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Design and Development of a Smart Home Temperature and Ventilation Regulation System for North East Nigeria

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***Abstract*—The increasing demand for healthy, comfortable, and energy-efficient homes has stimulated the application of smart technologies for monitoring and managing indoor environmental conditions. Conventional temperature and ventilation systems commonly rely on manual intervention, which can cause delayed responses to environmental changes, poor air circulation, unnecessary energy consumption, and variations in thermal comfort. This study was therefore undertaken to design and develop a Smart Home Temperature and Ventilation Regulation System for the automated monitoring and control of indoor environmental conditions. The study adopted a prototype-based design and development approach. The developed system consists of temperature, relative humidity, and indoor air-quality or carbon dioxide (CO_2) sensors integrated with an ESP32/Arduino microcontroller, relay or motor-driver circuits, ventilation fan, cooling components, display unit, and regulated power supply. An optional Internet of Things (IoT) interface was included to enable remote monitoring of indoor conditions. During system operation, the sensors continuously acquire environmental data and transmit the readings to the microcontroller for processing. The controller compares the acquired values with predetermined threshold levels and automatically activates the ventilation or cooling components whenever the monitored conditions exceed the specified limits. When the environmental parameters return to the acceptable range, the corresponding actuator is switched off or adjusted. This process enables continuous feedback-based regulation while minimizing the need for human intervention. The prototype was tested under different indoor environmental conditions to evaluate its monitoring and control performance. The findings showed that the system successfully identified temperature levels above the preset threshold and automatically activated the ventilation fan, resulting in a reduction of indoor temperature toward the desired range. It also successfully monitored humidity and air-quality/CO_2 levels and used the recorded parameters to support appropriate ventilation decisions. The study demonstrates that the developed system provides an effective and practical approach to automated residential temperature and ventilation control. The**

integration of continuous sensing, data processing, automated decision-making, and actuator control enhances responsiveness and reduces dependence on manual operation. Future developments could incorporate mobile applications, data logging, multi-room monitoring, energy-efficiency assessment, adaptive control techniques, fuzzy logic, and machine-learning algorithms.

***Index Terms*—Smart Home, Temperature Regulation, Ventilation Control, Internet of Things, Environmental Monitoring, ESP32, Microcontroller, Indoor Air Quality, Carbon Dioxide, Automation.**

I. INTRODUCTION

The continuous development of smart technologies has brought significant improvements to modern residential environments by providing innovative solutions for enhancing comfort, health, convenience, and energy efficiency. A major application of smart home technology is the intelligent monitoring and management of indoor environmental conditions, including temperature, humidity, ventilation, and air quality. Conventional heating, cooling, and ventilation systems largely depend on manual operation, which may result in delayed responses to environmental changes, unstable indoor conditions, and excessive energy consumption. The application of the Internet of Things (IoT), environmental sensors, microcontrollers, wireless communication, and automated control systems provides an effective approach to overcoming these limitations.

A Smart Home Temperature and Ventilation Regulation System is an IoT-based solution developed to continuously monitor and automatically control environmental conditions within residential buildings. The system uses environmental sensors to obtain real-time measurements of important parameters such as temperature, humidity, and air quality. These measurements are transmitted to a microcontroller, such as an ESP32 or Arduino, which processes the collected data and determines the appropriate control actions according to predefined threshold values.

The system is capable of responding automatically to changes in the indoor environment. When the measured temperature rises above the specified threshold, the system can activate a cooling fan or another appropriate cooling device to reduce the temperature. Likewise, when excessive humidity or unsatisfactory air quality is detected, the ventilation system can be activated to increase air circulation and improve the indoor environment. This automated process reduces the need for constant human intervention and allows the system to respond promptly to changing environmental conditions.

The incorporation of wireless communication, particularly Wi-Fi technology, further improves the functionality of the system by enabling remote monitoring and control. Using a mobile or web-based application, users can observe current temperature, humidity, and air-quality conditions, modify predefined system thresholds, control connected appliances, and receive notifications when unusual or undesirable conditions occur. Remote accessibility therefore

provides users with greater flexibility and convenience in managing their residential environment. Almadhor, et al (2025).

In addition, the automated control of cooling and ventilation appliances can support energy conservation. Rather than allowing these devices to operate continuously, the system activates them only when the monitored environmental parameters exceed predetermined levels. This demand-based operation can reduce unnecessary energy consumption while maintaining acceptable indoor environmental conditions. Consequently, the proposed system provides an intelligent and automated approach to residential temperature and ventilation management through the practical integration of IoT, sensing, communication, and control technologies.

II. RELATED WORKS

The advancement of smart-home technology has increasingly concentrated on enhancing indoor environmental quality, thermal comfort, energy efficiency, and automated control. Developments in the Internet of Things (IoT), environmental sensing technologies, artificial intelligence (AI), machine learning (ML), and intelligent control systems have made it possible to monitor indoor environmental conditions continuously and respond to changes automatically. In contrast to conventional approaches that largely depend on manual intervention or predetermined operating schedules, smart-home systems can dynamically respond to variations in temperature, humidity, carbon dioxide (CO_2), occupancy, and other air-quality parameters.

Smart Home Automation and Environmental Control: Smart-home automation involves the integration of sensors, processing units, communication technologies, and actuators to facilitate the monitoring and control of household devices and environmental conditions. In temperature and ventilation applications, sensors collect information about the indoor environment, while a microcontroller or IoT platform processes the collected data and determines the appropriate control action.

(2025), in their review of IoT-enabled building automation systems, reported that IoT technologies facilitate real-time environmental monitoring, data-driven automation, improved energy efficiency, enhanced occupant comfort, and reduction of CO_2 levels. However, their study also identified interoperability, cybersecurity, and scalability as continuing challenges. These findings demonstrate the relevance of integrating sensors and microcontrollers into automated residential environmental-control systems.

Temperature, Humidity and Thermal Comfort: Indoor temperature is a fundamental factor affecting human comfort, while relative humidity also plays an important role in determining the quality of the indoor thermal environment. Effective temperature regulation therefore requires systems capable of continuously monitoring environmental conditions and responding appropriately to changes.

