PRACTICAL WORK REPORT

ANALYSIS OF THE DESIGN OF AN AUTOMATIC AIR QUALITY CONTROL SYSTEM BASED ON SMART HOME TECHNOLOGY USING AN INDUSTRIAL ENGINEERING APPROACH

INTERNATIONAL COURSE PROGRAM (ICP)

Prepared by:

<u>HAFIZHA NING FIRDAU</u>

(238150016)

DEPARTMENT OF INDUSTRIAL ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF MEDAN AREA

2026

2/3/26

f 90 (A)

PRACTICAL WORK REPORT

ANALYSIS OF THE DESIGN OF AN AUTOMATIC AIR QUALITY CONTROL SYSTEM BASED ON SMART HOME TECHNOLOGY USING AN INDUSTRIAL ENGINEERING APPROACH

INTERNATIONAL COURSE PROGRAM (ICP)

Prepared by:

HAFIZHA NING FIRDAU

(238150016)

DEPARTMENT OF INDUSTRIAL ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF MEDAN AREA

2026

APPROVAL SHEET

PRACTICAL WORK REPORT

ANALYSIS OF THE DESIGN OF AN AUTOMATIC AIR QUALITY CONTROL SYSTEM BASED ON SMART HOME TECHNOLOGY USING AN INDUSTRIAL ENGINEERING APPROACH

Prepared by:

Hafizha Ning Firdau

NPM: (238150016)

Approved by:

Advisor

Nukhe Andri Silviana, S.T, M.T.

NIDN: 0127038802

Acknowledged by:

Head of Industrial Engineering Study Program

Chalis Fajri Hasibuan, ST., M.Sc.

NIDN: 0110068801

DEPARTMENT OF INDUSTRIAL ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF MEDAN AREA

2026

PREFACE

All praise and gratitude to Allah SWT for the blessings and guidance that have enabled the author to complete this project report entitled: "ANALYSIS OF THE DESIGN OF AN AUTOMATIC AIR QUALITY CONTROL SYSTEM BASED ON SMART HOME TECHNOLOGY USING AN INDUSTRIAL ENGINEERING APPROACH".

This report is prepared as a final assignment for the International Course Program (ICP) at Universitas Medan Area.

The author wishes to extend deepest appreciation to those who have provided invaluable support and guidance during the preparation of this report:

1. Beloved parents and family for their continuous prayers and support.
2. Respected supervisors and lecturers of the ICP program at Universitas Medan Area for their valuable guidance and advice throughout this project.
3. Friends and teammates who have contributed their support and cooperation.

The author acknowledges that this report is not without shortcomings. Therefore, constructive feedback and suggestions are highly appreciated. It is hoped that this report will provide academic benefits and inspire future developments in smart home technology and industrial engineering applications.

Medan, February 17, 2026

Hafizha Ning Firdau

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1. Background

Indoor air quality (IAQ) has become a critical factor in human health, considering that people spend more than 90% of their time indoors, whether at home, in offices, or in public facilities . Poor indoor air quality, caused by pollutants such as particulate matter (PM2.5 and PM10), carbon monoxide (CO), and volatile organic compounds (VOCs), can trigger various health problems ranging from mild irritation of the eyes and respiratory tract to serious illnesses such as asthma, heart disease, and even being a leading cause of death according to the World Health Organization .

In the context of modern residential areas, this problem is increasingly complex. Sources of pollution do not only come from indoor activities such as cooking or using household products, but also from outside sources. Smoke from waste burning, vehicle exhaust, and industrial emissions can easily enter homes through windows and ventilation, creating discomfort and significant health risks, especially for vulnerable groups such as children and the elderly . Traditional solutions that rely on manual actions such as closing windows or turning on fans prove ineffective, especially when residents are away or asleep.

Responding to this challenge, the concept of a "Smart Home" offers an intelligent and automatic solution. By integrating sensor technology, automation, and the Internet of Things (IoT), a system can be designed to autonomously detect, analyze, and respond to environmental changes. This approach aligns with the principles of Industrial Engineering, which focuses on system optimization, process efficiency, human factors (ergonomics), and the integration of technology to improve overall quality of life.

This research aims to analyze the design of an automatic air quality control system based on smart home technology. The analysis will not only focus on the technical aspects of the hardware and software but will also evaluate the system from an Industrial Engineering perspective, covering aspects of efficiency, reliability, and effectiveness in protecting occupants' health and comfort.

1.2. Problem Statement

1. How to design a conceptual model of an automatic air quality control system based on smart home technology that is capable of detecting pollutants and integrating data from indoor and outdoor environments?
2. How can the working logic of the designed system intelligently distinguish between pollution sources from outdoors and fire hazards from indoors through multi-sensor integration?
3. How to analyze the system design using an Industrial Engineering approach, particularly in terms of process efficiency, automation effectiveness, and its contribution to aspects of user health and comfort?

1.3. Objectives of the Project

1. To design a conceptual model of an automatic air quality control system based on smart home technology that is capable of detecting, analyzing, and responding to changes in indoor and outdoor air quality.
2. To analyze the working logic of the system in distinguishing between outdoor pollution sources and indoor fire hazards based on multi-sensor integration.

3. To evaluate the system design using an Industrial Engineering approach, focusing on aspects of process efficiency, automation effectiveness, and contribution to occupant health and comfort.

1.4. Benefits of the Project

1. For Residents: Providing a healthier and more comfortable living environment through automatic protection from exposure to outdoor smoke and early detection of indoor fire hazards.
2. For the Development of Science: Contributing to the body of knowledge in the application of smart home technology, particularly from the perspective of Industrial Engineering system design.
3. For the Industry: Offering a conceptual framework that can be developed into commercial products that prioritize energy efficiency, safety, and user convenience.

CHAPTER II

LITERATUR REVIEW

2.1. Indoor Air Quality (IAQ)

Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. The issue of IAQ has become a global concern requiring recognition and action due to its significant impact on occupant health, particularly vulnerable groups such as children and the elderly.

Data from the World Health Organization (WHO) indicates that poor indoor air quality is responsible for 3.8 million deaths worldwide each year. This figure reflects the magnitude of the public health crisis associated with indoor air pollution, which often receives less attention compared to outdoor air pollution. Furthermore, IAQ is linked to various serious health conditions, 32% of heart disease cases, 23% of stroke cases, 21% of lower respiratory infection cases, 19% of chronic obstructive pulmonary disease (COPD) cases, and 6% of lung cancer cases (WHO, 2021).

