A Digital Twin Framework for Indoor Environmental Quality using IoT and Wireless Mesh Networks

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***Abstract*—Indoor and outdoor air quality and environmental conditions are considered as public health concerns, especially in hospital settings. While existing studies, such as Menguito et al. [9], use wireless mesh networks for indoor air quality monitoring, they lack outdoor measurements and scalable environmental sensor nodes. Additionally, there is minimal integration of digital twin technology in hospital air quality and environment systems, which could enhance real-time visualization and intuitive analysis. This project developed a Wireless Mesh Network (WMN) and Internet of Things (IoT)-based digital twin system to monitor both indoor and outdoor air quality and environmental conditions. Key enhancements include the use of the low-power Seeed XIAO nRF52840 developmental board, separate environmental sensor node for scalability and implementation of OpenThread for energy-efficient and resilient communication among sensor nodes. Compared to previous work that used WiFi with an average power consumption of 1.9W, this system achieved a significantly lower average consumption total of 840.1mW, demonstrating improved energy efficiency. Autodesk Tandem provided a 3D interface for real-time data visualization, trend analysis and intuitive heatmaps. Onsite deployment generally recorded good to moderate levels of CO2, CO, PM2.5, relative humidity, and temperature for both indoor and outdoor. However, indoor TVOC levels were relatively high, suggesting thermal effects and pollutant concentration within the area. The Enhanced Air Quality Index, which combines air quality index and humidex, indicated good air quality, with occasional spikes due to certain events. Further analysis revealed positive correlations among all indoor and outdoor air quality and environment parameters.**

***Index Terms*—hospitals, indoor and outdoor air quality monitoring, wireless mesh network, thread, digital twin**

I. Introduction

According to the fifth edition of the State of Global Air (SoGA) report, air pollution is the second leading cause of death worldwide and is responsible for 8.1 million deaths in 2021 [1]. Alarmingly, 99% of the air that the global population breathes is hazardous, exceeding the World Health Organization's guideline limits [2]. In the Philippines, air pollution accounts for 45.3 deaths per 100,000 people, making it the third highest in the world, after China and Mongolia. Various pollutants lead to significant impact to human health, whether short- or long-term. This includes cancer, stroke, lung diseases, type 2 diabetes, obesity and systemic inflammation among others [4].

Healthcare facilities are high-risk environments where air quality plays a crucial role in ensuring the safety and well-being of patients and healthcare workers. Poor air quality exacerbates symptoms in vulnerable groups and may hinder recovery or contribute to the spread of airborne pathogens that may potentially increase the risk of hospital-acquired infections [5]. In cases where the area has limited HVAC systems, especially in public places like hospitals, the necessity for an AQM system becomes even more critical but there is a gap in recent studies on AQM that integrates both indoor and outdoor sensor nodes, especially within a hospital setting.

Recognizing these gaps, this research emphasizes the need for comprehensive air quality monitoring. Therefore, the primary objective of this project is to design a real-time indoor and outdoor air quality monitoring that utilizes a wireless mesh network (WMN) for reliable communication and is integrated with a digital twin (DT) platform for live data visualization. The WMN integrated into the system is based on the Thread networking protocol, which is a low power IPv6-based mesh networking technology designed for scalable communication among the sensor nodes. Additionally, the system will compute the Enhanced Air Quality Index (EAQI) by integrating both air quality parameters, such as PM2.5, TVOC, NO2, CO2 and CO, and environmental parameters, such as temperature and relative humidity, providing a more comprehensive assessment of the air quality conditions.

This paper presents an operational deployment of the system in which the prototype is tested at The University Laboratory for Small Satellites and Space Engineering Systems (ULyS^{3}ES), which is a research space at the Electrical and Electronics Engineering Institute in the University of the Philippines-Diliman. This environment provided a realistic setting to assess the functionality and to evaluate the performance of the real-time indoor and outdoor air quality monitoring system and digital twin integration. While the system is currently running in a non-clinical setting, the next phase is in hospital environments, which are the focus of our

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ongoing study.

