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RESEARCH ARTICLE

An IoT-Based Hygiene Monitoring System in the Restroom

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ABSTRACT Public restroom hygiene is a critical factor influencing public health and user comfort. Traditional maintenance approaches, which rely on manual labour and fixed cleaning schedules, are often inefficient and costly, requiring janitors regardless of actual conditions. This research presents an Internet of Things (IoT)-based restroom hygiene monitoring system designed to optimise cleaning by dispatching staff only when hygiene thresholds are exceeded, particularly during periods of elevated ammonia levels and poor Indoor Air Quality (IAQ). The system enables remote, continuous cleanliness assessment by monitoring ammonia levels and analyzing IAQ through humidity and gas resistance metrics. Alerts are triggered based on correlations among humidity, temperature, and occupancy data, enabling timely interventions. The system utilises the InfluxDB time-series database and the Message Queuing Telemetry Transport (MQTT) protocol over Wi-Fi to support real-time monitoring and long-term trend analysis, providing actionable insights for effective hygiene management. A five-month focused analysis within a two-year monitoring period (January 2023 to December 2024) revealed ammonia concentration spikes ranging from 0 ppm to 13×10^{12} ppm. These peaks were linked to sewer issues and cleaning without detergent, while poor IAQ levels (up to 466×10^3 ppm) were associated with excessive use of detergent and air fresheners. Statistical analysis revealed a strong inverse correlation ($r = 0.91$) between humidity and temperature regarding ammonia, as well as a moderate inverse correlation ($r = 0.45$) between humidity and gas resistance. Despite 274 users recorded in a single day, effective ventilation was maintained at safe ammonia levels. These findings suggest that overuse of cleaning agents may worsen air quality. The study demonstrates the potential of IoT-enabled systems for responsive, data-driven, and cost-effective restroom hygiene management.

INDEX TERMS Ammonia, environmental monitoring, health and safety, Internet of Things, indoor air quality.

I. INTRODUCTION

The availability of clean and well-maintained public restrooms is essential for public health, hygiene, and environmental sustainability. Despite their importance, millions of people worldwide lack access to adequate sanitary facilities. In Malaysia, for example, a significant number of public restrooms face persistent cleanliness and maintenance issues. According to 2013 statistics, 61% of the 10,257 public restrooms in the country were in poor condition, with only 3.4% receiving a five-star rating and 10% receiving the lowest rating of one star. The use of unsanitary restrooms poses serious health risks, including the spread of diseases linked to poor sanitation and exposure to harmful pollutants such as ammonia gas, viruses, and bacteria [1]. These pollutants can cause respiratory irritation, headaches, and other health problems, particularly in confined spaces with inadequate ventilation [2].

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Maintaining good indoor air quality (IAQ) is especially important in countries like Malaysia, where high humidity and temperatures are common throughout the year. According to the Department of Occupational Safety and Health [3], the use of gas resistance and humidity sensors is essential for providing accurate, real-time IAQ assessments in restrooms. These sensors detect harmful gases and monitor moisture levels, helping to prevent issues such as mold growth and support healthier indoor environments.

Smart restroom management systems powered by the Internet of Things (IoT) have emerged as effective solutions for improving facility hygiene and efficiency. These systems utilize real-time data on occupancy, cleanliness, and supply levels to optimize resource allocation and maintenance. By automating cleaning based on usage patterns and detecting harmful gases like ammonia, smart systems help reduce health risks and cut operational costs. IoT-enabled sensors also detect leaks and monitor maintenance needs, supporting more efficient and sustainable restroom operations [4]. Furthermore, integrated alert systems can notify personnel of hazardous conditions in real time through messaging applications, promoting safer urban environments [5].

The integration of IAQ monitoring, ammonia gas detection, and occupancy tracking in a single platform represents a novel approach to restroom hygiene management. This comprehensive system provides real-time insights by measuring ammonia concentration, humidity, and volatile organic compound (VOC) levels, allowing facility managers to make informed decisions regarding cleaning and maintenance. Although data were collected over a two-year period, five months were selected for detailed analysis due to observed pollution trends, which showed significant air quality degradation during those specific months. Notably, ammonia levels exceeded 5 ppm during this period. Exposure to concentrations between 5 and 50 ppm can cause symptoms such as nasal dryness and fatigue, while levels above 1000 ppm may result in severe respiratory effects, including chest discomfort, airway spasms, and potentially life-threatening pulmonary edema [6]. In contrast, the remaining months demonstrated stable air quality and minimal health risks. Focusing on the pollution-prone period allows for more precise analysis and targeted recommendations to improve user comfort and safety.

With the rapid advancement of smart technologies, the adoption of intelligent sanitary monitoring systems is becoming increasingly widespread. These systems offer several benefits, including enhanced hygiene, improved operational efficiency, and greater sustainability.

In this context, the objectives of the proposed system are threefold:

- To design a real-time monitoring system equipped with notification alerts and a counter reset feature.
- To develop an integrated restroom hygiene and occupancy counting system that utilizes the MQTT protocol for ammonia detection and IAQ monitoring.
- To evaluate the relationship between ammonia levels and IAQ under unhygienic environmental conditions in relation to occupancy trends.

To achieve these objectives, the system employs Wi-Fi and the MQTT protocol for efficient data transmission from sensors to cloud storage, enabling real-time visualization through a data dashboard. Further details and technical implementation are discussed in the methodology section.

II. RELATED WORKS

According to United Nations (UN) and World Health Organization (WHO) projections, by 2030, the global population of seniors over 65 will reach 1.4 billion, comprising 16.5% of the total population. To address the health monitoring needs of elderly individuals living alone. A study [7] introduced the concept of "iRestroom," a smart restroom cyberinfrastructure designed to assess frailty and support independent living. Based on user studies, socio-cultural factors, and technological trends, iRestroom was developed as a multi-sensory, interconnected environment enabling caregivers to access real-time interactive data and services. The prototype, tested at Texas A&M University-Kingsville, incorporated a Naive Bayes classifier to determine sensor placements and analyze data from various restroom locations. A pilot dataset and relevant web information were collected, and all procedures received Institutional Review Board (IRB) approval.

Another research [8] proposed an IoT restroom system consisting of three primary modules: one module counts restroom users and automatically turns off lights when unoccupied, another one monitors sink availability, and the third displays restroom occupancy status. Through the IoT-supported Blynk mobile application, users can efficiently monitor and control the system, ensuring a clean and functional restroom environment.

Further innovations in restroom hygiene management include Toilbot [9], an IoT-based toilet cleaning system specifically designed for Indian-style toilets. This cost-effective robotic solution, controlled by a Node Micro-Controller Unit (NodeMCU), automates the cleaning process by using minimal water while effectively scrubbing the toilet. Equipped with a mechanical arm that manages brushes and pipes, the robot dispenses water, applies cleaning agents, and thoroughly cleans the toilet. This innovation streamlines the cleaning process, reduces manual labour, and improves hygiene standards in public restrooms.

A smart restroom hygiene monitoring system was proposed in Study [10], incorporating a LoRa-based architecture that was built on a Wide Area Network (WAN) protocol using LoRa radio modulation and managed through a cloud server. The system was equipped with an MQ-137 sensor for monitoring ammonia levels and a Passive Infrared (PIR) sensor for detecting occupancy in the restroom. Notifications were generated and sent to the management once the defined thresholds were exceeded, prompting timely cleaning actions. The system was designed for low power consumption and long-range communication, making it suitable for battery-powered remote operations.

