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INDOOR AIR QUALITY IN LABORATORIES AND ITS RELATIONSHIP WITH PSYCHOLOGICAL PERFORMANCE AMONG UNIVERSITY STUDENTS IN MALAYSIA

Muhammad Nazman[1], Puteri Balqis Mohd Hatta[1], Nur Faseeha Suhaimi[1]*

[1]Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, UPM Serdang, Selangor 43400, Malaysia

Corresponding Author:
*) nurfaseeha@upm.edu.my

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Abstract

Introduction: *Poor indoor air quality (IAQ) in work environments can reduce productivity and decrease overall performance. This study examines IAQ in university laboratories and its relationship with psychological performance among students in Malaysia.* ***Methods:*** *This cross-sectional study was conducted from October to November 2023 in six laboratories at a Malaysian university, categorised into chemical and non-chemical. A total of 117 students aged 18 to 40 participated. IAQ was measured in real-time for 8 hours during weekdays using instruments for particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), total volatile organic compounds (TVOC), airborne microorganisms, carbon dioxide (CO_2), temperature, relative humidity (RH), and air movement. Psychological performance was assessed using the General Health Questionnaire (GHQ-12) and Post Occupancy Evaluation (POE). Data analysis was performed using Kruskal-Wallis, One-Way ANOVA, and Chi-Square tests.* ***Results and Discussion:*** *Significant differences in IAQ parameters were observed for $PM_{2.5}$ (p=0.007), PM_{10} (p=0.020), CO_2 (p=0.024) and RH (p=0.043). Psychological distress affected 41.9% of students based on the predefined threshold. High CO levels (≥0.67 ppm) and elevated temperatures (≥23.28°C) were significantly associated with increased psychological distress (p=0.011). Students exposed to these conditions were 1.3 times more likely to experience distress (OR=1.3).* ***Conclusion:*** *Specific IAQ parameters, particularly CO and temperature, critically impact students' psychological well-being. Improving IAQ by reducing CO levels and maintaining optimal temperatures may enhance mental health and performance. Improving IAQ by reducing CO levels and maintaining optimal temperatures may enhance mental health and performance. However, external factors such as personal stressors could not be entirely controlled.*

INTRODUCTION

Indoor air quality (IAQ) is a critical determinant of health and well-being, influencing various physical and psychological outcomes. Poor IAQ can cause multiple health issues, including respiratory problems, allergies, headaches, and fatigue (1–5). Traditionally, research on IAQ has primarily focused on its health and comfort-related consequences due to the widespread prevalence of exposure to polluted indoor air. The Covid19 pandemic underscored the importance of IAQ, highlighting its effects on psychological performance, mental cognition, and behaviour as people spent more time indoors (6–10). Previous studies have also demonstrated significant neurocognitive effects from air pollutants, ranging from behavioural changes to neurodegenerative disorders, which profoundly impact mental health (11–15).

A local study investigated the physical symptoms of Sick Building Syndrome (SBS), such as eye irritation and respiratory problems, alongside psychosocial factors affecting workers (16). Their findings emphasise the multifaceted impacts of IAQ on physical and psychological health. This study explores the link between IAQ and psychological factors among students, offering a more comprehensive understanding of IAQ's impact on their well-being. Meanwhile, another study emphasized the health risks associated with exposure to various pollutants (17). Their research highlighted that while natural ventilation in these laboratories is

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insufficient to ensure adequate IAQ, the installation of additional ventilation systems is necessary to mitigate health risks. Furthermore, the building environment, including design and interior architecture, significantly influences occupants' health, emotions, motivation, and performance (18–21).

Despite the recognised importance of IAQ, there is a notable gap in research specifically addressing its impact on psychological performance among university students in laboratory settings, particularly in Malaysia. This study addresses this gap by examining the relationship between IAQ and students' psychological performance in university laboratories. Understanding this relationship is crucial for optimising conditions in educational settings, thereby ensuring a conducive and healthy learning environment for students. Enhancing IAQ has the potential to boost productivity, foster a more comfortable learning environment, and reduce stress levels among students. Therefore, understanding the relationship between IAQ in university laboratories and its impact on students' well-being and academic performance is crucial for informing future strategies aimed at enhancing learning environments.

METHODS

Study Design and Sampling Methods

This cross-sectional study was conducted from October to November 2023 at six laboratories located within a faculty at a university in Malaysia. Given Malaysia's hot and humid climate, the laboratories have local and central air conditioning systems to ensure student comfort during activities, including practical and research work. These laboratories were chosen for their high usage by students, providing a relevant environment for assessing IAQ and its impact on students' well-being. Besides, the laboratories were categorised into chemical and non-chemical types to explore potential differences in IAQ and their effects on psychological performance. Chemical laboratories typically use chemicals and biological materials, while non-chemical laboratories focus on computational and theoretical work. Monitoring was equally distributed between both types to capture a comprehensive view of IAQ across different laboratory environments.