II. Air Quality Monitoring Systems

A. Enhanced Air Quality Index

The study used standard Air Quality Index (AQI) threshold from various sources. As defined by the United States Environmental Protection Agency (US EPA), AQI in this study is calculated using the standardized method to convert AQ data into a single value for easier evaluation [6].

Humidex will be computed as Equation 1 [7].

$$h = T + \frac{5}{9} \times (6.112x10^{7.5 \times \frac{T}{237.7+T} \times \frac{RH}{100}} - 10) \quad (1)$$

where T is air temperature in $°C$ and RH is relative humidity in %.

Parameter	Good	Moderate	Unhealthy for Sensitive Group	Unhealthy for All
Temp (°C)	27.5 - 33.5	-	-	≥27.5, ≤33.5
Rel. Humidity	62 - 82%	≤63%, 83 - 100%	-	-
CO2 (ppm)	0 - 800	801 - 1150	1151 - 1500	≥1500
CO (ppm)	≤0 - 35	35 - 50	51 - 70	≥70
NO2 (ppb)	≤0 - 100	101 - 175	175 - 250	≥250
PM2.5 (ug/m³)	0 - 15	16 - 20	21 - 30	≥30
TVOC (ppb)	0 - 400	401 - 601	601 - 800	≥800

Fig. 1. Existing AQM System's AQI Levels

To calculate the Enhanced Air Quality Index (EAQI), weightage factors according to the degree of comfort are considered in relationship with the humidex and AQI [7].

$$EAQI = (W_h \times h) + (W_{AQI}) \times AQI \quad (2)$$

$$W_T = W_h + W_{AQI} \quad (3)$$

where, W_h and W_{AQI} are the humidex and AQI weighing factors.

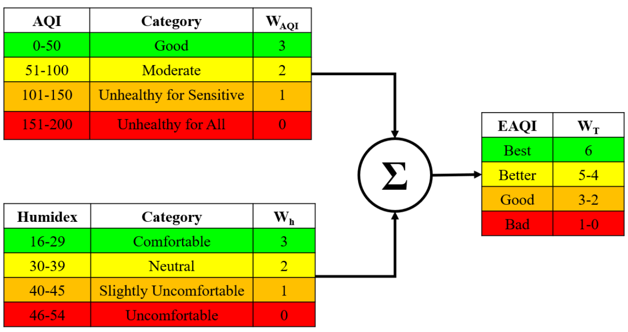

Fig. 2. Calculation procedure for EAQI

B. Existing Indoor and Outdoor AQM Systems

Gador et al. [8] developed a model using sensor data to analyze pollutant dynamics and examined the relationship between indoor and outdoor air quality (AQ) via their mean concentration ratio. Similarly, Chaloulakou et al. [30] evaluated an indoor AQ model using data from indoor and outdoor sensors which highlights how outdoor pollutants can infiltrate and impact indoor environments.

Menguito et al. [9] developed an AQM system similar to this project, using sensor nodes connected via a self-organizing wireless mesh network (painlessMesh) to monitor air quality in a hospital. The layered architecture of the study was adopted as a foundational reference for this project. However, this project builds upon and improves Meguito et al.'s work by incorporating outdoor air quality monitoring, utilizing different developmental board, and employing a separate, dedicated environmental sensor node, to enhance scalability. Additionally, a key innovation in this project's system is the integration of digital twin, which enables real-time visualization and intuitive heatmaps for air quality and environmental data, offering a more comprehensive platform for monitoring and decising-making in hospital settings.

Asare et al. [10] explores various platforms and software tools for DT implementation. IoT platforms play a crucial role in connecting the physical and digital environments. These typically link networked devices with applications that process and visualize data. Among the platforms reviewed [10], Autodesk Tandem was highlighted for its ease of setup, user-friendly and robust functionality. This was utilized in this project to support the DT integration.

