Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Analysis of Indoor CO_2 Changes According to Ventilation Conditions and Occupant Density in Karaoke

A Reum Park
Gyeongsang National University
Haeun Kim
Gyeongsang National University
Yuna Jang
Gyeongsang National University
Haedeun Park
Gyeongsang National University
Seong Jin Chang
sjc@gnu.ac.kr
Gyeongsang National University

Research Article

Keywords: Karaoke room, Carbon dioxide, Mechanical ventilation, Occupant density, CO2 change rate

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11368754/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

This study investigated changes in indoor carbon dioxide (CO_2) concentrations in karaoke rooms in relation to room size, occupancy, and mechanical ventilation operation. Field measurements were conducted in small, medium, and large rooms with occupancies of one to three persons, and CO_2 concentrations and change rates during singing were analyzed. Under Ventilation OFF conditions, the individual CO_2 release rate during singing was estimated, and the relationships of CO_2 change rate with room area and occupant density were examined. Under Ventilation ON conditions, the average CO_2 concentration during the singing period remained below 1,000 ppm in eight of the nine measurement conditions. Under Ventilation OFF conditions, the average CO_2 concentration exceeded 1,000 ppm in five of the nine conditions, and CO_2 concentrations increased in all measurement conditions. Under Ventilation OFF conditions, the CO_2 change rate increased with decreasing room size and increasing occupancy, and the average individual CO_2 release rate during singing was estimated to be 0.272 ± 0.071 L/min·person. The relationship between room area and CO_2 change rate showed an R^2 of 0.4433, whereas occupant density, which reflects both room size and occupancy, showed greater explanatory power with an R^2 of 0.9238. These findings indicate that continuous mechanical ventilation and appropriate occupancy management according to room size are important for controlling indoor CO_2 levels in karaoke rooms. The results can provide a basis for developing ventilation operation and indoor CO_2 management strategies for karaoke rooms.

1. Introduction

Karaoke rooms are representative indoor leisure spaces in which occupants remain in small individual rooms for a certain period while continuously engaging in singing and vocal activities, highlighting the need for appropriate indoor CO_2 management according to their spatial and usage characteristics. According to local administrative licensing data from the Ministry of the Interior and Safety, 26,594 karaoke businesses were registered as active or normally operating nationwide as of August 2026, indicating that karaoke rooms are widely used leisure facilities in Korea. Unlike large multipurpose indoor spaces, karaoke rooms are typically divided into multiple small individual rooms, where users remain in confined spaces for a certain period while continuously singing and engaging in vocal activities. A recent field study of coin-operated karaoke rooms in Korea measured indoor air quality, including CO_2, and highlighted the need for appropriate ventilation and indoor air quality management in such spaces (Yun et al., 2024). In addition, a field study of choir singing measured changes in CO_2 concentrations during singing under various room sizes, occupancy levels, and ventilation conditions, suggesting that singing duration, occupancy conditions, and spatial and ventilation characteristics may be closely associated with indoor CO_2 accumulation (Bauer et al., 2024). Accordingly, in karaoke rooms where multiple users occupy small individual rooms simultaneously, CO_2 accumulation arising from occupants' respiration and sustained singing activities should be evaluated under actual use conditions.

Indoor CO_2 concentrations are influenced by the combined effects of occupant-generated CO_2, occupancy level, spatial conditions, and ventilation rate. Occupant CO_2 generation rates may vary depending on physical characteristics and activity levels, with higher activity levels generally associated with increased CO_2 generation rates (Yang et al., 2020). In occupied spaces, occupant density and occupancy patterns have also been identified as major factors affecting indoor CO_2 concentrations, and studies of naturally ventilated classrooms have shown that occupant density and occupant-generated CO_2 can contribute to variations in indoor CO_2 levels (Korsavi et al., 2020a). A study conducted in a Korean educational facility further analyzed temporal changes in CO_2 concentrations associated with occupancy and changes in indoor air quality resulting from window opening, indicating that occupancy conditions and ventilation behavior can directly affect indoor CO_2 levels (Kwak, 2021). Because changes in indoor CO_2 concentrations reflect the combined effects of occupant CO_2 generation and outdoor air supply, CO_2 has been widely used as an indicator for evaluating ventilation conditions and air-exchange characteristics. More recent studies have also used measured CO_2 data from occupied spaces to quantitatively estimate occupant CO_2 generation rates and ventilation-related variables (Tugores et al., 2024). Taken together, indoor CO_2 can serve as a key indicator that reflects occupant activity level, occupant density, and ventilation conditions in occupied spaces.

Indoor CO_2 accumulation and spatial distribution can also vary depending on the ventilation method, indoor airflow, and air-exchange characteristics. A study conducted in Korean classrooms reported increases in CO_2 concentrations during occupancy and reductions following window opening, demonstrating that ventilation behavior can directly affect indoor CO_2 levels (Kwak, 2021). In addition, ventilation system operation and supply-air conditions can influence indoor pollutant removal, while building airtightness and infiltration can affect the resulting ventilation performance (Choi et al., 2020). A recent field study of modular classrooms further emphasized the need to improve ventilation configurations by considering occupancy, activity duration, indoor CO_2 concentrations, and airflow patterns together (Kang et al., 2025). Because ventilation strategies and indoor airflow distribution can also affect CO_2 removal and its spatial distribution within a room, the evaluation of indoor CO_2 accumulation should consider not only whether a ventilation system is operating, but also the actual air-exchange and airflow conditions.

Meanwhile, indoor CO_2 concentrations are not necessarily uniform throughout a space and may exhibit spatial variations depending on measurement location and indoor airflow conditions. A recent study conducted in university classrooms found that CO_2 concentration distributions can vary according to measurement location (Mahyuddin and Essah, 2024). Similarly, a CFD-based study of modular school classrooms in Korea showed that the spatial distributions of CO_2 concentration and age of air vary with changes in occupancy and ventilation rate, and that the representativeness of measured values may also depend on sensor location (Park et al., 2026). Occupant-related and building-related characteristics have also been reported to jointly affect actual ventilation rates (Korsavi et al., 2020b). Evaluations of indoor

CO_2 should therefore consider not only average concentration levels but also measurement location, airflow distribution, ventilation conditions, and occupancy characteristics.

In particular, karaoke rooms may exhibit CO_2 generation and accumulation characteristics that differ from those of conventional seated indoor environments because sustained singing and vocal activities take place within confined spaces. Occupant CO_2 generation rates have been reported to increase with higher activity levels (Yang et al., 2020), and a study of choir singing also identified relationships between changes in CO_2 concentrations during singing and occupancy, room size, and ventilation conditions (Bauer et al., 2024). In addition, a study conducted in a university classroom in Korea directly measured individual occupant CO_2 release rates and analyzed concentration changes under natural ventilation conditions (Lee and Choi, 2021), while more recent research has estimated occupant CO_2 generation rates using measured CO_2 data from actual educational facilities (Tugores et al., 2024). These studies indicate that evaluations of indoor CO_2 accumulation should consider not only the number of occupants but also occupant activity, spatial characteristics, and ventilation conditions.

