

DESIGN AND DEVELOPMENT OF A PORTABLE PELTIER-BASED AIR COOLER: PRACTICAL ALTERNATIVE TO MIST FANS WITH AN OPTIMISED FAN DESIGN

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Abstract

Portable mist-based fans, while economically attractive, exhibit significant performance degradation under high humidity conditions and incur substantial water consumption, thereby constraining their long-term sustainability. Thermoelectric Peltier cooling presents a water independent alternative for personal thermal management; however, its practical adoption remains limited due to suboptimal heat dissipation and insufficiently optimised airflow architectures. This study presents the development of a portable Peltier based air cooling system integrated with an Internet of Things IoT control framework and focuses on empirical optimisation of fan blade geometry to enhance thermal performance. Three custom blade configurations namely Straight Satu, Curved Dua, and Twisted Tiga were fabricated and experimentally evaluated against a conventional axial fan baseline. Experimental results indicate that the Curved Dua blade achieved superior performance, exhibiting the highest cooling rate of 0.22 °C per minute and a maximum temperature reduction of 1.1 °C within 5 minutes. This performance advantage is attributed to its ability to balance high near field airflow velocity of 5.0 m per second with sustained downstream air delivery of 1.4 m per second. The findings demonstrate that blade curvature enhances airflow coherence, thereby improving convective heat rejection from the Peltier module while simultaneously delivering a more uniform and natural cooling sensation to the user. Moreover, the system incorporates an IoT enabled dual mode control strategy with automatic and manual operation, enabling adaptive control and improved energy efficiency. Overall, the study confirms that fan blade geometry optimisation is a critical design factor in realising efficient, sustainable, and user friendly. Peltier based personal cooling systems, offering a viable alternative to mist-based cooling technologies across diverse climatic conditions.

List of Notations:

ESP8266	is the Wi-Fi enabled microcontroller used for system control and IoT communication
DHT22	is the digital temperature and humidity sensor
PWM	is the pulse width modulation signal used for fan speed control
DC	is the direct current power supply
Satu	is the straight fan blade configuration
Dua	is the curved fan blade configuration
Tiga	is the twisted fan blade configuration
IoT	is the Internet of Things-based monitoring and control system

1.0 INTRODUCTION

Portable air coolers provide a compact and energy-efficient method for localised temperature control in small spaces. While cost-effective, conventional mist-based coolers, which rely on water evaporation, face significant limitations. Their cooling efficiency drastically decreases in humid or poorly ventilated environments, leading to inconsistent performance (N. M. System, 2024). Additionally, their water consumption renders them unsustainable for water-scarce regions.

Thermoelectric (Peltier) cooling presents a promising, water-free alternative for such applications. However, its integration into personal air coolers remains underexplored, often due to suboptimal system design that fails to maximise its potential (Enescu & Virjoghe., 2014). A key challenge is the efficient dissipation of heat from the Peltier module, which is

highly dependent on optimised airflow dynamics which area requiring further research. Furthermore, the incorporation of smart features for enhanced usability and energy management in portable Peltier-based coolers is limited.

This project addresses these gaps through the design and development of a portable Peltier-based air cooler. The primary objective is to create a sustainable and efficient alternative to mist fans by eliminating water dependency. This report details the progress made in constructing a prototype that integrates a Peltier module as the core cooling element. A significant focus of the work is the empirical optimisation of the system's airflow through the testing of three distinct fan blade configurations to maximise cooling performance and air velocity. Additionally, the system is being embedded with IoT capabilities for remote

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monitoring and control, aiming to improve user experience and operational efficiency (Pal *et al.*, 2020; Ramady *et al.*, 2021). The performance of the prototype will be evaluated based on its cooling rate and achieved air velocity with the goal of validating its viability as a practical personal cooling solution.

1.1 Objective

- To design and develop a Peltier-based air-cooling system as an alternative to mist cooler fan.
- To analyse and compare the efficiency of three different fan blade designs in optimising airflow and heat dissipation.
- To integrate IoT technology for smart control of the cooling system, enhancing energy efficiency and user adaptability.

