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An IoT-Based Smart Restroom Monitoring System with Occupancy Detection, Automated Soap Supply Management, and Real-Time Air Quality Sensing: Development and ISO/IEC 25010 Evaluation

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ABSTRACT: Restroom management in educational institutions traditionally relies on scheduled maintenance rounds and manual monitoring, an approach that often fails to address real-time supply shortages, occupancy uncertainty, and deteriorating air quality. This study designed, developed, and evaluated a Smart Restroom Monitoring System (SRMS) for the Information Science Building of Centro Escolar University in Manila, Philippines. The prototype integrated an ESP32-WROOM-32 microcontroller, passive infrared (PIR) motion sensors for occupancy detection, HC-SR04 ultrasonic sensors coupled with a 12 V R385 pump for automated soap level monitoring and reservoir refilling, and the SEN0568 MEMS hydrogen sulfide (H_2S) gas detection sensor for continuous air quality reporting through a role-based, mobile-responsive web dashboard. A descriptive developmental research design was employed. Baseline data from 33 student respondents revealed pervasive deficiencies, including lack of soap (M = 4.79/5.00), unpleasant odors (M = 4.72), and unclean stalls (M = 4.70), with 87.9% of respondents reporting active avoidance of the facility. The deployed prototype was subsequently evaluated against the nine quality dimensions of the ISO/IEC 25010 software quality model using a four-point Likert-type instrument (N = 33). The system obtained a grand weighted mean of 3.85 (SD = 0.02), with all nine dimensions rated Excellent. All evaluators rated overall performance as Excellent and unanimously endorsed broader deployment. Findings demonstrate the technical viability of low-cost, sensor-driven facility management in educational settings and provide a replicable reference architecture for similar Internet of Things (IoT) deployments.

KEYWORDS: Internet Of Things; Smart Facility Management; Occupancy Detection; Hydrogen Sulfide; Air Quality Monitoring; ISO/IEC 25010; ESP32; Educational Institutions.

INTRODUCTION

Access to clean, well-supplied, and adequately maintained restroom facilities is a fundamental requirement in any institutional setting. For students and faculty, the availability of hygienic restrooms supports daily routines, physical comfort, and overall well-being. When restrooms are perceived as unhygienic, malodorous, or under-supplied, users frequently delay or avoid restroom use altogether—a behavior linked to adverse health outcomes such as urinary tract infections and kidney complications (Badshah et al., 2023). Long waiting times caused by inadequate occupancy information have likewise been identified as a persistent source of user dissatisfaction in public restrooms (Alfonso et al., 2022).

Conventional restroom management depends on scheduled cleaning rounds and manual inspection, an inherently reactive model that cannot accommodate fluctuating use patterns, sudden supply depletion, or transient air-quality issues. Maintenance personnel cannot continuously verify stall occupancy, monitor consumable inventories, or detect deteriorating air quality across multiple floors of a building. Consequently, deficiencies often persist for extended periods, prompting users to avoid the affected facility and seek alternatives elsewhere.

Empirical evidence collected at Centro Escolar University (CEU) underscores the magnitude of these challenges. A feasibility study involving 55 respondents revealed that 89.1% experienced soap shortages, 65.5% encountered cleanliness issues, and 34.5% reported overcrowding. The fourth and fifth floors accounted for 62% of total restroom traffic, with peak usage occurring during the afternoon period of 3:00–5:00 p.m. (58.2%). When asked about desired system features, 43.6% prioritized supply monitoring, 30.9% sought occupancy indicators, and 27.3% requested air-quality reporting. Critically, 76.4% expressed strong interest in an automated monitoring solution, with an additional 18.2% indicating conditional interest—a combined adoption potential of 94.6%.

These findings highlight a clear opportunity for the integration of Internet of Things (IoT) technologies into restroom facility management. IoT-enabled systems combine sensing, embedded computation, and wireless communication to provide real-time visibility into physical environments (Sathish & Smys, 2020; Ullo & Sinha, 2020). Although prior studies have explored various aspects of smart restroom design, including IoT-based environmental control (Thaenthong et al., 2022), occupancy detection (Azman et al., 2023), and odor monitoring (Wu & Zhang, 2024), Badshah et al. (2023) note that comparatively little research has examined fully integrated platforms that simultaneously combine occupancy detection, supply-level monitoring with automated refilling, and continuous air-quality sensing within a unified system tailored to educational settings.

Problem Statement

Current restroom management at CEU—and at comparable institutions—cannot reliably address real-time problems as they emerge. Despite scheduled maintenance occurring multiple times daily, supply shortages, hygiene issues, and odor problems persist at near-maximum frequency, deterring proper restroom use and compromising user health and comfort. There is therefore a need for an integrated, low-cost, sensor-driven solution that can provide continuous visibility into facility conditions, automate routine replenishment of consumables, and alert maintenance personnel only when intervention is genuinely required.

Research Objectives

This study aimed to design, develop, and evaluate a Smart Restroom Monitoring System (SRMS) tailored to the Information Science Building (ISC) of CEU. Specifically, the study sought to (a) identify and document the key issues in current restroom management with respect to user experience, hygiene standards, and operational efficiency; (b) design and implement an occupancy detection mechanism using passive infrared (PIR) motion sensors; (c) automate hygiene-supply management by integrating ultrasonic sensors with an automatic refilling mechanism; (d) provide continuous visibility into restroom air quality using the SEN0568 MEMS H_2S gas detection sensor; (e) deliver real-time updates and threshold-based alerts through a mobile-responsive web dashboard; (f) identify and justify the most suitable hardware and software components based on cost, accuracy, reliability, and integration considerations; and (g) evaluate the developed system using the ISO/IEC 25010 software quality model across nine quality dimensions: functional stability, performance efficiency, compatibility, interaction capability, reliability, security, maintainability, flexibility, and safety.

Scope and Delimitations

The study focused on the design and prototype-level deployment of the SRMS in restrooms of the ISC building. The system is intended for detection, monitoring, reporting, and automatic soap refilling only; it does not perform air filtration, water purification, or large-scale cleaning. Manual cleaning tasks, sewage management, integration with campus-wide building management systems, and predictive artificial intelligence for behavior forecasting are beyond the scope. The monitoring interface is implemented as a mobile-responsive web dashboard rather than a native mobile application.

The prototype was deployed and evaluated in a single building, and no longitudinal cost-benefit analysis was conducted. A limitation of the study is the gender skew of baseline respondents, which may influence the generalizability of perceptions related to facility conditions and usability.

LITERATURE REVIEW

This review synthesizes existing research on IoT-enabled smart systems, sensor-based environmental monitoring, smart facility management, and smart restroom applications, with particular attention to deployments in educational institutions. The review is organized thematically to establish the technological and conceptual foundations on which the present study builds and to identify the research gap that the proposed Smart Restroom Monitoring System addresses.

IoT-Enabled Smart Systems in Buildings and Campuses

Smart systems integrate sensing, data processing, communication, and automation to improve efficiency and decision making across diverse environments. The advancement of the IoT has enabled smart systems to move beyond isolated automation toward distributed, data-driven ecosystems (Sathish & Smys, 2020). Within buildings, IoT-enabled platforms support thermal comfort, security, and energy management. Alsaleem et al. (2020) developed an IoT framework for modeling and controlling thermal comfort, demonstrating that sensor-based monitoring with automated responses can reduce energy consumption while maintaining occupant comfort. Jadon et al. (2020) integrated IoT and machine learning to automate appliances, security, and environmental monitoring in residential settings.

Energy conservation remains a particularly active area of IoT research. Somefun et al. (2022) designed a smart home energy management system that achieved an approximately 17% reduction in household energy consumption through automated regulation of lighting, temperature, and appliance usage. Singh et al. (2022) and Thaenthong et al. (2022) extended such approaches to washroom and public restroom contexts, demonstrating how microcontroller-driven controls can reduce power use in intermittently occupied spaces. At a larger scale, Zaballos et al. (2020) introduced a digital twin model for a smart campus, while Sepasgozar et al. (2020) reviewed the convergence of IoT and artificial intelligence in residential automation, finding consistent gains in predictive control and centralized management. Across these studies, IoT consistently emerges as the foundational enabler of smart-system functionality, providing the connectivity through which sensors, controllers, and dashboards exchange information.

Sensor-Based Environmental and Air Quality Monitoring

Sensor-based monitoring underpins indoor environmental control, enabling continuous measurement of parameters such as temperature, humidity, particulate matter, and gas concentrations. These systems typically pair microcontrollers with embedded sensors and IoT communication modules to detect changes in real time and to trigger programmed responses. Pangestu et al. (2020) developed an IoT-based indoor air quality monitoring prototype that displays readings and activates indicators when measured values exceed established thresholds. Khadim et al. (2021) designed a laboratory monitoring system based on MQ-series sensors and Wi-Fi communication that displays gas concentrations on a mobile interface and alerts users when concentrations exceed recommended safety limits.