Boutahri and Tilioua (2024) developed a machine-learning-based model for thermal-comfort prediction and energy optimization using Raspberry Pi devices and environmental sensors. The study compared Support Vector Machine (SVM), Artificial Neural Network (ANN), Random

Forest (RF), and XGBoost algorithms and found that Random Forest and XGBoost produced strong results in predicting thermal comfort. Similarly, Shakhovska et al. (2025) demonstrated the application of machine-learning techniques for forecasting indoor temperature, highlighting their potential contribution to energy management and indoor climate control.

These studies indicate that environmental sensors provide important inputs for effective temperature management, while predictive algorithms can further improve the responsiveness of control systems. Nevertheless, predictive models generally require historical datasets, computational resources, and appropriate model development. For this reason, a threshold-based control strategy provides a practical starting point for a low-cost prototype, with machine learning serving as a possible future enhancement.

Ventilation and Indoor Air Quality: Adequate ventilation is essential for maintaining acceptable indoor air quality because it helps remove stale air, pollutants, excessive heat, moisture, and accumulated CO_2. Modern ventilation systems increasingly employ environmental sensors to identify deteriorating air conditions and initiate appropriate corrective actions.

Rizo-Maestre et al. (2026) reviewed recent developments in intelligent ventilation and identified demand-controlled ventilation, model predictive control, reinforcement learning, IoT-based monitoring, sensor validation, and digital-twin technologies as significant areas of development. Similarly, Tanveer et al. (2024) highlighted the growing use of IoT sensors, cloud computing, smart ventilation technologies, and intelligent controllers for monitoring and managing indoor air pollution. CO_2 concentration is particularly useful in determining ventilation requirements because elevated levels can indicate inadequate air exchange. Mota et al. (2025) developed a wireless CO_2 monitoring system using an ESP32-C6 microcontroller and an SCD40 sensor and demonstrated real-time monitoring within a smart-home environment. Their work illustrates the feasibility of employing relatively affordable microcontrollers and environmental sensors for residential air-quality monitoring.

Predictive Control and Energy Efficiency: Recent research has increasingly shifted from conventional ON/OFF environmental control toward predictive and optimization-based approaches. Khan et al. (2024) proposed a predictive framework that employed LSTM, RNN, and GRU models to forecast temperature, humidity, thermal comfort, and energy consumption. The study combined these predictive models with fuzzy control and an optimization algorithm, reporting energy-cost savings of approximately 35.98%–38.22% under the evaluated energy-pricing conditions.

Similarly, Luo et al. (2023) developed an occupant-centric smart thermostat designed to improve thermal comfort while reducing energy consumption. Their study reported potential annual reductions of approximately 7%–25% in heating energy and 15%–40% in cooling energy. Sood et al. (2025) further emphasized the importance of jointly considering energy consumption, thermal comfort, and CO_2 concentration when optimizing environmental conditions in residential buildings.

These findings demonstrate that intelligent environmental-control systems can contribute to both occupant comfort and energy conservation. However, highly predictive systems may involve

greater computational and implementation requirements than simpler embedded control solutions.

Empirical Studies and Intelligent Environmental Regulation: Empirical research has provided practical evidence of the benefits of IoT-based indoor environmental monitoring. A 2024 residential study involving 84 homes monitored CO_2, temperature, relative humidity, $PM_{2.5}$, and PM_{10}. The study reported a 10.3% reduction in mean CO_2 concentration in 52 homes during the intervention period. It also found that providing occupants with real-time environmental information encouraged behavioural changes aimed at improving indoor air quality. However, sensor aging and calibration were identified as important challenges affecting long-term reliability.

Other recent studies have investigated advanced machine-learning and intelligent-control techniques. Zheng et al. (2025) developed a CNN-BiLSTM model for predicting indoor temperature in residential buildings and reported strong predictive performance. Minassian et al. (2025) compared CNN, LSTM, and CNN-LSTM models for indoor environmental prediction, while Almadhor et al. (2025) proposed a digital-twin-based deep-learning framework for personalized thermal-comfort prediction and energy-efficient building operation.

Zhang et al. (2026) experimentally investigated machine-learning-based natural ventilation control and reported that their system was able to maintain CO_2 concentrations at approximately 800–900 ppm and indoor temperature below 26°C under the conditions evaluated. These studies demonstrate the potential of predictive and intelligent techniques for environmental regulation. However, their implementation can require substantial computational resources, large datasets, dependable communication infrastructure, and specialized technical expertise.

Conceptual Review: The proposed Smart Home Temperature and Ventilation Regulation System is founded on several interconnected concepts, including smart-home technology, IoT, environmental sensing, temperature regulation, humidity monitoring, indoor air quality, ventilation, microcontrollers, actuators, automatic control, set points, real-time monitoring, and energy efficiency.

The general relationship among these components can be expressed as:

Environmental Conditions → Sensors → Microcontroller → Control Decision → Actuators → Environmental Adjustment → Feedback

Temperature, humidity, and air-quality or CO_2 sensors provide environmental data to a programmable controller such as an Arduino or ESP32. The controller compares the measured values with predefined thresholds and determines whether ventilation fans or cooling equipment should be activated or deactivated. Continuous feedback from the sensors enables the system to repeatedly assess indoor conditions and adjust the operation of the connected devices, thereby creating a closed-loop environmental-control system.

Research Gap: The reviewed literature demonstrates considerable progress in smart-home temperature management, indoor-air-quality monitoring, intelligent ventilation, thermal-comfort prediction, and energy optimization. However, many existing systems either concentrate on individual environmental parameters or depend on relatively complex technologies such as deep

learning, reinforcement learning, digital twins, predictive optimization, and sophisticated cloud-based architectures.

Although these advanced technologies offer significant capabilities, they can increase system cost, computational requirements, development complexity, and dependence on reliable communication infrastructure. Consequently, there is a need for a simpler and more affordable residential solution capable of integrating several environmental parameters within a single automated control system.

