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Indoor Air Quality Analysis and Improvement in Universities

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Abstract

Purpose: Students spend long hours studying and living in school environments, making indoor air quality (IAQ) in school buildings a critical factor directly affecting their health and learning performance. This study aimed to assess the current status of IAQ in school buildings and analyze the effects of per capita occupancy volume, ventilation methods, and spatial characteristics on IAQ to propose improvement strategies. Measurements of particulate matter (PM10, PM2.5), carbon dioxide (CO_2), and total volatile organic compounds (TVOCs) were conducted in six locations, including classrooms and public spaces. The measured levels were compared to IAQ maintenance and recommended standards. Results indicated that particulate matter and TVOCs were within recommended levels across all locations. However, CO_2 exceeded recommended standards in classrooms with smaller per capita occupancy volumes, especially in enclosed classrooms relying solely on mechanical ventilation. Conversely, spaces incorporating natural ventilation showed relatively lower CO_2 concentrations.

This study empirically analyzed various factors affecting IAQ in schools and provides practical recommendations for improvement, such as enhancing ventilation systems, utilizing air-purifying plants, and installing CO_2 sensors. These findings are expected to contribute to the establishment of effective IAQ management policies and the creation of healthier learning environments.

Keywords : Indoor AIr Quality, School building, Field Measurement, Carbon dioxide, Ventilation System
JEL Classification Code: I12, I21, Q53

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1. Background and Objectives of the Study

Modern humans spend more than 80% of their daily 24 hours indoors. Particularly, students spend most of their time studying and living inside homes and schools, making the management of indoor air quality (IAQ) in these environments crucial for minimizing exposure to air pollutants (Yang, 2009). Indoor air pollution refers to the contamination of air in various indoor spaces such as public buildings and vehicles, which can result from highly complex factors. IAQ is influenced by external factors such as space size, the number of occupants, and the presence or absence of ventilation systems, and the impact of harmful substances varies accordingly. IAQ is one of the factors that significantly affect the health and comfort of occupants. Indoor air pollution in schools, caused by multiple complex factors, can directly or indirectly impact the health of students and staff, leading to symptoms such as dizziness, headaches, and vertigo.

According to a study by Shendell et al. (2004), an increase of 1,000 ppm in carbon dioxide (CO_2) levels in classrooms was associated with a 10-20% rise in student absenteeism due to the aforementioned symptoms. Yang et al. (2009) reported that Koreans spend an average of 14.23 hours per day indoors at home, 6.80 hours in other indoor environments (e.g., workplaces, schools, and other facilities), 1.75 hours commuting, and 1.26 hours outdoors on weekdays. Maintaining clean indoor air is essential to ensure comfort during long periods spent indoors.

As concerns about particulate matter (PM) and its effects on health grow, wearing masks indoors has also become a point of interest. Masks designed to block particulate matter are categorized into "medical masks" and "industrial masks," each with different performance standards. According to a study on the filtering efficiency of masks for protecting public health, medical masks are evaluated based on the KF (Korean Filter) standard issued by the Ministry of Food and Drug Safety, assessing factors such as dust collection efficiency, face suction resistance, and leakage rates. However, their standards are less stringent compared to the 14 criteria used for industrial masks. Given these factors, improving indoor air quality through purification and ventilation is necessary in cases of indoor air degradation.

This study aims to assess the current status of IAQ in schools and propose effective improvement strategies by investigating prior studies with keywords such as "indoor air quality," "school indoor air," and "IAQ measurement."

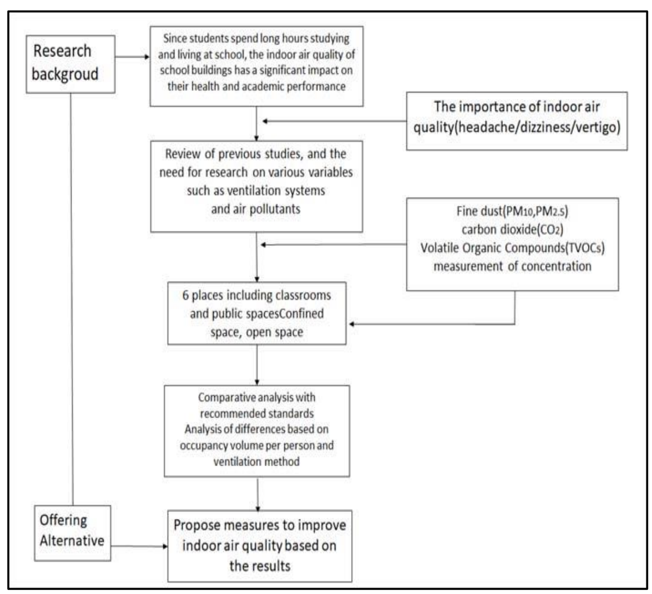
Previous studies have measured IAQ in schools but often focused on factors like external environments or building materials, as seen in studies such as "Characteristics of Indoor Air Quality in School Facilities in Island Areas" and "Measurement and Evaluation of Indoor Air Quality in School Buildings in the Changwon Area." Other studies compared IAQ across multiple schools.

