

Smart AQI Monitor & Awareness System for Campus

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Abstract—Urban campuses in India face a growing but often invisible challenge: degraded indoor air quality in classrooms, corridors, and hostels, with no accessible real-time monitoring in place. This paper presents the Smart AQI Monitor & Awareness System for Campus, a low-cost IoT-based platform built around an Arduino UNO microcontroller paired with MQ135, PMS3003, and DHT11 sensors. The system measures PM2.5, PM10, CO₂, temperature, and humidity, computes a composite AQI value using standard sub-index formulas, and communicates the result through a colour-coded LED array and an I2C LCD display. A buzzer alert activates whenever AQI exceeds the Moderate threshold. A structured pilot evaluation was conducted with 35 participants across four groups: students, teaching faculty, hostel residents, and campus administrators. All five usability dimensions met or exceeded the benchmark threshold of $\mu \geq 4.0$, with an average usability score of 4.25/5.0. The system was assembled for an estimated hardware cost of ₹1,400–1,500, which is substantially below commercial indoor AQI devices. A cost comparison across monitoring categories confirms savings of up to 85% relative to commercial alternatives. The project maps to three United Nations Sustainable Development Goals (SDG 3, 11, 13) and demonstrates measurable social impact in health awareness and environmental responsibility.

Index Terms—Air Quality Index, IoT, Arduino, Campus Health, Indoor Monitoring, PM2.5, SDG, Low-Cost Sensing, Environmental Awareness

I. INTRODUCTION

Air pollution is among the leading environmental health threats globally, with the World Health Organization estimating that 99% of the global population breathes air that exceeds WHO guideline

limits [1]. In urban India this risk is compounded inside built environments: classrooms, corridors, and hostel rooms accumulate PM2.5, PM10, carbon dioxide, and volatile organic compounds at levels that frequently exceed outdoor concentrations, yet occupants receive no real-time signal about their exposure [2].

Campuses are particularly vulnerable because high occupancy densities, limited ventilation, and proximity to urban traffic generate elevated pollutant loads throughout the academic day. Chronic exposure to poor indoor air quality is associated with headaches, fatigue, reduced cognitive performance, and long-term respiratory disease — outcomes that directly undermine the academic mission of educational institutions [3].

Despite the severity of the problem, commercially available AQI monitoring devices are priced between ₹10,000 and ₹50,000 per unit, placing campus-wide deployment out of reach for most Indian institutions. Existing public monitoring networks report only outdoor AQI at the city level and provide no indoor, room-level granularity. This paper addresses this gap by presenting the Smart AQI Monitor & Awareness System for Campus, a purpose-built, low-cost indoor air quality monitoring platform.

This paper investigates the following research questions:

- RQ1: Can a low-cost Arduino-based AQI monitor achieve acceptable usability ($\mu \geq 4.0/5.0$) across diverse campus user groups?
- RQ2: Is the hardware cost of the proposed system substantially lower than existing commercial alternatives?

- RQ3: Can a campus-deployed AQI monitor generate measurable positive impact aligned with UN SDG goals?

The remainder of this paper is structured as follows: Section 2 reviews related work. Section 3 describes the mathematical model. Section 4 covers system architecture and platform design. Section 5 presents the cost model. Section 6 details the experimental evaluation. Section 7 covers implementation and the technology stack. Section 8 analyses social and environmental impact. Section 9 discusses challenges and future scope.

II. LITERATURE REVIEW & RELATED WORK

Air quality monitoring systems and IoT-based environmental sensing have been subjects of active research. Nevertheless, no existing solution provides real-time indoor campus AQI monitoring at a cost that is deployable across multiple rooms by educational institutions in India.

2.1 Commercial AQI Devices

Commercial devices such as the Dyllos DC1100 and IQAir AirVisual Pro provide accurate indoor readings but are priced from ₹10,000 to ₹50,000 per unit. Zheng et al. review the landscape of commercial sensors and conclude that most devices at the lower price range exhibit significant calibration drift over time [4]. No commercial product specifically targets campus-wide multi-room deployment in India.

2.2 IoT and Arduino-Based Monitoring

Kumar and Singh demonstrate that MQ-series gas sensors combined with Arduino microcontrollers can deliver low-cost air quality readings with acceptable accuracy for awareness applications [3]. Sharma and Gupta extend this approach to IoT, showing that NodeMCU with ESP8266 can relay sensor data to cloud dashboards in real time [5]. The BorrowBox parallel confirms that Pi-to-peer systems generating structured digital data can be built for under ₹1,500 for hardware-constrained prototypes [11].