Sensor accuracy and reliability remain central considerations. Pangestu et al. (2020) reported error rates of 12% for dust monitoring and 1.06% for temperature readings when compared with a reference nephelometer, supporting the feasibility of low-cost sensor deployment for real-time monitoring. Saini et al. (2020), in a systematic review, observed that IoT-based indoor air quality systems increasingly adopt multi-sensor configurations integrated with cloud dashboards to support long-term monitoring and trend analysis. Studies by Basan (2020) and Kristiyana and Rinaldi (2020) further illustrated the growing role of Arduino- and ThingSpeak-based architectures in enabling remote monitoring through smartphones. De Capua et al. (2023) more recently proposed optimization strategies that improve sensing reliability and system responsiveness, positioning IoT-based sensor systems as efficient tools for maintaining safe indoor environments.

Smart Facility Management Systems

Smart Facility Management Systems (SFMS) integrate IoT, Building Information Modeling (BIM), artificial intelligence (AI), and Digital Twin (DT) technologies to optimize building operations and enhance resource efficiency. These systems transform traditionally passive facility management into proactive, data-driven operations (Abdelkarim et al., 2023; Olimat et al., 2023; Raendran et al., 2020). In the context of restroom monitoring, IoT platforms enable motion sensors, occupancy detectors, and air-quality sensors to collect and process data continuously, while web dashboards and mobile applications facilitate centralized oversight (Raendran et al., 2020). BIM contributes by providing comprehensive digital representations of buildings—supporting maintenance planning, 3D visualization, and centralized data access—and, when integrated with IoT, forms the basis for Digital Twin environments capable of real-time monitoring (Olimat et al., 2023; Paek & Sojkov, 2018). AI extends these capabilities by enabling predictive maintenance, peak-usage forecasting, and intelligent scheduling (Olimat et al., 2023).

Despite these benefits, the literature also identifies persistent barriers to SFMS adoption. High initial implementation costs, the need for specialized expertise, integration complexity across heterogeneous vendor platforms, and cybersecurity considerations remain significant challenges (Olimat et al., 2023; Paek & Sojkov, 2018). Nevertheless, the trajectory of research indicates sustained interest in extending smart facility management into specialized contexts, including healthcare, educational, and public-service environments (Faremi et al., 2021; Javaherikhah & Sarvari, 2025).

Hygiene and Environmental Monitoring in Sanitation Facilities

Hygiene and environmental monitoring systems are increasingly recognized as critical components of modern public-health infrastructure (Chandimali et al., 2025; Ullo & Sinha, 2020). Smart environmental monitoring systems exploit wireless sensor networks and IoT platforms to collect and analyze data from heterogeneous sources, supplying facility managers with continuous visibility into hygiene-relevant conditions (Ullo & Sinha, 2020). The advantage of these systems lies in their capacity to detect deviations from established standards and to enable proactive intervention before problems escalate.

Within sanitation facilities specifically, continuous monitoring is essential for ensuring functionality and hygiene. Assessment protocols increasingly examine both hardware components and user behavior, integrating cleanliness verification with odor evaluation to produce a comprehensive picture of facility quality (Giné et al., 2015). Implementation-science perspectives further emphasize that successful monitoring depends not only on technical infrastructure but also on organizational support, leadership commitment, transparent communication, end-user engagement, and adequate resourcing (Granqvist et al., 2024). For monitoring data to yield improvements, the information generated must be translated into actionable insight and embedded within ongoing facility-management decisions.

Smart Restroom Systems: Occupancy, Supply, and Air Quality Functions

The smart restroom concept has emerged as a focused application of IoT and sensor technologies, aiming to address recurring problems of hygiene, resource use, and user dissatisfaction in conventional public facilities (Fowjiya et al., 2025; Kumar et al., 2025; Shahakar et al., 2025). These systems typically combine touch-free fixtures (motion-activated faucets, automatic dispensers, sensor-based flushing) with environmental sensing to create more responsive and hygienic spaces (Shahakar et al., 2025).

Air-quality sensing in restroom contexts often targets hydrogen sulfide (H_2S) and ammonia (NH_3), the two gases most directly associated with restroom odors (Fowjiya et al., 2025; Wu & Zhang, 2024). Beyond environmental sensing, intelligent resource management is a defining feature. Sasikala et al. (2024) demonstrated an IoT-based system that monitors consumable levels and triggers automated reorder when supplies decline, illustrating a shift from reactive to predictive maintenance (Kumar et al., 2025). Occupancy detection, achieved through infrared sensors, pressure pads, or door-state switches, supports user-flow management and reduces unnecessary waiting (Fowjiya et al., 2025; Kumar et al., 2025; Wu & Zhang, 2024). When integrated with a mobile or web interface, real-time occupancy data substantially improves user experience by enabling informed decisions about which facility to use.

Smart Restroom Applications in Educational Institutions

Educational campuses face distinctive restroom-management challenges due to high user density and concentrated patterns of demand. Azman et al. (2023) developed a smart restroom monitoring system for residential colleges based on LoRa and Raspberry Pi, demonstrating the feasibility of replacing scheduled cleaning with usage-driven approaches and enabling long-term analysis of restroom use patterns. Thao et al. (2023) proposed a Long Short-Term Memory (LSTM) architecture using wireless sensor data on NH_3 concentrations and relative humidity to predict cleaning conditions in school restrooms, allowing more efficient scheduling of maintenance and reducing potential health risks.

Badshah et al. (2023) emphasized that maintaining adequate restroom conditions is essential for student health, citing the established association between urinary retention and urinary tract infections; smart systems that ensure cleanliness and supply availability can therefore mitigate such health risks by encouraging proper restroom use. The same authors reviewed the application of occupancy sensors, supply-level sensors integrated with refilling mechanisms, and air-quality sensors that monitor H_2S and other gases in real time. Rana et al. (2024) further argued that real-time notification mechanisms—typically delivered through mobile applications or web-based dashboards—are indispensable to smart hygiene solutions because they enable timely intervention by maintenance personnel. The same authors identified data privacy, user acceptance, infrastructure cost, and integration with existing campus systems as critical considerations for successful deployment.

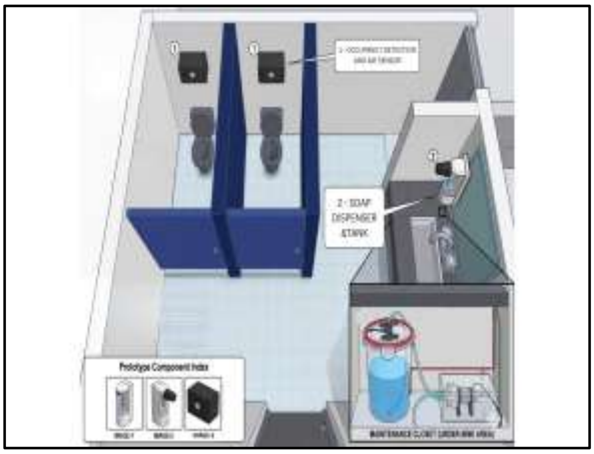
Research Gap

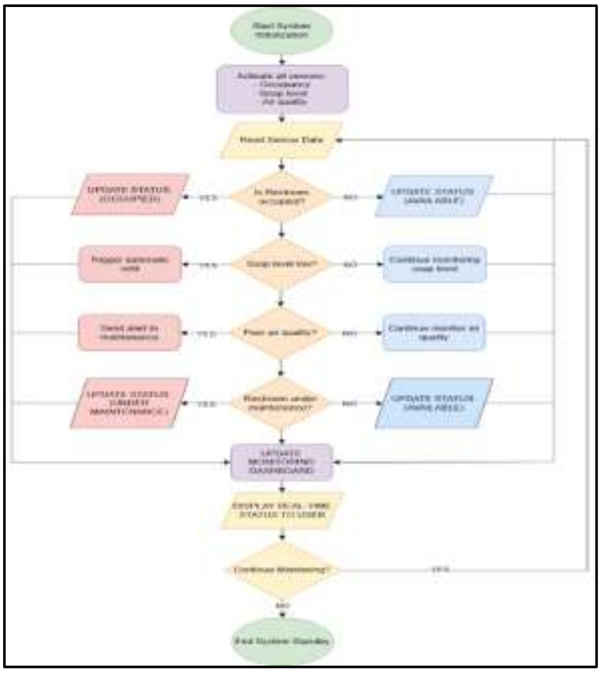
Collectively, the reviewed literature establishes a strong technological foundation for smart restroom monitoring in educational institutions. Individual subsystems—occupancy detection, supply monitoring, environmental sensing, and dashboard-based alerting—have each been investigated, often in isolation or in adjacent domains such as smart homes, smart campuses, and industrial monitoring. However, comparatively few studies report fully integrated systems that combine occupancy detection, automated supply-level monitoring with refilling, and continuous air-quality sensing within a single platform designed for educational settings (Badshah et al., 2023). The present study addresses this gap by developing and empirically evaluating an integrated, low-cost prototype tailored to a Philippine university context, with quality assurance grounded in the ISO/IEC 25010 software quality model.