Research such as "Measurement and Improvement Plans for IAQ in University Buildings by Usage" has also been conducted, but its limitations include a small sample size and a lack of detailed analysis across various conditions. While previous studies identified "sealing" as a cause of indoor air pollution, this study aims to measure IAQ under indoor conditions where air circulation occurs and compare the results with sealed spaces.

This study analyzes the differences in pollution levels in sealed versus ventilated spaces, as well as the effects of occupancy levels and per capita indoor volume on pollution levels. Key pollutants measured include particulate matter (PM2.5 and PM10), carbon dioxide (CO_2), and total volatile organic compounds (TVOCs). By selecting spaces within schools where students spend extended hours, this study seeks to measure pollutant concentrations and explore strategies to reduce these levels, ultimately creating a more comfortable indoor environment.

2. Research Methods

2.1. Research Flow



2.2. Selection of Measured Pollutants

In this study, PM10, PM2.5, CO_2, and TVOCs were selected as target pollutants among indoor air contaminants. PM10 and PM2.5 are particulate matter that is heavily influenced by human activity, as these particles are frequently introduced and emitted indoors. When their concentrations exceed acceptable levels, they can penetrate the lungs, reduce lung function, weaken the immune system, and cause various adverse health effects. Given the nature of indoor public spaces where many people are active, these pollutants were included in the study.

CO_2 is generated primarily through human respiration in indoor environments. High concentrations of CO_2 can lead to symptoms such as dizziness and drowsiness. It was selected for this study to evaluate conditions where CO_2 levels might continuously increase due to insufficient ventilation.

TVOCs are primarily emitted from the use of printers and copiers, pesticides and insect repellents, and dry cleaning products. Elevated concentrations of TVOCs can cause fatigue, headaches, and dizziness. As classrooms, libraries, and reading rooms—spaces frequently used by students—often involve the use of office equipment and periodic cleaning with chemicals, TVOCs were included as a target pollutant.

Table 1. Maintenance and Recommendation Standards(CLEAN AIR CONSERVATION ACT Korea)

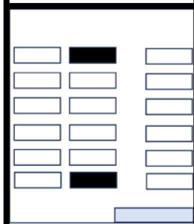
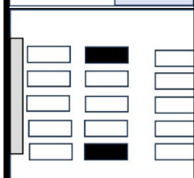
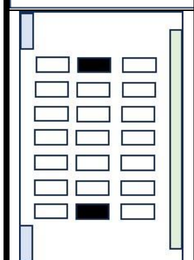
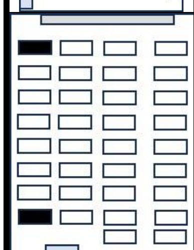
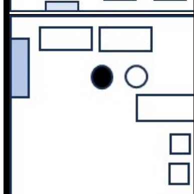
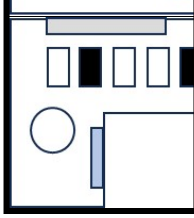
	Maintenance standards			Recommendation standards
Library, Classroom, Study Room, Lounge etc	PM_{10} (μg/m³)	$PM_{2.5}$ (μg/m³)	CO_2 (ppm)	TVOCs (μg/m³)
	≤ 100	≤ 50	≤ 1,000(1,500)	≤ 500

※ For libraries, movie theaters, private educational institutes, and business facilities for internet computer game services where natural ventilation is not possible and natural ventilation systems or mechanical ventilation systems are used, the carbon dioxide level must be maintained at 1,500 ppm or lower.

2.3. Measurement Locations

The concentrations of particulate matter (PM10, PM2.5), carbon dioxide (CO_2), and total volatile organic compounds (TVOCs) were measured in six indoor spaces within the school: locations A, B, C, D, E, and F. Locations A, B, and C were classrooms where students attend lectures, while locations D, E, and F were public spaces such as libraries or lounges

Table 2. Measurement location and overview

Floor plan	Measurement location	Measurement time	Number of people	Volume	Volume per person	Ventilation method
	A	5/27 14:00~17:00	40	275㎥	6.9㎥	Mechanical ventilation
	B	5/30 14:00~17:00	40	182㎥	4.6㎥	Mechanical ventilation
	C	5/31 09:30~12:00	45	318㎥	7.1㎥	Mechanical and Natural ventilation
	D	5/30 11:00~14:00	3~24	830㎥	277~34.6㎥	Mechanical ventilation
	E	5/31 9:30~12:00	20~30	2670㎥	133.5~89㎥	Mechanical ventilation
	F	5/31 13:00~15:00	20~30	1800㎥	90~60㎥	Mechanical ventilation

3. Measurement Results

3.1. Overview of Measurement Data

Measuring instrument A and **measuring instrument B** are identical devices. When placed in a classroom, **measuring instrument A** was positioned near the lectern at the front of the room, while **measuring instrument B** was placed at the back of the classroom. In public spaces, **measuring instrument A** was located closer to the entrance, and **measuring instrument B** was placed farther from the entrance.

