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Real-Time Environmental Intelligence for Indoor CO_2 Monitoring: An IoT-Based Sustainable Campus Study at Government Degree College, Rajendranagar, Telangana, India.

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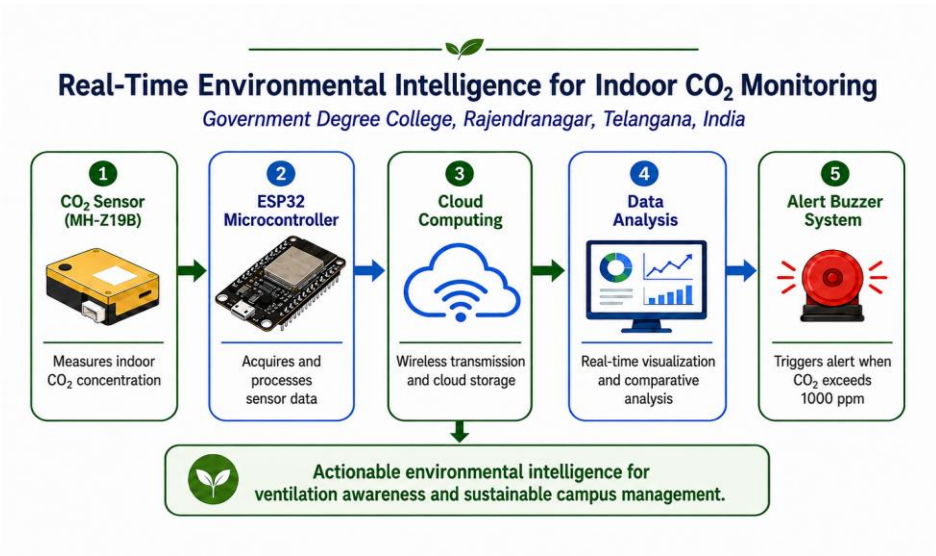
Highlights

- A low-cost MH-Z19B–ESP32 IoT system enabled real-time classroom CO_2 monitoring.
- Mean CO_2 followed Open Corridor (460.57) < Open Room (804.12) < Closed Room (1594.43 ppm).
- All 237 Closed Room observations exceeded the programmed 1000 ppm operational alert threshold.
- CO_2 peaked at 1:00 PM, with the strongest accumulation under restricted natural ventilation.
- The REIS framework links sensing, cloud visualization, alerts, ventilation action and campus SDGs.

Graphical Abstract



Abstract - Indoor carbon dioxide (CO_2) is widely used as a practical indicator of ventilation adequacy in occupied educational spaces, but periodic measurements may fail to capture strong spatial and time-of-day variability. This study developed and evaluated a low-cost Internet of Things (IoT)-based Real-Time Environmental Intelligence System (REIS) for comparative CO_2 monitoring at Government Degree College, Rajendranagar, Telangana, India. The system integrated an MH-Z19B (NK080X) non-dispersive infrared CO_2 sensor, ESP32 microcontroller, Wi-Fi transmission, cloud-based visualization and a locally programmed buzzer alert activated above 1000 ppm. Monitoring was conducted in an Open Corridor, an Open (Ventilated) Room and a Closed Room at 10:00 AM, 1:00 PM and 4:00 PM during February, March, April and June 2026. Across 711 observations, CO_2 ranged from 400–520 ppm in the Open Corridor, 700–900 ppm in the

Open Room and 1171–1800 ppm in the Closed Room. Overall means were 460.57 ± 35.12, 804.12 ± 60.08 and 1594.43 ± 131.82 ppm, respectively. The 1:00 PM period showed the highest mean concentration at all locations, most prominently in the Closed Room (1721.94 ppm). Every Closed Room observation exceeded the programmed 1000 ppm alert threshold, whereas none of the Open Corridor or Open Room observations did. The findings demonstrate that degree of enclosure and natural ventilation were the dominant determinants of measured CO_2 in the studied spaces. By combining real-time sensing, wireless data transmission, cloud visualization and a local threshold alert, the system converted passive monitoring into an actionable environmental-management pathway. The study supports campus-level contributions to SDGs 3, 4, 11, 12 and 13 while emphasizing that 1000 ppm is used here as an operational ventilation-management threshold, not a universal toxicological limit.

Keywords: Carbon dioxide; Indoor Air Quality; Internet of Things; Environmental Intelligence; MH-Z19B; ESP32; Smart campus; Sustainable Development Goals.

1. INTRODUCTION

Indoor environmental quality (IEQ) is an important component of healthy, resilient and sustainable educational infrastructure. Students and staff spend substantial periods in classrooms, laboratories, libraries and offices, where occupancy, enclosure, outdoor conditions and ventilation collectively influence indoor environmental conditions. Recent studies emphasize that ventilation, occupancy, building configuration and occupant activities should be considered together when assessing indoor air quality in educational facilities [1–2]. Carbon dioxide (CO_2) is particularly useful for such assessments because it is continuously generated by human respiration and responds rapidly to changes in occupancy and outdoor-air exchange.