III. Indoor and Outdoor AQM System

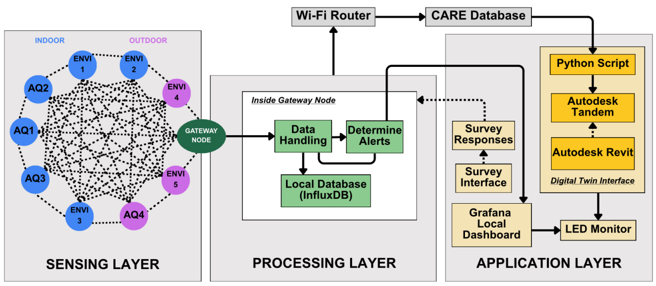

Fig. 3. Indoor and Outdoor Air Quality Monitoring System Diagram

This project adopts a layered framework structured into three main layers: the sensing layer, processing layer and application layer as seen in Figure 5.

A. Sensing Layer

The sensing layer serves as the foundation of the system integrating hardware for collecting air quality and environmental data. This project utilizes two base sensor nodes: the air quality (AQ) sensor node and environmental (ENVI) sensor node. The AQ sensor node consists of the developmental board, power supply module, and the AQ sensors, which includes MiCS-4514, SGP30, SCD41, and SEN55. On the other hand, the ENVI sensor node consists of the same board connected to a 5000 mAh Li-ion battery and AHT30.

Seeed Studio XIAO nRF52840 development board was used in this project. This has low power consumption and supports a variety of communication protocols, including Thread, which was the focus of this study.

B. Scalable Sensor Nodes

Scalable sensor nodes such as ENVI sensor nodes are essential for monitoring temperature and humidity, two key factors that influence air pollutant behavior and virus survival

TABLE I
SENSORS AND PARAMETERS

Sensors	Parameters
Air Quality Sensor Node (AQ Node)	
SEN55	PM2.5 (ug/m^3)
SCD41	CO2 (ppm)
SGP30	TVOC (ppb)
MiCS-4514	NO2 (ppm) & CO (ppm)
Environmental Sensor Node (ENVI Node)	
AHT30	Temperature (°C) & Relative Humidity (%)

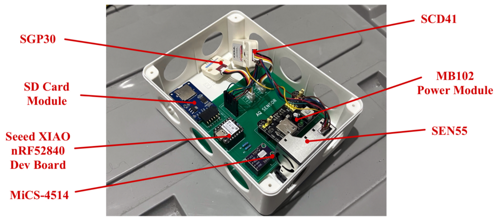

Fig. 4. AQ Sensor Node

[15]. Rising temperatures, especially in the Philippines due to climate change, can affect the stability of viral proteins and DNA, increasing the risk of transmission in various environments [15]. Humidity also plays a role. It impacts comfort and hygiene, and high levels can weaken the respiratory tract's protective lining, making individuals more vulnerable to infections [15].

C. Wireless Mesh Network

The sensor nodes communicate using the Thread protocol, which provides reliable, low-power full mesh networking with IPv6 support. Each node enables data forwarding, and self-healing which allows data rerouting if a sensor node fails to maintain network stability leading to a comparable packet loss compared to the previous study [9]. It also allows the system to scale since introduction of a new device does not disrupt working network connectivity. This setup was built using OpenThread which is an open-source implementation of the protocol.

D. Processing Layer

The sensing layer forwards the JSON-formatted data, which contains various sensor parameters and the computed AQI, to the processing layer. This was done through a COAP message containing the payload.

The processing layer consists of the gateway node which is built with a Raspberry Pi 4 and an nRF52840 dongle, enabling it to serve as a Thread that connect the system to the internet. It collects data from the sensor nodes, store it in a local InfluxDB, and hosts a Node.js server to capture patient survey responses on thermal comfort and symptoms.

E. Application Layer

The application layer is designed to facilitate comprehensive data visualization and user interaction through two key components: local dashboard and digital twin platform.

