ISSN: 2834-4928

Research Article

Journal of Electrical Electronics Engineering

Ventilation Inadequacy Revealed by Indoor CO_2 Dynamics in A Densely Occupied University Classroom Under Controlled and Real-Use Conditions

Wang Han Sheng*

Independent Researcher, China

***Corresponding Author**
Wang Han Sheng, Independent Researcher, China.

Submitted: 2026, Mar 10; **Accepted:** 2026, Apr 13; **Published:** 2026, Apr 27

Citation: Sheng, W. H. (2026). Ventilation Inadequacy Revealed by Indoor CO_2 Dynamics in A Densely Occupied University Classroom Under Controlled and Real-Use Conditions. *J Electrical Electron Eng, 5*(2), 01-12.

Abstract
Indoor air quality (IAQ) in higher-education environments has received increasing attention due to its implications for occupant health, comfort, and cognitive performance. Carbon dioxide (CO_2) is widely used as a practical indicator of ventilation adequacy and occupant-related pollutant accumulation. However, empirical evidence quantifying ventilation performance under both controlled and real teaching conditions in air-conditioned university classrooms remains limited, particularly in subtropical regions.

In this study, continuous CO_2 monitoring was conducted in a university classroom under three controlled experiments with fixed occupancy and five regular teaching sessions with high occupant density. A mass-balance modeling approach was applied to quantify air exchange rates and human CO_2 emission factors. Under controlled conditions, indoor CO_2 concentrations increased from background levels to 610–720 ppm, with estimated air exchange rates ranging from 1.60 to 1.79 h^{-1}. During regular teaching sessions, CO_2 concentrations frequently exceeded the regulatory threshold of 1,000 ppm, reaching peak values of 1,000–1,450 ppm, despite continuous air-conditioning operation. Although air exchange rates during real classroom use were higher than those observed under controlled conditions, they remained insufficient to offset the substantially increased emission load associated with dense occupancy.

These results demonstrate a systematic ventilation inadequacy in a typical air-conditioned university classroom, where thermal comfort does not necessarily translate into adequate outdoor air supply. The findings highlight the importance of CO_2-based ventilation assessment and management strategies for improving IAQ in higher-education learning environments.

Keywords: Indoor Air Quality, Carbon Dioxide, University Classroom, Ventilation Adequacy, Air Exchange Rate, Mass-Balance Model

1. Introduction

Indoor air quality (IAQ) has become an important environmental and public health issue as modern populations spend the majority of their time indoors. In educational settings, particularly universities, students and instructors may remain in enclosed classrooms for extended periods, making indoor pollutant exposure a critical factor influencing comfort, health, and cognitive performance [1,2]. Poor IAQ has been associated with symptoms such as headache, fatigue, and reduced concentration, which may directly affect learning efficiency and academic outcomes.

Among various IAQ indicators, carbon dioxide (CO_2) is commonly used as a surrogate parameter for ventilation adequacy and occupant-related pollutant accumulation. Although CO_2 itself is not toxic at concentrations typically encountered indoors, elevated levels often indicate insufficient outdoor air supply and have been linked to degraded perceived air quality and impaired cognitive performance [3]. Consequently, CO_2 monitoring has been widely adopted as a practical tool for evaluating ventilation performance in occupied indoor environments.

University classrooms present particular challenges for ventilation management due to high occupant density, intermittent usage patterns, and frequent reliance on air-conditioning systems with limited fresh-air intake. In many subtropical and warm-climate regions, classrooms are primarily designed to maintain thermal comfort rather than to ensure adequate ventilation, resulting in a potential disconnect between cooling performance and IAQ. Previous studies have reported that CO_2 concentrations in classrooms frequently exceed recommended limits during teaching periods, even when mechanical cooling systems are in operation.

Despite growing research on classroom IAQ, several knowledge gaps remain. Many existing studies rely on short-term measurements or focus on either controlled experimental settings or real classroom observations alone, without directly comparing these two scenarios within the same indoor environment [4-6]. Moreover, empirical data quantifying both air exchange rates and per-person CO_2 emission factors in air-conditioned university classrooms, particularly in subtropical regions, remain limited.

To address these gaps, this study investigates the temporal dynamics of indoor CO_2 concentrations in a university classroom through an integrated approach combining controlled experiments and real teaching sessions. By applying a mass-balance modeling framework to continuous CO_2 measurements, air exchange rates and human CO_2 emission factors were quantified under both scenarios. This dual-scenario design enables a systematic evaluation of ventilation performance and provides empirical evidence of ventilation adequacy—or inadequacy—under realistic classroom conditions.

2. Materials and Methods

This section outlines the study site characteristics, instrumentation, monitoring design, and analytical methods used to quantify the indoor CO_2 dynamics, air exchange rates, and human CO_2 emission factors. A mass-balance modeling approach was applied to evaluate ventilation performance under both controlled experimental conditions and actual classroom occupancy.

2.1. Study Site

The investigation was conducted at National Chung Cheng University (CCU), located in Minxiong Township, Chiayi County, Taiwan. The campus lies within the Yun-Chia-Nan Air Quality Region and is characterized by a subtropical monsoon climate with distinct seasonal variabilities in temperature, humidity, and prevailing wind patterns. The university occupies an area of approximately 134.23 hectares and accommodates nearly 11,000 students and faculty.

Indoor CO_2 monitoring was performed in Classroom 102 of the Earth Sciences Building (referred to as the “Seismology Hall”) within the College of Science. The classroom was selected because it represents a typical university lecture environment with common ventilation conditions [7-10]. The room is equipped with ceiling-mounted split-type air-conditioning units and has limited natural ventilation, except for a single entrance door and windows along one side of the room. This enclosed setting provides a suitable environment for assessing CO_2 accumulation and ventilation performance during teaching activities.

2.2. Instrumentation

Indoor CO_2 concentrations were measured using a calibrated **nondispersive infrared (NDIR) CO_2 analyzers** (Model HPC-AN15AD-TM, Han-Ping Corp., Taiwan). The instrument has a measurement range of 0–5,000 ppm (0–9,150 mg/m^3), an accuracy of ±30 ppm or ±3% of the reading (whichever is greater), and a resolution of 1 ppm. The analysis was factory-calibrated prior to the campaign, and a two-point field calibration check was performed using zero air and a certified standard span gas (1,000 ppm).

