

Post-Pandemic Campus Return: Evidence-Based Decision-Making for university learning spaces in Egypt

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ABSTRACT: Since March 2020, the pandemic forced higher-education students into remote learning. Since Autumn 2021, universities across the globe, including the American University in Cairo (AUC-Egypt), have set out plans to return to face-to-face instruction. The safety of learning spaces and the control of pathogen transmission are now decisive parameters in the planning and continuation of this physical return. This research presents some of the first findings collected from learning spaces post-COVID return in Egypt. The study gathers data for four learning spaces with varied characteristics and schedules, including CO2 concentration, occupancy, temperature, humidity, and behavioural dimensions such as doors, windows, and HVAC use. The findings highlight that the four spaces generally remained within the temperature and humidity comfort zone during occupied hours. Most of the time, the spaces remained below the 800 ppm threshold proposed for low transmission. With some exceptions, reduced occupancy allowances were also met. However, the ventilation rates estimated for the spaces are considerably low: barely meeting traditional standards and far from the enhanced ventilation proposed in recent COVID guidelines. The outcomes of this research are used to improve the current local and institutional policies to ensure that learning spaces are healthy, comfortable, and safe.

KEYWORDS: Post-COVID, Learning Spaces, CO2 Concentration, Health, Ventilation

1. INTRODUCTION

The environmental quality of enclosed spaces, which is impacted by factors such as air change rate, directly affects occupants' health and well-being and plays a vital role in controlling pathogen transmission. In the context of learning spaces, indoor environmental conditions are critical for student cognitive performance and the health and safety of students who will soon be returning to campuses. Over 3.3 million students are currently enrolled in higher-education institutes in Egypt. Since March 2020, they have been forced to learn remotely due to the global lockdown and rising infection rates, resulting in observable challenges for students, faculty, and institutions [1–3]. Remote learning has also created other societal and economic repercussions beyond campuses [4]. As university campuses start their return to face-to-face instruction in the Autumn of 2021, the safety of learning spaces and the control of pathogen transmission are now decisive parameters in the planning and continuation of this return [5].

Since the onset of the pandemic, researchers and policymakers have introduced a variety of responses. Such responses include emergency regulations that call for increased ventilation rates, reduced occupancy, hybrid modalities, and ventilation and disinfection breaks during occupancy [6].

2. AIM AND SCOPE

The research aims to create an evidence-based approach to inform the decision-making process surrounding these issues based on field data, providing reassurance for society and ensuring a post-COVID return that is both safe and comfortable for students and staff. Recent research has outlined that, in spaces where humans are the primary source of CO2 (i.e. through exhaling) in a well-mixed space, CO2 concentration can serve as a proxy for measuring the risk of transmission of COVID and other airborne viruses [7]. Therefore, this study will track the excess CO2 concentration in spaces during and following their use to examine the effectiveness of the existing ventilation. This study investigates learning spaces at The American University in Cairo (AUC)'s New Cairo Campus, which was inaugurated in 2008 and is home to 5,500 students and 1,500 staff and faculty. The campus resumed its face-to-face teaching operations in Autumn 2021.

This research aims to (i) collect and analyse occupant behaviour data, including abiding by maximum occupancy allowances. (ii) Examine the studied spaces' temperature and relative humidity conditions and (iii) measuring CO2 concentrations in studied spaces. (iv) Assess the comparative performance of learning spaces against the health recommendations required to curb the transmission of pathogens, such as COVID-19.

3. METHODOLOGY

We utilise a series of teaching and learning spaces at AUC, develop a monitoring protocol for two weeks before we analyze the data and compare it to the available and published operation guidelines for COVID and other airborne viruses.