METHODOLOGY

Research Design

The study employed a descriptive developmental research design to support the systematic creation, testing, and iterative refinement of a functional Smart Restroom Monitoring System (SRMS). This design was selected because it accommodates the cyclical nature of prototype development, in which hardware and software components are progressively refined based on observed performance. The objective was to design, build, and validate a working prototype capable of real-time occupancy detection, automated soap supply management, and continuous air-quality reporting within an authentic deployment environment.





Research Setting and Participants

The study was conducted at the Information Science Building (ISC) of Centro Escolar University (CEU) in Manila, Philippines. ISC serves a high-traffic student and faculty population and includes multiple floors with restroom facilities, providing an environment representative of typical educational deployments.

Two questionnaires were administered. Questionnaire A established baseline restroom-management conditions and was completed by 33 student respondents who regularly used ISC restrooms. Questionnaire B evaluated the deployed prototype using the ISO/IEC 25010 software quality model and was completed by 33 respondents comprising 27 student users and 6 maintenance staff. Purposive sampling was used because the study required participants who would directly interact with the prototype. The N = 33 sample exceeded the minimum of 30 specified in the sampling design. All participants physically interacted with the deployed prototype, completed Questionnaire B in full (100% completion rate), and represented both primary user groups (end users and operational users).

Data Collection Instruments

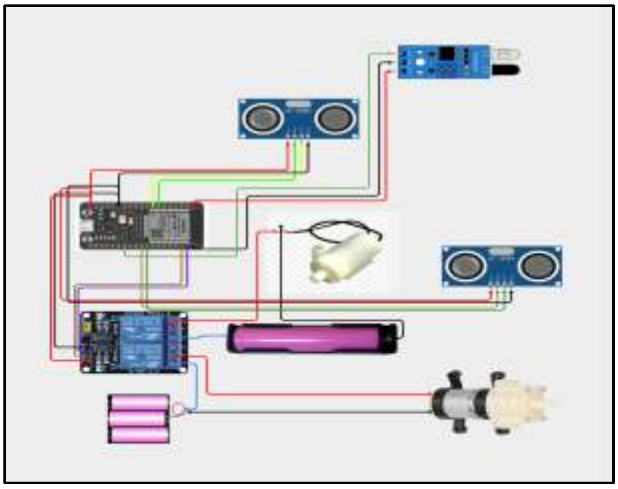
Two researcher-developed instruments were used. Questionnaire A addressed the first research objective by documenting baseline conditions across three sub-dimensions: user experience and facility accessibility, hygiene standards and sanitation quality, and operational efficiency and maintenance effectiveness. The questionnaire combined frequency-based items, 5-point Likert scales (1 = Never, 5 = Always), multiple-response items, and ranking tasks. Questionnaire B addressed the fourth research objective by evaluating the deployed prototype across the nine quality dimensions of the ISO/IEC 25010 model. Items used a four-point Likert-type scale to avoid neutral bias: 4 = Strongly Agree / Excellent, 3 = Agree / Very Satisfactory, 2 = Disagree / Fair, 1 = Strongly Disagree / Poor. Verbal interpretation ranges were set as follows: 3.25–4.00 = Excellent; 2.50–3.24 = Very Satisfactory; 1.75–2.49 = Fair; 1.00–1.74 = Poor.

System Development Framework

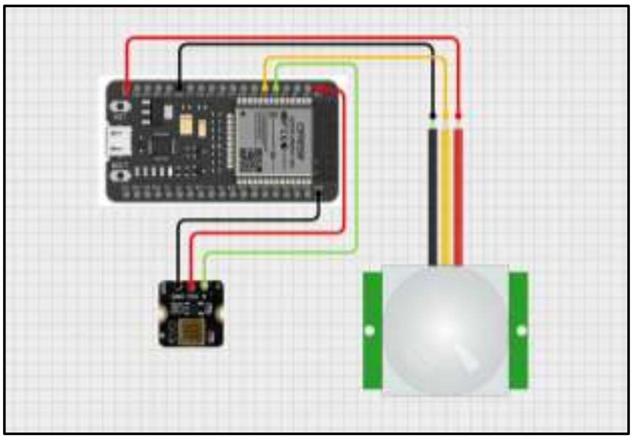
System development followed an Agile-aligned iterative framework comprising six phases: (a) requirement analysis, (b) design, (c) development, (d) quality assurance, (e) deployment, and (f) review. The Agile orientation was suited to the project because it permitted iterative refinement of both hardware and software in response to test results and stakeholder feedback. During requirement analysis, technical and operational needs were derived from the baseline survey and consultations with maintenance personnel. The design phase produced the system architecture, sensor placement plan, control-logic flow diagrams, and dashboard mock-ups. Development implemented core functionalities incrementally, beginning with occupancy detection, followed by soap-supply monitoring and refilling, and culminating in air-quality sensing and dashboard integration. Each iteration concluded with quality-assurance testing of accuracy, response time, reliability, and safety. Successful iterations were deployed in selected ISC restrooms, and post-deployment feedback informed subsequent development cycles.

System Architecture

The prototype adopts a sensor–controller–dashboard architecture. All sensors—PIR motion sensors for occupancy, HC-SR04 ultrasonic sensors for soap level, and the SEN0568 MEMS H_2S sensor for air quality—feed raw data into an ESP32-WROOM-32 microcontroller. The microcontroller applies



threshold logic, triggers actuators (relay-driven pumps) when conditions warrant, and transmits processed data to a cloud-hosted backend through the institutional Wi-Fi infrastructure. Users, maintenance personnel, and administrators access role-specific views of the data through a



mobile-responsive web dashboard. Historical readings are retained for administrative analysis and report generation.

Within each restroom, two component clusters are deployed. The first comprises the combined occupancy and air-quality sensor unit, mounted on the ceiling above each toilet stall to ensure unobstructed infrared detection coverage and continuous H_2S sampling. The second cluster comprises the soap dispenser and tank system, with the dispenser unit mounted above the sink for user accessibility and the reserve tank and pump assembly housed inside the under-sink maintenance closet to protect users from incidental contact with electrical and fluid components.

Hardware Components and Selection Rationale

Component selection followed a constraint-analysis approach in which alternatives were evaluated against three criteria: cost, accuracy and reliability, and power consumption and integration complexity. Table 1 summarizes the selected hardware components and the justification for each choice. Tables 2 through 5 present the constraint analyses for the principal sensing and actuation categories.

Table 1: Selected Hardware Components and Selection Justification

Component	System Role	Selection Justification
ESP32-WROOM-32 microcontroller	Central control unit; coordinates sensors, actuators, and Wi-Fi communication	Dual-core 240 MHz processor with built-in Wi-Fi and Bluetooth, sufficient GPIO pins, and low power consumption; best balance of connectivity and cost for continuous IoT operation
PIR motion sensor	Occupancy detection for restroom stalls	Low cost, low power consumption, and proven reliability for motion-based detection; selected over ultrasonic and reed-switch alternatives
HC-SR04 ultrasonic sensor	Soap supply level measurement	Non-contact distance measurement unaffected by liquid color or ambient light; well-supported trigger–echo interface; superior to load cells and optical sensors in cost–accuracy balance
SEN0568 MEMS H_2S sensor	Continuous air-quality monitoring	Selective detection of hydrogen sulfide—the primary restroom odor indicator; lower power than MQ-series sensors and lower cost than electrochemical alternatives
12 V R385 water pump	Automatic soap reservoir refilling	Simple, reliable, cost-effective fluid transfer; controllable via relay
Mini submersible motor pump (3–5 V DC)	On-demand soap dispensing	Compact form factor and direct relay-based control compatible with ESP32 logic
Relay module	Switching of high-current pump loads	Electrical isolation between low-voltage ESP32 signals and pump power supply
Rechargeable battery pack	Continuous and stable power supply	Provides uninterrupted operation and portable power management

Table 2: Constraint Analysis for Occupancy Detection Sensors

Sensor Type	Cost	Accuracy and Reliability	Power and Integration	Final Selection
PIR motion sensor	Low cost; widely available	Reliable for motion-based detection; may miss stationary occupants	Very low power; simple digital interface	Selected
Ultrasonic sensor	Slightly higher cost	Accurate for distance-based detection but sensitive to angle and ambient noise	Requires timing control; moderate power draw	Not selected
Magnetic reed switch	Very low cost	Reliable for door-state detection only; cannot sense stationary occupants	Very low power; easy digital integration	Not selected

Table 3: Constraint Analysis for Soap-Level Sensors

Sensor Type	Cost	Accuracy and Reliability	Power and Integration	Final Selection
Ultrasonic distance sensor	Low–moderate; widely available	Non-contact measurement, unaffected by color or ambient light; consistent across materials	Moderate power; standard trigger–echo interface	Selected