The system used Grafana as its local dashboard which retrieves data from InfluxDB. It presents these metrics in

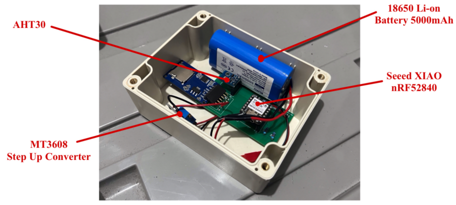

Fig. 5. ENVI Sensor Node

real-time, along with the categorized air quality description applied in this project. This will enable the users to easily interpret and respond to the AQ trends. To extend access beyond the local network, a tunneling software, Cloudflare Tunnel, will then be integrated with the local dashboard. This will enable secure remote access via web interface.

The system will also collect the thermal comfort and related symptoms of the patient in the deployed area using a survey terminal. The survey terminal is implemented through Node.js running in the gateway node. This will be accessible through its port 4000. For the users to access this, they must connect to the same network as the RPi 4 and access it through a QR code provided in the deployment.

F. Digital Twin Platform

A digital twin is a virtual replica of a physical entity, reflecting its lifecycle through data. [11]. The initial step is to develop the 3D model of the deployment location using Autodesk Revit, then integrate it into Autodesk Tandem for functionality. Sensor nodes represented in the model were used to map the sensor data stored in the CARE platform via an API in Python script running on the gateway node. Tandem's stream feature enables visualization and time-based heatmaps of the measured parameter.

G. Power Characterization Experiment

Power Profiler Kit II (PPK2) was used to measure real-time power consumption of the sensor nodes. Both the AQ sensor node and ENVI sensor node were supplied with the voltage of the PPK2. Through the use of nRF Connect for Desktop, the power ratings were monitored. This experiment is especially vital for the ENVI sensor nodes since these use batteries as its power supply, making energy efficiency a critical component in designing the system.

H. Calibration

In order to calibrate the sensors, commercial-grade devices were used. Aranet4 was used to calibrate the CO2 values of the SCD41, while ROAM measures PM 2.5 values which aided in the calibration of the SEN55. All four of the AQ nodes were deployed for 5 days, from May 9, 2025 to May 14, 2025. A simple linear regression model was created to adjust the sensors' values in relation to the reference instruments. The graphs of the adjusted values for both CO2 and PM2.5 can be seen in Figure 6 and Figure 7, respectively. Other values from the sensors such as CO, NO2, and TVOC, were not calibrated due to lack of control devices.

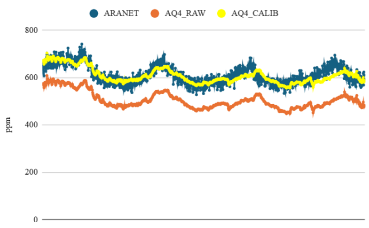

Fig. 6. AQ4 CO2 Calibration

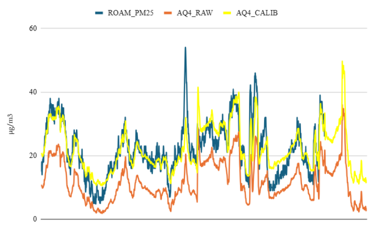

Fig. 7. AQ4 PM2.5 Calibration

I. Operational Deployment

The indoor and outdoor AQM system was intended to be deployed in the pediatric ward at Philippine General Hospital, but was deployed in ULyS³ES for 3 days. Figure 4 shows the sensor node placement in the facility. Each node is placed in a tripod to reach the average breathing level, as suggested by the United States Environmental Protection Agency (US EPA) [12], which is around 5 feet. Three AQ sensor nodes were placed inside the facility and one outside, while for the ENVI sensor nodes, three were installed indoors and two outdoors.

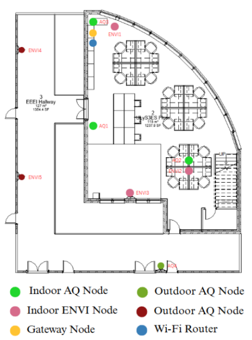

Fig. 8. Onsite Deployment Sensor Placement

Each node transmits data every 15 seconds allowing a stable mesh network. To avoid interruption in the internet connectivity and ensure continuous data uploads to the CARE platform database, a SIM-enabled Wi-Fi router was deployed alongside the system.

IV. Results and Discussion

A. Power Characterization Experiment

Figure 9 and Figure 10 show the current drawn by the AQ sensor node and ENVI sensor node, respectively. After boot-up, Thread initialization and sensor start-up occur, as indicated by the red box. The green box in each figure denotes the periodic sampling of sensors for each node. On average, the AQ sensor node consumes 840.1mW when it is continuously sampling and transmitting data to the gateway node with a 5V source. Similarly, power characterization for the environmental sensor node was also conducted. Since it only houses one sensor which uses 3.3V as input, its average power consumption is less – only drawing 29.21mW.

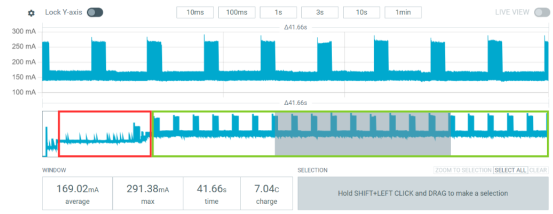

Fig. 9. Current Drawn by AQ Sensor Node

Power consumption was also monitored during the onsite deployment using a battery management library integrated in the sensor node code for the ENVI sensor nodes that utilized battery. An average battery level drop of 17.25% was observed across the active ENVI nodes over a 24-hour period from May 22, 4:00PM to May 23, 4:00PM.

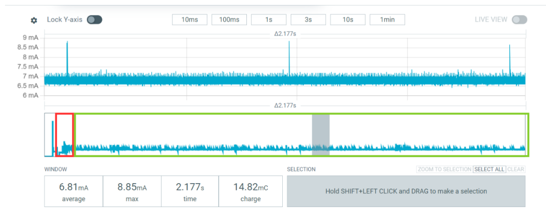

Fig. 10. Current Drawn by ENVI Sensor Node

B. System Characterization

The AQ sensor nodes powered via wall sockets consistently exhibited minimal packet loss, which shows 11.96% across all deployed AQ sensor nodes. In contrast, the ENVI sensor node, which operates on battery power, shows a noticeably different pattern with a peak rate of 44.59% indicating potential reliability issues related to the batteries used. Since the nodes used in the previous study are similar to the AQ nodes of the present study, they serve as a more appropriate basis for comparison. Notably, the previous iteration had only a third of the total number of data points yet exhibited a similar packet loss rate of approximately 12%. The larger dataset of this study lends greater reliability and confidence to the observed packet loss rates, highlighting improved system performance and reliability.

C. Operational Deployment

During the operational deployment period from May 19 to 22, the air quality sensor nodes reported a consistent reading of 0 ppb for NO2 level. Table II and Table III shows the average values obtained by the air quality sensor nodes and environmental sensor nodes.

Table II shows the AQ measurements in the ULyS³ES building. The AQ1 sensor node which was positioned near the doorway consistently recorded elevated readings. This is due to the frequent foot traffic that contributed to the increase in the pollutant levels. Similarly, AQ2 sensor node which was placed in the office table area also showed consistent high values. This indicates that indoor activities and limited ventilation contributed to the pollutant levels in the area. Higher parameter values were generally observed during working hours which suggests the correlation between human presence and pollutant accumulation. CO levels remained low indicating no significant presence of combustion-related pollutants. CO2 levels were noticeably higher indoors particularly during working hours. This is consistent with human presence and limited air flow. PM2.5 was slightly lower indoors since there are no sources from the outdoor. All the windows are always closed, cooking and smoking are strictly prohibited inside.

TABLE II
OPERATIONAL DEPLOYMENT AVERAGE AQ SENSOR NODE MEASUREMENT

Parameter	Average Indoor Value	Outdoor Value
CO	0.15ppm (Good)	0.2ppm (Good)
TVOC	1244.03ppb (Unhealthy)	343.77ppb (Good)
CO2	640.97ppm (Good)	586.38ppm (Good)
PM2.5	11.54µg/m3 (Good)	14.09µg/m3 (Good)
AQI	63 (Moderate)	54 (Moderate)

TABLE III
OPERATIONAL DEPLOYMENT AVERAGE ENVI SENSOR NODE MEASUREMENT

Parameter	Average Indoor Value	Outdoor Value
Temperature	32.13°C (Good)	31.34°C (Good)
Rel Humidity	43.83% (Moderate)	60.60% (Moderate)
Humidex	38 (Neutral)	41 (Slightly Uncomfortable)

As presented in Table III, indoor relative humidity is lower than outdoor. This lower humidity can contribute to an increase in TVOC concentrations, as it tends to disperse less effectively in dry environment [13]. Humidex indicates thermal discomfort, with slightly greater readings observed outdoors. High AQI may contribute to a less comfortable environment [14]. While temperature has a less direct effect on CO2 and PM2.5, it can influence air movement and occupant behavior, which in turn affects pollutant accumulation indoors.

Furthermore, using the EAQI, indoor air quality ranged from good to occasionally bad, due to the rise in TVOC levels. This suggests that indoor sources, such as occupant activities, such as spraying perfumes or alcohol-based products, may highly contribute to these fluctuations. Since the windows in the area are always closed and doors are almost always kept shut, the dispersion of accumulated TVOC is very slow. Thus, there is a need for a better ventilation of the site. In contrast, outdoor air quality consistently reflected good air quality, indicating effective circulation and ventilation.

To further connect the two observations, the system also revealed a strong correlation between indoor and outdoor environmental conditions. As seen in Table V, CO, PM 2.5, CO2, and TVOC levels exhibited strong correlations between the said environments. This implies that the outside air quality affects the indoor air quality significantly. Hence, monitoring both systems at the same time is essential to accurately assess exposure risks.

TABLE IV
AVERAGE EAQI RESULT

Placement	Average EAQI Value
Indoor	4 (Better)
Outdoor	3 (Good)

TABLE V
MEDIAN I/O RATIO

Parameter	Median I/O
CO	0.643
TVOC	1.195
CO2	1.064
PM2.5	0.8645

A LED monitor alongside the laptop running Autodesk Tandem provides real-time access to the digital twin and Grafana dashboard with sensor time-series data. Occupants can view Tandem's heatmaps as shown in Figure 12. Although the survey terminal works, it was not deployed effectively because the office had only 1–3 instructors present at a time, often none, due to varying class schedules.

D. *Digital Twin and Prediction*

Autodesk Tandem serves as the system's core visualization layer, offering the intuitive spatial trends of AQ and ENVI conditions as seen in Figure 12. By embedding the sensor data into a 3D model of the physical environment, Tandem enables users to quickly interpret what is happening in the environment without needing any background in data analysis or technical tools. This accessibility allows both technical and non-technical users to interpret patterns and identify anomalies within the space. Notably, the color gradient used in these heatmaps are chosen to directly correspond to the actual measurement range of each parameter. For instance yellow, orange, and red are used to indicate "Moderate" to "Unhealthy" AQ and ENVI parameters. While Tandem visualizes 2D data overlaid on 3D models, it does not represent true 3D volumetric data. Additionally, since Tandem does not provide estimate values at unmeasured locations, Inverse Distance Weighting (IDW) was applied. Aggregated data reduce data volume and smooth out short-term spikes. The "location-type-aware" IDW interpolates only values between sensor nodes, which are represented by red dots, within the same zone (indoor or outdoor), preventing unrealistic cross-wall estimations. The color scheme used in IDW is matched accordingly to the color range of the heatmaps used in Tandem.

V. CONCLUSION

A wireless monitoring system for indoor and outdoor air quality was successfully deployed, integrating a Thread-based mesh network with an IOT-based digital twin model via Autodesk Tandem. This significantly enhanced the spatial distribution of air quality parameters. Although numerical data wasn't directly shown, IDW interpolation estimated values in areas without sensor nodes, providing data across the monitored areas. During the onsite deployment, NO2 levels were consistently at 0 ppb which is likely due to sensor calibration, while other measured parameters – including twin framework for indoor environmental quality.

Acknowledgment

The authors extend their appreciation to the DOST for their financial support. Special thanks are also extended to Joshua C. Agar, and Paul Jason R. Co for providing insights in different areas of the capstone project. The authors would also like to acknowledge Jaere C. Medina and Joseph Hufner Calapre for their assistance in the deployment.

References

[1] UNICEF. “Air pollution accounted for 8.1 million deaths globally in 2021, becoming second leading risk factor”, UNICEF. (2024), [Online]. Available: https://www.unicef.org/press-releases/air-pollution-accounted-81-million-deathsglobally-2021- becoming-second-leading-risk.

[2] World Health Organization. “Air pollution”. (n.d.), [Online]. Available: https://www.who.int/health-topics/air-pollution

[3] I. V. Abano, “Health experts in the Philippines lead fight against dirty air,” 2019. [Online]. Available: https://asia.noharm.org/news/news-health-experts-philippines-lead-fight-against-dirty-air.

[4] European Environment Agency, “How air pollution affects our health,” [Online]. Available: https://www.eea.europa.eu/en/topics/in-depth/air-pollution/eow-it-affects-our-health.

[5] Camfil, “Determining specific indoor air quality goals in hospitals and healthcare facilities for optimum patient health outcomes,” 2024. [Online]. Available: https://cleanair.camfil.us/2024/05/23/determining-specific-indoor-air-quality-goals-in-hospitals-and-healthcare-facilities-for-optimum-patient-health-outcomes/.

[6] AirNow, “Technical assistance document for the reporting of daily air quality,” U.S. Environmental Protection Agency, Tech. Rep., 2014. [Online]. Available: https://document.airnow.gov/technical-assistance-document-for-the-reporting-of-daily-air-quailty.pdf.

[7] Q. P. Ha, S. Metia, and M. D. Phung, “Sensing data fusion for enhanced indoor air quality monitoring,” *IEEE Sensors Journal*, vol. 20, no. 8, pp. 4430–4441, 2020. DOI: 10.1109/JSEN.2020.2964396.

[8] J. E. M. Gador *et al.*, “Wireless sensor network and IoT-based monitoring system for indoor and outdoor air quality and dispersion assessment of the National Engineering Center building,” 2024.

[9] M. C. M. Menguito, L. A. V. Faderogao, D. D. O. Zapanta, N. D. F. Genuino, J. A. De Guzman, M. D. Rosales, P. Magpantay, J. J. Eslit, U. R. Agub, J. R. T. Lustro, V. B. Molina, M. D. Herrera, M. F. T. C. Lomboy, and J. R. E. Hizon, ”A real-time indoor air quality monitoring system for hospitals,” in *Proceedings of the 2024 31st IEEE International Conference on Electronics, Circuits and Systems (ICECS)*, 2024, pp. 1–4, doi: 10.1109/ICECS61496.2024.10848655.

[10] K. A. Asare, R. Liu, C. J. Anumba, and R. R. Issa, “Real-world prototyping and evaluation of digital twins for predictive facility maintenance,” *Journal of Building Engineering*, vol. 97, p. 110890, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352710224024586. DOI: https://doi.org/10.1016/j.jobe.2024.110890.

[11] D. Jones, C. Snider, A. Nassehi, J. Yon, and B. Hicks, “Characterising the digital twin: A systematic literature review,” *CIRP Journal of Manufacturing Science and Technology*, vol. 29, pp. 36–52, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1755581720300110. DOI: https://doi.org/10.1016/j.cirpj.2020.02.002.

[12] U.S. Environmental Protection Agency, “A guide to siting and installing air sensors,” [Online]. Available: https://www.epa.gov/air-sensor-toolbox/guide-siting-and-installing-air-sensors.

[13] P. Markowicz and L. Larsson, ”Influence of relative humidity on VOC concentrations in indoor air,” *Environmental Science and Pollution Research International*, vol. 22, Oct. 2014, doi: 10.1007/s11356-014-3678-x.