Indoor CO_2, however, should not be interpreted as a complete indicator of indoor air quality because particulate matter, volatile organic compounds, bioaerosols and other pollutants may vary independently [3-4]. Occupant-generated CO_2 is therefore more appropriately used as an indicator of ventilation adequacy relative to occupancy. Consequently, values such as 1000 ppm should be regarded as practical ventilation-management indicators rather than universal toxicological limits [4].

Classrooms are particularly susceptible to CO_2 accumulation because of relatively high occupant densities and repeated periods of occupation. Studies conducted in educational buildings across different geographical regions continue to report elevated CO_2 concentrations where ventilation is inadequate [5–6]. Natural ventilation through doors and windows can substantially improve air exchange, although its effectiveness depends on opening configuration, cross-ventilation pathways, outdoor conditions and occupant behaviour [7–8].

The growing use of real-time CO_2 feedback has demonstrated its potential to help occupants recognize poorly ventilated conditions and support ventilation-related decisions [9–10]. Advances in low-cost sensing and Internet of Things (IoT) technologies have enabled continuous environmental monitoring using sensors, microcontrollers, wireless communication, cloud storage and visualization [11–12]. ESP32-based platforms are particularly suitable because they combine embedded processing with wireless connectivity, while recent open-source systems demonstrate the feasibility of integrating CO_2 sensors with ESP32 hardware and cloud services [13–14].

The present study applies these developments through a Real-Time Environmental Intelligence System (REIS) comprising MH-Z19B CO_2 sensing → ESP32 processing → cloud computing → data analysis and visualization → threshold evaluation → buzzer alert.

In alignment with the United Nations 2030 Agenda, this study assessed spatial, time-of-day and monthly CO_2 variation across three ventilation conditions at Government Degree College, Rajendranagar, while evaluating the 1000 ppm operational alert and the potential of REIS as a sustainable-campus decision-support system [15].

2. LITERATURE REVIEW

Current literature distinguishes between CO_2 as an occupant-generated ventilation tracer and CO_2 as a comprehensive indoor-air-quality metric. Persily [16] emphasized that indoor CO_2 concentrations should be interpreted in relation to occupancy, ventilation and outdoor concentration rather than through a universal concentration threshold. ASHRAE further clarifies that Standard 62.1 does not define a single indoor CO_2 concentration below which all aspects of indoor air quality are necessarily acceptable [17,18]. Accordingly, the present study treats 1000 ppm as an operational ventilation-management trigger rather than as a toxicological boundary.

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Classroom investigations consistently demonstrate the influence of ventilation strategy on indoor CO_2. Long-term monitoring in Australian classrooms showed inadequate ventilation in several educational spaces [6]. While measurements in Beijing schools demonstrated elevated CO_2 under natural ventilation and lower concentrations where fresh-air systems were used [19]. Investigations in London schools likewise identified occupancy and room characteristics as important determinants of classroom environmental quality [20,21].

Natural ventilation can substantially reduce indoor CO_2 when sufficient air exchange is achieved. Studies examining door and window opening strategies demonstrated rapid reductions in classroom CO_2 through effective cross-ventilation [17,20].

Continuous CO_2 monitoring provides greater insight than isolated measurements because it captures concentration build-up, peak and decay periods. Recent studies have used continuous monitoring to estimate ventilation performance, assess renovation outcomes and support school-level decision-making [22,23]. Real-time visual or acoustic feedback has also been shown to encourage ventilation behaviour and reduce classroom CO_2 concentrations [24].

Low-cost sensing has increasingly evolved from stand-alone devices toward networked IoT monitoring systems. Othman et al. [12] demonstrated the feasibility of integrating low-cost CO_2 and environmental sensors within a connected monitoring platform. Pineda-Tobón et al. [25] further demonstrated an open-source ESP32-based CO_2 monitoring device with cloud integration, while recent systems extend this concept through calibration, forecasting, multipollutant sensing and automated analytics [26].

The existing literature therefore establishes the importance of classroom ventilation, continuous CO_2 monitoring and low-cost IoT technologies.

3. RESEARCH METHODOLOGY

3.1 Study area and design

The study was conducted at Government Degree College (GDC), Rajendranagar, Rangareddy District, Telangana, India. A comparative repeated-observation design was used. Three representative monitoring locations were selected to create a practical gradient of natural ventilation and enclosure: (1) an Open Corridor with continuous exposure to outdoor air, (2) an Open (Ventilated) Room with openings that permit natural air exchange, and (3) a Closed Room with restricted natural ventilation. The locations were monitored at the same three observation times—10:00 AM, 1:00 PM and 4:00 PM—during February, March, April and June 2026. The resulting dataset contained 79 monitored dates and 711 CO_2 observations (79 dates × 3 times × 3 locations).