Occupants spend approximately 90% of their lifetime indoors, whether at home, offices, schools, or other facilities. This figure has profound implications for the accumulation of pollutant exposure throughout life. Research shows that the temporal characteristics of variation and occupancy of each indoor environment highly depend on shift-based routines and specific operational schedules associated with each environment. The fact that humans spend most of their time indoors makes IAQ a primary determinant of public health, even more significant than outdoor air quality in the context of long-term exposure.

Indoor air pollution differs from ambient air in terms of contaminant sources, types, concentration levels, dispersion mechanisms, source proximity, emission rates, building design and age, and ventilation systems. Common indoor pollutants include particulate matter, ozone, radon, polycyclic aromatic hydrocarbons (PAHs), nitrogen oxides, sulfur dioxide, carbon monoxide (CO), as well as various volatile organic compounds (VOCs) and bioaerosols.

Recent studies using a health-based approach with the Disability-Adjusted Life-Year (DALY) metric to measure and compare chronic hazards caused by indoor air contaminants. Research results indicate that four contaminants cause more than 99% of the total chronic hazards in office environments, namely $PM_{2.5}$ (fine particles with diameter <2.5 μm), formaldehyde (HCHO), ozone (O_3), and $PM_{10-2.5}$ (coarse particles). When inhaled, coarse particles can reach the upper lungs, pharynx, and trachea. Meanwhile, fine particles ($PM_{2.5}$) can penetrate deep into the bronchi and alveoli of the lungs, triggering lung cancer, inflammatory reactions, oxidative stress, mutagenicity, as well as respiratory and cardiopulmonary diseases .

Carbon monoxide (CO) is an odorless and colorless gas produced from incomplete combustion. CO reduces the blood's ability to carry oxygen because its affinity for hemoglobin is 200 times greater than that of oxygen. Main symptoms associated with CO exposure include shortness of breath, headaches, and nausea. Carbon dioxide (CO_2) is also an odorless and colorless gas resulting from carbon combustion, with main sources being human metabolism and respiration, gas cooking appliances, as well as other combustion byproducts.

Recent research in elementary school environments showed a significant increase in bacterial and fungal loads after student activities in classrooms. Data showed significant increases for mesophilic bacteria, psychrophilic bacteria, and fungi, which correlated positively with temperature and humidity. This emphasizes the need for better IAQ management strategies including adequate ventilation and interventions to reduce microbiological pollutants.

IAQ not only affects the physical health of occupants but also disrupts various behavioral characteristics, sleep habits, learning abilities, and cognitive capabilities. In recent years, due to the COVID-19 pandemic, research on air quality control has shifted focus to indoor spaces, identifying behavioral and lifestyle changes with increasing levels of people staying indoors.

2.2. Sensor Technology and IoT for IAQ Monitoring

The development of sensor technology has produced low-cost sensors with adequate accuracy and reliability for IAQ monitoring applications in residential buildings. This low-cost characteristic, combined with Internet of Things (IoT) applications, makes IAQ monitoring affordable, flexible, and feasible even for ordinary occupants to ensure air quality in their homes (Tan, 2024).

A systematic study of 23 studies identified several aspects of active monitoring strategies in residential buildings, appropriate sensor deployment and target pollutants, selection of appropriate microcontroller units, sensor and device costs and their monitoring applications, data collection and storage methods, and calibration methods for low-cost sensors in applications.

Based on a systematic review of low-cost sensor applications, the following are commonly used sensors for IAQ monitoring in residential environments:

1. MQ-135: Detects CO_2, CO, ammonia, benzene, and smoke for general pollutant gas detection.
2. PMS5003/PMSA003I: Measures $PM_{1.0}$, $PM_{2.5}$, and PM_{10} for particulate matter monitoring.
3. DHT22: Measures temperature and relative humidity as basic environmental conditions.
4. MQ-2: Detects flammable gases and smoke for smoke and gas leak detection.Flame Sensor: Detects infrared flame spectrum for early fire detection.

Although offering accessibility, low-cost sensors have several limitations that need to be considered in system design, such as the need for long-term calibration to maintain accuracy, sensor performance degradation over time (sensor drift), limited sensor lifespan, and the influence of environmental conditions such as high temperatures, extreme humidity, and chemical exposure that can affect sensor performance.

IoT-based IAQ monitoring systems integrate several technology layers. The Field Layer consists of sensors collecting real-time air quality data. The Gateway Layer uses microcontrollers (such as Arduino) to process data and send it to the cloud. The Cloud Layer provides data storage and analysis platforms, while the Application Layer provides user interfaces for visualization and control.

2.3. Control Logic and Artificial Intelligence

Conventional systems often use simple threshold logic (e.g., if $PM_{2.5} > 35$ $\mu g/m^3$, close windows). However, this approach has limitations in distinguishing pollution sources and responding to complex environmental dynamics. Recent research shows that machine learning integration can significantly improve IAQ system accuracy. The Zephyr Sense project, for example, uses a pre-trained Support Vector Machine (SVM) model on an Arduino to classify air quality into "Good, Moderate, Poor, and Hazardous" categories.

LSTM (Long Short-Term Memory) based models can predict $PM_{2.5}$ and CO_2 levels with a mean absolute error below 5 µg/m³, enabling proactive rather than just reactive system responses. The latest innovation in IAQ monitoring is the adaptive sensor pruning and virtualization framework that utilizes temporal-spatial modeling and machine learning to maintain predictive accuracy while reducing the number of physical sensors required (Klepeis, 2001).

This approach explores various input model design strategies such as agnostic-fusion (data fusion without considering temporal/spatial order), temporal-first (priority on time dimension), spatial-first (priority on space dimension), and hybrid (combination of temporal and spatial approaches). Experimental results show that node-specific configurations (local and adaptive) yield better performance than globally optimized fixed configurations. This approach enables significant reduction in sensor infrastructure without sacrificing performance, offering a scalable and cost-effective path towards intelligent IAQ management in real-world environments.

2.4. Industrial Engineering Approach in System Design

The design of complex engineering systems such as intelligent air quality control systems faces multi-objective optimization challenges, where systems must be designed with several conflicting attributes that need to be simultaneously optimized within certain constraints. For example, when designing a system optimized for energy efficiency, the system may require lightweight and power-efficient components, but these components may not be reliable enough for accurate fire detection. Therefore, design must simultaneously prioritize between energy efficiency and safety.

Evolving manufacturing system optimization often requires consideration of interactions between various architectural design decisions. In the context of IAQ systems, design decisions include deployment decisions (sensor placement in optimal locations), topology decisions (centralized vs. distributed sensor network architecture), and planning decisions (edge vs. cloud processing task allocation). A multidimensional design space exploration approach is needed to synthesize these various architectural design decisions together, producing valid and optimal solutions .