2.3 Indoor Air Quality and Health

The WHO reports that indoor air pollution accounts for 3.2 million deaths per year globally, with PM2.5 as

the principal risk factor [1]. Patel and Shah document that Indian classroom CO₂ levels regularly exceed 1,500 ppm in mechanically unventilated rooms, impairing cognitive function by up to 15% [6]. These findings establish the health urgency motivating this work.

2.4 AQI Calculation Methods

The Central Pollution Control Board (CPCB) of India has standardised a sub-index aggregation methodology for AQI calculation covering eight pollutants: PM₁₀, PM_{2.5}, NO₂, SO₂, CO, O₃, NH₃, and Pb [2]. Each pollutant is mapped to a sub-index using a breakpoint interpolation formula, and the dominant (highest) sub-index is reported as the final AQI. This paper adopts the CPCB methodology as the computational basis of the system.

2.5 Campus and Smart City Monitoring

Kulkarni proposes an IoT-based campus monitoring system using Raspberry Pi but notes the cost barrier to multi-room deployment [7]. Maag et al. demonstrate that personal wearable air quality monitors can enable behaviour change, with users who received real-time feedback reducing their exposure by 23% [8]. This supports the hypothesis that localised display and alerting changes occupant behaviour.

2.6 Usability in Embedded Systems

Nielsen defines usability across five dimensions: learnability, efficiency, memorability, error recovery, and satisfaction [9]. Brooke's SUS scale has been validated for evaluating physical and embedded interfaces as well as software [10]. This paper applies both frameworks to evaluate the campus AQI monitor's interface.

2.7 Identified Gap

No platform in Indian educational institutions is found to provide: (i) real-time indoor AQI monitoring, (ii) multi-pollutant sensing, (iii) LED and buzzer threshold alerting, (iv) temperature and humidity display, and (v) a deployable hardware cost below ₹2,000.

Table I: Competitive Feature Comparison

Platform	Multi-Pollutant	Real-Time Alert	Temperature/Humidity	India-Ready	Cost ≤ ₹2,000
Commercial Devices	Yes	Yes	Some	Partial	No
NodeMCU/IoT Kits	Partial	Partial	Yes	Yes	Partial
CPCB Network	Yes	Yes	No	Yes	N/A (outdoor only)
Proposed System	Yes	Yes	Yes	Yes	Yes

III. MATHEMATICAL MODEL OF THE SYSTEM

The Smart AQI Monitor models pollutant measurement, sub-index calculation, and composite AQI computation using a formal mathematical framework consistent with the CPCB AQI methodology.

3.1 Pollutant Sub-Index Calculation

For each monitored pollutant p with a measured concentration C_p , the sub-index I_p is calculated using CPCB breakpoint interpolation:

$$I_p = [(I_{p}^{I_h} - I_{p}^{I_r}) / (C_{p}^{I_h} - C_{p}^{I_r})] \times (C_p - C_{p}^{I_r}) + I_{p}^{I_r}$$

Where $C_{p}^{I_h}$ and $C_{p}^{I_r}$ are the concentration breakpoints bracketing the measured value, and $I_{p}^{I_h}$ and $I_{p}^{I_r}$ are the corresponding index breakpoints from the CPCB table.

3.2 Composite AQI

The final AQI is the maximum sub-index across all monitored pollutants:

$$AQI = \max(I_{p1}, I_{p2}, \dots, I_{pn})$$

For the prototype, two sub-indices are computed: $I_{PM2.5}$ from the PMS3003 sensor and I_{gas} from the MQ135 sensor. The system is designed to expand to additional sub-indices as sensors are added. Example: if $PM2.5 = 55 \mu g/m^3$, the CPCB table places this in the Moderate breakpoint band ($51-90 \mu g/m^3 \rightarrow$ Index 101–200), giving $I_{PM2.5} = 112$.

3.3 Alert Threshold Logic

The buzzer and LED state transitions follow:

LED = Green, Buzzer = OFF if $AQI \leq 100$
 LED = Yellow, Buzzer = OFF if $101 \leq AQI \leq 200$
 LED = Red, Buzzer = ON if $AQI > 200$

This three-state model is consistent with the CPCB Good / Moderate / Poor classification and provides an unambiguous, training-free occupant signal.

3.4 Sensor Calibration Model

The MQ135 raw analog output R_s is converted to pollutant concentration C using the manufacturer's load resistance equation:

$$R_s / R_0 = a \times C^b$$

Where R_0 is the resistance in clean air, and a, b is gas-specific curve-fitting constants from the MQ135 datasheet. For the DHT11, temperature T and relative humidity RH are read directly as digital values with $\pm 2^\circ C$ and $\pm 5\%$ RH accuracy.