3.1 Space Selection

Criteria were developed to select learning spaces that ensured accessibility, suitability for study, and 'standard' characteristics that would enable the broader applicability of finding. With the return to campus in Autumn, AUC introduced new capacities for existing learning spaces that consider social distancing requirements. Thus, four spaces were selected: two studio spaces (S.1 and S.2), one computer lab (Comp), and one classroom (Class). All the selected spaces included operable windows, and all, except the classroom, had central mechanical ventilation – including mechanical fresh air input in the rooms. The classroom only had recirculating fan coil units, with no mechanical injection of fresh air. Table 1 presents the details of the four spaces studied.

Table 1:

Description of investigated spaces

	Std. 1	Std. 2	Comp.	Class
Area (m ²)	141	93	61	86
Volume (m ³)	705	465	305	430
Max Occ.	30	25	20	22
	✓	✓	✓	✓
Op. Windows	(2 large)	(2 large)	(1 small)	(4 large)
	✓	✓	✓	✓
Doors	(2)	(1)	(1)	(1 – open to outdoor)
Mech. Fresh Air	✓	✓	✓	✓

The university sets the maximum occupancy indicated in Table 1 based on the size of the classroom and its expected use. The teaching and learning spaces selected follow different occupancy schedules and rates.

3.2 Definition of the Monitoring Protocol

The team extracted the course and lecture schedules from the AUC class schedule. Each classroom had a different operation schedule, including classes, studios, and general open-use time for students.

EXTECH Portable Indoor Air Quality CO₂ Meter, capable of measuring indoor CO₂ concentrations (1 ppm resolution, 5%rdg + 50ppm), dry-bulb temperature (0.1 °C resolution, +/- 0.6°C), and relative humidity (0.1% resolution, +/-3% Rh from 10 to 90% and +/- 5% for RH below 10 or above

90%). The instrument was calibrated using the kits available from the manufacturer. In-situ CO₂ monitoring devices were unavailable on campus, and fitting this equipment in classes was impossible during the experiment.

To overcome the lack of continuous data logging, the main limitation in the study, an extensive monitoring schedule was created:

- Two readings are to be recorded for each measurement point, with a time difference of at least 5 minutes between them.
- For each reading, two-minute time average is used (weighted average calculated by device).
- A minimum of two measurements are to be collected during each scheduled course in the learning space.
- A minimum of two measurements are to be collected after the last scheduled course.
- A maximum of two hours and minimum thirty-minute interval between all measurements (to calculate decay curves).

Table 2 presents the parameters recorded.

Table 2:

Parameters recorded for each measurement point

	Description	Recorded
Temperature	Dry bulb	Highest
Relative humidity	-	Highest
Occupancy	Number of people present in the room	Maximum
Door open	T/F	
Windows Open	T/F	
Mech Vent. or A/C	On/Off	

3.3 Data collection and analysis

The data collection for this study was set for two weeks, between 28 November 2021 and 11 December 2021. Overall, 3,699 data points were collected for 302 measurement points: 80 for Studio 1, 87 for Studio 2, 63 for the computer lab, and 72 for the classroom.

The collected data was analysed to study the temperature and relative humidity based on ASHRAE 55 [8] and the overall carbon concentration levels, in comparison to the 800 ppm suggested by the UK Scientific Advisory Group for Emergencies (SAGE) [9,10]. The maximum occupancy allowance violations were recorded, and their effect on CO₂ accumulation was studied. Additionally, the usefulness of windows, doors and mechanical ventilation on CO₂ accumulation was also assessed.

Finally, the ventilation rates for the rooms were calculated using the decay curves method. The process was informed by the recent work published on the topic, including [11–14]. We identified periods of zero occupancies following occupied periods, which mainly happened at the end of each

learning day. We utilised the equation proposed by Roulet and Faradini [12], presented in Equation 1:

$$C_N = (C(t) - C(0)) / (C(0) - C_o) \quad (1)$$

Where C_N is the normalised concentration of CO_2 in ppm, $C(t)$ is the measured CO_2 concentration at a given time from time zero, $C(0)$ is the CO_2 concentration at time 0 (i.e. the start of the decay), and C_o is the base concentration. C_o was attained by the minimum value of long decay periods for each space (as per [12]). Nonlinear regression was used to estimate the exponential decay curves, with the air changes per hour (ACH) as the equation's exponent – as suggested in [15].

