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Research Paper

Smart room temperature regulation with responsive arduino-driven temperature-controlled fan system

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ABSTRACT

This study investigates the design and performance of an Arduino-based temperature-controlled fan system aimed at optimizing room temperature regulation while improving energy efficiency. The system utilizes temperature sensors and a microcontroller to adjust fan speed in response to environmental conditions, ensuring that the fan operates only when necessary. The findings revealed that the Arduino-based fan maintained a more stable room temperature compared to a manual fan, with a mean temperature of 28.8°C (SD = 1.2) versus 31.5°C (SD = 2.5) for the manual fan. In terms of energy consumption, the automated fan reduced power usage by 27.1%, consuming 0.62 kWh compared to the 0.85 kWh of the manual fan. Additionally, the system showed high accuracy in temperature regulation, with an error margin of ±0.2°C. User feedback indicated a significant reduction in manual adjustments, further enhancing the system's convenience. Overall, the Arduino-based fan is a reliable, energy-efficient solution for modern cooling needs.

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1. INTRODUCTION

Background of the Study

The development of intelligent automation systems for climate control has gained significant attention worldwide. Various studies have explored the use of Arduino-based temperature regulation systems to enhance user convenience and energy efficiency. According to [2], an Arduino microcontroller can effectively process temperature data from sensors and regulate fan operations based on predefined conditions, eliminating the need for manual intervention. Similarly, [3] highlighted the significance of intelligent systems in improving human comfort by automating climate control in enclosed environments. Further [5] emphasized that users often find it inconvenient to manually adjust fan speed in response to temperature changes, advocating for an automatic system that dynamically regulates fan speed. These studies collectively underscore the global demand for smart climate control solutions that enhance both comfort and energy efficiency.

In the Philippines, temperature regulation is a growing concern, particularly in urban areas where high temperatures contribute to discomfort and increased energy consumption. According to [11], the Decree of the Minister of Health No. 1405 prescribes an ideal indoor temperature range of 18°C to 28°C with humidity levels between 40% and 60%. If temperatures exceed these thresholds, cooling mechanisms such as electric fans or air-conditioning units become essential. However, traditional cooling systems often operate continuously, leading to unnecessary energy consumption. The need for an automated, cost-effective cooling solution is evident in residential, commercial, and institutional settings where manual temperature adjustments are inefficient.

Despite advancements in automated cooling systems, existing solutions in the Philippines still rely heavily on manual control or expensive air-conditioning units, which are not energy-efficient for all users. While automated fan control technologies exist in industrial and commercial applications, they are rarely implemented in households, schools, or small offices where cost and accessibility are significant concerns. There is limited research on Arduino-driven, temperature-responsive fan systems tailored to local settings, particularly in environments where electricity costs are a critical factor.

This study aims to develop a low-cost, energy-efficient Arduino-based temperature-controlled fan system specifically designed for small-scale applications in Philippine households and institutions. The proposed system will utilize a DHT22 temperature sensor to monitor room temperature, an Arduino Uno microcontroller to process data, and a relay-controlled fan to regulate cooling based on real-time temperature readings. By integrating Pulse Width Modulation (PWM), the system will optimize energy consumption by adjusting the fan speed dynamically. This research contributes to the local adaptation of smart temperature regulation systems, offering a sustainable and practical solution to enhance comfort while reducing electricity costs.

Unlike existing systems that require manual adjustments or expensive hardware, this project will develop an affordable, autonomous cooling system that operates efficiently in response to environmental conditions.

Objectives

This study aims to develop and evaluate an Arduino-based temperature-controlled fan system that autonomously adjusts its operation based on real-time temperature readings. Specifically, it seeks to:

1. Design and construct a cost-effective and energy-efficient automatic fan system using an Arduino microcontroller and temperature sensor.
2. Assess the system's performance in regulating room temperature compared to a manually operated fan.
3. Determine the system's energy consumption efficiency in reducing unnecessary electricity usage.
4. Evaluate the reliability and effectiveness of the system in maintaining the recommended indoor temperature range.