Recent studies have evaluated indoor CO_2 concentrations and ventilation characteristics in small public-use facilities, including karaoke rooms. A field study of coin-operated karaoke rooms in Korea measured indoor air quality, including CO_2, and assessed concentration changes according to ventilation conditions (Yun et al., 2024). Another study estimated air exchange rates using occupant-generated CO_2 and evaluated ventilation conditions in small public-use facilities, including coin-operated karaoke rooms (Shin et al., 2025). However, these studies have primarily focused on indoor air quality levels and ventilation performance. Relatively few studies have simultaneously considered room size, occupancy level, and ventilation conditions to analyze temporal changes and accumulation rates of CO_2 while quantitatively evaluating occupant CO_2 release characteristics during singing.

Despite the potential for CO_2 accumulation, karaoke rooms are not directly included within the scope of the current indoor air quality management system, highlighting the need for quantitative assessment that reflects actual use conditions. Under the current Indoor Air Quality Control Act, indoor air quality maintenance standards are applied to certain large-scale public-use facilities, including subway stations, medical facilities, libraries, movie theaters, private educational institutes, and internet computer game facilities. These standards include criteria for particulate matter (PM10 and PM2.5), CO_2, formaldehyde (HCHO), total airborne bacteria, and carbon monoxide (CO), with CO_2 required to be maintained at or below 1,000 ppm. However, karaoke rooms are not separately included among the applicable facility types and are therefore not directly subject to the indoor air quality maintenance standards, including the CO_2 criterion.

Accordingly, this study investigated changes in indoor CO_2 concentrations in karaoke rooms through field measurements conducted under different spatial conditions, occupancy levels, and mechanical ventilation operating conditions. In addition, the relationship between occupancy relative to room size and the CO_2 change rate was quantitatively analyzed, and occupant CO_2 release characteristics during

singing were estimated to evaluate CO_2 accumulation in karaoke rooms. The findings are intended to provide basic data for developing indoor CO_2 management strategies that account for ventilation operation and appropriate occupancy levels in karaoke rooms.

2. Research Methods

2.1 Study Sites

To analyze changes in indoor CO_2 concentrations according to room size, occupancy, and mechanical ventilation operation in karaoke rooms, two karaoke rooms located in Jinju and Daejeon were selected as the study sites. Karaoke Room A is located in a reinforced concrete building completed in 2019, whereas Karaoke Room B is located in a reinforced concrete building completed in 2006. Both sites operate in a typical karaoke-room configuration consisting of multiple independent rooms. Building information for the study sites and the sizes of the measured rooms are presented in Table 1.

Because it was difficult to secure a separate measurement period outside business hours at Karaoke Room A, measurements were conducted under actual operating conditions. A preliminary assessment of measurements with the mechanical ventilation system turned off showed that the CO_2 concentration was already high, at approximately 2,100 ppm, from the beginning of the measurement and remained elevated without a clear decrease over time. This was considered to reflect residual and accumulated CO_2 from previous users due to the continuous turnover of occupants during operation, making it difficult to repeatedly obtain comparable initial conditions under Ventilation OFF conditions. Therefore, measurements at Karaoke Room A were conducted with the mechanical ventilation system operating, and the entrance door was opened for approximately 10 min before each measurement to ventilate the room. In addition, measurements began shortly after the start of business hours to minimize the influence of CO_2 accumulation from previous occupants.

Because measurements at Karaoke Room B could be conducted after business hours, the experiment was performed without user entry or exit. Before each measurement, the room was ventilated for approximately 10 min by operating the mechanical ventilation system and opening the entrance door. The mechanical ventilation system was then turned off, and measurements were conducted with the room vent closed. Because the available measurement period was limited, additional repeated measurements under Ventilation ON conditions could not be conducted at the same site. Nevertheless, CO_2 concentration changes under the Ventilation OFF condition could be observed while user entry and exit were controlled.

Changes in CO_2 concentrations under mechanical ventilation ON and OFF conditions were analyzed using field measurement data obtained from actual karaoke room operations. The study sites included small, medium, and large rooms, and the same measurement procedure was applied under occupancy conditions of one to three persons. Based on these measurements, CO_2 concentration patterns

according to mechanical ventilation operation were compared and analyzed under actual operating conditions, with the aim of examining the importance of ventilation in karaoke rooms.

2.2 Measurement Spaces and Experimental Conditions

At each karaoke room, small, medium, and large rooms were selected to compare changes in CO_2 concentrations according to room size and occupancy. Although the measured rooms at the two study sites were similar in spatial configuration and usage, their floor areas differed. The rooms were therefore classified according to the actual room-size categories used at each karaoke room. The detailed floor area of each measurement space is presented in Table 1. Occupancy conditions were set at one, two, and three persons in each measurement space.

Measurements at Karaoke Room A were conducted with the mechanical ventilation system operating, whereas measurements at Karaoke Room B were conducted with the mechanical ventilation system turned off and the room vent closed. In the subsequent analysis, the measurement condition at Karaoke Room A was classified as Ventilation ON, and that at Karaoke Room B was classified as Ventilation OFF.

All measurements were conducted without additional artificial airtight treatment to reflect actual karaoke room conditions as closely as possible. Therefore, some natural air exchange may have occurred through door gaps and building leakage.

2.3 Field Measurement of Indoor Air Quality

A TSI 7545 indoor air quality monitor was used to measure temporal changes in CO_2 concentrations in the karaoke rooms. The instrument has a CO_2 measurement range of 0–5,000 ppm, an accuracy of ± 3% of the reading or ± 50 ppm, whichever is greater, and a resolution of 1 ppm (Kim et al., 2021). To minimize the direct influence of air supplied from or exhausted through the ventilation openings, the instrument was positioned near the center of each room, away from the vents, at a height of 1.3 m above the floor. Indoor CO_2 concentrations can exhibit spatial variations depending on measurement location and indoor airflow, and previous studies have also reported that measured values may vary with sampling height and sensor placement (Mahyuddin and Essah, 2024; Muelas et al., 2022; Park et al., 2026). Accordingly, the measurement location was selected near the center of the occupied space, where it was not directly affected by the ventilation openings, to obtain a representative indoor CO_2 concentration.

