design system and performance analysis of fish storage box by utilizing solar energy

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ABSTRACT

Indonesia is a maritime country and many people work as traditional fishermen. Traditional fishermen generally use thermos filled with wet ice, ice boxes, or ice blocks to maintain the freshness of fish. The temperature obtained is still insufficient to maintain the fish's quality and freshness. Furthermore, some existing technologies are expensive and use fossil fuels. Researchers designed and manufactured a cool box that utilizes solar energy to store fish. The experimental research method was conducted by testing the performance of the cool box device at four different locations. The results showed that the solar panel produced an average of 2,527.2 W of energy in a day, which can power the cool box device for 10 hours. To maintain the fish's freshness with the reference temperature of 0-5 °C, the device uses temperature control to prevent the fish from freezing, which damages its structure. The temperature control also helps the tool save energy, allowing it to last 170 minutes longer than without using the temperature control feature.

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1. INTRODUCTION

Fish is a food requirement that is a source of protein and nutrients that is widely consumed by the public [1]. Based on Food and Agriculture Organization (FAO) data, the growth in world fish consumption has currently reached 20.5 kg per capita [2]. One country that has large fisheries resources is the Republic of Indonesia which has a vast maritime area, its sea area reaches 5.4 million km^2 [3]. Indonesia has around 8,500 types of fish [4] and based on data from The Ministry of Maritime Affairs and Fisheries (KKP) in the Republic of Indonesia in 2020, they have reported that the country produced 23.16 million tons of fish, with around 8 million tons (33.26%) coming from fisheries that caught in the sea. The amount of fish caught has been increasing every year due to rising export demands and public consumption [5].

Indonesia's abundant marine wealth makes many residents work as fishermen, including traditional fishermen [6]. Traditional fishermen use simple fishing technology. Operational cruising capability is limited to the waters around coastal areas, this condition makes it impossible for them to have a refrigerator [7]. Many traditional fishermen employ the simple method to preserve the freshness of their caught fish. Usually, traditional fishermen implement cooling techniques by using ice boxes or ice cubes. This method can help maintain fish freshness, but it does not completely kill the bacteria and stop enzymatic activity [8]. The fundamental purpose of fish refrigeration is to slow down bacterial metabolism, prevent bacterial growth, and ensure that the fish does not rot or deteriorate [9]. Storing fish with wet ice, ice boxes, or ice blocks in a cool box or conventional thermos is ineffective because the ice melts quickly. Traditional fishermen often spend the whole day at sea with a limited supply of wet ice. The weight, cost, and dimensions of ice make it very difficult to carry a lot of ice on fishing vessels, so the fish they catch can experience a decline in freshness quality [10]. Sometimes, traditional fishermen also add salt to the wet ice and fish to preserve the fish for longer, but this can change the taste of the fish, making it saltier, which is not a good concept [11].

Indonesia's fishing industry is facing a quality issue despite an increase in production. Usually, the fish caught are often stored for several hours in the fishermen's boat cargo, which leads to a decrease in the freshness of the fish. As a result, the quality of the fish caught does not match up with the increased production [12]. Fish have a water content that is quite high, reaching 60-70%, this makes the fish quickly undergo a rotting process [13], [14]. Fish that are no longer fresh have a lower price than fish that are still fresh [15], [16]. Concrete evidence can be seen in several types of fish in markets in Lampung [17], Kulon Progo [18], and Ambon [19], the price of fish that is no longer fresh can drop to half the normal price. The reality of this condition also occurs for fishermen in Glagah Beach, Jatimalang Beach, Baru Beach, and Logending Beach. Many of the fish brought by fishermen from the sea are not yet fresh. When the fish is on land for several hours, the price of the fish decreases drastically because the quality decreases.