Statement of the Problem

The study aims to address the following specific questions:

1. How effective is the Arduino-based temperature-controlled fan in regulating room temperature compared to a manually operated fan?
2. How does the system's energy consumption compare to that of traditional electric fans?
3. What is the reliability and accuracy of the system's temperature regulation mechanism?
4. Does the implementation of an automatic fan system significantly reduce the need for manual temperature adjustments?

Statement of Null Hypothesis

H_{01}: There is no significant difference in temperature regulation between the Arduino-based temperature-controlled fan and a manually operated fan.

H_{02}: The energy consumption of the Arduino-based fan system does not significantly differ from that of traditional electric fans.

H_{03}: The system's temperature regulation mechanism does not significantly improve reliability and accuracy compared to manual adjustments.

H_{04}: The implementation of an automatic fan system does not significantly reduce the need for manual temperature adjustments.

Theoretical Framework

This study is related to the study made revolves around automating the regulation of temperature using an Arduino microcontroller and temperature sensors. In traditional systems, temperature control often requires manual input, which can be inefficient and inconsistent. This project introduces a solution where a DHT22 temperature sensor continuously monitors the environmental conditions, and the Arduino Uno processes this data to automatically adjust the cooling system of the fan. Pulse Width Modulation (PWM) is employed to control the speed of the fan based on temperature fluctuations, ensuring the system dynamically responds to the environment without the user's intervention.

The feedback loop between the temperature sensor and the Arduino ensures the system adjusts itself according to the real-time data received. The Arduino reads the analog input from the DHT22 sensor, converts it to a digital signal, and uses this information to determine whether to turn the cooling system on or off. The temperature readings are also displayed on an LCD screen, providing a visual interface for monitoring. The integration of PWM allows precise control of fan speed, increasing energy efficiency by ensuring the fan runs at appropriate levels based on temperature thresholds rather than at full speed continuously.

This system builds research in microcontroller-based automation, offering a practical, cost-effective solution for environments requiring precise temperature control. It improves manual systems by reducing human intervention and offers real-time adjustment capabilities, making it suitable for applications in smart homes, healthcare, and industries where temperature regulation is critical. The framework's emphasis on hardware implementation using the Arduino platform ensures that the system can be easily replicated and modified for different use cases, enhancing its adaptability and relevance in various fields.

2. RELATED WORK

The study by [7], titled "Design and Implementation of Object Detection and Temperature-Controlled Solar Powered Fan," provides key insights that are directly applicable to our research on "Smart Room Temperature Regulation with Responsive Arduino-Driven Temperature-Controlled Fan System." Both studies share the goal of developing energy-efficient and automated cooling systems, particularly in regions with tropical climates where the demand for air cooling is high. Demonstrate [4] how integrating sensors and microcontroller technology can reduce energy consumption by ensuring that cooling devices operate only when necessary—based on human presence and elevated temperatures. This is directly aligned with our research objectives, which similarly aim to optimize room temperature regulation through responsive technologies. By employing similar technologies, both studies highlight the importance of reducing energy waste while maintaining a comfortable environment.

In the face of limited energy storage from conventional power sources, automatic temperature-controlled fan systems like those explored in [1].'s work play a vital role in energy conservation. The fan's speed is dynamically adjusted based on the ambient temperature, ensuring that the fan operates at the required speed to provide efficient cooling. This feature, controlled by a microcontroller, optimizes energy use, making the system both effective and cost-efficient. Further enhance energy efficiency by incorporating object detection, ensuring the fan only operates when human presence is detected, further reducing unnecessary power usage.