Before each measurement, the entrance door was opened and the room was ventilated for approximately 10 min to minimize the influence of residual CO_2 from previous use or the preceding measurement. Measurements at Karaoke Room A were then conducted with the mechanical ventilation system operating, whereas measurements at Karaoke Room B began after the mechanical ventilation system had been turned off and the room vent had been closed. Each measurement lasted 15 min to continuously capture the background CO_2 concentration before occupancy and the subsequent changes associated with singing activity. The initial 5 min were defined as the Baseline period, during which the

indoor background CO_2 concentration was measured under unoccupied conditions. This was followed by a 10 min singing period, during which the designated number of occupants remained seated and sang approximately three songs. CO_2 concentrations were recorded at 1 min intervals throughout the entire measurement period, and the same procedure was applied to the small, medium, and large rooms under occupancy conditions of one, two, and three persons. Temporal changes in CO_2 concentrations associated with occupant activity and ventilation conditions have been used to evaluate indoor ventilation conditions and occupant-generated CO_2 characteristics (Lee and Choi, 2021; Kwak, 2021; Tugores et al., 2024). Accordingly, this study continuously measured CO_2 concentrations before and during singing to analyze CO_2 accumulation characteristics under each measurement condition. The measurement dates, times, and detailed experimental conditions are presented in Table 2.

For interpretation of the measured CO_2 concentration levels, the indoor air quality maintenance standards for public-use facilities specified in the Enforcement Rule of the Indoor Air Quality Control Act were referenced. Under these standards, CO_2 concentrations in applicable public-use facilities are generally required to be maintained at or below 1,000 ppm.

Because karaoke rooms are not directly subject to this CO_2 maintenance standard, the 1,000 ppm level was used in this study not as a criterion for determining legal compliance, but as a reference value for comparing and interpreting the measured CO_2 concentrations.

Table 2
Indoor air quality measurement method

Measurement date	**A Building**	**B Building**
	2026. 05. 23.	**2026. 05. 16.**
Measurement time	10:00 AM to 01:00 PM	2:00 AM to 5:00 AM
Measurement items	Carbon dioxide; CO_2 (ppm)	
Measurement method	5 min baseline measurement → 10 min singing activity Approximately three songs were performed 1 min measurement interval	

2.4 Data Analysis

CO_2 concentrations and change rates were analyzed to quantitatively compare concentration changes and accumulation characteristics according to ventilation operation, room size, and occupancy. The Baseline CO_2 concentration was calculated as the average concentration measured during the initial 5 min under unoccupied conditions, while the CO_2 concentration during the singing period was calculated as the average concentration measured over the subsequent 10 min during singing. The CO_2 change rate

was calculated by dividing the difference between the CO_2 concentration at 5 min, when singing began, and that at 15 min, when the measurement ended, by the 10 min singing period, as shown in Eq. (1).

$$C = \frac{C_{15} - C_5}{10} \quad (1)$$

In Eq. (1), C represents the CO_2 change rate (ppm/min), C_5 represents the CO_2 concentration at 5 min after the start of measurement (ppm), and C_{15} represents the CO_2 concentration at 15 min after the start of measurement (ppm). To simultaneously account for the effects of room size and occupancy, occupant density was included as an additional analysis variable. Occupant density was calculated by dividing the number of occupants in each room by the corresponding floor area, as shown in Eq. (2).

$$O = \frac{N}{A} \quad (2)$$

In Eq. (2), O represents occupant density (person/m^2), N represents the number of occupants (person), and A represents the floor area of the room (m^2).

Because the room volume and occupancy differed among the karaoke rooms, the measured CO_2 change rate alone was insufficient to directly compare occupant-related CO_2 generation characteristics. Accordingly, the individual CO_2 release rate during singing was estimated based on a mass-balance relationship using changes in indoor CO_2 concentration and room volume. Recent studies have likewise applied mass-balance approaches that relate indoor CO_2 concentration, room volume, ventilation rate, and occupant-generated CO_2 to evaluate CO_2 generation rates and ventilation characteristics (Kuga et al., 2021; Persily, 2022; Tugores et al., 2024). The volume of each room was calculated using the measured floor area and a ceiling height of 2.6 m.

The CO_2 release rate was calculated for the Ventilation OFF condition to minimize the influence of CO_2 removal by mechanical ventilation. Assuming that indoor CO_2 was uniformly mixed, the total CO_2 release rate during singing was calculated using the measured CO_2 change rate and room volume, as shown in Eq. (3). Because no additional airtight treatment was applied even under the Ventilation OFF condition, the calculated values were interpreted as CO_2 release rates estimated from the increase in indoor CO_2 concentration under actual room conditions in which natural air exchange through infiltration and leakage may have occurred.

$$T = C \times R \times 10^{-3} \quad (3)$$

In Eq. (3), T represents the total CO_2 release rate (L/min), C represents the CO_2 change rate (ppm/min), R represents the room volume (m^3), and 10^{-3} is the unit conversion factor used to convert ppm·m^3 to liters. The total CO_2 release rate was then divided by the number of occupants to calculate the average individual CO_2 release rate, as shown in Eq. (4).

$$\mathrm{I}=\frac{\mathrm{T}}{\mathrm{N}}$$

4

In Eq. (4), I represents the individual CO_2 release rate (L/min·person), T represents the total CO_2 release rate (L/min), and N represents the number of occupants (person).

Finally, to quantitatively examine the relationships of room size and occupancy level with the CO_2 change rate, linear regression analyses were performed using the measurement results obtained under the Ventilation OFF condition. Room area and occupant density were separately used as independent variables, and the CO_2 change rate was used as the dependent variable. Regression equations and coefficients of determination (R^2) were calculated for the relationships between each independent variable and the CO_2 change rate. The coefficient of determination was used as an indicator to compare the extent to which each independent variable explained the variation in the CO_2 change rate.

3. Results

3.1 Changes in CO_2 Concentration According to Ventilation Condition

Baseline CO_2 concentrations varied according to room size and occupancy condition, with the highest level observed in the small room with three occupants. Baseline CO_2 concentrations, average CO_2 concentrations during the singing period, and CO_2 change rates according to ventilation condition, room size, and occupancy are presented in Table 3. In the small room with three occupants, the Baseline CO_2 concentration was 1,018.0 ppm under Ventilation ON and 1,119.2 ppm under Ventilation OFF, representing the highest values under each ventilation condition. These elevated initial concentrations may reflect residual CO_2 from previous use and preceding measurements, together with insufficient short-term air exchange within the room even after ventilation. In occupied spaces, indoor CO_2 levels can vary substantially depending on the ventilation method and ventilation rate, and high CO_2 concentrations may persist under natural ventilation when outdoor air supply is insufficient (Cai et al., 2021). Indoor CO_2 concentrations may also vary according to occupant distribution and measurement location (Lee and Choi, 2021), while CFD-based studies have shown that the spatial distributions of CO_2 concentration and age of air can vary with occupancy and ventilation conditions (Park et al., 2026).