The study population was comprised of laboratory students at the faculty, including undergraduate and postgraduate students aged 18 to 40 years. The sampling frame was obtained from the faculty administration's undergraduate and postgraduate students' records. Participants were randomly selected from the name lists provided. Both male and female students who were actively engaged in laboratories were included in the study.

Study Instrumentation

This study involved a series of steps, including obtaining management approvals, distributing questionnaires to respondents, and assessing IAQ using specific instruments. A comprehensive walkthrough inspection was conducted in all six laboratories. Factors such as ventilation type, window openings, ongoing activities, instruments, machines, and occupancy levels were considered. Sampling points were marked based on the design plan and the total area of each laboratory to ensure representative IAQ measurements. Additionally, the students were selected based on their frequent presence in the laboratory, thereby reducing the potential impact of external factors unrelated to the laboratory setting.

IAQ was measured in real-time at each sample location for 8 hours during regular working days from 8 a.m. until 5 p.m. with a 1-hour break between 1 to 2 p.m. Measurements were taken at a height of 1 metre above the floor and at least 1 metre away from walls, doors, and heating systems to ensure accuracy and consistency in building temperatures. Data were recorded at 1-hour intervals to capture fluctuations in IAQ parameters throughout the day. Each of the laboratories has a total floor area of 336 m^2. The following instruments were used, which were DustTrak II Aerosol Monitor (TSI, USA; model 8532) for measuring particulate matter ($PM_{2.5}$ and PM_{10}), Q-Trak IAQ Monitor (TSI, USA; model 7565) for assessing air temperature (AT), relative humidity (RH), carbon dioxide (CO_2), and carbon monoxide (CO), VelociCalc Multi-function Ventilation Meter (TSI, USA; model 9565) for measuring air movement (AM), handheld VOC Monitor (RAE Systems, USA; model PpbRAE 3000) for detecting total volatile organic compounds (TVOC) and Duo SAS High Volume Microbial Air Sampler (International PBI, Italy; model 360) for sampling airborne microorganisms.

While IAQ focuses on the air quality inside a building, indoor environmental quality (IEQ) encompasses a broader range of factors. Perceptions of IEQ were identified from the questionnaire, which comprised seven questions, each rated on a seven-point Likert scale. The questions were designed to capture various aspects of the occupants' IEQ in their laboratory environment to investigate how perception aligns with or differs from the measured parameters. Response options ranged from 1 (indicating a negative perception) to 7 (indicating a positive perception).

Standardised questionnaires from the General Health Questionnaire (GHQ-12) (22) and Post Occupancy Evaluation (POE) (23)were used to assess psychological factors affecting mental health among students. The questionnaires were translated from English to Malay, subjected to a pilot test, and verbally explained by the researcher to ensure clarity. Mental health scores were calculated using the GHQ-12 (22), a 12-item unidimensional measure of mental health designed to capture various aspects of psychological well-being and distress experienced by individuals over a recent period. The GHQ-12 was graded on the four-point Likert scale for the factor analysis, with each item ranging from 0 to 3. For negatively worded items, '0' indicated "Not at all", '1' indicated "No more than usual", '2' indicated "More than usual", and '3' indicated "Much more than usual", while positively worded items were reversely scored. All items were added to obtain the total score, making the score range 0-36, with a higher score indicating worse psychological distress.

The methodology for assessing psychological performance through POE involves a structured questionnaire of six questions, each rated on a seven-point Likert scale. The questions are designed to capture various aspects of the occupants' psychological experiences in their laboratory environment (23). The aggregated scores provide a comprehensive understanding of the overall psychological well-being of the occupants, highlighting both areas of strength and potential improvements in the laboratory environment. Additionally, during the administration of the questionnaires, respondents were verbally guided to focus their responses on their experiences within the laboratory, minimizing the influence of external stressors such as personal or family-related issues. These measures were implemented to ensure that the psychological factors assessed were primarily influenced by the laboratory environment, thus enhancing the validity of the findings related to the laboratory's impact on students' psychological performance.

Statistical Analysis

Data analysis was performed using SPSS™ Version 29. The normality of the data was assessed using the Shapiro-Wilk test. Frequency and percentage were used to describe the respondents' socio-demographic information and psychological performance. For the data that did not follow a normal distribution, median and interquartile range (IQR) were used to describe the non-normal parameters, followed by the Kruskal-Wallis test for comparison between laboratories. Meanwhile, normally distributed data used mean and standard deviation (SD) to describe the parameters, followed by the One-Way ANOVA test for comparison between laboratories. The Chi-Square Test of Independence was employed to explore the association between IAQ parameters and students' psychological performance.