Furthermore, research [11] has explored a smart toilet system for maintaining cleanliness by integrating various sensors and an app-based interface for efficient washroom management. The system aimed to monitor restroom hygiene by using mobile applications and IoT sensors such as the MQ135, ammonia gas sensor, and water level sensor. It monitored data in real-time and sent alerts when hygiene levels fell below acceptable thresholds. The system was easily integrated with existing infrastructure and provided insights into usage patterns, aiming to improve public hygiene and optimize restroom maintenance.

Another research [12] presented an affordable, mobile-based system using Raspberry Pi technology to improve shopping mall toilet management. The system enabled supervisors to schedule cleanings, monitor progress, and collect user feedback while cleaning staff were able to respond quickly to requests. Usability tests showed that 81% user satisfaction was achieved, demonstrating improved operational efficiency and communication among supervisors, cleaners, and users. Better hygiene standards were promoted by this solution, consumer perceptions were enhanced, and mall business outcomes were positively impacted.

Furthermore, the study [13] reviews the development and application of IoT-based IAQ monitoring platforms across various built environments, highlighting their effectiveness in providing reliable IAQ data. With the rise of affordable sensors, these platforms have gained research interest in improving IAQ management. The review emphasizes the need for regular sensor replacement every 4–6 months to maintain accuracy and recommends integrating data-driven algorithms for predictive analysis and efficient ventilation control. However, only 9.1% of current platforms incorporate such models. The study identifies key challenges, including the trade-off between energy efficiency and air quality, and suggests future efforts focus on integrating digital twins and involving occupants to enhance occupant-centric IAQ management.data-driven algorithms for predictive analysis and efficient ventilation control. However, only 9.1% of current platforms incorporate such models. The study identifies key challenges, including the trade-off between energy efficiency and air quality, and suggests future efforts focus on integrating digital twins and involving occupants to enhance occupant-centric IAQ management.

Additionally, advancements in home automation have influenced restroom monitoring innovations [14]. One smart home monitoring system utilizes Espressif Systems-32 (ESP32) microcontrollers to enhance security by detecting intruders, triggering alarms, capturing images, and sending alerts to homeowners' smartphones. The system also monitors temperature and displays sensor data online via a web server. With Wi-Fi, Bluetooth, and MQTT capabilities, the ESP32 efficiently functions as a web server, while a GSM modem enables remote home management through SMS commands such as "unlock" or "lock.

Moreover, research [15] has been conducted to investigate the air quality and ventilation systems of 22 public toilets in railway stations in China, finding that approximately 80% met Ammonia gas concentration standards, while 20% exceeded them, with pollutant levels mainly related to user numbers and ventilation. To improve air quality, the researchers proposed a design method calculating toilet cubicle numbers, with female toilets having a service capacity of 12 cubicles per hour and male toilets, depending on the ratio of squatting pans to urinals (suggested 1:1 to 1:0.8), having 16 to 20 cubicles per hour; CFD simulations showed bottom exhaust was better than top exhaust and a fresh air supply unnecessary, recommending 20 air changes per hour, to address gender imbalance, avoid queuing, and providing a reference for public toilet renovation and design to maintain healthy indoor environments.

Studies on smart restroom-related work have been reviewed and summarized in Table 1. The proposed system is included in the summary to highlight its key features in comparison to existing systems. As shown in the table, the proposed system aims to address the limitations of current solutions, providing a more effective approach to restroom hygiene monitoring. By optimizing resource usage through occupancy tracking and automated cleaning schedules, smart restrooms can reduce excessive water and cleaning supply consumption, minimizing waste and promoting sustainability.

A comparative analysis of existing smart restroom systems across 14 technical criteria reveals that the proposed system offers notable enhancements. In particular, it integrates ammonia concentration monitoring, indoor air quality (IAQ) analysis, and a passive infrared (PIR) based occupancy counter within a single cohesive platform, thereby enabling data-driven and usage-based cleaning schedules. Additionally, the incorporation of a Telegram-based notification feature along with remote reset control significantly improves operational responsiveness, which is a capability often missing in earlier implementations.

Most previous systems primarily utilize Wi-Fi-enabled NodeMCU controllers for basic environmental or IAQ monitoring. However, these solutions generally lack the integration of essential hygiene indicators such as ammonia concentration, real-time occupancy tracking, and reset mechanisms. The proposed design addresses these limitations by evaluating IAQ based on humidity and volatile organic compound (VOC) levels that are particularly relevant in restroom environments due to consistently high humidity and the frequent use of air fresheners. Although such air fresheners are intended to neutralize unpleasant odours, their chemical composition may contribute to poor IAQ and potentially affect user health.

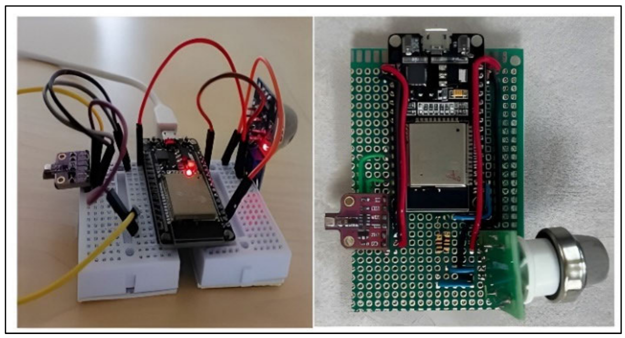
Furthermore, the system demonstrates additional strengths through its real-time implementation, dashboard-based visualization using Grafana, and remote monitoring capabilities. These features, which are achieved in only a limited number of previous studies, support continuous awareness of

TABLE 1. Related works on smart restroom.

	Focus Criteria											
Io-Based restroom	Ammonia monitoring	IAQ	Counter	Environmental monitoring	Wireless Interface	Controller	Real Implementation	Database	Dashboard	Notification	Reset system	Long Range Remote monitoring
Rahman et al. [7]				✓	Wi-Fi	ATMega 1280		✓		✓		✓
Thaenthong et al. [8]			✓		Wi-Fi	NodeMCU			✓			✓
Malini et al. [9]					Wi-Fi	NodeMCU			✓			✓
Fareesha et al. [10]	✓		✓		LoRa	LoRaWAN		✓	✓	✓		✓
Patil et al. [11]	✓			✓	Wi-Fi	NodeMCU		✓	✓	✓		
Wee et al. [12]	✓		✓		Mobile network	Raspberry Pi		✓	✓	✓		✓
Dai et al. [13]		✓										
Babiuch et al. [14]	✓			✓	Wi-Fi/ Bluetooth	NodeMCU		✓	✓			✓
Yu et al. [15]	✓	✓		✓			✓					
Smart Restroom	✓	✓	✓	✓	WiFi	NodeMCU	✓	✓	✓	✓	✓	✓

restroom conditions and allow for data-driven analysis of usage trends. Such insights are valuable for optimizing janitorial schedules or initiating automated cleaning processes when necessary.

Moreover, the integration of NodeMCU with Wi-Fi connectivity and IoT-based data logging enhances the overall cost-effectiveness and deployment flexibility of the system, making it especially suitable for urban public environments. As a result, the proposed smart restroom solution not only matches the hardware capabilities of existing systems but also extends their functionality by incorporating more hygiene-focused sensors, intelligent automation features, and a scalable cloud-based platform for real-time hygiene monitoring and facility management.



(a) (b)

FIGURE 1. Hygiene monitoring system prototype.