The identified gap provides an opportunity to develop a simple, affordable, integrated, and locally deployable smart-home system that simultaneously monitors temperature, humidity, and air quality while automatically controlling ventilation and cooling equipment. In addition, sensor calibration and practical testing within residential environments remain important considerations for ensuring system reliability and effectiveness.

Contribution of the Proposed Study: The proposed Smart Home Temperature and Ventilation Regulation System seek to integrate environmental sensors, a microcontroller, control algorithms, and actuators into a unified residential environmental-control platform. The system will continuously monitor temperature, humidity, and air quality or CO_2 concentration and automatically activate or deactivate ventilation and cooling devices when predefined environmental thresholds are reached.

The system will also provide users with information about current indoor environmental conditions and minimize unnecessary operation of connected equipment, thereby supporting energy efficiency. Its architecture is intended to remain relatively simple and affordable while providing the essential functions required for automated residential environmental management.

Overall, the reviewed literature establishes the feasibility of sensor-based environmental monitoring and automated regulation in residential buildings. The proposed study contributes by integrating established IoT and embedded-system technologies into a low-cost, practical, automated, and physically testable residential solution. Furthermore, the system can serve as a foundation for future enhancements involving mobile connectivity, occupancy detection, machine learning, predictive control, and more advanced intelligent-building technologies.

III. METHODOLOGY

The proposed Smart Home Temperature and Ventilation Regulation System will be developed using a prototype-based design and development methodology. This methodology is appropriate for the study because the project involves the design, construction, programming, integration, testing, and evaluation of a physical prototype comprising environmental sensors, a microcontroller, actuators, control algorithms, and a user interface.

The methodology provides a systematic framework for transforming the identified system requirements into a functional prototype. It will enable the researcher to develop the hardware and software components, integrate them into a unified system, and evaluate their performance under controlled indoor environmental conditions. The major phases of the development process

will include requirement analysis, system design, hardware development, software development, system integration, testing, and evaluation. The overall development process is represented as follows:

Requirement Analysis → System Design → Hardware Development → Software Development → System Integration → Testing → Evaluation

Requirement Analysis

The first stage of the study will involve identifying and analysing the functional and environmental requirements of the proposed smart-home system. The system will be designed to continuously monitor important indoor environmental parameters, particularly temperature, relative humidity, and air quality or carbon dioxide (CO_2) concentration.

In addition to environmental monitoring, the system will be required to automatically regulate ventilation and cooling equipment whenever the monitored conditions exceed predefined threshold values. For example, excessive temperature may trigger the operation of a ventilation fan or cooling device, while elevated CO_2 concentration may cause the ventilation system to operate.

The identified requirements will provide the basis for selecting appropriate sensors, processing units, actuators, communication technologies, power components, and software tools required for implementation.

System Design

At this stage, the overall architecture of the proposed system will be designed. The design will consist of both hardware and software components that work together to monitor and regulate indoor environmental conditions.

The hardware architecture will include environmental sensors, an ESP32 or Arduino microcontroller, relay or motor-driver modules, a ventilation fan, an optional cooling device, a display unit, communication components, and a suitable power supply.

The software architecture will specify how sensor data will be acquired, processed, analysed, and converted into appropriate control actions. The control program will compare measured environmental parameters with predefined threshold values and determine the appropriate response.

Where Internet of Things (IoT) functionality is incorporated, the wireless communication capability of the ESP32 can be used to transmit environmental information to a web-based or mobile monitoring platform.

Hardware Development

The hardware development phase will involve the selection, connection, configuration, and testing of the electronic components required for the prototype.

A temperature and humidity sensor will be used to measure the thermal and moisture conditions within the indoor environment. An air-quality or CO_2 sensor will provide information about changes in indoor air conditions.

The sensors will be connected to the microcontroller, which will serve as the central processing and decision-making unit. The microcontroller will receive the sensor measurements, process the information, and determine the appropriate response based on the programmed control rules.
Relay modules or motor-driver circuits will be employed to interface the microcontroller with the ventilation fan, cooling device, and other electrical loads. Appropriate power-regulation and protection components will also be incorporated to promote safe, stable, and reliable operation of the prototype.

Software Development
The software development phase will involve programming the microcontroller to acquire, process, and interpret environmental measurements obtained from the connected sensors.
The control program will continuously compare the measured values with predetermined threshold levels. Based on the results of this comparison, the system will determine whether the ventilation or cooling equipment should be activated, deactivated, or adjusted.
For instance, when the measured temperature rises above the defined upper threshold, the controller will issue a control signal to activate the ventilation fan or cooling device. Similarly, when the CO_2 concentration or air-quality measurement exceeds the specified limit, the controller will activate the ventilation system to improve indoor air circulation.

The fundamental control process can be expressed as:
Sensor Reading → Data Processing → Threshold Comparison → Control Decision → Actuator Activation
When the measured environmental parameters return to their acceptable ranges, the controller will deactivate the relevant equipment or modify its operation accordingly.
3.5 System Integration
After the hardware and software components have been developed individually, they will be integrated to form a complete functional prototype.
The integration process will involve connecting the environmental sensors, microcontroller, relay and control circuits, ventilation fan, cooling device, display unit, power supply, and communication interface. Each component will be configured to communicate correctly with the others and operate as part of a unified control system.
Where IoT functionality is implemented, environmental measurements can be transmitted through Wi-Fi to a web or mobile dashboard. This will provide users with the opportunity to monitor indoor environmental conditions remotely while the automatic control functions continue to operate locally.
System integration will also involve checking communication between the sensors and controller, verifying actuator responses, and ensuring that the complete system performs according to the specified design requirements.
Testing and Evaluation

The completed prototype will undergo systematic testing under different indoor environmental conditions. The purpose of the testing will be to determine whether the system performs according to its functional and technical requirements.