Both instruments were installed in various locations to determine whether measurements showed excessively high or low values at specific positions. In the table, **measuring instrument A** is abbreviated as 'A,' and **measuring instrument B** is abbreviated as 'B.'

3.1.1. Measurement Location A

Table 3. location A Measurement Table

A									
population	**time**	PM10(μg/m³)		PM2.5(μg/m³)		TVOCs(μg/m³)		CO_2(ppm)	
		a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
40	14:00	7.8	10.8	3.5	4.5	566.0	242.0	410.0	1,784.0
	14:30	6.4	6.3	3.6	3.7	85.0	4.0	2,168.0	2,102.0
	15:00	5.4	6.4	3.1	3.7	174.0	45.0	2,377.0	2,254.0
	15:30	6.0	6.7	3.4	3.8	231.0	95.0	2,655.0	2,075.0
	16:00	5.6	7.9	3.1	3.4	226.0	69.0	2,534.0	2,220.0
	16:30	5.6	7.2	3.0	3.6	2,882.0	100.0	2,471.0	1,988.0
0	17:00	5.3	6.4	3.0	3.5	247.0	252.0	1,919.0	1,590.0

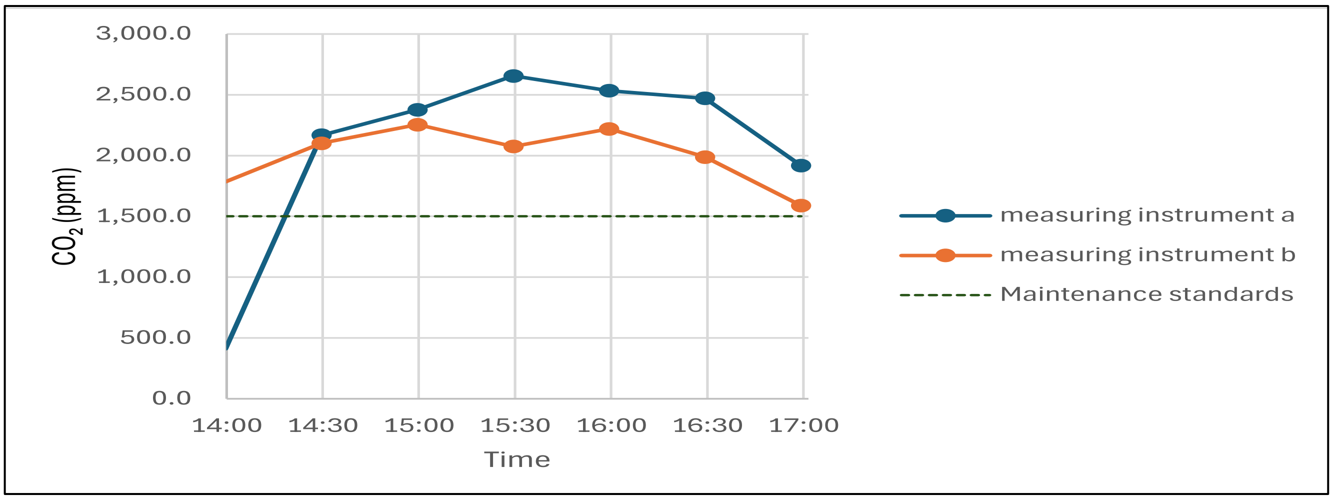


Figure 1: CO_2 Measurement Graph for Location A

Location A is an underground space with no windows or access for external air, relying solely on mechanical ventilation. According to the indoor air quality maintenance and recommended standards for multi-use facilities, the

concentrations of both types of particulate matter (PM10 and PM2.5) and TVOCs were below the threshold. However, the CO_2 concentration significantly exceeded the recommended standard of 1,500 ppm for most of the class duration.
At 14:00, immediately after the measuring instruments were turned on, **measuring instrument A** recorded a low CO_2 concentration of 410 ppm. In contrast, **measuring instrument B**, located in the same space, showed a value over four times higher. This suggests that **measuring instrument A** temporarily displayed a lower value due to its activation phase.
Additionally, **measuring instrument A** recorded a high TVOC concentration of 2,882 µg/m³ at around 16:30. However, **measuring instrument B** recorded much lower values at the same time, and its readings before and after this period were also low, indicating that the high value from **measuring instrument A** may have been caused by a temporary sensor error. The class ended at approximately 16:30, after which the CO_2 concentration gradually decreased, reflecting reduced occupancy.