2.0 BACKGROUND STUDY

2.1 Literature Review of Fan Design

A critical analysis of recent research reveals that optimising fan design is a primary lever for enhancing the performance, efficiency, and acoustics of cooling systems. Several studies demonstrate the efficacy of modifying blade geometry. For instance, research on a cooling fan for a low-voltage motor utilised Computational Fluid Dynamics (CFD) and physical testing to compare three blade designs. The optimal design (Case 2) succeeded in reducing mechanical energy loss by 16%, proving that strategic changes to blade size and shape can yield significant gains in efficiency and energy savings (Jang *et al.*, 2019).

Similarly, a design study for a radiator fan used 3D modelling and simulation to increase the pressure difference across the fan, thereby enhancing airflow and cooling efficiency at a specified optimal RPM (Mageet & Mayeed., 2024). Beyond pure performance, the acoustic impact of fan operation is a key consideration. An investigation into an automotive cooling fan analysed airflow patterns and noise characteristics at different speeds (Ren *et al.*, 2023). The study found that while higher RPMs produced a more concentrated, spiral airflow, they also led to increased noise, particularly from the blade tips and edges. This highlights a critical trade-off between cooling capacity and acoustic comfort that must be managed in fan design.

Pushing the boundaries of conventional design, a novel approach developed a bionic impeller for a laptop cooling system, inspired by the aerodynamics of an eagle's head and a car spoiler (Amer, 2023). This bio-inspired design, validated through both simulation and experiment, resulted in a more than 20% increase in airflow, higher static pressure, and significantly reduced noise levels. Its success, evidenced by multiple patents, underscores the high potential of innovative, nature-inspired geometries to overcome traditional design limitations.

2.2 Literature Review of Peltier Module

Research into Peltier-based cooling systems consistently identifies efficient hot-side heat dissipation as the paramount factor for improving cooling performance and energy efficiency. Studies demonstrate that liquid cooling methods, utilising water blocks and radiators, provide superior heat rejection compared to traditional heatsink-fan assemblies, enabling higher temperature differentials and more compact designs (Jang *et al.*, 2019).

The integration of microcontroller-based automation, such as Arduino or specialised temperature controllers, is widely adopted for precise thermal regulation and system optimisation, enhancing the coefficient of performance (COP) (Mageet & Mayeed, 2024; Ramady *et al.*, 2021). Configurational choices, including the use of multiple modules and careful electrical parameter adjustment, significantly impact outcomes; for instance, a system employing twelve Peltier modules achieved a COP of 1.13 with a cooling capacity of 648 W (Mageet & Mayeed, 2024). Furthermore, innovative approaches like using sand-filled tanks as thermal mass (Pal *et al.*, 2020) or integrating renewable solar power with Maximum Power Point Tracking (MPPT) (Ren *et al.*, 2023) highlight pathways toward sustainable, portable, and off-grid capable cooling solutions. The consensus across these works is that an optimal Peltier air cooler requires a synergistic design combining advanced heat dissipation, intelligent control logic, and strategic module configuration to balance cooling power with energy efficiency.

2.3 Research Gap Identification

The existing body of literature provides a robust foundation for understanding the critical role of thermal management in electronic systems. Studies consistently affirm that fan blade design is a primary determinant of heat transfer efficiency and overall system performance (Ren *et al.*, 2023; Arjun Kumar *et al.*, 2023). Furthermore, researchers have successfully validated the use of computational fluid dynamics (CFD) simulations alongside experimental comparative testing as a reliable methodology for fan optimisation (Amer, 2023). These foundational principles have been effectively applied to optimise cooling in specific, enclosed applications such as electric motors, automotive radiators, and high density electronic enclosures (Benke *et al.*, 2020; Daniel *et al.*, 2022; Kamble *et al.*, 2019).

However, a significant application gap exists. The direct translation of these well-established fans principles to the domain of personal cooling, and more specifically to systems based on thermoelectric (Peltier) modules, has been largely overlooked. Current research (Talamayan *et al.*, 2025). Predominantly focuses on managing heat within a device to prevent component failure, rather than on utilising the generated cool air for human thermal comfort in an open environment. The specific aerodynamic requirements for maximising the delivery of conditioned air from a compact, Peltier based source remain undefined (Nandakishora *et al.*, 2025; SaiKumar *et al.*, n.d.).