The evaluation will focus on the following performance parameters:

1. Sensor measurement accuracy
2. Temperature monitoring performance
3. Humidity monitoring performance
4. Air-quality or CO_2 detection performance
5. System response time
6. Fan activation and deactivation
7. Temperature reduction performance
8. Ventilation effectiveness
9. Overall system reliability
10. IoT monitoring performance, where implemented
11. Energy consumption, where appropriate measurement facilities are available

The results obtained from the testing process will be analyzed to determine the effectiveness, responsiveness, reliability, and overall performance of the proposed system.

Operation of the Existing System

Conventional residential temperature and ventilation management generally depends on manual intervention by occupants. Under this approach, the occupant observes the indoor environmental conditions and determines whether corrective action is required.

When intervention is considered necessary, the occupant may manually switch a fan or air conditioner on or off, open or close windows, or take other measures to improve the indoor environment. The occupant then observes the conditions again to determine whether the desired level of comfort has been achieved.

The operational process can therefore be represented as:

Occupant Observes Condition → Occupant Makes Decision → Fan/AC/Window is Manually Operated → Occupant Observes Condition Again

This approach provides limited automated feedback because environmental conditions are not continuously analysed and acted upon by an electronic control system. Consequently, the effectiveness and timeliness of environmental regulation depend largely on the occupant's awareness, availability, and willingness to respond to changing conditions.

Analysis of the Proposed System

The proposed Smart Home Temperature and Ventilation Regulation System is designed to address the limitations associated with conventional manual temperature and ventilation control. The system will continuously monitor indoor environmental conditions and automatically regulate ventilation and cooling equipment according to predefined control rules.

Environmental sensors will obtain real-time measurements of temperature, relative humidity, and air quality or CO_2 concentration. The collected measurements will be transmitted to the microcontroller for processing and analysis. The controller will compare the measured values with predefined threshold levels and initiate the appropriate control response.

For example, the temperature-control process can be represented as:
High Temperature → Temperature Sensor → Microcontroller → Threshold Exceeded → Fan/Cooling Device ON
Similarly, the air-quality control process can be represented as:
High CO_2/Poor Air Quality → Air-Quality Sensor → Microcontroller → Threshold Exceeded → Ventilation ON
When the environmental conditions return to the acceptable range, the controller will deactivate the relevant actuator or modify its operation.
This arrangement forms a closed-loop control system, since environmental measurements are continuously obtained from sensors and fed back to the controller. The feedback information is then used to determine subsequent control actions.

Major Components of the Proposed System

Component	Function
ESP32/Arduino Microcontroller	Processes sensor information and controls overall system operation.
Temperature Sensor	Measures indoor temperature.
Humidity Sensor	Measures relative humidity within the indoor environment.
Air-Quality/CO_2 Sensor	Detects changes in indoor air quality or CO_2 concentration.
Relay Module	Provides electrical switching between the controller and connected appliances.
Motor Driver	Controls a DC ventilation fan where required.
Ventilation Fan	Circulates or removes indoor air.
Cooling Device	Provides additional cooling when environmental conditions require it.
LCD/OLED Display	Displays current environmental measurements and system status.
Wi-Fi/IoT Interface	Provides wireless communication and supports remote monitoring.
Power Supply	Provides the required electrical power to the system components.
Software/Control Algorithm	Processes sensor measurements and determines appropriate actuator operations.

Proposed System Operation

The proposed system will operate through a continuous sequence of sensing, processing, decision-making, and actuation. The operational procedure will consist of the following steps:

1. The environmental sensors will collect measurements of indoor temperature, humidity, and air quality or CO_2 concentration.
2. The collected sensor readings will be transmitted to the microcontroller.
3. The microcontroller will receive and process the incoming measurements.
4. Each environmental parameter will be compared with its corresponding predefined threshold.
5. When the temperature exceeds the specified threshold, the controller will activate the ventilation fan or cooling device.
6. When humidity or air-quality conditions exceed their specified limits, the ventilation system will be activated.
7. When the measured conditions return to acceptable levels, the controller will deactivate or adjust the relevant equipment.
8. Current environmental measurements and system status can be displayed on an LCD or OLED display.
9. Where IoT functionality is incorporated, environmental measurements can also be transmitted to a mobile or web-based monitoring platform.
10. The sensors will continue collecting environmental data, allowing the control cycle to repeat automatically.

The continuous interaction between the sensors, microcontroller, and actuators establishes a feedback mechanism through which the system can respond to changes in indoor environmental conditions without requiring continuous human intervention.

Advantages of the Proposed System

Automatic Temperature Regulation

The system will continuously monitor indoor temperature and automatically activate the appropriate cooling or ventilation equipment whenever the measured temperature exceeds the predetermined threshold.

Automatic Ventilation

The ventilation fan will operate automatically when temperature, humidity, or air-quality measurements indicate that additional air circulation or ventilation is required.

Real-Time Environmental Monitoring

The system will provide current information concerning indoor temperature, relative humidity, and air quality. The information can be displayed locally and, where IoT functionality is implemented, accessed remotely through a mobile or web interface.

Improved Indoor Comfort

By automatically maintaining environmental conditions within predefined acceptable ranges, the proposed system can contribute to more consistent indoor thermal and environmental comfort.

Improved Energy Management

The proposed system will operate ventilation and cooling equipment according to measured environmental conditions rather than requiring continuous operation. This approach can reduce unnecessary operation and support more efficient energy use.

Improved Indoor Air Quality: The integration of an air-quality or CO_2 sensor enables the system to identify deteriorating indoor air conditions and automatically activate ventilation when necessary.

Reduced Human Intervention: The system reduces the need for occupants to continuously observe environmental conditions and manually operate fans, ventilation equipment, or cooling devices.

Remote Monitoring: When an IoT interface is incorporated, users will be able to monitor indoor environmental measurements remotely using a mobile device or web-based dashboard.

Expandability: The proposed architecture can be extended by incorporating additional environmental sensors, actuators, communication technologies, or smart appliances according to future requirements.

Data Logging: The system can be configured to store historical environmental measurements. These records can be used to analyzed temperature, humidity, and air-quality patterns and support future system optimization.

