

Influence of Ventilation and Enclosure on Multi-Parameter Indoor Environmental Conditions: A BME680-Based IoT Study at Government Degree College, Rajendranagar

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Highlights

Four-month BME680 monitoring resolved spatiotemporal indoor environmental variations across open, ventilated and enclosed campus settings.

Ventilation and degree of enclosure produced the clearest differentiation in the BME680 metal-oxide gas-resistance response.

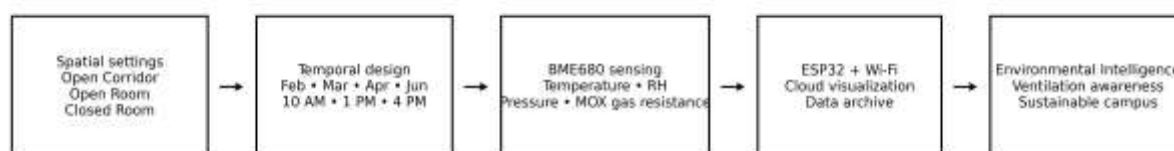
Gas resistance followed a persistent Open Corridor > Open Room > Closed Room pattern, consistent with stronger VOC-related reducing-gas response under restricted air exchange.

Temperature was dominated by seasonal and diurnal variation, whereas relative humidity and atmospheric pressure showed comparatively limited spatial differentiation.

The BME680–ESP32–cloud framework links spatiotemporal IEQ surveillance with sustainable-campus management and SDGs 3, 4, 9, 11, 12 and 13.

Graphical Abstract

Ventilation-Enclosure Gradient and Spatiotemporal BME680 Response



Key gaseous pattern: higher gas resistance in open air → lower resistance with increasing enclosure

Interpretation: relative VOC-related/reducing-gas response only; not compound-specific VOC or TVOC concentration

Abstract

Ventilation and enclosure are primary determinants of indoor environmental heterogeneity in naturally ventilated educational buildings, yet their influence is expressed differently across thermal, hygrometric, barometric and gaseous variables. This study investigated the spatiotemporal variation of BME680-derived environmental parameters using an Internet of Things (IoT)-enabled Real-Time Environmental Intelligence System (REIS) at Government Degree

College, Rajendranagar, Telangana, India. A Bosch BME680 sensor integrated with an ESP32 microcontroller was deployed across an Open Corridor, an Open (Ventilated) Room and a Closed Room, representing progressively greater degrees of enclosure and reduced natural air exchange. Temperature, relative humidity, atmospheric pressure and metal-oxide-semiconductor (MOX) gas resistance were monitored at 10:00 AM, 1:00 PM and 4:00 PM during February, March, April and June 2026; pressure-derived altitude was retained as a contextual variable. The four-month dataset revealed parameter-specific spatiotemporal behaviour. Temperature exhibited pronounced seasonal and diurnal variability, with warmer conditions during April and June and frequent midday elevation. Relative humidity and atmospheric pressure showed comparatively limited location-dependent separation. In contrast, gas resistance displayed the clearest and most persistent spatial gradient, following Open Corridor > Open Room > Closed Room across the monitoring period. Under comparable sensor operating conditions, the lower gas resistance observed in the more enclosed environment is consistent with stronger interaction of the MOX sensing layer with reducing gases and VOC-related mixtures under restricted dispersion. This response is interpreted conservatively because the BME680 gas element is non-selective, cross-sensitive to multiple compounds and environmentally dependent; therefore, gas resistance is treated as a semi-quantitative indicator of relative VOC-related gaseous variability rather than as a direct concentration of individual VOCs or total VOCs. Integration of BME680 sensing with ESP32 processing, Wi-Fi communication and cloud visualization enabled spatiotemporal IEQ surveillance and evidence-informed ventilation awareness. The study demonstrates how low-cost multi-parameter IoT sensing can support sustainable-campus environmental management and aligns with SDGs 3, 4, 9, 11, 12 and 13 through healthier learning environments, sustainability education, digital infrastructure, responsible building operation and climate-responsive institutional practice.

Keywords: BME680; Internet of Things; indoor environmental quality; gas resistance; volatile organic compounds; temperature; relative humidity; ESP32; Environmental Intelligence; sustainable campus

1. Introduction

Indoor environmental quality (IEQ) in educational buildings is a dynamic outcome of interactions among outdoor meteorology, building envelope characteristics, occupancy, internal sources and ventilation. In naturally ventilated institutions, the degree of enclosure and availability of air exchange can generate distinct microenvironmental conditions even within the same campus. A scientifically informative monitoring strategy must therefore resolve both spatial variation among locations and temporal variation across the academic day and season. Recent educational-building studies increasingly adopt multi-parameter monitoring because temperature, relative humidity and gaseous indicators do not necessarily respond to the same environmental drivers [1–5].

The present investigation focuses on this spatiotemporal perspective. Three campus settings—an Open Corridor, an Open (Ventilated) Room and a Closed Room—were selected as a practical ventilation–enclosure gradient. Repeated observations at 10:00 AM, 1:00 PM and 4:00 PM during February, March, April and June 2026 enabled environmental variability to be examined simultaneously across location, time of day and month. This design is particularly relevant to naturally ventilated higher-education buildings, where indoor conditions can change rapidly with solar heat gain, occupancy, door/window status and outdoor-air exchange.

The Bosch BME680 provides a compact platform for such multi-dimensional observation because it integrates temperature, relative humidity, barometric pressure and a heated metal-oxide-semiconductor (MOX) gas sensor within a single device [6–8]. Coupling the sensor with an ESP32 microcontroller and Wi-Fi connectivity enables acquisition, cloud transmission, visualization and archival storage of environmental measurements. In this study, the IoT architecture is not treated as an end in itself; rather, it functions as the enabling infrastructure for resolving spatiotemporal IEQ patterns and translating them into Environmental Intelligence.

Particular emphasis is placed on the BME680 gas-resistance channel. Indoor educational environments contain complex mixtures of volatile and semi-volatile chemicals originating from cleaning agents, furnishings, coatings, teaching materials, human metabolism, personal-care products and outdoor infiltration. Analytical studies in university buildings have demonstrated that VOC composition and abundance vary with occupancy, room function, season,

source activity and ventilation [9,10]. Ventilation therefore influences not only thermal conditions but also the dilution, removal and persistence of gaseous contaminants.

The BME680 does not directly quantify these compounds. Its MOX sensing layer is heated and undergoes resistance changes when surface reactions occur with reducing or oxidizing constituents of the surrounding air. For many reducing VOC-related gases, increased interaction with the sensing surface is associated with a decrease in resistance. However, the magnitude and direction of response depend on chemical identity, concentration, temperature, relative humidity, heater profile, sensor aging and prior exposure [8,11–16]. Cross-sensitivity is intrinsic to low-cost MOX sensing; consequently, raw resistance cannot be interpreted as a chemically selective VOC concentration or a regulatory TVOC value without validated calibration against an appropriate reference method.

This limitation does not eliminate the environmental value of the signal. When sensor type, deployment protocol and operating conditions are held reasonably consistent, gas resistance can provide a useful semi-quantitative indicator of relative changes in the gaseous environment. A persistent spatial gradient across locations with different ventilation characteristics may therefore reveal ventilation-associated differences in VOC-responsive reducing-gas burden, even when chemical speciation is unavailable. The simultaneous measurement of temperature and relative humidity is essential because both variables can influence MOX response and must be considered when interpreting apparent gaseous trends [11–16].

Temperature and relative humidity provide complementary information on the thermo-hygrometric environment. In naturally ventilated classrooms, temperature frequently exhibits strong diurnal and seasonal forcing, whereas spatial differences within the same campus may be smaller [1–4,17]. Relative humidity is influenced by outdoor moisture, occupancy and ventilation and may also modify perceived comfort and gas-sensor response. Atmospheric pressure and pressure-derived altitude have a different interpretive role: because the monitoring locations are co-located within one campus, major spatial differences are not expected, and these variables serve mainly as supporting environmental context.

The research gap addressed by this work is therefore not merely the absence of another low-cost sensor platform. Existing literature includes BME680-based IoT systems, low-cost IEQ networks and studies of VOCs in educational buildings [6,7,9–16,18–26]. Fewer studies explicitly examine how a ventilation–enclosure gradient is expressed across multiple BME680 channels over several months while maintaining scientifically conservative interpretation of the non-specific MOX gas signal. This distinction is important because over-conversion of gas resistance into unvalidated VOC concentration can lead to misleading environmental conclusions.

Accordingly, the primary objective was to determine how ventilation, degree of enclosure, month and time of day shape the spatiotemporal behaviour of BME680-derived indoor environmental parameters at Government Degree College, Rajendranagar. Specific objectives were to: (i) characterize seasonal and diurnal temperature variation; (ii) evaluate spatial and temporal patterns in relative humidity; (iii) describe atmospheric-pressure and pressure-derived-altitude behaviour as contextual variables; (iv) examine whether BME680 gas resistance exhibits a persistent ventilation- and enclosure-associated gradient; (v) interpret the gas-resistance signal as a relative VOC-related response within the known limitations of MOX sensing; (vi) demonstrate ESP32–Wi-Fi–cloud integration for real-time Environmental Intelligence; and (vii) map the resulting environmental-management framework to SDGs 3, 4, 9, 11, 12 and 13 without overstating direct SDG achievement.

The central hypothesis guiding the descriptive interpretation was that variables dominated by common outdoor meteorology would show stronger temporal than spatial variation, whereas the VOC-responsive gas-resistance signal would show clearer differentiation with degree of enclosure and natural air exchange. The manuscript therefore places spatiotemporal variation—and especially the ventilation-sensitive gaseous response—at the centre of the Results and Discussion.