3.2 CO_2 sensing principle and hardware

CO_2 was measured with an MH-Z19B (NK080X) non-dispersive infrared (NDIR) sensor. NDIR sensing exploits the selective absorption of infrared radiation by CO_2 molecules within an optical path. The detector response is processed electronically and converted to concentration in parts per million. NDIR technology is widely used in indoor monitoring because it offers direct CO_2 measurement, compact size and compatibility with embedded systems [27]. The sensor was interfaced with an ESP32 microcontroller, which acted as the central unit for acquisition, threshold comparison and wireless communication. Manufacturer-recommended initialization and stabilization procedures were followed before systematic monitoring [28].

3.3 IoT Design and cloud visualization

The developed REIS followed the data pathway: Environmental conditions → MH-Z19B sensor → ESP32 → Wi-Fi network → cloud platform → real-time dashboard → data storage → comparative analysis. The ESP32 acquired serial sensor data, processed each reading and transmitted the information over the available Wi-Fi network. The cloud platform provided a centralized record and allowed remote visualization of environmental changes [27–29].

3.4 Threshold-based alert and ventilation response

A buzzer was incorporated as a local alert. The ESP32 continuously compared the measured CO_2 concentration with a programmed operational threshold of 1000 ppm. When the threshold was exceeded, the buzzer was activated to indicate that attention to ventilation was required; when the concentration returned below the programmed condition, the alert logic deactivated the buzzer. The 1000 ppm value was adopted as a pragmatic management threshold because it is commonly used in schools and building guidance, but it is not presented as a universal health limit [30].

3.5 System testing and quality assurance

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Before deployment, the complete system was checked for stable power delivery, sensor communication, Wi-Fi connectivity, cloud transmission, dashboard visualization and buzzer operation. Sensor initialization, stabilization and baseline behaviour were verified. The monitoring device was then exposed to changing indoor conditions to confirm that changes in CO_2 were captured and transmitted consistently. These procedures constitute operational validation rather than laboratory-grade metrological certification; this distinction is retained in the interpretation of the results.

3.6 Data handling and descriptive interpretation

Data were organized by monitoring date, month, time of day and location. Interpretation was based on the observed concentration ranges, repeated location-wise patterns, time-of-day trends, monthly variation and the occurrence of values above the programmed 1000 ppm operational alert threshold. The purpose was to present and interpret the measured CO_2 variation directly in relation to enclosure, natural ventilation and the functioning of the IoT-based REIS.

4. RESULTS AND DISCUSSION

4.1 Monthly variation

CO_2 concentrations (ppm) in February 2026: Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM are shown in Table-1. February provided the widest Closed Room range because several morning values were comparatively lower (minimum 1171 ppm), while repeated 1:00 PM values reached 1800 ppm. In contrast, the Open Corridor never exceeded 520 ppm and the Open Room remained at or below 900 ppm.

Table-1: CO_2 concentrations (ppm) in February 2026; Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM.

Date	Day	OC	OC	OC	OR	OR	OR	CR	CR	CR
		10AM	1 PM	4 PM	10AM	1 PM	4 PM	10AM	1 PM	4 PM
2026-02-02	Monday	494	514	479	770	790	755	1302	1682	1412
2026-02-03	Tuesday	428	448	413	735	755	720	1408	1800	1518
2026-02-04	Wednesday	413	433	400	873	893	858	1489	1800	1599
2026-02-05	Thursday	514	520	499	839	859	824	1302	1642	1412
2026-02-06	Friday	475	495	460	808	828	793	1308	1628	1418
2026-02-09	Monday	403	423	400	843	863	828	1280	1670	1390
2026-02-10	Tuesday	491	511	476	866	886	851	1179	1799	1289
2026-02-11	Wednesday	469	489	454	807	827	792	1256	1676	1366
2026-02-12	Thursday	457	477	442	850	870	835	1171	1691	1281
2026-02-13	Friday	503	520	488	701	721	700	1494	1800	1604
2026-02-16	Monday	419	439	404	755	775	740	1395	1800	1505
2026-02-17	Tuesday	443	463	428	726	746	711	1223	1643	1333
2026-02-18	Wednesday	448	468	433	724	744	709	1491	1711	1601
2026-02-19	Thursday	508	520	493	788	808	773	1554	1774	1664
2026-02-20	Friday	433	453	418	711	731	700	1586	1800	1696
2026-02-23	Monday	470	490	455	775	795	760	1560	1780	1670
2026-02-24	Tuesday	479	499	464	792	812	777	1547	1767	1657
2026-02-25	Wednesday	424	444	409	880	900	865	1417	1637	1527
2026-02-26	Thursday	405	425	400	869	889	854	1458	1678	1568
2026-02-27	Friday	498	518	483	774	794	759	1420	1640	1530

CO_2 concentrations (ppm) in March 2026: Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM are shown in Table-2. March reproduced the same hierarchy. Closed Room values ranged from 1423 to 1800 ppm, whereas Open Room values remained 700–894 ppm and the Open Corridor remained 400–520 ppm. The persistence of this ordering across 18 monitored dates suggests that the result is structural rather than episodic. Similar field studies in school

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buildings have reported elevated CO_2 when ventilation is insufficient and lower concentrations when mechanical or more effective natural ventilation is available [6–12].