Air samples were drawn through a **5 m polytetrafluoroethylene (PTFE)** sampling tube to minimize adsorption or chemical interaction. The sampling inlet was positioned approximately 1.1 m above the floor to represent the human breathing zone and to avoid stratification biases. Indoor temperature and relative humidity were simultaneously recorded using a HOBO data logger (Onset Computer Corporation, USA) to support interpretation of CO_2 variations under different thermal conditions. For reference, outdoor CO_2 concentrations were periodically measured near the building entrance.

2.3. Monitoring Design

Indoor CO_2 concentrations were monitored under two distinct scenarios:
(1) **Controlled Experiments** with a fixed number of occupants and ventilation settings and
(2) **Real Classroom Teaching Sessions** with naturally varying occupancies.
The monitoring period consisted of three controlled experiments, each lasting approximately 60–90 min, and five classroom sessions lasting 100–150 min. All monitoring was performed on weekdays during regular academic schedules. In the controlled setting, seven volunteer participants remained seated and refrained from unnecessary movement to standardize metabolic CO_2 output. The classroom door remained closed, windows were slightly opened (~3–5 cm), and the air conditioning system was operated continuously at a constant fan speed.

During actual teaching sessions, the instructor conducted the class under routine conditions, and no restrictions were imposed on student movement or behavior. Occupancy ranged from 42 to 52 individuals. Entry and exit times, door opening frequency, and noticeable changes in ventilation conditions were recorded throughout the sessions.

Indoor CO_2 concentrations were logged at **10-second intervals (0.1 Hz)** to capture short-term variations. The temporal resolution allowed accurate analysis of the CO_2 build-up and decay phases, ensuring reliable estimation of air exchange and emission rates.

2.4. Mass-Balance Model for CO_2 Dynamics

Changes in the indoor CO_2 concentration were analyzed using a standard **mass-balance model**, which assumes that CO_2 within the classroom is well mixed. The temporal variation in the CO_2 concentration is governed by the following differential equation:

$$\frac{dC(t)}{dt} = a[C_{\text{out}} - C(t)] + \frac{S}{V} \qquad (1)$$

where

$C(t)$ = indoor CO_2 concentration at time (ppm)
C_{out} = outdoor CO_2 concentration (ppm)
a = air exchange rate (h^{-1})
S = total indoor CO_2 emission rate (mg/h)
V = volume of the classroom (m^3)

To accommodate regulatory reporting conventions, CO_2 concentrations are presented primarily in ppm, with equivalent values in mg/m³ given in parentheses. The conversion was performed as follows:

$$CO_2\ (\text{mg/m}^3) = CO_2\ (\text{ppm}) \times 1.83 \qquad (2)$$

assuming 25°C and 1 atm pressure.

- **Decay Phase (Calculation of the Air Exchange Rate)**

During the decay phase—after occupants exited the classroom—the emission term becomes negligible, and Equation (1) simplifies to:

$$\frac{dC(t)}{dt} = a[C_{\text{out}} - C(t)] \qquad (3)$$

The solution yields:

$$\ln\left(C(t) - C_{\text{out}}\right) = -at + \ln\left(C_0 - C_{\text{out}}\right) \qquad (4)$$

where C_0 is the indoor CO_2 concentration at the start of decay.

The air exchange rate a was determined as the **slope of the linear regression** of $\ln(C(t)-C_{out})$ versus time.

- **Bulit-Up Phase (Calculation of the CO_2 Emission Rate)**

During occupancy, CO_2 increases toward a steady-state concentration. The emission rate was estimated from the rising curve using:

$$S = V\left[\frac{dC(t)}{dt} + a(C(t) - C_{\text{out}})\right] \qquad (5)$$

For each experiment, S was computed over 5-min intervals during the build-up phase to reduce noise and improve the stability of the estimates.

The **per-person emission rate (SP)** was then derived as follows:

$$SP = \frac{S}{N} \qquad (6)$$

where N is the number of occupants.

2.5. Data Processing and Quality Control

All CO_2 time-series data were screened to remove anomalous spikes caused by sudden door opening, instrument disturbance, or sensor resetting. Outliers exceeding three standard deviations from local running means were inspected and removed only when attributable to nonrepresentative events [11]. The data were then smoothed using a 30-second moving average to reduce high-frequency noise while retaining short-term dynamic responses.

For each experiment and class session, the following procedures were applied:

- **Identification of Key Time Intervals:**
- background period,
- build-up phase,
- steady state (if reached), and
- decay phase.

- **Estimation of Parameters:**
  Air exchange rates were estimated from the decay phase;
  CO_2 emission rates and were computed from the build-up phase.

- **Cross-Validation:**

The calculated and values were cross-validated using multiple time windows to ensure consistency. Results differing by >15% were re-evaluated for data noise or unrecorded ventilation events.

Instrument calibration records and environmental metadata were archived to ensure reproducibility.

2.6. Ethical Considerations

All participants involved in the controlled experiments were adult volunteers recruited from the university and provided informed consent. No personal data was collected, and no physiological measurements were taken [12]. The study exclusively monitored indoor CO_2 levels and general environmental parameters; therefore, it did not involve human subject research requiring institutional review board (IRB) approval. Nonetheless, ethical guidelines on privacy and voluntary participation were strictly followed.

2.7. Summary of Methods

This study combined continuous CO_2 monitoring with mass-balance modeling to evaluate the indoor ventilation performance and human CO_2 emissions in a university classroom. Table 1 summarizes the key parameters and variables adopted in this study.

Symbol	Definition	Unit
$C(t)$	Indoor CO_2 concentration at time	ppm (mg/m³)
C_{out}	Outdoor CO_2 concentration	ppm (mg/m³)
a	Air exchange rate	h^{-1}
S	Total CO_2 emission rate	mg/h
SP	Per-person CO_2 emission rate	mg/h/person
N	Number of occupants	persons
V	Indoor volume of classroom	m³

The methodological framework enabled quantitative assessment of CO_2 accumulation and removal under both controlled and real classroom occupancy conditions, providing a robust basis for identifying ventilation inefficiencies and informing IAQ improvement strategies.

3. Results

Background CO_2 concentrations prior to occupancy ranged from approximately 430 to 470 ppm and were comparable between indoor and outdoor environments, indicating stable initial conditions. Under controlled experimental conditions, CO_2 concentrations increased to 610–720 ppm, with air exchange rates of 1.60–1.79 h^{-1}, remaining below commonly recommended ventilation levels for classrooms.

During regular teaching sessions with 42–52 occupants, CO_2 concentrations rose rapidly and frequently exceeded the 1,000-ppm threshold, reaching peaks of 1,000–1,450 ppm. Although air exchange rates during real-use conditions were higher (1.72–3.46 h^{-1}), they were insufficient to counterbalance the increased emission load associated with dense occupancy. These results indicate that increased ventilation rates do not necessarily guarantee acceptable IAQ when occupant density is high.