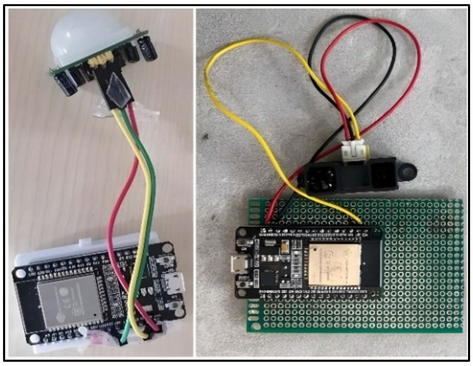
III. METHODOLOGY

A. PROTOTYPE DEVELOPMENT

The system development began with a prototype, where the initial step involved assembling ESP32, infrared (IR) sensor, BME680 sensor, and MQ-137 sensor and testing them in an office environment.

Figure 1(a) shows the prototype used during a one-month testing period. The hardware components were carefully selected to ensure accurate, reliable, and real-time restroom monitoring. The MQ-137 sensor was chosen over the MQ-135 for its higher sensitivity to ammonia, making it suitable for detecting odours associated with poor hygiene. Its wide detection range and cost-effectiveness support continuous monitoring in public settings. The BME680 sensor was included for its ability to measure temperature, humidity, pressure, and gas resistance, enabling comprehensive IAQ analysis in a compact and energy-efficient design.

However, both ammonia gas sensors and IAQ have their limitations. The MQ-137 ammonia sensor, while highly sensitive to NH3, it exhibits cross-sensitivity to other gases, including organic amines such as trimethylamine and cholamine, which can compromise measurement accuracy without proper calibration. Its semiconductor-based SnO2 sensing material also responds to variations in oxygen concentration and humidity, potentially leading to signal drift or false positives under fluctuating environmental conditions. Whereas, the BME680 sensor is used for IAQ monitoring, and integrates multiple sensing elements such as gas, temperature, humidity, and pressure. Nevertheless, it faces limitations in isolating specific gas concentrations due to overlapping responses to volatile organic compounds VOC



(a) (b)

FIGURE 2. Counting system prototype.

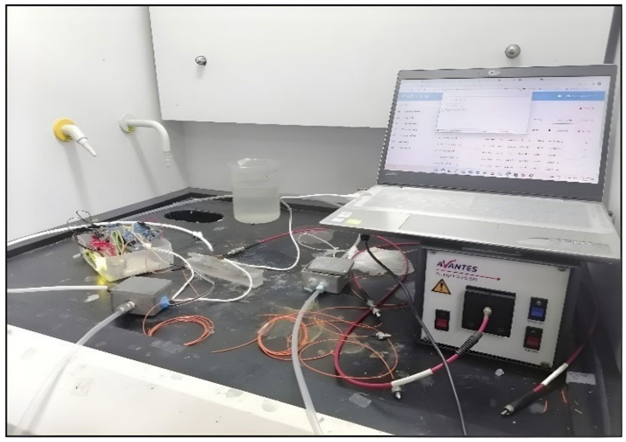


FIGURE 3. Ammonia gas laboratory testing.

and environmental interference, thereby reducing gas specificity.

During the observation period, the ammonia sensor was replaced with a more stable model, and resistors were added to prevent malfunctions. After testing, the system demonstrated stable data transmission and received positive feedback. Consequently, it was soldered onto a thin printed circuit board (PCB) to produce a lightweight version for deployment. Figure 1(b) illustrates the fabricated system ready for field use.

Figure 2 illustrates the prototype of the counting system, where Figure 2(a) shows the initial prototype and Figure 2(b) presents the fabricated version designed for field deployment. Similar to the hygiene monitoring system, the counter system underwent modifications in its sensor components. Specifically, the IR sensor was chosen over traditional PIR sensors due to its superior accuracy and stability in detecting user presence and movement, thereby enhancing people-counting capabilities for usage tracking and cleaning optimization. However, while the IR sensor is effective for occupancy detection, it may be affected by occlusion, angle sensitivity, and interference from ambient infrared sources, potentially reducing counting accuracy in crowded or complex restroom layouts. Therefore, careful calibration is required before deployment in real-world settings.

B. SENSORS CALIBRATION AND DEPLOYMENT

Figure 3 shows the ammonia gas laboratory testing. The sensitivity of the MQ-137 ammonia gas sensor has been tested in the lab by exposing it to a flow of ammonia gas, followed by a flow of pure air. Before implementing the sensor in a graphical dashboard, its sensitivity is evaluated to ensure accuracy. The test results are monitored and collected in a database.

Figure 4 presents the recorded ammonia concentration data. The sensor readings increased progressively on a per-second basis as the MQ-137 sensor detected the presence of ammonia gas, demonstrating it is high sensitivity sensor. When the concentration exceeded 5.30 ppm, a "CLEAN IT NOW!" notification was automatically triggered. Subsequently, as the ammonia gas gradually dissipated, the readings steadily declined, eventually reaching 0 ppm, indicating the presence of clean air.

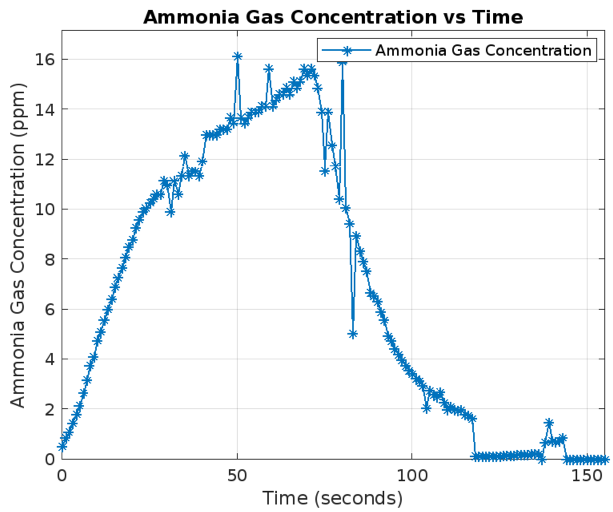


FIGURE 4. Ammonia gas collected data.

Figure 5 illustrates the deployment of a hygiene monitoring system equipped with environmental and ammonia gas sensors, housed in a waterproof and vandalism-proof casing. The system was installed at a height of 120 cm with a surface area of 0.96 m^2 and it is positioned centrally relative to the toilet bowl. The electrical diagrams show the internal connections of the hygiene monitoring system, which utilizes an ammonia gas sensor, a BME680 sensor for IAQ measurements, and a 1k ohm resistor integrated with an ESP32 board. The system is mounted at an elevated position because ammonia gas is lighter than air and tends to rise; it typically does not accumulate in low-lying areas. However, in certain conditions, low-lying spaces may still become saturated with ammonia gas [16]. Additionally, the environmental sensor measures the

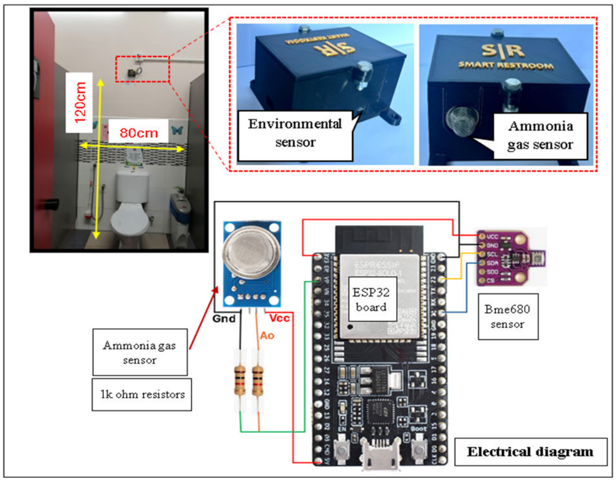


FIGURE 5. Deployment of hygiene monitoring system.