On the other hand, there is refrigerated sea water (RSW) as a cooling technology that uses a mechanical refrigeration system to preserve the fish. The technology employs low temperatures to inhibit enzyme and microbial activity [20]. Refrigeration will extend the shelf life of fish. At a temperature of 15-20 °C, fish can be stored for up to about two days, at a temperature of 5 °C fish will last for 5-6 days. The temperature commonly maintained during the fish storage process ranges from 0-5 °C because fish will be fresh for 9-14 days [21]. The RSW technology, while promising, comes with a hefty investment cost for its initial setup, operation, and maintenance. Moreover, using non-environmentally friendly fossil fuels to operate is also a weakness of this technology [22]. In addition, Indonesia has excellent potential for renewable energy, particularly solar energy, owing to its geography and natural conditions. However, the potential of solar energy has not been utilized optimally due to the limited availability of energy conversion technologies [23], [24]. To address this issue, researchers are planning to design and manufacture a solar-powered fish storage device. This research developed a solar-powered fish cooling system as an affordable, environmentally friendly, and efficient solution to maintain the freshness of fish caught by traditional fishermen. It utilizes the abundant renewable energy in Indonesia to overcome the challenges of preserving fish quality during fishing trips at sea. This system is more sustainable compared to conventional cooling systems that use fossil fuels, with affordable investment and operational costs for traditional fishermen.

2. PROPOSED METHOD

Cool boxes are insulated boxes used to store food or to store materials that require other cold conditions such as fish, juice, vaccines, blood, and so on [25]. The cool box innovation technology that will be made has the main components in the form of solar photovoltaic, thermoelectric cooler (TEC), charge controller, Arduino UNO, and shock device. To utilize solar energy, in this study, the cool box developed will use solar photovoltaic. This component uses the sun directly as an alternative energy source to replace fossil energy that can be stored in batteries [26]-[28]. The energy conversion system converts solar energy into electricity by using semiconductors, the conductivity of semiconductors widely known as PV cells [29]. Some materials exhibit a property known as the photoelectric effect that causes solar photovoltaics to absorb photons of light and release electrons. When these free electrons are captured, an electric current is generated which can be used as electricity [30]. In general, energy-generating modules are connected in series and parallel to obtain the desired current, voltage, and power values [31]-[33].

The other main components are thermoelectric cooler (TEC) also named Peltier cooler or thermoelectric module. TEC is a semiconductor-based electronic component that works as a heat pump by transferring heat from one side to another side of the device and producing a heating or cooling effect [34]. TEC works with a Peltier effect that transfers heat from one side of the device to the other side [35]-[36]. Researchers chose TEC because TEC has been widely used. Moreover, it has the advantages of being easy to operate and light [37]. In addition, TEC has no moving parts, uses no working fluid, does not involve chemical reactions, and produces no emissions [38], [39]. TEC has seen beck principle, the side of the Peltier element that gets cold or hot depends on the direction of the DC current flowing from the source [40].

Furthermore, this study used a charge controller as an electronic device to regulate the direct current which is charged to the battery and taken from the battery to the load. This tool plays a role in regulating overcharging (excess charging because the battery is fully charged) and excess voltage from certain sources

[41]. Then, the electrical control used in this research is Arduino UNO. It is a microcontroller board based on the ATmega328 [42]. This component can support automatic control of the device and can be connected to a computer using a USB cable [43]. The ATMega328 performs data processing and notifications, commands are displayed on the LCD as notifications via the display layer and a buzzer as a notification indicator [44].

Not only are the main components for cooling fish, but the main component of killing bacteria in fish using electric shock can also be a feature to prevent fish from decay. Electric shock devices can help maintain fish freshness while fishermen are out at sea by using electric shock devices that have a voltage of up to 2,500 volts [45]. A non-thermal food preservation method is to use a high-voltage electric shock, often called a pulsed electric field (PEF). Using electric shocks can help preserve fish and suppress the number of microbes on the fish. From research references, it is proven that there is a significant difference ($P > 0.05$) between untreated samples and treated samples. This indicates that electric shocks of 30-60 kV can suppress the number of bacteria. Higher intensity treatments can be used for the inactivation of microorganisms by irreversible damage to the cell membrane [46]. Although the electric shock can kill bacteria quickly and effectively. However, the use of this electric shock can affect the texture of fish meat because fish meat that is given an electric shock treatment will not be as hard as fish meat without treatment. The higher the voltage applied to the fish can cause the texture value is get lower, although it did not give a difference in the pH, taste, and smell of the fish [47]. Even though it kills bacteria quickly and keeps the fish from rotting quickly, the texture of the fish will be softer than before. Texture is an important parameter for fish meat quality and is vital in product acceptance for consumers [48].

3. RESEARCH METHOD

This study employs an experimental methodology with a quantitative approach to demonstrate the scientific value and measurement strength of the research design and analysis. The research was conducted in four coastal areas in the Republic of Indonesia that have many fishing groups: Kulon Progo, Purwerejo, Bantul, and Kebumen (Special Region of Yogyakarta and Central Java Province). The stages that have been carried out include data collection, idea generation, device design and calculation, collection of tools and materials, device manufacturing, trials, data analysis, and performance evaluation.