IV. SYSTEM ARCHITECTURE & PLATFORM DESIGN

4.1 Hardware Architecture

The system is built around three sensing modules connected to a single Arduino UNO: (i) the MQ135 gas sensor for CO_2 and volatile organic compound detection, (ii) the PMS3003 particulate matter sensor for $PM2.5$ and $PM10$, and (iii) the DHT11 sensor for temperature and relative humidity. The Arduino reads all sensor outputs via digital and analog GPIO pins, performs on-device AQI computation, and drives the output peripherals.

4.2 Output and Alerting Subsystem

Three colour-coded LEDs (green, yellow, red) provide continuous passive AQI status display visible from across a classroom. An active buzzer triggers when AQI exceeds the Moderate threshold. A 16×2 I2C LCD display shows the numeric AQI value, the current AQI category label, and temperature and humidity readings in alternating four-second intervals.

This design requires no smartphone, no network connectivity, and no user training.

4.3 End-to-End Sensing Workflow

The measurement cycle consists of eight sequential steps executed on a continuous loop: (1) Air sampling via sensor intake ports. (2) Pollutant measurement — PM2.5/PM10 from PMS3003, gas concentration from MQ135. (3) Temperature and humidity reading from DHT11. (4) Sub-index calculation per the CPCB breakpoint formula. (5) Dominant pollutant selection (maximum sub-index). (6) Final AQI computation. (7) AQI category classification into one of six bands. (8) Output update: LCD refresh, LED state change, and buzzer activation if threshold is exceeded.

4.4 Core System Features

Five fundamental features enable safe and meaningful operation: real-time multi-pollutant sensing; on-device AQI computation without cloud dependency; three-tier visual alert using colour-coded LEDs; audio alarm for unsafe conditions; and simultaneous display of AQI, temperature, and humidity on the LCD. All features operate on the ₹1,400–1,500 hardware budget.

V. COST MODEL & FEASIBILITY

5.1 Hardware Bill of Materials

Table II: Hardware Bill of Materials

Component	Qty	Unit Cost (₹)	Total (₹)
Arduino UNO	1	260	260
MQ135 Gas Sensor	1	80	80
PMS3003 PM Sensor	1	700	700
DHT11 Temp/Humidity	1	80	80
I2C LCD Display (16x2)	1	200	200
USB Cable / Power Supply	1	100–150	100–150
Total Estimated Cost			₹1,400–1,500

5.2 Cost Comparison with Commercial Alternatives

To contextualise the hardware cost, Table III benchmarks the proposed system against three classes of existing AQI monitoring solutions across five evaluation criteria.

Table III: Cost Comparison with Alternatives

Solution Type	Typical Cost (₹)	Indoor AQI	Per-Room Deployment	Alert System
Commercial AQI Device	10,000 – 50,000	Yes	No (cost)	Yes
IoT Cloud Kit (DIY)	3,000–8,000	Partial	Partial	Partial
CPCB Station	N/A (city infra)	No (outdoor)	No	Portal only
Proposed System	1,400–1,500	Yes	Yes	Yes (LED + Buzzer)

The proposed system delivers a cost reduction of approximately 85–97% versus commercial devices while retaining the core functional requirements of indoor AQI display and threshold alerting.

5.3 Scalability Model

A campus with 20 rooms requiring individual monitoring can deploy the full system for an estimated total hardware cost of ₹28,000–30,000, compared to ₹200,000–₹1,000,000 for commercial alternatives. Each additional unit is independently operational, requiring no shared infrastructure or subscription service.

VI. EXPERIMENTAL EVALUATION & USER TESTING

6.1 Study Design & Participant Profile

A structured pilot evaluation of the Smart AQI Monitor prototype was conducted with $n = 35$ participants. Participants were purposively sampled across four groups representing the primary user populations of the system.

The first group comprised 10 students who evaluated the device as classroom occupants, assessing real-time AQI readability, LED alert comprehension, and ease of interpreting the LCD output. The second group of 8 teaching faculty members assessed the system from a room-management perspective, focusing on the speed of identifying unsafe conditions and the usefulness of temperature/humidity data. The third group of 12 hostel residents tested the system in a dormitory setting, evaluating the utility of continuous overnight monitoring and the appropriateness of the buzzer threshold. The fourth group of 5 campus administrators and subject-matter experts assessed

overall system robustness, sensor placement logic, and scalability across multiple rooms.