3.1.2. Measurement Location B

Table 4. location B Measurement Table

B										
population	time	PM10(µg/m³)		PM2.5(µg/m³)		TVOCs(µg/m³)		CO_2(ppm)	
		a	b	a	b	a	b	a	b
40	14:00	10.3	9.0	5.4	5.4	247.0	245.0	500.0	1,458.0
	14:30	7.1	7.4	5.0	5.3	330.0	293.0	1,644.0	1,808.0
	15:00	7.7	7.1	5.2	5.8	328.0	293.0	1,877.0	2,085.0
	15:30	7.2	7.2	4.6	4.6	288.0	213.0	2,343.0	2,658.0
	16:00	8.0	7.4	4.5	4.3	214.0	121.0	2,933.0	3,155.0
	16:30	7.5	8.2	4.6	4.7	215.0	65.0	2,816.0	3,369.0
0	17:00	7.2	6.9	4.9	4.6	222.0	156.0	2,487.0	2,322.0

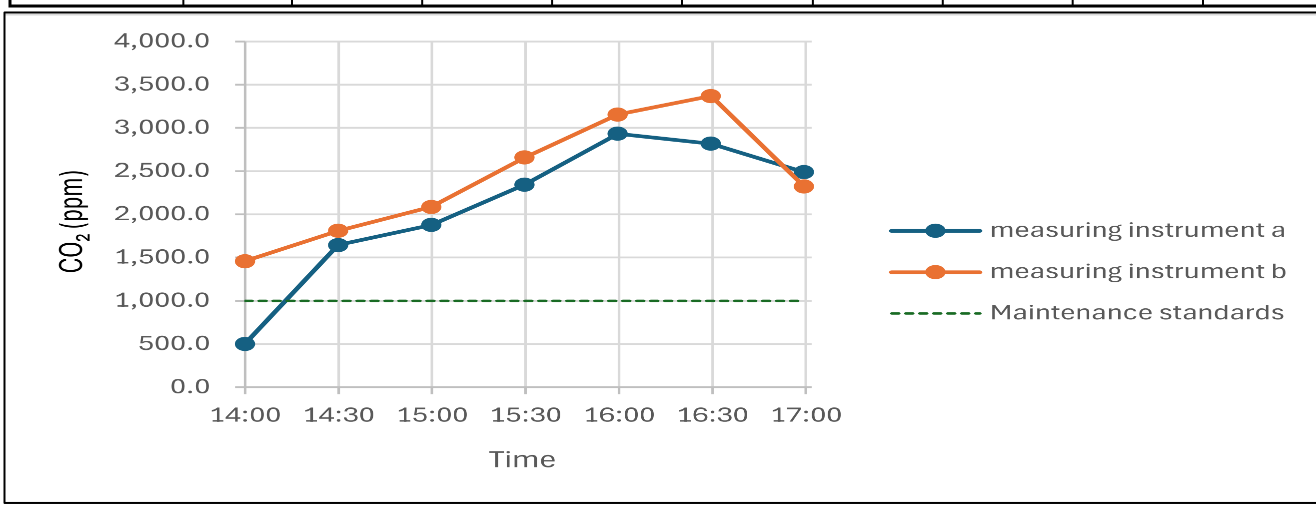


Figure 2: CO_2 Measurement Graph for Location B

Measurement Location B was smaller in size compared to other locations, resulting in the smallest per capita occupancy area. The class ended at approximately 16:30. Similar to Measurement Location A, the concentrations of both types of particulate matter (PM10 and PM2.5) and TVOCs remained below the recommended thresholds. However, the CO_2 concentration steadily increased after the start of measurements, eventually exceeding 3,000 ppm, the highest

value recorded among all measurements. This concentration gradually decreased after the class ended.
Although the TVOCs did not exceed the standard threshold and thus did not directly impact health, their levels increased for about 30 minutes after the class began and then gradually decreased. Interestingly, TVOC levels rose again immediately after the students left the room. This suggests that the students' movements influenced changes in TVOC concentrations.

3.1.3. Measurement Location C

Table 5. location C Measurement Table

C										
population	time	PM10(μg/m³)		PM2.5(μg/m³)		TVOCs(μg/m³)		CO_2(ppm)	
		a	b	a	b	a	b	a	b
14	9:30	7.9	9.3	4.9	5.5	125.0	158.0	629.0	706.0
45	10:00	7.7	10.1	5.0	5.4	272.0	192.0	719.0	701.0
	10:30	8.4	8.7	6.2	5.5	113.0	170.0	1,114.0	930.0
	11:00	7.9	6.8	6.0	5.6	208.0	161.0	1,385.0	1,363.0
	11:30	7.9	9.4	6.3	7.2	152.0	270.0	1,344.0	966.0
0	12:00	8.6	8.3	7.4	6.6	176.0	306.0	1,265.0	771.0