Quality Control

A pilot test was conducted to validate and assess the effectiveness of the questionnaire used in the study, which involved 10% of the intended sample size. The internal consistency reliability of the questionnaire items was evaluated using Cronbach's alpha coefficient, which was 0.75. A high Cronbach's alpha value indicated that the questionnaire items were consistent and reliable for measuring the intended psychosocial risk factors. Moreover, all instruments used for IAQ measurements were calibrated before the commencement of air sampling to ensure validity and reliability.

Ethical Concern

Before conducting the study and data collection, ethical approval was obtained from the Ethics Committee for Research Involving Human Subjects (Ref. No.: JKEUPM-2023-399). Additionally, permission for data collection was secured from the faculty dean. Informed consent was obtained from all participants, ensuring they understood the study procedures and their rights.

RESULTS

Characteristics of the Students

Table 1 provides an overview of the general characteristics of students in the selected chemical and non-chemical laboratories. Both laboratory types have a mixed distribution of male and female students. However, the gender distribution between chemical and non-chemical laboratories was not significantly different ($p=0.153$). The age distribution was also similar between the two groups but not significantly different, with the majority of students aged 20-29 and a smaller proportion in the 30-39 age range ($p=0.124$). Most students in both types of laboratories possess knowledge about IAQ, but there was no significant difference in the distribution of this knowledge between the groups ($p=0.557$). Nonetheless, there was a significant difference in the average hours spent in the laboratory per day between the two groups ($p=0.004$). A higher proportion of students in chemical laboratories tend to spend more (5-8 hours) than those in non-chemical laboratories.

Table 1. General Characteristics of Students at Each Selected Laboratory

Characteristics	Chemical Laboratory (n=66)				Non-Chemical Laboratory (n=51)		χ^2	p
	Number (%)							
	A	B	C	D	E	F		
Gender								
Male	10 (20.0)	13 (26.0)	7 (14.0)	3 (6.0)	10 (20.0)	7 (14.0)	2.05	0.153
Female	14 (20.9)	12 (17.9)	2 (3.0)	6 (9.0)	20 (29.9)	13 (19.4)		
Age								
20-29	20 (20.0)	20 (20.0)	8 (8.0)	6 (6.0)	26 (26.0)	20 (20.0)	2.37§	0.124
30-39	4 (23.5)	5 (29.4)	1 (5.9)	3 (17.6)	4 (23.5)	0 (0.0)		
Knowledge on IAQ								
Yes	24 (27.3)	18 (5.7)	5 (5.7)	4 (4.5)	30 (34.1)	7 (8.0)	0.34	0.557
No	0 (0.0)	7 (24.1)	4 (13.8)	5 (17.2)	0 (0.0)	13 (44.8)		
Average Hour in Lab Per Day								
1-4	16 (16.8)	20 (21.1)	7 (7.4)	5 (5.3)	27 (28.4)	20 (21.1)	8.44§	**0.004***
5-8	8 (36.4)	5 (22.7)	2 (9.1)	4 (18.2)	3 (13.6)	0 (0.0)		

*n = 117; *Significant at p<0.05; §By χ^2 test with Yates' correction for expected values <5*

Indoor Air Quality (IAQ) Parameters in the Laboratories

Table 2 comprehensively compares IAQ parameters across six different laboratories categorised into chemical (A, B, C and D) and non-chemical (E and F) types. The study aimed to assess variations in IAQ parameters between these six laboratories, comparing the IAQ levels to the acceptable standards established by organisations such as the Department of Occupational Safety and Health (DOSH) Malaysia and the Department of Environment (DOE) Malaysia.

Table 2. Comparison of Mean/Median Concentration on Indoor Air Quality Parameters at Six Laboratories

Parameters	PEL	A	B	C	D	E	F	p
		Chemical Laboratory				Non-Chemical Laboratory		
		Mean/Median						
Chemical Contaminants								
CO (ppm)[a]	10[δ]	0.32	1.02	1.32	0.68	0.67	0.42	0.158
$PM_{2.5}$ (µg/m³)[b]	35[ε]	14.36	30.21	22.66	8.58	8.36	15.08	**0.007***
PM_{10} (µg/m³)[b]	100[ε]	25.56	39.04	28.09	18.21	18.01	25.92	**0.020***
TVOC (ppb)[a]	3000[δ]	0.00	0.00	0.00	0.00	0.00	0.00	0.304
Biological Contaminants								
Total Bacterial Count (CFU/m³)[a]	500[δ]	36.00	22.00	49.00	29.00	80.00	74.00	0.076
Total Fungal Count (CFU/m³)[a]	1000[δ]	34.00	94.00	54.0	67.00	60.00	68.00	0.930
Ventilation Performance Indicator								
CO_2 (ppm)[a]	1000[δ]	617.47	479.04	466.80	319.38	668.69	604.24	**0.024***
Physical Parameters								
Air Temperature (°C)[a]	23 – 26[δ]	22.0	23.3	25.6	24.0	23.6	21.9	0.076
Relative Humidity (%)[a]	40 – 70[δ]	70.8	72.3	61.3	62.6	79.6	64.7	**0.043***
Air Movement (m/s)[b]	0.15 – 0.50[δ]	0.14	0.16	0.12	0.17	0.16	0.17	0.063

*[a] One-way ANOVA; [b] Kruskal-Wallis test; *Significant at p<0.05; PEL = Permissible Exposure Limit.*

[δ] Industrial Code of Practice on Indoor Air Quality (DOSH Malaysia, 2010); [ε] New Malaysia Ambient Air Quality Standard (DOE Malaysia, 2021).