Load cell with HX711 amplifier	Higher cost; requires amplifier	Accuracy depends on calibration; sensitive to temperature drift	Requires dedicated amplifier and additional wiring	Not selected
Optical/IR sensor	Low cost	Binary detection only; affected by residue, dust, and surface interference	Very low power; insufficient functionality	Not selected

Table 4: Constraint Analysis for Air-Quality Sensors

Sensor Type	Cost	Accuracy and Reliability	Power and Integration	Final Selection
SEN0568 MEMS H_2S sensor	Moderate	Selective to H_2S, key restroom odor indicator	Low–moderate power; analog/I²C interface	Selected
MQ-series gas sensor	Low	Poor selectivity; long warm-up; sensitive to humidity	High power due to heater element	Not selected
Electrochemical H_2S sensor	High	Very high accuracy and selectivity (industrial grade)	Low power but requires specialized interfacing	Not selected

Table 5: Constraint Analysis for Refilling-Mechanism (Pump) Selection

Pump Type	Cost	Accuracy and Reliability	Power and Integration	Final Selection
Mini submersible pump (3–5 V)	Low cost; readily available	Reliable fluid transfer with limited dosing precision	Operates via relay or MOSFET; compatible with ESP32	Selected
Peristaltic pump	Moderate–high	Highly accurate dosing; hygienic; long lifespan	Requires motor driver and higher power	Not selected
Solenoid valve system	Moderate	Effective for pressurized systems; less suitable for small dispensers	Requires relay and reservoir pressure management	Not selected

Software Components

The software ecosystem comprises four elements: the Arduino IDE for firmware development and deployment, custom control-logic firmware running on the ESP32, a mobile-responsive web dashboard for user-facing display and notification, and cloud-based storage for historical sensor data. Table 6 summarizes the software components and their justifications

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Table 6: Software Components and Justification

Software / Platform	Function	Justification
Arduino IDE	ESP32 firmware development and upload	Extensive library support for sensor integration, actuator control, and Wi-Fi communication; supports iterative Agile development
Custom control-logic firmware	Occupancy detection, soap-level monitoring, automatic refilling,	Tailored algorithms for precise threshold detection and reliable actuator activation within the ESP32 runtime

	air-quality sensing, and threshold-based alerting	
Mobile-responsive web dashboard	Real-time status display, alerts, and administrative reporting	Accessible to users, maintenance staff, and administrators across devices without dedicated application installation; supports role-based access control
Cloud storage and database	Historical sensor data, usage patterns, and administrative reports	Supports data-driven decision making and the transition from reactive to proactive facility management

Sensor Threshold Configuration

Threshold values determine when automated actions are triggered and when alerts are dispatched. Thresholds were established based on the physical characteristics of the installed hardware, calibration measurements collected during prototype development, and reference guidelines drawn from internationally recognized standards. Soap-level configuration covers two tanks. Tank 1, the reserve reservoir, employs an HC-SR04 sensor mounted at the top of the tank: a shorter sensor-to-soap distance corresponds to a fuller tank. The refill pump activates when the sensor distance reaches 7.70 cm (approximately 20% remaining) and deactivates at 2.30 cm (approximately 80% full). A hysteresis margin of ±0.20 cm is applied to prevent relay flickering at the threshold boundaries, consistent with standard relay-control practice in embedded systems.

Tank 2, the dispenser unit, is monitored continuously to compute a real-time soap percentage for display on the dashboard. A reading of 2.64 cm corresponds to full (100%) and 13.63 cm to the minimum acceptable level (20%). The displayed percentage is computed by interpolating between these calibrated reference points. A low-level alert is dispatched when Tank 2 reaches the 20% threshold, prompting either manual inspection or automatic refill from Tank 1. A five-condition fail-safe protocol governs pump operation. Under normal conditions, the pump activates when Tank 2 falls below 20% while Tank 1 remains above 20%, and deactivates when Tank 2 reaches approximately 80%. If Tank 1 reaches the critical threshold of 5.00 cm or below, the pump is immediately disabled and a critical alert is displayed. If the pump runs for 120 s without measurable change in Tank 2, the pump is halted and a malfunction warning is issued.

Administrators may override pump operation manually through the dashboard.

Air-quality thresholds for H_2S are anchored to recognized exposure and odor-perception guidelines. The SEN0568 sensor has a detection range of 0.5–50 ppm, suited to toilet, sewer, and sanitation environments according to the manufacturer's documentation. Rather than expose raw ppm values, the system maps sensor readings to a normalized 0–100% index for intuitive display. The 60% alert threshold was established by reference to: (a) the human odor-perception range of 0.0005–0.3 ppm for H_2S, indicating that occupants perceive odor at concentrations well below health-risk levels; (b) the World Health Organization Air Quality Guideline of 0.005 ppm over 30 min for avoidance of odor annoyance (WHO, 2006); (c) the Occupational Safety and Health Administration permissible exposure limit of 20 ppm as an 8-hr time-weighted average and the American Conference of Governmental Industrial Hygienists short-term exposure limit of 5 ppm over 15 min; (d) sanitation-facility research reporting H_2S levels of 0.22–3.17 ppm in dry sanitation toilets, with discomfort observed at concentrations as low as 0.05 ppm; and (e) industry practice in commercial smart restroom platforms that trigger early-warning ventilation alerts on threshold breach. The 60% setting therefore reflects a conservative, user-comfort–centered boundary aligned with WHO guidance, occupational standards, peer-reviewed sanitation research, and industry practice. Table 7 consolidates the system's sensor thresholds.

Table 7: Summary of System Sensor Thresholds and Triggered Actions

Sensor / Location	Parameter	Threshold	Action Triggered
Ultrasonic (Tank 1)	Soap level low	7.70 cm (~20%)	Refill pump ON
Ultrasonic (Tank 1)	Soap level full	2.30 cm (~80%)	Refill pump OFF
Ultrasonic (Tank 1)	Hysteresis band	±0.20 cm	Relay stabilization
Ultrasonic (Tank 1)	Critical empty	≤5.00 cm	Pump disabled; critical alert
Ultrasonic (Tank 2)	Dispenser full	2.64 cm	100% displayed
Ultrasonic (Tank 2)	Dispenser low alert	13.63 cm	20% low-level alert

SEN0568 H_2S sensor	Air quality poor	≥60% index	Maintenance alert dispatched

Maintenance Response Protocol

All alerts are delivered through the web dashboard. Soap-low alerts identify the tank and current level (e.g., "Tank 2 at 18% – refill needed"), instructing staff to add soap to the reservoir. Air-quality alerts at ≥60% prompt staff to ventilate the restroom, inspect drains for blockage, and temporarily restrict access if levels exceed 80%. Pump-malfunction warnings prompt inspection of the pump connector and relay. Each alert includes a sequence of recommended response steps to standardize maintenance practice and reduce response time.

Statistical Treatment

Two analytical strands were applied. For technical-performance metrics, three formulae were used: (a) Functional Success Rate, FSR = (Total Successful Triggers / Total Test Trials) × 100, evaluating sensor reliability in triggering correct system responses; (b) Average Response Time, ART = (Σ Time from Sensor Trigger to Dashboard Update) / Total Number of Updates, capturing system latency; and (c) Sensor Accuracy Rate, SAR = 100% − (Average Percentage Error between Sensor and Manual Reading), comparing sensor output with reference measurements for H_2S and soap level. For user and expert evaluation, descriptive statistics were computed: the weighted mean, $WM = \Sigma(f \cdot w) / N$, where f denotes response frequency, w the scale weight, and N the total number of respondents; the standard deviation, $SD = \sqrt{\Sigma(x - \bar{x})^2 / N}$, used to assess inter-rater consistency; and frequency and percentage distributions, $P = (f / n) \times 100$, applied to demographic and prevalence data.

Each ISO/IEC 25010 dimension score was computed as the weighted mean of all items within that dimension. The overall system quality score was derived from the grand mean across the nine dimensions. Verbal interpretations followed the four-point scale: 3.25–4.00 = Excellent; 2.50–3.24 = Very Satisfactory; 1.75–2.49 = Fair; 1.00–1.74 = Poor.

RESULTS

This section presents the results in four parts corresponding to the research objectives. The first part documents the baseline restroom-management challenges identified through Questionnaire A (N = 33). The second part describes the design and implementation of the prototype's four core functionalities. The third part presents the selected hardware and software components and their justification. The fourth part reports the ISO/IEC 25010 evaluation results, comprising the per-dimension weighted means, standard deviations, and verbal interpretations of the prototype (N = 33).

Baseline Restroom-Management Challenges

Respondent Profile

Table 8 presents the demographic profile of the 33 baseline respondents. All were students, with 87.9% male and 12.1% female. The 6th floor was the most frequently used restroom location (36.4%), and 96.9% of respondents reported using the restroom two or more times per day, indicating high reliance on ISC facilities.