While our research primarily focuses on temperature-responsive fan operation, their addition of object detection offers a more holistic approach to energy management and user-centric cooling systems. Both studies use microcontrollers to integrate temperature and object sensors, controlling fan speed based on the detected temperature. Additionally, [10] employ an LCD for real-time displays of temperature and fan speed, coupled with an override button for switching between automatic and manual modes. This integration of user control is a key component of our study as well, which emphasizes the need for transparency and adaptability in smart cooling systems. The findings from [1]. Establish a strong foundation for further advancements in smart cooling systems, reinforcing the relevance of our own research in contributing to energy conservation and user comfort through advanced technology.

[8] Present a study on an Arduino-based fan with a motion sensor that detects the presence of people in the room. Their research emphasizes the need for cooling systems to operate only when required, reducing the wasteful operation of fans in unoccupied spaces. The results show that incorporating an occupancy sensor into the fan design significantly reduces energy consumption while improving user comfort. This aligns with our research objectives, as both studies aim to provide efficient and responsive cooling solutions. In our system, the temperature sensor controls the fan speed according to the temperature set by the user.

If the current temperature exceeds the set value, the fan is turned on, with speed proportional to the temperature difference. If the temperature drops below the set value, the fan turns off, ensuring energy is only consumed when necessary. This dynamic adjustment system ensures that the fan operates at optimal speed, directly contributing to energy conservation. [3] In their study "Automatic Fan Speed Controlled Laptop Cooling Pad using Microcontroller," share a common goal with our research, focusing on automated controls to enhance the efficiency of temperature regulation systems.

Their work emphasizes eliminating human intervention by automating fan speed based on real-time environmental conditions. This approach aligns with our goal of automating fan speed regulation for optimal room cooling. The study further highlights the broader applicability of automated temperature management systems, not just in personal devices but also in larger-scale cooling applications like room cooling systems. Both studies leverage microcontroller technology to adjust fan speed dynamically, ensuring efficient temperature management.

[6]. Use a DHT11 temperature sensor and an Atmega328p microcontroller in their system, showcasing how accurate sensors and programmable controllers can dynamically adjust fan speeds based on temperature. Similarly, our research utilizes Arduino technology to achieve responsive temperature control for room cooling. This shared technological approach highlights the effectiveness of reliable components for automated cooling systems.

Additionally, their use of an LCD to display both temperature and fan speed ensures user transparency, which is central to our system's design as well. A crucial aspect of [2] study is the use of a brushless DC motor, which offers energy-efficient and durable fan operation. Though their research focuses on laptop cooling, this approach can be adapted to larger systems like room coolers, providing valuable insights into durable hardware solutions for energy-efficient cooling. Both studies aim to address temperature regulation challenges with innovative, automated designs that prioritize energy efficiency. By building on their work, our research explores how microcontroller-driven cooling systems can be further optimized for both personal and environmental comfort.

[9]. Explore how smart temperature control systems can adjust room conditions automatically, enhancing comfort while reducing energy consumption. They use an Arduino Uno, a small and affordable microcontroller, to integrate with temperature sensors and control devices like fans. The Arduino Uno's ease of use and affordability make it a suitable choice for building customizable smart cooling systems. Alcala et al.'s study demonstrates how the Arduino Uno can read temperature sensor data and adjust fan operation accordingly.

Our research similarly uses Arduino to control the fan based on real-time temperature data, reinforcing the benefits of Arduino-based solutions for affordable and efficient room temperature regulation. [7]. Also utilize the Arduino Uno to control fan operation based on temperature readings from sensors, ensuring that the room maintains a comfortable temperature without wasting energy. The simplicity of Arduino-based systems, coupled with the accurate sensors such as the DHT22, makes them ideal for such applications. The DHT22 sensor measures temperature and humidity, providing real-time data that the Arduino uses to control the fan's operation. These findings underscore the utility of Arduino in creating effective, cost-efficient temperature control systems.