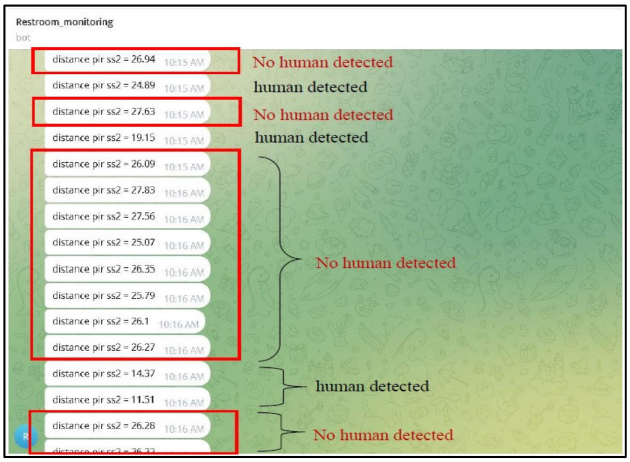


FIGURE 6. IR counter calibration.

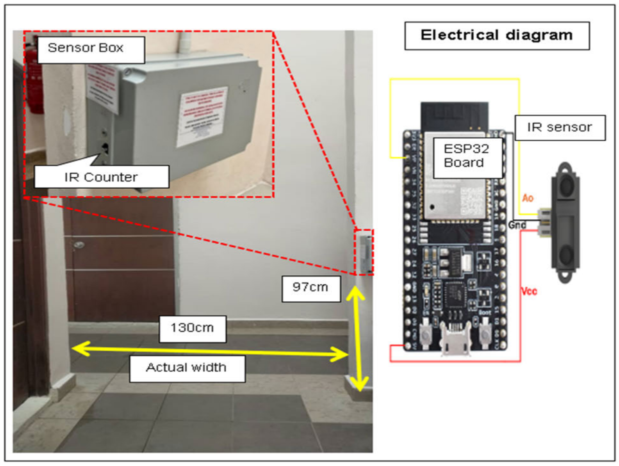


FIGURE 7. Deployment of the counting system.

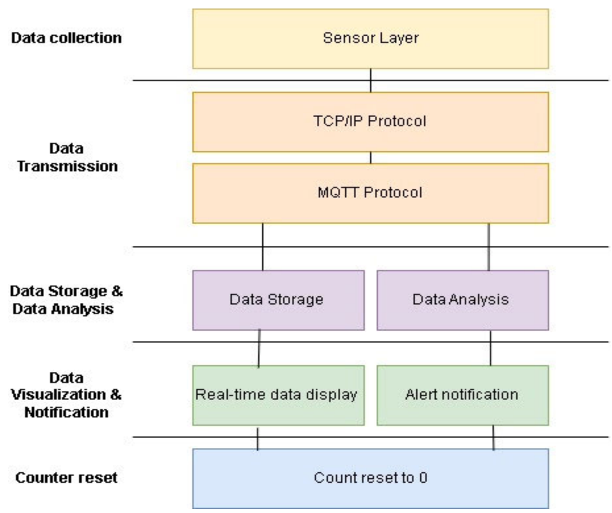


FIGURE 8. System architecture.

restroom's IAQ by analyzing parameters such as humidity and gas resistance.

Figure 6 illustrates the IR counter calibration that observes the sensitivity of when humans are detected and when no human is detected. The data was displayed through telegram notification as a testing method. In this case, the sensitivity of the sensor is tested with distance since the IR is an analogue sensor that measures distances. The figure shows that no human is detected at a measured distance beyond 27.63 cm, which is equivalent to 130 cm (ratio of 1:4.7 after calibration).

Figure 7 shows the deployment of the counting system equipped with an IR sensor integrated into the ESP32 board through an electrical diagram representation. The IR sensor is used as a people counter to count the number of people using the restroom. The system was installed at the entrance, positioned at an average child height of 97 cm from the ground [17].

Figure 8 illustrates the system architecture, which consists of five phases. The first phase is the data collection phase. This system is powered by a reliable power source and begins by gathering inputs from several sensors such as an IR sensor for a counting system, the BME680 environmental sensor and the MQ-137 ammonia gas sensor to monitor environmental conditions and ammonia gas levels, respectively. All the sensors are integrated into the ESP32 microcontroller. The ammonia gas sensor outputs an analogue voltage corresponding to the ammonia gas concentration. In contrast, the environmental sensor provides analogue data for five parameters: temperature (°C), humidity (%), gas resistance (Ω), VOC (ppm), and IAQ (ppm).

In the second phase, these data points are transmitted to an MQTT broker, facilitating data migration and storage. The third phase involves data storage in an InfluxDB database. Once collected, the data is subscribed to by the Telegram notification system and the database. The fourth phase involves the real-time visualization and notifications services. If ammonia gas levels exceed 5 ppm or IAQ surpasses 100 ppm, janitors and management are alerted via

Telegram, indicating potential health hazards. Both data visualization and notification occur in this phase.

The final phase involves the nightly reset of the toilet counting system at 10:00 PM, coinciding with restroom closure.

C. DATA COLLECTION

The MQ-137 sensor's effectiveness in monitoring ammonia levels is attributed to its ability to minimize interference from other gases commonly present in restroom environments. To calculate the concentration of ammonia gas using the MQ-137 sensor, the following formula (1) is employed:

$$10^{\left(\frac{\log\left(\frac{Ro}{Rs}\right)-b}{m}\right)} ppm \tag{1}$$

where:

Rs = Sensor resistance in gas
Ro = Sensor resistance in clean air
m = Slope of the MQ-137 calibration curve
b = Y-intercept of the calibration curve

This formula accurately converts sensor readings into ammonia concentrations by using a logarithmic transformation of the resistance ratio. This makes the relationship between sensor response and gas concentration easier to analyze across a wide range. The slope and intercept can change with environmental conditions and sensor ageing. Using this formula, the system can reliably track ammonia levels, helping to manage restroom hygiene and take quick action when levels become too high.

An environmental sensor (BME680) is used to measure the IAQ in the restroom. Smart algorithms within the BSEC software convert these raw values into an IAQ index, ranging from 0 (clean air) to 500 (severely polluted air). Besides, the IAQ is also affected by humidity levels, and the sensor automatically calibrates itself based on the environment in which it operates, taking recent measurement history into account to maintain reliable performance. The formula can be represented as in (2).

$$\left(\frac{VOC}{RL}\right) \times 75 + \left(\frac{40 + HumOffset}{40} \times 25\right) \tag{2}$$

where:

VOC = Volatile organic compounds gas resistance
RL = Sensor resistance in gas
$Hum\ offset$ = Current humidity – 40 (Optimal humidity)

The calculation of the IAQ index using the BME680 sensor takes humidity and gas resistance into account. Equation (2) integrates these factors by assigning a significant weight to gas resistance (75%) and a lesser weight to humidity (25%). This approach reflects the sensor's capability to detect changes in air quality through gas resistance, which is a critical indicator of pollutants. The humidity component adjusts the score based on deviations from optimal humidity levels, typically around 40% [18].

Using this formula, the IAQ index provides a comprehensive assessment of indoor air condition enabling timely interventions to maintain a healthy environment. The formula's structure allows for adjustments based on specific environmental conditions, making it versatile for various applications.

D. DATA TRANSMISSION

Figure 9 shows the MQTT topology. The data transmission from the sensors node to the cloud database was assisted by Wi-Fi protocol and MQTT protocol. The integration uses the MQTT client to publish data from ESP32 to the MQTT broker before it is sent to the subscribers via the cloud database. The subscribers in this MQTT protocol are real-time dashboard and Telegram notification. All the sensors' data transmission from the sensor to the MQTT client was done in a Node-red-based flow application.