The mean CO concentrations across the laboratories ranged from 0.32 ppm to 1.32 ppm, with the highest levels observed in C. Although C had the highest CO concentration, the overall differences in CO levels among the laboratories were not statistically significant (p=0.158). All values were well below the permissible exposure limit (PEL) of 10 ppm. Additionally, median $PM_{2.5}$ concentrations showed significant differences among the laboratories (p=0.007). Chemical laboratories had higher $PM_{2.5}$ levels, particularly B (30.21 µg/m³), compared to non-chemical laboratories with lower median concentrations (8.36 to 15.08 µg/m³). This finding indicates higher particulate matter in chemical environments. Similarly, PM_{10} levels varied significantly (p=0.020), with chemical laboratories exhibiting higher concentrations, especially B (39.04 µg/m³), in contrast to the non-chemical laboratories, which had lower levels (18.01 to 25.92 µg/m³). These findings reflect the higher particulate pollution in chemical laboratories. On the other hand, TVOC levels were consistently low or below the detection limit (0.00 ppb) across all laboratories, showing no significant differences (p=0.304) and well below the PEL of 3000 ppb.

The mean bacterial counts ranged from 22.00 to 80.00 CFU/m³, with E showing the highest counts. Despite this variability, the differences were not statistically significant (p=0.076). Likewise, fungal counts varied across laboratories (34.00 to 94.00 CFU/m³), with B showing the highest levels. However, these differences were not significant (p=0.930), and all counts were below the PEL of 1000 CFU/m³.

The mean CO_2 levels ranged from 319.38 ppm to 668.69 ppm, with significant differences among laboratories (p=0.024). D had the lowest mean CO_2 concentration (319.38 ppm), while E had the highest (668.69 ppm). All values were below the PEL of 1000 ppm.

In the same way, relative humidity (RH) levels varied significantly (p=0.043), with E showing the highest RH (79.6%), exceeding the upper recommended limit of 70%. Other laboratories had RH levels within the acceptable range. On the other hand, mean air temperatures (AT) ranged from 21.9°C to 25.6°C, with no significant differences (p=0.076). Most laboratories maintained AT within (B, C, D and E) or close to (A and F) the recommended range of 23-26°C. Furthermore, air movement (AM) varied from 0.12 m/s to 0.17 m/s across laboratories, with no significant differences observed (p=0.063). Most values were within the recommended range of 0.15-0.50 m/s (B, D, E and F), although some were slightly below this range (A and C).