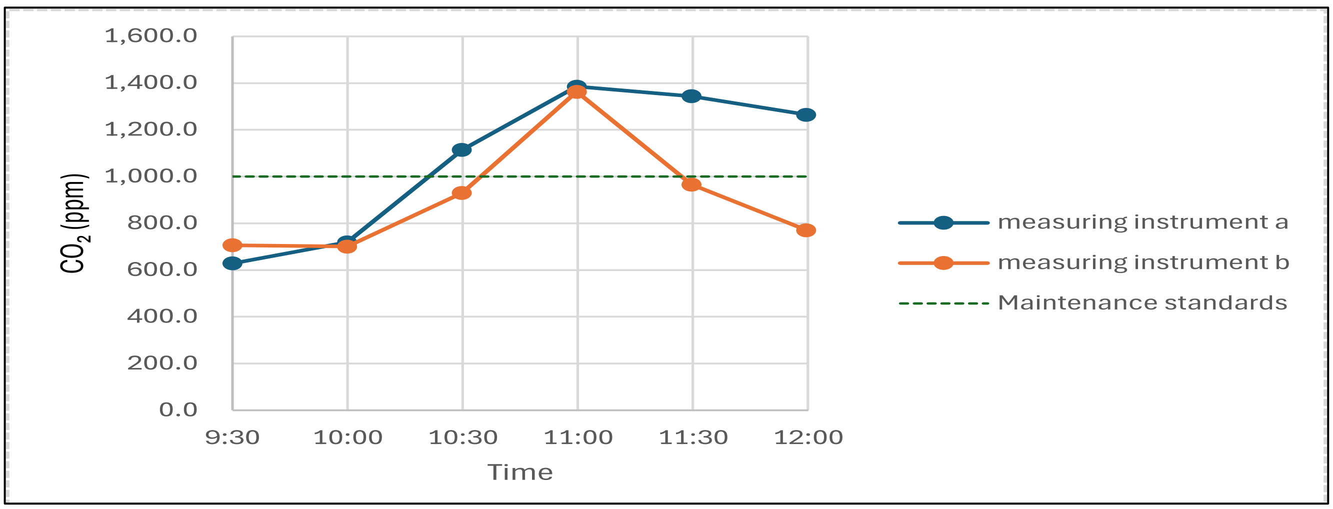


Figure 3: CO_2 Measurement Graph for Location C

Measurement Location C had all windows open, making it the most naturally ventilated location among those measured. Classes in this location started at approximately 10:00 and ended around 11:30. The concentrations of both types of particulate matter (PM10 and PM2.5) and TVOCs remained below the recommended thresholds, similar to the previous locations. However, TVOC levels increased after 11:30 when the class ended and students exited the room, as shown by the graph.

For carbon dioxide (CO_2), **measuring instrument A** recorded four instances of exceeding the threshold, while **measuring instrument B** recorded one instance. Although CO_2 levels were not consistently below the threshold, the overall concentrations were relatively low compared to other locations.

3.1.4. Measurement Location D

Table 6. location D Measurement Table

D									
population	**time**	PM10(μg/m³)		PM2.5(μg/m³)		TVOCs(μg/m³)		CO_2(ppm)	
		a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
7	11:00	3.7	4.1	2.4	2.0	187.0	275.0	914.0	774.0
2	11:30	2.4	4.1	1.9	2.2	308.0	338.0	770.0	704.0
5	12:00	4.4	2.3	2.4	1.8	332.0	288.0	709.0	787.0
15	12:30	4.3	2.6	2.2	1.8	327.0	276.0	758.0	807.0
22	13:00	5.1	3.7	2.9	2.0	333.0	288.0	854.0	913.0
26	13:30	4.8	4.3	2.7	2.0	331.0	283.0	876.0	954.0
24	14:00	3.2	4.7	1.8	2.5	283.0	316.0	994.0	1,062.0