Table-2: CO_2 concentrations (ppm) in March 2026; Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM

Date	Day	OC	OC	OC	OR	OR	OR	CR	CR	CR
		10AM	1 PM	4 PM	10AM	1 PM	4 PM	10AM	1 PM	4 PM
2026-03-02	Monday	481	501	466	793	813	778	1441	1661	1551
2026-03-03	Tuesday	447	467	432	790	810	775	1453	1673	1563
2026-03-05	Thursday	519	520	504	874	894	859	1565	1785	1675
2026-03-06	Friday	409	429	400	855	875	840	1562	1782	1672
2026-03-09	Monday	448	468	433	769	789	754	1563	1783	1673
2026-03-10	Tuesday	488	508	473	842	862	827	1456	1676	1566
2026-03-11	Wednesday	487	507	472	783	803	768	1596	1800	1706
2026-03-12	Thursday	499	519	484	714	734	700	1458	1678	1568
2026-03-13	Friday	505	520	490	708	728	700	1480	1700	1590
2026-03-16	Monday	440	460	425	754	774	739	1567	1787	1677
2026-03-17	Tuesday	463	483	448	801	821	786	1564	1784	1674
2026-03-18	Wednesday	458	478	443	736	756	721	1467	1687	1577
2026-03-20	Friday	471	491	456	837	857	822	1467	1687	1577
2026-03-23	Monday	446	466	431	756	776	741	1435	1655	1545
2026-03-24	Tuesday	465	485	450	826	846	811	1423	1643	1533
2026-03-26	Thursday	419	439	404	860	880	845	1440	1660	1550
2026-03-27	Friday	501	520	486	874	894	859	1508	1728	1618
2026-03-30	Monday	467	487	452	764	784	749	1541	1761	1651

CO_2 concentrations (ppm) in April 2026: Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM are shown in Table-3. April showed the highest Open Room monthly mean (819.93 ppm) but it remained well below the Closed Room mean of 1616.55 ppm. Multiple Closed Room observations reached 1800 ppm at 1:00 PM. The Open Corridor remained low despite seasonal warming, reinforcing the importance of air exchange.

Table-3: CO_2 concentrations (ppm) in April 2026; Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM.

Date	Day	OC	OC	OC	OR	OR	OR	CR	CR	CR
		10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-04-01	Wednesday	492	512	477	729	749	714	1574	1794	1684
2026-04-02	Thursday	513	520	498	837	857	822	1592	1800	1702
2026-04-06	Monday	400	420	400	884	900	869	1584	1800	1694
2026-04-07	Tuesday	433	453	418	828	848	813	1595	1800	1705
2026-04-08	Wednesday	422	442	407	829	849	814	1427	1647	1537
2026-04-09	Thursday	511	520	496	860	880	845	1476	1696	1586
2026-04-10	Friday	507	520	492	863	883	848	1529	1749	1639
2026-04-13	Monday	469	489	454	899	900	884	1535	1755	1645
2026-04-15	Wednesday	441	461	426	825	845	810	1404	1624	1514
2026-04-16	Thursday	414	434	400	792	812	777	1478	1698	1588
2026-04-17	Friday	430	450	415	714	734	700	1461	1681	1571
2026-04-20	Monday	504	520	489	717	737	702	1594	1800	1704
2026-04-21	Tuesday	468	488	453	896	900	881	1432	1652	1542
2026-04-22	Wednesday	416	436	401	868	888	853	1521	1741	1631

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2026-04-23	Thursday	470	490	455	742	762	727	1467	1687	1577
2026-04-24	Friday	467	487	452	855	875	840	1508	1728	1618
2026-04-27	Monday	491	511	476	779	799	764	1502	1722	1612
2026-04-28	Tuesday	485	505	470	866	886	851	1495	1715	1605
2026-04-29	Wednesday	456	476	441	832	852	817	1515	1735	1625
2026-04-30	Thursday	415	435	400	763	783	748	1457	1677	1567

CO_2 concentrations (ppm) in June 2026: Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM are shown in Table-4. June monitoring again confirmed the same ordering after the April monitoring period. The Closed Room recorded 1800 ppm on several dates, while the Open Corridor never exceeded 520 ppm. The return of the same pattern after the interval between April and June strengthens the interpretation that enclosure and ventilation characteristics were persistent determinants of the measured CO_2 environment.

Table-4: CO_2 concentrations (ppm) in June 2026; Open Corridor (OC), Open Room (OR) and Closed Room (CR) at 10:00 AM,1:00 PM and 4:00 PM.