4. Discussion

The findings demonstrate that air exchange rate alone is an incomplete indicator of ventilation adequacy in densely occupied classrooms. While higher air exchange rates were observed during real classroom use, CO_2 concentrations still exceeded regulatory limits, highlighting a mismatch between ventilation capacity and occupant-driven emission loads.

From an IAQ management perspective, reliance on intermittent behavioral interventions, such as door opening or window adjustment, is insufficient for maintaining acceptable CO_2 levels. Continuous CO_2 monitoring offers a practical and low-cost tool for real-time assessment of ventilation performance and can support timely interventions, including increased outdoor air supply or occupancy management.

Regulatory frameworks based on time-averaged CO_2 concentrations may underestimate short-term exposure peaks during classroom occupancy. Ventilation systems capable of dynamically responding to occupancy variations, such as demand-controlled or hybrid ventilation strategies, may be necessary to ensure both thermal comfort and adequate IAQ in university classrooms.

5. Conclusion

This study provides empirical evidence of systematic ventilation inadequacy in a typical air-conditioned university classroom [13]. Despite continuous air-conditioning operation, ventilation rates were insufficient to maintain indoor CO_2 concentrations below recommended limits during high-occupancy teaching sessions. These findings underscore the need for CO_2-based ventilation assessment and improved IAQ management strategies in higher-education environments.

Acknowledgement

The author would like to express his deepest gratitude to Professor Cheng-Wei Fan, whose patience, guidance, and encouragement have been invaluable throughout the course of this research. Professor Fan not only provided insightful advice on theoretical analysis and CO_2 monitoring techniques but also offered personal support during a period of financial and emotional difficulty, which enabled the author to persevere through the challenges of academic and personal life.

The author also extends sincere appreciation to Professor Bing-Mu Hsu, whose valuable feedback during the final stages of this thesis greatly improved its academic quality. Special thanks are given to Mr. Cheng-Yu Wu for his technical assistance in data processing and Excel-based analysis, which significantly enhanced the precision of the study. The author is also indebted to Professor Chien-Yi Chen and Professor Ching-Yi Hung, the oral defense committee members, for their constructive comments that contributed to refining the final manuscript.

Grateful acknowledgment is also made to the author's colleagues and classmates in the Executive Master's Program at National Chung Cheng University. Their companionship, encouragement, and guidance—particularly from Hui-Ting Hsu, Geng-Chang Chang, Chien-Chung Huang, and Kuan-Yi Lin—played a crucial role in both academic achievement and personal growth. The author would also like to thank Mr. Yi-Shen Tsai and other classmates for their kindness and support, which provided motivation during difficult times and helped restore the author's confidence and direction in life.

Finally, the author wishes to express heartfelt gratitude to his wife and to Dr. Li-Chun Chang of the Division of Gastroenterology, Department of Internal Medicine, National Taiwan University Hospital. The author’s wife has been a constant source of strength and understanding during the most challenging period of his life, while Dr. Chang’s dedicated medical care and encouragement during a severe episode of acute hepatitis were instrumental in enabling the author to complete this thesis.

The author sincerely thanks all professors, committee members, laboratory colleagues, classmates, and medical professionals whose guidance, support, and compassion made this academic journey possible.

Highlights

- Continuous indoor CO_2 monitoring was conducted under both controlled and real classroom occupancy conditions.
- Air exchange rates were quantified using a mass-balance model based on the temporal variation in CO_2 concentrations.
- CO_2 emission factors per person were estimated and compared between controlled experiments and actual teaching sessions.
- Indoor CO_2 frequently exceeded 1,000 ppm (1,830 mg/m^3), surpassing regulatory limits and indicating insufficient ventilation.

These findings provide evidence-based implications for IAQ assessment in higher education learning environments.