Overall System Analysis

The proposed system provides an automated approach to indoor temperature and ventilation management by integrating continuous environmental sensing, automated decision-making, feedback control, and optional IoT connectivity. The system receives environmental information from the sensors and transmits the measurements to the microcontroller for processing. The controller compares the measured values with predefined threshold levels and determines whether ventilation or cooling equipment should be activated, deactivated, or adjusted.

Unlike conventional manual systems, the proposed approach reduces dependence on continuous human intervention and enables environmental conditions to be monitored and regulated more consistently.

The architecture is suitable for prototype development because it can be implemented using readily available components, including an ESP32 or Arduino microcontroller, temperature and humidity sensors, an air-quality or CO_2 sensor, relay modules, ventilation fans, display units, and wireless communication interfaces.

However, several implementation considerations must be addressed. These include sensor calibration, appropriate threshold selection, power-supply stability, component reliability, system maintenance, electrical safety, and cybersecurity where IoT connectivity is employed. Proper

calibration and testing will therefore be necessary to ensure that the sensors provide reliable measurements and that the system responds appropriately to changing environmental conditions.
In summary, the prototype-based methodology provides a structured framework for designing, implementing, integrating, testing, and evaluating the Smart Home Temperature and Ventilation Regulation System. The approach will enable the researcher to develop a functional residential prototype capable of continuously monitoring indoor environmental conditions and automatically regulating ventilation and cooling equipment according to predefined control requirements.

Block Diagram for the proposed system

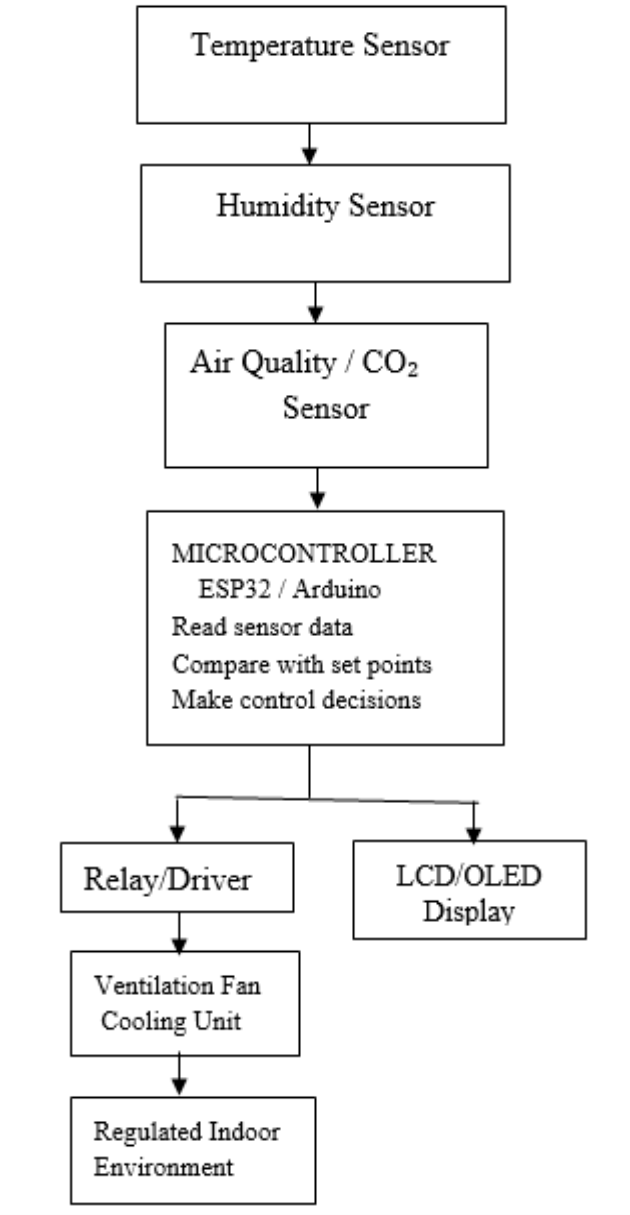


Figure 3.1 Block Diagram of the Proposed System

Block Diagram Description

The temperature, humidity, and air-quality/CO_2 sensors collect information about the indoor environment. The ESP32/Arduino microcontroller processes the sensor readings and compares them with predefined threshold values. When the measured conditions exceed the acceptable limits, the controller sends a signal to the relay or driver, which activates the ventilation fan or cooling unit. The display provides the user with information about the current environmental conditions.

The system begins with the temperature, humidity, and air-quality/CO_2 sensors, which continuously measure indoor environmental conditions. The readings are sent to the ESP32/Arduino microcontroller for processing.

The microcontroller compares the measured values with predefined threshold values. If the temperature or air-quality level becomes unacceptable, it sends a signal to the relay/driver to activate the ventilation fan or cooling unit. The current environmental readings can be displayed on an LCD/OLED display.

