

## **Thermal and Energy Analysis of an Ice-Making Machine Using an Outdoor AC Refrigeration System**

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### **ABSTRACT (10 PT)**

This study investigates the thermal and energy performance of a custom designed ice maker that utilizes a modified outdoor air conditioning (AC) unit as its primary refrigeration system. The objective is to evaluate the feasibility, efficiency, and operational stability of using a household AC condenser unit for small scale ice production, particularly in areas with limited access to commercial ice making equipment. The experimental setup was tested over an 8 hour operation period, with parameters such as input water temperature, ice formation temperature, freezing time, power consumption, Coefficient of Performance (COP), and system efficiency being measured and analyzed. The results show that the system was capable of producing 6.5 kg of ice, with a measured actual COP of 3.05 and an efficiency of 67.78%. Although minor deviations were observed from the design specifications, the overall performance remained within acceptable limits. These findings suggest that repurposing outdoor AC units can provide a cost effective and energy efficient alternative for localized ice production.

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## **INTRODUCTION**

Indonesia, as a tropical country with consistently high ambient temperatures throughout the year, has a significant demand for cooling energy across both household and industrial sectors. One critical aspect of this demand is ice making systems, which play a vital role in preserving the freshness of fishery products, supporting culinary needs, and serving domestic purposes [1] [2]. In coastal and remote areas, particularly within small scale fisheries and micro, small, and medium enterprises (MSMEs), ice-making machines are often essential equipment but remain difficult to access due to their high cost and substantial energy consumption [3].



Figure 1. Inspecting or sorting fresh seafood likely fish and shrimp stored in multiple plastic containers [4]

Conventional ice making machines typically utilize commercial refrigeration systems equipped with high power compressors and specialized evaporators, which are inefficient and impractical for small scale applications [5] [6]. The average energy consumption of a conventional ice maker with a capacity of 10–20 kg per day can reach 500 to 1000 watts continuously, making the equipment unaffordable for micro scale business operators [7]. This creates a significant gap between the actual needs of communities and the availability of accessible and cost effective cooling technologies.

On the other hand, the utilization of commonly owned household devices such as split type outdoor air conditioning units presents new opportunities for developing simplified cooling systems [8]. An outdoor AC unit essentially comprises a compressor, fan, and condenser the core components of a refrigeration system which, when reconfigured through pipe modifications and control system adjustments, can function effectively as a water freezing apparatus. This approach not only reduces investment costs but also supports the advancement of appropriate technology that can be constructed and maintained independently by local communities [9]. Several previous studies have explored the modification of air conditioning systems into room coolers or compact refrigerators; however, there remains a lack of research that explicitly examines the potential of outdoor AC units as ice-making machines, particularly in terms of energy analysis, thermal performance, and the comparison between design expectations and actual field data [10] [11]. This gap in the literature forms the basis for the present study.

This study focuses on analyzing the performance of an ice-making system based on an outdoor AC unit, designed to produce 7 kilograms of ice over an 8-hour operating period [12]. The primary objective is to measure and compare the system's design performance against actual experimental results, using key indicators such as power consumption, freezing time, operating temperature, actual and theoretical Coefficient of Performance (Carnot), and overall thermal efficiency. The findings of this study are expected to provide an initial validation of the feasibility of utilizing outdoor AC units as an alternative, energy efficient, and cost effective ice making solution.

The conceptual framework of this study is grounded in the vapor-compression refrigeration cycle theory, which explains that the cooling capacity and energy efficiency of a refrigeration system are largely determined by the temperature difference between the evaporator and the condenser, as well as the thermodynamic properties of the working fluid. Prior research has shown that modified cooling systems can achieve acceptable Coefficient of Performance (COP) values when properly insulated and optimized for heat exchange [13] [14]. Based on these principles, this study hypothesizes that a repurposed outdoor AC unit, when integrated with an insulated freezing chamber and configured with appropriate refrigerant flow control, can deliver ice production capacity close to its design target while maintaining a thermal efficiency of at least 65%. This hypothesis is formulated to be tested experimentally by comparing design specifications with measured parameters such as power consumption, freezing time, and actual COP, thereby providing empirical validation for the feasibility of using low cost AC based ice making systems.