Industrial Engineering (IE) contributes to automated system design through a holistic approach that considers the integration of humans, materials, information, equipment, and energy. In the context of a Smart Air Quality Protection System, the IE approach focuses on:

1. System Optimization

   Ensuring the system operates at peak efficiency, minimizing response time (e.g., reacting to pollution in less than 6 seconds) and energy consumption (e.g., achieving up to 30% energy savings through predictive control).

2. Ergonomics and Human Factors

   Designing the interaction between humans and systems (human-machine interface) to be intuitive, non-disruptive, and supportive of occupant well-being. A good system works in the background, maintaining comfort without requiring constant user intervention, creating a "calm technology" experience.

3. Reliability and Quality Control

   Applying redundancy and verification logic to ensure the system makes correct decisions. The use of multiple sensors to detect related phenomena creates redundancy that increases diagnostic reliability and reduces the likelihood of false positives.

4. Sustainability

   Integrating energy-efficient components and operational logic to reduce the building's carbon footprint. By preventing outdoor pollutants from entering and only activating appliances when necessary, the system supports the creation of a more sustainable living environment.

Recent research recommends a comprehensive air quality management framework that serves as a valuable resource for researchers, engineers, practitioners, and policymakers . This framework considers factors affecting IAQ, exacerbated health risks, different control programs, and specific requirements for critical environments (Badiru, 2019).

2.5. State of the Art and Research Novelty

Based on a comprehensive literature review, this research offers novelty in several aspects. In terms of focus, previous research generally focused on monitoring alone or simple control, while this research offers integration of detection, source differentiation analysis, and automatic response within a single framework.

In terms of detection logic, research often used single thresholds, while this research uses multi-sensor logic with spatio-temporal differentiation to distinguish between outdoor pollution vs. indoor fire. In terms of analysis approach, previous research tended to be purely technical (electronics/informatics), while this research uses a holistic Industrial Engineering approach (efficiency, ergonomics, reliability, sustainability). In terms of application context, this research focuses on residential environments with consideration for vulnerable groups, unlike previous research which was general or commercial in nature.

Thus, this research bridges the gap between advanced sensor technology, intelligent control logic, and Industrial Engineering principles to produce a system design that is not only technically competent but also efficient, reliable, ergonomic, and sustainable for application in modern residential environments.

CHAPTER III

METHODELOGY

3.1. Development Method

The design of this automatic air quality control system falls under the category of prototype development or design and build. This method was chosen because the main objective of this research is to produce a working model (prototype) that can validate the system's concept and logic before it is implemented in a real-world setting.

Based on a literature review, such as the research conducted by (Saputra, 2017) in the development of an Indoor Air Quality Control Prototype Based on the ATmega 328p Microcontroller, a suitable method for this type of project consists of six main stages:

1. Needs Identification, understanding the main problems that necessitate the system.
2. Needs Analysis, determining the technical and functional specifications the system must meet to address the identified problems.
3. System Design, creating the system architecture design, including component selection and control logic.
4. Software Design, writing the program code to be executed by the microcontroller.
5. Device Fabrication, assembling the hardware components into a unified system.
6. Device Testing, evaluating the prototype's performance against the design objectives.

These six stages align with general system development models and serve as the main foundation for the analysis in this chapter. In the context of this project, these stages are carried out using an Industrial Engineering scientific approach to ensure the resulting solution is not only technically functional but also efficient, ergonomic, and provides added value for the user .

3.2. Design Approach

The design of this Smart Air Quality Protection System uses an integrated system approach that aligns with Industrial Engineering principles, viewing the system as a unified whole consisting of input, process, output, and control mechanism components. This approach aims to create a holistic, efficient, and effective solution for improving the quality of the residential environment. With this approach, each technical component is not seen in isolation but as interconnected subsystems that influence each other in achieving the main objective, intelligent air quality protection.

3.3. Design Framework

To operationalize the six stages of the design and build method, the system design framework follows the Plan-Do-Check-Act (PDCA) cycle adapted for product development. This cycle ensures a process of continuous improvement in every development step (Setiawan, 2021).

1. Plan

   This stage combines the Needs Identification and Needs Analysis steps.

   a. Identification

      Based on the problem analysis in the introduction (PDF, pp. 2-3), the primary user (resident) needs are identified, specifically the requirement for an automatic response to outdoor smoke pollution and potential indoor fire hazards.

b. Needs Analysis

From these needs, the necessary technical specifications are analyzed, such as the type of sensors capable of distinguishing pollution sources, actuators for physical movement, and an alarm system for early warning.

2. Design

This stage combines the System Design and Software Design steps.

a. System Design

Designing the technical solution by determining the system architecture, including the selection of components such as MQ-2 and DHT22 sensors, a microcontroller (Arduino), servo motor, relays, buzzer, and LED. At this stage, the zoning and threshold control logic, as well as the overall system workflow.

b. Software Design

Writing the program code that will implement the control logic into the microcontroller, including algorithms for reading sensor data, comparing it with threshold values, and executing commands to the actuators.

3. Do (Prototyping/Fabrication)

This stage is the realization of the Device Fabrication step.

a. Prototyping

This simulation allows for testing component interconnections and program logic without the risk of damaging physical devices, while also validating the concept before further implementation. Implementing the design into a functional simulation using the Wokwi platform provided link (https://wokwi.com/projects/456754081670360065).

4. Check (Analysis/Testing)

This stage is the execution of the Device Testing step.

a. Analysis

Testing and analyzing the prototype's performance against the design objectives. The analysis is conducted using an Industrial Engineering approach, which includes:

a) Process Efficiency and Effectiveness: Measuring the system's response speed and the accuracy of the actions taken.

b) System Reliability: Evaluating the logic for differentiating pollution sources (outdoor vs. indoor) and potential failure modes.

c) Ergonomic and Safety Aspects: Assessing the reduction in user cognitive load and the enhancement of occupant safety.

d) The results of this analysis will serve as feedback for future system improvements, which is the core of the PDCA cycle.

By integrating the six-stage design and build method into the PDCA framework, the system development process becomes structured, measurable, and oriented towards continuous quality improvement.

CHAPTER IV

ANALYSIS RESULTS

4.1. Validation and Simulation

Before futher implementation, the system concept was validated through a functional simulation built on the *Wokwi* platform. The simulation integrates the key components described in the system design: two MQ series gas sensors (to simulate outdoor and indoor detection), a DHT22 temperature sensor, a servo motor (for automatic window actuation), relays (for air purifier/fan control), and a buzzer with an LED for the alarm system. The simulation environment allows for the testing of control logic and system response times.