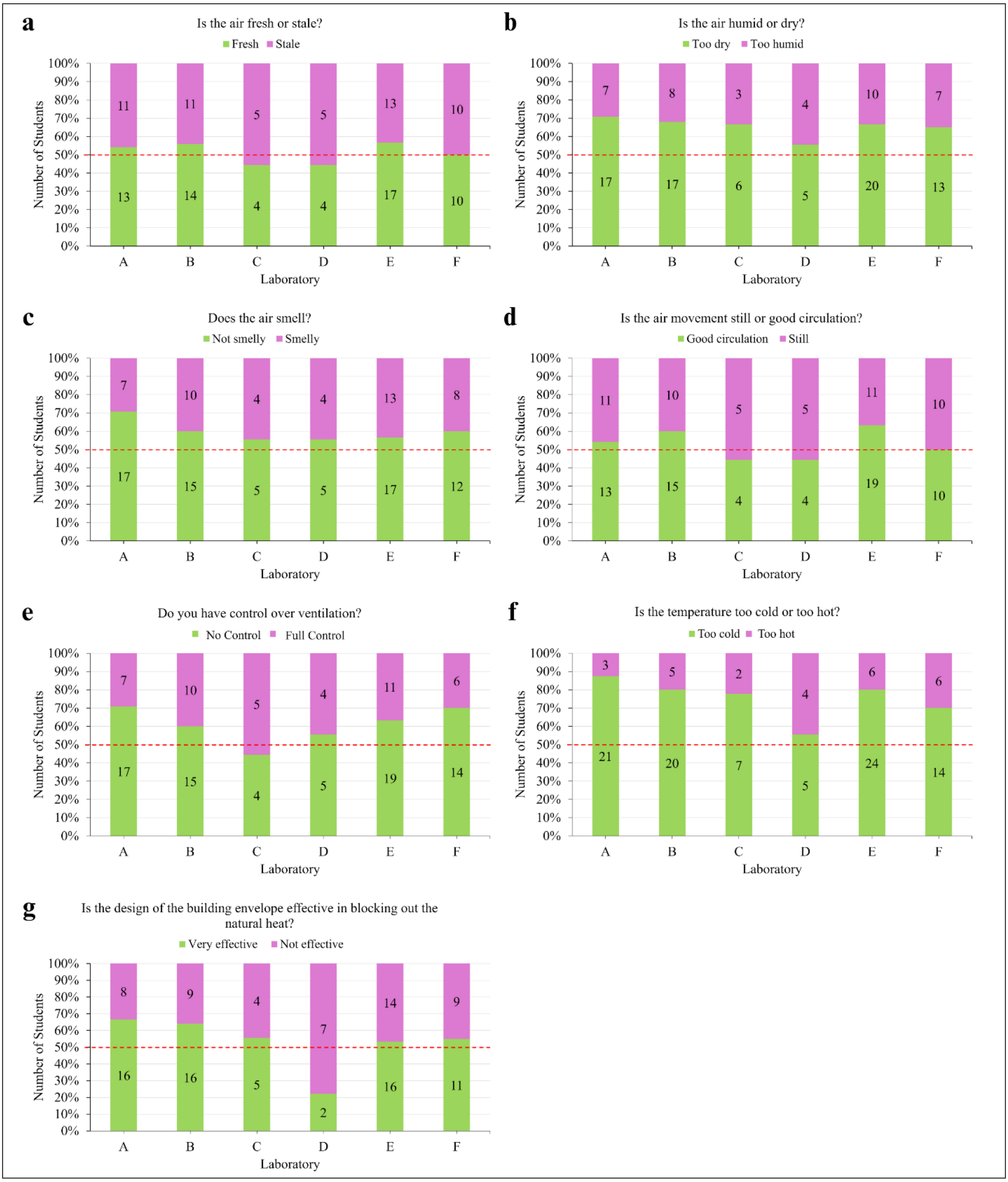

Figure 1. Comparison of Students' Perceptions on Indoor Environmental Quality Factors in Chemical and Non-Chemical Laboratories. (a) Air Freshness; (b) Air Humidity; (c) Air Smell; (d) Air Movement; (e) Ventilation Control; (f) Air Temperature; (g) Building Design.

Perceptions of Students on Indoor Environmental Quality (IEQ) in the Laboratories

Figure 1 compares students' perceptions of various IEQ factors across six laboratories (A-F). The data is represented using the number and percentage of respondents in each category. For analysis purposes, responses to each question were categorised into two groups based on the median response value, which served as the cut-off point. Responses from 1 to the value just below the median were classified as 'positive' perceptions, while responses from median to 7 were classified as 'negative' perceptions.

The first question, "Is the air fresh or stale?" is scored from 1 (stale) to 7 (fresh). Across all laboratories, the students perceive the air freshness to be neither stale nor fresh but relatively neutral or slightly fresh (median=4; IQR=4). Two chemical laboratories (A and B) and one non-chemical laboratory (E) were identified as having fresh air. In contrast, two non-chemical laboratories (C and D) were identified as having stale air. Laboratory F had a neutral rating of fresh and stale air.

The second question, "Is the air humid or dry?" is scored from 1 (humid) to 7 (dry). Across all laboratories, the students perceive the air humidity as neither humid nor dry but relatively neutral or slightly dry (median=4; IQR=1). For each laboratory, the percentage of 'too dry' responses is higher than that of 'too humid' responses.

The third question, "Does the air smell?" is scored from 1 (smelly) to 7 (not smelly). Across all laboratories, it appears that the students perceive the air smell to be neither smelly nor not smelly (median=4; IQR=2). For each laboratory, the percentage of 'not smelly' responses is higher than that of 'smelly' responses.

The fourth question, "Is the air movement still or good circulation?" is scored from 1 (still) to 7 (good circulation). Across all laboratories, the students perceive the air movement to be neither significantly still nor good but relatively neutral or slightly good (median=4; IQR=3). Two chemical laboratories (A and B) and one non-chemical laboratory (E) were rated as having good air circulation. In contrast, two chemical laboratories (C and D) were rated as having still air circulation. Laboratory F was rated as having a neutral air circulation.

The fifth question, "Do you have control over ventilation?" is scored from 1 (no control) to 7 (full control). Across all laboratories, the students had no control over ventilation (median=2; IQR=3). Two chemical laboratories (A, B and D) and two non-chemical laboratories (E and F) were identified as having no control over ventilation. In contrast, one chemical laboratory (C) was identified as having full control over ventilation.