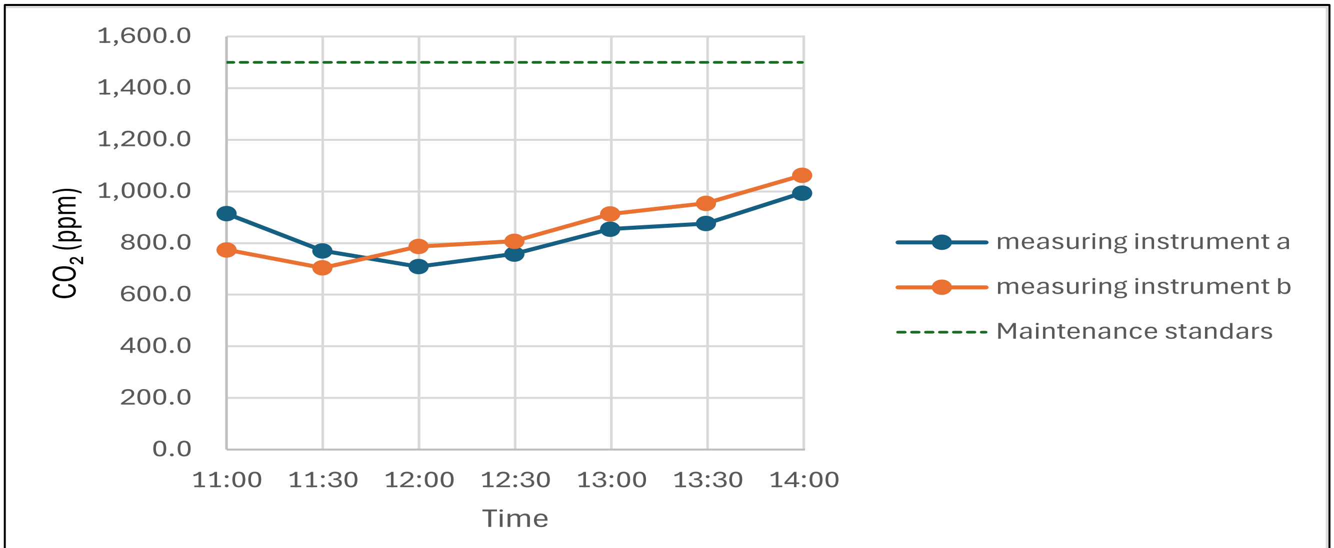


Figure 4: CO_2 Measurement Graph for Location D

Measurement Location D had windows, but they remained closed during the measurement period, allowing for natural ventilation only. Despite having a relatively small number of occupants compared to its volume, CO_2 levels gradually increased as the number of occupants grew. Some measurements exceeded the natural ventilation threshold of 1,000 ppm. It can be inferred that CO_2 levels would have exceeded the threshold during exam periods when the occupancy is typically higher.

3.1.6. Measurement Location E

Table 7. location E Measurement Table

E										
population	time	PM10(μg/m³)		PM2.5(μg/m³)		TVOCs(μg/m³)		CO_2(ppm)	
		a	b	a	b	a	b	a	b
29	13:00	6.9	6.4	3.6	3.8	157.0	267.0	500.0	740.0
26	13:30	4.1	4.9	3.1	3.4	260.0	291.0	786.0	787.0
21	14:00	3.8	5.1	2.8	3.2	255.0	287.0	849.0	901.0
24	14:30	4.8	5.4	3.1	2.5	252.0	248.0	895.0	899.0
22	15:00	4.9	4.7	3.1	2.5	36.0	230.0	849.0	970.0

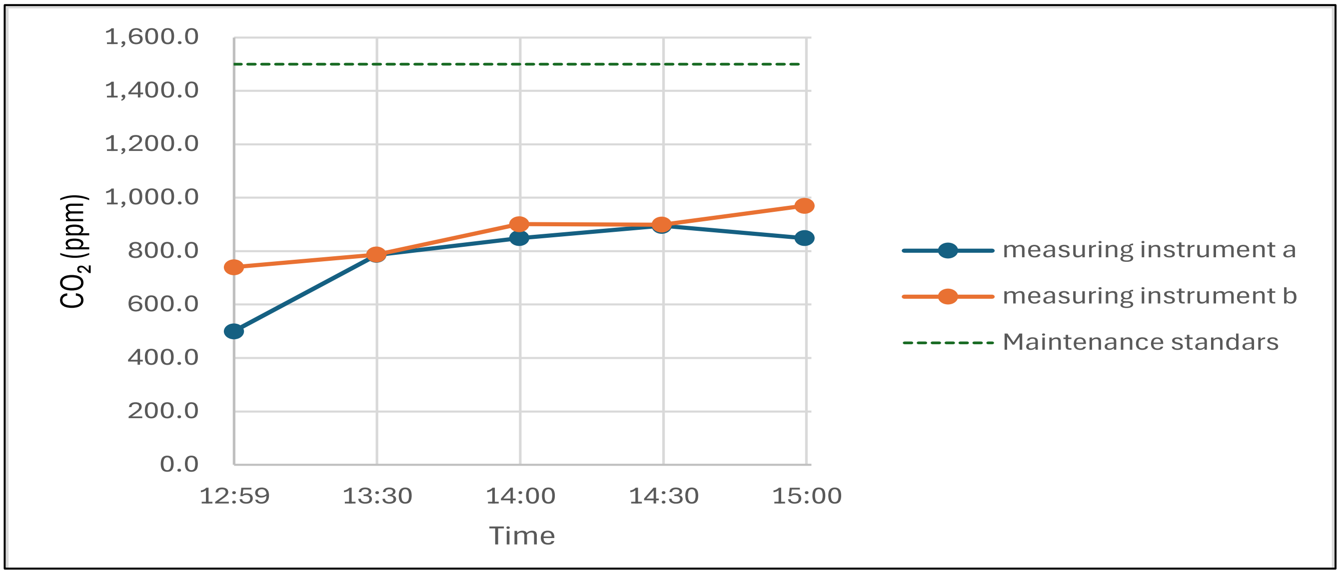


Figure 5: CO_2 Measurement Graph for Location E

Measurement Location E also had windows, but they remained closed, with only mechanical ventilation in operation. Due to the relatively small seating capacity compared to the overall size of the space, the per capita occupancy area was maintained at a spacious level. As a result, no measured parameters exceeded the recommended thresholds for indoor air quality.