The complete simulation can be accessed and reviewed via the following link (https://wokwi.com/projects/456754081670360065). Figure 4.1 below shows the complete system design as implemented in the Wowki simulation, illustrating the interconnections between sensors, microcontroller, and actuators.

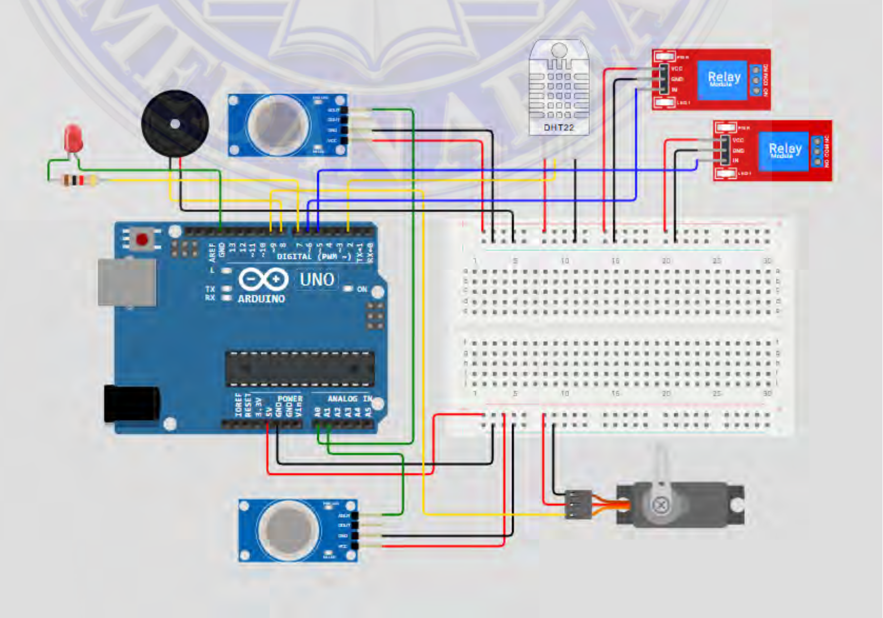


Figure 4. 1 System Design Simulation

4.2. Components Analysis

The systems functionality relies on the correct selection and integration of hardware components. The simulation on Wokwi utilizes virtual representations of these components, allowing for validation of their roles within the control logic.

1. Sensors

   a. Gas Sensors (MQ Series)

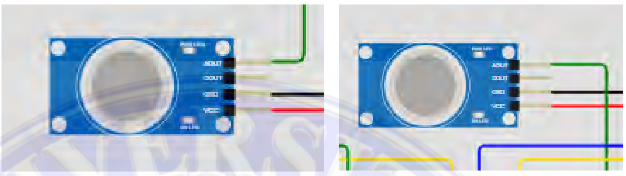


Figure 4. 2 MQ Sensor

Two MQ sensors are employed to simulate outdoor and indoor air quality monitoring. Their analog outputs (AOUT) provide variable voltage corresponding to gas concentration. In the simulation, these sensors generate data that the microcontroller reads via analog pins, enabling threshold-based decisions. This setup successfully replicates the dual-sensor logic required to differentiate pollution sources based on activation sequence.

   b. Temperature and Humidity Sensor (DHT22)

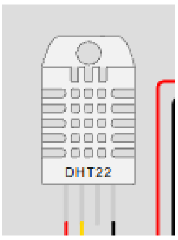


Figure 4. 3 Temperature and Humidity Sensor

The DHT22 sensor measures ambient temperature. Its data is crucial for distinguishing between smoke from outdoor pollution (no temperature rise) and potential indoor fire (temperature increase). The simulation confirms that combining gas and temperature readings enhances detection accuracy.

2. Actuators

a. Servo Motor

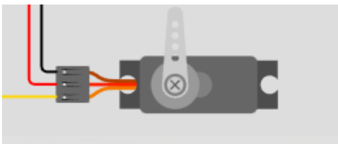


Figure 4. 4 Servo Motor

The servo motor simulates automatic window actuation. It responds to control signals from the microcontroller by moving to predefined angles (e.g., 0° for closed, 90° for open). This demonstrates the feasibility of integrating mechanical movement with electronic control.

b. Relays

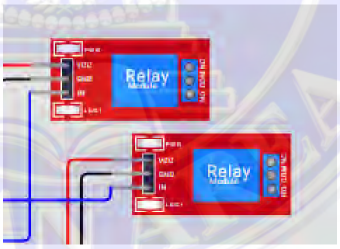


Figure 4. 5 Relay

Two relay modules are used to control high-power devices like air purifiers and ventilation fans. The relays switch on/off based on digital signals from the microcontroller, effectively isolating the low-power control circuit from high-power loads. This is essential for safety and practical implementation.

c. Buzzer and LED

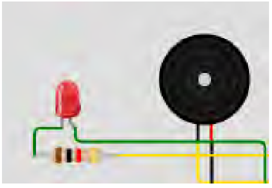


Figure 4. 6 Buzzer and LED

These provide audible and visual alerts. The buzzer emits sound, and the LED lights up when an indoor fire hazard is detected. Their fast response in the simulation validates their role as effective warning indicators.

3. Controller

a. Microcontroller (Arduino Uno)

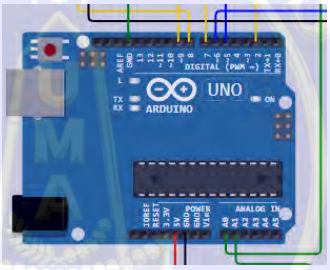


Figure 4. 7 Microcontroller (Arduino Uno)

The Arduino Uno processes sensor data, executes the decision logic, and commands actuators. Its multiple I/O pins allow simultaneous connection of all components. The simulation runs the code that implements the threshold logic and differentiation algorithms, proving that the controller can handle the required tasks efficiently.

4. Supporting Components

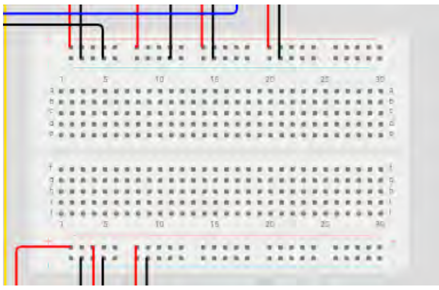


Figure 4. 8 Resistor and Power Supply

a. Resistor

A current-limiting resistor is used with the LED to prevent damage, ensuring reliable operation.

b. Power Supply

In the simulation, power is implicitly provided, but in a real system, adequate power supplies for sensors, actuators, and the microcontroller are critical. The design must account for voltage and current requirements.

5. Integrartions and Communication

All components communicate via wired connections to the microcontroller. The simulation verifies that data flows correctly and that the system responds as a unified whole. The use of standard interfaces (analog, digital, PWM) ensures compatibility and ease of assembly.

This component-level analysis confirms that each part functions as intended and contributes to the overall system objectives. Potential issues such as sensor calibration, power consumption, and mechanical reliability in real-world conditions remain to be addressed in future iterations.

4.3. Analysis of System Performance

This stage involves testing and analyzing the simulated prototype's performance against the design objectives using an Industrial Engineering approach.

1. Analysis of Process Efficiency and Effectiveness

   Efficiency and effectiveness were measured by the system's response speed and the accuracy of its automated actions based on the predefined logic.

   a. Response Speed

      The simulation demonstrates that the microcontroller (Arduino Uno) processes sensor data and executes commands (servo movement, relay switching) within milliseconds of a threshold breach. This confirms the system's ability to react in real-time, effectively mitigating pollutant ingress immediately upon detection.

   b. Action Accuracy

      The system logic, as programmed, correctly differentiates between scenarios. For example, when the "outdoor" gas sensor (gas1) reading spikes while the indoor temperature (DHT22) remains normal, the system effectively triggers the window servo (closing) and the air purifier relay. This validates the core effectiveness of the automated protection loop.

2. Analysis of System Reliability

   Reliability was evaluated by examining the logic for differentiating pollution sources and identifying potential failure modes within the simulation.

   a. Differentiation Logic

The system successfully implements the multi-sensor logic outlined in the design. By comparing the activation sequence of the two gas sensors and cross-referencing with temperature data from the DHT22, it can distinguish between an outdoor pollution event (external sensor activates first, no heat) and a potential indoor fire hazard (internal sensor activates with a temperature rise). This dual-logic approach significantly enhances the system's reliability in responding appropriately to different threats.

b. Failure Mode Potential

The simulation highlights a potential single point of failure: the microcontroller. If the main controller fails, the entire system becomes inoperative. Future iterations could consider a fail-safe mechanical design for windows or a redundant control module.

3. Analysis of Ergonomic and Safety Aspects

This assessment focuses on the human interaction with the system and the enhancement of occupant safety.

a. Reduction in Cognitive Load

By automating the detection and response process, the system eliminates the need for residents to constantly monitor air quality or manually close windows and turn on purifiers. This significantly reduces cognitive load and frees up user attention for other tasks, aligning with smart home principles of convenience and "invisible" technology.

b. Enhancement of Occupant Safety

The integration of an audible (buzzer) and visual (LED) alarm system provides an immediate, clear warning to occupants in the event of a detected indoor fire hazard. This feature directly enhances safety by ensuring rapid occupant notification, which is crucial for timely evacuation and damage control, addressing a key objective from the initial problem statement.

4. Feedback for System Improvement

The analysis results provide critical feedback for the next iteration of the PDCA cycle. Key areas for improvement include:

a. Calibration of Thresholds

The simulation uses fixed thresholds (e.g., PM2.5 > 35 µg/m³). Future iterations should incorporate adaptive algorithms or user-adjustable setpoints to account for different environmental backgrounds and user sensitivities.

b. Data Logging

Implementing a data logging feature to record sensor readings and system actions over time would enable long-term performance analysis and predictive maintenance.

By integrating the six-stage design and build method into the PDCA framework, this analysis confirms the validity of the Smart Air Quality Protection System design and provides a clear path for refinement in subsequent development cycles.

4.4. System Limitations and Weaknesses

Despite the successful validation of the core concepts through simulation, several limitations and weaknesses have been identified. These findings are crucial for guiding future iterations and improvements within the PDCA framework.

1. Simulation Limitations
   a. Virtual vs. Real-World Conditions

      The Wokwi simulation operates in an idealized environment. Sensor readings are simulated and do not account for real-world noise, interference, or calibration drift. Factors such as humidity effects on gas sensors, component aging, and electrical noise are not represented.

   b. Simplified Actuator Behavior

      The servo motor movement in simulation is instantaneous and perfect. In reality, mechanical systems face friction, load variations, and potential jamming. The relay switching does not account for inductive loads (e.g., motor starting currents) that can cause contact wear or electrical noise.

2. Sensor-Related Weaknesses
   a. Calibration Requirements

      The MQ series sensors require warm-up time and periodic calibration to maintain accuracy. The simulation uses fixed thresholds that do not adapt to baseline drift or environmental changes (e.g., altitude, humidity).

   b. Cross-Sensitivity

      MQ sensors are sensitive to multiple gases. For example, an MQ-2 responds to CO_2, CO, NH_3, and others. This cross-sensitivity can lead to false positives or difficulty in identifying specific pollutants.

   c. Single-Point Sensing

      Each zone (indoor/outdoor) uses only one sensor. In a real home, pollutant distribution may be uneven, and a single sensor might not represent overall air quality accurately.

3. Logic and Decision-Making Weaknesses

   a. Simplified Differentiation Logic

      The system distinguishes pollution vs. fire based primarily on temperature change and activation sequence. However, scenarios such as hot outdoor air (heatwave) combined with pollution or slow-smoldering fires that produce smoke without immediate temperature rise could confuse the logic.

   b. Lack of Historical Data Analysis

      The system makes decisions based on instantaneous readings without considering trends or historical data. A sudden spike might trigger a response, but a gradual, sustained increase could be equally important but handled differently.

   c. No User Override

      The current design lacks a manual override feature. If the system malfunctions or makes an incorrect decision, users cannot easily intervene to open windows or silence alarms.

4. Actuator and Mechanical Weaknesses

   a. Servo Motor Limitations

      Standard servo motors are not designed for continuous operation or heavy loads. Operating a window mechanism requires higher torque and possibly limit switches to prevent motor burnout or mechanical damage.

   b. Relay Contact Rating

      The relays used are suitable for small fans but may fail if used with high-power air purifiers without proper contact rating and snubber circuits.

c. Single Point of Failure - Window Mechanism

If the servo or linkage fails, the window could become stuck in an undesirable position (open during pollution or closed permanently).

5. Power and Reliability Concerns

a. Power Dependency

The entire system relies on a stable power supply. During a power outage, the system becomes non-functional, potentially leaving occupants vulnerable to both pollution and fire hazards. No battery backup is included.

b. Electromagnetic Interference

High-power actuators (relays switching motors) can generate electromagnetic interference that might disrupt sensor readings or microcontroller operation if not properly filtered.

6. Ergonomic and Usability Weaknesses

a. No User Interface

The system lacks a user interface (display, buttons, or mobile app) for monitoring current air quality, adjusting thresholds, or receiving notifications. This reduces user trust and engagement.

b. Alarm Fatigue

The buzzer provides a single, undifferentiated alarm. Repeated false alarms could lead occupants to ignore or disable the system.

c. No Status Indication

There is no clear indication of the system's current state (e.g., "Monitoring," "Pollution Mode," "Fire Alarm") other than observing window position and alarm status.

7. Safety Considerations

   a. Fire Alarm Reliability

      While the buzzer alerts occupants, the system does not include any fire suppression mechanism or automatic emergency call feature.

   b. Window Operation Safety

      Automatic window closing could pose a pinch hazard if occupants or pets are in the way. No safety sensors (e.g., obstacle detection) are included.

These weaknesses highlight the gap between a simulated prototype and a production-ready system. Addressing these limitations will be the focus of the next PDCA cycle, with emphasis on robust hardware selection, refined logic, user-centered design, and fail-safe mechanisms.

CHAPTER V

CONCLUSION

5.1. Conclusion

This project successfully designed and validated an automatic air quality control system based on smart home technology using an Industrial Engineering approach. The following conclusions can be drawn from the design, simulation, and analysis phases:

1. A conceptual model of an automatic air quality control system based on smart home technology has been successfully designed. The system integrates MQ series gas sensors and a DHT22 sensor with an Arduino Uno microcontroller, and utilizes actuators including a servo motor, relays, a buzzer, and LEDs. Simulation results using Wokwi confirm that all components function as intended, with the microcontroller effectively processing sensor data and executing control logic without delay.
2. The dual-sensor logic implemented in the system successfully distinguishes between outdoor pollution sources and indoor fire hazards through multi-sensor integration. By analyzing activation sequences and temperature changes, the system demonstrates the ability to provide appropriate responses closing windows and activating air purifiers for outdoor pollution, while triggering alarms and safety protocols for indoor fire detection.
3. Evaluation of the system design from an Industrial Engineering approach confirms its effectiveness in multiple aspects. The system demonstrates process efficiency through automated responses, reduces cognitive load on users (ergonomic contribution), and enhances occupant safety and comfort. The

integration of the six-stage design method within the PDCA framework establishes a foundation for continuous improvement, ensuring the system can evolve based on future analysis and feedback.

References

Klepeis, N. E. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, 231-252.

Saputra, R. A. (2017). Prototipe Pengendali Kualitas Udara Indoor Berbasis Mikrokontroler ATMEGA 328P. *Jurnal Teknik Elektro*, 1-7.

Badiru, A. B. (2019). *Systems Engineering Models: Theory, Methods, and Applications.* CRC Press.

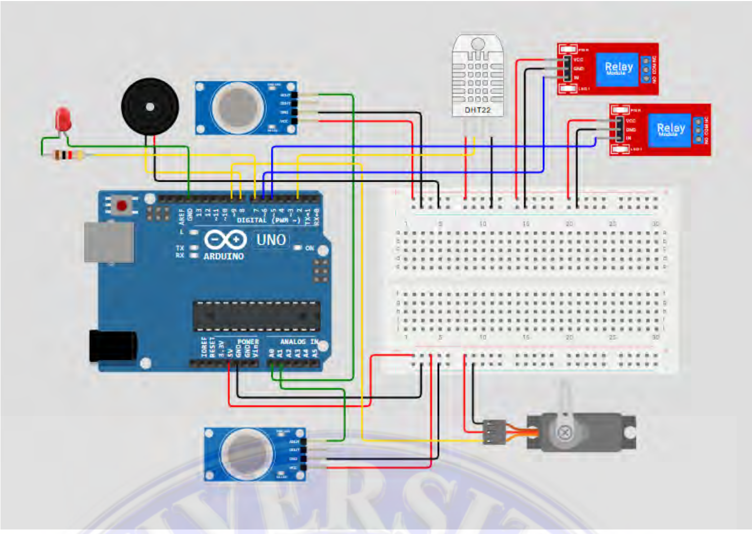
Setiawan, H. &. (2021). Penerapan Konsep Siklus Plan-Do-Check-Action (PDCA) untuk Meningkatkan Kinerja Load Lugger. *Jurnal Tekik Industri*, 1-8.

WHO. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.* Geneva, Switzerland: World Health Organization Guidelines.

Tan, H. d. (2024). Revolutionizing Indoor Air Quality Monitoring Through IoT Innovations: a comprehensive systematic review and bibliometric analysis. *Environmental Science and Pollution Research*, 44463-444488.

https://wokwi.com/projects/456754081670360065

Attachment

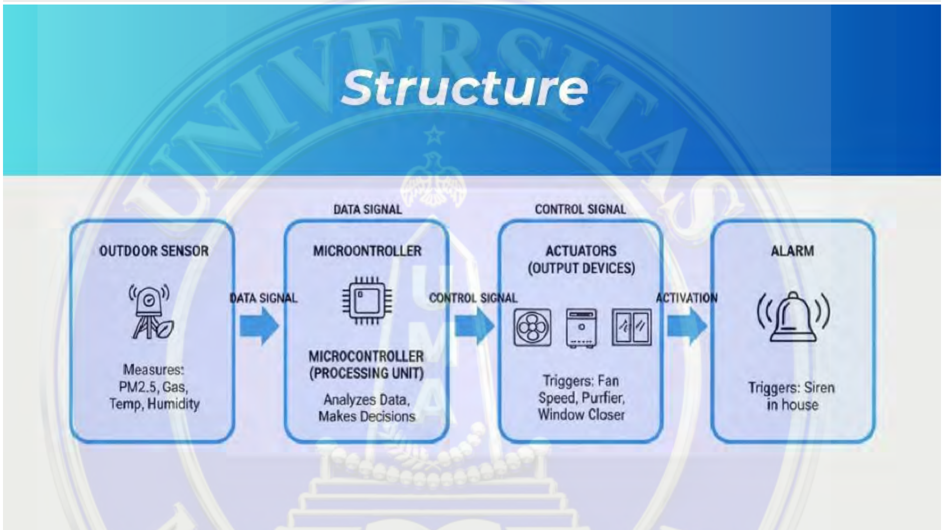


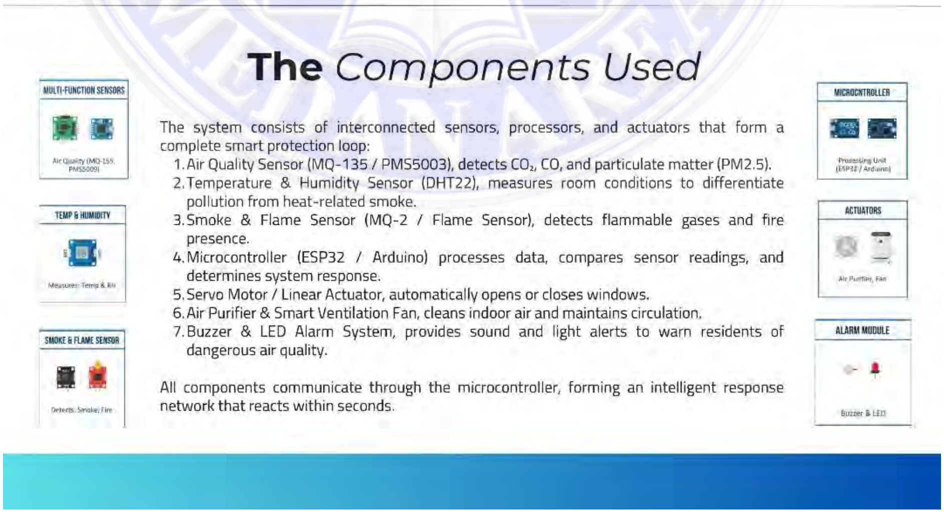

MAIN CONTROL HUB
AIR QUALITY
WINDOW SENSOR
MOTDOIN/OCCUPANCY SENSOR
ENVIRONMENT
PRESENCE
SECURITY
CLIMATE
Smart Air Quality Protection System
Prepared by group 2

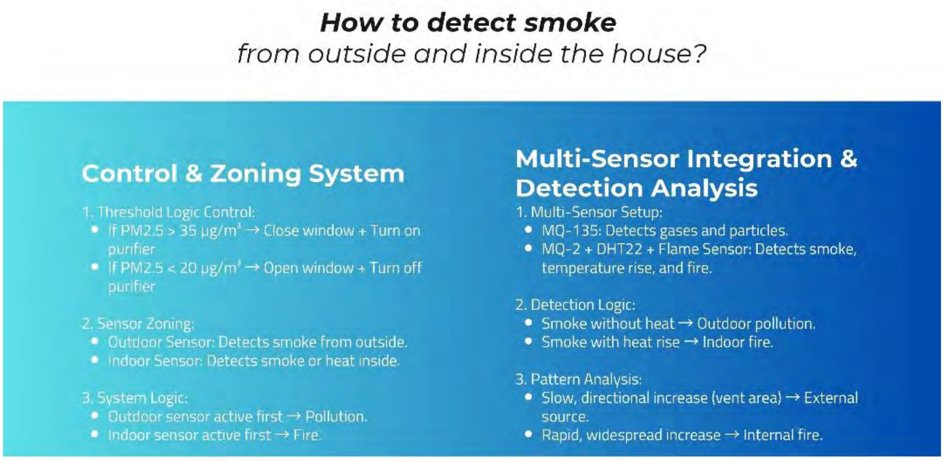

Introduction
In modern residential areas, maintaining indoor air quality has become a major concern. Pollution and smoke from outside source, such as waste burning, can easily enter through windows and ventilation, reducing comfort and threating health.
This presentation introduces a **"Smaert Air Quality Protection System"**, designed to detect and control smoke automatically using sensor technology, automation, and IoT integration. It represent the concept of a **"smart home"** that reacts intelligently to environmental changes.
SMART PROTECTION ACTIVE

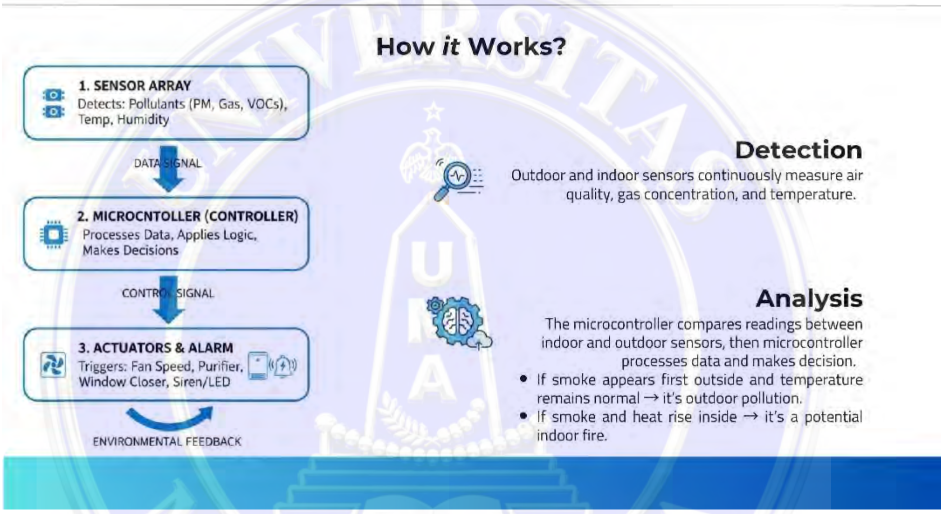

The Problem
1. Many people experience discomfort when neighbors burn trash or other materials.
2. The smoke spreads through open windows and stays inside, causing eye irritation, breathing difficulties, and unpleasant smells.
3. Traditional solutions rely on manual action closing windows or turning on fan, which is ineffective if residents are away.
4. Prolonged exposure to smoke also increases health risks, especially for children and the elderly.
Therefore, a smart, automatic system is needed to prevent outdoor smoke from entering homes while still ensuring proper ventilation.

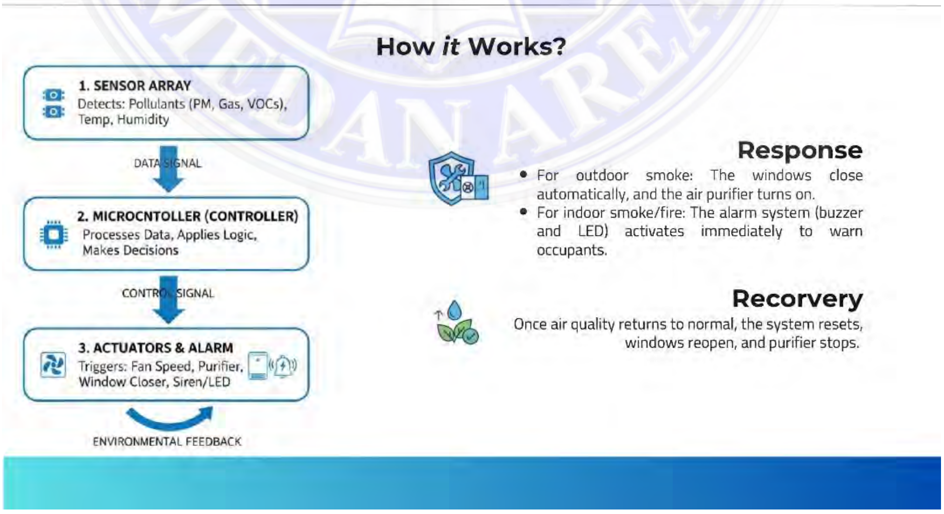

The Smart Solution
The Smart Air Quality Protection System is an automated, IoT-based solution that:
1. Detects smoke and harmful gases both outside and inside the house.
2. Automatically closes windows and activates air purifiers when outdoor smoke is detected.
3. Differentiates between outdoor smoke (pollution) and indoor smoke (fire hazard).
4. Triggers an alarm for residents when abnormal air conditions are detected from inside the house.
The system creates a balance between safety, healthy, and comfort by combining automation and environmental sensing technology.


Structure
OUTDOOR SENSOR
Measures: PM2.5, Gas, Temp, Humidity
DATA SIGNAL
DATA SIGNAL
MICROONTROLLER
MICROCONTROLLER (PROCESSING UNIT)
Analyzes Data, Makes Decisions
CONTROL SIGNAL
CONTROL SIGNAL
ACTUATORS (OUTPUT DEVICES)
Triggers: Fan Speed, Purfier, Window Closer
ACTIVATION
ALARM
Triggers: Siren in house


The Components Used
MULTI-FUNCTION SENSORS
TEMP & HUMIDITY
SMOKE & FLAME SENSOR
MICROCNTROLLER
ACTUATORS
ALARM MODULE
The system consists of interconnected sensors, processors, and actuators that form a complete smart protection loop:
1. Air Quality Sensor (MQ-135 / PMS5003), detects CO_2, CO, and particulate matter (PM2.5).
2. Temperature & Humidity Sensor (DHT22), measures room conditions to differentiate pollution from heat-related smoke.
3. Smoke & Flame Sensor (MQ-2 / Flame Sensor), detects flammable gases and fire presence.
4. Microcontroller (ESP32 / Arduino) processes data, compares sensor readings, and determines system response.
5. Servo Motor / Linear Actuator, automatically opens or closes windows.
6. Air Purifier & Smart Ventilation Fan, cleans indoor air and maintains circulation.
7. Buzzer & LED Alarm System, provides sound and light alerts to warn residents of dangerous air quality.
All components communicate through the microcontroller, forming an intelligent response network that reacts within seconds.


How to detect smoke
from outside and inside the house?
Control & Zoning System
1. Threshold Logic Control:
If PM2.5 > 35 µg/m³ → Close window + Turn on purifier
If PM2.5 < 20 µg/m³ → Open window + Turn off purifier
2. Sensor Zoning:
Outdoor Sensor: Detects smoke from outside.
Indoor Sensor: Detects smoke or heat inside.
3. System Logic:
Outdoor sensor active first → Pollution.
Indoor sensor active first → Fire.
Multi-Sensor Integration & Detection Analysis
1. Multi-Sensor Setup:
MQ-135: Detects gases and particles.
MQ-2 + DHT22 + Flame Sensor: Detects smoke, temperature rise, and fire.
2. Detection Logic:
Smoke without heat → Outdoor pollution.
Smoke with heat rise → Indoor fire.
3. Pattern Analysis:
Slow, directional increase (vent area) → External source.
Rapid, widespread increase → Internal fire.


How it Works?
1. SENSOR ARRAY
Detects: Pollutants (PM, Gas, VOCs), Temp, Humidity
DATA SIGNAL
2. MICROCNTOLLER (CONTROLLER)
Processes Data, Applies Logic, Makes Decisions
CONTROL SIGNAL
3. ACTUATORS & ALARM
Triggers: Fan Speed, Purifier, Window Closer, Siren/LED
ENVIRONMENTAL FEEDBACK
Detection
Outdoor and indoor sensors continuously measure air quality, gas concentration, and temperature.
Analysis
The microcontroller compares readings between indoor and outdoor sensors, then microcontroller processes data and makes decision.
If smoke appears first outside and temperature remains normal → it's outdoor pollution.
If smoke and heat rise inside → it's a potential indoor fire.


How it Works?
1. SENSOR ARRAY
Detects: Pollutants (PM, Gas, VOCs), Temp, Humidity
DATA SIGNAL
2. MICROCNTOLLER (CONTROLLER)
Processes Data, Applies Logic, Makes Decisions
CONTROL SIGNAL
3. ACTUATORS & ALARM
Triggers: Fan Speed, Purifier, Window Closer, Siren/LED
ENVIRONMENTAL FEEDBACK
Response
For outdoor smoke: The windows close automatically, and the air purifier turns on.
For indoor smoke/fire: The alarm system (buzzer and LED) activates immediately to warn occupants.
Recorvery
Once air quality returns to normal, the system resets, windows reopen, and purifier stops.

Benefits

1. **Health Protection**: Reduces exposure to outdoor smoke and harmful gases.
2. **Automatic Safety**: Detects and reacts without manual intervention.
3. **Dual Detection Logic**: Distinguishes between pollution and fire.
4. **Immediate Alerts**: Alarm system provides direct warning for quick action.
5. **Energy Efficiency**: Operates only when necessary, saving electricity.
6. **Enhanced Comfort**: Maintains a clean, fresh, and pleasant indoor environment.

Conclusion

The **Smart Air Quality Protection System** integrates sensors, automation devices, and an alarm notification system to protect indoor environments.
By automatically detecting, analyzing, and responding to air pollution or fire hazards, it enhances safety and comfort for residents.

This project demonstrates how smart building technology can improve everyday life, making our homes not only smarter but also healthier and safer.

Thank you!!

CREDITS: This presentation template was created by **Slidesgo**, and it includes icons by **Flaticon**, infographics & images by **Freepik**

Please keep this slide for attribution