Figure 10 shows the flow structure of the Hygiene monitoring system. The data from ESP32 is published over an MQTT broker in ''JavaScript Object string'' which has converted to a JavaScript Object Notation (JSON) encoded string message payload using the JSON node. The algorithm of ammonia gas detection and IAQ were done in a function node. Ammonia gas data and IAQ values. The threshold of ammonia was set up to 5 ppm, which indicates the accumulation of ammonia gas in the restroom, causing a smelly restroom. Whereas the IAQ threshold is set to 101ppm and more as lightly polluted to extremely polluted. Lastly, a message payload node is used to display the debugging message or the output of the ammonia gas sensor and IAQ through the BME680 environmental sensor.

The IAQ index in the dashboard is categorized by range.

Figure 11 shows the value mappings for the IAQ index It helps in setting a threshold of IAQ threshold for notification purposes as an alert to the management regarding the poor IAQ environment. The value mappings are referred to the Bosch Sensortec Community [19]. Reading below the threshold value is categorized as good and vice versa.

After the categorization, the data passes to the InfluxDB database to be integrated with Grafana.

Figure 12 shows the function node's connection to the database, under the measurement of toilet_gas2. The data is also used for notification through the Telegram application and for a real-time graph dashboard.

Figure 13 shows the connection of function nodes to the notification system. The encoded data in the function nodes are passed to the notification system whenever the ammonia gas level or IAQ exceeds the threshold value. A notification will then be sent via ''Telegram'' to the respective management and janitor for appropriate cleaning action.

Figure 14 shows the flow structure of the people counting system. The data from ESP32 is published over an MQTT broker in ''JavaScript Object string'' which has converted to a JSON encoded string message payload using the JSON node. The encoded data passes to the PIR sum value node and PIR

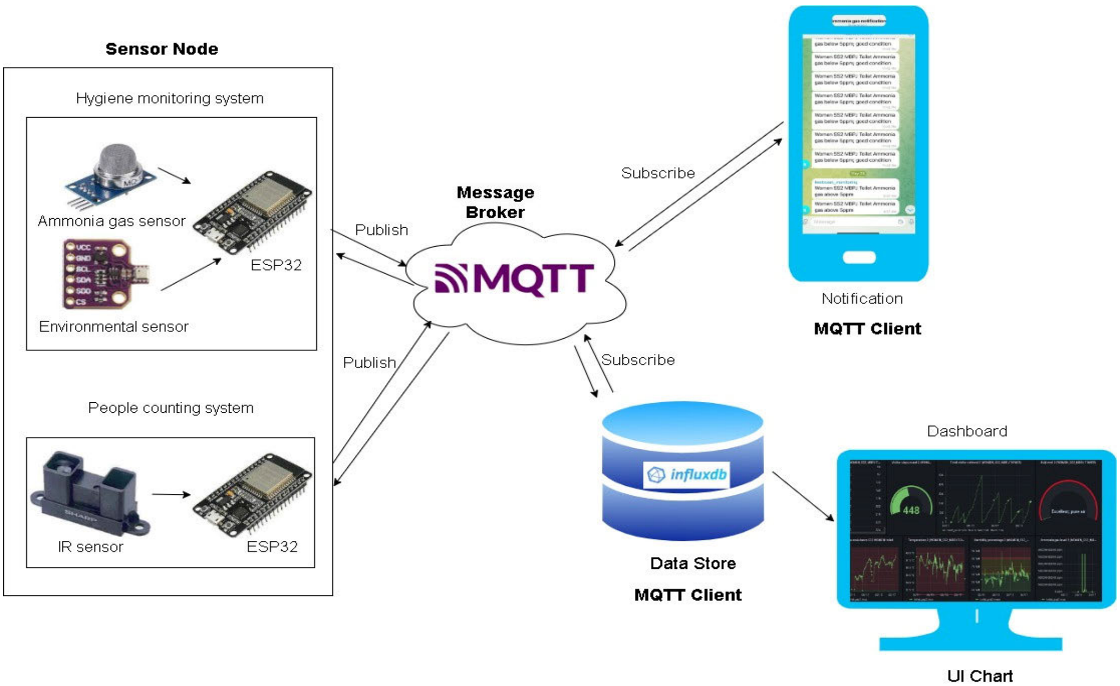


FIGURE 9. MQTT topology.

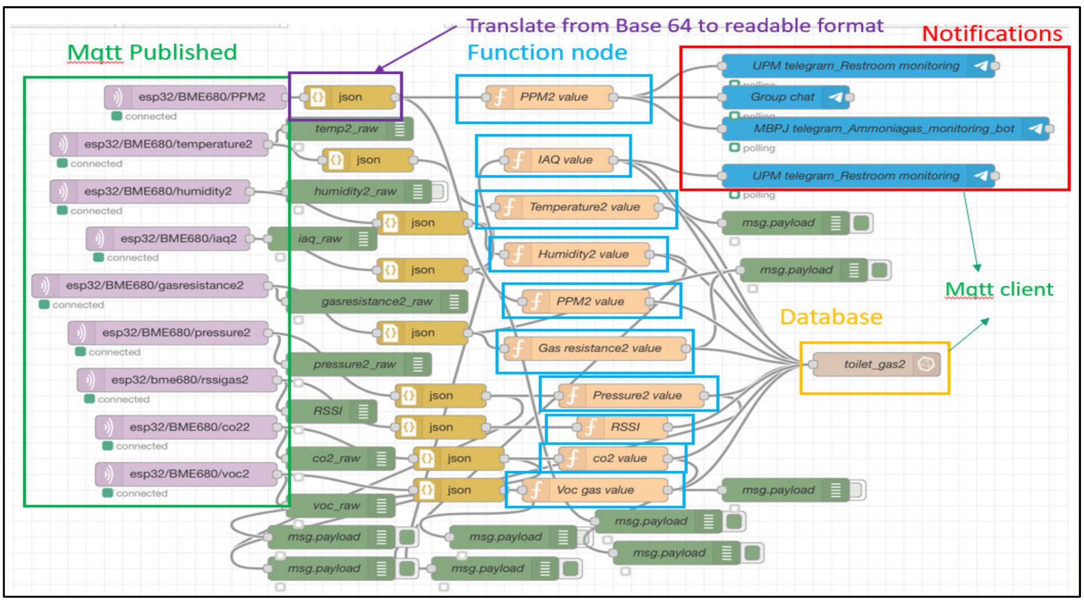


FIGURE 10. Flow structure of the hygiene monitoring system.

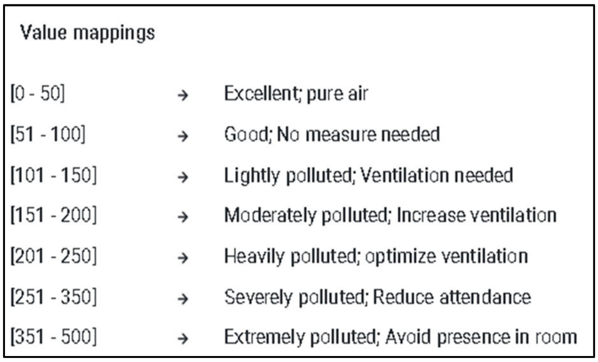
value. The PIR sum value node represents the number of steps users entered and left the restroom while the PIR value node represents the count of users using the restroom in a day.

E. DATA STORAGE AND DATA ANALYSIS

The trend analysis of ammonia gas levels and IAQ was determined using a Probability Density Function (PDF) graph. This analysis was further supported by examining the correlation between ammonia readings and IAQ. The PDF graph requires the z-score and density to plot the data. The z-score is calculated from raw ammonia gas and IAQ data.