This leads to a more critical design optimisation gap. While studies have characterised the performance of individual fans in isolation (Ren *et al.*, 2023), there is a conspicuous absence of comparative analyses that directly link specific fan blade configurations (blade count, angle and shape) to key performance metrics such as cooling rate ($\Delta T/\Delta t$) and outlet air velocity within the unique thermal constraints of a portable Peltier system. The interplay between the heat sink's thermal resistance, the Peltier module's heat pumping capacity, and the fan's ability to overcome this resistance through forced convection is a complex, system-level challenge that has not been systematically investigated.

Therefore, the central research gap is the lack of an integrated, system-level optimisation framework for portable Peltier coolers. This project will directly address this gap by applying a comparative methodology. It will move beyond studying components in isolation to systematically test three distinct fan configurations within a fully functional prototype, thereby establishing the optimal airflow design for maximising the cooling rate and efficiency of a developed portable Peltier device.

2.4 Problem Statement

While Thermoelectric (Peltier) coolers present a compelling solid-state alternative to conventional vapour-compression or evaporative mist-based personal coolers, offering advantages such as refrigerant-free operation, compact size, and high reliability due to the absence of moving parts (N. M. System, 2024). Despite these inherent benefits, the widespread adoption of Peltier technology for personal thermal comfort in open-air environments is impeded by two interconnected research deficits, the understanding of which is crucial for advancing the technology.

The first problem is an application deficit. Research to date has predominantly confined the potential of Peltier systems to niche applications like small scale electronics cooling and portable beverage coolers, where the goal is pointing cooling of a solid object (Kamble *et al.*, 2019; Sahu *et al.*, 2019). There is a distinct lack of dedicated research into the system level engineering required for effective personal climate control. This involves not just generating a temperature differential but efficiently transferring that cooling effect to a moving airstream and delivering it to a user in an open environment, a challenge that introduces significant thermodynamic and fluid dynamic complexities not yet adequately addressed in the literature.

Second problem is a system level design and optimisation deficit, which forms the core of this investigation. The performance of a Peltier module is fundamentally limited by its ability to reject heat from its hot side (Electronic Specifier, 2020). This heat rejection is a direct function of forced convection, making the fan and heat sink assembly the single most critical determinant of overall system cooling capacity. While recent research in 2023-2024 has continued to explore advanced heat sink geometries and novel materials for Peltier systems (Boardway Building, 2020; Ramarao *et al.*, 2020) the specific role of the fan has been comparatively neglected. Crucially, the relationship between fan blade geometry and the resultant cooling efficiency within a compact, ducted Peltier system remains unquantified (Dağlı & Üner, n.d.). General fan studies, even recent ones, often focus on industrial or HVAC applications (Cirillo *et al.*, 2022) and do not address the unique constraints of a low-voltage, portable device where the fan must operate against the backpressure of a dense heat sink fin array. This creates a clear absence of comparative, application-specific data that directly links a simple, modifiable variable to critical performance outcomes like achievable cooling rate ($\Delta T / \Delta t$) and air velocity at the outlet.

Therefore, the core problem this research addresses is the absence of an empirically derived design framework for portable Peltier coolers. This gap stems from a historical

focus on component-level improvements rather than system-level optimisation, and a specific failure to investigate how aerodynamic components like the fan must be tailored to maximise the technology's inherent advantages for personal comfort. This project directly confronts this problem by systematically developing a prototype and conducting a comparative performance analysis with three distinct fan configurations.

3.0 METHODOLOGY

3.1 Overall System

Figure 1 shows the system block diagram illustrating the complete architecture of the Peltier-based cooling system. The design incorporates a TEC1-12706 Peltier module as the core cooling element, controlled by an ESP8266 microcontroller that processes inputs from temperature sensors and user interface selections. The system operates through two distinct modes: manual mode for direct speed control and auto mode that automatically adjusts fan speed based on ambient temperature readings. Power management is handled through a 12V/10A adapter with buck conversion for low-voltage components, while mosfet and relay modules regulate motor and Peltier operation.