Table 8: Respondent Profile (Questionnaire A, N = 33)

Profile Variable	Category	Frequency (Percentage)
Classification	Student	33 (100.0%)
Gender	Male	29 (87.9%)
	Female	4 (12.1%)
Most frequently used floor	6th Floor	12 (36.4%)
	3rd Floor	6 (18.2%)
	5th Floor	5 (15.2%)
	2nd Floor	4 (12.1%)
	4th Floor	3 (9.1%)
	1st Floor	3 (9.1%)
Daily restroom-usage frequency	Once	1 (3.0%)
	Twice	15 (45.5%)
	Three times	9 (27.3%)
	Four or more times	8 (24.2%)

Table 9 summarizes user-experience indicators. The majority (63.6%) waited 1–3 min for an available stall, and a further 15.2% waited four or more minutes. Notably, 75.8% had left the restroom without using it due to long waits, and 87.9% had actively avoided ISC restrooms in favor of other facilities. Among those who avoided ISC restrooms (n = 29), the dominant reasons were absence of soap (89.7%), poor cleanliness (86.2%), and unpleasant odor (82.8%).

Table 9: User Experience and Facility Accessibility (N = 33)

Indicator	Response	Frequency (Percentage)
Typical wait time for a stall	No waiting	7 (21.2%)
	1–3 minutes	21 (63.6%)
	4–7 minutes	3 (9.1%)
	More than 7 minutes	2 (6.1%)
Left restroom due to long wait	Yes	25 (75.8%)
	No	8 (24.2%)
Avoided ISC restroom for a better facility	Yes	29 (87.9%)
	No	4 (12.1%)
Primary reasons for avoidance (n = 29)[a]	No soap available	26 (89.7%)
	Poor cleanliness	25 (86.2%)
	Unpleasant odor	24 (82.8%)
	Overcrowding / long wait	17 (58.6%)
	No water supply	4 (13.8%)

Table 10 presents the frequency with which respondents encountered specific hygiene problems, measured on a 5-point scale (1 = Never, 5 = Always). The lack of soap in dispensers obtained the highest mean rating (M = 4.79), approaching the maximum frequency. Unpleasant odors (M = 4.72) and dirty stalls (M = 4.70) were similarly chronic. Insufficient water supply (M = 4.36) was also frequently encountered, while overcrowding (M = 3.09) was moderately frequent

Table 10 : Frequency of Hygiene Problems in ISC Restrooms (1 = Never, 5 = Always, N = 33)

Hygiene Problem	1	2	3	4	5	M
Lack of soap in dispensers	0	0	0	7	26	4.79
Unpleasant odors	0	0	0	9	23	4.72
Dirty or unclean stalls	0	0	1	8	24	4.70
Insufficient water supply	1	1	3	8	20	4.36
Overcrowding during peak hours	11	3	3	4	12	3.09

Table 11 reports operational findings. A paradoxical pattern emerged: 72.7% of respondents perceived maintenance as occurring several times daily, yet 75.8% reported often encountering restrooms in which soap had not been promptly refilled, and a further 21.2% experienced this sometimes—a combined 97% who had experienced supply depletion. Equally striking, all 33 respondents (100%) strongly endorsed the proposition that an automated monitoring system would improve their restroom experience.

Table 11: Operational Efficiency and Maintenance Effectiveness (N = 33)

Indicator	Response	Frequency (Percentage)
Current frequency of maintenance and cleaning	Very frequent (several times daily)	24 (72.7%)
	Frequent (once daily)	6 (18.2%)
	Infrequent (every few days)	3 (9.1%)
Encountered restroom where soap was not refilled promptly	Often	25 (75.8%)
	Sometimes	7 (21.2%)
	Rarely	0 (0%)
	Never	0 (0%)
Belief that an automated monitoring system would improve restroom experience	Strongly Yes	33 (100%)
	Yes	0 (0%)
	No	0 (0%)
	Strongly No	0 (0%)

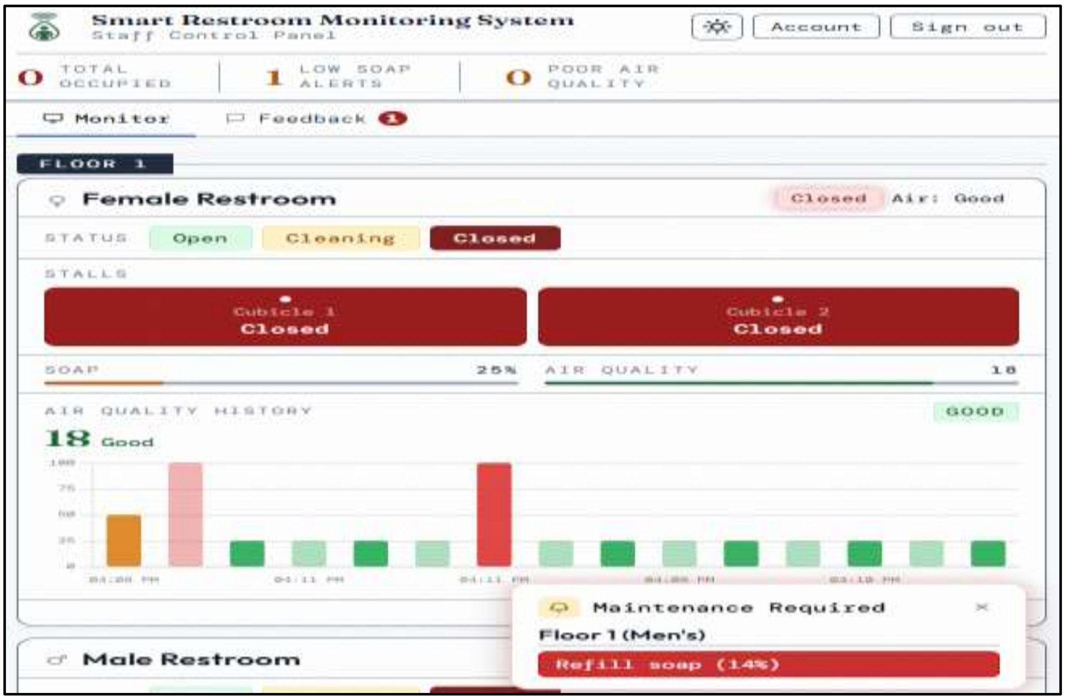
Respondents were asked to rank five proposed system features by importance (1 = Most Important, 5 = Least Important). Table 12 summarizes the ranking results. The lowest average rank corresponds to the highest perceived importance. The automatic soap-refilling notification was ranked most important (M = 2.39), consistent with the high frequency of soap shortages. This was followed by maintenance alerts to staff (M = 2.76), real-time occupancy status (M = 3.12), mobile or dashboard access (M = 3.33), and air-quality or odor-monitoring display (M = 3.39).

Table 12: Feature Priorities for a Smart Restroom Monitoring System (Rank 1–5; 1 = Most Important; N = 33)

Feature	1	2	3	4	5	Avg. Rank
Automatic soap-refilling notification	13	4	8	6	2	2.39
Maintenance alert to staff	5	11	8	5	4	2.76
Real-time occupancy status	6	6	8	4	9	3.12
Mobile app / dashboard access	6	6	3	7	11	3.33
Air-quality / odor-monitoring display	3	6	6	11	7	3.39

Design and Implementation of the Smart Restroom Monitoring System

The prototype implemented four interconnected functionalities, each designed in direct response to the baseline findings.



Real-Time Occupancy Detection

PIR motion sensors were installed at each restroom stall. The sensor detects infrared radiation emitted by occupant body heat and signals the ESP32 microcontroller, which updates the stall status (Occupied or Available) on the dashboard in real time. Continuous polling of sensor inputs ensures that status changes are reflected without perceptible delay. This functionality directly addresses the 75.8% of respondents who had left restrooms because of waiting and the 87.9% who had sought alternative facilities.