Figure 1 compares the Baseline and average CO_2 concentrations during the singing period under the two ventilation conditions. Under Ventilation ON conditions, the average CO_2 concentration during singing remained below 1,000 ppm in eight of the nine measurement conditions, exceeding 1,000 ppm only in the small room with three occupants, where it reached 1,066.1 ppm. Under Ventilation OFF conditions, the average CO_2 concentration exceeded 1,000 ppm in five of the nine conditions: the small room with one, two, and three occupants, and the medium room with two and three occupants. In the small room, the average CO_2 concentration increased from 1,205.9 ppm with one occupant to 1,402.1 ppm with two occupants and 1,881.0 ppm with three occupants. The value for three occupants was 675.1 ppm higher than that for one occupant. These results indicate that CO_2 accumulation increased with occupancy in the small room under Ventilation OFF conditions.

CO_2 concentrations during singing were higher under Ventilation OFF conditions than under Ventilation ON conditions, with greater CO_2 accumulation observed in smaller rooms and at higher occupancy levels. Under Ventilation OFF conditions, CO_2 concentrations increased as room size decreased and occupancy increased, indicating that CO_2 accumulation in karaoke rooms is influenced not only by ventilation operation but also by room size and occupancy level. To evaluate these relationships more quantitatively, additional analyses were conducted using the CO_2 change rate according to room size and occupancy conditions.

Table 3
CO_2 measurement results according to ventilation condition, room type, and occupancy

Room	Occupancy	Ventilation ON			Ventilation OFF		
		Baseline CO_2 (ppm)	Singing CO_2 (ppm)	Change rate (ppm/min)	Baseline CO_2 (ppm)	Singing CO_2 (ppm)	Change rate (ppm/min)
Small	1	878.8	889.5	0.9	956.2	1205.9	34.5
	2	812.4	907.5	14.7	911.0	1402.1	71.3
	3	1018.0	1066.1	1.2	1119.2	1881.0	107.7
Medium	1	648.6	637.0	-2.3	813.6	949.6	24.5
	2	577.4	690.6	12.1	821.8	1118.6	55.6
	3	701.0	839.6	11.3	899.8	1303.6	56.2
Large	1	517.4	544.6	2.6	775.0	927.5	18.4
	2	598.6	673.4	7.3	734.0	849.1	21.3
	3	689.0	798.5	9.1	664.8	933.4	41.8

3.2 CO_2 Change rate According to Ventilation Condition, Room Size, and Occupancy

Analysis of the CO_2 change rate showed that the increase in CO_2 concentration during singing was relatively small under Ventilation ON conditions, whereas larger increases were observed under all measurement conditions with Ventilation OFF. Figure 2 presents the CO_2 change rates according to room size and occupancy under each ventilation condition. The average CO_2 change rate was 6.3 ppm/min under Ventilation ON and 47.9 ppm/min under Ventilation OFF. Under Ventilation ON conditions, CO_2 concentration decreased in the medium room with one occupant, while the change rates remained below 3 ppm/min in the small room with one and three occupants and in the large room with one occupant, indicating only limited increases during singing. Under Ventilation OFF conditions, positive change rates were observed in all measurement conditions, indicating continuous indoor CO_2 accumulation during singing.

Under Ventilation OFF conditions, CO_2 accumulation proceeded more rapidly as room size decreased and occupancy increased. Figure 3 compares the CO_2 change rates according to room size and occupancy under Ventilation OFF conditions. The average CO_2 change rates by room type were 71.2 ppm/min in the small room, 45.4 ppm/min in the medium room, and 27.2 ppm/min in the large room, with the value for the small room being approximately 2.6 times higher than that for the large room. These results indicate that, when mechanical ventilation was not operating, CO_2 concentrations increased more rapidly during singing in smaller rooms.

The increase in CO_2 change rate with increasing occupancy was most pronounced in the small room. In the small room, the CO_2 change rate increased from 34.5 ppm/min with one occupant to 107.7 ppm/min with three occupants, corresponding to an approximately 3.1-fold increase. In the medium room, the change rate increased markedly from one to two occupants, whereas the value for three occupants was similar to that for two occupants. In the large room, the increase associated with occupancy was smaller than that observed in the small room. These results indicate that the CO_2 change rate does not increase at the same rate across all room sizes as occupancy increases and that the influence of occupancy may vary depending on room size. Studies conducted in educational facilities have likewise reported that occupant density and room size are important factors affecting indoor CO_2 concentrations, with higher occupant density associated with a greater potential for CO_2 accumulation (Franco and Leccese, 2020; Korsavi et al., 2020a). Previous research has also shown that the accumulation of occupant-generated CO_2 is influenced by ventilation rate and spatial conditions (Lee and Choi, 2021). Therefore, both occupancy and room size should be considered when evaluating CO_2 accumulation in karaoke rooms.

3.3 Individual CO_2 Release rate During Singing

Under Ventilation OFF conditions, the individual CO_2 release rate during singing varied among the measurement conditions, with an overall mean of 0.272 ± 0.071 L/min·person. Because room volume and occupancy differed among the karaoke rooms, the measured CO_2 change rate alone was not sufficient to directly compare CO_2 generation characteristics across conditions. Therefore, the total CO_2 release rate and individual CO_2 release rate during singing were calculated. Under Ventilation ON conditions, occupant-generated CO_2 was continuously removed by mechanical ventilation, making it difficult to estimate the release rate using only the measured CO_2 change rate. Accordingly, the analysis was conducted for the Ventilation OFF condition to minimize the influence of CO_2 removal by mechanical ventilation. As shown in Table 4, the total CO_2 release rate ranged from 0.202 to 0.842 L/min, while the individual CO_2 release rate ranged from 0.202 to 0.376 L/min·person.

The individual CO_2 release rate estimated during singing was compared with values reported in previous studies under typical seated conditions. Lee and Choi (2021) reported an average individual CO_2 release rate of 0.191 ± 0.0344 L/min·person for occupants in a university classroom, while Sakamoto et al. (2022) reported CO_2 release rates of approximately 0.235–0.297 L/min·person for seated occupants performing light activities. The estimated individual CO_2 release rate was higher than that reported by Lee and Choi (2021) for a classroom setting, while remaining within the range observed by Sakamoto et al. (2022) under sedentary conditions. Occupant CO_2 generation has been reported to vary depending on activity level as well as other physical and environmental factors (Sakamoto et al., 2022; Yang et al., 2020). Although the present study differed from typical seated conditions in that continuous singing and vocalization were performed while seated, the observed differences in CO_2 release rates should be interpreted by considering activity characteristics, occupant characteristics, and measurement conditions rather than attributing them solely to singing activity.