2. Literature Review

Contemporary IEQ research increasingly emphasizes simultaneous monitoring rather than reliance on a single indicator. Educational spaces are dynamic microenvironments in which temperature, humidity, ventilation, occupancy and pollutant sources change over the day. Studies in schools and universities have therefore combined physical measurements with occupant surveys, building characteristics and ventilation information [1–5]. The BME680 integrates temperature, humidity, pressure and MOX gas sensing in a compact package [8]. Its digital interfaces simplify connection to microcontrollers, and its small footprint is suitable for distributed sensing nodes. BME680-based IoT studies have demonstrated room monitoring, web dashboards, environmental sensing in harsh conditions and university-campus deployment [6,7]. The present work follows this architecture but applies the sensor systematically across three ventilation/enclosure conditions and four monitoring months.

MOX sensors operate through changes in electrical conductivity or resistance at a heated sensing surface. Their low cost, compactness and rapid response make them attractive for real-time monitoring, but the signal is inherently non-specific. Reviews and experimental evaluations identify cross-sensitivity, humidity effects, drift, warm-up requirements and compound-dependent sensitivity as major limitations [11–16]. Consequently, raw gas resistance is most defensibly used for relative comparison and trend detection unless a validated calibration model converts the signal to a specific concentration. This principle is central to the present manuscript.

University and school environments contain VOC sources associated with occupants, personal-care products, cleaning, furniture, building materials, teaching activities and outdoor-air infiltration. Investigations of densely occupied university buildings identified broad VOC mixtures and demonstrated that room function, season, occupancy and ventilation influence concentrations [9,10].

Thermal and moisture conditions influence both occupants and sensors. Educational-building studies show that comfort depends on season, climate, ventilation system, air movement and adaptive behaviour [1–4,17]. In naturally ventilated settings, daytime temperature changes may be more pronounced than location-to-location differences within the same building.

IoT platforms combine sensing, edge processing, connectivity, databases and dashboards. Educational deployments demonstrate that such systems can support environmental management while also providing experiential learning opportunities [5,7,17]. Smart-campus architectures extend this concept by connecting multiple monitoring domains, including air quality, energy and building operation. REIS adopts the same technological logic but emphasizes environmental interpretation and awareness as the final output rather than data collection alone.

The present study addresses these gaps by using a four-month, three-location, three-time-point design to examine spatiotemporal BME680 behaviour along a ventilation–enclosure gradient and by retaining raw gas resistance as a semi-quantitative VOC-related response rather than converting it to unvalidated concentration units.

3. Research Methodology

3.1 Study area and comparative design

The study was conducted at Government Degree College, Rajendranagar, Telangana, India. A comparative spatiotemporal design was adopted in which three environments represented a progressive ventilation–enclosure gradient: (i) Open Corridor, continuously exposed to outdoor air and representing maximum natural exchange; (ii) Open (Ventilated) Room, representing partial enclosure with natural ventilation; and (iii) Closed Room, representing restricted air exchange. The spatial design was crossed with three observation times—10:00 AM, 1:00 PM and 4:00 PM—and four monitoring months—February, March, April and June 2026. This structure enabled descriptive assessment of location-, time- and month-dependent environmental behaviour without inferential statistical testing.

3.2 BME680 multi-parameter sensor

The Bosch BME680 was used as the principal multi-parameter sensing element. It provided ambient temperature (°C), relative humidity (%), atmospheric pressure (hPa) and MOX gas resistance (k Ω); altitude (m) was derived from

pressure and retained only as a contextual parameter. The gas-sensing element consists of a heated metal-oxide layer whose resistance changes in response to the surrounding chemical environment [8]. Because the response is non-selective and influenced by multiple reducing gases, humidity, temperature, heater profile and sensor history [11–16], the present study reports gas resistance directly and interprets it only as a relative VOC-related gaseous-response indicator. No compound-specific VOC or TVOC concentration is claimed.

3.3 ESP32 microcontroller and IoT Design

The BME680 was interfaced with an ESP32 microcontroller. The ESP32 served as the data-acquisition and communication unit, receiving the digital BME680 outputs and transmitting measurements through Wi-Fi to a cloud-based platform for visualization and storage. The functional chain was: indoor environment → BME680 → ESP32 → Wi-Fi → cloud platform → real-time dashboard → stored environmental record. This architecture follows established low-cost IoT approaches in which compact sensor nodes provide time-resolved information through networked dashboards [6,7,23–26].

3.4 Monitoring schedule

Measurements were recorded during February, March, April and June 2026. Observations were made at 10:00 AM, 1:00 PM and 4:00 PM at each of the three locations. The repeated schedule was selected to represent morning, midday and late-afternoon conditions during the academic day. The exact date-wise observations retained in the project dataset are reproduced in the tables of Section 4 without interpolation, normalization or replacement.

3.5 Data handling and descriptive interpretation

The dataset was organized by month, monitoring location and time of day to preserve its spatiotemporal structure. Interpretation was descriptive and process-oriented rather than inferential. The analysis examined whether each environmental parameter was dominated primarily by temporal forcing, spatial setting or both. Particular attention was given to the persistence of the gas-resistance hierarchy across the ventilation–enclosure gradient. Monthly and location summaries were used for visualization only; Gas-resistance interpretation was constrained to relative VOC-related response under comparable deployment conditions.

3.6 Quality assurance and limitations of sensor interpretation

Before field monitoring, sensor communication, power stability, Wi-Fi transmission and dashboard display were checked. The BME680 was allowed to stabilize before observations. Because low-cost MOX gas sensors can respond to multiple compounds and are influenced by temperature, humidity, heater history and drift [11–16], the present study does not claim chemical speciation or regulatory-grade VOC quantification. Similarly, pressure-derived altitude is treated as a contextual calculation rather than evidence of physical elevation differences among rooms on the same campus.

4. Results and Discussion

4.1 Integrated overview of BME680 environmental variation

The four-month dataset resolved a clear separation between temporally dominated variables and spatially differentiated variables. Temperature exhibited the strongest seasonal and diurnal signature, reflecting common meteorological forcing across the campus. Relative humidity and atmospheric pressure showed comparatively modest spatial separation, and pressure-derived altitude remained effectively stable. In contrast, BME680 gas resistance exhibited a persistent spatial hierarchy aligned with the ventilation–enclosure gradient. This pattern identifies the MOX gas channel as the BME680 variable most sensitive to differences among the Open Corridor, Open Room and Closed Room and provides the central evidence for a ventilation-associated gaseous microenvironment effect.

4.2 Temperature variation

Temperature showed relatively small spatial differences among the Open Corridor, Open Room and Closed Room compared with the month-to-month change. February represented the cooler part of the monitoring period, March showed transitional warming, and April and June showed higher temperatures. Within individual days, the 1:00 PM observation commonly exceeded the corresponding 10:00 AM and 4:00 PM values, consistent with daytime heat gain. The modest differences among locations indicate that all three spaces were influenced by the same campus-scale outdoor thermal regime, while enclosure and air movement produced secondary local effects. This behaviour is consistent with educational-building studies in which thermal conditions are shaped by climate, time of day, natural ventilation and adaptive operation [1–4,17].

The month-wise temperature observations are presented in Tables 1–4.

Table 1. Temperature (°C) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — February 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-02-02	MONDAY	27.2	28.7	27.5	28.2	29.2	28.5	29	30.4	29.3
2026-02-03	TUESDAY	30.3	31.8	30.6	30.9	32.4	31.2	31.5	33.7	31.8
2026-02-04	WEDNESDAY	29	30.5	29.3	29.8	31.4	30.1	30.5	31.9	31.1
2026-02-05	THURSDAY	27.2	28.7	27.5	27.7	29.7	28.3	29	30.4	29.2
2026-02-06	FRIDAY	27.6	29.1	27.9	28.2	30	28.4	29.4	30.5	29.2
2026-02-09	MONDAY	29.6	31.1	29.9	30.2	32.1	30.4	31.6	32.8	31.4
2026-02-10	TUESDAY	27.3	28.8	27.6	28	29.5	28.2	29.2	30.5	29.5
2026-02-11	WEDNESDAY	26.7	28.2	27	27.5	28.8	27.6	28.5	29.5	28.6
2026-02-12	THURSDAY	27.9	29.4	28.2	28.6	30.1	29.2	29.2	30.6	30
2026-02-13	FRIDAY	28.6	30.1	28.9	29.5	30.8	29.6	30.3	31.8	30.8
2026-02-16	MONDAY	29.3	30.8	29.6	29.9	31.7	30.5	30.8	32.3	31.4
2026-02-17	TUESDAY	27.6	29.1	27.9	28.2	29.6	28.7	29	30.6	29.3
2026-02-18	WEDNESDAY	27.8	29.3	28.1	28.4	29.8	28.9	29.2	31.3	29.7
2026-02-19	THURSDAY	27.8	29.3	28.1	28.6	30.1	28.8	29.8	31.2	29.7
2026-02-20	FRIDAY	29.5	31	29.8	30.3	32	30.8	31	32.8	31.2
2026-02-23	MONDAY	30.3	31.8	30.6	30.8	32.3	31.6	32.1	33.1	32

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-02-24	TUESDAY	25.7	27.2	26	26.4	27.8	26.9	27.2	29.1	27.5
2026-02-25	WEDNESDAY	30.4	31.9	30.7	31.3	32.9	31.4	32.2	33.6	32.4
2026-02-26	THURSDAY	26	27.5	26.3	26.5	28.3	26.8	27.7	28.9	27.7
2026-02-27	FRIDAY	28.9	30.4	29.2	29.8	31.1	29.9	30.5	31.7	30.6

Table 2. Temperature (°C) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — March 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-03-03	TUESDAY	32.5	34	32.8	33.2	34.9	33.5	34.2	35.8	34.4
2026-03-05	THURSDAY	33.9	35.4	34.2	34.6	36.1	35.2	35.6	37.1	36.1
2026-03-06	FRIDAY	30.1	31.6	30.4	31.1	32.4	30.9	31.8	33.4	32
2026-03-09	MONDAY	31.7	33.2	32	32.2	33.7	32.5	33.5	34.9	33.8
2026-03-10	TUESDAY	31.9	33.4	32.2	32.6	34.1	32.9	33.6	35.1	34.2
2026-03-11	WEDNESDAY	30.7	32.2	31	31.4	32.8	31.5	32.2	33.7	33
2026-03-12	THURSDAY	32.3	33.8	32.6	32.8	34.3	33.4	33.8	35.5	34.2
2026-03-13	FRIDAY	30.6	32.1	30.9	31.4	32.8	31.5	32.3	33.6	32.7
2026-03-16	MONDAY	30.8	32.3	31.1	31.6	33	32	32.2	33.5	32.7
2026-03-17	TUESDAY	33.9	35.4	34.2	34.5	35.9	35.2	35.8	37.3	35.6
2026-03-18	WEDNESDAY	34.5	36	34.8	35.1	36.8	35.5	35.8	37.4	36.8
2026-03-20	FRIDAY	33.3	34.8	33.6	34.2	35.4	34.6	34.9	36.7	35.6
2026-03-23	MONDAY	31.6	33.1	31.9	32.1	33.9	32.8	33.3	35.1	33.8
2026-03-24	TUESDAY	32	33.5	32.3	32.7	34	33.3	33.9	35.1	33.9
2026-03-26	THURSDAY	33.1	34.6	33.4	33.8	35.2	34	34.4	35.9	35.4

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-03-27	FRIDAY	29.3	30.8	29.6	29.9	31.7	30.4	30.8	32.6	31.1
2026-03-30	MONDAY	31.4	32.9	31.7	32.4	33.9	32.7	33.4	34.9	33.6

Table 3. Temperature (°C) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — April 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-04-01	WEDNESDAY	36.9	38.4	37.2	37.8	38.9	38.1	38.7	40.2	38.8
2026-04-02	THURSDAY	37.3	38.8	37.6	38.3	39.7	38.5	38.8	40.6	39.3
2026-04-06	MONDAY	36.7	38.2	37	37.3	39	37.6	38.1	39.8	38.9
2026-04-07	TUESDAY	37.2	38.7	37.5	37.7	39.5	38.4	38.8	40	39.2
2026-04-08	WEDNESDAY	32.8	34.3	33.1	33.3	35.1	33.6	34.5	36	35.1
2026-04-09	THURSDAY	37.8	39.3	38.1	38.5	40.3	38.9	39.8	40.8	39.7
2026-04-10	FRIDAY	36.6	38.1	36.9	37.6	38.9	37.8	38	39.6	38.7
2026-04-13	MONDAY	33.8	35.3	34.1	34.8	36.3	35.1	35.2	37.1	36.1
2026-04-15	WEDNESDAY	31.8	33.3	32.1	32.4	34.3	33.1	33.3	34.9	34
2026-04-16	THURSDAY	36.6	38.1	36.9	37.1	39.1	37.8	37.8	39.5	38.2
2026-04-17	FRIDAY	32.8	34.3	33.1	33.3	35	33.9	34.1	36.2	34.5
2026-04-20	MONDAY	37.3	38.8	37.6	37.9	39.4	38.5	39	40.8	39
2026-04-21	TUESDAY	35.5	37	35.8	36.3	37.5	36.7	37.1	38.9	37.1
2026-04-22	WEDNESDAY	34.7	36.2	35	35.2	37	35.5	36.2	38.2	36.5
2026-04-23	THURSDAY	37	38.5	37.3	37.8	39	38.3	38.5	40.5	38.8
2026-04-24	FRIDAY	34.5	36	34.8	35.1	36.7	35.6	35.8	37.4	36.1
2026-04-27	MONDAY	38.1	39.6	38.4	38.6	40.6	39.4	40	41.3	40.4

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-04-28	TUESDAY	35.8	37.3	36.1	36.6	38	37	37.2	38.7	37.9
2026-04-29	WEDNESDAY	35	36.5	35.3	35.5	37.4	35.9	36.3	37.9	36.6
2026-04-30	THURSDAY	37.3	38.8	37.6	38	39.3	38.2	38.9	40.7	38.8

Table 4. Temperature (°C) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — June 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-06-01	MONDAY	37.9	39.4	38.2	38.7	40.4	39.2	39.9	41.3	40
2026-06-02	TUESDAY	40.2	41.7	40.5	41.2	42.2	41	42.1	43.7	42.5
2026-06-03	WEDNESDAY	38.3	39.8	38.6	39.2	40.5	39.2	39.8	41.8	40.5
2026-06-04	THURSDAY	40.5	42	40.8	41.4	42.5	41.7	42.1	43.5	42.1
2026-06-05	FRIDAY	38.7	40.2	39	39.6	41	39.7	40.5	42.1	40.2
2026-06-08	MONDAY	32.3	33.8	32.6	33.2	34.7	33.1	34.3	35.6	34.1
2026-06-09	TUESDAY	39.1	40.6	39.4	39.8	41.5	40.4	40.3	42.5	40.9
2026-06-10	WEDNESDAY	34.4	35.9	34.7	35.3	36.8	35.2	36	37.2	36.6
2026-06-11	THURSDAY	33.9	35.4	34.2	34.8	36	34.8	35.8	37.4	35.7
2026-06-12	FRIDAY	32.6	34.1	32.9	33.5	34.7	33.5	34	35.8	34.8
2026-06-15	MONDAY	39.3	40.8	39.6	40.3	41.5	40.4	41.1	42.6	41.4
2026-06-16	TUESDAY	38.1	39.6	38.4	39.1	40.1	39.1	40	41.5	40
2026-06-17	WEDNESDAY	38.4	39.9	38.7	39.4	40.6	39.2	40.3	41.3	40.7
2026-06-18	THURSDAY	35.4	36.9	35.7	36.3	37.6	36.6	36.7	38.2	37.4
2026-06-19	FRIDAY	32.2	33.7	32.5	32.7	34.6	33.5	33.8	35.7	34.3
2026-06-20	MONDAY	34.7	36.2	35	35.6	37.2	35.7	36.6	37.6	36.5

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
06-22										
2026-06-23	TUESDAY	36.4	37.9	36.7	36.9	38.7	37.2	37.6	39.5	38.2
2026-06-24	WEDNESDAY	34	35.5	34.3	34.6	36.4	34.9	35.2	37.3	35.6
2026-06-25	THURSDAY	35.9	37.4	36.2	36.9	37.9	37	37.7	39.2	37.9
2026-06-29	MONDAY	36.2	37.7	36.5	36.9	38.2	37	37.6	39.2	38.5
2026-06-30	TUESDAY	33	34.5	33.3	33.8	35.4	33.8	34.3	36.3	35.2

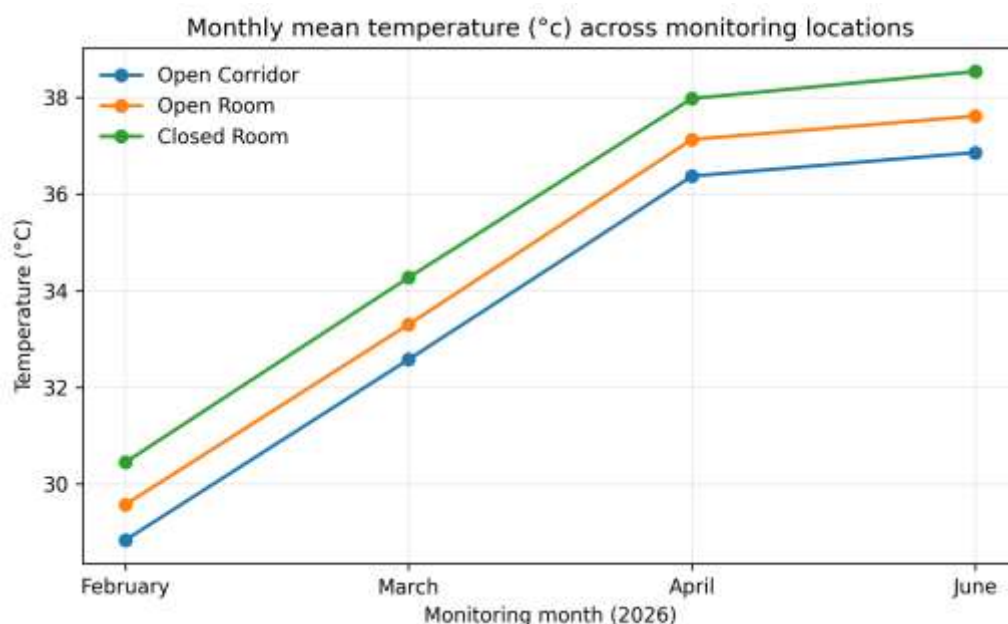


Figure 1. Monthly mean temperature across the three monitoring locations.

4.3 Relative humidity variation

Relative humidity remained broadly comparable among the three monitoring locations over the four months. The original report yielded overall mean values of approximately 62.73% in the Open Corridor, 62.56% in the Open Room and 62.51% in the Closed Room. The absence of a strong location-dependent hierarchy suggests that moisture conditions were largely governed by the common ambient environment rather than degree of enclosure alone. RH is nevertheless essential context for interpreting the gas sensor because MOX responses can be affected by ambient humidity [12–14]. Accordingly, the gas-resistance gradient should be interpreted alongside, rather than independently of, the humidity observations. The month-wise relative-humidity observations are presented in Tables 5–8.

Table 5. Relative Humidity (%) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — February 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-02-02	MONDAY	64	64	68	68	55	61	68	66	65
2026-02-03	TUESDAY	64	65	57	69	69	69	60	64	67
2026-02-04	WEDNESDAY	58	69	59	59	55	58	62	70	57
2026-02-05	THURSDAY	59	62	67	70	62	63	68	69	60
2026-02-06	FRIDAY	62	70	62	55	66	64	61	68	67
2026-02-09	MONDAY	69	59	68	68	66	57	62	58	64
2026-02-10	TUESDAY	63	55	61	67	65	55	69	68	63
2026-02-11	WEDNESDAY	60	61	61	66	68	65	70	69	55
2026-02-12	THURSDAY	63	70	58	64	59	70	61	64	62
2026-02-13	FRIDAY	61	61	63	69	69	64	64	57	62
2026-02-16	MONDAY	61	63	59	67	55	69	70	64	67
2026-02-17	TUESDAY	69	59	67	58	59	70	62	60	64
2026-02-18	WEDNESDAY	62	67	62	59	69	70	68	65	63
2026-02-19	THURSDAY	67	57	65	69	55	59	59	70	56
2026-02-20	FRIDAY	59	62	68	58	69	60	56	57	62
2026-02-23	MONDAY	67	66	57	63	70	64	68	60	61
2026-02-24	TUESDAY	62	59	67	57	69	64	67	66	58
2026-02-25	WEDNESDAY	61	58	69	69	62	66	59	68	58
2026-02-26	THURSDAY	66	62	65	55	63	59	59	61	57
2026-02-27	FRIDAY	57	57	65	64	69	55	69	66	58

Table 6. Relative Humidity (%) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — March 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-03-03	TUESDAY	56	55	61	66	68	58	56	57	63
2026-03-05	THURSDAY	59	62	58	65	60	57	57	68	58
2026-03-06	FRIDAY	64	69	69	65	59	69	70	69	69
2026-03-09	MONDAY	65	59	67	59	59	57	57	68	66
2026-03-10	TUESDAY	67	68	60	62	64	70	56	68	66
2026-03-11	WEDNESDAY	62	55	65	62	69	66	58	58	64
2026-03-12	THURSDAY	70	55	62	68	58	64	70	59	70
2026-03-13	FRIDAY	65	59	56	56	67	66	57	66	57
2026-03-16	MONDAY	69	66	66	69	56	59	56	57	67
2026-03-17	TUESDAY	65	66	57	64	70	61	58	55	60
2026-03-18	WEDNESDAY	68	57	59	66	69	59	60	66	62
2026-03-20	FRIDAY	56	60	69	55	70	64	55	57	56
2026-03-23	MONDAY	59	65	65	67	56	56	58	59	58
2026-03-24	TUESDAY	60	67	59	55	70	63	70	64	70
2026-03-26	THURSDAY	57	66	69	64	58	67	64	64	61
2026-03-27	FRIDAY	60	68	70	56	58	68	63	59	58
2026-03-30	MONDAY	66	68	70	64	58	64	65	64	55

Table 7. Relative Humidity (%) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — April 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-04-01	WEDNESDAY	68	66	67	56	57	70	55	67	63
2026-04-02	THURSDAY	63	61	58	55	64	69	59	66	58
2026-04-06	MONDAY	68	64	59	65	61	66	69	66	64
2026-04-07	TUESDAY	59	62	57	70	60	56	65	63	70
2026-04-08	WEDNESDAY	63	67	57	55	68	60	70	70	55
2026-04-09	THURSDAY	63	56	57	68	65	58	57	56	57
2026-04-10	FRIDAY	56	58	68	67	65	67	55	61	59
2026-04-13	MONDAY	59	64	65	64	55	67	70	57	66
2026-04-15	WEDNESDAY	67	65	68	57	58	62	70	67	68
2026-04-16	THURSDAY	61	70	66	58	64	68	62	69	66
2026-04-17	FRIDAY	55	61	69	60	65	68	58	55	65
2026-04-20	MONDAY	61	68	58	58	58	63	62	64	56
2026-04-21	TUESDAY	60	65	64	68	60	59	57	69	58
2026-04-22	WEDNESDAY	57	67	63	67	70	59	68	56	63
2026-04-23	THURSDAY	56	58	69	65	64	65	57	69	66
2026-04-24	FRIDAY	61	70	57	60	56	67	59	64	60
2026-04-27	MONDAY	68	68	67	57	55	57	65	59	67
2026-04-28	TUESDAY	60	58	55	62	56	62	61	59	65
2026-04-29	WEDNESDAY	60	66	60	68	63	57	63	60	66
2026-04-30	THURSDAY	56	60	62	68	62	65	56	55	62

Table 8. Relative Humidity (%) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — June 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-06-01	MONDAY	65	67	68	68	70	60	58	69	69
2026-06-02	TUESDAY	60	65	58	61	61	61	69	59	59
2026-06-03	WEDNESDAY	69	58	62	60	64	63	64	68	55
2026-06-04	THURSDAY	61	64	69	61	69	62	56	67	67
2026-06-05	FRIDAY	57	65	62	59	65	56	68	63	63
2026-06-08	MONDAY	57	64	69	55	57	56	57	62	63
2026-06-09	TUESDAY	66	61	68	59	58	56	64	59	64
2026-06-10	WEDNESDAY	64	57	61	57	63	58	58	60	56
2026-06-11	THURSDAY	57	63	59	66	59	65	66	65	68
2026-06-12	FRIDAY	66	55	62	66	67	62	55	67	61
2026-06-15	MONDAY	64	57	61	56	60	63	68	55	62
2026-06-16	TUESDAY	56	58	57	58	55	61	60	63	60
2026-06-17	WEDNESDAY	68	63	61	66	58	68	68	68	66
2026-06-18	THURSDAY	63	64	66	66	63	67	61	65	68
2026-06-19	FRIDAY	56	67	67	67	55	57	60	58	61
2026-06-22	MONDAY	60	70	65	68	66	55	55	70	58
2026-06-23	TUESDAY	56	70	66	59	58	58	70	61	62
2026-06-24	WEDNESDAY	67	58	65	66	67	60	63	67	62
2026-06-25	THURSDAY	59	70	55	60	59	62	65	66	60
2026-06-29	MONDAY	68	64	66	69	63	69	69	59	59
2026-06-30	TUESDAY	62	60	67	55	68	64	55	55	59

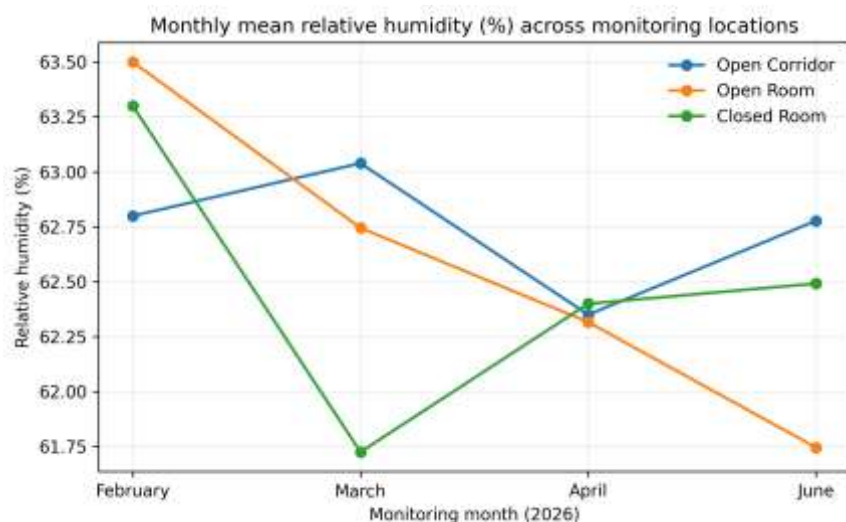


Figure 2. Monthly mean relative humidity across the three monitoring locations.

4.4 Atmospheric pressure and altitude

Atmospheric pressure remained within a relatively narrow range, approximately 949.1–965.5 hPa across the study. Differences among the three locations were generally small. Because the sites were located within the same college campus, this result is expected and confirms that pressure did not exhibit the pronounced spatial differentiation seen in the gas-resistance channel. Pressure-derived altitude similarly remained close to 510 m, with the project report giving overall means of 510.22 m for the Open Corridor, 510.33 m for the Open Room and 510.16 m for the Closed Room. These small variations reflect the mathematical sensitivity of altitude estimation to pressure rather than meaningful geographical differences among the rooms.

The atmospheric-pressure observations are presented in Tables 9–12; the corresponding pressure-derived altitude values are provided in Tables 13–16 as contextual data.

Table 9. Atmospheric Pressure (hPa) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — February 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-02-02	MONDAY	962.7	961.7	963.2	950.7	949.7	951.2	951.6	950.6	952.1
2026-02-03	TUESDAY	959.9	958.9	960.4	959.8	958.8	960.3	955.7	954.7	956.2
2026-02-04	WEDNESDAY	958.4	957.4	958.9	956	955	956.5	950.4	949.4	950.9
2026-02-05	THURSDAY	951.2	950.2	951.7	961.5	960.5	962	963.4	962.4	963.9
2026-02-06	FRIDAY	958.2	957.2	958.7	955.7	954.7	956.2	956.2	955.2	956.7
2026-02-09	MONDAY	964.4	963.4	964.9	955.2	954.2	955.7	953	952	953.5
2026-02-10	TUESDAY	954.2	953.2	954.7	961.3	960.3	961.8	961.6	960.6	962.1
2026-02-11	WEDNESDAY	954.7	953.7	955.2	957.1	956.1	957.6	959.7	958.7	960.2

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-02-12	THURSDAY	964.5	963.5	965	950.8	949.8	951.3	964.7	963.7	965.2
2026-02-13	FRIDAY	961.1	960.1	961.6	957.8	956.8	958.3	952.2	951.2	952.7
2026-02-16	MONDAY	961.4	960.4	961.9	964.6	963.6	965.1	956.2	955.2	956.7
2026-02-17	TUESDAY	957.1	956.1	957.6	956.9	955.9	957.4	959.1	958.1	959.6
2026-02-18	WEDNESDAY	952.8	951.8	953.3	957.3	956.3	957.8	961.6	960.6	962.1
2026-02-19	THURSDAY	955.1	954.1	955.6	951.5	950.5	952	955.7	954.7	956.2
2026-02-20	FRIDAY	955.6	954.6	956.1	951.5	950.5	952	961.4	960.4	961.9
2026-02-23	MONDAY	964.5	963.5	965	962.5	961.5	963	954.4	953.4	954.9
2026-02-24	TUESDAY	951.7	950.7	952.2	959.2	958.2	959.7	960.1	959.1	960.6
2026-02-25	WEDNESDAY	956	955	956.5	953.3	952.3	953.8	961.1	960.1	961.6
2026-02-26	THURSDAY	952	951	952.5	961.6	960.6	962.1	955	954	955.5
2026-02-27	FRIDAY	963.6	962.6	964.1	959.9	958.9	960.4	951	950	951.5

Table 10. Atmospheric Pressure (hPa) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — March 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-03-03	TUESDAY	955.9	954.9	956.4	957.7	956.7	958.2	952.4	951.4	952.9
2026-03-05	THURSDAY	960.9	959.9	961.4	955.1	954.1	955.6	963.8	962.8	964.3
2026-03-06	FRIDAY	957.6	956.6	958.1	964.6	963.6	965.1	952.7	951.7	953.2
2026-03-09	MONDAY	957.9	956.9	958.4	952.9	951.9	953.4	965	964	965.5
2026-03-10	TUESDAY	961.5	960.5	962	956.7	955.7	957.2	960.8	959.8	961.3
2026-03-11	WEDNESDAY	951.2	950.2	951.7	951.4	950.4	951.9	963.1	962.1	963.6
2026-03-12	THURSDAY	950.9	949.9	951.4	958.2	957.2	958.7	954.3	953.3	954.8
2026-03-13	FRIDAY	959.4	958.4	959.9	963.1	962.1	963.6	952.8	951.8	953.3

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-03-16	MONDAY	959.1	958.1	959.6	959.1	958.1	959.6	964.7	963.7	965.2
2026-03-17	TUESDAY	951.3	950.3	951.8	956.7	955.7	957.2	954.2	953.2	954.7
2026-03-18	WEDNESDAY	957.9	956.9	958.4	958.3	957.3	958.8	960.5	959.5	961
2026-03-20	FRIDAY	956.8	955.8	957.3	959.3	958.3	959.8	950.6	949.6	951.1
2026-03-23	MONDAY	963.4	962.4	963.9	953	952	953.5	962.4	961.4	962.9
2026-03-24	TUESDAY	958.8	957.8	959.3	962	961	962.5	962.4	961.4	962.9
2026-03-26	THURSDAY	950.6	949.6	951.1	960.8	959.8	961.3	964.6	963.6	965.1
2026-03-27	FRIDAY	964.7	963.7	965.2	959.6	958.6	960.1	958.4	957.4	958.9
2026-03-30	MONDAY	964.8	963.8	965.3	952.4	951.4	952.9	954	953	954.5

Table 11. Atmospheric Pressure (hPa) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — April 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-04-01	WEDNESDAY	959.7	958.7	960.2	951	950	951.5	954.6	953.6	955.1
2026-04-02	THURSDAY	955.2	954.2	955.7	950.1	949.1	950.6	963.1	962.1	963.6
2026-04-06	MONDAY	958.3	957.3	958.8	957	956	957.5	954.2	953.2	954.7
2026-04-07	TUESDAY	950.1	949.1	950.6	952.5	951.5	953	964.2	963.2	964.7
2026-04-08	WEDNESDAY	962.2	961.2	962.7	964.7	963.7	965.2	960	959	960.5
2026-04-09	THURSDAY	958.5	957.5	959	951.2	950.2	951.7	960.3	959.3	960.8
2026-04-10	FRIDAY	964.6	963.6	965.1	953.6	952.6	954.1	962.8	961.8	963.3
2026-04-13	MONDAY	962.2	961.2	962.7	951.6	950.6	952.1	956.3	955.3	956.8
2026-04-15	WEDNESDAY	960.2	959.2	960.7	959.6	958.6	960.1	951.1	950.1	951.6
2026-04-16	THURSDAY	955.1	954.1	955.6	950.4	949.4	950.9	960.3	959.3	960.8
2026-04-17	FRIDAY	956.5	955.5	957	952.6	951.6	953.1	962.2	961.2	962.7

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-04-20	MONDAY	960.8	959.8	961.3	961.5	960.5	962	958.5	957.5	959
2026-04-21	TUESDAY	959	958	959.5	960.7	959.7	961.2	953.9	952.9	954.4
2026-04-22	WEDNESDAY	963.2	962.2	963.7	962.4	961.4	962.9	951.4	950.4	951.9
2026-04-23	THURSDAY	961.4	960.4	961.9	957.4	956.4	957.9	963	962	963.5
2026-04-24	FRIDAY	951.4	950.4	951.9	960	959	960.5	956.4	955.4	956.9
2026-04-27	MONDAY	954.3	953.3	954.8	964.3	963.3	964.8	964.8	963.8	965.3
2026-04-28	TUESDAY	961.1	960.1	961.6	960.5	959.5	961	957.7	956.7	958.2
2026-04-29	WEDNESDAY	950.8	949.8	951.3	950.4	949.4	950.9	961.7	960.7	962.2
2026-04-30	THURSDAY	951.8	950.8	952.3	950.5	949.5	951	957.6	956.6	958.1

Table 12. Atmospheric Pressure (hPa) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — June 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-06-01	MONDAY	959.1	958.1	959.6	950.7	949.7	951.2	959.5	958.5	960
2026-06-02	TUESDAY	959.8	958.8	960.3	962.9	961.9	963.4	964.6	963.6	965.1
2026-06-03	WEDNESDAY	955.4	954.4	955.9	961.3	960.3	961.8	960.1	959.1	960.6
2026-06-04	THURSDAY	959.1	958.1	959.6	961.2	960.2	961.7	954.3	953.3	954.8
2026-06-05	FRIDAY	958.3	957.3	958.8	952.3	951.3	952.8	955.7	954.7	956.2
2026-06-08	MONDAY	954.5	953.5	955	951.8	950.8	952.3	953.8	952.8	954.3
2026-06-09	TUESDAY	961.2	960.2	961.7	964.2	963.2	964.7	961.2	960.2	961.7
2026-06-10	WEDNESDAY	953.5	952.5	954	954.4	953.4	954.9	953.8	952.8	954.3
2026-06-11	THURSDAY	952.6	951.6	953.1	954.2	953.2	954.7	958.5	957.5	959
2026-06-12	FRIDAY	951.4	950.4	951.9	961.6	960.6	962.1	963.4	962.4	963.9
2026-06-15	MONDAY	963.2	962.2	963.7	958.6	957.6	959.1	952.4	951.4	952.9

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
2026-06-16	TUESDAY	952.7	951.7	953.2	955.8	954.8	956.3	959	958	959.5
2026-06-17	WEDNESDAY	963.2	962.2	963.7	961.5	960.5	962	961.6	960.6	962.1
2026-06-18	THURSDAY	958.3	957.3	958.8	956.4	955.4	956.9	955.6	954.6	956.1
2026-06-19	FRIDAY	955.6	954.6	956.1	950.8	949.8	951.3	953.4	952.4	953.9
2026-06-22	MONDAY	955.1	954.1	955.6	962	961	962.5	956.9	955.9	957.4
2026-06-23	TUESDAY	958.1	957.1	958.6	959.3	958.3	959.8	963.6	962.6	964.1
2026-06-24	WEDNESDAY	960.1	959.1	960.6	950.5	949.5	951	957.4	956.4	957.9
2026-06-25	THURSDAY	952.9	951.9	953.4	954.2	953.2	954.7	964.4	963.4	964.9
2026-06-29	MONDAY	961.2	960.2	961.7	963	962	963.5	961.1	960.1	961.6
2026-06-30	TUESDAY	956.6	955.6	957.1	957.2	956.2	957.7	952.3	951.3	952.8

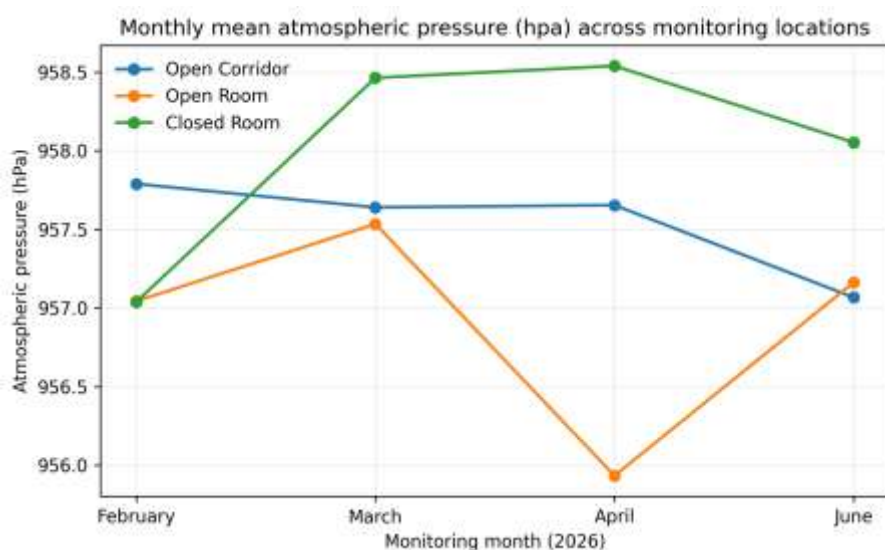


Figure 4. Monthly mean atmospheric pressure across the three monitoring locations.

Table 13. Altitude (m) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — February 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-02-02	MONDAY	508.1	508.6	507.8	506.9	507.4	506.6	507.7	508.2	507.4
2026-	TUESDAY	512.4	512.9	512.1	510.8	511.3	510.5	511.6	512.1	511.3

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
02-03										
2026-02-04	WEDNESDAY	509.6	510.1	509.3	508.8	509.3	508.5	507	507.5	506.7
2026-02-05	THURSDAY	513.9	514.4	513.6	511.4	511.9	511.1	514.5	515	514.2
2026-02-06	FRIDAY	512.5	513	512.2	512.7	513.2	512.4	510.4	510.9	510.1
2026-02-09	MONDAY	506.1	506.6	505.8	512.8	513.3	512.5	514.4	514.9	514.1
2026-02-10	TUESDAY	507.6	508.1	507.3	509.5	510	509.2	514.2	514.7	513.9
2026-02-11	WEDNESDAY	512.2	512.7	511.9	510.8	511.3	510.5	511.9	512.4	511.6
2026-02-12	THURSDAY	508.4	508.9	508.1	505.5	506	505.2	511	511.5	510.7
2026-02-13	FRIDAY	511.1	511.6	510.8	507.3	507.8	507	505.5	506	505.2
2026-02-16	MONDAY	511.3	511.8	511	508.2	508.7	507.9	506.6	507.1	506.3
2026-02-17	TUESDAY	509.8	510.3	509.5	514.1	514.6	513.8	514.7	515.2	514.4
2026-02-18	WEDNESDAY	508.2	508.7	507.9	515	515.5	514.7	505.7	506.2	505.4
2026-02-19	THURSDAY	514.7	515.2	514.4	513.5	514	513.2	514.1	514.6	513.8
2026-02-20	FRIDAY	507.9	508.4	507.6	509.3	509.8	509	512.2	512.7	511.9
2026-02-23	MONDAY	506.4	506.9	506.1	514.1	514.6	513.8	505.9	506.4	505.6
2026-02-24	TUESDAY	515	515.5	514.7	508.3	508.8	508	511.7	512.2	511.4
2026-02-25	WEDNESDAY	508.6	509.1	508.3	511.9	512.4	511.6	509.2	509.7	508.9
2026-02-26	THURSDAY	513.7	514.2	513.4	507.3	507.8	507	505.5	506	505.2
2026-02-27	FRIDAY	509.9	510.4	509.6	514.1	514.6	513.8	506.1	506.6	505.8
2026-03-03	TUESDAY									

Table 14. Altitude (m) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — March 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-03-03	TUESDAY	505.5	506	505.2	507.2	507.7	506.9	505.5	506	505.2
2026-03-05	THURSDAY	508.5	509	508.2	508.1	508.6	507.8	513.3	513.8	513
2026-03-06	FRIDAY	505.6	506.1	505.3	508.2	508.7	507.9	511.6	512.1	511.3
2026-03-09	MONDAY	512.4	512.9	512.1	512.7	513.2	512.4	514.5	515	514.2
2026-03-10	TUESDAY	509.4	509.9	509.1	512.5	513	512.2	514	514.5	513.7
2026-03-11	WEDNESDAY	508.9	509.4	508.6	513.3	513.8	513	511.4	511.9	511.1
2026-03-12	THURSDAY	511.2	511.7	510.9	513.3	513.8	513	506.4	506.9	506.1
2026-03-13	FRIDAY	512.3	512.8	512	505.2	505.7	504.9	510.7	511.2	510.4
2026-03-16	MONDAY	510.7	511.2	510.4	506.4	506.9	506.1	507.7	508.2	507.4
2026-03-17	TUESDAY	509.5	510	509.2	507.6	508.1	507.3	508.1	508.6	507.8
2026-03-18	WEDNESDAY	512.2	512.7	511.9	505.3	505.8	505	512.1	512.6	511.8
2026-03-20	FRIDAY	509.1	509.6	508.8	510.7	511.2	510.4	514.2	514.7	513.9
2026-03-23	MONDAY	506.5	507	506.2	512.5	513	512.2	510.5	511	510.2
2026-03-24	TUESDAY	512.2	512.7	511.9	510.8	511.3	510.5	508.4	508.9	508.1
2026-03-26	THURSDAY	506.5	507	506.2	514.3	514.8	514	507.2	507.7	506.9
2026-03-27	FRIDAY	514.6	515.1	514.3	510.3	510.8	510	507.7	508.2	507.4
2026-03-30	MONDAY	509.5	510	509.2	509.7	510.2	509.4	509.5	510	509.2

Table 15. Altitude (m) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — April 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-04-01	WEDNESDAY	514.8	515.3	514.5	508.4	508.9	508.1	511.7	512.2	511.4
2026-04-02	THURSDAY	507.5	508	507.2	507.2	507.7	506.9	514.6	515.1	514.3
2026-04-06	MONDAY	505.2	505.7	504.9	514.8	515.3	514.5	508.2	508.7	507.9
2026-04-07	TUESDAY	505.5	506	505.2	512.9	513.4	512.6	510.5	511	510.2
2026-04-08	WEDNESDAY	510.3	510.8	510	507.7	508.2	507.4	511.2	511.7	510.9
2026-04-09	THURSDAY	511.9	512.4	511.6	512	512.5	511.7	507.3	507.8	507
2026-04-10	FRIDAY	510	510.5	509.7	506.6	507.1	506.3	506.8	507.3	506.5
2026-04-13	MONDAY	508.3	508.8	508	507	507.5	506.7	509.3	509.8	509
2026-04-15	WEDNESDAY	514.8	515.3	514.5	510.4	510.9	510.1	512.9	513.4	512.6
2026-04-16	THURSDAY	508.5	509	508.2	508.4	508.9	508.1	510.6	511.1	510.3
2026-04-17	FRIDAY	511.4	511.9	511.1	507.4	507.9	507.1	508	508.5	507.7
2026-04-20	MONDAY	505.4	505.9	505.1	512.4	512.9	512.1	506.7	507.2	506.4
2026-04-21	TUESDAY	510.3	510.8	510	508.5	509	508.2	505.3	505.8	505
2026-04-22	WEDNESDAY	511.3	511.8	511	512.1	512.6	511.8	511.8	512.3	511.5
2026-04-23	THURSDAY	513.9	514.4	513.6	513.2	513.7	512.9	510.8	511.3	510.5
2026-04-24	FRIDAY	505.9	506.4	505.6	505.8	506.3	505.5	514.9	515.4	514.6
2026-04-27	MONDAY	509	509.5	508.7	512.6	513.1	512.3	514.8	515.3	514.5
2026-04-28	TUESDAY	508.1	508.6	507.8	505.7	506.2	505.4	508.1	508.6	507.8
2026-04-29	WEDNESDAY	510.1	510.6	509.8	512.7	513.2	512.4	510.2	510.7	509.9
2026-04-30	THURSDAY	510.7	511.2	510.4	514.6	515.1	514.3	507.3	507.8	507

Table 16. Altitude (m) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — June 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-06-01	MONDAY	511.6	512.1	511.3	510.3	510.8	510	505.5	506	505.2
2026-06-02	TUESDAY	514.8	515.3	514.5	512	512.5	511.7	514.6	515.1	514.3
2026-06-03	WEDNESDAY	510.4	510.9	510.1	507	507.5	506.7	512.1	512.6	511.8
2026-06-04	THURSDAY	510.5	511	510.2	505.5	506	505.2	513	513.5	512.7
2026-06-05	FRIDAY	512.9	513.4	512.6	512.1	512.6	511.8	510.1	510.6	509.8
2026-06-08	MONDAY	512.9	513.4	512.6	508.9	509.4	508.6	506.8	507.3	506.5
2026-06-09	TUESDAY	508	508.5	507.7	508.7	509.2	508.4	507.2	507.7	506.9
2026-06-10	WEDNESDAY	511.7	512.2	511.4	510.5	511	510.2	511.2	511.7	510.9
2026-06-11	THURSDAY	510.5	511	510.2	511.4	511.9	511.1	510.8	511.3	510.5
2026-06-12	FRIDAY	510	510.5	509.7	509.7	510.2	509.4	512.3	512.8	512
2026-06-15	MONDAY	511.4	511.9	511.1	505.4	505.9	505.1	507.1	507.6	506.8
2026-06-16	TUESDAY	511.1	511.6	510.8	507.3	507.8	507	513.3	513.8	513
2026-06-17	WEDNESDAY	507.8	508.3	507.5	509.8	510.3	509.5	514	514.5	513.7
2026-06-18	THURSDAY	508.7	509.2	508.4	513.5	514	513.2	510.2	510.7	509.9
2026-06-19	FRIDAY	507.6	508.1	507.3	511.8	512.3	511.5	506.2	506.7	505.9
2026-06-22	MONDAY	512.5	513	512.2	512	512.5	511.7	509.6	510.1	509.3
2026-06-23	TUESDAY	512.6	513.1	512.3	507.5	508	507.2	511.8	512.3	511.5
2026-06-24	WEDNESDAY	505.1	505.6	504.8	514.4	514.9	514.1	513.7	514.2	513.4
2026-06-25	THURSDAY	513.6	514.1	513.3	513.5	514	513.2	507.7	508.2	507.4
2026-06-29	MONDAY	509.6	510.1	509.3	514.2	514.7	513.9	507.3	507.8	507
2026-06-30	TUESDAY	513.8	514.3	513.5	514.5	515	514.2	509.1	509.6	508.8

4.5 BME680 gas resistance and VOC-related response

The BME680 gas-resistance channel showed the most pronounced and persistent spatial differentiation in the dataset. Across February, March, April and June, the general hierarchy remained Open Corridor > Open Room > Closed Room, with typical ranges of approximately 66–75 k Ω , 56–65 k Ω and 45–55 k Ω , respectively. The consistency of this gradient across multiple months and observation times is environmentally significant because it parallels the degree of enclosure and expected efficiency of natural dilution. The Open Corridor, continuously exposed to outdoor air, exhibited the highest resistance; the naturally ventilated room occupied an intermediate position; and the Closed Room showed the lowest resistance. Under comparable BME680 operating conditions, lower MOX resistance is consistent with stronger interaction of the sensing surface with reducing gases and VOC-related mixtures.

The interpretation must remain qualitative. The BME680 does not identify whether the response arose from ethanol, cleaning-product vapours, human-emitted compounds, building materials or other reducing gases. University studies using analytical VOC methods show that densely occupied educational buildings contain complex mixtures whose composition changes with occupancy, season, room function, human activities and ventilation [9,10]. Recent experimental evaluations further demonstrate that different MOX sensors respond differently to individual VOCs and can be influenced by humidity and temperature [11–16]. Consequently, the present gas-resistance data are best understood as a reproducible relative environmental signal rather than as a direct measure of total or individual VOC concentration.

Ventilation modifies the indoor gaseous environment through dilution and removal. In an open or well-ventilated setting, VOC-related compounds emitted indoors are more readily mixed with outdoor air and dispersed. In a more enclosed room, the same emission processes can produce longer residence times and greater accumulation, although adsorption to surfaces, chemical reactions and source intermittency also influence the resulting mixture. The persistent decrease in BME680 gas resistance with increasing enclosure is therefore physically consistent with reduced dispersion of reducing VOC-related gases, but the sensor alone cannot establish the identity or concentration of the responsible compounds.

The MOX sensing mechanism provides a further reason for caution. At the heated metal-oxide surface, adsorbed oxygen species participate in reactions with surrounding gases, altering charge-carrier density and electrical resistance. Reducing compounds can therefore produce resistance changes, but different VOCs generate different sensitivities and response kinetics. Water vapour competes for surface sites and may modify sensor response, while temperature and heater history affect adsorption–reaction processes [11–16]. The BME680 output is consequently an integrated response to a chemically complex atmosphere rather than a selective analytical measurement. For this reason, the present study deliberately avoids converting the observed 45–75 k Ω resistance range into ppm or ppb VOC values. Such conversion would require compound-specific or mixture-specific calibration, preferably against reference analytical instrumentation such as gas chromatography or a validated photoionization-based method. Instead, the repeated location-dependent resistance pattern is used as evidence of relative gaseous-environment variability.

The simultaneous stability of relative humidity across locations provides useful context but does not eliminate MOX cross-sensitivity. Because humidity values were broadly similar among the three sites, the persistent spatial resistance gradient is less readily explained by gross RH differences alone. Nevertheless, without controlled calibration and reference VOC measurements, the contribution of individual environmental covariates cannot be separated quantitatively. The appropriate conclusion is therefore that ventilation and enclosure were associated with a reproducible VOC-related MOX response, not that a specific VOC burden was measured directly. The BME680 gas-resistance observations, central to the VOC-related ventilation–enclosure interpretation, are presented in Tables 17–20.

Table 17. Gas Resistance (kΩ) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — February 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-02-02	MONDAY	68.3	72	70.5	58.6	55.7	61.6	49.4	54.8	46.2
2026-02-03	TUESDAY	73.2	72.5	71.7	61.8	60.1	62.9	50.5	45	47.9
2026-02-04	WEDNESDAY	73	71.7	74.9	62.8	57.2	63	49.6	53.9	50.8
2026-02-05	THURSDAY	71.9	72.1	65.6	59.4	62.1	57.3	52.4	49.7	47.6
2026-02-06	FRIDAY	67.7	69.9	68.9	62.5	63.5	64.5	54	50.8	52
2026-02-09	MONDAY	66.8	70.2	71.5	60.1	58.4	63.5	53.5	51	46.2
2026-02-10	TUESDAY	65.9	72.2	69.9	59.9	58.3	59.9	48.2	47.5	54.3
2026-02-11	WEDNESDAY	72.4	67.8	70.9	58.5	59.5	58.1	45.9	47.2	51.9
2026-02-12	THURSDAY	73.2	69	65.7	56	55.1	57.8	48.6	48	52.1
2026-02-13	FRIDAY	71.6	66.6	66.7	63.6	64.9	58.1	46.2	52.6	51.1
2026-02-16	MONDAY	74.3	69.4	72	59.1	56.9	58.6	53.1	50.5	49.5
2026-02-17	TUESDAY	66.9	71	72.5	64.3	57.9	62.1	50.5	50.5	45.9
2026-02-18	WEDNESDAY	73.6	69.1	68.2	58.5	60.5	60.4	53.2	47.8	48
2026-02-19	THURSDAY	73.5	73.6	68.8	59.1	61.5	56.5	46.3	54.7	48.3
2026-02-20	FRIDAY	70.7	72.9	66.7	61.9	64	55.5	51.3	54.2	55
2026-02-23	MONDAY	72.9	65.1	70.4	62.5	58.4	56.2	46.3	50.4	54.7
2026-02-24	TUESDAY	69.5	71.7	72.4	61.5	56.2	55.5	51.7	49.7	51.2
2026-02-25	WEDNESDAY	65.9	67.1	71.4	56	61.9	60.4	53.3	51.2	54.4
2026-02-26	THURSDAY	65.2	67.7	66.3	64.9	60.4	63	53.3	50.5	50.9
2026-02-27	FRIDAY	71.1	65.7	67.8	55.6	59.8	59	49.5	47.2	51.2
2026-03-03	TUESDAY									

Table 18. Gas Resistance (k Ω) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — March 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-03-03	TUESDAY	68	67.1	66.4	57.8	61.8	59.9	49.4	49.2	51.1
2026-03-05	THURSDAY	66.5	67	71	60.1	56.1	60.1	47.4	50.9	50.2
2026-03-06	FRIDAY	65.4	68.7	67.9	55.7	59.4	58	51.8	53.8	51.4
2026-03-09	MONDAY	66.5	66.8	71.9	58	62.9	60.1	45.2	48.1	54.5
2026-03-10	TUESDAY	73.2	73	66.4	64	56.9	61.8	51.8	47.4	49.4
2026-03-11	WEDNESDAY	74.3	73.4	71.5	64.3	59.1	59	45.8	46.6	49.5
2026-03-12	THURSDAY	72.2	67.9	65	57.4	56.2	57.4	49.5	45.1	45.8
2026-03-13	FRIDAY	68.5	68.4	71.4	57.5	55.2	62.9	54.5	50.4	52.9
2026-03-16	MONDAY	69.4	65.8	66.4	55.7	62.8	58.7	48.6	53	51.8
2026-03-17	TUESDAY	70.5	67.9	68	56.2	63.5	59.5	50	48.9	50.6
2026-03-18	WEDNESDAY	74.7	71.4	69.5	61.1	55.9	58.1	46.2	47	46.4
2026-03-20	FRIDAY	69.2	69.6	68.4	61.4	58	57.4	54.5	52.7	47.6
2026-03-23	MONDAY	66.6	74.9	72.4	55.4	62.1	63	48.9	52.9	48.4
2026-03-24	TUESDAY	73.2	67.4	70.7	64.7	62.8	62.8	53.2	48.7	51.7
2026-03-26	THURSDAY	71.6	72.5	67.1	64	58.9	58.5	51.9	49.9	49.8
2026-03-27	FRIDAY	69.8	67	74.6	58.3	59.7	61.8	51.2	50.9	47.4
2026-03-30	MONDAY	72.6	73	73.3	58.7	57.2	64.6	47.6	48.6	47.4