The sixth question, "Is the temperature too cold or too hot?" is scored from 1 (too cold) to 7 (too hot). Across all laboratories, the students perceive the air temperature to be slightly cold (median=3; IQR=1). For each laboratory, the percentage of 'too cold' responses is higher than that of 'too hot' responses.

The seventh question, "Is the design of the building envelope effective in blocking out the natural heat?" is scored from 1 (not effective) to 7 (very effective). Across all laboratories, the students perceive the building design to be neither not effective nor effective, but relatively neutral or slightly effective in blocking out the natural heat (median=4; IQR=3). Three chemical laboratories (A, B and C) and two non-chemical laboratories (E and F) were identified as 'very effective'.

Psychological Performance among Students

Table 3 presents the results of the GHQ-12, which was used to assess psychological distress among students in the study. The table includes mean scores and standard deviations (SD) for each item of the GHQ-12. The total scale score, calculated by summing the scores across all 12 items, provides an overall measure of psychological distress experienced by the students, with higher scores indicating greater distress. Table 3 presents the number and percentage of students categorised as experiencing psychological distress based on predefined thresholds, which classified scores over the cut-off point of 12 as cases. It was discovered that 41.9% of the students were classified as experiencing psychological distress based on the predefined threshold. Conversely, 58.1% did not meet the criteria for psychological distress.

Table 3. Distribution of General Health Questionnaire (GHQ-12) Results among the Respondents

Items	Mean (SD)
1. Lost much sleep over worry	1.02 (0.81)
2. Felt constantly under strain	1.03 (0.88)
3. Felt you could not overcome your difficulties	1.05 (0.99)
4. Been feeling unhappy or depressed	0.91 (1.00)
5. Been losing confidence in yourself	1.00 (0.92)
6. Been thinking of yourself as a worthless person	1.12 (1.02)
7. Been able to concentrate on what you are doing	1.12 (0.94)
8. Felt that you are playing useful part in things	0.92 (0.97)
9. Been able to face up to your problem	1.06 (0.98)
10. Felt capable of making decisions about things	0.92 (0.97)
11. Been feeling reasonably happy, all things considered	0.75 (0.77)
12. Been able to enjoy your normal day to day activities	0.81 (0.83)
Scale Total	11.72 (4.28)
Presence of Psychological Distress	**n (%)**
Yes	49 (41.9)
No	68 (58.1)