CO_2 release during singing is more appropriately interpreted in terms of sustained vocalization and the associated respiratory demand than in terms of vocal intensity or a specific song genre itself. Although vocal intensity and genre are difficult to regard as direct determinants of CO_2 release, respiratory frequency and breathing volume may increase depending on lyric density and the duration of continuous vocalization. Therefore, when evaluating CO_2 release associated with singing, greater emphasis should be placed on factors such as the actual duration of singing, lyric density, and respiratory frequency rather than genre or vocal intensity. Future studies should quantify these factors and examine their relationships with CO_2 release rates.

Table 4
Total and average individual CO_2 release rates during singing under ventilation OFF conditions

Room	Occupancy	Total CO_2 release rate (L/min)	Individual CO_2 release rate (L/min·person)
Small	1	0.202	0.202
	2	0.417	0.209
	3	0.630	0.210
Medium	1	0.331	0.331
	2	0.752	0.376
	3	0.760	0.253
Large	1	0.371	0.371
	2	0.429	0.215
	3	0.842	0.281
Average individual CO_2 release rate			0.272 ± 0.071

3.4 Relationship of Spatial and Occupancy Characteristics with CO_2 Change Rate

To quantitatively examine the relationships of room size and occupancy level with the CO_2 change rate, linear regression analyses were conducted using the Ventilation OFF data. Room area and occupant density were separately set as independent variables, while the CO_2 change rate was used as the dependent variable. The relationships between each variable and the CO_2 change rate were compared using the regression equations and coefficients of determination (R^2), with R^2 used as an indicator of the extent to which each independent variable explained the variation in the dependent variable.

Room area showed a negative relationship with the CO_2 change rate, although room area alone did not sufficiently explain the variation in the change rate. As shown in Fig. 4(a), the CO_2 change rate tended to decrease as room area increased, with the regression equation expressed as $y = -8.0188x + 88.551$ and a coefficient of determination of $R^2 = 0.4433$. This result indicates that although room size was related to the CO_2 change rate, room area alone had relatively limited explanatory power for the differences in change rate among the measurement conditions.

In contrast, occupant density, which reflects both room size and occupancy, showed a strong positive relationship with the CO_2 change rate. As shown in Fig. 4(b), the CO_2 change rate clearly increased with increasing occupant density, with the regression equation expressed as $y = 72.418x + 10.989$ and a coefficient of determination of $R^2 = 0.9238$. This explanatory power was substantially higher than that

obtained when room area was used as the sole independent variable (R^2 = 0.4433), indicating that occupant density, which accounts for occupancy relative to room size, was a more useful variable for explaining variations in the CO_2 change rate under the Ventilation OFF conditions examined in this study. Occupant density and occupancy level have been reported to be major factors affecting indoor CO_2 concentrations and ventilation requirements (Franco and Leccese, 2020; Korsavi et al., 2020a), while the accumulation of occupant-generated CO_2 may also vary depending on room size and ventilation conditions (Lee and Choi, 2021). Considering these findings, CO_2 accumulation in small occupied spaces is more appropriately interpreted by accounting for both room size and occupancy level.

4. Conclusion

This study analyzed changes in indoor CO_2 concentrations in karaoke rooms according to room size, occupancy, and mechanical ventilation operation through field measurements. To identify the factors affecting CO_2 accumulation under actual use conditions, CO_2 concentrations and change rates were compared across room sizes and occupancy levels, and the individual CO_2 release rate and its relationship with occupant density were quantitatively analyzed.

Under Ventilation ON conditions, the increase in CO_2 concentration during singing was suppressed, whereas CO_2 continuously accumulated under all measurement conditions when ventilation was turned off. Under Ventilation ON conditions, the average CO_2 concentration during the singing period remained at or below 1,000 ppm in eight of the nine measurement conditions, whereas under Ventilation OFF conditions, it exceeded 1,000 ppm in five of the nine conditions. These results indicate that continuous operation of mechanical ventilation plays an important role in controlling indoor CO_2 levels in small enclosed spaces where singing activities are sustained.

Under Ventilation OFF conditions, the CO_2 accumulation rate increased as room size decreased and occupancy increased, and occupant density, which reflects both room size and occupancy, showed the highest explanatory power for the CO_2 change rate (R^2 = 0.9238). In addition, the average individual CO_2 release rate during singing was estimated to be 0.272 ± 0.071 L/min·person, suggesting that the increased breathing volume and respiratory frequency associated with continuous singing and vocalization are important factors contributing to CO_2 generation.

Based on the findings of this study, indoor CO_2 management in karaoke rooms requires continuous operation of mechanical ventilation during use and appropriate control of occupancy according to room size. In addition, not only whether the ventilation system is operating, but also whether its ventilation capacity and performance are appropriate for the room size and occupancy should be considered. The results of this study can provide basic data for establishing ventilation operation strategies and occupancy management plans for individual karaoke rooms. Future studies should quantify the actual duration of singing, lyric density, and respiratory frequency and examine their relationships with ventilation performance.

Declarations

Author Contribution

A Reum Park conducted the experiments, analyzed the data, and wrote the main manuscript. Haeun Kim and Yuna Jang contributed to the experimental investigation and data collection. Haedeun Park contributed to the methodology, data interpretation, and manuscript review. Seong Jin Chang supervised the study, contributed to the research design, and reviewed and edited the manuscript. All authors reviewed and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Data availability

The data used for this study will be made available on request.

References

1. Lee, D.H., Choi, Y.B., 2021. Measurements and CFD Analysis for Release Rate of CO2 and Characteristics of Natural Ventilation in Lecture Room. Journal of the Korean Society of Safety 36, 86–94. https://doi.org/10.14346/JKOSOS.2021.36.1.86
2. Kim, H.J., Lee, H.G., Oh, J.S., Cho, Y.H., 2021. Experimental Study on the Indoor CO2 Concentration Prediction. Journal of Korean Institute of Architectural Sustainable Environment and Building Systems 15, 613–623. https://doi.org/10.22696/jkiaebs.20210051
3. Bauer, K., Hardege, R., Neumann, S., Schwarze, R., Fuchs, M., Heinrich Pieper, L., 2024. How Safe is Singing Under Pandemic Conditions? - CO2-Measurements as Simple Method for Risk Estimation During Choir Rehearsals. Journal of Voice 38, 1529.e17-1529.e27. https://doi.org/10.1016/j.jvoice.2022.05.003
4. Cai, C., Sun, Z., Weschler, L.B., Li, T., Xu, W., Zhang, Y., 2021. Indoor air quality in schools in Beijing: Field tests, problems and recommendations. Build. Environ. 205. https://doi.org/10.1016/j.buildenv.2021.108179
5. Choi, H., Lee, J., Jia, R., Kim, D., Na, H., Kim, T., 2020. Development of supply ventilation strategy to reduce pm2.5 in school classrooms. Journal of the Architectural Institute of Korea 36, 119–129. https://doi.org/10.5659/JAIK.2020.36.9.119
6. Franco, A., Leccese, F., 2020. Measurement of CO2 concentration for occupancy estimation in educational buildings with energy efficiency purposes. Journal of Building Engineering 32. https://doi.org/10.1016/j.jobe.2020.101714
7. Kang, H.S., Shin, J.H., Lee, S., Park, J.S., 2025. A Study on the Architectural Planning Considering the Comfortable Learning Environment by Improving the Ventilation Structure of Modular Classrooms.