The z-score of the IAQ can be obtained through equation (3).

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-\left(\frac{x-\mu}{\sigma}\right)^{2}}{2}} \tag{3}$$


Value mappings

[0 - 50]	→	Excellent; pure air
[51 - 100]	→	Good; No measure needed
[101 - 150]	→	Lightly polluted; Ventilation needed
[151 - 200]	→	Moderately polluted; Increase ventilation
[201 - 250]	→	Heavily polluted; optimize ventilation
[251 - 350]	→	Severely polluted; Reduce attendance
[351 - 500]	→	Extremely polluted; Avoid presence in room

FIGURE 11. Value mappings for IAQ index.

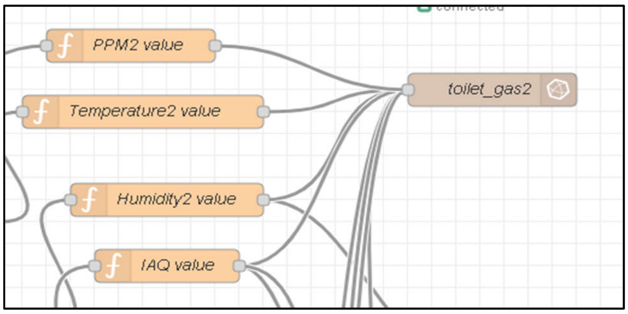


FIGURE 12. Function node's connection to the database.

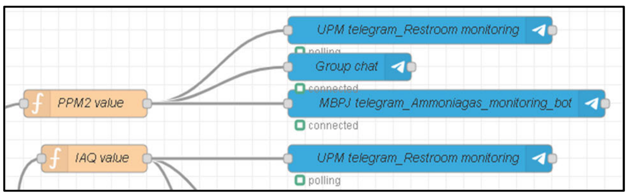


FIGURE 13. Function nodes connection to notification.

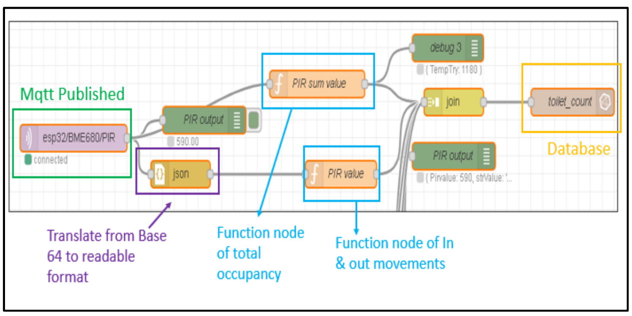


FIGURE 14. Flow structure of the people counting system.

where:

e = Base of the natural logarithm
π = Constant pi (approximately 3.14159)
μ = population means
σ = population standard deviation

Moreover, the correlation analysis is used to measure the strength of the linear relationship between two variables. The correlation between humidity and temperature parameters is related to ammonia gas. Whereas the correlation between humidity and gas resistance parameters is related to IAQ.

The correlation analysis can be obtained through equation (4).

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \tag{4}$$

where:

r = correlation coefficient
x_i = values of the x-variable in a sample
x^- = mean of the values of the x-variable
y_i = values of the y-variable in a sample
y^- = mean of the values of the y-variable

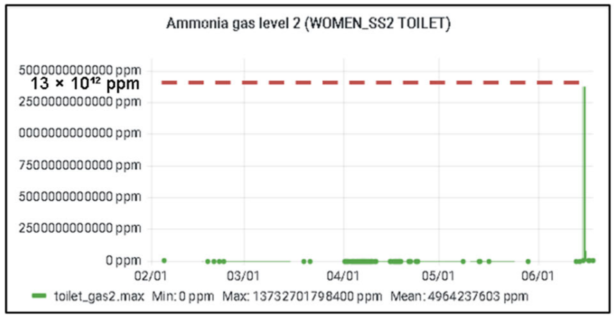


FIGURE 15. Ammonia gas trend in 5 months.

IV. RESULT AND DISCUSSION

The results collected over five months were analyzed to observe trends in ammonia gas levels, daily restroom occupancy, and IAQ in a high-footfall area. Although the system was installed and operated for two years, this specific five-month dataset was selected to highlight the key factors contributing to elevated ammonia concentrations and poor IAQ conditions. The analysis aims to improve user comfort and address long-term public health concerns by identifying and mitigating the health risks associated with ammonia exposure and poor air quality, such as dizziness, eye irritation, and respiratory issues like asthma.

A. DATA VISUALIZATION AND NOTIFICATION

Figure 15 depicts the ammonia gas trend in 5 months. The ammonia gas remained within acceptable ranges, except for June 2024. The results show a high ammonia detection up to This stability is likely due to the restroom's effective ventilation system. During June, the data shows higher ammonia detection up to 13×10^{12} ppm with fewer intermediate values. It is very high and can cause bad health to the restroom user such as cause irritation to human eyes, nausea and vomiting [20].

Figure 16 shows the ammonia gas detection notification which serves as a monitoring and cleaning notification after the ammonia gas sensor senses ammonia gas above 5 ppm.

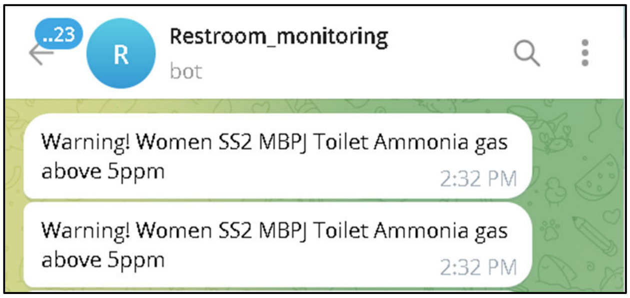


FIGURE 16. Ammonia gas detection warning.

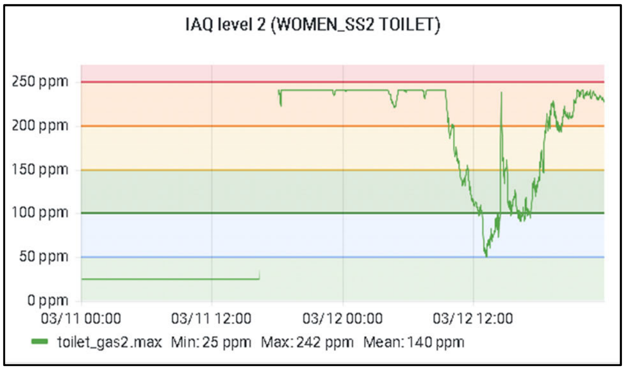


FIGURE 17. IAQ dashboard with the division of IAQ interval.

A notification "Warning! Women SS2 MBPJ Toilet Ammonia gas above 5ppm" indicating that the restroom is dirty is displayed. This notification indicates foul smells excreted by the urine and sewer.

Figure 17 indicates the IAQ dashboard with the division of IAQ interval. This time range is taken to highlight the varies of IAQ from good to poor air quality on 12th March 2024. The dashboard is divided into 6 layers according to the BME680 datasheet [21] which represents the air quality. From the bottom, the first layer indicates pure air and the IAQ is detected below 50 ppm. The second layer where the IAQ is between 51 ppm to 100 ppm indicates good air quality. The third layer, the IAQ between 101 ppm to 150 ppm, indicates lightly polluted air in which ventilation is needed. The fourth layer, the IAQ between 151 ppm to 200 ppm indicates moderately polluted air. Therefore, an increase in ventilation will be suggested. The fifth layer of IAQ between 201 ppm and 250 ppm indicates the heavily polluted air which requires prompt cleaning action because it is a harmful environment to humans and may lead to headaches [22]. A value above 350 ppm is considered hazardous [23].