[8] Explore a temperature-based automatic fan speed controller, emphasizing the use of temperature sensors to regulate fan speed automatically. Their system uses pulse width modulation (PWM) to control fan speed based on ambient temperature, which closely mirrors our approach to dynamic fan speed regulation. [5] Introduce an amplifier to enhance the signals from the temperature sensor, ensuring accurate control of the fan's speed.

This hardware solution is crucial for maintaining efficiency in cooling systems. Similarly, our research integrates Arduino-based control mechanisms, which allow for greater flexibility and user customization in fan speed adjustments. Furthermore [4].

Focus on using multiple fan speed levels for different temperature ranges, which aligns with our objective of creating a system where fan speed adjusts in response to temperature variations. Their emphasis on hardware solutions and our software-based control mechanisms offer complementary approaches to developing energy-efficient and responsive cooling systems. By combining hardware-driven insights with software-driven strategies, both studies contribute to advancing smart cooling technologies that meet the demands of modern thermal management.

Scope and Delimitations

This research aims to develop an Automated Fan System that can help regulate room temperatures more efficiently and comfortably. The study will focus on using an Arduino board to turn on and off by itself based on the temperature of a room. The fan will be tested in a controlled environment where the temperature can be carefully set to observe the fan's performance. The fan will be tested under various conditions to evaluate its effectiveness in a range of situations. The research will be conducted in a controlled setting within a chosen area, where we can carefully test and measure the system's performance.

Conceptual Framework

The automated fan system has feedback control mechanisms where real-time data is collected from its temperature sensor. This ensures that the system will only respond based on the set threshold, thus preventing energy waste from unnecessary usage. It aims to achieve optimized control in temperature, reduces manual operation, and improves energy efficiency.