Date	Day	OC	OC	OC	OR	OR	OR	CR	CR	CR
		10 AM	1 PM	4 PM	10 AM	1 PM	4 PM	10 AM	1 PM	4 PM
2026-06-01	Monday	433	453	418	900	900	885	1600	1800	1710
2026-06-02	Tuesday	458	478	443	773	793	758	1508	1728	1618
2026-06-03	Wednesday	489	509	474	887	900	872	1600	1800	1710
2026-06-04	Thursday	471	491	456	869	889	854	1583	1800	1693
2026-06-05	Friday	462	482	447	739	759	724	1448	1668	1558
2026-06-08	Monday	407	427	400	891	900	876	1480	1700	1590
2026-06-09	Tuesday	407	427	400	712	732	700	1549	1769	1659
2026-06-10	Wednesday	461	481	446	828	848	813	1535	1755	1645
2026-06-11	Thursday	420	440	405	714	734	700	1530	1750	1640
2026-06-12	Friday	410	430	400	747	767	732	1417	1637	1527
2026-06-15	Monday	415	435	400	845	865	830	1463	1683	1573
2026-06-16	Tuesday	474	494	459	852	872	837	1410	1630	1520
2026-06-17	Wednesday	479	499	464	720	740	705	1507	1727	1617
2026-06-18	Thursday	484	504	469	849	869	834	1544	1764	1654
2026-06-19	Friday	466	486	451	780	800	765	1466	1686	1576
2026-06-22	Monday	450	470	435	733	753	718	1571	1791	1681
2026-06-23	Tuesday	482	502	467	776	796	761	1517	1737	1627
2026-06-24	Wednesday	440	460	425	892	900	877	1418	1638	1528
2026-06-25	Thursday	401	421	400	817	837	802	1559	1779	1669
2026-06-29	Monday	512	520	497	717	737	702	1462	1682	1572
2026-06-30	Tuesday	447	467	432	772	792	757	1440	1660	1550

The same location hierarchy persisted during February, March, April and June 2026. Monthly mean CO_2 concentrations during February, March, April and June 2026 are shown in Figure-1. Open Corridor values remained within 400–520 ppm throughout the study, and Open Room values remained within 700–900 ppm. Closed Room values were consistently much higher, ranging from 1171–1800 ppm. Although day-to-day and month-to-month fluctuations were evident, the fundamental pattern did not change: the most open environment showed the lowest CO_2, the ventilated room showed intermediate concentrations, and the closed environment showed the greatest accumulation. This consistency across four separate monitoring months strengthens the ventilation-related interpretation of the dataset.

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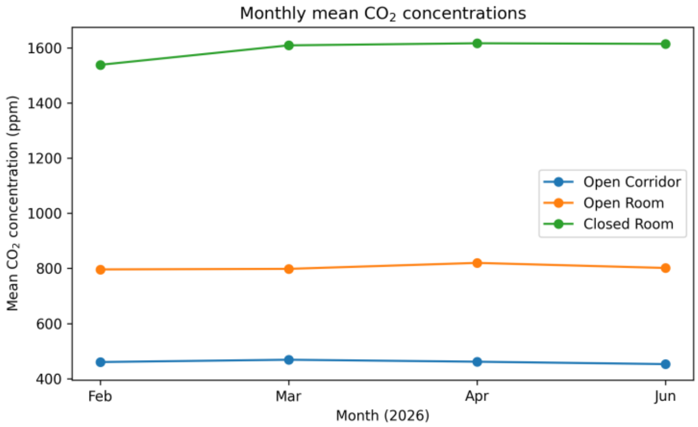
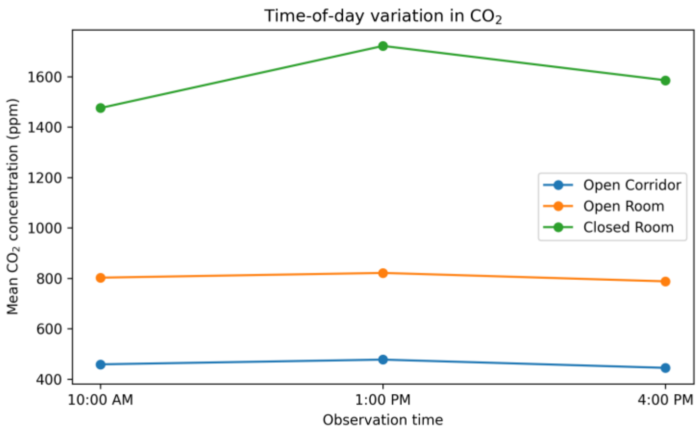
Figure-1: Monthly mean CO_2 concentrations during February, March, April and June 2026.



4.2 Time-of-day variation

Across the four monitored months, CO_2 generally increased from 10:00 AM toward 1:00 PM and declined by 4:00 PM. The pattern was most pronounced in the Closed Room, where 1:00 PM readings frequently approached or reached 1800 ppm. Mean time-of-day CO_2 variation at the three monitoring locations are shown in Figure-2. The Open Corridor remained comparatively low at all three observation times, while the Open Room showed intermediate values. The repeated midday maximum is consistent with progressive accumulation during occupied periods followed by later dilution; however, because synchronized occupancy counts were not recorded, the pattern should be interpreted as an observed temporal association rather than a direct quantitative estimate of occupancy effects.