During the research, the problems with traditional fish cooling techniques were explored by conducting interviews with fishermen in four different fishing villages. In addition, the researchers searched for relevant materials from trusted sources on fish cooling techniques, photovoltaic calculations, manufacturing techniques, and the power generated by galvanic cells. In the second stage, the collected data was analyzed to find the best solutions to overcome the problems. These ideas were then transformed into an appropriate technology. The third stage involved designing the device using Autodesk Inventor to obtain the optimal system design for cooling fish. The design included a solar photovoltaic as a source of electricity from the sunlight, and galvanic cells that utilize seawater electrolytes. A charge controller regulates the two energy sources to prevent overloading and ensure that the electrical energy produced meets the requirements. The resulting energy is stored in a battery, which powers the thermoelectric cooler to cool the fish in the cool box.

The device creation process starts with analyzing the temperature distribution in the room to determine the placement and quantity of thermoelectric coolers, as well as the dimensions of the cooling room. Following this, the researcher calculates the required photovoltaic power and battery capacity. Once the calculations are finished, the researcher selects the necessary tools and materials based on their price and quality. Essential equipment includes soldering tools, scissors, saws, glue, rulers, hammers, and nails. The materials used in manufacturing the cool box consist of solar photovoltaics for power supply, a charge controller, a battery for energy storage, a TEC thermoelectric cooler for energy conversion, a heat sink, cables, and an LCD display for monitoring battery capacity, temperature, and humidity. This stage is critical for ensuring that the appropriate components and tools are assembled before moving forward with the manufacturing process.

The research was conducted to design, assemble, and test a solar-powered cool box device. The device was designed by integrating solar photovoltaics, a charge controller, battery storage, and a thermoelectric cooler into a cool box unit. The manufacturing process included assembling the solar panels and controller, constructing the cooling chamber with the thermoelectric cooler and heat sink, before assembling all components. The device underwent two trials - a limited lab trial, followed by field trials with fishermen at Glagah, Jatimalang, Baru, and Logending beaches to ensure optimal functioning of the components in real-world conditions for cooling the catch. Afterward, a detailed performance analysis was conducted, including the working system, stability, temperature reduction, cooling time, and impact on fish quality, with results documented. The performance was then evaluated to determine if the device met the research objectives for creating a scientific journal. Based on the evaluation, the researcher would either proceed to make a scientific report and article if deemed feasible or repair and revise the device if not, after re-verifying the design and calculations. Finally, a scientific article was created to report the detailed results from implementing the device, with all activities documented through photos and videos for archiving.

4. RESULTS AND DISCUSSION

4.1. Device working principle

The solar photovoltaic cool box for fish is a hybrid device powered by solar energy, utilizing the Peltier effect on a thermoelectric cooler to chill the caught fish. The design includes a fish storage area (cooling chamber) with a thermoelectric cooler element, a battery as the DC source, and a charge controller for voltage regulation. The cool box is placed on a water-filled block, where seawater guards the temperature difference across the thermoelectric cooler elements. It features temperature, humidity, and weight sensors for technological sophistication. An electric shock system protects fish from bacteria longer than other cooling devices. With a rectangular dimension, this mobile cool box allows fishermen and fish vendors to reduce preservation costs while maintaining freshness as shown in Figure 1.

The cool box is implemented on a traditional fishing boat as shown in Figure 2 the dimensions of this device are 92×50×28 centimeters because it adjusts the width and height of the hull of traditional fishing boats in general. The solar cool box has two working systems: an electric shock system and a solar photovoltaic + thermoelectric cooler system. The electric shock system features a fish shocking process using a 2000 V electrical voltage from a step-up transformer to kill germs and inhibit spoilage, as shown in Figure 3. Following a 10-second shocking process, the fish undergoes cooling within a solar-powered refrigeration unit equipped with a Peltier cooling system, effectively preventing bacterial contamination.