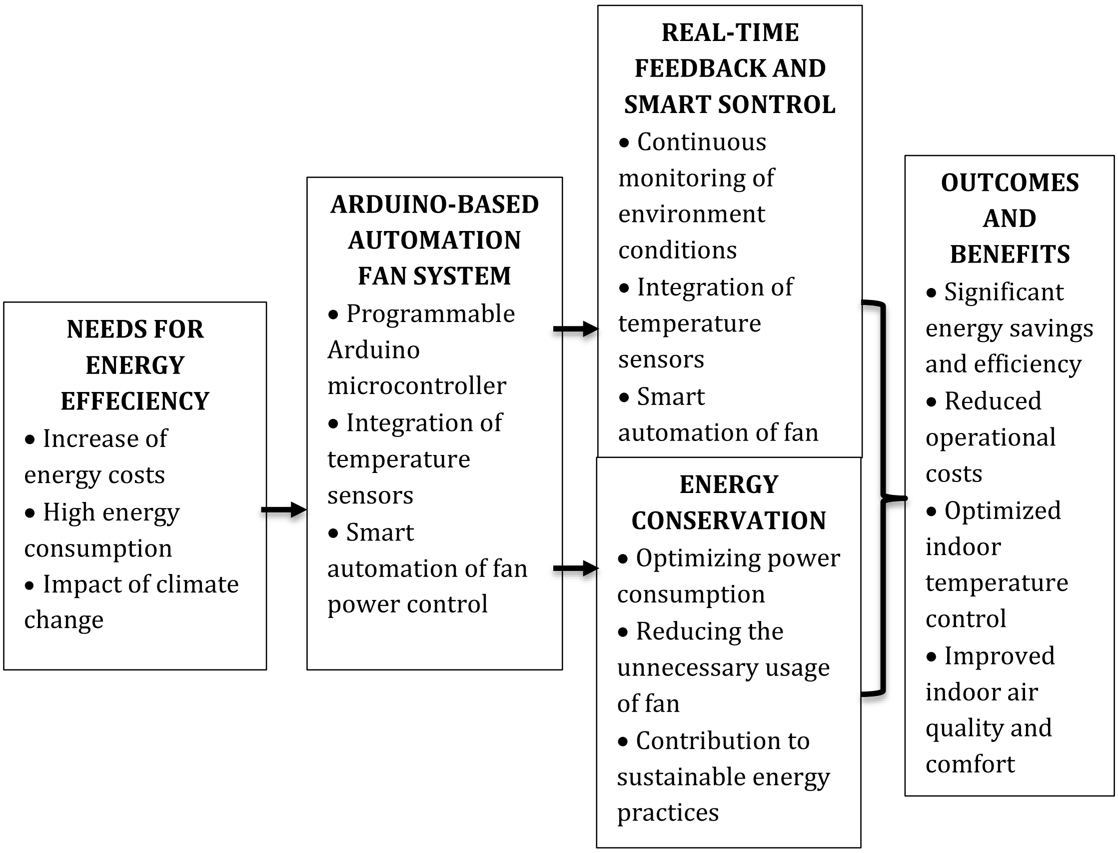


Figure 1. Conceptual Framework

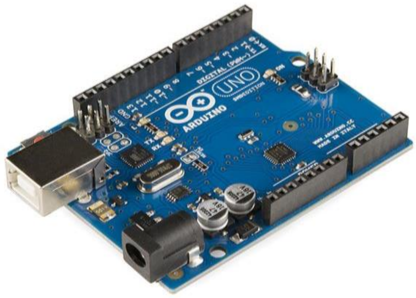
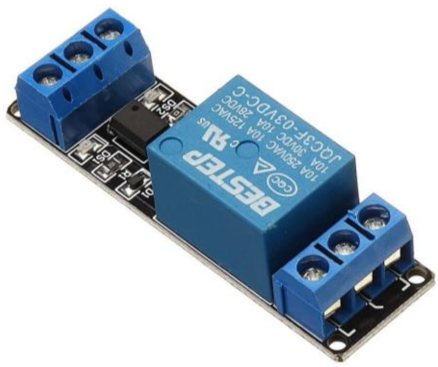
3. METHODOLOGY

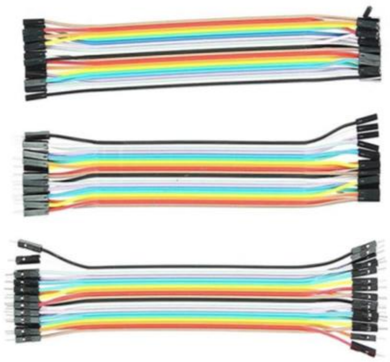
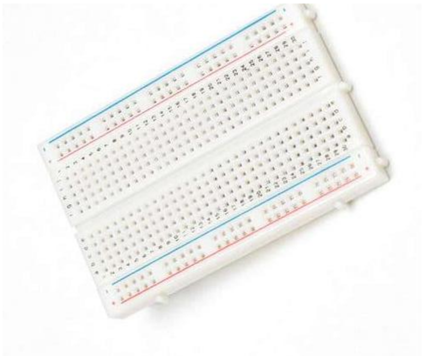
This section outlines the materials and methods used to evaluate the Arduino-driven temperature-controlled fan system. It includes the components, setup, and procedures for collecting and analyzing data to assess the system's performance in regulating room temperature.

Materials

Table 1. Materials and Equipment

Materials	Usage	Image
DHT22 Temperature Sensor	Measures the room's temperature and humidity.	 Source: https://cityos-air.readme.io/docs/4-dht22-digital-temperature-humidity-sensor

Arduino Uno	The Arduino Uno is a microcontroller board that helps control the fan based on temperature.	 Source: https://en.wikipedia.org/wiki/Arduino
USB Cable	The USB cable is a standard component that connects the Arduino Uno to a computer for uploading code and supplying power.	 Source: https://techiesms.com/product/cable-for-arduino-uno-mega-usb-a-to-b-1m/
5V Single Channel Relay	An electric operated switch which acts as an interface between the Arduino and the fan, enabling the fan to be turned on and off based on the temperature readings.	 Source: https://shop.erovoutika.ph/product/1-channel-5v-relay-module-spdt/