Journal of the Architectural Institute of Korea 41, 15–22. https://doi.org/10.5659/JAIK.2025.41.10.15

8. Korsavi, S.S., Montazami, A., Mumovic, D., 2020a. Indoor air quality (IAQ) in naturally-ventilated primary schools in the UK: Occupant-related factors. Build. Environ. 180. https://doi.org/10.1016/j.buildenv.2020.106992
9. Korsavi, S.S., Montazami, A., Mumovic, D., 2020b. Ventilation rates in naturally ventilated primary schools in the UK; Contextual, Occupant and Building-related (COB) factors. Build. Environ. 181. https://doi.org/10.1016/j.buildenv.2020.107061
10. Kuga, K., Ito, K., Wargocki, P., 2021. The effects of warmth and CO2 concentration, with and without bioeffluents, on the emission of CO2 by occupants and physiological responses. Indoor Air 31, 2176–2187. https://doi.org/10.1111/ina.12852
11. Kwak, R.Y., 2021. Evaluation on trend analysis of improvement of air environment by occupants' behaviour of environmental control in high school classroom. Journal of the Architectural Institute of Korea 37, 175–182. https://doi.org/10.5659/JAIK.2021.37.1.175
12. Mahyuddin, N., Essah, E.A., 2024. Spatial distribution of CO2 Impact on the indoor air quality of classrooms within a University. Journal of Building Engineering 89. https://doi.org/10.1016/j.jobe.2024.109246
13. Muelas, Á., Remacha, P., Pina, A., Tizné, E., El-Kadmiri, S., Ruiz, A., Aranda, D., Ballester, J., 2022. Analysis of different ventilation strategies and CO2 distribution in a naturally ventilated classroom. Atmos. Environ. 283. https://doi.org/10.1016/j.atmosenv.2022.119176
14. Park, J., Oh, I., Park, B., Oh, W., 2026. Evaluation of CO2 Sensor Placement in a Modular School Classroom using CFD Analysis of CO2 Concentration and Age of Air. Journal of the Architectural Institute of Korea 42, 285–291. https://doi.org/10.5659/JAIK.2026.42.4.285
15. Persily, A., 2022. Development and application of an indoor carbon dioxide metric. Indoor Air 32. https://doi.org/10.1111/ina.13059
16. Sakamoto, M., Li, M., Kuga, K., Ito, K., Bekö, G., Williams, J., Wargocki, P., 2022. CO2 emission rates from sedentary subjects under controlled laboratory conditions. Build. Environ. 211. https://doi.org/10.1016/j.buildenv.2021.108735
17. Shin, H.W., Kim, J.M., Kang, D.H., 2025. Assessment of Winter Ventilation Conditions and Air Exchange Rates in Small-sized Multi-use Facilities using Multiple-formulas Method. Journal of the Architectural Institute of Korea 41, 227–236. https://doi.org/10.5659/JAIK.2025.41.11.227
18. Tugores, J., Macarulla, M., Gangolells, M., 2024. Estimation of children's CO2 generation rates in naturally ventilated educational buildings. Build. Environ. 257. https://doi.org/10.1016/j.buildenv.2024.111550
19. Yang, L., Wang, X., Li, M., Zhou, X., Liu, S., Zhang, H., Arens, E., Zhai, Y., 2020. Carbon dioxide generation rates of different age and gender under various activity levels. Build. Environ. 186. https://doi.org/10.1016/j.buildenv.2020.107317

20. Yun, Y., Ryu, W., Yun, W.-S., Hong, W.-H., n.d. A Field Study on Indoor Air Quality in Coin Karaoke Rooms. Journal of Asian Urban Environment. https://doi.org/10.69457/aiue.20240066

Table

Table 1 is available in the Supplementary Files section.