Soap Supply Monitoring and Automatic Refilling

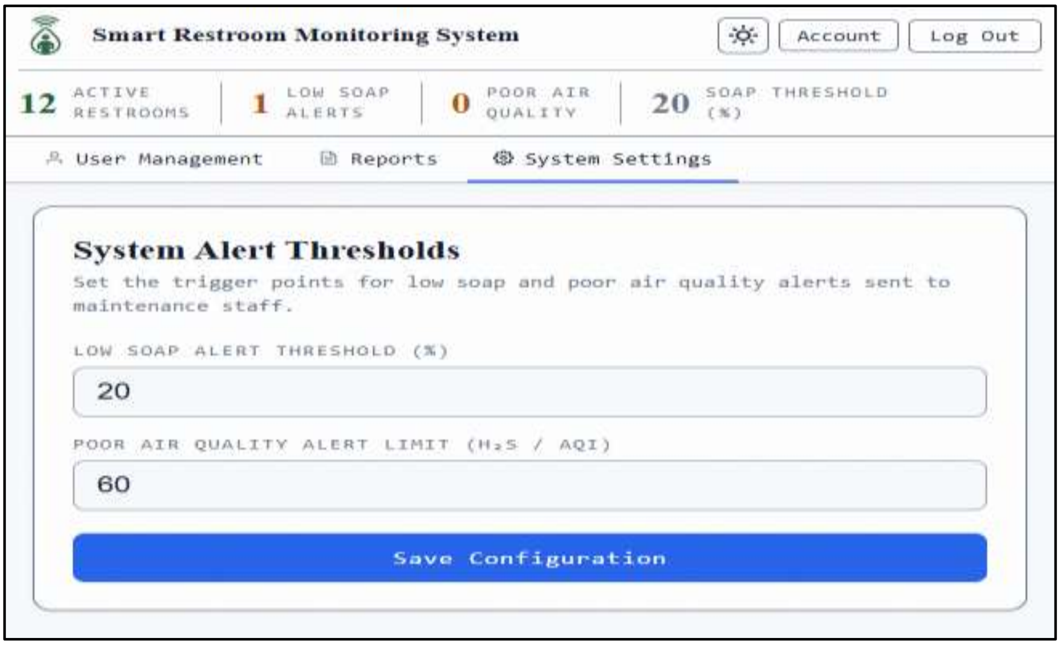
HC-SR04 ultrasonic sensors were mounted on the lids of soap dispensers and reserve tanks to measure remaining soap volume non-invasively. When sensor readings indicate that the soap level has fallen below the configured threshold, the ESP32 control logic activates the 12 V R385 water pump, drawing soap from the reserve container to refill the dispenser without manual intervention. A separate mini submersible motor pump (3–5 V DC) handles user-initiated soap dispensing. This mechanism converts soap management from a schedule-based to a threshold-triggered process and directly addresses the 97% of respondents who had experienced soap depletion.

Real-Time Air Quality Sensing

The SEN0568 MEMS H_2S sensor continuously samples restroom air. Hydrogen sulfide was selected because it is the principal compound responsible for restroom odor and is well within the sensor’s 0.5–50 ppm detection range. The ESP32 transmits real-time readings to the dashboard as a normalized 0–100% index. When the index reaches or exceeds 60%, the system dispatches a maintenance alert prompting staff to ventilate the area or address the underlying source. This functionality addresses the 82.8% of respondents who cited unpleasant odors as a reason to avoid the restroom and the M = 4.72 frequency rating for unpleasant odors.

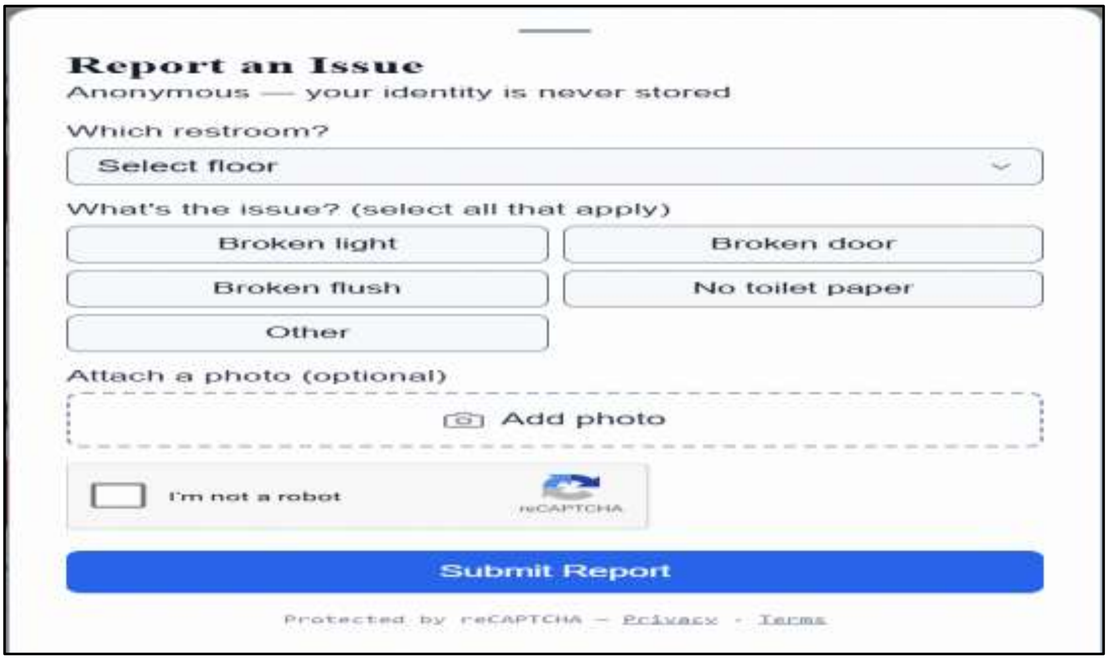
Real-Time Updates and Notifications

All sensor data are aggregated and displayed through the role-based, mobile-responsive web dashboard. Three views are provided: a user view that shows occupancy and supply status for navigation purposes; a maintenance-staff view that adds threshold-triggered alerts, manual status overrides, and air-quality history; and an administrator view that provides user management, threshold configuration, and CSV report export. Alerts are delivered through dashboard badges and toast notifications. This operationalizes the shift from reactive to proactive management identified in the literature (Kumar et al., 2025; Sasikala et al., 2024) and addresses the 100% unanimous endorsement of an automated solution recorded in the baseline survey.



Hardware and Software Component Selection

Detailed selection rationales for hardware and software components are presented in the Methodology section (Tables 1–6). In summary, the ESP32-WROOM-32 was selected as the central control unit because of its dual-core processing capability, built-in Wi-Fi for dashboard communication, and sufficient general-purpose I/O for the required sensors and actuators. The PIR sensor was preferred over ultrasonic and reed-switch alternatives for occupancy detection because of cost, simplicity, and proven reliability. The HC-SR04 was selected for soap-level measurement on the basis of non-contact accuracy and integration simplicity. The SEN0568 was selected for air-quality sensing because of its H_2S selectivity and lower power requirements relative to MQ-series and electrochemical alternatives. The software stack combined the Arduino IDE for firmware development, custom ESP32 control logic, a web-based dashboard, and cloud storage for historical analysis.



ISO/IEC 25010 System Evaluation

The deployed prototype was evaluated against the nine quality dimensions of the ISO/IEC 25010 software quality model by 33 respondents (27 student users and 6 maintenance staff) using a 4-point Likert-type scale: 4 = Strongly Agree (SA), 3 = Agree (A), 2 = Disagree (D), and 1 = Strongly Disagree (SD). Weighted means (WM) and standard deviations (SD) were computed per item and per dimension. Verbal interpretations were applied as follows: 3.25–4.00 = Excellent; 2.50–3.24 = Very Satisfactory; 1.75–2.49 = Fair; 1.00–1.74 = Poor.

Table 13: Functional Stability (QC1, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Occupancy detection correctly identifies stall status	32	1	0	0	3.97	0.17
Soap supply sensor accurately detects current level	26	7	0	0	3.79	0.41
Automatic refilling activates when below threshold	30	3	0	0	3.91	0.29

Air-quality sensor accurately reads H_2S concentration	26	7	0	0	3.79	0.41
Dashboard displays correct and up-to-date data	27	6	0	0	3.82	0.39
System sends accurate alerts when thresholds exceeded	30	3	0	0	3.91	0.29
Dimension Weighted Mean					3.86	0.33

As shown in Table 13, Functional Stability obtained a dimension weighted mean of 3.86 (Excellent). The highest-rated item was occupancy detection accuracy (WM = 3.97), with 32 of 33 respondents selecting Strongly Agree. Item standard deviations ranged from 0.17 to 0.41, indicating strong inter-rater agreement.

Table 14: Performance Efficiency (QC2, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Occupancy status updates in real time without delay	28	5	0	0	3.85	0.36
Alerts are delivered promptly upon triggering events	27	6	0	0	3.82	0.39
Dashboard loads and refreshes data quickly	27	6	0	0	3.82	0.39
System operates continuously without degradation	26	6	0	0	3.81	0.39
System uses power resources efficiently	29	3	0	0	3.91	0.29
Dimension Weighted Mean					3.84	0.36

Table 14 reports a dimension weighted mean of 3.84 (Excellent). Power efficiency received the highest rating (WM = 3.91), and continuous operation without degradation received the lowest within-dimension rating (WM = 3.81), which, although still within the Excellent range, suggests that extended longitudinal testing may reveal stability dynamics that were not observable within the prototype evaluation window.

Table 15: Compatibility (QC3, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
System operates within restroom physical environment (humidity, temperature)	29	3	0	0	3.91	0.29
Monitoring interface is accessible across devices	27	6	0	0	3.82	0.39
System integrates with institutional Wi-Fi infrastructure	28	5	0	0	3.85	0.36
System does not interfere with other electronic devices nearby	29	4	0	0	3.88	0.33
Dimension Weighted Mean					3.86	0.34

Compatibility (Table 15) achieved a dimension weighted mean of 3.86 (Excellent). The highest-rated item was the system's operation within the physical environment of the restroom (WM = 3.91), confirming that the SEN0568 and HC-SR04 sensors performed reliably under actual humidity and temperature conditions. All items exceeded 3.25, indicating robust compatibility across evaluated environmental parameters.