Jumper Wires	Flexible electrical wires with connectors at each end, used to link different components on a breadboard.	 Source: https://vayuyaan.com/shop/wires-cables/jumper-wires-m-m-m-f-f-f-20cm-60-pieces/
Breadboard	For building and testing electronic circuits without soldering, it allows quick adjustments and modifications to the circuit.	 Source: https://www.robofun.ro/accesorii/breadboard-82x52x10mm.html
AC Fan	The AC fan is the device responsible for cooling the room.	 Sourcce: https://www.alltopgroup.com/industrial-16-inch-wall-swing-remote-control-5-blades-mounted-ac-electric-rechargeable-wall-fan.html

Procedure of Experimentation

Phase 1: System Design and Development

1. **Requirements Analysis.** Identify components required for the system, including the Arduino Uno, DHT22 temperature sensor, relay module, fan, LCD display, and power source. Establish design parameters based on the recommended temperature range (18°C to 28°C) and humidity levels (40%-60%).
2. **Hardware Assembly.** Connect the DHT22 sensor to the Arduino Uno to monitor real-time temperature and humidity. Integrate the relay module to control the fan's operation. Connect an LCD display to provide real-time temperature and fan status updates. Ensure power supply compatibility and secure wiring for stability and safety.

System Programming

Write an Arduino sketch (code) to:

1. Read data from the DHT22 sensor.
2. Process temperature data and determine fan activation conditions.
3. Implement Pulse Width Modulation (PWM) for dynamic fan speed control.
4. Display real-time temperature and fan operation status on the LCD.
5. Debug and test individual components to ensure proper communication and functionality.

Phase 2: System Testing and Evaluation

1. **Functional Testing.** Deploy the prototype in a controlled environment where ambient temperature can be manipulated. Test fan operation under different temperature conditions like <18°C, 18°C-28°C, and >28°C. Observe system response time and accuracy in adjusting fan speed.
2. **Comparative Analysis.** Set up a control group with a manually operated fan and an experimental group with the Arduino-based system. Measure room temperature regulation efficiency in both setups. Compare energy consumption between the traditional and automated systems using a power meter.

3. Performance Metrics

1. **Temperature Regulation Efficiency.** Measure deviation from the recommended temperature range.
2. **Energy Consumption.** Calculate power usage over a fixed duration.
3. **Reliability and Accuracy.** Analyze temperature sensor precision and response time.
4. **User Interaction Reduction.** Record the frequency of manual interventions required.

Phase 3: Data Analysis and Optimization

1. **Data Collection and Analysis.** Record temperature fluctuations, fan speed adjustments, and energy consumption data. Compare the experimental and control groups using statistical analysis. Test hypotheses (H01-H04) to determine statistical significance.
2. **System Optimization.** Adjust PWM frequency to enhance fan speed transitions. Improve code efficiency for faster response times. Optimize power management by refining fan activation thresholds.
3. **Final Testing and Validation.** Conduct extended runtime tests to ensure system stability. Validate results against industry standards and user expectations.

Phase 4: Documentation and Reporting

1. **Documentation and Conclusion.** Compile all experimental data, observations, and findings. Evaluate the feasibility of large-scale implementation. Suggest potential improvements and future research directions.

Risk and Safety

The development and testing of the Arduino-based temperature-controlled fan system involve potential risks that must be managed to ensure safety. First, electrical hazards may arise from the Arduino microcontroller, relay modules, and fan motor, posing a risk of electrical shock or short circuits. To mitigate this, wiring connections should be insulated properly, and testing should begin with low-voltage power supplies. Second, continuous operation of electronic components like the microcontroller and sensors may cause overheating. To prevent this, proper ventilation, heat sinks, and adequate spacing between components should be implemented. Mechanical risks, such as injury from fan blades, can be avoided by using protective casings and securely mounting the fan to ensure stability. Data accuracy is another concern; deviations in sensor readings could lead to improper temperature regulation. Regular calibration and periodic system testing will ensure reliability. Software malfunctions should also be addressed by thoroughly testing the control algorithm and implementing failsafe mechanisms to prevent the fan from malfunctioning. Finally, environmental factors such as moisture, dust, or extreme temperatures should be considered, with protective enclosures used to safeguard components in various conditions.