3.1.6. Measurement Location F

Table 7. location F Measurement Table

F									
population	**time**	PM10(μg/m³)		PM2.5(μg/m³)		TVOCs(μg/m³)		CO_2(ppm)	
		a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
3	12:00	5.0	5.8	3.0	2.7	80.0	192.0	500.0	514.0
6	12:30	5.0	5.5	3.2	3.6	253.0	322.0	444.0	410.0
6	13:00	5.5	6.7	3.6	4.1	286.0	325.0	428.0	410.0
7	13:30	6.4	6.7	4.3	4.6	281.0	333.0	435.0	413.0
7	14:00	6.0	6.5	4.2	4.4	285.0	330.0	453.0	414.0
8	14:30	6.1	6.8	4.2	4.6	288.0	334.0	461.0	430.0
11	15:00	6.2	6.8	4.7	4.7	284.0	333.0	479.0	436.0

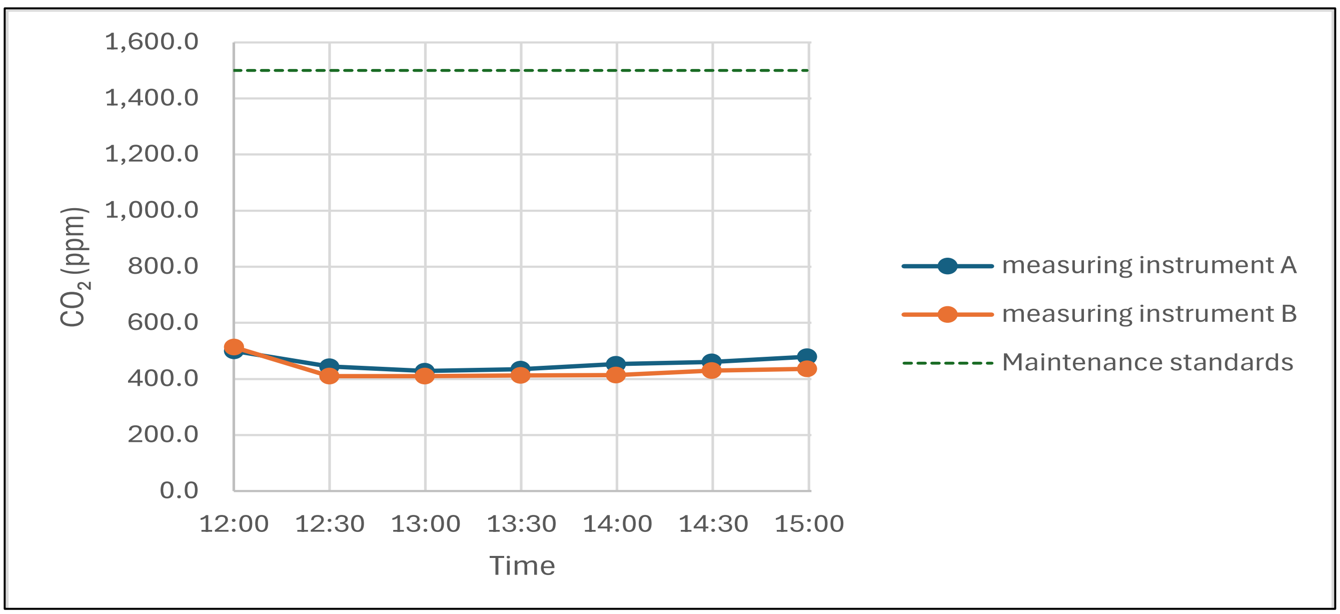


Figure 6: CO_2 Measurement Graph for Location F

Measurement Location F also had closed windows with mechanical ventilation in operation. The library had the largest per capita occupancy area, which contributed to no parameters exceeding the recommended thresholds for indoor air quality. Notably, the CO_2 concentration recorded the lowest average levels among all the measured locations.

3.2. Comparison and Analysis of Conditions at Each Measurement Location

In classrooms with a per capita occupancy volume of less than 10 m³, carbon dioxide (CO_2) concentrations generally exceeded the recommended thresholds. Measurement Locations A and B relied solely on mechanical ventilation, and both significantly exceeded the threshold. Notably, Measurement Location B, which had the smallest per capita occupancy volume, recorded much higher CO_2 levels compared to Measurement Location A.
Measurement Location C, which had a similar per capita occupancy volume to Location A, demonstrated relatively lower CO_2 levels due to natural ventilation.

In public spaces, mechanical ventilation was also the only ventilation method applied, but the CO_2 levels were low due to the smaller number of occupants relative to the size of the spaces. None of these locations exceeded the recommended thresholds. However, at Measurement Location D, the CO_2 levels gradually increased as the number of occupants grew over time.

4. Results and Discussion

The results of this study can be summarized as follows:
In Measurement Locations A, B, and C, where a large number of people were concentrated and the per capita occupancy volume was less than 10 m³, carbon dioxide (CO_2) levels exceeded the recommended thresholds for most of the measurement period. However, Measurement Location C, which had open windows allowing for natural ventilation, recorded the lowest average CO_2 concentration among the three locations.
In Measurement Locations D, E, and F, the per capita occupancy volume ranged from a minimum of 60 m³ to a maximum of 277 m³. Although these spaces did not have natural ventilation, the larger per capita volume prevented any of the locations from exceeding the CO_2 threshold. However, even in these locations, CO_2 levels increased as the number of occupants grew and the duration of occupancy lengthened.
These findings indicate that to effectively reduce CO_2 levels in school indoor environments, simple mechanical ventilation alone is insufficient. More sophisticated improvement strategies that account for the characteristics of the space, per capita occupancy volume, and duration of occupancy are required.