3.2 Hardware Design and Selection

Table 1 details the hardware for the Peltier cooling system, prioritising thermal efficiency and portability. It uses a TEC1-12706 module, aluminium heatsinks with thermal paste, and a PVC foam enclosure for insulation. Three PLA/PETG fan prototypes with different geometries were made to optimise airflow for cooling efficiency.

Figure 2 presents the fully assembled prototype. All listed components were integrated using a fitted tight construction method, which facilitates easy access for maintenance to the fan and electronic compartments.

3.3 Circuit Connection

The overall system's electrical integration is depicted in Figure 3, which illustrates the complete circuit architecture governing the portable cooler's operation. At the core of this system, an ESP8266 microcontroller serves as the central processing unit, coordinating all functions. It is connected to the TCL-1206 Peltier module, which acts as the primary cooling engine, with the wiring confirming the correct positive polarity required for effective heat pumping. The circuit also encompasses the control and power delivery for the specialised high-static-pressure fan prototypes, ensuring synchronised operation for optimal heatsink cooling.

Table 1: System components and specifications

Component	Specification	Purpose
Peltier Module	TEC1-12706, 12V, 6A	Core cooling element
Microcontroller	ESP8266	System control and IoT
Power Supply	12V, 10A DC	Main power source
Temperature Sensor	DHT22	Temperature monitoring
Fan Blades	PLA, PETG	Airflow optimisation
Enclosure Material	PVC Foam Board (Armer, 2023)	Thermal insulation

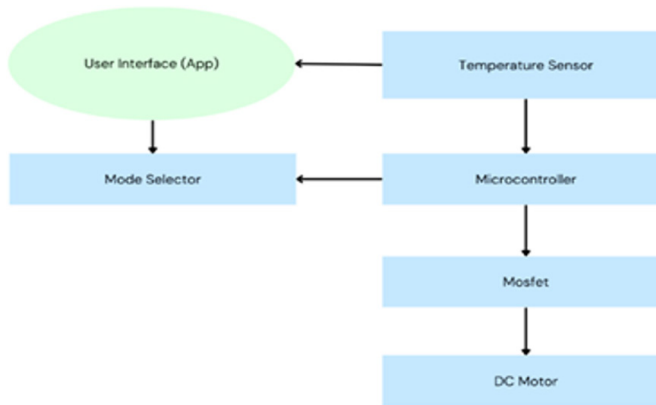


Figure 1: System Block Diagram



Figure 2: The prototype

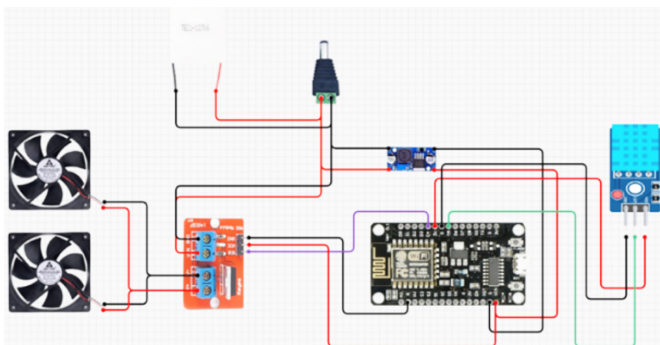


Figure 3: Overall system circuit diagram

Furthermore, the diagram includes the supporting circuitry for the IoT capabilities, such as the Wi-Fi module and the interface for the KME Smart application, enabling the dual-mode (Auto/Manual) control that defines the system's user interactivity. This integrated design validates the successful electronic unification of the thermal, aerodynamic, and smart control subsystems into a single functional prototype.

3.4 Software and IoT Implementation

Figure 4 illustrates the IoT control flowchart implemented through KME mobile application integration. The software architecture enables dual operational modes: manual mode allows users to directly select from three predefined fan speeds, while auto mode employs temperature-based control logic where the system automatically switches to high speed

at temperatures above 29°C, maintains medium speed until reaching the target temperature, and reverts to low speed for energy efficient maintenance cooling. The ESP8266 microcontroller facilitates wireless communication and real-time sensor data processing, creating a responsive and user-adaptable cooling system that optimises energy consumption based on environmental conditions (Ramarao *et al.*, 2020).