The cool box has a solar photovoltaic and thermoelectric cooler working system. As shown in Figure 4, it absorbs sunlight through a 300 Wp monocrystalline solar photovoltaic panel, converting solar energy into electrical energy to power the cool box. A charge controller regulates the power generated by the solar cells, which is stored in a 12 V 50 Ah battery. This stored power activates the TEC1-12710 thermoelectric cooler, creating a temperature difference between the two plates. The inner plate faces the storage chamber, producing distributed cold temperature, while the outer plate faces a heatsink. Part of the heatsink is submerged in water on a large block, increasing the temperature delta between the thermoelectric cooler's outer and inner sides. If the outside media temperature is very cold, the storage room temperature will be colder. The TEC1-12710 datasheet shows a 35 °C temperature difference between the hot and cold sides of the thermoelectric cooler.

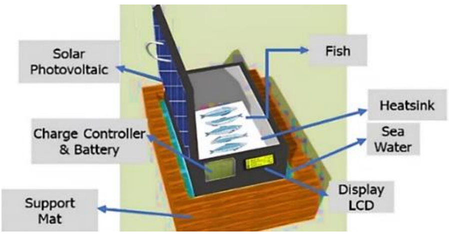

Figure 1. Cool box parts

Figure 2. Cool box implementation

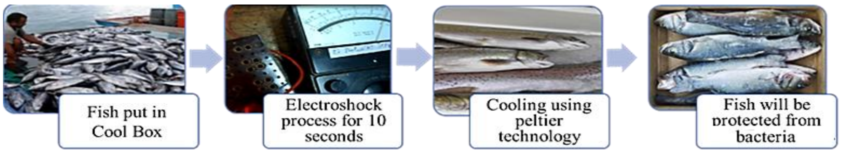

Figure 3. Electric shock system

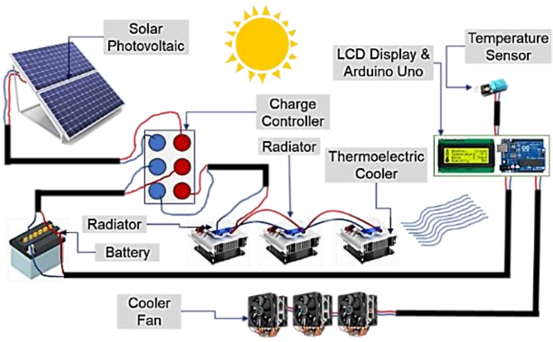

Figure 4. Solar photovoltaic and thermoelectric cooler system

4.2. Calculations on device manufacturing

The average catch of Glagah, Jatimalang, Baru, and Logending Beaches fishermen is 23-30 kilograms of fish per day. Usually, the fish caught are skipjack tuna, banyar fish, milkfish, yellow-tail fish, pomfret, and tuna mackerel. However, the majority of the fish caught were usually dominated by skipjack tuna (*Cakalang*) which had a length of 40cm, a width of 15 cm, a thickness of 6 cm, and an average weight per fish of 600-1000 grams. Assuming the fish caught are of the same size, it can be estimated that the number of fish caught is around 50 fish. Skipjack tuna has a density of about 920 kg/m^3, so the volume of the box required is 0.03261 m^3. Based on the specifications of the cool boxes sold in the market, the size of a fish box that is sufficient is 125 cm long, 90 cm wide, and 60 cm high or in other words has a capacity of 30 kg fish. Based on ASHRAE, product load calculation is the load required to reduce the temperature of the product (fish), then that it can be preserved [49], [50]. This product load calculation uses the (1).

$$Q_{fish} = m_{fish} \, . \, C_{p\,fish} \, . \, \Delta T_{fish}$$

$$Q_{fish} = (30)\times(3{,}550)\times(27.87\text{- }0)$$

$$Q_{fish} = 2{,}968.1 \text{ kJ}$$

$$Q_{product} = \frac{Q_{fish}}{t_{cooling}}$$

$$Q_{product} = \frac{2{,}968.1}{5\times3600} = 0.1648944 \text{ kW}$$

$$Q_{product} = 164.8944 \text{ W/hour} \tag{1}$$

Average catch of fish per day is 30 kg, average fishing time per day is 5 hours. Then, the Cp fish skipjack tuna (*cakalang*) is 3550 J/Kg °K. Average Sea temperature in Yogyakarta is 27.87 °C. Before creating the device, required to calculate transmission load. Transmission load is a load caused by heat losses that occur in cool box walls. Cool Box has dimensions of 125 cm long, 90 cm wide, and 60 cm high. The wall of the cool box is made from a combination of polystyrene (ps) layers, aluminum foil (af), plastic insulator (pi), and wood (w). The heat loss consists of the bottom side, top side, right side, left side, front side, and back side. Regarding the outer wall of cool box, the bottom, right, left, front, and back side are covered with polystyrene (ps), aluminum foil (af), plastic insulator (pi), and wood (w). Meanwhile, the top is covered by polystyrene (ps), aluminum foil (af), and plastic insulator (pi). Heat transfer by convection is negligible because there is no air moving on the wall side of this cool box. Furthermore, the value of heat loss from each wall can be assumed by the calculations in (2) and (3).