[14] L.-R. Jia, J. Han, X. Chen, Q.-Y. Li, C.-C. Lee, and Y.-H. Fung, ”Interaction between thermal comfort, indoor air quality and ventilation energy consumption of educational buildings: A comprehensive review,” *Buildings*, vol. 11, no. 12, p. 591, Dec. 2021, doi: 10.3390/buildings11120591.

[15] Vijaykrishna G., G. Balaji , ”Impact of Indoor Temperature and Humidity in IAQ of Health Care Buildings,” Civil Engineering and Architecture, Vol. 11, No. 3, pp. 1273 - 1279, 2023. DOI: 10.13189/cea.2023.110313

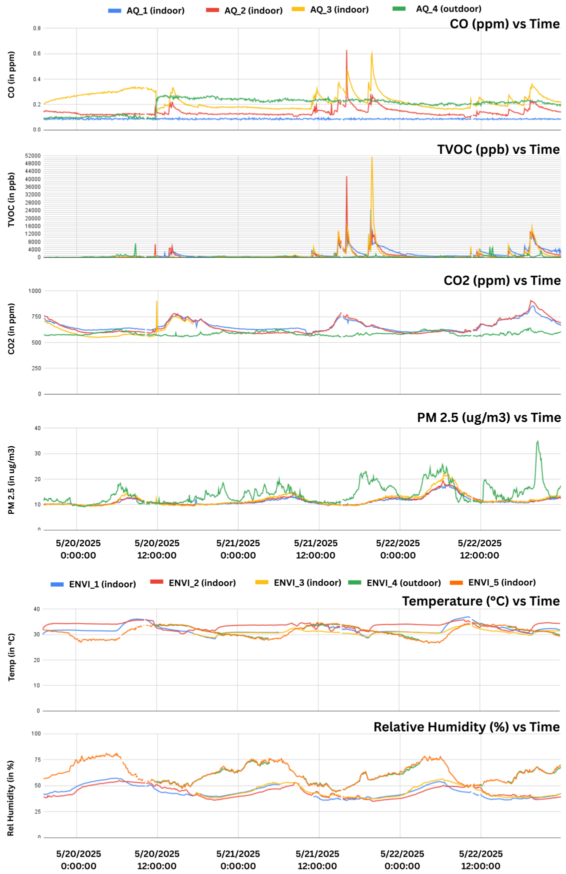

Fig. 11. AQ and ENVI Measurements from Onsite Deployment

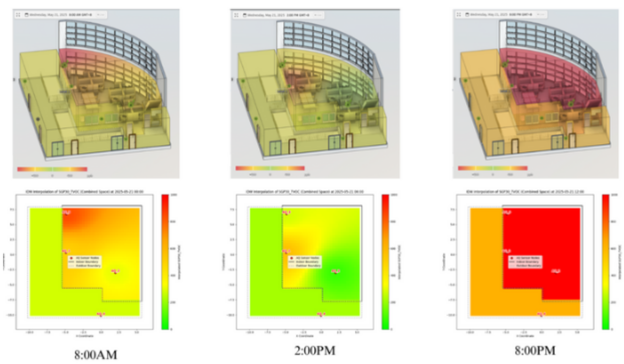

Fig. 12. Digital Twin Model vs Prediction of Onsite Deployment

CO2, PM2.5, CO, TVOC, temperature, and relative humidity – indicated good to moderate air quality as reflected in the EAQI rating of 3-4. Temperature and relative humidity also influenced pollutant levels, highlighting the need to consider thermal comfort alongside air quality metrics. Indoor and outdoor air quality also showed strong correlation for all sensors ranging from 0.643 to 1.195, which denotes a relationship between internal and external environment conditions. Another key advancement in this system was the reduction of power consumption from 380mA in its earlier iteration to 168.02mA. This was achieved through the use of a low-power Seeed XIAO nRF52840 and Thread networking protocol. Overall, the system was able to produce a digital