Figures

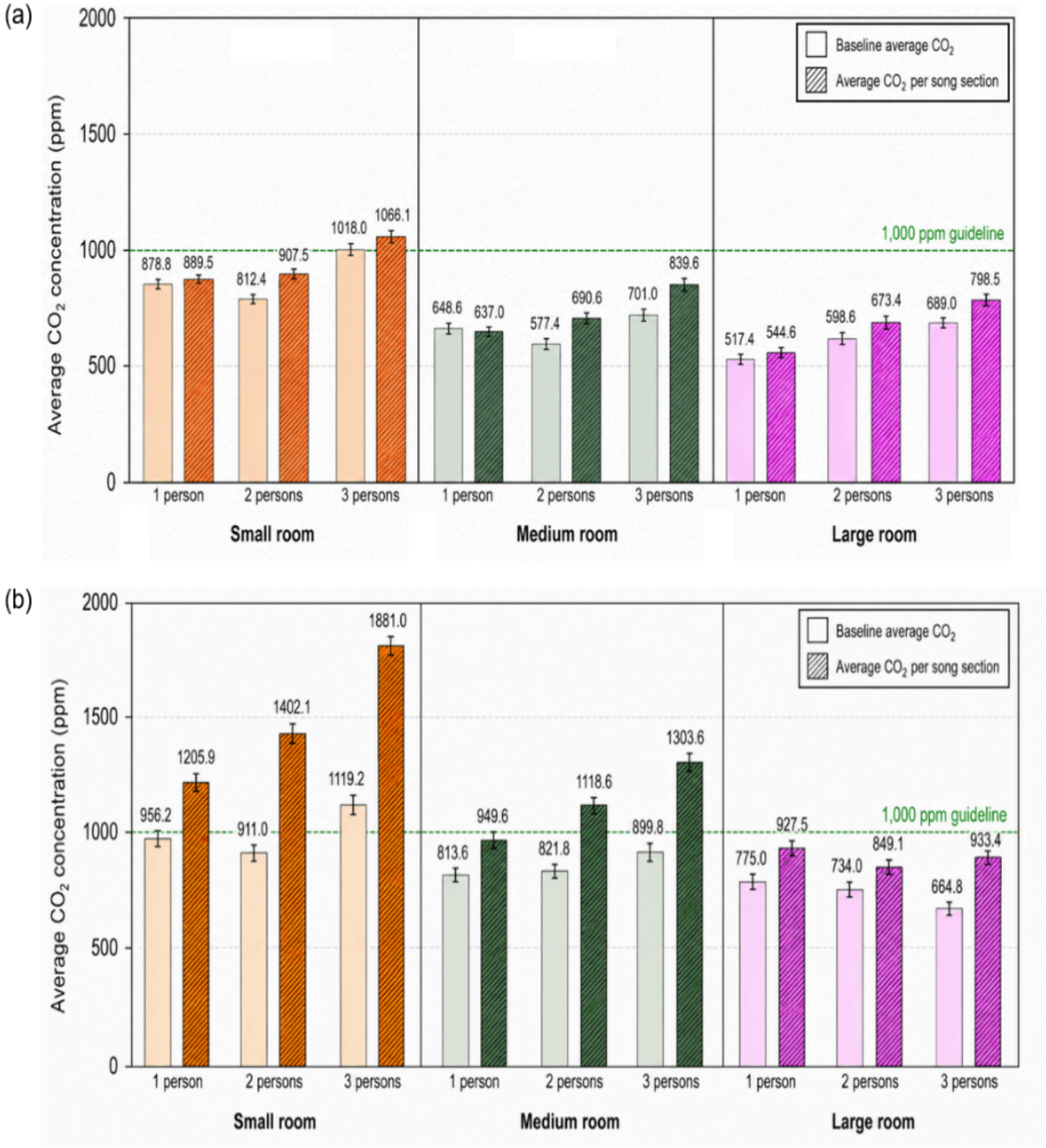


Figure 1

Comparison of baseline and singing-period average CO_2 concentrations under Ventilation ON and OFF conditions: (a) Ventilation ON, (b) Ventilation OFF