Figure-2: Mean time-of-day CO_2 variation at the three monitoring locations.



4.3 Overall location-wise variation

CO_2 showed a pronounced and consistent spatial gradient across the three monitoring environments. Observed concentrations ranged from 400–520 ppm in the Open Corridor, 700–900 ppm in the Open Room and 1171–1800 ppm in the Closed Room. The Open Corridor remained close to outdoor conditions throughout the monitoring period, while the Open Room consistently occupied an intermediate range. The Closed Room showed the highest concentrations on every monitoring date and time point. This repeated ordering—Open Corridor < Open Room < Closed Room—demonstrates a clear association between degree of enclosure, natural air exchange and CO_2 accumulation in the monitored spaces. Overall descriptive statistics for CO_2 by monitoring location are shown in Table-5.

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Table-5: Overall descriptive statistics for CO_2 by monitoring location.

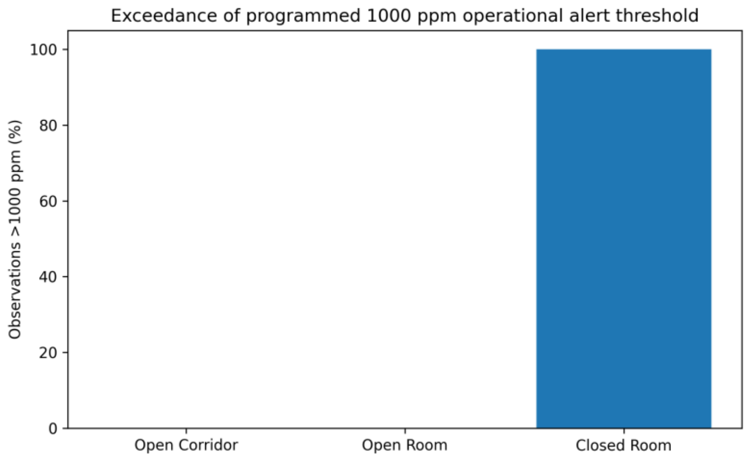
Location	n	Mean (ppm)	SD	Minimum	Maximum
Open Corridor	237	460.57	35.12	400	520
Open Room	237	804.12	60.08	700	900
Closed Room	237	1594.43	131.82	1171	1800

Note: n- No. of observations, SD- Standard Deviation

4.4 Operational threshold and real-time alert

All 237 Closed Room measurements exceeded the programmed 1000 ppm operational alert threshold (100% exceedance), as shown in Figure-3, whereas none of the Open Corridor or Open Room observations exceeded this value.

Figure-3: Percentage of observations above the programmed 1000 ppm operational alert threshold.



The present findings are consistent with previous school-based studies. Honan et al. [4] reported a median CO_2 concentration of 1487 ppm in naturally ventilated primary-school classrooms, while Sørensen and Kristensen [5] found that 70% of 75 Danish classrooms exceeded 1000 ppm for more than half of occupied time. Andamon et al. [6] reported classroom means above 2000 ppm in some Australian schools. A key contribution of this study is the within-campus comparison using a common monitoring protocol. Mean CO_2 concentrations of 461 ppm in the Open Corridor, 804 ppm in the Open Room and 1594 ppm in the Closed Room demonstrate a clear ventilation gradient.

4.5 From monitoring to Environmental Intelligence

The REIS converts measurement into a simple decision pathway. The sensor quantifies CO_2, the ESP32 processes and transmits the reading, the cloud dashboard makes the condition visible, and the buzzer converts a programmed threshold exceedance into an immediate local signal. This designed study is consistent with the broader evolution of low-cost IoT environmental systems [31-32]. The practical advantage is behavioural accessibility: occupants do not need to continuously interpret a ppm display; an alert can prompt inspection of doors/windows and consideration of ventilation action.

4.6 Sustainable Development Goal Alignment

The REIS supports SDG 3 through improved recognition of under-ventilated conditions, SDG 4 through healthier learning spaces [33], SDG 11 through scalable smart-building practices, SDG 12 through informed use of ventilation and resources [34], and SDG 13 through environmental literacy and climate-responsive campus management [35]. These linkages reflect the system's sustainability potential but do not directly quantify health, educational, energy or emission outcomes.

5. CONCLUSION

The present study demonstrates the effectiveness of a low-cost IoT-based Real-Time Environmental Intelligence System (REIS) for indoor CO_2 monitoring at Government Degree College, Rajendranagar. Across February, March, April and June 2026, CO_2 consistently followed the gradient Open Corridor < Open Room < Closed Room, with ranges of 400–520, 700–900 and 1171–

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1800 ppm and mean concentrations of 460.57, 804.12 and 1594.43 ppm, respectively, highlighting the influence of enclosure and natural ventilation.

CO_2 generally peaked at 1:00 PM, particularly in the Closed Room. All 237 Closed Room observations exceeded the programmed 1000 ppm operational threshold, while none of the Open Corridor or Open Room observations did, demonstrating its practical value as a ventilation-management trigger rather than a universal health limit.