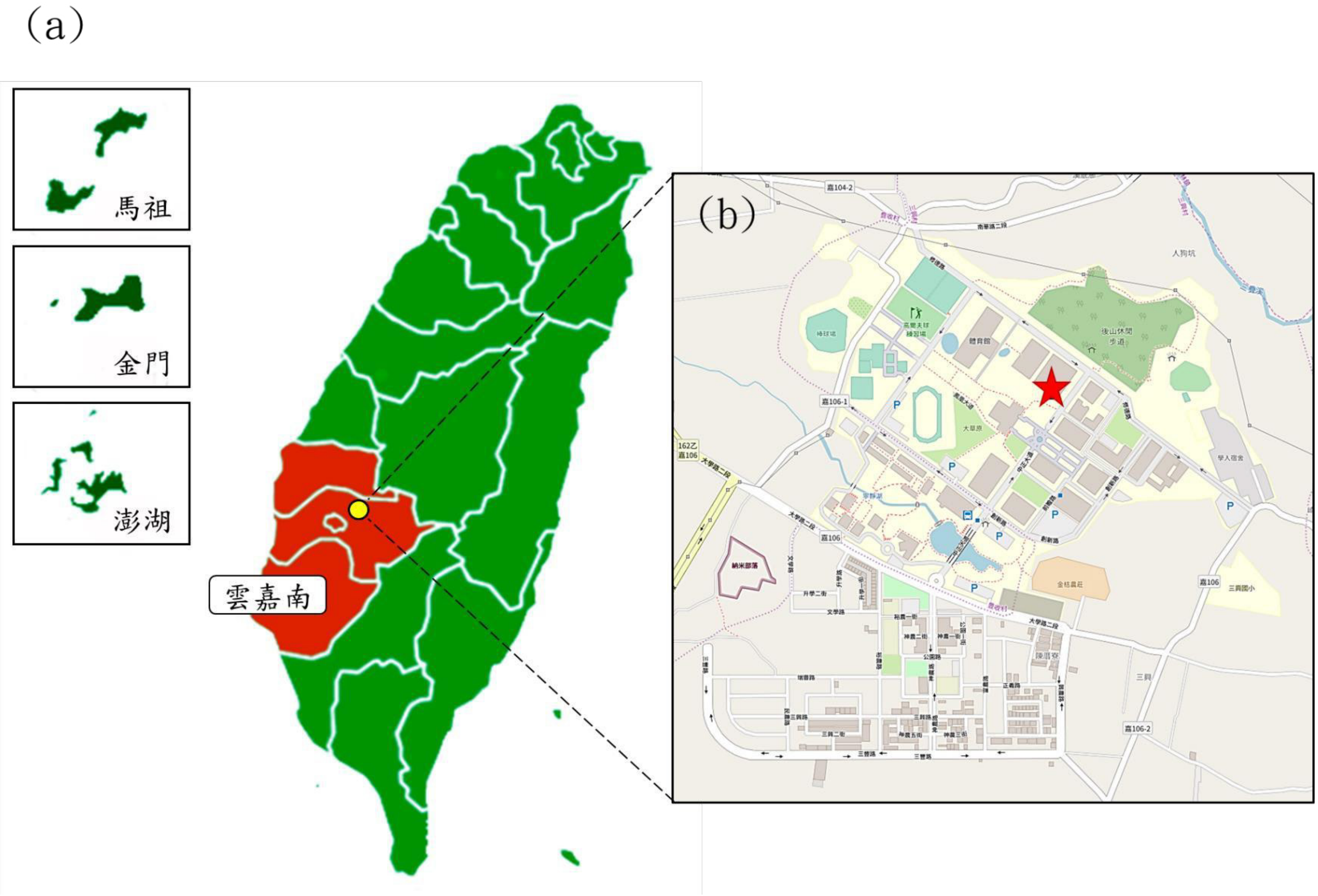
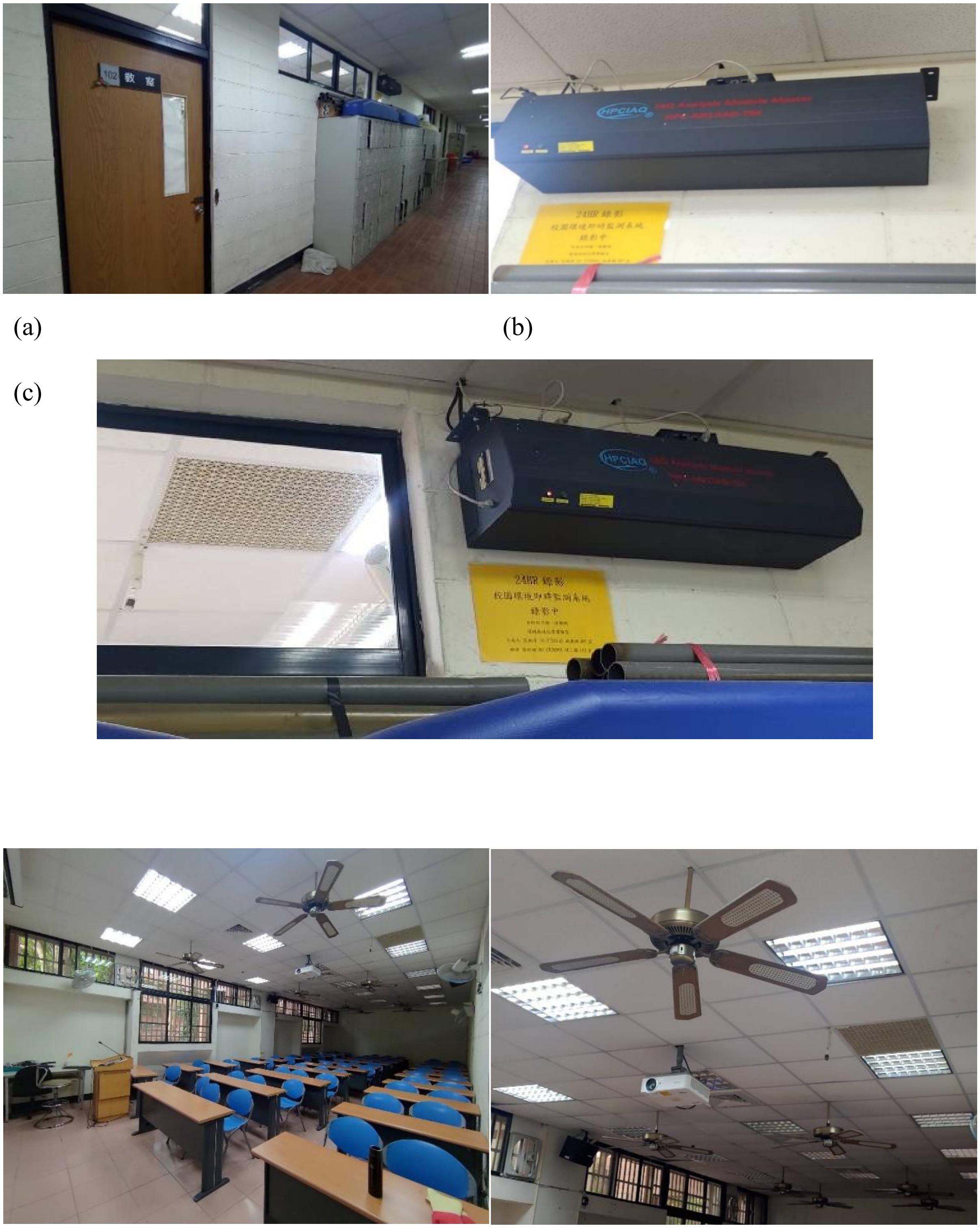


Figure 1: Location of National Chung Cheng University within the Yun-Chia-Nan Air Quality Region in Taiwan