5. Conclusions

This study aimed to assess the current state of indoor air quality (IAQ) in school buildings and propose improvement strategies by measuring IAQ. Additionally, the study collected and compared differences in pollution levels under various indoor conditions, such as sealed and ventilated spaces, as well as differences based on the number of occupants and per capita occupancy volume. The results showed that, while all six locations maintained particulate matter (PM10, PM2.5) and TVOCs within the recommended thresholds, certain locations exceeded the CO_2 threshold. Based on these findings, the following improvement strategies are proposed.
To fundamentally reduce CO_2 levels in school indoor environments and quickly expel generated CO_2 while introducing fresh air to lower concentrations, the implementation of an advanced ventilation system is necessary. This includes installing CO_2 sensors and optimizing ventilation cycles. The installation of CO_2 sensors allows real-time monitoring of air quality through displays, enabling individuals to make data-driven decisions rather than relying on subjective judgment. This facilitates appropriate ventilation based on quantified data. Optimizing ventilation cycles can further help maintain lower CO_2 levels.
By taking into account indoor occupancy and activity levels, appropriate ventilation cycles can be identified. Operating the ventilation system before CO_2 levels exceed the threshold (1,000 ppm, or 1,500 ppm in the absence of natural ventilation) will ensure a comfortable indoor environment. This, in turn, can prevent symptoms such as dizziness and drowsiness caused by high CO_2 levels, ultimately enhancing the academic performance and concentration of students utilizing the facilities.

References

Hae-bum Lee, Seo-jeong Kim, Hung-Soo Joo, Hui-Joo Cho (2019). Performance and reusability of certified and uncertified face masks. Particle and aerosol research, 15(4), 191-202
Han-Young Choi. (2003). A Study on the Indoor Environment of school classrooms in Seoul area . Journal of environmental and Sanitary engineering, 18(2), 67-74.
Jeong-Min Choi. (2009). A Proposal for the Improvement of IAQ in School Classrooms. Review of the Korean Institute of Educational Facilities, 16(1), 21-26
Jeong-soo Bong, Seung-Jei Yang, Kyung-Soon Park. (2018). Effects of vegetation on in door air quality. Korean Society of Equipment Engineering, 18(254), 996-999
Jung-Jae Lee, Seok-geun Kim, Seok-yong Choi. (2005). A Field Survey on the Indoor Air Quality of Newly Built Schools in Busan. Journal of the architectural institute of Korea, 21(6), 175-182
Mi-kyung Kim. (2014). Determinations of Total Culturable Bacteria in the University Spaces. Journal of environmental health sciences, 20(2), 43-48.
Sang-Hyun Kang. (2016). Indoor Air Quality Management of Apartment Houses - Indoor Air Quality Management Plan (Air Purifier). Korea Air Cleaning Association 29(1), 43-50
Su-Won song, Jeong-Yeon Yu, Jung-Sik Cho, Yoon-Kyu Lee (2019). Analysis of Indoor Air Quality (IAQ) according to the Operation Conditions of an Air-cleaner and Natural Ventilation through Windows in A Small Office. Korean Society of Equipment Engineering, 19(116), 442-445
Sung-Woo Choi. (1998). Effective Control of Indoor Air Pollutant using VAV/BPFS. Journal of the environmental sciences, 7(3), 327-333
Tae-Jin Cho, Bu-Soon Son, Han-Seam Choi, Young-Teak Jeon, Jong-Dae Lee, Hye-Mee Jou. (2008). The Study of Indoor Air Quality at Schools in Chung-Nam Area. Journal of the environmental sciences, 17(5), 501-507
Won-Ho Yang. (2005). Assessment of Indoor Air Quality of

Classroom in School by Means of Source Generation - Case Study. Journal of the environmental sciences, 14(10), 979-983

Won-Ho Yang. (2009). School Indoor Air Quality and Health Effects. Journal of environmental health sciences, 35(3), 143-152.

Won-Ho Yang. (2014). Time-activity Pattern of Students and Indoor Air Quality of School Educational facilities, 21(6), 17-22.

Woo-Taeg Kwon, Min-Jae Jung, Bum-Soo Kim, Woo-Sik Lee & Lee-Seung Kwon. (2020). Study of face mask filtration efficiency to prevent fine dust to secure people's right to health. *The Journal of Odor and Indoor Environment*, *19*(2), 186-193

Yoon-Shin Kim. (2005). Efficiency of Removal for Indoor air pollutants by Air Cleaners in the Indoor Environments. Journal of the environmental sciences, 14(5), 491-497

Young-Hee Kim, Moon-Hyeon Kim, Won-Ho Yang. (2006). Evaluation Method for Improvement of Indoor Air Quality Using Mass Balance. Journal of the environmental sciences, 15(10), 913-918

Young-Seon Kim. (2021). Measurement and Analysis on the Indoor Air Quality of Apartment Housing Complexes' Fitness Centers. Korean journal of human ecology 30(1), 193-205