Table 16: Interaction Capability / Usability (QC4, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Monitoring dashboard is easy to understand and navigate	29	4	0	0	3.88	0.33
Occupancy indicators are clearly visible and intuitive	24	9	0	0	3.73	0.45
Air-quality readings are presented understandably	27	6	0	0	3.82	0.39
Maintenance staff can easily identify and respond to alerts	29	4	0	0	3.88	0.33
Users with minimal technical knowledge can use the system	26	7	0	0	3.79	0.41
System provides helpful feedback on errors or unusual conditions	29	4	0	0	3.88	0.33
Dimension Weighted Mean					3.83	0.37

Interaction Capability obtained a dimension weighted mean of 3.83 (Excellent; Table 16). Three items tied for the highest within-dimension rating (WM = 3.88): dashboard navigability, alert response usability, and error feedback. The intuitiveness of occupancy indicators received the lowest within-dimension rating (WM = 3.73, SD = 0.45), pointing to potential visual-design refinements—such as larger icons or color-coded stall maps—that may improve perceptual clarity.

Table 17: Reliability (QC5, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
System operates without unexpected failures or crashes	28	5	0	0	3.85	0.36
Occupancy sensor reliably detects stall status changes	30	3	0	0	3.91	0.29
Soap sensor consistently provides accurate readings	32	1	0	0	3.97	0.17
Automatic refilling mechanism reliably activates and stops	26	7	0	0	3.79	0.41
System recovers quickly after power interruption or sensor error	29	4	0	0	3.88	0.33
Dimension Weighted Mean					3.88	0.31

Reliability obtained the highest dimension weighted mean among the nine dimensions (M = 3.88; Table 17). The soap supply sensor's reading consistency obtained the highest single-item rating across the entire evaluation (WM = 3.97, SD = 0.17), with 32 of 33 respondents selecting Strongly Agree. The automatic refilling mechanism received the lowest within-dimension rating (WM = 3.79), still within the Excellent range, suggesting that pump-activation timing may be further refined through threshold calibration in subsequent iterations.

Table 18: Security (QC6, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Configuration access is restricted to authorized personnel	29	4	0	0	3.88	0.33
Dashboard requires authentication before admin functions	27	6	0	0	3.82	0.39
Sensor-to-dashboard data is protected from interception	30	3	0	0	3.91	0.29
System does not collect personally identifiable information	29	4	0	0	3.88	0.33
System provides logs / audit trails for admin actions	28	5	0	0	3.85	0.36
Dimension Weighted Mean					3.87	0.34

Security obtained a dimension weighted mean of 3.87 (Excellent; Table 18). The highest-rated item was the protection of sensor-to-dashboard data from unauthorized interception (WM = 3.91). The privacy-by-design principle of not collecting personally identifiable information (WM = 3.88) is particularly relevant for institutional deployment, supporting compliance with the Data Privacy Act of 2012 (Republic Act No. 10173) of the Philippines.

Table 19: Maintainability (QC7, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Hardware components can be replaced without significant difficulty	27	6	0	0	3.82	0.39
Software can be updated without disrupting core functions	27	6	0	0	3.82	0.39
Error messages and logs are informative for diagnosis	30	3	0	0	3.91	0.29
Design allows easy recalibration of sensors	31	1	0	0	3.97	0.17
System documentation is sufficient for maintenance staff	29	4	0	0	3.88	0.33
Dimension Weighted Mean					3.88	0.31

Maintainability obtained a dimension weighted mean of 3.88 (Excellent; Table 19). Sensor recalibration ease received the highest within-dimension rating (WM = 3.97, SD = 0.17), the second-narrowest standard deviation in the evaluation. Diagnostic utility of error messages and logs (WM = 3.91) was also highly rated.

Table 20: Flexibility (QC8, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Alert thresholds can be adjusted for different facility needs	27	6	0	0	3.82	0.39
System can be scaled to additional stalls or facilities	26	7	0	0	3.79	0.41
Monitoring interface accommodates layout changes	25	8	0	0	3.76	0.43
Sensor components can be repositioned for different layouts	30	3	0	0	3.91	0.29
Dimension Weighted Mean					3.82	0.38

Flexibility obtained the lowest dimension weighted mean among the nine evaluated dimensions, though still within the Excellent range (M = 3.82; Table 20). Sensor repositionability for different restroom layouts received the highest within-dimension rating (WM = 3.91). The lowest within-dimension rating was for monitoring-interface layout adaptability (WM = 3.76, SD = 0.43), suggesting that dashboard customization features could strengthen the system's perceived flexibility across diverse institutional contexts.

Table 21: Safety (QC9, N = 33)

Evaluation Item	SA (4)	A (3)	D (2)	SD (1)	WM	SD
Electrical components are safely installed to prevent hazards	28	5	0	0	3.85	0.36
Automatic refilling operates safely without overflow or spillage	25	8	0	0	3.76	0.43
Power supply is stable without electrical hazards	27	6	0	0	3.82	0.39
Components use materials appropriate for humid environments	28	5	0	0	3.85	0.36
Air-quality alerts support safety without causing alarm	29	4	0	0	3.88	0.33
Dimension Weighted Mean					3.83	0.37

Safety obtained a dimension weighted mean of 3.83 (Excellent; Table 21). The highest-rated item concerned calibration of air-quality alerts to support user safety without producing false alarms (WM = 3.88). The lowest within-dimension rating concerned overflow and spillage prevention in the automatic refilling mechanism (WM = 3.76), indicating an area in which physical containment design or a secondary overflow sensor could be introduced in future iterations.

Table 22 consolidates the weighted means and standard deviations for all nine quality dimensions, together with the grand mean representing overall system quality.

Table 22: Summary of ISO/IEC 25010 Evaluation Results (N = 33)

Code	Quality Dimension	WM	SD	Verbal Interpretation
QC1	Functional Stability	3.86	0.33	Excellent
QC2	Performance Efficiency	3.84	0.36	Excellent
QC3	Compatibility	3.86	0.34	Excellent
QC4	Interaction Capability (Usability)	3.83	0.37	Excellent

QC5	Reliability	3.88	0.31	Excellent
QC6	Security	3.87	0.34	Excellent
QC7	Maintainability	3.88	0.31	Excellent
QC8	Flexibility	3.82	0.38	Excellent
QC9	Safety	3.83	0.37	Excellent
Grand Mean		3.85	0.02	Excellent

Table 22 shows a grand mean of 3.85 (SD = 0.02), rated Excellent across all nine ISO/IEC 25010 dimensions. Dimension weighted means ranged from 3.82 (Flexibility) to 3.88 (Reliability and Maintainability). The very low grand standard deviation (0.02) indicates remarkable consistency across dimensions, suggesting that no single dimension is disproportionately stronger or weaker than the others—consistent with balanced system design. Reliability and Maintainability emerged as the strongest dimensions, driven by near-perfect consensus on soap-supply sensor consistency (WM = 3.97) and sensor recalibration ease (WM = 3.97). Flexibility was the lowest-rated dimension, an expected pattern for prototype systems in which scalability and interface customization typically mature with successive iterations.

In addition to dimension-specific evaluations, respondents provided an overall performance rating and an explicit recommendation regarding deployment. Table 23 reports these results.

Table 23: Overall Assessment of the Smart Restroom Monitoring System (N = 33)

Assessment Item	Response	Frequency (Percentage)
Overall performance rating of the system	4 – Excellent	33 (100%)
	3 – Very Good	0 (0%)
	2 – Fair	0 (0%)
	1 – Poor	0 (0%)
Recommendation for deployment in other restrooms	Strongly Yes	33 (100%)
	Yes	0 (0%)
	No	0 (0%)
	Strongly No	0 (0%)

Table 23 reports unanimous results: 100% of respondents rated overall performance as Excellent, and 100% strongly recommended deployment in additional restroom facilities within the institution. No respondent selected Very Good, Fair, or Poor for overall performance, and no respondent selected anything other than Strongly Yes for deployment. Combined with the grand mean of 3.85 across the nine ISO/IEC 25010 dimensions, these results indicate strong empirical endorsement of the prototype by its intended end users.

Open-ended responses identified the most-impressive system features and the aspects most in need of improvement. Five feature categories were identified. Air-quality monitoring and H_2S sensing was the most frequently cited "most impressive" feature (approximately 37% of respondents), followed by the automatic refilling and dispensing system (≈27%), real-time occupancy detection (≈20%), the notification and alert system (≈7%), and automatic soap dispensing specifically (≈7%). The prominence of air-quality monitoring likely reflects its technological novelty: it provides objective, sensor-based measurement of a previously subjective and difficult-to-quantify problem. Regarding areas for improvement, most respondents indicated "N/A" or no specific concern. Among those who identified targeted refinements, the occupancy sensor was mentioned by two respondents—consistent with the slightly lower rating on occupancy indicator intuitiveness (WM = 3.73)—and one respondent identified air-quality calibration as an area for refinement, aligned with the slightly lower rating on H_2S sensor accuracy (WM = 3.79). The qualitative findings thus align coherently with the quantitative evaluation.