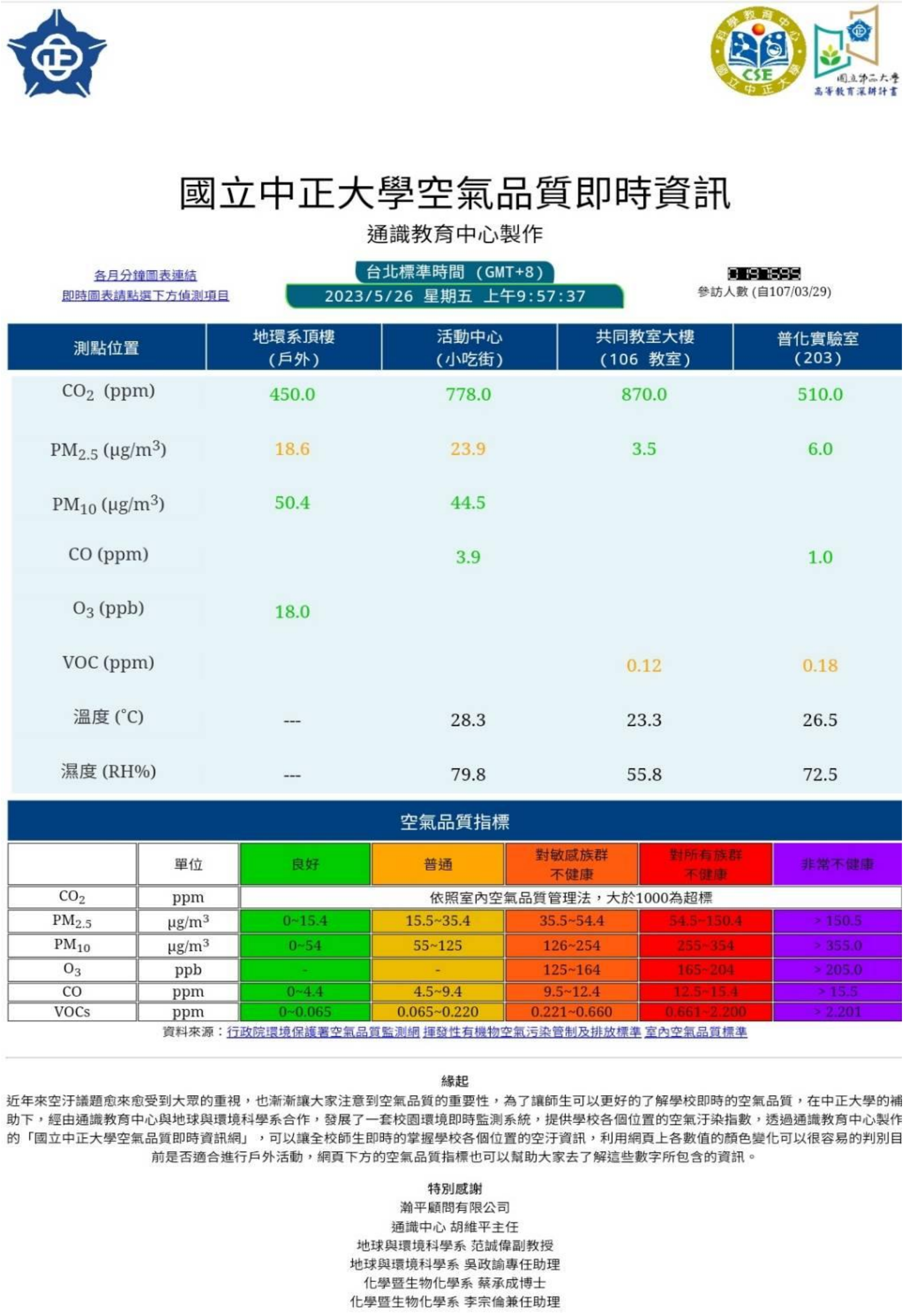


(a) (b)

(c)

(d) (e)

Figure 2: Floor plan of the monitored classroom in the Earth Sciences Building showing the sampling inlet and instrument placement



國立中正大學空氣品質即時資訊

通識教育中心製作

各月分鐘圖表連結

即時圖表請點選下方偵測項目

台北標準時間（GMT+8）

2023/5/26 星期五 上午9:57:37

0197695

參訪人數 (自107/03/29)

測點位置	地環系頂樓（戶外）	活動中心（小吃街）	共同教室大樓（106 教室）	普化實驗室（203）
CO_2 (ppm)	450.0	778.0	870.0	510.0
$PM_{2.5}$ (μg/m^3)	18.6	23.9	3.5	6.0
PM_{10} (μg/m^3)	50.4	44.5		
CO (ppm)		3.9		1.0
O_3 (ppb)	18.0			
VOC (ppm)			0.12	0.18
溫度 (°C)	---	28.3	23.3	26.5
濕度 (RH%)	---	79.8	55.8	72.5

空氣品質指標

	單位	良好	普通	對敏感族群不健康	對所有族群不健康	非常不健康
CO_2	ppm	依照室內空氣品質管理法，大於1000為超標				
$PM_{2.5}$	μg/m^3	0~15.4	15.5~35.4	35.5~54.4	54.5~150.4	> 150.5
PM_{10}	μg/m^3	0~54	55~125	126~254	255~354	> 355.0
O_3	ppb	-	-	125~164	165~204	> 205.0
CO	ppm	0~4.4	4.5~9.4	9.5~12.4	12.5~15.4	> 15.5
VOCs	ppm	0~0.065	0.065~0.220	0.221~0.660	0.661~2.200	> 2.201

資料來源：行政院環境保護署空氣品質監測網 揮發性有機物空氣污染管制及排放標準 室內空氣品質標準

緣起

近年來空汙議題愈來愈受到大眾的重視，也漸漸讓大家注意到空氣品質的重要性，為了讓師生可以更好的了解學校即時的空氣品質，在中正大學的補助下，經由通識教育中心與地球與環境科學系合作，發展了一套校園環境即時監測系統，提供學校各個位置的空氣汙染指數，透過通識教育中心製作的「國立中正大學空氣品質即時資訊網」，可以讓全校師生即時的掌握學校各個位置的空汙資訊，利用網頁上各數值的顏色變化可以很容易的判別目前是否適合進行戶外活動，網頁下方的空氣品質指標也可以幫助大家去了解這些數字所包含的資訊。

特別感謝

瀚平顧問有限公司

通識中心 胡維平主任

地球與環境科學系 范誠偉副教授

地球與環境科學系 吳政諭專任助理

化學暨生物化學系 蔡承成博士

化學暨生物化學系 李宗倫兼任助理

Figure 3: Indoor CO₂ concentration time series for the three controlled experiments, showing build-up and decay patterns