Figure 5 shows the KME Smart mobile application interface and its integration with the microcontroller code. The app provides real-time temperature monitoring and allows users to switch between Auto and Manual control modes. In Auto mode, the ESP8266 executes a temperature-based control algorithm that automatically adjusts fan speed based on predefined temperature thresholds. In Manual mode, users can directly set the fan speed through the app's interface.

The smartphone application interface in figure 6 is for the IoT control system displays real-time environmental parameters, recording a temperature of 31°C and a humidity level of 78%. The manual Dimmer control is set to 0%, indicating the fan is currently off or at its minimum speed in this manual operating mode. This interface demonstrates the system's dual mode capability, allowing for both real-time data display and direct user control over the cooling system's output.

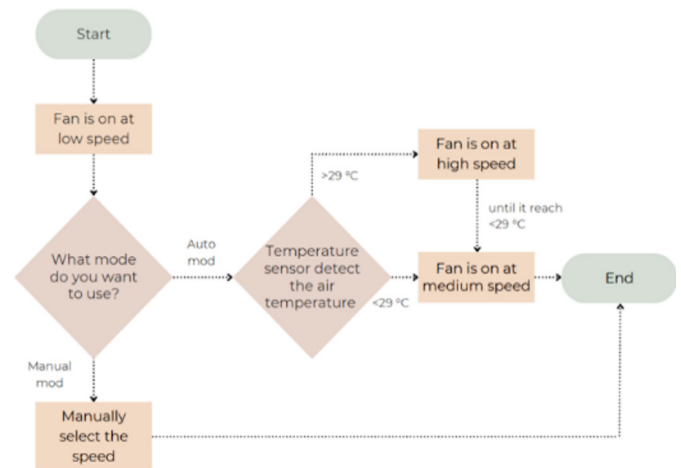


Figure 4: IoT Flowchart



Figure 5: KME Smart App on Laptop

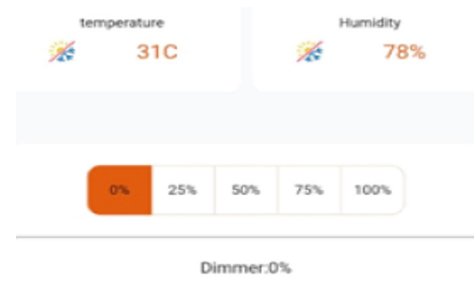


Figure 6: KME Smart application interface showing real-time environmental monitoring and manual dimmer control

The application interfaces demonstrate the setup of a dual-threshold automated control system for proactive climate control. Two distinct scenes are configured: the prototype is programmed to activate when the temperature falls below 29°C, triggering a moderate fan speed of 50% for efficient low-power operation (Figure 8). It is also set to activate when the temperature reaches or exceeds 32°C, commanding a maximum fan speed of 100% for aggressive cooling (Figure 7). Together, these rules define a complete control strategy, enabling the system to automatically modulate its cooling intensity across a temperature range, thereby optimising both performance and energy use in the 'Auto' mode.