- Top side heat loss

$$\frac{1}{U_1} = \frac{d_{ps}}{k_{ps}} + \frac{d_{af}}{k_{af}} + \frac{d_{pi}}{k_{pi}}$$

$$\frac{1}{U_1} = \frac{2{,}1\ x\ 10^{-2}}{3{,}3\ x\ 10^{-2}} + \frac{2\ x\ 10^{-4}}{180} + \frac{3\ x\ 10^{-4}}{0{,}15}$$

$$\frac{1}{U_1} = 1.566 \text{ m}^2\text{K/W}$$

$$U = 0.6385 \text{ w/(m}^2\text{K)} \tag{2}$$

- Bottom, right, left, front, and behind heat loss

$$\frac{1}{U_1} = \frac{d_{ps}}{k_{ps}} + \frac{d_{af}}{k_{af}} + \frac{d_{pi}}{k_{pi}} + \frac{d_w}{k_w}$$

$$\frac{1}{U_1} = \frac{2{,}1x10^{-2}}{3{,}3x10^{-2}} + \frac{2x10^{-4}}{180} + \frac{3x10^{-4}}{0{,}15} + \frac{4x10^{-3}}{0{,}16}$$

$$\frac{1}{U_1} = 1.5074 \text{ m}^2\text{K/W}$$

$$U = 0.6633 \text{ w/(m}^2\text{K)} \tag{3}$$

The ambient temperature of the coastal environment is 38 °C, while the sea temperature is 27.87 °C and the skipjack tuna (*cakalang*) temperature is 27 °C. Then, the total transmission load from each side can be seen in (4)-(7).

- Top side

$$Q_{top} = U_1.A_{top}.(T_{ambient}-T_{fish})$$

$$Q_{top} = 0.6385\times(1.25\times0.9)\times(38-27)$$

$$Q_{top} = 0.6385\times(1.125)\times(11)$$

$$Q_{top} = 8.64\ W \quad (4)$$

- Bottom side

$$Q_{bottom} = U_2.A_{bottom}.(T_{sea}-T_{fish})$$

$$Q_{bottom} = 0.6633\times(1.25\times0.9)\times(27.87-27)$$

$$Q_{bottom} = 0.6633\times(1.125)\times(0.87)$$

$$Q_{bottom} = 0.65\ W \quad (5)$$

- Right and left side

$$Q_{right\ \&\ left} = U_2.A_{right/left}.(T_{ambient}-T_{fish}).2$$

$$Q_{right\ \&\ left} = 0.6633\times(0.6\times0.9)\times(38-27)\ x\ 2$$

$$Q_{right\ \&\ left} = 0.6633\times(0.54)\times(11)\times2$$

$$Q_{right\ \&\ left} = 7.88\ W \quad (6)$$

- Front and behind side

$$Q_{front\ \&\ behind} = U_2.A_{front/behind}.(T_{ambient}-T_{fish}).2$$

$$Q_{front\ \&\ behind} = 0.6633\times(1.25\times0.6)\times(38-27)\times2$$

$$Q_{front\ \&\ behind} = 0.6633\times(0.75)\times(11)\times2$$

$$Q_{front\ \&\ behind} = 11.05\ W \quad (7)$$

Based on the calculations that have been conducted, then add up all the loads according to (8) to become the total of transmission load.

$$Q_{transmission} = Q_{top} + Q_{bottom} + Q_{right\ \&\ left} + Q_{front\ \&\ behind}$$

$$Q_{transmission} = 8.64 + 0.65 + 7.88 + 11.05$$

$$Q_{transmission} = 28.22\ W \quad (8)$$

Furthermore, calculations related to the infiltration load on the cool box device also need to be conducted. The infiltration load is the load caused by the seepage of heat into the cooling chamber. This seepage occurs due to air exchange when the cool box is opened [51]. The air temperature in the cool box is T_R = 0 °C with a relative humidity of 95% and has an enthalpy of $h_{U,R}$ 8.99 Kj/kg. Outside air temperature T_U = 38 °C with a relative humidity of 45% and enthalpy h_U 86.7 kJ/kg. Next, the volume of the cool box (V_{cb}) is 0.675 m^3 because it has 125 cm long, 90 cm wide, and 60 cm high with an air density of 1.34 kg/m^3. The number of air exchanges per day (n) can be calculated by (9).

$n = 3\times V_{cb}$

$n = 3\times 0.675$

$$n = 2.025 \approx 2 \text{ times} \quad (9)$$

The amount of infiltration load can be calculated by the formula in (10).

$$Q_{infiltration} = \frac{P_{U,R}.V_{cb}.(h_u - h_{U,R})n}{24\ x\ 3600}$$

$$Q_{infiltration} = \frac{1.34\times 0.675\times (86.7-8.99)\times 2\times 1000}{66{,}400}$$

$$Q_{infiltration} = \frac{140{,}577}{66{,}400}$$

$$Q_{infiltration} = 2.1171\ W \quad (10)$$

The final calculation required is the total system loss on cool box device. Total system loss is generated by calculating total product load, transmission load, and infiltration load. The equation related to this calculation can be in (11).

$$Q_{system\ loss} = Q_{product} + Q_{transmission} + Q_{infiltration} \quad (11)$$

$$Q_{system\ loss} = 164.8944 + 28.22 + 2.1171 = 195.2315\ W$$

Based on the calculation, the total system loss is 195.2315 W. Furthermore, three thermoelectric coolers with specifications of 12 V and 6 A with a total power of 228 W (76 W/unit) are used. This power is able to handle cool box load power.

4.3. Power generated

In Table 1, it is found that the electrical power produced by solar photovoltaic at four different research locations does not show significant differences. The trial was conducted on four different beaches, such as Glagah Beach, Jatimalang Beach, Baru Beach, and Logending Beach which are in four different cities. The solar photovoltaic power data were taken during the trial by conducting observations and power calculations for nine hours from morning to evening with the detail 7 AM to 4 PM (GMT +7) in sunny weather conditions to get the highest power results that can be produced by solar photovoltaic. Data was collected using a solar cool box device with a 300 Wp solar photovoltaic, yielding an average output of 2527.2 watts per day.

Table 1. Calculation of solar photovoltaic power generated on cool box

Time (hour)	Power (watt)			
	Glagah Beach	Jatimalang Beach	Baru Beach	Logending Beach
07.00 AM	117.9	116.1	117.5	118
08.00 AM	127.7	127.4	128.1	128
09.00 AM	261.8	261.3	260	262.7
10.00 AM	278	278.4	278.5	279
11.00 AM	289	290	290	289
00.00 PM	297	296.6	297	296
01.00 PM	297	295	297	296.4
02.00 PM	293	293.9	294	291.3
03.00 PM	288	290	289.2	288
04.00 PM	277.2	278.3	277.4	278
Total power (watt)	2,526.6	2,527	2,528.7	2,526.4
Average (watt)	2,527.2			

The average energy generated under sunny conditions amounts to 2,527.2 watts. This energy is utilized to power three thermoelectric coolers, collectively consuming 228 watts, as well as supporting components for a 10-hour duration. The energy output during daylight hours proves ample for fishermen preparing to venture out to sea during the night. Nonetheless, in the event of rain throughout the day resulting in an empty battery, fishermen as the user must charge electricity from the grid to recharge it.

4.4. Energy consumption

Figure 5 demonstrates that the cool box device without a temperature control system can only be active for 530 minutes based on the test results using and without using the temperature control system. This limitation arises because employing the thermoelectric cooler (TEC) without control leads the system to either cool below freezing (approximately -4 °C) or operate at maximum power. Conversely, when the control system is implemented, the device can endure for 700 minutes, as the TEC is solely engaged in maintaining the reference temperature. If the temperature falls within the specified range, the thermoelectric component automatically deactivates. This cooling duration proves to be sufficient for beachside fishermen to preserve their catch during standard fishing expeditions.

Consequently, the system using temperature control can run uninterruptedly for over 10 hours. This result is also better than the implementation of conventional ice thermos that use ice cubes. Figure 5 provides a comparison between the device and a conventional ice thermos. Cool box devices equipped with temperature control excel in maintaining a reference temperature range of 4 °C to 5 °C. In contrast, traditional ice flasks can only achieve temperatures as low as 13 °C. These findings affirm that the Cool Box, integrated with temperature control, emerges as the most effective and efficient device.

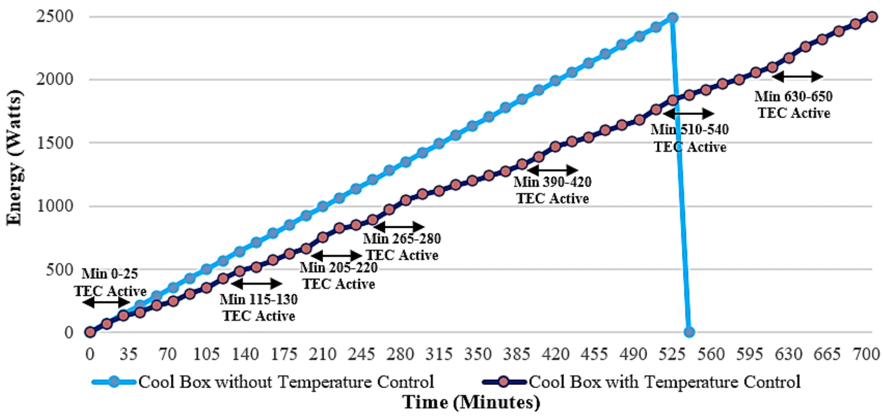

Figure 5. Comparison of energy consumption for solar Cool Box with and without temperature control

4.5. Temperature regression

Various methods are employed to increase the quality value of the fish by controlling storage conditions. Since temperature is the primary factor that affects the value of the catch, it is essential to investigate controlled temperature. Fishermen do not need excessively low or freezing temperatures when storing the fish they catch at sea. Their main goal is to cool the fish to inhibit bacterial growth and preserve its freshness before bringing it to the coastal area or market. The fish they sell are fresh fish, not frozen fish [52]. Fresh fish is deemed to possess higher quality in the market compared to frozen fish, as frozen storage can diminish the protein quality of fish due to denaturation [53]. Previous studies indicate that freezing fish results in short-term physical changes, encompassing weight loss, color alteration, and structural modifications induced by the formation of ice crystals [54], [55]. Preserving fish freshness can be achieved through refrigerated storage within temperatures ranging from 0 °C to 4 °C [56], [57]. Other research suggests that storing fish at 5 °C is also sufficient to maintain freshness [58], [59]. According to references on fresh fish, researchers typically stipulate a reference temperature range of 0-5 °C.

The objective of evaluating the temperature comparison the cool box with temperature control, cool box without temperature control, and conventional ice thermos is to assess the device's effectiveness in cooling fish, aiming to preserve the freshness and quality of the fish captured by fishermen. In the experiment, two variables were considered: temperature, monitored with a temperature sensor, and cooling speed, estimated by observing elapsed time using a timer. Figure 6 illustrates the graph depicting the experimental results. The maximum temperature achievable by a Cool Box device without utilizing temperature control is -4 °C. The research results also show that using a conventional ice thermos filled with ice cubes can only reach a temperature as low as 13 °C. This temperature reduction does not reach the reference temperature so it is not enough to maintain the fish's freshness.

Based on these experiment tests, researchers established a benchmark temperature range of 4–5 °C to regulate the operation of the cool box device. Since the device's temperature has the potential to dip below the freezing point (below 0 °C), the implementation of a temperature control mechanism becomes essential. To maintain the reference temperature stable within the range of 0–5 °C, the cool box device employs an automatic temperature management system. This technique not only conserves energy but also ensures the freshness of the fish by preventing freezing and maintaining the desired temperature. The temperature sensor continuously monitors the storage room, and once it detects a temperature within the reference range of 0-5 °C, the energy supply to the thermoelectric system is automatically cut off. This system can save energy by not needing to be active continuously, maintaining storage temperature stable in the reference temperature. Then, the device can use energy from the battery for more than 170 minutes than the device without temperature control. Conversely, if the temperature surpasses 5 °C, the energy supply to the thermoelectric cooler is automatically activated.

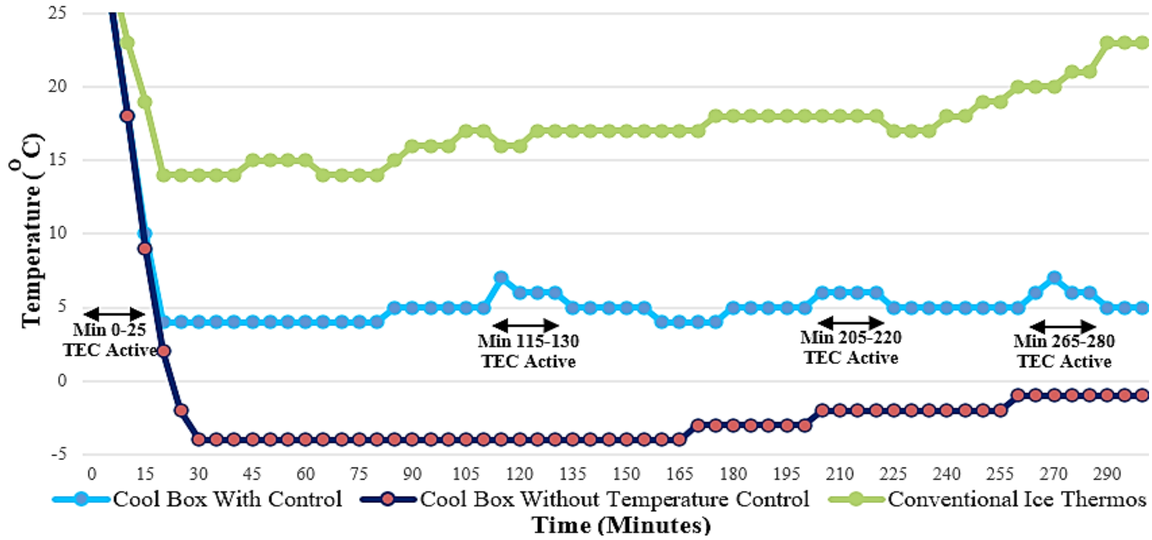

Figure 6. Comparison of energy consumption for solar cool box with and without temperature control

4.6. Maintenance and durability

The solar-powered cool box technology and its related components require routine maintenance to ensure optimal performance and longevity. However, this is not an insurmountable obstacle in the development of an innovative solar-powered cool box for traditional fishermen. Some actions that need to be taken are designing the cool box with durable and robust materials to withstand the harsh marine environment, including exposure to saltwater and rough handling during fishing activities. Selecting the right materials and a rugged design can increase the reliability and lifespan of the cool box. Moreover, although traditional fishermen may face challenges in accessing maintenance services or spare parts in remote areas, this can be overcome by providing adequate training and maintenance guidance to the fishermen. With a good understanding of how to maintain and repair the cool box, fishermen can independently maintain the device and extend its service life.

Additionally, dependence on weather conditions is indeed a consideration in the use of a solar-powered cool box. However, by taking into account the patterns of sea breezes and land breezes in the Indonesian archipelago, which can influence rainfall and cloudy conditions, the cool box can be designed with adequate energy storage capacity to overcome periods of poor weather over a certain period of time. Sea breezes are winds that move from the sea to the land, while land breezes move from the land to the sea. These wind movements can affect rainfall patterns in the island region. For example, sea breezes can bring moisture from the sea and cause rain in coastal areas, while land breezes can bring dry air from the land and reduce the likelihood of rain [60]. By considering these factors in the design and operation of the cool box, as well as providing adequate training to fishermen, the solar-powered cool box innovation can become a sustainable and reliable solution for maintaining the freshness of the catch of traditional fishermen.

5. CONCLUSION

The cool box device that has been designed, manufactured and implemented has dimensions of 92×50×28 centimeters which have been matched to the width and height of traditional fishermen’s boat hull. This device has several electronic components such as solar photovoltaic, Arduino Uno, TEC, electric shock feature, LCD, battery, charge controller, heatsink, styrofoam, and temperature sensor. Data collection was carried out at four different locations in sunny weather and produced the average power of 2,527.2 Watts. The power produced can support device operations for up to 10 hours. The use of temperature control which can activate and deactivate TEC automatically is also installed on this device to prevent fish in the cool box from freezing. Utilizing this temperature control can also save energy in the battery. The use of this cool box can maintain the freshness of the fish compared to the use of conventional ice thermos which can only reach the lowest temperature of 13 °C. Apart from that, the temperature in the storage room of this cool box is also more stable.

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