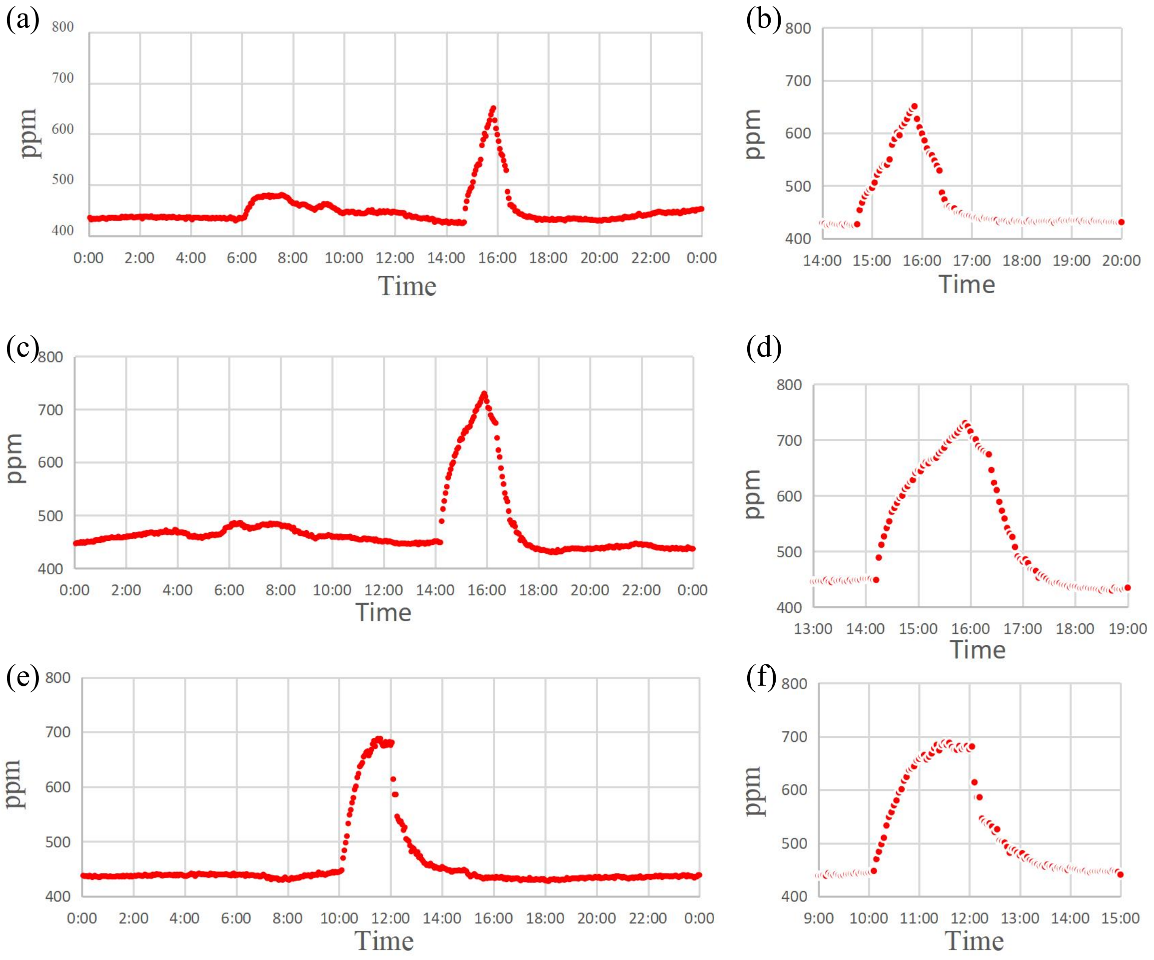
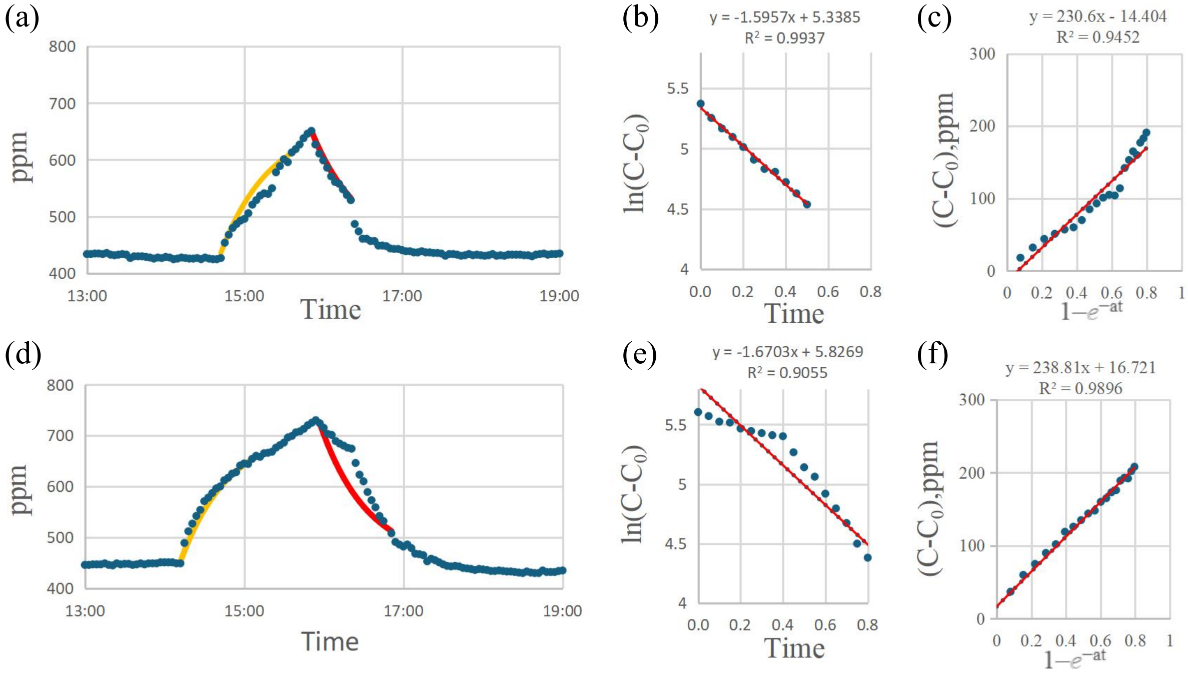


Figure 4: Linear regression of ln(C(t) − Cout) versus time for decay analysis to determine air exchange rates (a)