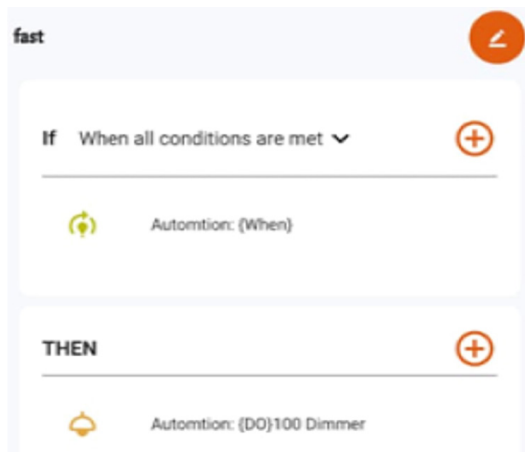


Figure 7: Configurable automation rules for thermal management

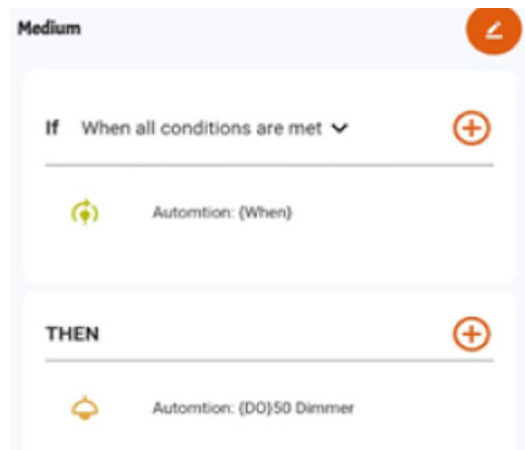


Figure 8: Configurable automation rules for thermal management

3.5 Experimental Setup

The experimental setup for fan performance testing was designed to ensure consistent and comparable measurements across all prototype configurations using a digital anemometer, a regulated 12V DC power supply, a standardised test jig for fan mounting, and measurement tape for distance standardisation.

The procedure began by securely mounting each fan design in the test jig. The anemometer was then positioned at standardised locations (side, and 15cm distance), after which a stable 12V power input was applied, followed by a 30-second stabilisation period. For each test, air velocity measurements were recorded at 10-second intervals over two minutes. This

entire process was repeated for three independent trials per fan design, and the order of testing the three fan designs was randomised to eliminate any potential order effects.

Figure 9 shows the experimental setup with precise measurement positions and equipment arrangement to ensure reproducible results.

Figure 10 shows the setup evaluates the cooling performance of different fan blades. The core experimental procedure holds the initial hot side temperature and heat dissipation constant while switching only the fan blade at the cold side. Temperature on the cold side is recorded over a 5-minute interval for each blade to determine which fan can reduce the temperature most rapidly (Cirillo *et al.*, 2022).



Figure 9: Airflow test setup Figure 10: Cooling rate test setup

4.0 RESULT

4.1 Analysis

Table 2 compares fan airflow, with the Dua (Curved) blade achieving the highest velocity both directly (5.0 m/s) and at 15cm (3.2 m/s average). The Satu (Straight) blade performed well proximally (4.6 m/s) but had the poorest airflow retention at distance (0.9 m/s).

Table 3 (Cooling Performance of Fan Designs) directly measures the core functional outcome which is the ability to cool a ambient air over five minutes, starting from an identical initial temperature of 29°C. The Dua (Curved) blade was again the top performer, achieving the largest total temperature drop (1.1°C) and the fastest cooling rate (0.22°C/minute). The Tiga (Twisted) blade demonstrated the weakest cooling performance, with a drop of only 0.5°C.

Table 2: Fan performance testing resulting

Design	Side (m/s)	15cm Distance (m/s)	Average (m/s)
Laptop Fan	4.5	2.5	3.5
Satu (Straight)	4.6	0.9	2.75
Dua (Curved)	5.0	1.4	3.2
Tiga (Twisted)	4.0	1.5	2.75

Table 3: Cooling performance of fan design

Design	Initial Temp (°C)	Final Temp after 5 min (°C)	Total Temp Drop (°C)	Cooling Rate (°C/minute)
Laptop Fan	29	28	1	0.2
Satu (Straight)	29	28.3	0.7	0.14
Dua (Curved)	29	27.9	1.1	0.22
Tiga (Twisted)	29	28.5	0.5	0.1