4. RESULTS AND DISCUSSION

4.1 Temperature and Relative Humidity

Figure 1 presents the distribution of the temperature and relative humidity readings from the four spaces throughout the two weeks. The thermal comfort zone highlighted in Figure 1 was obtained through *ASHRAE 55* [8], assuming an internal airspeed of 0.1 m/s, a metabolic rate of 1.0 (writing) and typical winter clothing (1.0 clo) since the study took place in winter.

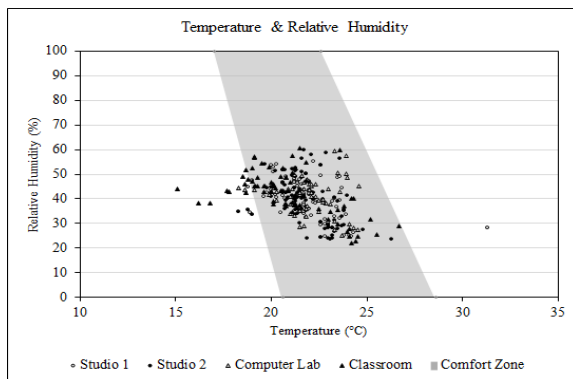


Figure 1: Temperature and humidity measurements for the four spaces in reference to the comfort zone indicated in *ASHRAE 55* [8]

Most of the data points fall within the comfort zone shown in the figure. The expectations mainly occurred in the early morning hours (i.e. first scheduled sessions). Specifically, we identified that the spaces with the windows or door(s) open overnight were more prone to temperatures below the proposed comfort level. However, the spaces were within the expected temperature and humidity comfort conditions.

4.2 General CO_2 Concentrations and Occupancy Allowance Violations

The basic analysis of the CO_2 data for the four spaces is presented in Figure 2. The averages and the upper quartiles for all the spaces fall within the

800 ppm suggested by the UK Scientific Advisory Group for Emergencies (SAGE) [9,10]. However, in some instances, the spaces exceeded this limit. Specifically, Studio 1 exceeded 800 ppm from 5:15PM to 6:15PM on 29 November, following an extended studio session from 2PM to 6:30PM. Again, a similar situation happened on 9 December in the same studio session, starting at 3:15PM.

Studio 2 presents comparable situations, where the CO_2 concentration accumulated to more than 1000 ppm by 6:15PM on 30 November, following a studio session that started at 2PM. The same scenario also appears in the computer lab and the classroom, with concentrations crossing 800 ppm in later afternoons or mid-day following extended morning scheduled sessions. However, in the early morning, the computer lab had one instance where CO_2 concentration crossed 1000 ppm. Architecture students utilise the lab at night-time, the room accumulated CO_2 overnight. In one case, the concentration at 9AM before starting any scheduled session was 1142 ppm, after students used the space overnight, with the windows and doors closed, and the ventilation switched off. The lab remained above the 800-ppm threshold until 12:45PM.

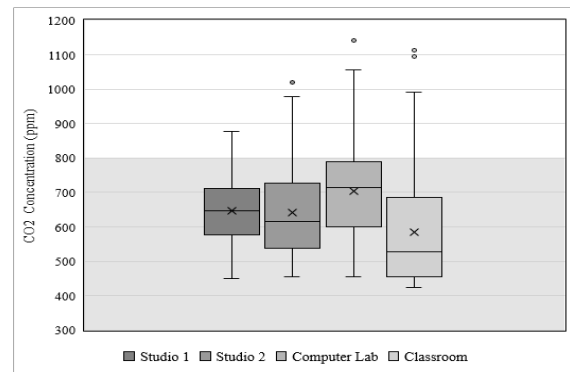


Figure 2: CO_2 measurements for the four spaces in reference to the 800 ppm reference level suggested by the UK Scientific Advisory Group for Emergencies (SAGE) [9,10]

Generally, the CO_2 concentration was below 800 ppm for 92.5% of the measurements taken in Studio 1, 87.4% of those taken in Studio 2, 77.8% of those taken in the computer lab, and 88.9% of the measurements taken in the classrooms. Overall, the computer lab had the highest average concentration of CO_2 and the most significant 800 ppm threshold violations.

Additionally, the computer laboratory had the largest and most severe occupancy limit violation, with more than 30 occupants in the space at one time observed on multiple occasions (the maximum allowed is 20). Other spaces were underutilised,

with only the classroom exceeding its allowed occupancy of 22 by one user in one observation.

4.3 CO₂ Concentrations, Occupancy and Density

Table 3 presents the occupancy and density data. Figure 3 (A to D) shows the CO₂ concentration with the occupancy.

Table 3:

Occupancy and density in four spaces

	S. 1	S. 2	Comp	Class
Area (m ²)	141	93	61	86
Median Occupancy	6.5	12	9.5	12
Average space per occupant (m ²)	21.6	11.75	14.84	11.75

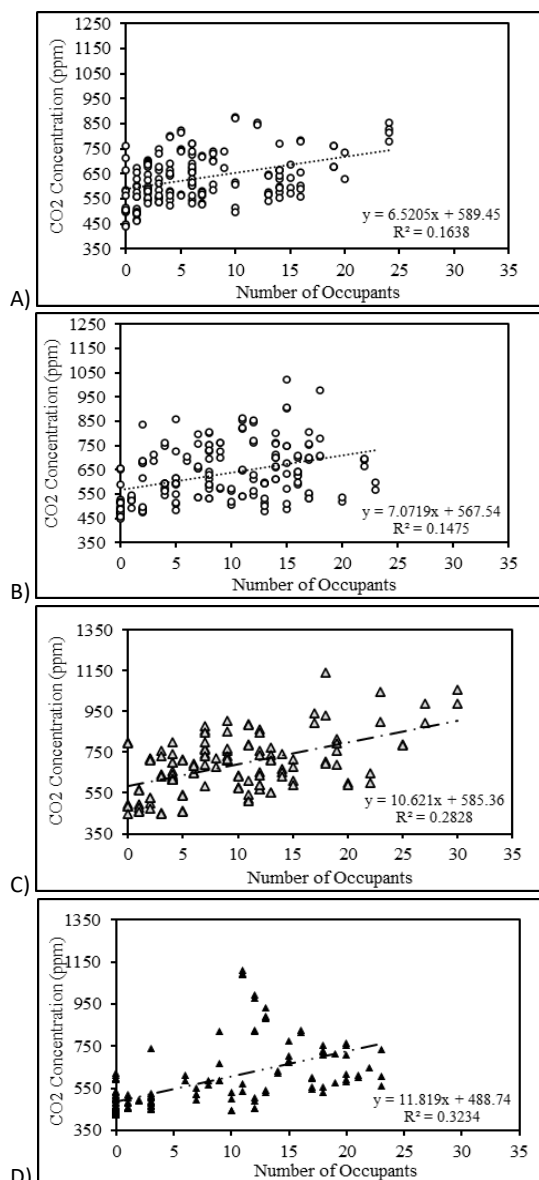


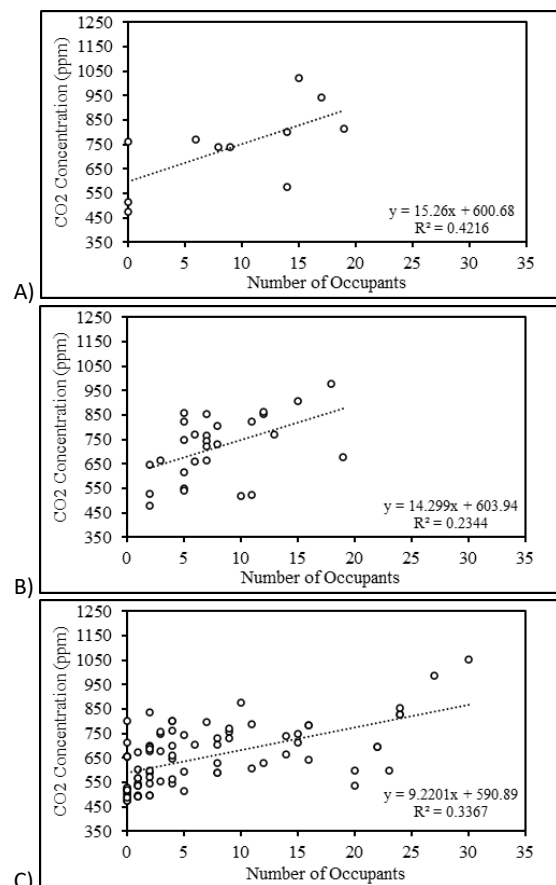
Figure 3:

CO₂ measurements for the four spaces in relation to occupancy. A) Studio 1, B) Studio 2, C) Computer lab, D) classroom.

The graphs in figure 3 have low coefficients of determination values mainly because they are an aggregate of the measurements that disregard time. In the case of CO₂ measurements, a time delay is expected in the concentration and occupancy. The graphs also ignore other factors, including whether the mechanical ventilation is functioning and if the doors and windows are closed or open. The study's dependence on discrete measurements also increased uncertainty. From Table 3 and Figure 3, we can see that the rooms with mechanical ventilation installed (namely the two studios and computer lab) had a lower CO₂ accumulation curve. The accumulation of CO₂ is negatively correlated with the space area (i.e., the larger the area, the lower the accumulation for the same occupancy).

4.3 The Effectiveness of Ventilation Sources

The data collection happened with no interference with the activities in the spaces, as well as user preferences, including their choice to open or close the windows, doors, and the HVAC system operation. Instead, the team observed the conditions of these parameters during the measurements. Figure 4 shows the aggregate effects of these parameters across the four spaces. Please note that only weak correlations were deduced from the data due to the reasons mentioned in section 4.2.



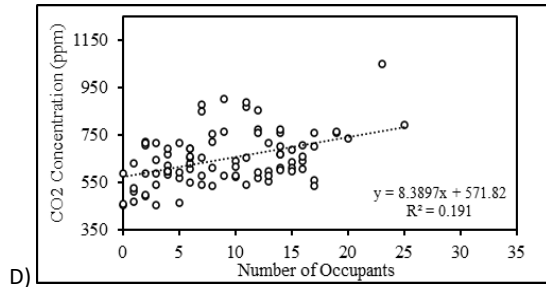


Figure 4:

Aggregate CO₂ measurements of the four spaces in relation to occupancy, with varying ventilation conditions. A) Doors and windows closed and HVAC off, B) Doors and windows closed and HVAC on, C) Windows closed, Doors open and HVAC on, and D) Windows and doors open, and HVAC ON.

It is important to note that the classroom is excluded from the data presented in Figure 4 since it does not have an HVAC system installed. From Figure 4, we can see that the HVAC can reduce the accumulation of CO₂ in the spaces from 15.3 ppm per occupant to 14.3 ppm/occupant (about 7%). Opened doors further lower the rate to 9.2 ppm/occupant (an added 34% reduction), and opening the windows lowers the rate to 8.4 ppm/occupant (and added 6%). Overall, having the HVAC ON, and the doors and windows open reduces the accumulation of CO₂ per occupant by more than 45%.

The findings point to the fact that, without the ventilation or fresh air from the windows and doors in the spaces, CO₂ accumulation would be significant, even with the institution's proposed maximum occupancy. While mechanical ventilation helps mitigate the concentration slightly, the data shows that it was insufficient to inhibit the CO₂ concentration from passing the 800-ppm threshold proposed. This is explicitly clear during extended studio sessions.