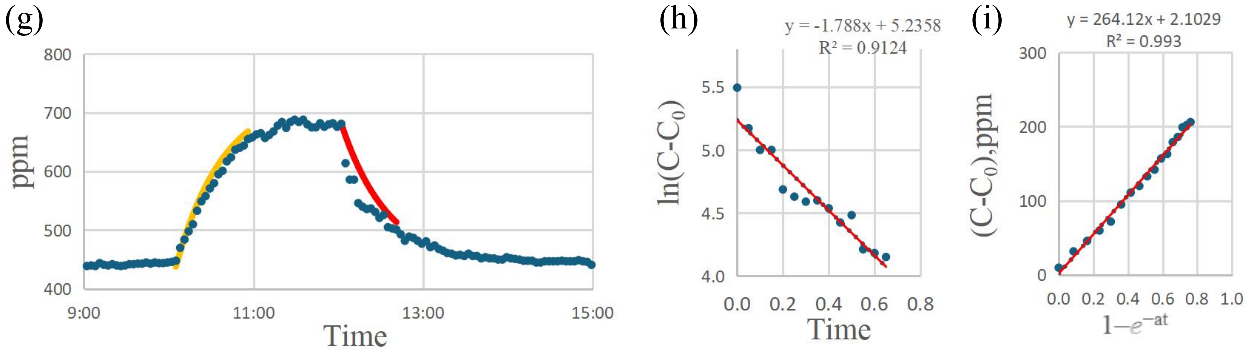
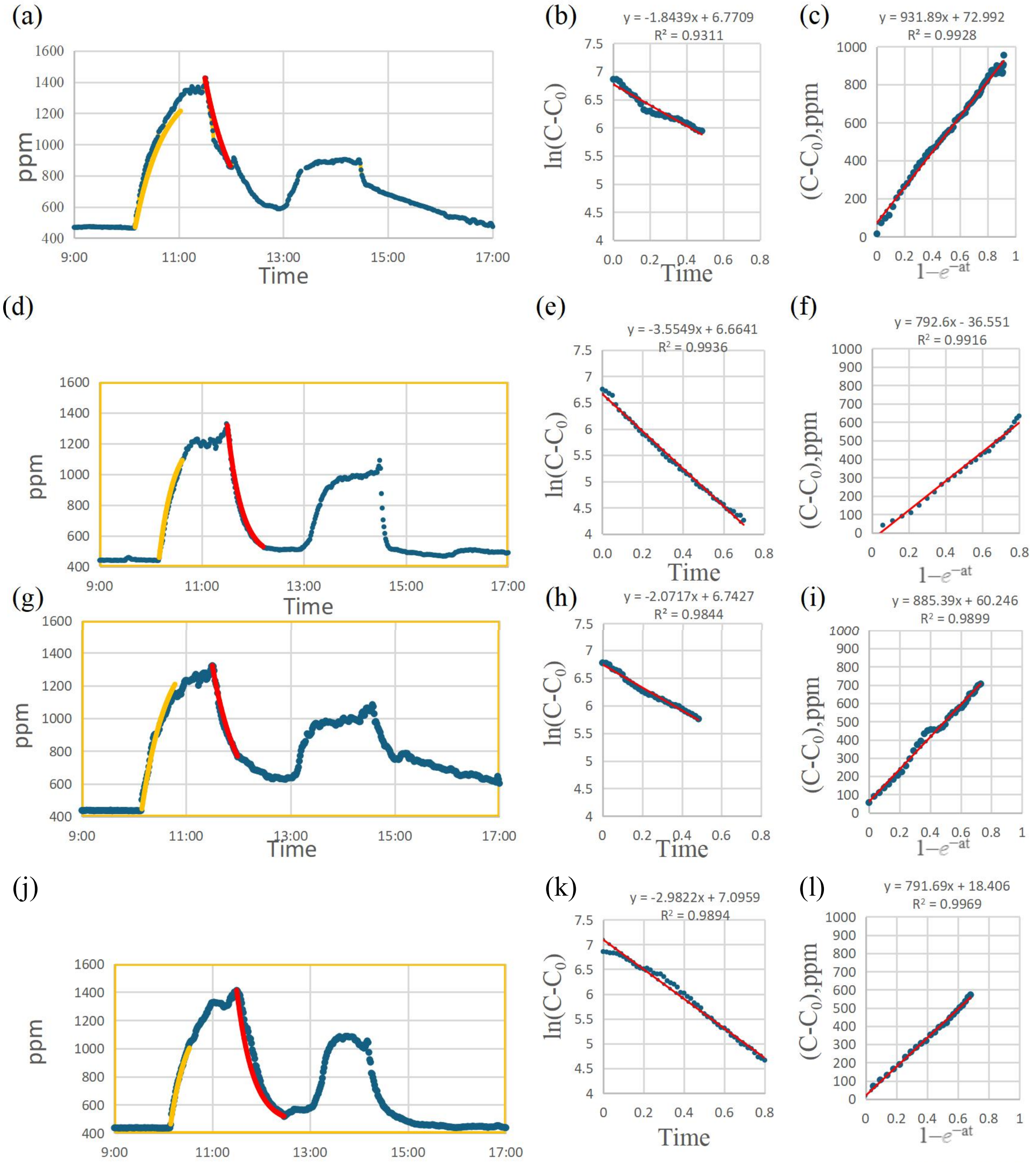


Figure 5: CO₂ concentration profiles during five regular teaching sessions, indicating peak values and exceedances of the 1,000 ppm threshold



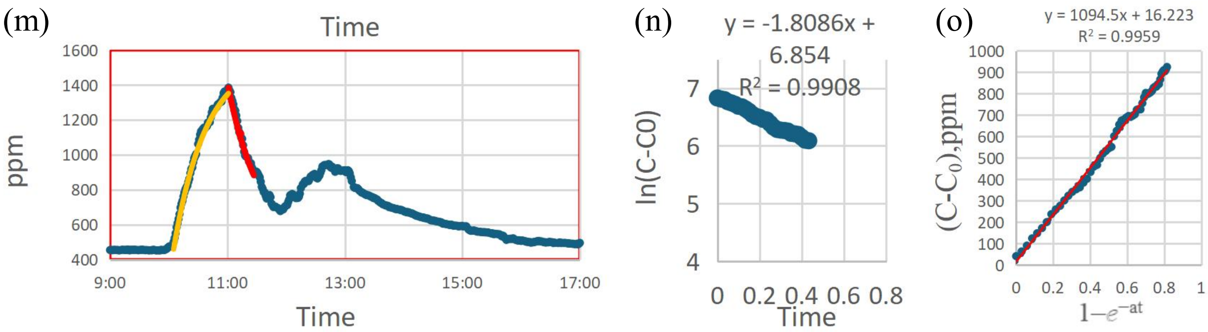


Figure 6: Comparison of air exchange rates between controlled experiments and actual classroom sessions

Item	**Standard Averaging**	**Standard Value Period**	**Unit**
Carbon dioxide			
(CO_2)	8-hour average	1000	ppm (parts per million by volume)
Carbon monoxide			
(CO)	8-hour average	9	
Formaldehyde (HCHO)	1-hour average	0.08	
Total volatile organic compounds (TVOC, including the sum of 12 volatile organic compounds)	1-hour average	0.56	
Ozone (O_3)	8-hour average	0.06	
Bacteria	Maximum value	1500	CFU/m³ (colony-forming units per cubic meter)
FungiSS	Maximum value	1000	
Particulate matter ≤10 µm (PM_{10}))	24-hour average	75	µg/m³ (micrograms per cubic meter)