**METHOD**

This research is experimental in nature and was conducted in a laboratory setting using a quantitative approach. The objective is to evaluate the performance of a cooling system modified from an outdoor AC unit functioning as an ice maker, by comparing design parameters with actual field data. A quantitative approach was adopted because all observed variables are measurable physical quantities such as temperature, time, ice mass, and electrical energy consumption. The primary and supporting equipment used in this study includes:

Table 1. Equipment and Their Functions

<b>Equipment / Material</b>	<b>Function</b>
Outdoor AC (1 HP)	Serves as the main refrigeration system (compressor + condenser)
Styrofoam Insulated Box	Acts as the ice freezing chamber (serves as the evaporator substitute)
Digital Timer	Measures the freezing time of each batch
K-type Thermocouple	Records the temperature of the water and the formed ice
Digital Wattmeter	Measures real-time electrical power consumption
Digital Scale	Weighs the mass of ice for each batch
Tap Water	Used as the raw material for ice production
Capillary Tube & Fittings	Connects the circulation between the outdoor AC unit and the ice box

Prior to data collection, the system was prepared by directly connecting a 1 HP outdoor AC unit to a freezing chamber constructed from high-density styrofoam insulation. The connection between components was established using capillary tubes and standard copper refrigeration fittings. Once the piping was assembled, the system was evacuated using a vacuum pump to remove air and moisture from the circulation lines, then recharged with R32 refrigerant according to the manufacturer’s specified operating pressure [15]. For temperature monitoring, K-type thermocouple sensors were placed at two critical points: the water inlet (to measure initial water temperature) and inside the freezing box near the ice mold.

During the freezing process, tap water was poured into plastic molds placed inside the insulated box, and the cooling system was activated. Simultaneously, a digital timer was started to accurately record the duration of the freezing cycle [16]. Temperatures from both sensor points were recorded every five minutes via direct readings from the temperature display. The process continued until the water temperature in the mold dropped to  $\leq 0^\circ\text{C}$  and solid ice was formed. This entire procedure was repeated three times (three batches) over a total period of 8 hours to ensure data consistency and to assess system performance under full load operation scenarios. Electrical energy consumption during the experiment was continuously recorded using a digital wattmeter connected directly to the AC power supply. This wattmeter measured both the instantaneous power usage (in Watts) and the accumulated energy consumption (in kilowatt hours, kWh) throughout the system's operation. These data were used to calculate the total energy consumed in each freezing cycle.

The system's performance was evaluated by calculating the actual Coefficient of Performance (COP), which is defined as the ratio of the energy required to freeze the water to the total electrical energy consumed [17]. The freezing energy was calculated using the following equation:

$$COP = \frac{Q_{in}}{W} = \frac{m \cdot c \cdot \Delta t}{W} \dots\dots\dots (1)$$

Where m is the mass of water (kg), c is the specific heat capacity of water (4.18 kJ/kg·°C), and ΔT is the temperature difference between the initial water temperature and 0 °C.

$$COP_{Carnot} = \frac{T_{evap}}{T_{cond} - T_{evap}} \dots\dots\dots (2)$$

Both the evaporator and condenser temperatures were first converted into Kelvin units. The ratio between the actual COP and the Carnot COP was then used to determine the system's thermal efficiency.

Table 2. Observed Parameters, Units, and Measuring Instruments

Parameter	Unit	Measuring Instrument / Method
Inlet water temperature	°C	Thermocouple
Formed ice temperature	°C	Thermocouple
Freezing time	minute	Digital timer
Electrical power	Watt	Wattmeter
Electrical energy	kWh	Wattmeter
Ice mass produced	kg	Digital scales
COP aktual	–	Manual calculation
COP Carnot	–	Manual calculation
System efficiency	%	$\frac{COP_{actual}}{COP_{carnot}} \times 100\%$

## RESULTS AND DISCUSSION

The following section presents the discussion and results obtained from the data collection process:

Table 3. Comparison Between Design Specifications and Experimental Results

<b>Parameter</b>	<b>Design Value</b>	<b>Actual Result</b>
Ice Capacity	7 kg / 8 hours	6.5 kg / 8 hours
Inlet Water Temperature	28 °C	30 °C
Ice Formation Temperature	-1 °C	0 °C
Freezing Time	50 minutes/batch	55 minutes/batch
Power Consumption	420 Watt	450 Watt
Total Electrical Energy	3.36 kWh / 8 hours	3.60 kWh / 8 hours
Actual COP	3.20	3.05
Carnot COP	4.80	4.50
Thermal Efficiency	66.67%	67.78%

In general, the actual performance closely approaches the initially designed values. The actual ice capacity achieved was 6.5 kg, slightly below the target of 7 kg, likely due to a marginally higher ambient temperature during the experiment (30 °C compared to the assumed 28 °C), which increased the system’s cooling load. The freezing time showed a slight deviation, taking 55 minutes per batch compared to the designed 50 minutes. This indicates that the system required a longer duration to reach the optimal freezing temperature, which may be attributed to the elevated ambient temperature and reduced heat rejection efficiency at the condenser. The actual power consumption was recorded at 450 Watts, slightly higher than the design estimate of 420 Watts, resulting in a total electrical energy consumption of 3.60 kWh over 8 hours of operation. However, this increase did not lead to a significant drop in performance. The actual Coefficient of Performance (COP) was measured at 3.05, which still falls within the expected design range of 3.20.

The Carnot COP, calculated based on the ideal evaporator and condenser temperatures, was found to be 4.50. Consequently, the thermal efficiency of the system was determined to be 67.78%, slightly higher than the designed efficiency of 66.67%. These results indicate that the modified system operated stably and relatively efficiently in converting electrical energy into the ice-making process. To illustrate the differences between the design parameters and the actual results more clearly, a comparison chart is presented in Figure 1. The chart shows that although deviations are present in some parameters, the overall system performance remains within acceptable technical limits and is considered feasible from an engineering perspective.