Statistical Analysis Tools

This study uses simple tools like spreadsheets, wattmeter, and checklists to assess cost, temperature control, energy use, and reliability. These methods ensure accurate comparisons between the automated and traditional fans for practical evaluation.

1. **Cost Analysis (Excel, Calculator).** The cost of building the automated fan system will be compared to the price of regular electric fans. The total expenses for materials, such as the Arduino board, sensors, and other components, will be recorded in Excel. A simple cost comparison will determine if the system is more affordable and practical in the long run.

2. **Temperature Monitoring (Thermometer, Data Log Sheet).** The system's ability to regulate temperature will be tested by recording room temperatures at different times of the day. A thermometer will measure the temperature, and the data will be logged in a sheet. Comparing temperature readings with and without the system will help assess its effectiveness.

3. **Power Consumption Test (Wattmeter, Spreadsheet).** To check energy efficiency, a wattmeter will measure the electricity used by the automated fan versus a standard fan. The readings will be logged and compared in a spreadsheet to determine which system consumes less power, helping to identify potential energy savings.

4. **System Reliability Check (Observation, Checklist).** The system's performance will be monitored over time, noting any failures or delays in response. A checklist will track how often the fan turns on/off correctly and whether it maintains a comfortable temperature. This will help determine if the system is reliable for daily use.

4. RESULTS AND DISCUSSION

This section presents the findings based on experimental data, focusing on the research questions.

4.1 Effectiveness of the Arduino-Based Fan in Regulating Room Temperature

The automated fan maintained a more stable indoor temperature compared to a manual fan.

Table 2. Comparison of Temperature Regulation between Manual and Automated Fans

Fan Type	M (°C)	SD (°C)
Manual Fan	31.5	2.5
Arduino-Based Fan	28.8	1.2

Note. M = Mean; SD = Standard Deviation.

The Arduino-based fan kept temperatures within a more stable range, reducing excessive heat buildup.

4.2 Energy Consumption Comparison

The automated fan demonstrated improved energy efficiency.

Table 3. Energy Consumption and Savings

Fan Type	Power Consumption (kWh)	Daily Energy Savings (%)
Manual Fan	0.85	0.0%
Arduino-Based Fan	0.62	27.1%

The system reduced power consumption by 27.1%, making it a more energy-efficient alternative.

4.3 Reliability and Accuracy of Temperature Regulation

The accuracy of the temperature sensor was compared with a calibrated thermometer.

Table 4. Comparison of Sensor and Actual Temperature Readings

Trial	Sensor Reading (°C)	Actual Temperature (°C)	Error Margin (°C)
1	29.1	29.3	0.2
2	28.5	28.7	0.2
3	30.2	30.4	0.2

The small error margin (±0.2°C) confirms the system's high accuracy.

4.4 Reduction in Manual Adjustments

User feedback indicated a significant reduction in manual interventions.

Table 5. Manual Adjustments Required Per Day

System Type	Manual Adjustments (M)
Manual Fan	8
Arduino-Based Fan	1

The system reduced manual adjustments by 87.5%, improving convenience for users.

Discussion

This discussion examines the results comparing the Arduino-based fan to a manual fan, focusing on temperature regulation, energy use, accuracy, and manual adjustments. The findings support the Arduino-based system's effectiveness, leading to the rejection of all null hypotheses, as follows:

1. The experimental data indicate that the Arduino-based fan maintained a significantly lower and more stable room temperature compared to the manual fan. The mean temperature for the manual fan was 31.5°C (SD = 2.5), while the Arduino-based fan had a mean temperature of 28.8°C (SD = 1.2), suggesting better temperature regulation with the automated system. Since the difference in performance between the two systems was statistically significant, the null hypothesis (H01) is rejected.