Architectural Diagram

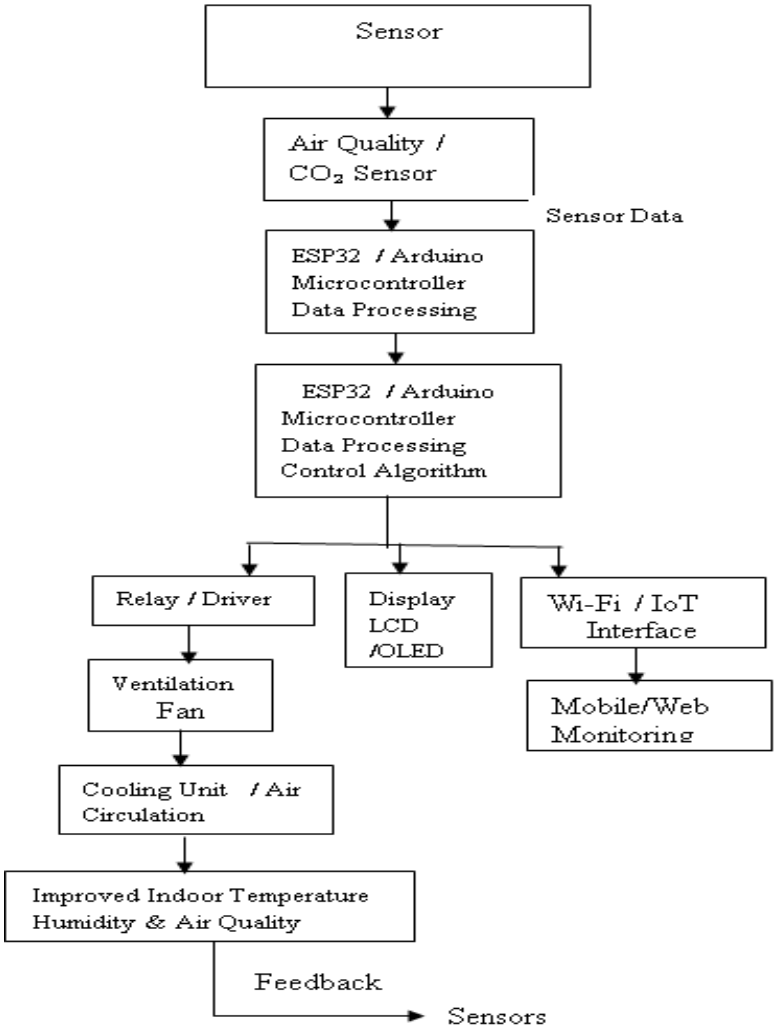


Figure 3.2 Architectural Diagram of the Proposed System

Architectural Layers

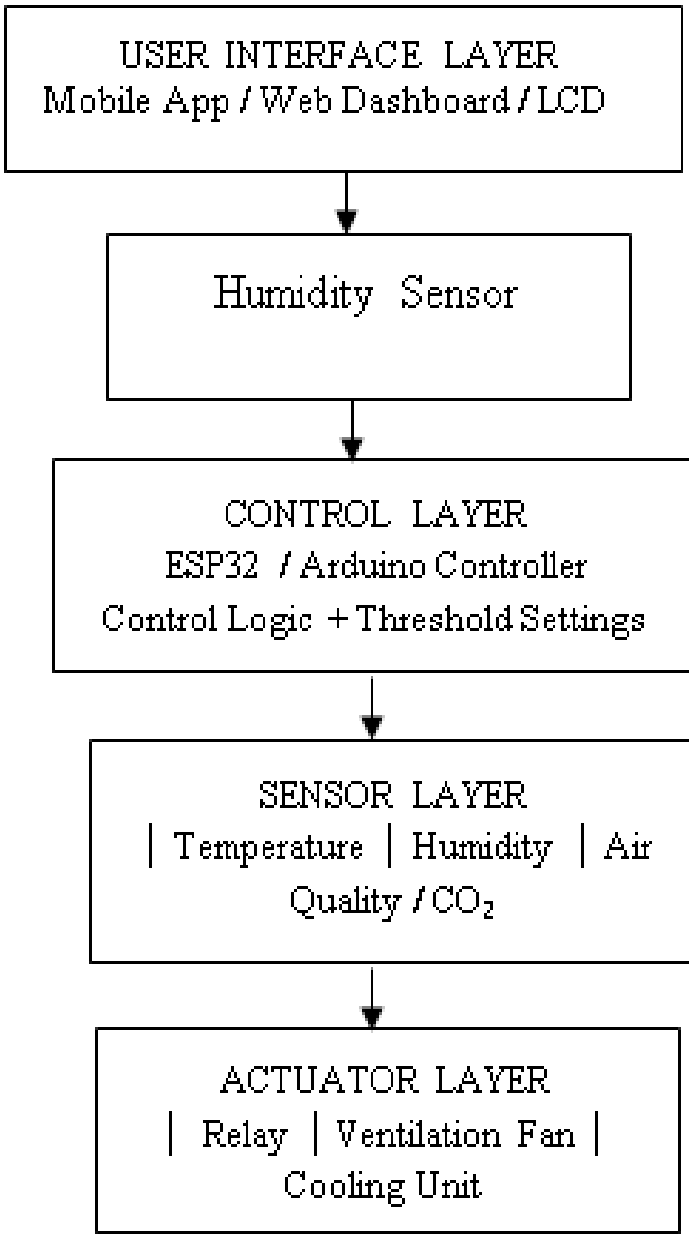


Figure 3.3 Architectural Layers of the Proposed System

The architecture can also be presented in four major layer.
The architecture follows the sequence:
Sensing → Processing → Decision Making → Actuation → Feedback
This means that the system continuously senses the indoor environment, processes the measurements through the microcontroller, determines whether intervention is required, activates the appropriate ventilation or cooling device, and then measures the environment again to determine whether the desired condition has been achieved.

System Flowchart

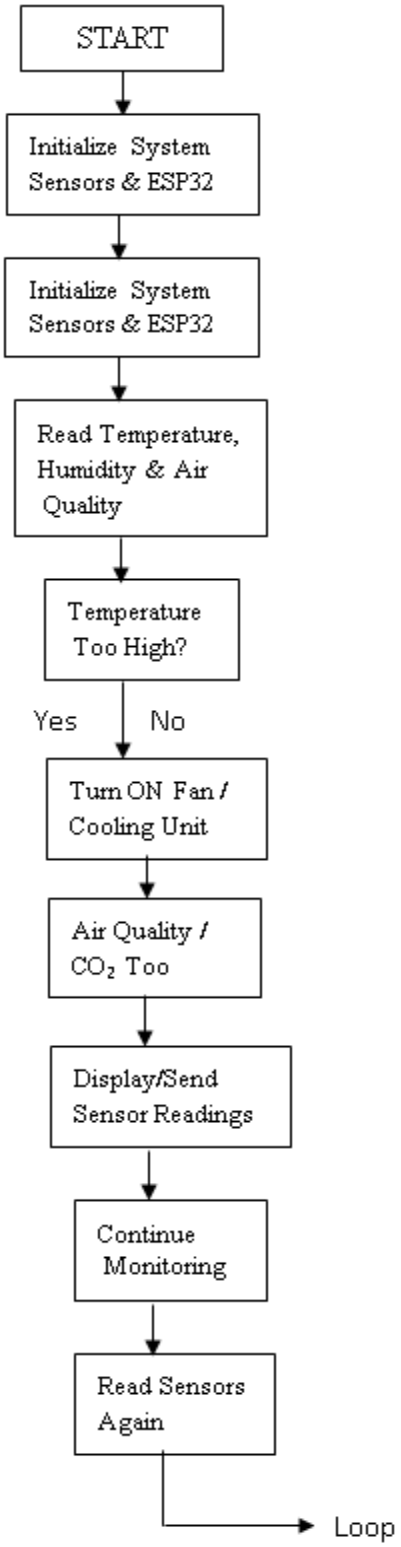


Figure 3.4 System Flowchart of the Proposed System

Flowchart Logic

The operation can be summarized as:

Start → Initialize Sensors → Read Environmental Data → Check Temperature → Check Air Quality → Activate/Deactivate Ventilation or Cooling → Display Results → Continue Monitoring.

Suggested Control Conditions

Parameter	Condition	System Response
Temperature	Above set limit	Fan/Cooling ON
Temperature	Within acceptable range	Fan/Cooling OFF
Humidity	Above set limit	Ventilation ON
CO_2/Air quality	Above set limit	Ventilation ON
All conditions normal	Within limits	Maintain normal state

This design provides a closed-loop automatic control system, because the sensors continuously measure the indoor environment and provide feedback to the ESP32/Arduino controller for subsequent decisions.

IV. DISCUSSION, *FINDINGS AND RESULTS*

Results of System Testing

The developed Smart Home Temperature and Ventilation Regulation System was subjected to a series of practical tests under different indoor environmental conditions to evaluate its ability to monitor and control temperature, humidity, and air quality. During the testing process, the environmental sensors continuously captured relevant measurements and transmitted the data to the microcontroller for processing and analysis. When any monitored parameter exceeded its predefined threshold, the control unit automatically initiated the appropriate ventilation or cooling response.

The test results showed that the ventilation fan was activated whenever the measured temperature exceeded the predetermined threshold of 30°C. After the fan was switched on, the temperature gradually decreased towards the acceptable operating range. This behaviour demonstrates that the developed prototype was capable of detecting variations in indoor environmental conditions and initiating an appropriate response without requiring continuous manual intervention.

Table 4.1: Summary of Temperature and Ventilation Test Results

Test	Initial Temperature (°C)	Threshold (°C)	Peak Temperature (°C)	Fan Status	Final Temperature (°C)	Result
1	27.1	30.0	30.4	ON	28.6	Successful
2	27.8	30.0	31.2	ON	28.9	Successful
3	28.2	30.0	30.7	ON	29.1	Successful

4	27.5	30.0	32.0	ON	29.0	Successful
5	28.0	30.0	30.9	ON	28.7	Successful

As shown in Table 4.1, the system responded to temperature increases by activating the ventilation fan whenever the measured temperature exceeded 30°C. The reduction observed in the final temperature after fan activation indicates that the ventilation mechanism was effective in bringing the indoor temperature back towards the desired range.

V. FINDINGS

The implementation and evaluation of the prototype produced the following major findings:

1. Effective Temperature Monitoring: The system successfully monitored indoor temperature continuously and transmitted the measured values to the microcontroller for processing and control.
2. Automatic Ventilation Control: The ventilation fan was automatically activated whenever the monitored environmental conditions exceeded the programmed threshold.
3. Automatic Deactivation: The system was capable of switching off the ventilation fan after the environmental conditions returned to the acceptable operating range.
4. Reduced Manual Intervention: The automated monitoring and control mechanism reduced the need for occupants to continuously observe indoor conditions and manually operate the ventilation equipment.
5. Comprehensive Environmental Monitoring: The integration of temperature, humidity, and air-quality/CO_2 sensors provided a broader assessment of indoor environmental conditions.
6. Real-Time Response: Continuous acquisition of sensor data enabled the system to detect changes in environmental conditions and respond according to the programmed control rules.
7. Feedback-Based Operation: The interaction among the sensors, microcontroller, and ventilation actuator established a closed-loop mechanism for monitoring and regulating indoor conditions.
8. Potential Energy Efficiency: Operating the ventilation system only when environmental conditions require intervention may help reduce unnecessary equipment operation and associated energy consumption.
9. System Expandability: The prototype can be enhanced through the integration of IoT connectivity, mobile applications, data-logging facilities, additional sensors, and other smart-home technologies.

Discussion of Results and Findings

The results obtained from the implementation and testing of the prototype demonstrate the feasibility of using a sensor-based automated system for indoor environmental monitoring and ventilation regulation. In contrast to conventional approaches that largely depend on occupants to observe environmental conditions and operate ventilation devices manually, the proposed system

continuously collects environmental information and uses the measurements to determine appropriate control actions.

The temperature monitoring results indicate that the system successfully detected increases in indoor temperature and responded by activating the ventilation fan when the predefined threshold was exceeded. The subsequent reduction in temperature demonstrates effective coordination between the temperature sensor, microcontroller, and ventilation actuator. This confirms that the system can provide an automatic response to changing indoor temperature conditions.

The inclusion of humidity monitoring provides additional information for evaluating indoor environmental comfort. Temperature alone may not provide a complete representation of indoor conditions because variations in relative humidity can influence comfort and ventilation requirements. Similarly, air-quality or CO_2 monitoring extends the functionality of the system by enabling it to identify conditions associated with inadequate ventilation, even when the measured temperature remains within an acceptable range.

The automated control mechanism also contributes to reducing human involvement in the operation of the system. The control process follows the sequence:

Environmental Condition → Sensor Detection → Data Processing → Threshold Comparison → Control Decision → Actuator Response → Feedback

Through this process, environmental conditions are continuously monitored, processed, and compared with predetermined limits. Appropriate control actions are then initiated based on the results of the comparison. This establishes a feedback-based system capable of responding dynamically to changes within the indoor environment.

