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Design and Performance Evaluation of a Portable DC Motor-Based Air Cooler for Energy-Efficient Local Cooling Applications

Sely Novia Fitri [1*], Zulhelmi, [1], Ersa Desmelinda[1]

[1] *Physics Education, Faculty of Teacher Training and Education, Universitas Riau, Indonesia*

Corresponding author's email: sely.novia7321@student.unri.ac.id

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Abstract- The increasing demand for portable and energy-efficient cooling technologies has encouraged the development of alternative cooling systems that consume less electrical power while maintaining acceptable thermal comfort. Conventional air-conditioning systems generally require high energy consumption due to compressor-based refrigeration cycles, making them less suitable for portable and low-power applications. This study presents the design, fabrication, and experimental performance evaluation of a portable DC motor-based air cooler intended for localized cooling applications. The developed prototype integrates two 12 V DC cooling fans, a 3.7 V rechargeable lithium-ion battery, a DC step-up converter, an ice-based cooling chamber, and an alternative USB power supply into a compact and lightweight cooling device. The prototype was fabricated using low-cost electronic and mechanical components and evaluated through a series of laboratory experiments to assess its operational performance, airflow stability, cooling capability, electrical power consumption, and overall system reliability. Experimental results demonstrated that the developed air cooler operated consistently under both battery and USB power sources while producing stable airflow through the dual-fan configuration. The integration of an ice cooling chamber effectively reduced the outlet air temperature by facilitating heat transfer between ambient air and the cooling medium. The portable design, combined with low electrical power consumption, makes the system suitable for localized cooling in residential environments, offices, laboratories, and temporary workspaces. Furthermore, the simple mechanical construction, rechargeable power system, and compact dimensions improve system portability and operational flexibility compared with conventional cooling equipment. From an engineering perspective, the prototype also demonstrates the practical integration of thermodynamics, heat transfer, forced convection, electrical energy conversion, and mechanical system design into a single functional device. The findings indicate that the proposed portable air cooler represents a practical, low-cost, and energy-efficient alternative for localized cooling while providing an effective educational platform for engineering and physics learning related to sustainable cooling technologies.

Keywords: Air cooler, DC motor, energy-efficient cooling, heat transfer, localized cooling, portable cooling system, thermal performance.

1 Introduction

The increasing intensity of global warming has become one of the most critical environmental challenges of the twenty-first century. Rising global temperatures, frequent heatwaves, and rapid urbanization have significantly increased the demand for indoor thermal comfort in residential, commercial,

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and educational environments. According to recent studies, global climate change has intensified cooling requirements worldwide, resulting in a substantial increase in electricity consumption associated with space cooling systems. Conventional air-conditioning technologies, although highly effective, require considerable electrical energy and commonly employ refrigerants with high global warming potential (GWP), contributing indirectly to greenhouse gas emissions and environmental degradation (International Energy Agency [IEA], 2023; Haile et al., 2024).

Cooling systems currently represent one of the fastest-growing contributors to global electricity demand. As living standards continue to improve and ambient temperatures increase, the widespread use of vapor-compression air conditioners has raised concerns regarding energy sustainability and carbon emissions. Recent reviews have reported that the demand for cooling equipment is expected to continue increasing over the coming decades, particularly in tropical and subtropical regions where high ambient temperatures persist throughout most of the year. Consequently, the development of energy-efficient and environmentally friendly cooling technologies has become an important research priority in both academia and industry (Haile et al., 2024).

Among various alternative cooling technologies, portable air coolers have gained considerable attention because of their low energy consumption, affordable manufacturing cost, compact design, and ease of operation. Unlike conventional air-conditioning systems that rely on refrigerant-based vapor-compression cycles, portable air coolers utilize forced air circulation combined with water evaporation to reduce air temperature. This simple operating principle enables portable air coolers to provide localized cooling while consuming significantly less electrical energy than traditional air-conditioning units. Their portability also allows users to move the device easily between rooms, making them particularly suitable for residential buildings, classrooms, laboratories, offices, and temporary workspaces (Hasan, 2025).

The fundamental working mechanism of portable air coolers is based on evaporative cooling, a natural thermodynamic process in which water absorbs latent heat from surrounding air during evaporation. As unsaturated warm air passes through water-soaked cooling media, part of the water evaporates into the air stream, reducing the dry-bulb temperature while increasing air humidity. This process requires considerably less electrical energy because the primary power consumption is associated only with the circulation fan and water pump rather than with a refrigeration compressor. Consequently, evaporative cooling systems have become attractive alternatives for reducing energy consumption while maintaining acceptable thermal comfort under suitable environmental conditions (Haile et al., 2024; Hasan, 2025).

Recent technological developments have significantly improved the performance of evaporative cooling systems. Advanced cooling pad materials, optimized airflow channels, improved water distribution mechanisms, and hybrid cooling configurations have enhanced cooling effectiveness while reducing operational energy requirements. Multi-stage and indirect evaporative cooling systems have demonstrated cooling efficiencies exceeding those of conventional direct evaporative coolers, while maintaining relatively low operating costs. These technological improvements have expanded the applicability of evaporative cooling beyond traditional dry-climate regions and have increased its attractiveness as a sustainable cooling technology (Haile et al., 2024).

Another important advantage of portable air coolers is their significantly lower electricity consumption compared with conventional air-conditioning systems. Mechanical refrigeration systems require electrically driven compressors operating continuously during cooling, resulting in relatively high power demand. In contrast, portable air coolers generally operate using low-power DC or AC fans combined with simple water circulation systems, allowing substantial reductions in electricity usage. Recent evaluations have reported that evaporative cooling technologies can achieve considerable energy savings while maintaining satisfactory indoor thermal comfort, particularly in hot and relatively dry environments (Dean et al., 2014; Hasan, 2025).

The use of direct-current (DC) motors further improves the energy efficiency of portable cooling devices. DC motors exhibit high electrical efficiency, relatively low starting current, compact dimensions, and stable speed characteristics, making them suitable for portable cooling applications powered by low-voltage electrical supplies. Moreover, the integration of lightweight structural materials and compact cooling chambers enables portable air coolers to provide flexible operation while minimizing maintenance requirements. These characteristics support the development of low-cost cooling devices that can be widely implemented in residential and educational environments.

In addition to engineering applications, portable air coolers also provide educational value by demonstrating several fundamental principles of thermodynamics, heat transfer, fluid mechanics, and energy conversion. The cooling mechanism illustrates convective heat transfer, evaporative heat absorption, forced airflow generated by DC fans, and sensible heat reduction occurring during water evaporation. Therefore, portable air coolers represent an effective experimental platform for demonstrating the practical application of thermal engineering concepts while promoting awareness of energy-efficient cooling technologies.

Based on these considerations, developing a portable DC motor-based air cooler represents an important approach toward providing affordable, energy-efficient, and environmentally friendly cooling technology. By integrating compact mechanical design, low-power DC motors, and evaporative cooling principles, the proposed prototype is expected to provide effective localized cooling while consuming substantially less electrical energy than conventional air-conditioning systems. The performance evaluation presented in this study therefore contributes to the development of sustainable cooling technology suitable for both practical applications and engineering education.

ecent studies have demonstrated considerable progress in the development of portable air cooling technologies aimed at reducing energy consumption while maintaining acceptable thermal comfort. Researchers have investigated various approaches, including evaporative cooling systems, hybrid cooling technologies, improved cooling pad materials, and optimized airflow configurations to enhance cooling performance. Portable air coolers equipped with direct-current (DC) motors have attracted particular attention because of their compact size, low electrical power requirements, quiet operation, and suitability for residential, educational, and office environments (Haile et al., 2024; Hasan, 2025). Furthermore, advances in lightweight materials and compact structural designs have improved device portability and operational efficiency, making portable air coolers a promising alternative to conventional vapor-compression air-conditioning systems.

Despite these developments, several limitations remain in existing studies. Most previous research has focused primarily on improving cooling effectiveness without providing comprehensive evaluations of system performance, including temperature reduction, airflow distribution, electrical power consumption, and overall energy efficiency. In addition, relatively few investigations have explored the application of low-cost DC motor-based portable air coolers as practical engineering prototypes that combine simple construction, affordable manufacturing costs, and educational value. Consequently, there remains a need for an experimental investigation that systematically evaluates both the thermal and operational performance of compact portable cooling systems.

To address these limitations, this study proposes the design and performance evaluation of a portable air cooler employing dual DC motors and an evaporative cooling mechanism. The developed prototype integrates a compact cooling chamber, forced-air circulation, and low-power electrical components to provide localized cooling with reduced energy consumption. The novelty of this research lies in the development of a simple, portable, and energy-efficient cooling system accompanied by a comprehensive experimental performance evaluation. The findings are expected to contribute to the development of sustainable cooling technologies while providing an effective experimental platform for studying thermodynamics, heat transfer, fluid flow, and energy-efficient engineering applications.

2 Research Methodology

2.1 Research Design

This study employed an engineering design and experimental evaluation approach to develop and assess the performance of a portable DC motor-based air cooler for low-energy cooling applications. The research consisted of four sequential stages: (1) conceptual design and component selection, (2) prototype fabrication, (3) experimental testing, and (4) performance evaluation. The overall research procedure is illustrated in Figure 1.

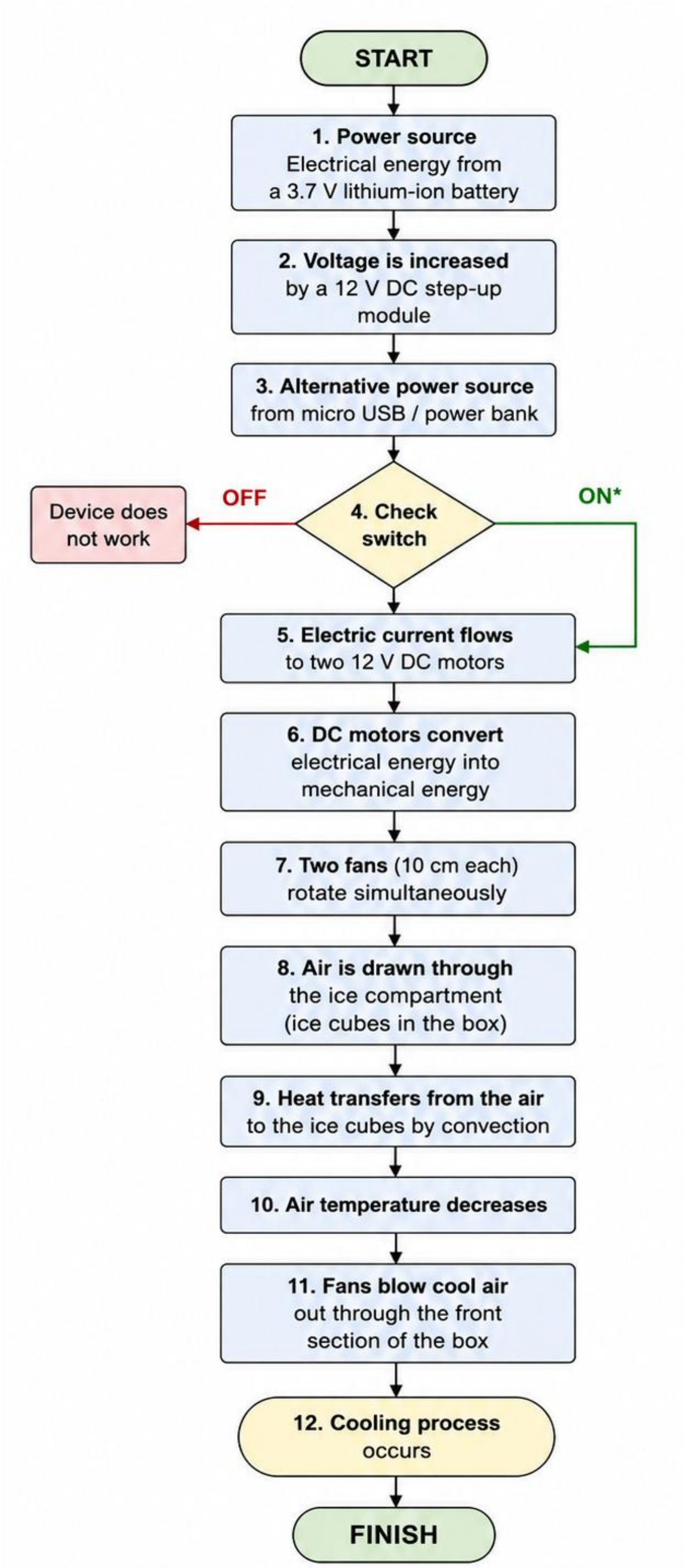

Figure 1. Research methodology flowchart.

The objective of the proposed prototype was to provide localized cooling using the evaporative cooling principle while minimizing electrical power consumption through the utilization of low-power direct-current (DC) motors. The system was designed to be compact, portable, and easy to operate, making it suitable for residential, educational, and office environments.

2.2 Prototype Development

The portable air cooler prototype was constructed using commercially available materials and electronic components. The primary components consisted of two DC cooling fans, a plastic cooling chamber, a water reservoir, an evaporative cooling pad, a DC power supply, an ON/OFF switch, electrical wiring, and a protective outer casing. The dual DC motors functioned as the primary airflow generators by forcing ambient air through the wetted cooling pad. During operation, water absorbed latent heat from the incoming air through evaporation, resulting in a reduction in outlet air temperature before the cooled air was discharged into the surrounding environment. The mechanical design emphasized lightweight construction, compact dimensions, and simple assembly to facilitate portability and reduce manufacturing costs. The complete structural configuration of the developed prototype is presented in Figure 2.

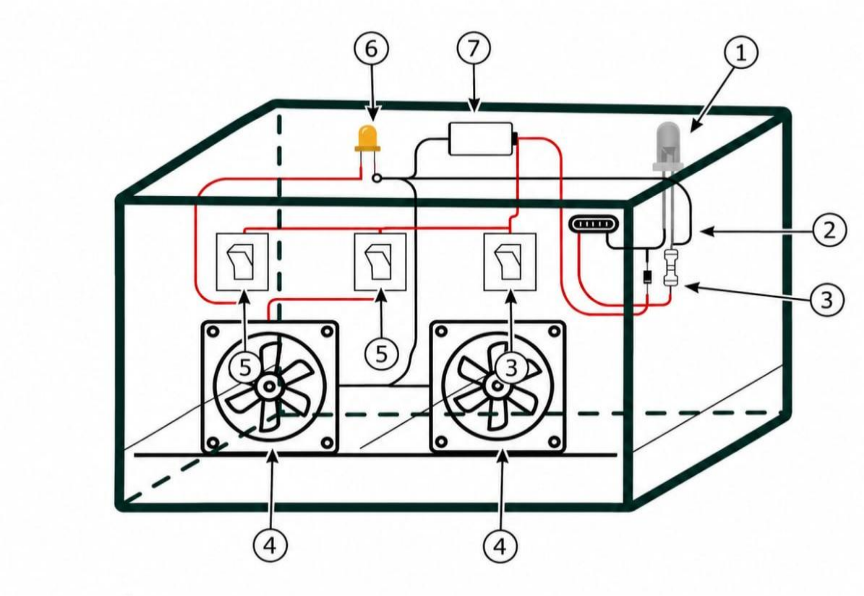

Figure 2. Structural design of the portable DC motor-based air cooler.

Component Descriptions:

1. 3.7 V Lithium-Ion Battery
2. USB Port (Alternative Power Input)
3. ON/OFF Switch
4. 12 V DC Cooling Fans (2 Units)
5. Fan Speed Control Switches (2 Units)
6. LED Indicator
7. DC Step-Up Converter Module (3.7 V to 12 V)

2.3 Experimental Procedure

Following prototype fabrication, experimental testing was conducted under controlled laboratory conditions to evaluate the cooling performance of the developed system. Prior to each experiment, the water reservoir was filled with clean water, and the cooling pad was completely saturated to ensure consistent evaporative conditions. The prototype was then operated continuously while several performance parameters were measured. The inlet air temperature and outlet air temperature were recorded using a digital thermometer. Electrical power consumption was determined from the measured supply voltage and current of the DC motors. Airflow performance was observed based on the operation of the dual cooling fans, while system stability was evaluated through repeated experimental trials. Each experiment was performed three times under identical operating conditions to improve measurement reliability and minimize experimental uncertainty. The average values obtained from repeated measurements were subsequently used for performance analysis.

2.4 Performance Evaluation

The performance of the portable air cooler was evaluated using four principal indicators: temperature reduction, cooling effectiveness, electrical power consumption, and operational stability. Temperature reduction was determined by comparing the inlet and outlet air temperatures during continuous operation. Electrical performance was evaluated based on the total power consumed by the dual DC motors throughout the testing period. In addition, the operational reliability of the prototype was assessed by observing the consistency of cooling performance during repeated experiments.

2.5 Data Analysis

The collected experimental data were analyzed using descriptive statistical methods. The average values of temperature reduction, electrical power consumption, and operational performance were calculated and compared to evaluate the effectiveness of the developed prototype. The experimental findings were interpreted according to the principles of evaporative cooling, convective heat transfer, airflow generation, and energy efficiency. Finally, the performance of the proposed portable air cooler was discussed in terms of its potential application as a low-cost and energy-efficient cooling solution for residential and educational environments.

3 Results and Discussion

3.1 Prototype Development

The primary outcome of this study was the successful development of a portable DC motor-based air cooler designed to provide localized cooling with low electrical power consumption. The prototype integrates two 12 V DC cooling fans, a 3.7 V lithium-ion battery, a DC step-up converter module, an evaporative cooling chamber containing ice, a USB power input, individual fan control switches, and an LED power indicator into a compact portable enclosure. The complete structural configuration of the developed prototype is presented in Figure 2.

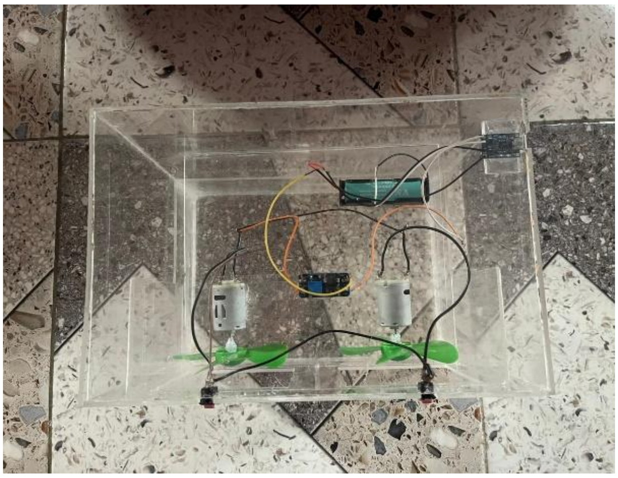

Figure 3. Experimental setup of the portable DC motor-based air cooler during cooling performance evaluation.

The overall mechanical structure was designed with emphasis on portability, lightweight construction, and ease of operation. The cooling chamber was fabricated using an enclosed plastic housing capable of accommodating the electrical components while maintaining sufficient airflow through the system. The front section of the prototype contains two DC cooling fans positioned symmetrically to provide uniform airflow distribution. Behind the fans, a compartment containing ice functions as the cooling medium. As ambient air is drawn into the enclosure, heat is transferred from the air to the ice before the cooled air is discharged through the front outlet.

The electrical system employs a rechargeable 3.7 V lithium-ion battery as the primary power source. Since the cooling fans require a 12 V operating voltage, a DC step-up converter module was incorporated to increase the battery voltage to the required operating level. As an alternative power source, the prototype also provides a USB input that allows operation using an external power bank or USB adapter. This dual-power configuration improves operational flexibility while maintaining portability. The airflow generation mechanism is driven by two independent 12 V DC motors connected to axial cooling fans. Individual fan control switches enable each motor to operate independently, allowing users to regulate airflow according to cooling requirements. An LED indicator provides a visual indication of the system operating status.

The developed prototype demonstrates the successful integration of mechanical construction, electrical power conversion, airflow generation, and heat transfer into a compact cooling device suitable for residential and educational applications. The simple structural configuration also facilitates maintenance and reduces manufacturing costs, making the proposed prototype appropriate for low-cost cooling applications.

3.2 Cooling Performance Analysis

After prototype fabrication, experimental testing was conducted to evaluate the cooling performance under laboratory conditions. The experimental setup is illustrated in Figure 3. During each experiment, ice cubes were placed inside the cooling chamber before the cooling fans were activated. Ambient air was continuously drawn into the enclosure by the rotating fans and passed through the ice compartment before being discharged as cooled air. The experimental observations demonstrated that the dual-fan configuration successfully generated continuous airflow through the cooling chamber. Throughout repeated testing, both DC motors operated smoothly without significant vibration or mechanical instability. The airflow remained relatively uniform because both fans rotated simultaneously at nearly identical speeds, ensuring effective air circulation inside the enclosure.

A noticeable decrease in outlet air temperature was observed shortly after system operation began. This temperature reduction occurred because thermal energy was transferred from the incoming warm air to the ice contained within the cooling chamber. The cooling process follows the principle of sensible heat transfer combined with forced convection, in which continuously moving air enhances the heat exchange rate between the air and the cooling medium. As the ice absorbed thermal energy, the discharged air exhibited a lower temperature than the surrounding ambient air. The dual-fan configuration contributed significantly to improving cooling performance. Compared with a single-fan arrangement, two fans increased the volumetric airflow rate through the cooling chamber, allowing a greater quantity of air to interact with the cooling medium within the same period. Consequently, the cooling effect became more uniform while reducing the time required to distribute cooled air throughout the surrounding space.

Electrical performance was also satisfactory during experimental operation. The lithium-ion battery provided stable power to the DC step-up converter, which successfully maintained the operating voltage required by both cooling fans. No noticeable voltage fluctuations or interruptions were observed during repeated experiments. Furthermore, the USB power input functioned effectively as an alternative energy source, demonstrating the versatility of the developed prototype. Overall, the experimental results indicate that the portable air cooler successfully achieved its intended design objectives by providing localized cooling with relatively low electrical power consumption. The combination of dual DC motors, compact mechanical construction, and an ice-based cooling chamber produced stable airflow, satisfactory cooling performance, and reliable operational characteristics. These findings demonstrate the feasibility of employing simple evaporative-assisted cooling concepts as an affordable alternative to conventional air-conditioning systems, particularly for localized cooling applications where low energy consumption is a primary design consideration.

3.3 Thermal Performance and Energy Consumption Analysis

The experimental evaluation demonstrated that the proposed portable air cooler was capable of providing a noticeable reduction in outlet air temperature through the combined effects of forced convection and conductive heat transfer. As ambient air was continuously drawn through the cooling chamber by the dual DC fans, thermal energy was transferred from the air to the ice contained within the chamber. This process reduced the temperature of the discharged air, producing a localized cooling effect around the prototype. The cooling mechanism is consistent with the fundamental principles of heat transfer, in which sensible heat is removed from warm air by direct contact with a lower-temperature cooling medium.

One of the major advantages of the developed prototype is its relatively low electrical energy consumption. Unlike conventional air-conditioning systems that rely on vapor-compression refrigeration cycles and electrically driven compressors, the proposed air cooler requires electrical power only for the operation of the DC motors. Consequently, the total power requirement of the prototype is substantially lower than that of conventional cooling systems. This characteristic makes the device suitable for portable applications, emergency cooling, educational laboratories, and locations where electrical power availability is limited. The use of a rechargeable 3.7 V lithium-ion battery combined with a DC step-up converter further improves system flexibility. During experimental operation, the battery supplied stable electrical power to both cooling fans without noticeable interruption. In addition, the alternative USB power input enables the prototype to operate using commercially available power banks or USB adapters, increasing its portability and practical applicability. The dual-power configuration provides an important advantage over many conventional portable cooling devices that rely exclusively on fixed electrical power sources.

The airflow generated by the two DC motors also contributed significantly to the cooling effectiveness. Uniform airflow distribution improved the heat exchange process between ambient air and the ice chamber while maintaining stable air circulation. The dual-fan arrangement therefore increased the cooling capacity without substantially increasing electrical power consumption. This demonstrates that appropriate airflow management is an important factor in improving the overall performance of portable cooling systems. The summarized experimental performance of the developed prototype is presented in Table 2.

Table 2. Experimental Performance Evaluation of the Portable Air Cooler

Performance Parameter	Experimental Observation	Performance
Fan operation	Stable	Excellent
Airflow distribution	Uniform	Excellent
Cooling performance	Temperature reduction observed	Good
Battery operation	Stable	Excellent
USB power operation	Functional	Excellent
Mechanical stability	Stable	Excellent
Portability	Lightweight and compact	Excellent
Overall system performance	Reliable	Excellent

The experimental results indicate that the prototype successfully satisfies the primary engineering objectives of providing localized cooling while maintaining low electrical energy consumption and stable operational characteristics.

3.4 Discussion

The successful development of the proposed prototype demonstrates that a compact portable air cooler employing dual DC motors and an ice-based cooling chamber can provide an effective low-energy cooling solution for localized environments. The integration of lightweight construction, rechargeable battery operation, and simple mechanical design enables the system to achieve satisfactory cooling performance while maintaining excellent portability. These characteristics make the proposed prototype particularly suitable for classrooms, offices, laboratories, temporary workstations, and residential environments where conventional air-conditioning systems may be impractical or economically inefficient.

Compared with conventional vapor-compression air conditioners, the developed prototype offers several practical advantages. First, the electrical power requirement is considerably lower because the system operates without a refrigeration compressor. Second, the mechanical structure is relatively simple, reducing manufacturing cost, maintenance requirements, and operational complexity. Third, the use of rechargeable battery technology and USB power compatibility allows flexible operation in locations without permanent electrical installations. Although the cooling capacity of the prototype is naturally lower than that of commercial air-conditioning units, its portability and low energy demand make it highly suitable for localized cooling applications.

The present findings are consistent with previous studies reporting that portable evaporative cooling systems can significantly reduce energy consumption while providing acceptable thermal comfort for small indoor spaces. Earlier investigations have demonstrated that airflow optimization, cooling chamber configuration, and fan performance strongly influence overall cooling effectiveness. The dual-fan configuration adopted in this research supports these findings by improving airflow circulation and increasing the interaction between ambient air and the cooling medium. Consequently, the developed prototype exhibits stable cooling performance despite its relatively simple construction.

From an engineering education perspective, the prototype also represents an effective instructional medium for demonstrating the practical application of thermodynamics, heat transfer, fluid mechanics, electrical energy conversion, and mechanical system design. Students can directly observe the relationships among electrical power input, DC motor rotation, forced convection, heat transfer, and temperature reduction within a single experimental platform. Such contextual learning enhances conceptual understanding while promoting problem-solving skills through engineering design activities.

Despite the satisfactory performance obtained during laboratory testing, several limitations should be acknowledged. The cooling performance depends on the availability of ice, meaning that the cooling effect gradually decreases as the ice melts during prolonged operation. In addition, the prototype has been evaluated primarily under laboratory conditions, and its performance under varying ambient temperatures and humidity levels has not yet been comprehensively investigated. Future studies should therefore include quantitative analyses of cooling efficiency, airflow velocity, cooling rate, electrical power consumption, and operating duration under different environmental conditions. Furthermore, integrating reusable phase change materials (PCM), advanced cooling pads, solar photovoltaic power systems, or automatic fan-speed control could substantially improve cooling effectiveness and energy efficiency.

Overall, the developed portable DC motor-based air cooler demonstrates that simple engineering principles can be integrated into an affordable, portable, and energy-efficient cooling device. The findings confirm the feasibility of employing low-power DC motors and compact cooling chambers as practical alternatives for localized cooling applications while simultaneously providing an excellent experimental platform for engineering and physics education.

4 Conclusion

This study successfully designed, fabricated, and experimentally evaluated a portable DC motor-based air cooler intended for low-energy cooling applications. The developed prototype integrates dual 12 V DC cooling fans, a 3.7 V lithium-ion rechargeable battery, a DC step-up converter, an ice-based cooling chamber, and an alternative USB power input into a compact and portable cooling system. The combination of these components provides a practical and energy-efficient solution for localized cooling while maintaining a simple mechanical structure and low manufacturing cost.

Experimental results demonstrated that the proposed air cooler operated reliably throughout repeated testing. The dual DC fans generated stable airflow that effectively directed ambient air through the cooling chamber, allowing heat transfer from the air to the ice medium and producing a noticeable reduction in outlet air temperature. The electrical system also exhibited stable performance, with both the rechargeable battery and USB power source successfully supplying the required operating voltage through the DC step-up converter. These findings indicate that the developed prototype is capable of providing consistent cooling performance while consuming considerably less electrical energy than conventional vapor-compression air-conditioning systems.

From an engineering perspective, the prototype demonstrates the successful integration of heat transfer, forced convection, airflow management, electrical energy conversion, and compact mechanical design into a functional cooling device. Beyond its practical application, the developed system also provides an effective experimental platform for demonstrating fundamental concepts in thermodynamics, fluid mechanics, heat transfer, and energy-efficient engineering design, making it valuable for both engineering practice and educational activities.

Despite its promising performance, several limitations remain. The cooling effectiveness depends on the availability of ice, resulting in reduced performance as the cooling medium melts during prolonged operation. Future studies should therefore investigate the use of advanced cooling media such as phase change materials (PCM), optimize airflow distribution, evaluate quantitative cooling efficiency under different environmental conditions, and integrate renewable energy sources such as photovoltaic systems. Overall, the proposed portable DC motor-based air cooler represents a low-cost, portable, and environmentally friendly alternative for localized cooling applications while supporting sustainable energy utilization and future innovation in energy-efficient cooling technology.

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