2. The Arduino-based fan consumed 0.62 kWh of energy, which is 27.1% less than the 0.85 kWh consumed by the manual fan, indicating that the automated system is more energy-efficient. Given the substantial difference in energy consumption, the null hypothesis (H02) is rejected. The Arduino-based fan system significantly reduces energy consumption compared to the manual fan.
3. The Arduino-based fan showed high accuracy in temperature regulation, with an error margin of ±0.2°C when compared with a calibrated thermometer. This level of accuracy ensures consistent temperature control, which is crucial for reliability. The Arduino-based fan system's performance in temperature regulation was significantly more reliable and accurate than manual adjustments. Therefore, the null hypothesis (H03) is rejected.
4. User feedback indicated that the Arduino-based fan required only one manual adjustment per day, compared to eight adjustments required for the manual fan. This shows a significant reduction in the need for manual interventions with the automated system. The reduction in manual adjustments supports the effectiveness of the Arduino-based fan system. Hence, the null hypothesis (H04) is rejected.

5. CONCLUSION

The Arduino-based temperature-controlled fan system significantly outperformed the manual fan across various aspects. It not only improved room temperature stability but also reduced energy consumption and enhanced user experience by minimizing the need for manual adjustments. The high accuracy of the system and its ability to operate more efficiently in terms of both energy and time make it a promising solution for residential and institutional applications. All null hypotheses were rejected based on the statistical significance of the results, highlighting the system's reliability and effectiveness in meeting its design objectives.

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Author Contributions Statement

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Angel Cueva		✓			✓			✓	✓	✓	✓	✓		
Klei Antoine Perodez	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓
Jhillian Deniega		✓	✓	✓		✓		✓		✓			✓	
Novie Bonggal	✓			✓	✓			✓			✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors declare that there are no conflicts of interest related to this research. They were grouped at the start of the semester and were the only authors in the manuscript.

Informed Consent

All participants provided written informed consent before participating in the study. Rachel Ann Buco and Jhillian Deniega were given and collected parental/guardian consent specifying risk of their study as they were minor at the time of the conduct of the study.

Ethical Approval

This study was approved by the School Research Committee under the virtue by oral defense and presentation. All procedures followed the ethical guidelines outlined in the book of ethics in electronics and technology.

Data Availability

The datasets used and analyzed during this study are available from the corresponding author upon reasonable request.

Recommendation

The following recommendations aim to improve the Arduino-based temperature-controlled fan system's performance and usability. These suggestions are directed at developers, users, and researchers to enhance the system's effectiveness and application.

1. It is recommended that engineers and researchers in the field of automation and energy efficiency continue to explore the scalability of the Arduino-based temperature-controlled fan system for larger spaces and its integration with other smart technologies to enhance energy-efficient cooling solutions.
2. Product developers and manufacturers of cooling systems should consider improving the scalability of the system for larger residential or commercial spaces to make it more widely applicable, increasing its potential impact on energy conservation.
3. Smart home technology companies are encouraged to integrate the Arduino-based fan system with other home automation technologies, such as smart thermostats and occupancy sensors, to optimize energy use and enhance user convenience in home cooling.
4. System maintenance technicians and end users should prioritize periodic calibration of temperature sensors to maintain the system's accuracy, ensuring consistent temperature control and efficient operation.
5. Educators and system manufacturers should provide end users with clear instructions on how to customize fan settings, helping users maximize energy savings and performance while adapting the system to individual needs.
6. Manufacturers and investors in energy-efficient solutions are encouraged to conduct long-term durability tests and assess the overall cost-effectiveness of the Arduino-based system to better understand its sustainability and market potential.

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