SD = Standard Deviation

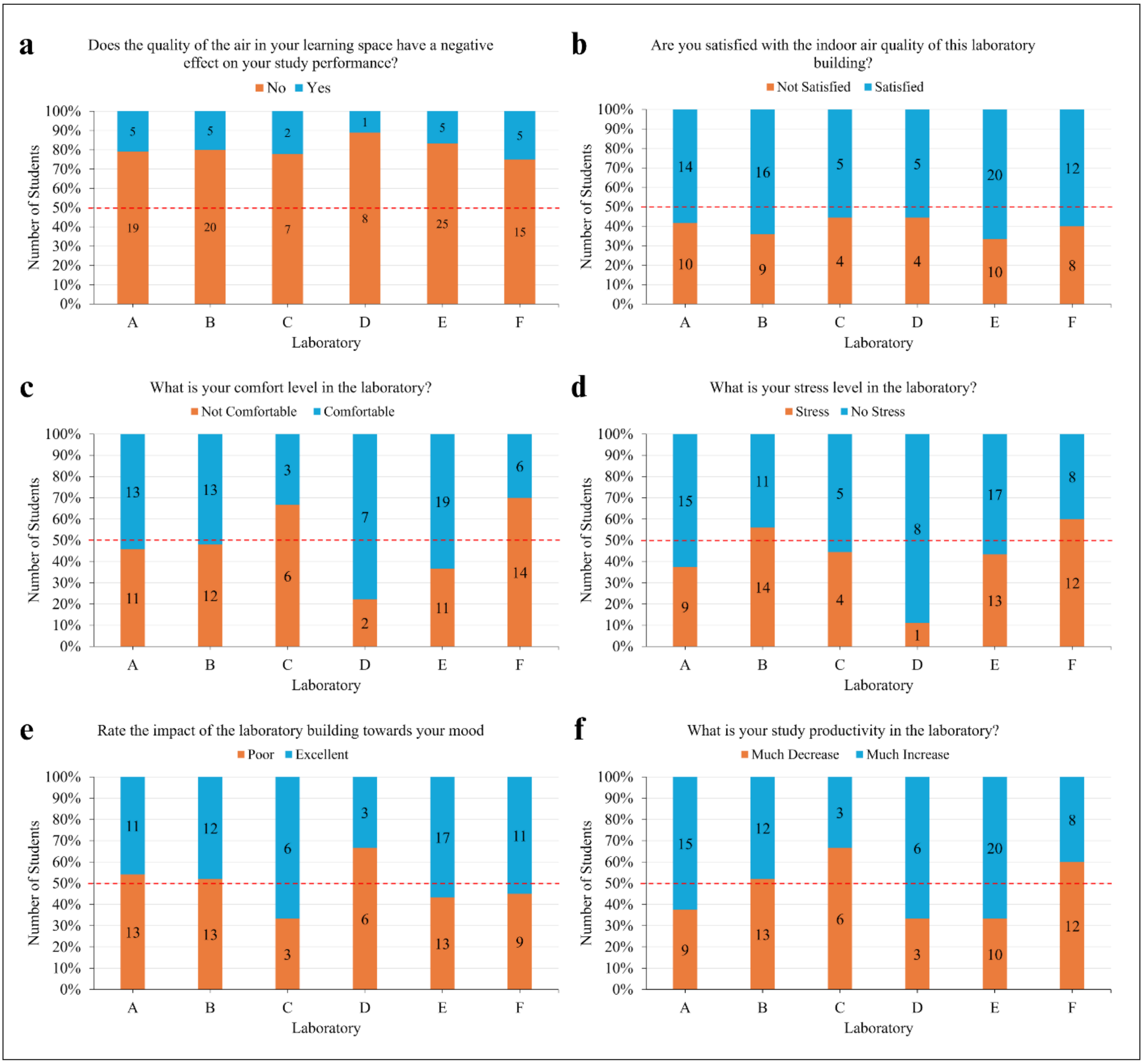

Figure 2. Comparison of Students' Psychological Performance Factors in Laboratories. (a) Performance; (b) Satisfaction; (c) Comfort; (d) Stress; (e) Mood; (f) Productivity.

Figure 2 compares students' perceptions regarding various psychological performance factors across six different laboratories (A-F). The data is represented using the number and percentage of respondents in each category. For analysis purposes, responses to each question were categorised into two groups based on the median response value, which served as the cut-off point. Responses from 1 to the value just below the median were classified as 'Low' perceptions, while responses from median to 7 were classified as 'High' perceptions.

The first question, "Does the quality of the air in your learning space have a negative effect on your study performance?" is scored from 1 (yes) to 7 (no). This question aims to determine how poor air quality adversely affects study performance, with higher scores indicating a greater negative impact. Across all laboratories, it appears that the students' perceptions of the negative effects of IAQ on their study performance are relatively low (median=6; IQR=0). For each laboratory, the percentage of 'no' responses (indicating a positive effect) is higher than that of 'yes' responses (indicating a negative effect).

The second question, "Are you satisfied with the indoor air quality of this laboratory building?" is scored from 1 (not satisfied) to 7 (really satisfied), measuring the occupants' satisfaction with the IAQ, where higher scores reflect higher satisfaction levels. Across all laboratories, the students' satisfaction with IAQ appears neither positive nor negative but relatively neutral or slightly positive (median=4; IQR=3). For each laboratory, the percentage of 'satisfied' responses (indicating a positive effect) is higher than that of 'not satisfied' responses (indicating a negative effect).

The third question, "What is your comfort level in the laboratory?" is scored from 1 (not comfortable) to 7 (comfortable), assessing the overall comfort level of the occupants, with higher scores indicating greater comfort. Across all laboratories, the students perceive their comfort levels to be neither positive nor negative but relatively neutral or slightly positive (median=4; IQR=3). Three chemical laboratories (A, B and D) and one non-chemical laboratory (E) were identified as 'comfortable', whereas another two laboratories (C and F) were identified as 'not comfortable'.

The fourth question, "What is your stress level in the laboratory?" is scored from 1 (stress) to 7 (no stress), which gauges the stress levels experienced by the occupants. Across all laboratories, it appears that the students' stress levels in the laboratory are relatively low (median=5; IQR=1). Generally, students did not perceive high-stress levels in their laboratory environments, which is a positive indication of the well-being and academic performance factors being studied. Three chemical laboratories (A, C and D) and one non-chemical laboratory (E) were identified as 'no stress', whereas another two laboratories (B and F) were identified as 'stress'.

The fifth question, "Rate the impact of the laboratory building towards your mood," is scored from 1 (poor) to 7 (excellent). This question evaluates the influence of the laboratory environment on the occupants' mood, with higher scores indicating a more positive impact. Across all laboratories, the students feel that their mood in the laboratory environment is neither poor nor excellent but relatively neutral or slightly excellent (median=4; IQR=2). One chemical laboratory (C) and two non-chemical laboratories (E and F) were rated as 'excellent', whereas another three laboratories (A, B and D) were rated as 'poor'.