Table 4: Comparative analysis with others research

Feature	(Benke <i>et al.</i> , 2020)	(Daniel <i>et al.</i> , 2022)	(Arjun Kumar <i>et al.</i> , 2023)	(Ramady <i>et al.</i> , 2021)	Peltier based Air Cooler
Primary Goal	Find cost-optimum module count for large-scale cooling	Maximise COP & minimise cost via parameter optimisation	Compare fundamental COP in heating vs. cooling mode	Develop a functional automated cooling prototype	Create affordable, portable, user-friendly personal cooler
No. of Peltier Modules used	2, 4, 6	1, 2, 3, 4	1	1	1
Peltier Model	TEC1-12706	TEC1-12706	TEC1-12715	TEC1-12706	TEC1-12706
Heat Rejection Method	Water-cooled	Water-cooled	Water-cooled	Air-cooled (implied)	Air-cooled
Cooling Side Airflow	30–80 m ³ /h	30–78 m ³ /h	Not specified (enclosed box)	Not specified	~2.75–3.5 m/s (fan-dependent)
Input Power Range	20–130 W (total system)	22–60 W (total system)	~40 W (estimated)	12V DC	12V DC (adapter)
Control System	Manual	Manual	Manual	XH-W3001	ESP8266
Design	Sealed experimental rig	Sealed experimental rig	Sealed test box	Sealed prototype	Easily accessible
Economic Focus	Lifecycle cost	Parameter contribution to cost	Not a primary focus	Component cost & error	Low capital cost (RM 350)
Primary Application	Large-scale commercial cooling	Optimised portable cooling	Experimental comparison box	Simulated room air conditioning	Personal spot cooling
Unique Feature	SPECO economic modelling	Taguchi optimisation analysis	Heating/cooling COP comparison	Thermostat integration	IoT control + user serviceable design

Table 4 synthesises key features from four prior studies and contrasts them with the present work, the Peltier based Air Cooler. The comparison highlights the distinct research goals, technical specifications, and application focuses across these systems.

4.2 Discussion

The superior performance of the Curved (Dua) blade can be attributed to its ability to generate a focused yet broad airflow pattern or radial airflow, which enhances heat dissipation from the Peltier modules heatsink while delivering comfortable cooling to the user. This aligns with bio-inspired aerodynamic studies where curved blades improve flow coherence and reduce entropy generation in compact cooling devices (Kamble *et al.*, 2019). In contrast, the Straight (Satu) blade produced chaotic turbulence, which, although high in local velocity, failed to transport cooled air effectively to the target area, a phenomenon noted in recent personal cooling research (Sahu *et al.*, 2019).

Moreover, the Dua blade's design promotes a radial like airflow distribution, which mimics natural wind patterns and improves thermal comfort without requiring direct user alignment. This is particularly advantageous for personal cooling, where user movement and variable positioning are common. Recent ergonomic studies highlight that distributed airflow improves perceived comfort compared to concentrated jets (Boardway Building, 2020).

4.3 Comparative Summary

This project developed a portable, single-module Peltier-based air cooler and compared its performance with findings from previous thermoelectric cooling research. Earlier studies often used multiple Peltier modules with water-cooling systems to maximise cooling capacity, efficiency, or economic feasibility (Shi *et al.*, 2023; Abdulghani, 2022; Afshari, 2020) While these

laboratory setups achieved higher performance, they were designed for controlled environments and are not suitable for lightweight or portable applications.

In contrast, the present system uses only one TEC1-12706 module with an air-cooled configuration to maintain simplicity, low cost, and true portability. Although its measured cooling rate is lower than water-cooled laboratory systems, the prototype successfully fulfills the needs of personal spot cooling by combining optimised airflow design, energy-efficient operation, and IoT-based control. This practical approach aligns more closely with consumer use cases, where low maintenance, water-free operation, and mobility are more important than maximising thermodynamic performance (Ramady *et al.*, 2021; SaiKumar *et al.*, n.d.) Compared to previous works emphasising theoretical optimisation or parameter studies (Shi *et al.*, 2023; Abdulghani, 2022), this project focuses on translating thermoelectric principles into a functional product that can operate effectively in real environments.

This is especially relevant in humid or water-scarce regions, where mist coolers fail to perform efficiently. The results demonstrate that with proper fan blade optimisation, a single module Peltier system can deliver meaningful cooling while remaining compact, affordable, and user friendly. This positions the prototype as a viable personal cooling solution that bridges the gap between laboratory thermoelectric research and practical, everyday applications.

5.0 FINDING AND FUTURE IMPROVEMENT

5.1 Key Finding

The DUA fan, featuring a curved blade geometry, achieved the best overall cooling performance, recording a total temperature drop of 1.1°C and a cooling rate of 0.22°C per minute. This design effectively balances high near-field airflow

(5.0 m/s at the side) with adequate airflow focus at a distance (1.4 m/s at 15 cm). The curved blades generate a coherent and directed airflow, which enhances heat dissipation from the Peltier module and improves user comfort through a natural breeze like effect (Liao *et al.*, 2025). This finding aligns with recent studies on blade curvature improving flow coherence and cooling efficiency in compact thermal systems (Zhu *et al.*, 2025).