All participants completed a facilitated walkthrough of the device, two unaided interaction tasks, and a post-session Likert scale survey (1 = Very Poor, 5 = Excellent) covering five usability dimensions. Benchmark threshold was set at $\mu \geq 4.0$, consistent with SUS equivalents [10].

6.2 Statistical Analysis of Usability Scores

The mean (μ), standard deviation (σ), and 95% confidence interval ($CI = \mu \pm 1.96 \times \sigma/\sqrt{n}$) were computed for all five usability dimensions. All dimensions met or exceeded the benchmark threshold.

Table IV: Statistical Summary of Usability Evaluation (n = 35)

Metric	Mean (μ)	Std Dev (σ)	95% CI	Benchmark	Status
Ease of Use	4.30	0.45	[4.15, 4.45]	≥ 4.0	✓ Met
AQI Readability	4.25	0.50	[4.08, 4.42]	≥ 4.0	✓ Met
Alert Comprehension	4.40	0.36	[4.28, 4.52]	≥ 4.0	✓ Met
LCD Information Quality	4.10	0.52	[3.93, 4.27]	≥ 4.0	✓ Met
Overall Satisfaction	4.20	0.44	[4.05, 4.35]	≥ 4.0	✓ Met

Table IV — Usability dimensions and statistical results (n = 35, benchmark $\mu \geq 4.0$)

6.3 Per-Cohort Satisfaction Analysis

Alert Comprehension received the highest mean score ($\mu = 4.40, \sigma = 0.36$), indicating that the three-LED colour scheme and buzzer are highly intuitive across all user groups. Faculty scored Alert Comprehension highest of all cohorts (4.6), consistent with their role in making rapid room-management decisions. Students scored AQI Readability at 4.3, reflecting the accessibility of the LCD numeric display format for the primary campus population. Hostel residents gave the highest score in the Ease-of-Use dimension (4.4), likely reflecting the simplicity of always-on passive monitoring requiring no interaction. LCD Information Quality showed the widest confidence interval [3.93, 4.27], indicating variability in how different groups valued the dual AQI/temperature display — administrators preferred dedicated AQI-only output, while students and hostel residents valued the combined environmental data.

6.4 Baseline Comparison — Usability

For comparative purposes, 20 participants with prior experience of existing air quality awareness methods

were surveyed using the same five-dimension Likert scale applied to two baselines: Baseline A (manual AQI check via smartphone/CPCB app) and Baseline B (no monitoring — awareness from physical sensation alone). The proposed system outperformed both baselines on all five usability dimensions.

6.5 Baseline Comparison — Cost Efficiency

On average, deploying the proposed system costs 85.3% less per monitoring point than the lowest-priced commercial equivalent. Across the four campus deployment contexts tested — single classroom, corridor, hostel room, and administrative block — the proposed system delivered comparable or superior alerting functionality at a fraction of the commercial cost.

VII. SYSTEM IMPLEMENTATION & TECHNOLOGY STACK

7.1 Hardware Implementation

All components are mounted on a standard 830-point breadboard, powered via USB. The PMS3003 is connected to Arduino digital pins 2 and 3 using Software Serial. The MQ135 output connects to

Arduino analog pin A0. The DHT11 connects to digital pin 4. The I2C LCD is interfaced through the hardware I2C bus (SDA/SCL, pins A4/A5). Three LEDs with current-limiting resistors connect to digital pins 9, 10, and 11 (green, yellow, red). The active buzzer connects to digital pin 8.

7.2 Software Implementation

Firmware is written in the Arduino C++ dialect using the Arduino IDE. Key libraries include: PMS library for PMS3003 serial parsing, DHT library for DHT11 reading, LiquidCrystal_I2C for LCD control, and a custom AQI calculation module implementing the CPCB sub-index formula. The main loop executes the eight-step sensing workflow at a 2-second sample interval, with LCD content alternating between AQI and environmental data at 4-second intervals.

7.3 Architecture and Deployment

The system is fully self-contained and operates without network connectivity, cloud dependency, or companion applications. Each unit is independently powered and independently operational, making distributed campus deployment straightforward. The modular codebase supports parametric threshold configuration, enabling institutions to adjust alert levels to suit specific environmental contexts.

7.4 Architectural Rationale

The decision to implement all computation on-device rather than in the cloud eliminates network dependency, reduces latency to below 2 seconds, and avoids data privacy concerns associated with continuous environmental logging. The I2C bus reduces wiring complexity, and the SoftwareSerial approach for PMS3003 frees the hardware UART for debugging. TypeScript-based BorrowBox architecture [11] was consulted for modular design principles, adapted to the embedded context.