4.4 Estimated Ventilation Rates

The decay curves of each space were extracted from the data: by isolating situations of large occupancy, followed by several hours of no occupancy. Specifically, for Studio 1, three decay situations were seen as appropriate, two for Studio 2, five for the computer lab, and four for the classroom. Normalised concentrations were calculated based on the methodology proposed in [12]. Multiple normalized curves were averaged to obtain a mean ACH value across the two weeks observed.

It is important to note that the conditions of the rooms were not controlled (i.e. HVAC, door, and window conditions were not changed or altered by the team). Thus, the ventilation rates calculated here represent the operational conditions of the

spaces during the observation period with no intervention. Table 4 presents the estimates

Table 4:

Estimated ventilation rates in four spaces

	S. 1	S. 2	Comp	Class
Estimated ACH	0.591	1.144	0.736	0.935
R2	0.992	0.978	0.986	0.974
Max. Recorded Occupancy	24	23	30	24
l/s-person	4.58-	6.10-	1.97-	4.42-
(95% confidence)	5.06	6.75	2.18	4.89

Except for Studio 2 and the classroom, the ventilation rates are below the ASHRAE minimum requirements of 5 l/s-person [8]. The overall air change rate in all the rooms is also below the 6 ACH proposed by the CDC [5].

5. CONCLUSION AND FUTURE RESEARCH

Motivated by the need to ensure safe and comfortable learning spaces after returning to campuses, this study examined how learning spaces in AUC compare to the health recommendations and best practices proposed to curb COVID-19 transmission. This study is the first of its kind undertaken post-COVID in Egypt. It broadens the ventilation-specific focus of previous work in this area by synchronously considering the space's safety, comfort, performance, and operational variables. The study focused on analysing the spaces with little or no intervention to capture their regular post-COVID operation.

Findings revealed that users' behaviour and lack of willingness to conform to guidelines, including maximum density allowances, resulted in the accumulation of CO₂, which could indicate an increased risk of transmission and infection. The observed density and classroom usage patterns also revealed gaps in policy enforcement. The analysis revealed that while the spaces were able to remain within the 800 ppm threshold set in the literature, untraditionally extended class sessions in the spaces resulted in a significant CO₂ accumulation that ventilation systems struggled to mitigate. Additionally, the use of the spaces outside regular operation hours resulted in similar accumulations.

In the spaces analysed, it was found that mechanical ventilation alone was not sufficient during close to full occupancy, with opened doors and windows reducing the average accumulation per occupant by close to 40%. The decay curves revealed that the ventilation rates in the four spaces are significantly below the recommended enhanced levels of 6 ACH for educational spaces and barely meet the minimum standard of 5 l/s-person. While there might be design and

operation parameters to consider, the observations indicate that the ventilation gaps can be attributed to users' behaviour, including shutting down HVAC systems and closing doors and windows. Based on the findings, we offer four key recommendations:

- Revise mechanical ventilation performance in all occupied spaces, and ensure that HVAC equipment remains functional during occupancy.
- Ensure that mechanical ventilation schedules conform to actual usage – to ensure that after-hours and outside working hours used spaces remain well ventilated.
- Ensure that extended scheduled sessions in rooms have embedded breaks for ventilation and propose occupancy limits beyond which doors and windows must remain open as much as possible.
- Further, enforce guidelines and policy regarding maximum occupancy allowances.

We also recommend that the institution add CO₂ sensors in rooms for their health and safety monitoring for the post-COVID campus return.

Within a broader context, the findings can be applied across universities in Egypt to guide a return to university campuses that ensures that learning spaces are healthy, comfortable, and safe. Further research will expand the work explored here to a broad range of learning spaces. In addition, a study that will compare the performance of AUC learning spaces (cooling-dominated) to comparable spaces at UCL (UK- heating-dominated) is planned.

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