Figure 18 shows the IAQ trend in 5 months of observation. The result shows IAQ readings indicate a significant spike up to 466×10^3 ppm, when the restroom is cleaned with detergents and air fresheners are applied. The use of detergents likely introduces VOC, which can degrade air quality despite the surface cleanliness. Moreover, Air fresheners further worsen this situation by adding more VOC, leading to poorer IAQ [24]. Although detergents and air fresheners may enhance the perception of cleanliness and odour, they also contribute to elevated VOC levels, thereby negatively impacting IAQ. As soon as poor IAQ is detected in the restroom, notification is given to alert the janitors. Furthermore, other gases that affect the VOC such as gases come from alcohols including Ethanol, Alcohol and Carbon Monoxide [25].

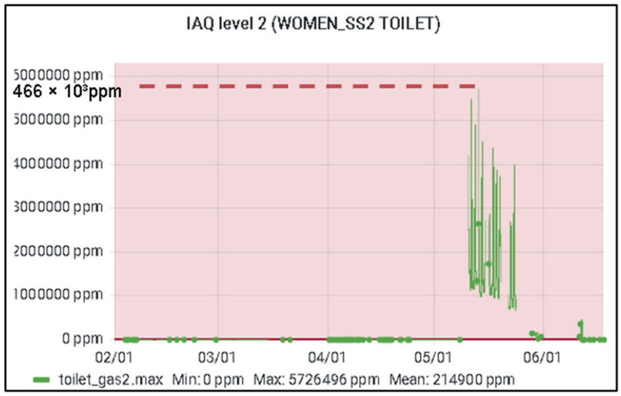


FIGURE 18. IAQ trend in 5 months.

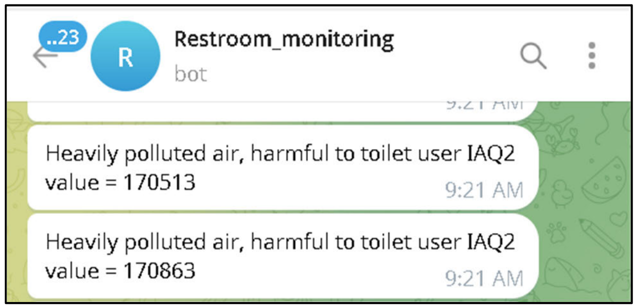


FIGURE 19. IAQ warning notification.

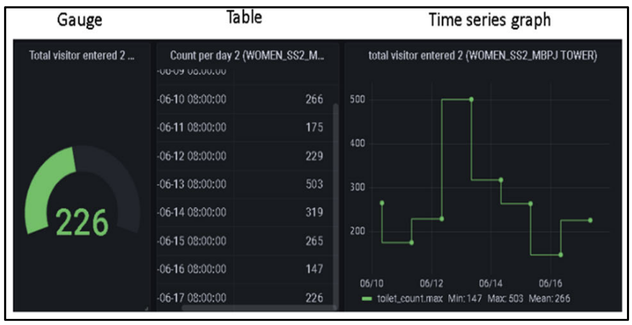


FIGURE 20. Counting system dashboard.

Figure 19 depicts the IAQ warning notification. A warning is triggered when the IAQ surpasses 100 ppm, alerting the janitor and the restroom supervisor to act on providing clean air to the user with recommendations of appropriate measures. For instance, the IAQ warning notification indicates that the restroom is severely polluted, creating health risks for users. In response, the janitor will close the restroom for 5 minutes and carry out cleaning to restore safe air quality.

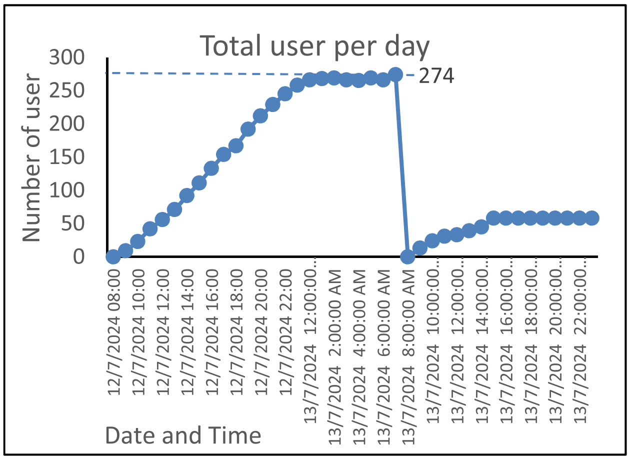


FIGURE 21. Accumulation of the number of users per day.

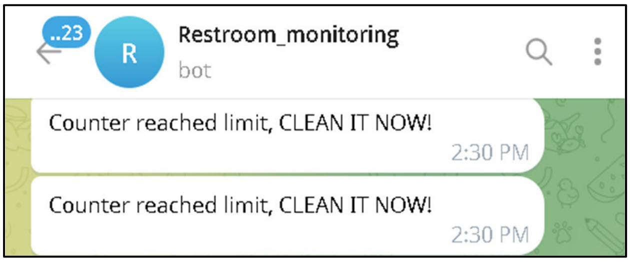


FIGURE 22. Counter notification.

Figure 20 presents the counting system dashboard, which includes a gauge dashboard, a table dashboard, and a time series dashboard, each serving distinct functions. The gauge dashboard displays the current number of visitors in the restroom, while the table dashboard shows the total number of visitors per day. Additionally, the time series dashboard provides a chronological view of restroom usage, helping management to understand and monitor usage patterns more effectively.

Figure 21 depicts the accumulation of the number of users per day. The data shows that there were 274 users on that day. This large number of users usually happens on Monday since there is a Monday night market operated in front of the restroom. Thus, the counter threshold is set to 50. Upon reaching this threshold, a notification is automatically sent to the janitorial staff, prompting immediate cleaning. Although the human body excretes only a small amount of ammonia through urine, with an average daily excretion rate of about 2–3 μg, equivalent to 0.002 ppm-0.003 ppm, which represents approximately 0.01% of the total body load [26]. A continuous accumulation from multiple users without timely cleaning could lead to elevated ammonia levels and deteriorating restroom conditions. Therefore, implementing a cleaning cycle for every 50 users helps to prevent ammonia buildup and ensures consistent sanitation.

Figure 22 shows the counter notification given to the janitor for cleaning the restroom and restocking supplies when needed. This notification helps the janitor to alert on restocking supplies such as soap and tissue as well as cleaning restroom cubicle that looks dirty and smelly.

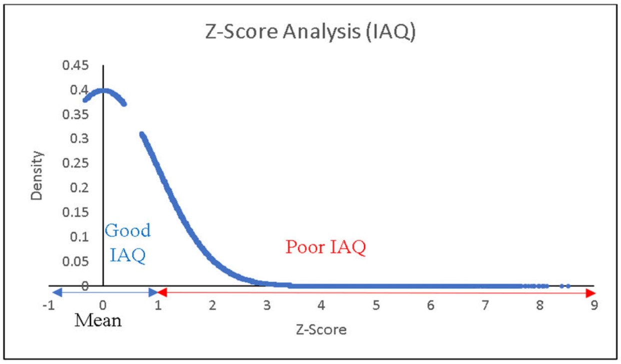


FIGURE 23. 5 months of IAQ trend analysis.