Table 1: Summary of key variables and symbols used in the CO_2 mass-balance model

Notes

1. **1-hour Average:** Refers to the arithmetic means of measurements obtained within one hour or the value from cumulative sampling over one hour.
2. **8-hour Average:** Refers to the arithmetic means of measurements obtained continuously over eight hours or the value from cumulative sampling over eight hours.
3. **24-hour Average:** Refers to the arithmetic means of measurements obtained continuously over twenty-four hours or the value from cumulative sampling over twenty-four hours.
4. **Maximum Value:** Refers to the sampling and analytical value obtained following the sampling methods specified by the central competent authority.
5. **Total Volatile Organic Compounds (TVOCs):** The TVOC standard is based on the total concentration of twelve volatile organic compounds, including benzene, carbon tetrachloride, chloroform (trichloromethane), 1,2-dichlorobenzene, 1,4-dichlorobenzene, dichloromethane, ethylbenzene, styrene, tetrachloroethylene, trichloroethylene, toluene, and xylene (para-, meta-, and ortho-isomers).
6. **The Indoor-To-Outdoor Fungal Concentration Ratio** was defined as the ratio of the indoor fungal concentration to the outdoor fungal concentration. The relative sampling positions for the indoor and outdoor sites complied with the *Regulations for Indoor Air Quality Inspection and Determination Methods* issued by the Environmental Protection Administration (EPA) of Taiwan.
7. **Source:** Environmental Protection Administration, Executive Yuan, Taiwan.

	Event number	**date**	**member**	**Laboratory time**	***a value* initial time**	***S value* Initial time**
1	200813 (Th)	2020/8/13	7	14:39~ 16:20	15:51~16:21	14:42~15:42
2	200818 (Tu)	2020/8/18	7	14:10~ 16::45	15:57~16:51	14:12~15:09
3	200820 (Th)	2020/8/20	7	10:05~ 13:00	12:03~12:42	10:06~10:51

Table 2: Background indoor and outdoor CO_2 concentrations prior to each experiment and class session

	Event number	**C_0 0ppm**	**C_f 0ppm**	**a h^{-1}**	**R^2**	***n***
1	200813 (Th)	436	651	1.60	0.9937	11
2	200818 (Tu)	452	724	1.67	0.9055	19
3	200820 (Th)	438	681	1.79	0.9124	14
Average value		4429	68537	1.690.09		

Table 3: Summary of CO_2 build-up characteristics and per-person emission rates for controlled experiments

	Event number	**C_o**	***n***	***S/V/a* (ppm)**	**R^2**	***S* g/h**	**member**	**Sp**
1	200813 (Th)	436	21	231	0.9495	162	7	23.1
2	200818 (Tu)	452	20	239	0.9896	176	7	25.1
3	20020 (Th)	438	16	263	0.9923	208	7	29.5
Average value		442 ± 9		244 ± 17		182 ± 24		25.9 ± 3.3

Table 4: Air exchange rates derived from decay-phase analysis for controlled experiments and classroom sessions

	Event number	**C_0 ppm**	**C_f ppm**	**a h^{-1}**	**R^2**	***n***
1	220907 (wed)	471	1426	1.84	0.9311	30
2	220914 (wed)	459	1318	3.55	0.9936	43
3	220919 (mom)	447	1322	2.07	0.9844	30
4	220921 (wed)	464	1413	2.98	0.9894	59
5	220928 (wed)	460	1385	1.80	0.9908	27
Average value		4609	137350	2.450.78		

Table 5: Peak CO_2 concentrations and exceedance duration for each monitored classroom session

	Event number	**C_o**	***n***	***S*/*V*/*a* (ppm)**	**R^2**	***S* g/h**	**member**	***Sp***
1	220907 (wed)	471	53	952	0.9948	774	42	18.4
2	220914 (wed)	459	28	793	0.9916	1242	46	27.0
3	220919 (mom)	447	39	885	0.9899	808	52	18.3
4	220921 (wed)	464	24	792	0.9869	1041	52	20.0
5	220928 (wed)	460	57	1095	0.9959	872	49	17.8
Average value		460 ± 9		909 ± 127		947. ± 194		20.4 ± 4.4

Table 6: Peak CO_2 concentrations and exceedance duration for each monitored classroom session

References

1. Chang, Y. Y. (2020). *Regional variation of fine particulate matter concentration and meteorological data in campus environments*. Master's thesis, National Chung Cheng University, Chiayi, Taiwan.
2. Huang, K. C. (2019). *Analysis and improvement of indoor air quality in classrooms*. Master's thesis, National Chin-Yi University of Technology, Taichung, Taiwan.
3. Chen, C. W. (2015). *Discussion on the application of carbon dioxide monitoring results in workplace environments*. Research report, Institute of Labor, Occupational Safety and Health, Ministry of Labor, Taipei, Taiwan.
4. Indoor Air Quality Association Taiwan. *Understanding indoor air quality* (2022).
5. New Taipei City Environmental Protection Department. *Indoor pollution prevention: Indoor air quality and pollutant testing methods and standards*.
6. Laws & Regulations Database of The Republic of China (Taiwan). *Indoor Air Quality Management Act*.
7. Environmental Protection Administration, Executive Yuan. *Indoor Air Quality Information Platform*.
8. Fan C.W., Zhang, J. F. (2001). Characterization of emissions from portable household combustion devices: particle size distributions, emission rates and factors, potential exposures. *Atmos. Environ. 35*, 1281–1290.
9. Hines, A. L., Ghosh, T. K., Loyalka, S. K., Warder, R. C. (1993). Jr. *Indoor Air: Quality and Control*. Englewood Cliffs, NJ: Prentice-Hall.
10. McNeil, V.-F. (2022). Room-level ventilation in schools and universities. *Atmos. Environ.: X 13*, 100152.

11. Vesilind, P. A., Morgan, S. M., Heine, L. G. (2010). *Introduction to Environmental Engineering*, 3rd edn. Stamford, CT: Cengage Learning.
12. Westgate, S., Ng, N. L. (2022). Using in-situ CO_2, PM_1, $PM_{2.5}$, and PM_{10} measurements to assess air change rates and indoor aerosol dynamics. *Build. Environ. 224*, 109559.
13. Yan, Y., Niu, C., Zhou, J., Liu, Y.T., Bai, Z.P., Zhang, J.F. & Zhang, N. (2012). Measurement of air exchange rates in different indoor environments using continuous CO_2 sensors. *J. Environ. Sci. 24*, 657–664.

Copyright: *©2026 Wang Han Sheng. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.*