The SATU (Straight) blade design recorded a high side airflow of 4.6 m/s but exhibited the lowest airflow at a distance (0.9 m/s), resulting in poor cooling performance (0.14°C/min). This indicates that chaotic, dissipative turbulence near the fan outlet reduces the effective delivery of cooled air to the user. Recent research emphasises that organised and directed airflow is more critical for convective cooling than raw airspeed alone (Jiang, 2024).

The DUA design's ability to provide a wider yet focused airflow coverage creates a more comfortable and distributed cooling effect, ideal for personal use where direct aiming is impractical. This supports the concept that radial-like airflow patterns improve thermal comfort in localised cooling applications (Hakim & Ikaputra, 2025).

5.2 Future Improvements

To enhance the viability and performance of the portable Peltier-based cooler, the following improvements are proposed. First, future iterations should explore hybrid cooling methods, such as integrating heat pipes or phase-change materials on the hot side of the Peltier module to improve thermal rejection efficiency, as suggested in recent studies on compact thermoelectric systems (Hakim & Ikaputra, 2025).

Second, computational Fluid Dynamics (CFD) simulations should be employed to further optimise blade geometry for noise reduction and airflow coherence, building upon bio-inspired designs shown to improve aerodynamic performance (Omidvarnia & Sarhadi, 2024). Third, incorporating solar panels with Maximum Power Point Tracking (MPPT) could enable off grid operation, enhancing sustainability and portability, as demonstrated in recent renewable-powered cooling prototypes (Arjun Kumar *et al.*, 2023).

Last, implementing machine learning algorithms for predictive thermal management could further optimise energy use based on user behaviour and environmental patterns, a growing trend in smart HVAC systems (Alfatmi *et al.*, 2025).

6.0 CONCLUSION

This study presented the design, development, and evaluation of a portable Peltier-based air cooler as a water-free alternative to conventional mist fan systems. A compact prototype was successfully developed using a TEC1-12706 thermoelectric module integrated with aluminium heatsinks, custom fan blades, and an ESP8266-based control system. The system demonstrates that thermoelectric cooling can be implemented in a portable configuration suitable for localised personal cooling.

Experimental analysis was conducted to evaluate three fan blade geometries, namely Straight (Satu), Curved (Dua), and Twisted (Tiga), to determine their influence on airflow and cooling performance. The results showed that fan blade

geometry significantly affects heat dissipation and airflow distribution. Among the tested designs, the Curved (Dua) blade configuration achieved the best performance, producing the highest airflow velocity of 5.0 m/s near the outlet and 1.4 m/s at a distance of 15 cm. This improved airflow resulted in the largest temperature reduction of 1.1 °C within 5 minutes and the highest cooling rate of 0.22 °C/min, demonstrating more effective heat removal from the Peltier module.

The system was further enhanced through the integration of an IoT-based control platform using an ESP8266 microcontroller and the KME Smart application. This allows real-time monitoring and dual operating modes, enabling users to manually adjust fan speed or activate automatic temperature-based control. The smart control functionality improves system adaptability and operational efficiency under varying environmental conditions.

The results indicate that optimising fan blade geometry plays a critical role in improving airflow effectiveness and cooling performance in compact thermoelectric systems. The developed prototype demonstrates that a single module Peltier cooling device combined with optimised airflow design and smart control can provide practical localised cooling while maintaining portability, affordability, and water-free operation. ■

DATA AVAILABILITY

The data used for the research shall be made available on request through the email address of the corresponding author.

AUTHORS' CONTRIBUTIONS

Mardhiah Lyana Muhammad Lium	Conceptualisation, Methodology, Investigation, Data curation, Formal analysis, Visualisation, Writing original draft.
Lay Sheng Ewe	Conceptualisation, Supervision, Project administration, Resources, Writing, review & editing.
Emadaddin Abdo Mohammed Alazzani	Supervision, Writing, review & editing.
Sara Kit Yee Lee	Writing, review & editing.
Chee Fui Wong	Writing, review & editing.

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