Integration of the MH-Z19B CO_2 sensor, ESP32 microcontroller, cloud computing, data analysis and buzzer alert transformed monitoring into an actionable Environmental Intelligence framework. The scalable REIS approach can support healthier learning environments, evidence-based campus management and institutional contributions to SDGs 3, 4, 11, 12 and 13, positioning higher educational institutions as practical platforms for sustainable campus transformation.

Declarations

Ethics statement: The study involved environmental monitoring of campus spaces and did not collect personal, medical or identifiable participant data.

Funding: No specific external funding is received.

Conflict of interest: The authors declare no competing interests.

Data availability: The complete CO_2 observations used in this manuscript are presented in Tables 1-4. Additional details may be made available by the corresponding author subject to institutional requirements.

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
Konka Mahesh and Kappari Uma Renuka: Sensor assembly, Data collection and monitoring.

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REFERENCES

[1] Branco PTBS, Sousa SIV, Dudzińska MR, et al. A review of relevant parameters for assessing indoor air quality in educational facilities. Environmental Research. 2024;261:119713. doi:10.1016/j.envres.2024.119713.

[2] Grassie D, Milczewska K, Renneboog S, Scuderi F, Dimitroulopoulou S. Impact of Indoor Air Quality, Including Thermal Conditions, in Educational Buildings on Health, Wellbeing, and Performance: A Scoping Review. Environments. 2025;12(8):261. doi:10.3390/environments12080261.

[3] Sadrizadeh S, Yao R, Yuan F, et al. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. Journal of Building Engineering. 2022;57:104908. doi:10.1016/j.jobe.2022.104908.

[4] Honan D, Gallagher J, Garvey J, Littlewood J. Indoor Air Quality in Naturally Ventilated Primary Schools: A Systematic Review of the Assessment & Impacts of CO2 Levels. Buildings. 2024;14(12):4003. doi:10.3390/buildings14124003.

[5] Sørensen SB, Kristensen K. Low-cost sensor-based investigation of CO2 and volatile organic compounds in classrooms: Exploring dynamics, ventilation effects and perceived air quality relations. Building and Environment. 2024;254:111369. doi:10.1016/j.buildenv.2024.111369.

[6] Andamon MM, Rajagopalan P, Woo J. Evaluation of ventilation in Australian school classrooms using long-term indoor CO2 concentration measurements. Building and Environment. 2023;237:110313. doi:10.1016/j.buildenv.2023.110313.

[7] Zhang D, Ding E, Bluyssen PM. Guidance to assess ventilation performance of a classroom based on CO2 monitoring. Indoor and Built Environment. 2022. doi:10.1177/1420326X211058743.

[8] Gil-Baez M, Lizana J, Becerra Villanueva JA, Molina-Huelva M, Serrano-Jimenez A, Chacartegui R. Natural ventilation in classrooms for healthy schools in the COVID era in Mediterranean climate. Building and Environment. 2021;206:108345. doi:10.1016/j.buildenv.2021.108345.

[9] Zivelonghi A, Lai M. Mitigating aerosol infection risk in school buildings: the role of natural ventilation, volume, occupancy and CO2 monitoring. Building and Environment. 2021;204:108139. doi:10.1016/j.buildenv.2021.108139.

[10] Stabile L, Pacitto A, Mikszewski A, Morawska L, Buonanno G. Ventilation procedures to minimize the airborne transmission of viruses in classrooms. Building and Environment. 2021;202:108042. doi:10.1016/j.buildenv.2021.108042.

[11] Peixe J, Marques G. Low-cost IoT-enabled indoor air quality monitoring systems: A systematic review. Journal of Ambient Intelligence and Smart Environments. 2024;16(2):167-180. doi:10.3233/AIS-220577.

[12] Othman H, Azari R, Guimarães T. Low-Cost IoT-based Indoor Air Quality Monitoring. Technology|Architecture + Design. 2024;8(2):250-270. doi:10.1080/24751448.2024.2405403.

International Journal of Engineering Research & Technology (IJERT)
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[13] Chojer H, Branco PTBS, Martins FG, Sousa SIV. A novel low-cost sensors system for real-time multipollutant indoor air quality monitoring – Development and performance. Building and Environment. 2024;266:112055. doi:10.1016/j.buildenv.2024.112055.
[14] Yu Y, Gola M, Settimo G, Buffoli M, Capolongo S. Feasibility and Affordability of Low-Cost Air Sensors with Internet of Things for Indoor Air Quality Monitoring in Residential Buildings: Systematic Review. Atmosphere. 2024;15(10):1170. doi:10.3390/atmos15101170.
[15] Bakare MS, Abubaker K. IoT-based indoor environmental monitoring system using multi-parameter sensing and ESP32-WROOM integration. Discover Electronics. 2026;3:6. doi:10.1007/s44291-026-00157-3.
[16] Persily A. Development and application of an indoor carbon dioxide metric. Indoor Air. 2022;32(7):e13059. doi:10.1111/ina.13059.
[17] ASHRAE. Position Document on Indoor Carbon Dioxide. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2022.
[18] ASHRAE. Indoor Carbon Dioxide, Ventilation and Indoor Air Quality: Public Policy Brief. Updated June 2025. Atlanta: ASHRAE; 2025.
[19] Cai C, Sun Z, Weschler LB, Li T, Xu W, Zhang Y. Indoor air quality in schools in Beijing: Field tests, problems and recommendations. Building and Environment. 2021;205:108179. doi:10.1016/j.buildenv.2021.108179.
[20] Kumar P, Hama S, Abbass RA, Abhijith KV, Tiwari A, Grassie D, Mitsakou C. Environmental quality in sixty primary and secondary school classrooms in London. Journal of Building Engineering. 2024;91:109549. doi:10.1016/j.jobe.2024.109549.
[21] Kumar P, et al. The underpinning factors affecting the classroom air quality, thermal comfort and ventilation in 30 classrooms of primary schools in London. Environmental Research. 2023;236(Pt 2):116863. doi:10.1016/j.envres.2023.116863.
[22] Zapata-Lancaster MG, Ionas M, Toyinbo O, Smith TA. Carbon Dioxide Concentration Levels and Thermal Comfort in Primary School Classrooms: What Pupils and Teachers Do. Sustainability. 2023;15(6):4803. doi:10.3390/su15064803.
[23] Clinchard S, Haverinen-Shaughnessy U, Shaughnessy R. Assessing ventilation performance in schools using continuous CO2 monitoring: Insights from renovation projects. Building and Environment. 2025;269:112406. doi:10.1016/j.buildenv.2024.112406.
[24] Rawat N, Kumar P, Hama S, Williams N, Zivelonghi A. Improving classroom air quality and ventilation with IoT-driven acoustic and visual CO2 feedback system. Science of the Total Environment. 2025;980:179543. doi:10.1016/j.scitotenv.2025.179543.
[25] Pineda-Tobón DM, Espinosa-Bedoya A, Branch-Bedoya JW. Aquality32: A low-cost, open-source air quality monitoring device leveraging the ESP32 and google platform. HardwareX. 2024;20:e00607. doi:10.1016/j.ohx.2024.e00607.
[26] Vasile V, Catalina T, Dima A, Ion M. Pollution Levels in Indoor School Environment—Case Studies. Atmosphere. 2024;15(4):399. doi:10.3390/atmos15040399.
[27] Vijay N, Sarasamma J. A Critical Review on the Indoor Air Quality Status of Schools in India. Current World Environment. 2024;19(3):1061-1076. doi:10.12944/CWE.19.3.3.
[28] Espressif Systems. ESP32 Series Datasheet. Shanghai: Espressif Systems; 2025.
[29] Marquez-Zepeda MJ, Santos-Ruiz I, Pérez-Pérez EJ, Navarro-Díaz A, Delgado-Aguiñaga JA. Internet-of-Things-Based CO2 Monitoring and Forecasting System for Indoor Air Quality Management. Mathematical and Computational Applications. 2025;30(2):36. doi:10.3390/mca30020036.
[30] Subirana M, Sunyer J, Colom-Cadena A, Bordas A, Casabona J, Gascon M. Monitoring and assessment of CO2 and NO2 in schools within the Sentinel Schools Network of Catalonia during the COVID-19 era. Chemosphere. 2024;362:142575. doi:10.1016/j.chemosphere.2024.142575.
[31] Arigela R, Kannan S, Jejurkar P, Sethi V, Sinha K, Balasubramanian S. Assessment of classroom ventilation strategies and infection risk using spatiotemporal modelling of CO2 concentrations. Building and Environment. 2026;294:114393. doi:10.1016/j.buildenv.2026.114393.
[32] Ge B, Tieskens K, Vyas P, Botana Martinez MP, Yuan Y, Walsh KH, Main L, Bolton L, Yajima M, Fabian MP. Decision tools for schools using continuous indoor air quality monitors: a case study of CO2 in Boston Public Schools. The Lancet Regional Health – Americas. 2025;48:101148. doi:10.1016/j.lana.2025.101148.
[33] Rawat N, Kumar P. Interventions for improving indoor and outdoor air quality in and around schools. Science of the Total Environment. 2023;858(Pt 2):159813. doi:10.1016/j.scitotenv.2022.159813.
[34] Muelas A, Remacha P, Piña A, Tizné E, El-Kadmiri S, Ruiz A, Aranda D, Ballester J. Analysis of different ventilation strategies and CO2 distribution in a naturally ventilated classroom. Atmospheric Environment. 2022;283:119176. doi:10.1016/j.atmosenv.2022.119176.
[35] Mendell MJ, Chen W, Ranasinghe DR, Castorina R, Kumagai K. Carbon dioxide guidelines for indoor air quality: a review. Journal of Exposure Science & Environmental Epidemiology. 2024;34:555-569. doi:10.1038/s41370-024-00694-7.