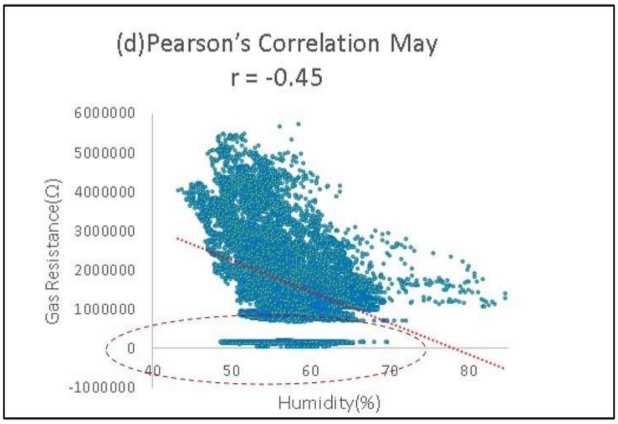


FIGURE 24. Scatterplots of an extremely poor IAQ.

B. POOR IAQ AND HIGH AMMONIA DETECTION ANALYSIS

Figure 23 shows the 5 months of IAQ trend analysis. IAQ readings have trended towards the poorer range, indicating that the IAQ varies from good IAQ to Extremely poor IAQ. This is because the graph regularly shows high positive z-scores above 1, suggesting pollutant levels well above the average, indicating poor air quality. The benchmark for good IAQ is an average pollutant level of 100 ppm, with a z-score of 0 marking this standard. IAQ surpasses 100 ppm, (IAQ >100) indicates as unhealthy [27]. Furthermore, data points with z-scores between -1 and 1 reflect IAQ levels at or below 100 ppm, which denotes as an acceptable air quality. However, in May, the IAQ levels reached 5×10^6 ppm, signifying extremely poor air quality. The frequent presence of outliers with high positive z-scores points to a recurring issue, likely due to excessive use of detergent while cleaning the restroom and installing lots of air fresheners in the restroom.

Figure 24 presents scatterplots of an extremely poor IAQ depicting the relationship between humidity(x-axis) and gas resistance (y-axis). In May, the scatterplots reveal a moderate correlation, with a lower resistance approaching zero in a

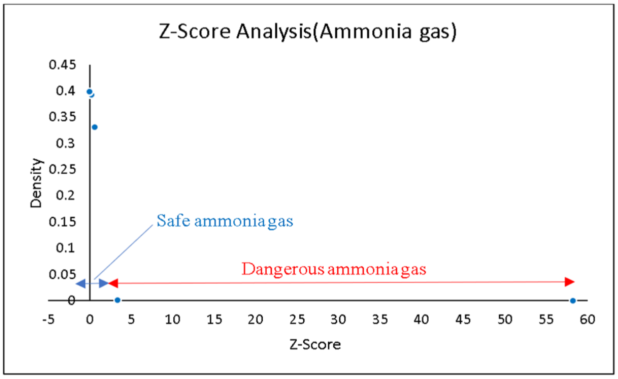


FIGURE 25. 5 months of ammonia gas trend analysis.

TABLE 2. Ammonia gas trend analysis.

Statistical parameters	Value
Min	0 ppm
Max	13×10^{12} ppm
Mean	5×10^{10} ppm
Standard deviation	83×10^{10} ppm

humid environment. This indicates the existence of VOC resulting in a poor IAQ in the restroom.

Figure 25 shows the 5 months of ammonia gas trend analysis. The Z-score analysis reveals a highly skewed distribution, where most data points are clustered around a Z-score near 0, indicating normal ammonia levels. However, a significant outlier is observed with an extremely high Z-score approaching 58, corresponding to an ammonia concentration spike of approximately 13×10^{12} ppm, which happened in June. This suggests an anomalous event as there are no intermediate Z-score instances between the baseline and the extreme value.

The trend analysis is supported by Table 2 presenting data on ammonia gas concentrations during periods of high detection (exceeding 5 ppm). The collected data revealed notable variations in ammonia levels. The minimum concentration recorded was 0 ppm, indicating instances of negligible or no ammonia presence. The maximum concentration reached 13×10^{12} ppm, primarily occurring when emissions from the sewer were present and the restroom was cleaned using only water, without the application of any neutralizing agents. Sewage treatment contributed approximately 4% of the total ammonia emissions [28].

The mean concentration of ammonia gas was calculated to be approximately 5×10^{10} ppm, suggesting that ammonia presence was generally moderate across the monitoring period, though occasional spikes were recorded. Additionally, a standard deviation of 83×10^{10} ppm was observed, reflecting significant fluctuations in the concentration levels. Thus, an alert notification is given to the janitors for cleaning action.

Figure 26 displays a scatterplot of a high ammonia gas detected in June that explores the relationship between

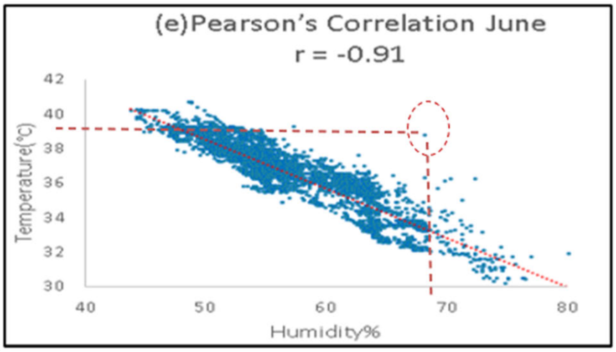


FIGURE 26. Scatterplots of a high ammonia gas detected.

humidity and temperature concerning ammonia gas levels. The scatterplot of humidity against gas resistance shows a strong correlation ($r = -0.91$), with data points tightly clustered, forming a narrow band. This suggests a stable and predictable link between the two variables, where changes in one are closely followed by changes in the other.

High humidity and elevated temperatures lead to an increase in ammonia gas levels in the restroom, as ammonia gas becomes more volatile at higher temperatures and more prevalent in humid conditions [29]. Consequently, higher humidity and temperature can promote the release and buildup of ammonia gas in the environment. In June, there were several days with humidity exceeding 60%, at 39°C to 40°C.

V. SUMMARY

Over a five-month monitoring period, ammonia levels were observed to range from a minimum of 0 ppm to a maximum of 13×10^{12} ppm. Elevated ammonia concentrations were primarily detected when sewer emissions were present, and the restroom was cleaned using only water. Conversely, poor IAQ with levels reaching up to 466×10^3 ppm, was recorded when excessive amounts of detergents and air fresheners were used. Although these products may improve cleanliness and odour control, their overuse was found to negatively impact IAQ. Moreover, the analysis revealed a strong inverse correlation ($r = -0.91$) between humidity and temperature, affecting ammonia detection. High ammonia levels were associated with high humidity and warm temperatures. IAQ analysis also indicated poor air quality, with a moderate inverse correlation ($r = -0.45$) between humidity and gas resistance. Moreover, restroom occupancy can reach up to 274 users on certain days, especially on Mondays. However, this high level of usage does not have a major impact on the detection of ammonia gas. This is mainly due to the presence of an effective ventilation system, which efficiently disperses and eliminates ammonia and other airborne pollutants.

VI. CONCLUSION

In conclusion, all research objectives have been successfully achieved. The proposed system effectively optimizes cleaning operations by deploying janitorial resources only, when necessary, based on real-time data such as ammonia levels, humidity, temperature, and occupancy. The strong correlations identified between environmental factors and IAQ indicators support accurate assessments of restroom conditions. Despite high user occupancy, effective ventilation maintains safe ammonia levels. However, the excessive use of cleaning agents may negatively impact air quality. Overall, the system presents a promising approach to enhancing restroom hygiene management, reducing operational costs, and improving user comfort and safety.

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