DISCUSSION

The findings of this study converge on three principal observations: that current restroom management at ISC is empirically inadequate despite high stated maintenance frequency, that an integrated IoT-based prototype can address the identified deficiencies, and that the resulting system meets established software-quality benchmarks across all nine ISO/IEC 25010 dimensions. Each observation is interpreted below in relation to the broader literature.

Inadequacy of Reactive Maintenance Models

The most striking finding from the baseline survey is the disconnect between maintenance frequency and outcomes: although 72.7% of respondents perceived restroom maintenance as occurring several times daily, 97% reported encountering restrooms in which soap had not been refilled promptly, and 87.9% had actively avoided ISC restrooms in favor of other facilities. This pattern confirms what prior work has suggested: schedule-based maintenance cannot accommodate the temporal variability of consumable depletion or environmental degradation (Azman et al., 2023; Kumar et al., 2025). Alfonso et al. (2022) similarly observed that inadequate communication of facility status produces avoidable user inconvenience in public restrooms. The present results extend this observation by quantifying the behavioral consequences of inadequate facility management in an educational context, demonstrating that even frequent manual rounds are insufficient absent the real-time visibility that sensor-based monitoring affords.

Integration of Functions in a Unified System

The prototype combines four functional capabilities—occupancy detection, soap-level monitoring with automated refilling, continuous air-quality sensing, and role-based notification—within a single platform. Each capability has antecedents in the literature. PIR-based occupancy detection is well established for restroom contexts (Fowjiya et al., 2025; Wu & Zhang, 2024). Ultrasonic supply monitoring with automated reorder has been demonstrated by Sasikala et al. (2024). H_2S monitoring as the primary indicator of restroom odor is consistent with sanitation-facility research and with industry practice (Fowjiya et al., 2025; WHO, 2006). However, Badshah et al. (2023) noted that comparatively few studies have integrated these functions in a single platform tailored to educational institutions. The system reported here demonstrates that such integration is technically feasible and can be achieved at modest cost using widely available components (ESP32, HC-SR04, SEN0568, R385 pump). The architecture's sensor–controller–dashboard structure provides a replicable reference design that can be adapted to comparable institutional contexts.

Threshold Design Anchored in External Standards

A distinctive feature of the implementation is the explicit anchoring of sensor thresholds to internationally recognized guidelines. The 60% air-quality alert threshold was derived by reference to WHO odor-annoyance guidance (WHO, 2006), Occupational Safety and Health Administration permissible exposure limits, American Conference of Governmental Industrial Hygienists short-term exposure limits, and toilet-specific sanitation research. This standards-grounded approach addresses a recurring critique of low-cost IoT deployments—that thresholds are often selected ad hoc—and provides a defensible, conservative, user-comfort–oriented basis for alert generation. The two-tank soap configuration, with hysteresis-mediated pump control and a critical-empty fail-safe, similarly applies standard relay-control practice from embedded-systems engineering to a sanitation context.

ISO/IEC 25010 Evaluation Results

The grand weighted mean of 3.85 (SD = 0.02) and the unanimous Excellent rating across all nine quality dimensions indicate that the prototype meets the criteria for deployment-ready status under the ISO/IEC 25010 framework. Of particular note are the highest-rated single items: soap-supply sensor consistency (WM = 3.97) and sensor recalibration ease (WM = 3.97). These items concern, respectively, the dependability of the most-prioritized baseline function (automatic soap refilling) and the maintainability of the system over time—both of which are critical to long-term operational success. The low grand standard deviation (0.02) suggests balanced performance across dimensions, a desirable property in system design that often signals attentive engineering across all quality attributes rather than concentration on a subset.

The relatively lower (though still Excellent) ratings on Interaction Capability's occupancy-indicator intuitiveness (WM = 3.73), Flexibility's interface-layout adaptability (WM = 3.76), and Safety's refilling overflow prevention (WM = 3.76) identify three concrete refinement targets. The first two are interface-design issues amenable to user-experience iteration—for example, larger occupancy icons, color-coded stall maps, and configurable dashboard layouts. The third points to a physical-design consideration: incorporation of a secondary float sensor or overflow cut-off switch would mitigate any residual concern about spillage during automatic refilling. None of these issues threatens the overall fitness of the system for deployment; rather, they constitute a prioritized roadmap for the next development iteration.

Implications for Smart Facility Management in Educational Institutions

The results provide empirical support for the broader proposition—advanced by Olimat et al. (2023) and Raendran et al. (2020)—that smart facility management can transform passive, complaint-driven maintenance into proactive, data-driven operations. By shifting from scheduled rounds to threshold-triggered intervention, the system reduces the latency between problem onset and corrective action. From a user perspective, the visible occupancy and supply status reduces avoidance behavior; from a maintenance perspective, alert-driven response replaces inspection-driven monitoring; from an administrative perspective, historical sensor data supports evidence-based planning and resource allocation. Crucially, the system was designed to be implementable within existing institutional infrastructure (Wi-Fi network, custodial staff workflows) without requiring new networking standards or specialized personnel, addressing one of the principal barriers to SFMS adoption identified in the literature (Olimat et al., 2023; Paek & Sojkov, 2018).

LIMITATIONS

Several limitations qualify these findings. The baseline and evaluation samples were drawn from a single institution and a single building. The gender distribution of respondents was heavily skewed toward male respondents (87.9%), which may limit the generalizability of perceptions related to female restrooms. The evaluation period was constrained to the prototype testing phase; longitudinal performance over six to twelve months has not yet been validated, which is relevant to claims about continuous operation without performance degradation. The system's scope is explicitly limited to detection, monitoring, reporting, and automatic soap refilling; it does not include air filtration, automated cleaning, or integration with campus-wide building management systems. Finally, a formal cost–benefit analysis comparing the IoT solution against current scheduled-maintenance practices remains to be conducted.

CONCLUSION

This study designed, implemented, and evaluated an integrated, low-cost Smart Restroom Monitoring System for a Philippine university setting. Baseline survey results documented the chronic and pervasive deficiencies of conventional restroom management at the Information Science Building of Centro Escolar University: lack of soap, unpleasant odors, and unclean stalls occurred at near-maximum frequency, and 87.9% of student respondents actively avoided ISC restrooms in favor of alternative facilities. Critically, 97% of respondents had encountered restrooms in which soap had not been refilled promptly—despite 72.7% perceiving maintenance as occurring several times daily—demonstrating that scheduled maintenance alone cannot address real-time supply depletion.

In response, the developed system combined an ESP32-WROOM-32 microcontroller with PIR motion sensors for occupancy detection, HC-SR04 ultrasonic sensors for soap-level monitoring with a 12 V R385 pump for automated refilling, and the SEN0568 MEMS H_2S sensor for continuous air-quality reporting. All data are aggregated and displayed through a role-based, mobile-responsive web dashboard, with threshold-triggered alerts dispatched to maintenance staff. Sensor thresholds were calibrated against international guidelines and toilet-specific sanitation research, providing a defensible, user-comfort–oriented basis for alert generation.

Empirical evaluation against the ISO/IEC 25010 software quality model (N = 33) produced a grand weighted mean of 3.85 (SD = 0.02), with all nine quality dimensions rated Excellent: Functional Stability (3.86), Performance Efficiency (3.84), Compatibility (3.86), Interaction Capability (3.83), Reliability (3.88), Security (3.87), Maintainability (3.88), Flexibility (3.82), and Safety (3.83). Reliability and Maintainability emerged as the strongest dimensions, driven by near-perfect consensus on soap-supply sensor consistency and sensor recalibration ease. All 33 respondents rated overall performance as Excellent and unanimously recommended broader deployment.

The study contributes (a) an integrated reference architecture for IoT-based smart restroom monitoring suited to educational institutions, (b) a standards-anchored framework for sensor-threshold configuration, and (c) empirical evidence that low-cost, sensor-driven facility management can address chronic restroom-management problems that resist resolution through scheduled maintenance alone. Within the limitations noted, the findings support institutional deployment in additional ISC restrooms and provide a basis for replication studies in comparable settings.

Future research is warranted in several directions. Longitudinal performance testing over six to twelve months would validate continuous-operation claims and identify component fatigue or sensor drift. Comparative cost–benefit analyses against current maintenance practices would support institutional budgeting decisions. Pre- and post-deployment user-satisfaction studies could quantify the system's impact on the documented avoidance behavior. Predictive analytics drawing on accumulated sensor data—for example, applying machine-learning models to forecast peak occupancy and soap-depletion windows—could extend the system from reactive threshold alerts to truly predictive facility management. Replication in other facility types, including public restrooms, commercial establishments, and healthcare facilities, would further validate the architecture's generalizability.

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