The comparison with conventional manual environmental control further indicates that the proposed system provides additional monitoring and automation capabilities. These include automatic temperature monitoring, sensor-based environmental assessment, automatic ventilation control, real-time response, and the possibility of remote monitoring where IoT functionality is implemented. Consequently, the system provides a more automated approach to residential environmental management.

Nevertheless, the reliability and effectiveness of the system may depend on several technical factors. These include the accuracy and calibration of the sensors, appropriate selection of threshold values, stability of the power supply, reliability of the ventilation actuator, and variations in the surrounding environmental conditions. Proper calibration, suitable threshold configuration, and regular maintenance are therefore important for achieving consistent system performance.

Achievement of Project Objectives

The results obtained from the design, implementation, and testing of the prototype indicate that the major objectives of the project were substantially achieved. The system was successfully developed using environmental sensors, a microcontroller, control circuitry, and ventilation equipment.

The objective of monitoring indoor environmental conditions was achieved through the integration of temperature, humidity, and air-quality/CO_2 sensors. These sensors provided real-time environmental measurements to the microcontroller for processing and decision-making.

The objective of automatically regulating ventilation was achieved through the implementation of threshold-based control logic. The microcontroller activated the ventilation fan when the measured environmental conditions exceeded the predefined limits and deactivated the fan when the conditions returned to the acceptable range.

The objective of reducing dependence on manual control was also achieved because the system could independently monitor environmental conditions and initiate appropriate ventilation responses without requiring continuous human intervention.

The final objective, which involved evaluating the performance of the developed system, was achieved through a series of tests involving temperature monitoring, ventilation activation, environmental condition changes, and observation of the overall operational behaviour of the prototype.

Overall Result

The overall results demonstrate that the developed Smart Home Temperature and Ventilation Regulation System successfully performed its fundamental functions of indoor environmental monitoring and automated ventilation control.

The operational process of the prototype can be represented as:

Sensing → Processing → Decision-Making → Actuation → Feedback

Through this process, the system continuously obtained environmental measurements, transmitted the data to the microcontroller, compared the measurements with predefined thresholds, and automatically controlled the ventilation equipment based on the detected conditions.

The findings demonstrate the feasibility of applying microcontroller and sensor technology to residential temperature and ventilation management. The developed prototype provides a practical framework for reducing manual intervention and improving the automation of indoor environmental control.

The system also provides opportunities for further development through the incorporation of IoT-based remote monitoring, environmental data logging, energy-consumption monitoring, additional environmental sensors, mobile applications, and advanced control techniques such as adaptive, fuzzy-logic, or machine-learning-based control.

In conclusion, the developed prototype provides a functional foundation for automated indoor environmental monitoring and ventilation regulation and demonstrates the potential of smart-home technology for improving the management of residential indoor conditions. The numerical values in Table 4.1 should be used in the final project only if they represent the actual measurements obtained during your prototype testing. If they are sample or illustrative values, they should be replaced with the corresponding experimental readings before final submission.

VI. CONCLUSION

The Smart Home Temperature and Ventilation Regulation System was successfully designed, developed, and implemented to provide automated monitoring and regulation of indoor environmental conditions. The system integrates environmental sensors with a microcontroller to continuously measure temperature and other relevant conditions and automatically control ventilation based on predefined threshold values.

The implementation established that sensor-based automation can minimize reliance on manual intervention while providing a timely and responsive means of maintaining suitable indoor environmental conditions. The integration of sensors, a microcontroller, control circuitry, and ventilation equipment provides a practical framework for managing temperature and ventilation within residential environments. Furthermore, the automatic operation of the ventilation system can help minimize unnecessary equipment usage and promote more efficient energy consumption.

The project therefore demonstrates the feasibility of applying a microcontroller-based control system to automatic temperature and ventilation management in a smart-home environment. The developed prototype provides a useful platform for future improvements involving greater intelligence, connectivity, scalability, and energy efficiency. With further development, the system can evolve into a more comprehensive residential environmental management solution capable of integrating multiple sensors, smart appliances, remote monitoring, and advanced control techniques.

VII. FUTURE WORK

Future enhancement of the Smart Home Temperature and Ventilation Regulation System should concentrate on improving its functionality, intelligence, reliability, energy efficiency, and scalability. The following areas are recommended for further investigation and development:

1. IoT and Remote Monitoring: Internet connectivity should be incorporated to enable users to monitor indoor environmental conditions and control the system remotely through a mobile application or web-based platform.
2. Humidity and Air-Quality Monitoring: Additional sensors should be integrated to measure relative humidity, CO_2 concentration, and other relevant air-quality parameters, thereby providing a more comprehensive assessment of indoor environmental conditions.
3. Energy Management: Energy-efficient ventilation and cooling devices, together with intelligent control strategies, should be adopted to minimize unnecessary power consumption while maintaining acceptable indoor conditions.
4. Multiple-Sensor Deployment: Sensors can be installed in multiple rooms or strategic locations within a building to provide broader environmental coverage and support room-specific temperature and ventilation control.

5. Data Logging and Analysis: Future versions should incorporate data-storage capabilities for recording temperature, humidity, air-quality, and ventilation information. The collected data can be analyzed to identify environmental patterns and support future system optimization.
6. Automatic Alerts and Notifications: A notification mechanism should be developed to inform users whenever environmental parameters exceed specified limits or when abnormal system conditions are detected.
7. Advanced Control Algorithms: Future studies should investigate the application of fuzzy logic, adaptive control, predictive control, and machine-learning techniques to improve the accuracy, responsiveness, and efficiency of environmental regulation.
8. Smart-Home Integration: The system can be integrated with other household devices, such as air conditioners, automated windows, lighting systems, and security systems, to provide a more comprehensive and coordinated smart-home environment.
9. Backup Power Supply: Battery storage, solar power, or an uninterruptible power supply (UPS) can be incorporated to maintain essential sensing, monitoring, and control functions during power interruptions.
10. Extended Testing and Validation: Further evaluation should be conducted under different room sizes, occupancy levels, environmental conditions, and extended operating periods to determine the system's long-term reliability, measurement accuracy, response time, and energy performance.

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