Table 19. Gas Resistance (k Ω) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — April 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-04-01	WEDNESDAY	69.5	74.2	68.8	55.3	59.1	62.7	53.2	52.5	50.8
2026-04-02	THURSDAY	65.3	71.6	71.1	61.7	60.4	60.3	46.8	50.4	50.3
2026-04-06	MONDAY	67	67.3	70.7	58.1	55.5	63.6	47.6	50.1	50
2026-04-07	TUESDAY	72.1	65.1	70.1	60.2	63.4	55.7	54.7	51.4	49.9
2026-04-08	WEDNESDAY	68.7	69.1	70.7	56.1	56	56.5	45.1	50.5	45.1
2026-04-09	THURSDAY	71.8	67.8	70.4	63.9	64.2	57.3	49.1	48.8	49.8
2026-04-10	FRIDAY	67.3	65.8	71.1	62.6	56.4	64.9	52.5	52.1	49
2026-04-13	MONDAY	71	72	69.8	58.3	61.2	63	47.5	47.5	51.3
2026-04-15	WEDNESDAY	66.1	66	67.2	61.6	58.6	61.5	50.4	52.9	48.6
2026-04-16	THURSDAY	69.8	69.4	72	64.2	55.9	63.3	48.9	52.7	50.9
2026-04-17	FRIDAY	70.9	68.9	72	64.6	57.3	59.1	51.5	51.8	46.6
2026-04-20	MONDAY	72.4	71.5	67.5	62.8	63.2	58.7	47.7	50.4	46.7
2026-04-21	TUESDAY	67.9	67.7	73.6	62.8	63.1	63.1	52.8	47.4	53.1
2026-04-22	WEDNESDAY	71.9	73.8	69.5	60.8	57.7	59.1	53.7	46.3	53.7
2026-04-23	THURSDAY	65.2	74.3	66.6	60.5	56.3	63.5	53.5	53	49
2026-04-24	FRIDAY	66.3	67.3	71.8	61.3	62.3	62.6	53.7	53.8	45.9
2026-04-27	MONDAY	65.8	70.4	71.2	55.1	57.2	64.2	53.6	50.7	48.7
2026-04-28	TUESDAY	72.1	72	66.6	55.9	59.3	59.5	48.9	51.3	53.3
2026-04-29	WEDNESDAY	67.6	66	70.7	57.6	64.8	61.3	46.3	52.8	47.7
2026-04-30	THURSDAY	73	74.8	74.5	57.5	64.2	58.2	45.5	48.6	54.2

Table 20. Gas Resistance (kΩ) in Open Corridor, Open Room and Closed Room at 10:00 AM, 1:00 PM and 4:00 PM — June 2026.

Date	Day	Open Corridor	Open Corridor	Open Corridor	Open Room	Open Room	Open Room	Closed Room	Closed Room	Closed Room
Date	Day	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-06-01	MONDAY	74.8	74.2	72.6	61.9	56.7	63.2	51.6	54.6	46.3
2026-06-02	TUESDAY	72.6	70.6	70.8	61.2	57.9	58.5	49.1	52	52.5
2026-06-03	WEDNESDAY	72.4	70.6	67.4	56.5	55.6	62.8	50.2	45.3	46.5
2026-06-04	THURSDAY	66.8	71.8	66.9	64.1	62	61.5	49.2	52.9	51.9
2026-06-05	FRIDAY	74.6	70.2	72.9	62.7	61.3	63.4	46.3	50.8	47.6
2026-06-08	MONDAY	68.8	73.2	65.3	62	55.7	64.3	49.1	49.5	49
2026-06-09	TUESDAY	74.1	73.5	66.4	55.1	61	60.4	51.8	54.1	53
2026-06-10	WEDNESDAY	68.2	69.5	71.2	57	60.8	64.5	53.5	54.3	54.9
2026-06-11	THURSDAY	73.9	67	72.3	63.8	59.6	58.6	46.7	48.1	52.9
2026-06-12	FRIDAY	73.5	73.1	71.1	63.9	60.9	63.6	54.1	50.5	50.4
2026-06-15	MONDAY	69.5	74.9	73.7	64.2	60.2	59.1	45.4	50.7	46.6
2026-06-16	TUESDAY	69.8	66.3	71	60.2	64.1	61.8	52.2	48.4	49.5
2026-06-17	WEDNESDAY	65.1	72.4	65.1	56.3	59.8	57.3	53.7	52	49.3
2026-06-18	THURSDAY	72.7	69	66.4	62.5	59.1	62.8	48.6	46.5	51.5
2026-06-19	FRIDAY	71.1	70.2	72.1	63.2	59.7	61	50.1	52.9	53
2026-06-22	MONDAY	68.5	73.9	67.7	62	57.6	57.9	47.6	48.8	52.9
2026-06-23	TUESDAY	71.2	69.9	74.9	64.2	61.8	61.6	52.4	53.7	47.1
2026-06-24	WEDNESDAY	68.6	73.6	66.9	59.6	56.2	60.2	52.5	46.3	50.3
2026-06-25	THURSDAY	66.8	70	75	63.1	62.2	63	50	47.1	52
2026-06-29	MONDAY	69.8	67.3	65.9	56.4	64.5	60.4	50.3	46.7	45.4
2026-06-30	TUESDAY	73.3	67.2	65.8	61	63	60.5	48.4	49.7	45.1

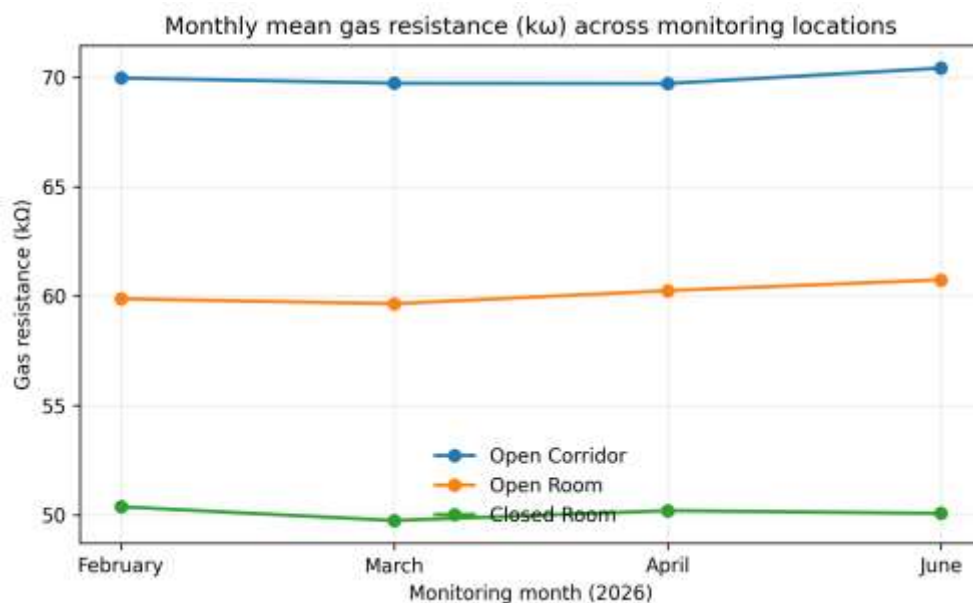


Figure 3. Monthly mean BME680 gas resistance across the three monitoring locations.

4.6 IoT-based Environmental Intelligence

The IoT design enabled the observed spatiotemporal patterns to be converted from isolated measurements into a persistent environmental record. BME680 outputs were acquired by the ESP32, transmitted through Wi-Fi and visualized on a cloud platform, permitting comparison across location, month and time of day. In the context of this study, Environmental Intelligence therefore denotes the transformation of multi-parameter sensor data into interpretable information about ventilation, enclosure and environmental variability. The strongest example is the persistent gas-resistance gradient, which becomes operationally meaningful only when viewed together with spatial setting, temporal context, temperature and humidity.

5. Conclusion

This study demonstrates that ventilation, enclosure and temporal variation produced distinct BME680 environmental-response patterns at Government Degree College, Rajendranagar. Temperature was influenced mainly by seasonal and diurnal changes, whereas relative humidity and atmospheric pressure showed comparatively limited spatial differentiation. The most consistent location-dependent response was observed for BME680 gas resistance, which followed the order Open Corridor > Open Room > Closed Room. The lower resistance in the more enclosed environment is consistent with a stronger MOX response to reducing gases and VOC-related mixtures under restricted air exchange.

Because the BME680 gas element is non-selective and affected by environmental and sensor-operating conditions, gas resistance should be interpreted as a semi-quantitative indicator of relative VOC-related variability rather than as a direct VOC or TVOC concentration. Integration of BME680 sensing with ESP32, Wi-Fi and cloud visualization provides a practical low-cost framework for spatiotemporal indoor environmental surveillance and ventilation awareness. The approach supports sustainable-campus management and provides enabling alignment with SDGs 3, 4, 9, 11, 12 and 13. Future studies should incorporate reference VOC measurements, occupancy information, air-exchange measurements and longer-term monitoring to strengthen quantitative interpretation.

Declarations

Ethics approval: The study involved environmental monitoring of campus spaces and did not involve clinical intervention or collection of personally identifiable human-subject data.

Consent for publication: All authors should confirm approval of the final manuscript before submission.

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Data availability: The four-month BME680 observations supporting this manuscript are reproduced in the manuscript tables. Additional raw electronic files may be made available by the corresponding author subject to institutional requirements.

Author contributions: Author contributions:

Sara Durga Bhavani: Conceptualization, literature review, research design and methodology, data analysis and interpretation, manuscript preparation, and writing.

Satyanarayana Maheshwaram: Technical support for data management, data analysis and interpretation.

Mekala Himabindu: Review, proofreading, and critical revision of the manuscript.

Ali Ahmed Siddiq: Cloud computing, and cloud-platform integration

Ansh Tyagi and A. Dhatri Sai Ram: Sensor assembly, Data collection and monitoring.

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