VIII. IMPACT ANALYSIS

8.1 Health and Wellbeing Impact

Deployment of real-time AQI alerting in campus spaces directly addresses documented causes of student health degradation. Continuous monitoring enables occupants and facility managers to take corrective action — improving ventilation, reducing indoor crowding — before health effects manifest.

The WHO estimates that reducing PM_{2.5} exposure by 10 µg/m³ reduces all-cause mortality risk by 6–7% [1], providing a quantitative basis for the health benefit of the system.

8.2 SDG Mapping & Sustainability Alignment

Three United Nations Sustainable Development Goals are directly addressed: SDG 3 (Good Health and Well-Being), by reducing campus occupant exposure to harmful indoor pollutants and providing actionable health warnings; SDG 11 (Sustainable Cities and Communities), by enabling data-driven facility management and supporting the development of smarter, safer campus environments in urban India; and SDG 13 (Climate Action), by promoting environmental literacy and evidence-based awareness of air pollution among students and staff, building the cultural foundation for climate-conscious behaviour.

8.3 Social Impact

- Provides equal, passive, real-time health protection to all campus occupants regardless of smartphone access or technical literacy.
- Empowers facility managers with actionable environmental data for ventilation and occupancy decisions.
- Builds environmental awareness among students through daily, tangible exposure to AQI data.
- Creates a replicable model for low-cost campus health infrastructure scalable across Indian higher education institutions.
- Supports institutional alignment with India's National Clean Air Programme (NCAP) targets.

IX. CHALLENGES & FUTURE SCOPE

9.1 Challenges Encountered

Several technical and operational challenges were encountered during the development phase. Sensor calibration drift in MQ135 required establishing a per-unit clean-air baseline R₀ value before deployment; this step adds approximately 30 minutes to each installation. The PMS3003 exhibited sampling latency of up to 1.5 seconds in high-humidity conditions, introducing occasional LCD flicker. Power supply consistency was identified as a vulnerability for hostel deployments where USB outlets are shared. Ambient temperature above 40°C in unventilated rooms

introduced a +3°C systematic bias in DHT11 readings, which required a compensation offset.

9.2 Pilot Study Limitations

The pilot study carries limitations inherent to its scale and design. The sample size of $n = 35$ is below the $n = 100$ recommended for $\alpha = 0.05$ statistical power. Participant recruitment through a single institution introduces tech-literacy bias. The usability evaluation was conducted with a prototype in a controlled demonstration setting, which may not fully represent real-world continuous unattended operation. Sensor accuracy was assessed against manufacturer specifications rather than a certified reference instrument.

9.3 Future Scope

The immediate next steps include a Wi-Fi-enabled variant using NodeMCU/ESP8266 to enable cloud logging and historical trend visualisation, allowing facility managers to review overnight and weekly AQI patterns. Machine learning anomaly detection can be applied to sensor time-series data to identify localised pollution events before AQI thresholds are crossed. Expansion of the sensor suite to include NO_2 (MQ-135 supplemented by electrochemical cell), O_3 , and CO would bring the sub-index count to five, improving composite AQI accuracy to full CPCB compliance. A mobile companion application would enable push notifications to faculty and administrators when any campus unit triggers a threshold alert. Long-term, the platform can be integrated with campus building management systems to automate HVAC ventilation responses to AQI exceedance events.

X. CONCLUSION

The Smart AQI Monitor & Awareness System for Campus demonstrates that real-time indoor air quality monitoring with meaningful threshold alerting is achievable within a hardware budget of ₹1,400–1,500 — roughly 85–97% below commercial alternatives. A structured pilot evaluation with 35 participants across four campus user groups returned an overall usability score of 4.25/5.0, with all five usability dimensions meeting the benchmark threshold of $\mu \geq 4.0$. The system's three-LED visual display and buzzer alert mechanism proved highly intuitive, achieving the

highest usability score (4.40) of any measured dimension.

By providing continuous, passive, indoor AQI awareness in classrooms, corridors, and hostel rooms, the system directly addresses SDG 3 (Good Health), SDG 11 (Sustainable Cities), and SDG 13 (Climate Action). As India's urban campuses face growing air quality challenges, the proposed system offers a scalable, affordable, and evidence-backed model for healthier learning environments. Future work will expand the sensor suite, add Wi-Fi connectivity for historical logging, and conduct a full-scale randomised evaluation across multiple institutions.

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