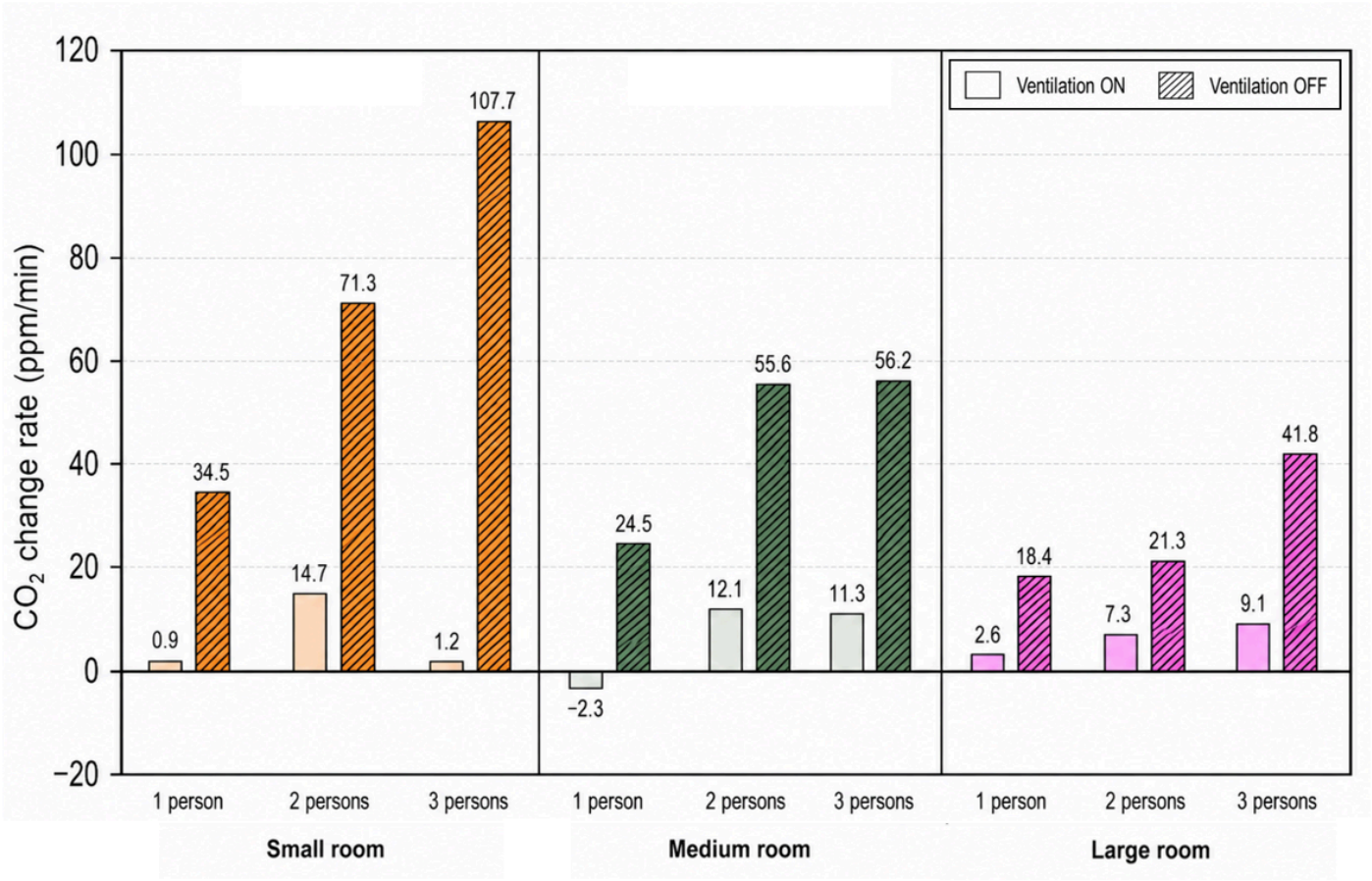


Figure 2

Comparison of CO_2 change rates under Ventilation ON and OFF conditions

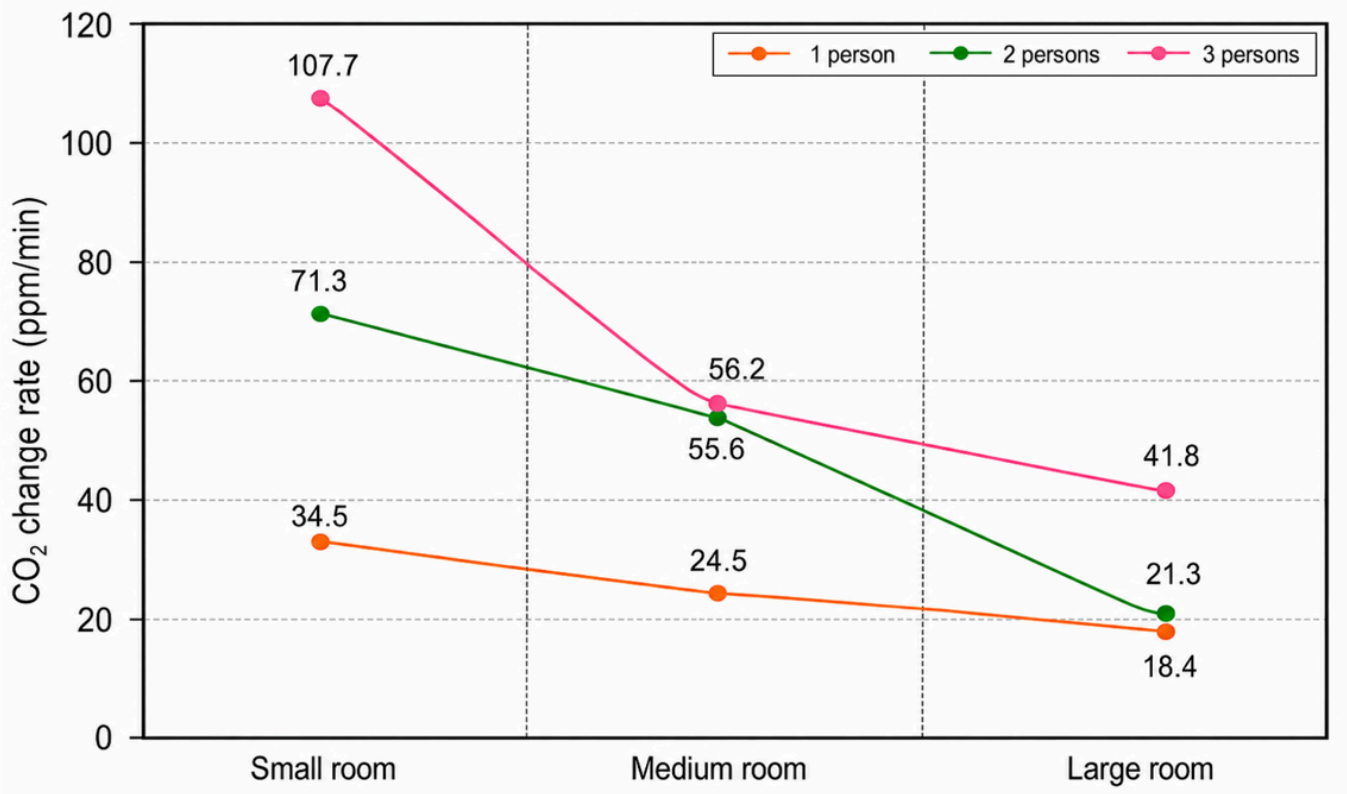


Figure 3

Comparison of CO_2 change rates according to room type and occupancy under Ventilation OFF conditions

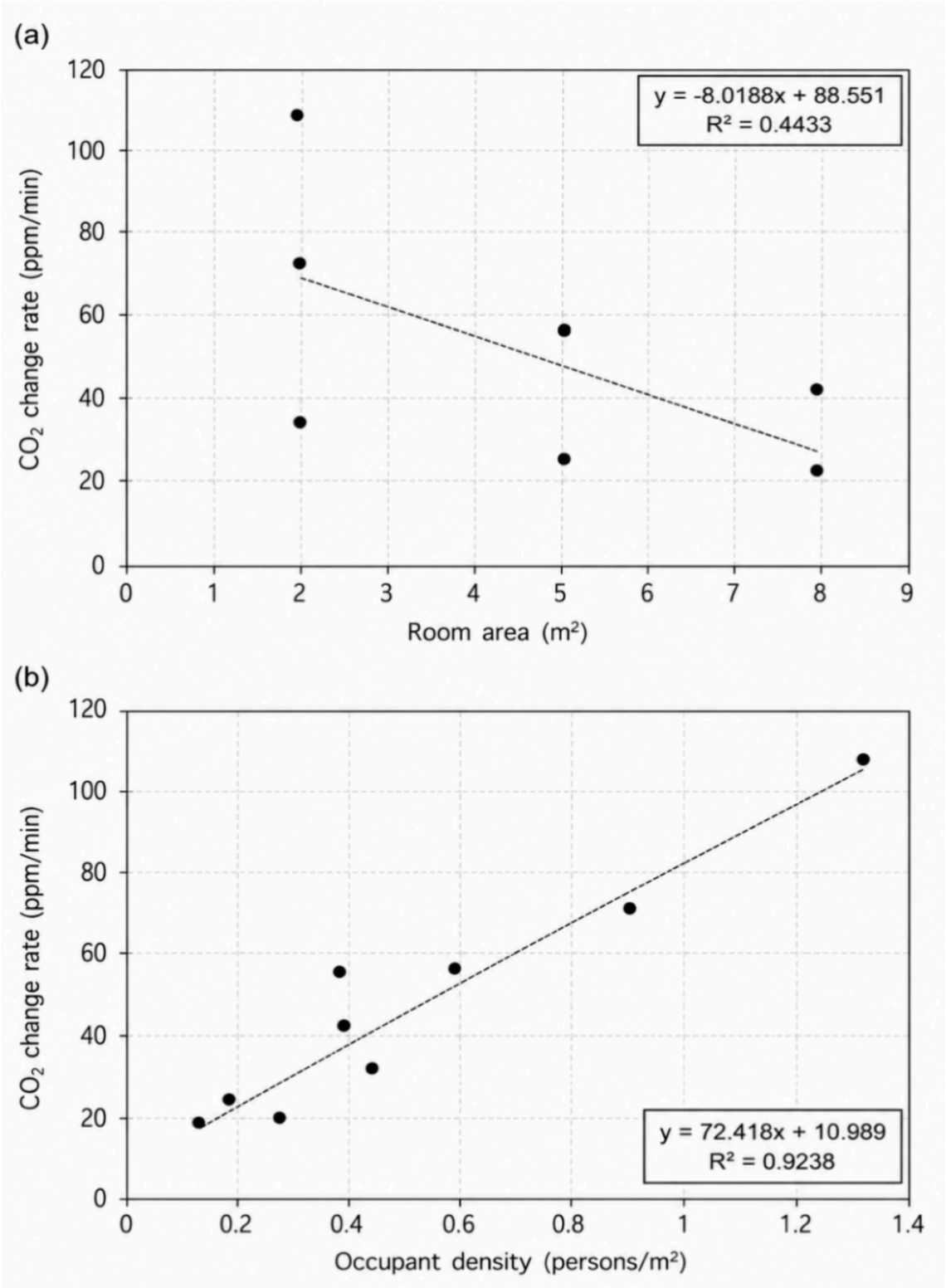


Figure 4

Relationships of room area and occupant density with CO_2 change rate under Ventilation OFF conditions: (a) Room area, (b) Occupant density

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx