A Review of IoT-Based Air Quality Monitoring and Purification System

Mrs. Tejaswini G V[1], Ankita[2], Chaithra N[3], Devaki M[4], Mehasin M[5]

[1]Assistant Professor, Dept. of ECE, K S School of Engineering and Management, Bengaluru, India
[2,3,4,5] Students, Dept. of ECE, K S School of Engineering and Management, Bengaluru, India

---***---

Abstract - *Indoor air quality (IAQ) has emerged as a critical concern for human health and well-being, particularly in urban environments characterized by high population density and limited natural ventilation. The rapid proliferation of Internet of Things (IoT) technology has enabled the development of low-cost, real-time air quality monitoring systems that were previously impractical for household or small-scale use. This review paper critically examines fourteen research works published between 2012 and 2025, covering IoT-based sensing, communication protocols, cloud platforms, and purification mechanisms for indoor air quality management. The studies are analyzed in terms of hardware architecture, sensor selection, connectivity, automation level, and limitations. A recurring finding across the literature is that most systems address either monitoring or purification in isolation, leaving a significant gap for integrated, automated, and cost-effective solutions. This paper identifies key research gaps and highlights the need for unified systems that combine real-time detection with autonomous corrective action.*

Keywords: IoT, Indoor Air Quality, Air Purification, Sensor Networks, ESP32, MQ-135.

1. INTRODUCTION

Air pollution ranks among the most severe environmental challenges of the 21st century, with its consequences extending well beyond outdoor environments. Research consistently indicates that individuals spend approximately 80–90% of their time indoors, yet indoor air quality (IAQ) remains far less rigorously monitored than outdoor pollution. Common indoor pollutants including fine particulate matter (PM2.5), carbon dioxide (CO_2), ammonia (NH_3), carbon monoxide (CO), and volatile organic compounds (VOCs) accumulate in confined spaces and contribute to respiratory diseases, cardiovascular complications, cognitive impairment, and reduced life expectancy.

Traditional air quality monitoring infrastructure is expensive, bulky, and designed primarily for large-scale environmental surveillance. These limitations have historically prevented continuous IAQ monitoring in homes, classrooms, offices, and healthcare facilities. The emergence of the Internet of Things (IoT) has fundamentally changed this landscape. Low-cost microcontrollers, miniaturized sensors, and ubiquitous wireless connectivity now enable real-time, distributed, and remotely accessible monitoring at a fraction of traditional costs.

Despite the proliferation of IoT-based monitoring systems, a critical deficiency persists: most systems are limited to sensing and alerting, without any integrated mechanism to actively remediate detected pollution. Conversely, conventional air purifiers operate without environmental feedback, leading to wasteful continuous operation or delayed activation. This review surveys fourteen representative studies to characterize the current state of the art, identify architectural patterns, and synthesize open research challenges.

2. SCOPE AND REVIEW METHODOLOGY

This review covers peer-reviewed conference papers published between 2012 and 2025, selected from IEEE Xplore and related proceedings. Studies were included if they addressed IoT-based indoor or outdoor air quality monitoring, automated air purification, or a combination of both. The reviewed works are evaluated along five dimensions: (i) hardware and microcontroller platform, (ii) sensing modalities and target pollutants, (iii) communication and cloud infrastructure, (iv) degree of automation and corrective action, and (v) identified limitations and suggested future work.

3. REVIEW OF LITERATURE

3.1 Health-Motivated Monitoring Systems

A major strand of research focuses on deploying IoT sensors for health-driven IAQ monitoring. Komarudin et al. [1] developed a compact, sensor-based system to monitor temperature, humidity, and gaseous pollutants in real time during the COVID-19 pandemic. The work underscored the link between aerosol-laden indoor air and airborne disease transmission, and demonstrated how IoT connectivity enables continuous environmental awareness in hospitals and offices. However, the system offered no purification capability, limiting its role to passive awareness rather than active health protection.

Similarly, Ali et al. [6] designed a real-time monitoring system with an explicit focus on occupant health, providing accurate pollutant detection and immediate feedback. While the system was found to be reliable, it shared the same fundamental limitation: detection without remediation. Murdan and Jeetun [13], working in a post-pandemic context, extended this paradigm by incorporating email and SMS alerts via the ThingSpeak platform, along with a cloud-based chatbot interface. Their use of multiple MQ-series sensors (MQ2, MQ3, MQ9, MQ135) and the DSP310 atmospheric pressure sensor on an Arduino Mega platform represents one of the more comprehensive sensing arrays in the reviewed literature, yet it too lacked automated corrective capability.

3.2 Domestic Safety and Gas Leak Detection

Gupta et al. [2] addressed a specific domestic hazard cooking gas leaks by deploying MQ-series sensors in residential kitchens. The system transmitted readings to an IoT platform and generated real-time user alerts, providing a cost-effective safety solution. The work highlights how IoT-based monitoring can be tailored to specific use cases. Nevertheless, the system functioned purely as a warning tool; once a hazardous condition was detected, corrective action remained entirely manual. This gap between detection and remediation characterizes much of the reviewed literature.

3.3 Ventilation-Integrated Systems

Ahmad Nizar et al. [3] took a step beyond pure monitoring by integrating air quality sensing with automated ventilation control. Their IoT-based system dynamically adjusted airflow based on real-time sensor readings, reducing pollutant concentration through increased fresh-air circulation. This represents a meaningful advance over alert-only architectures; however, ventilation alone is insufficient in heavily polluted environments or during adverse outdoor air quality conditions. The system notably lacked active filtration such as HEPA or activated carbon stages meaning fine particulate matter and toxic gases could not be effectively removed.

3.4 Integrated Monitoring and Purification

Two studies stand out for attempting full integration of sensing and purification. Kadarkarai et al. [4] developed an IoT-based system that combined sensor-driven monitoring with an automatic filtration unit, activating purification when thresholds were exceeded. The system delivered demonstrably improved performance relative to standalone solutions, validating the integrated design philosophy. Constraints related to cost, scalability, and energy consumption were identified as barriers to broader deployment.

Deepa et al. [7] developed a smart air purifier with embedded AQI monitoring, enabling demand-driven purification that activates only when pollution levels warrant it. This approach reduces unnecessary energy consumption compared with always-on purifiers and represents a commercially relevant design pattern. Like [4], cost and scalability were cited as unresolved challenges.

3.5 Cloud-Connected and Remote Monitoring Platforms

Faiazuddin et al. [5] demonstrated the scalability potential of IoT-based IAQ systems by implementing cloud-connected monitoring on a Raspberry Pi 4. The platform supports remote data access, making it suitable for deployment across diverse environments. The study reinforces the value of cloud integration but does not address purification.

Garg et al. [10] presented a more recent and capable platform using the ESP32 microcontroller paired with MQ135, DHT11, and BMP180 sensors, transmitting data to the Blynk IoT cloud. The system supported both indoor and outdoor monitoring and provided mobile-accessible dashboards. Hapsari et al. [12] adopted the MQTT lightweight messaging protocol with a NodeMCU ESP8266 platform and three distributed wireless sensor nodes on a university campus, demonstrating the utility of multi-node architectures for building-scale IAQ assessment. Both systems remained confined to monitoring and lacked purification functionality.

3.6 Low-Cost and Constrained-Resource Designs

Malik et al. [8] addressed affordability constraints by designing an outdoor monitoring device based on the ATmega328 microcontroller and ESP8266 Wi-Fi module. Using the MQ135 sensor for gas detection and DHT11 for temperature and humidity, the system achieved cloud connectivity at minimal hardware cost. The authors identified data analytics and predictive modeling as natural extensions for future work.

Anitha et al. [11] presented an Arduino UNO-based system with MQ135 and an optical dust sensor that displayed AQI

on a 16×2 LCD and triggered buzzer alerts when thresholds were exceeded.
Tested over five days in a kitchen environment, the system demonstrated reliable basic detection. Its constraint was the absence of IoT connectivity and remote monitoring capability, confining its utility to local, standalone deployments.

Tijani et al. [14] developed a wireless sensor node capable of measuring odor, CO, methane, dust, humidity, and temperature, with onboard SD card storage for offline data logging. The node's LED-based status indicators make the system accessible to non-technical users. The limitation of a single-node design was acknowledged; scaling to a full building would require a coordinated network of nodes with appropriate routing protocols.

3.7 Energy-Autonomous and Wireless Sensor Network Approaches

Wang et al. [9] addressed long-term monitoring sustainability through a self-powering wireless sensor network. Their Octopus II nodes used ZigBee communication and solar-plus-battery power with a sleep mechanism to extend operational lifetime. Remote GSM-based control of the PM sensor further reduced energy demand during periods of low monitoring priority. The system monitored CO and particulate matter in urban environments; the exclusion of other pollutants was attributed to sensor cost and durability limitations.

4. COMPARATIVE ANALYSIS

Table 1 summarizes the fourteen reviewed works across key technical dimensions. The comparison reveals several consistent patterns. First, sensor choice converges on a small set of commercially available components MQ135 for mixed gas detection and DHT11 for temperature/humidity reflecting their low cost and ease of integration. Second, microcontroller platforms have evolved from Arduino UNO and ATmega328 toward ESP8266 and ESP32, driven by the need for built-in Wi-Fi and greater processing capacity.

Table 1: Comparative Summary

Ref.	Authors	Platform / Sensors	Key Contribution	Limitation
[1]	Komarudin et al.	IoT sensors; temp & humidity	Real-time health monitoring during COVID-19	No purification mechanism
[2]	Gupta et al.	MQ-series gas sensors; IoT platform	Gas leak detection with real-time alerts	Alert only; no auto-purification
[3]	Ahmad Nizar et al.	IoT sensors; ventilation control	Automated ventilation based on AQI	No HEPA/carbon filtration
[4]	Kadarkarai et al.	IoT sensors; filtration unit	Integrated monitoring & purification	Cost and scalability issues
[5]	Faiazuddin et al.	Raspberry Pi4; cloud platform	Scalable remote monitoring	No purification mechanism
[6]	Ali et al.	IoT sensors; real-time feedback	Human health-focused monitoring	No automated corrective action
[7]	Deepa et al.	Smart sensors; purifier + AQI	Integrated AQI + smart purifier	Cost & scalability challenges
[8]	Malik et al.	ATmega328 + ESP8266; MQ135, DHT11	Low-cost outdoor monitoring with alerts	No purification; outdoors only
[9]	Wang et al.	WSN; ZigBee; CO & PM sensors	Solar-powered self-sustainable WSN	Monitors CO & PM only
[10]	Garg et al.	ESP32; MQ135, DHT11, BMP180; Blynk	Advanced IoT with cloud dashboard	No purification; needs calibration
[11]	Anitha N et al.	Arduino UNO; MQ135; dust sensor	Low-cost AQI with buzzer alerts	Local monitoring only; no IoT
[12]	Hapsari et al.	NodeMCU ESP8266; MQTT; WSN	Multi-node campus monitoring via MQTT	No purification; limited environment
[13]	Murdan et al.	Arduino Mega; multiple MQ sensors; ThingSpeak	Post-pandemic IoT with SMS/email alerts	No auto-purification; needs internet
[14]	Tijani et al.	Wireless sensor node; CO, CH4, dust	LED-based IAQ with offline storage	Single node; no purification

A critical observation from Table 1 is the almost universal absence of automatic purification. Only references [4] and [7] provide integrated purification, and both identify cost and scalability as unresolved barriers. Systems employing ventilation control [3] represent a partial solution, but physical filtration of fine particles and toxic gases requires dedicated filter stages (e.g., HEPA, activated carbon) that most architectures omit.

5. RESEARCH GAPS AND FUTURE DIRECTIONS

The foregoing analysis reveals several persistent gaps in the IoT-based IAQ literature:

1) Integration of monitoring with active purification: The majority of systems are detection-only. A closed-loop architecture that seamlessly couples sensing, decision-making, and filtration remains rare and represents the most impactful open challenge.
2) Sensor diversity and multi-pollutant coverage: Most systems target a narrow pollutant subset. Comprehensive IAQ management requires simultaneous monitoring of PM2.5, CO_2, CO, NH_3, VOCs, and other context-specific gases.
3) Energy efficiency: Continuous sensor operation and cloud communication impose a non-trivial energy burden. Adaptive duty-cycling, edge computing, and energy harvesting (as demonstrated in [9]) deserve broader adoption.
4) Predictive and AI-driven control: Current threshold-based control is reactive. Machine learning models trained on historical sensor streams could enable predictive purification and anomaly detection, reducing response latency and energy waste.
5) Scalability and cost reduction: Systems that integrate monitoring and purification tend to be constrained by cost. Further miniaturization and commoditization of sensor and filter components are needed for widespread residential adoption.
6) Standardized benchmarking: No common performance benchmark exists across reviewed systems, making direct comparison difficult. Standardized test conditions, calibration procedures, and reporting metrics would strengthen the field.

6. PROPOSED SYSTEM IN CONTEXT

The gap analysis in Section 5 directly motivates a system that combines real-time multi-pollutant monitoring with automated filtration. An architecture employing the ESP32 microcontroller, a PMS5003 particulate matter sensor (PM1.0/PM2.5/PM10), and an MQ-135 gas sensor addresses both particulate and gaseous pollution in a single platform. Threshold-based logic within the ESP32 autonomously activates a dual-stage purification unit comprising an activated carbon filter for VOC and gas absorption and a HEPA filter for fine particle capture when pollution levels exceed safe limits. Real-time status is communicated via an LCD display.

This design directly resolves the most pervasive limitation identified across the literature: the absence of closed-loop remediation. By integrating low-cost, well-validated components within a compact and scalable architecture, the system is suitable for homes, offices, healthcare facilities, and industrial environments addressing the deployment breadth recommended by multiple reviewed works.

7. CONCLUSION

This review has systematically examined fourteen IoT-based air quality monitoring and purification studies published between 2012 and 2025. The body of work demonstrates clear and sustained progress in sensor integration, cloud connectivity, and miniaturized hardware. At the same time, a consistent and critical limitation pervades the literature: the separation of monitoring and purification functions. Systems that detect pollutants but cannot remediate them provide incomplete protection; systems that purify without dynamic sensing waste energy and may respond too slowly to acute pollution events.

The reviewed literature converges on a shared vision an intelligent, low-cost, automated indoor air quality management system but most individual contributions realize only part of that vision. Future systems must close the sensing-to-actuation loop, expand pollutant coverage, incorporate predictive intelligence, and demonstrate scalability across diverse deployment contexts. These imperatives define the frontier of IoT-based IAQ research and underscore the value of integrated monitoring-and-purification architectures.

REFERENCES

1) M. Komarudin et al., "Air quality monitoring device for smart health solution during Covid-19 pandemic," in Proc. ICCTEIE, 2021, pp. 78–81, doi: 10.1109/ICCTEIE54047.2021.9650638.
2) K. Gupta, G. K. G, and A. T, "An IoT-based system for domestic air quality monitoring and cooking gas leak detection," in Proc. ICCSP, 2020, pp. 705–710,
3) A. N. A. Nizar et al., "IoT-based home air quality monitoring and ventilation system," in Proc. InECCE, 2025, pp. 380–385, doi: 10.1109/INECCE64959.2025.11150898.
4) P. Kadarkarai et al., "IoT-based air quality monitoring and air purifier system," in Proc. ICTMIM, 2025, pp. 1188–1193, doi: 10.1109/ICTMIM65579.2025.10988388.
5) S. Faiazuddin et al., "IoT-based indoor air quality monitoring system using Raspberry Pi4," in Proc. ICECA, 2020, pp. 714–718, doi: 10.1109/ICECA49313.2020.9297425.
6) F. A. Ali, S. Prakash, and S. Mali, "IoT-based real-time monitoring system for indoor air quality for human health," in Proc. ICAIHC, 2023, doi: 10.1109/ICAIHC59020.2023.10431482.
7) S. Deepa et al., "Smart air purifier and AQI monitoring system," in Proc. ICICAT, 2024, doi: 10.1109/ICICAT62666.2024.10923162.
8) P. K. Malik et al., "Development of a low-cost IoT device using ESP8266 and Atmega328 for real-time monitoring of outdoor air quality with alert," in Proc. AECE, 2023, pp. 125–129, doi: 10.1109/AECE59614.2023.10428098.
9) C.-H. Wang et al., "A self-sustainable air quality monitoring system using WSN," in Proc. IEEE SOCA, 2012, pp. 1–6, doi: 10.1109/SOCA.2012.6449427.
10) R. Garg et al., "Advanced air quality monitoring system using IoT and sensor technology," in Proc. IDCIoT, 2025, pp. 687–692, doi: 10.1109/IDCIOT64235.2025.10915106.
11) N. Anitha et al., "Air quality monitoring system," in Proc. ICCEBS, 2023, pp. 1–5, doi: 10.1109/ICCEBS58601.2023.10448553.
12) A. A. Hapsari et al., "Real-time indoor air quality monitoring system based on IoT using MQTT and WSN," in Proc. ICETAS, 2019, pp. 1–7, doi: 10.1109/ICETAS48360.2019.9117518.
13) A. P. Murdan and M. U.-R. Jeetun, "Post-pandemic air quality monitoring system using IoT," in Proc. ICAIS, 2023, pp. 12–18, doi: 10.1109/ICAIS56108.2023.10073718.
14) I. B. Tijani et al., "Wireless sensor node for indoor air quality monitoring system," in Proc. ASET, 2018, pp.1–6,doi: 10.1109/ICASET.2018.8376839.