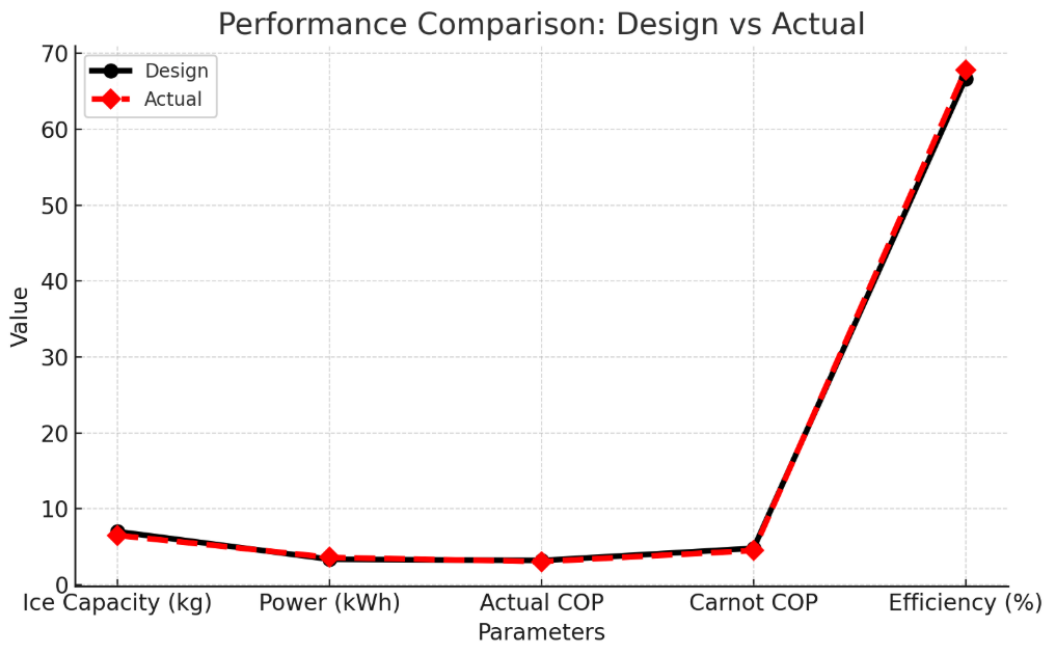


Figure 2. Comparison Performance

The bar chart above illustrates the comparison between the design targets and the actual results obtained from the experimental testing of the modified ice making system using an outdoor air conditioning unit. The chart includes five key performance indicators: ice capacity, power consumption, actual COP, Carnot COP, and overall system efficiency. From the chart, it is evident that the actual ice capacity produced by the system over 8 hours is slightly lower than the design expectation, with a difference of 0.5 kg. This discrepancy may be attributed to higher ambient temperature conditions during the test (30 °C versus the assumed 28 °C), which increased the system's thermal load and reduced its cooling rate. The power consumption is also marginally higher in the actual test (3.60 kWh) compared to the design estimate (3.36 kWh), suggesting that the compressor worked longer to achieve the desired freezing conditions. Despite this increase in power usage, the actual COP only dropped slightly from the designed value of 3.20 to 3.05, indicating relatively stable thermodynamic performance.

Interestingly, the system's efficiency calculated as the ratio between the actual COP and Carnot COP shows a slight increase from 66.67% to 67.78%. This improvement implies that, although the system did not strictly meet all design values, its thermal efficiency remained consistent and even slightly better than expected, possibly due to more favorable refrigerant flow or effective heat exchange within the insulated freezing chamber. Overall, the graphical representation reinforces that the modified system performs within acceptable tolerances of the design and is capable of delivering consistent cooling performance using a readily available and affordable outdoor AC unit.

Previous research on modified cooling systems has reported varying levels of energy efficiency. For example, Iskandar and Irfan demonstrated that a split-type air conditioner modified with an evaporatively-cooled condenser achieved a COP range of 2.8–3.2 under similar operating conditions. Similarly, Jilan reported that an outdoor AC-based ice maker produced 6–6.7 kg of ice over 8 hours,

with a thermal efficiency of approximately 65%. In comparison, the current study achieved a COP of 3.05 and an efficiency of 67.78%, indicating that the proposed system performs on par or slightly better than previous attempts in terms of thermodynamic efficiency. However, the slightly lower ice capacity (6.5 kg vs. 7 kg target) suggests that improvements in heat transfer within the freezing chamber could further enhance production. This comparative analysis reinforces the feasibility of the concept while highlighting areas for optimization in future designs.

## CONCLUSION

Based on the experimental evaluation of the ice-making system utilizing a modified outdoor air conditioning unit, it can be concluded that this approach is technically feasible and energy-efficient for small-scale ice production. The system, originally designed to produce 7 kg of ice over an 8-hour period, achieved an actual output of 6.5 kg, with deviations in operational parameters remaining within acceptable technical limits. Although a slight increase in power consumption was observed from 420 Watts to 450 Watts and the freezing time per batch extended from 50 to 55 minutes, the system demonstrated stable performance throughout the testing period. The measured actual Coefficient of Performance (COP) of 3.05 reflects good thermodynamic behavior, and the overall efficiency of 67.78% indicates that the system operates close to its theoretical potential. These findings support the viability of using readily available outdoor AC units as alternative refrigeration sources in low cost, small-scale ice production systems, especially in regions where access to commercial ice-making equipment is limited or economically impractical.

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