The sixth and final question, "What is your study productivity in the laboratory?" is scored from 1 (much decrease) to 7 (much increase), measuring perceived changes in study productivity due to the laboratory environment, with higher scores suggesting an increase in productivity. Across all laboratories, the students perceive their study productivity to be neither significantly decreased nor increased but relatively neutral or slightly increased (median=4; IQR=3). Two chemical laboratories (A and D) and one non-chemical laboratory (E) were identified as 'increase productivity', whereas another three laboratories (B, C and F) were rated as 'decrease productivity'.

Association between Indoor Air Quality (IAQ) Parameters and Psychological Performance

Table 4 provides a detailed analysis of the association between various IAQ parameters and psychological distress among students in laboratory environments. Each parameter is examined to determine its impact on the students' psychological well-being, with specific thresholds used to differentiate between high and low exposure levels.

Table 4. Associations between IAQ Parameter and Presence of Psychological Distress among Laboratory Students

Variables	Presence of Psychological Distress		OR (95% CI)	χ^2	p
	Yes n (%)	No n (%)			
Chemical Contaminants					
High CO (≥ 0.67 ppm)	24 (32.9)	49 (67.1)	1.3 (1.17 – 1.81)	6.47	**0.011***
Low CO (< 0.67 ppm)	25 (56.8)	19 (43.2)			
High $PM_{2.5}$ (≥ 15.08 µg/m^3)	37 (47.4)	41 (52.6)	2.0 (0.90 – 4.58)	2.97	0.085
Low $PM_{2.5}$ (< 15.08 µg/m^3)	12 (30.8)	27 (69.2)			
High PM_{10} (≥ 25.92 µg/m^3)	37 (47.4)	41 (52.6)	2.0 (0.90 – 4.58)	2.97	0.085
Low PM_{10} (< 25.92 µg/m^3)	12 (30.8)	27 (69.2)			
High TVOC (≥ 113 ppb)	21 (42.9)	28 (57.1)	1.1 (0.51 – 2.26)	0.03	0.856
Low TVOC (< 113 ppb)	28 (41.2)	40 (58.8)			
Biological Contaminants					
High Total Bacterial Count (≥ 49 CFU/m^3)	26 (44.1)	33 (55.9)	1.2 (0.58 – 2.50)	0.23	0.629
Low Total Bacterial Count (< 49 CFU/m^3)	23 (39.7)	35 (60.3)			
High Total Fungal Count (≥ 60 CFU/m^3)	36 (42.9)	48 (57.1)	1.2 (0.51 – 2.62)	0.12	0.733
Low Total Fungal Count (< 60 CFU/m^3)	13 (39.4)	20 (60.6)			
Ventilation Performance Indicator					
High CO_2 (≥ 602.24 ppm)	35 (47.3)	39 (52.7)	1.9 (0.85 – 4.07)	2.43	0.119
Low CO_2 (< 602.24 ppm)	14 (32.6)	29 (67.4)			
Physical Parameters					
High Air Temperature (≥ 23.28 °C)	24 (32.9)	49 (67.1)	1.3 (1.17 – 1.81)	6.47	**0.011***
Low Air Temperature (< 23.28 °C)	25 (56.8)	19 (43.2)			
High Relative Humidity (≥ 70.84 %)	31 (39.2)	48 (60.8)	0.7 (0.33 – 1.57)	0.70	0.404
Low Relative Humidity (< 70.84 %)	18 (47.4)	20 (52.6)			
High Air Movement (≥ 0.16 m/s)	34 (45.3)	41 (54.7)	1.5 (0.69 – 3.25)	1.02	0.312
Low Air Movement (< 0.16 m/s)	15 (35.7)	27 (64.3)			

**Significant at p<0.05.*

The presence of high CO levels (≥0.67 ppm) was significantly associated with an increased likelihood of psychological distress among students (p=0.011). Specifically, students exposed to higher CO levels had 1.3 times greater odds of experiencing psychological distress compared to those exposed to lower CO levels. Moreover, elevated air temperatures (≥23.28 °C) were also significantly associated with a higher incidence of psychological distress among students (p=0.011). Students in warmer laboratory environments were 1.3 times more likely to experience psychological distress compared to those in cooler settings. On the contrary, no significant association was observed between psychological distress and most of the studied IAQ parameters ($PM_{2.5}$, PM_{10}, TVOC, total bacterial counts, total fungal counts, CO_2, relative humidity and air movement).

DISCUSSION

Characteristics of the Students

The findings from Table 1 show a comparable distribution of gender and age groups, which suggests that these socio-demographic factors may not play a critical role in influencing psychological performance and IAQ perceptions among students. This finding allows for focusing on environmental and experiential factors as primary influences. Given that most students reported having knowledge of IAQ, this awareness might influence their perceptions and evaluations of their laboratory environments (24). This awareness is crucial as it could lead to more critical assessments of IAQ. However, since knowledge levels are similar across groups, other factors must be considered to explain differences in psychological responses (25).

The significant difference in laboratory exposure time could be a pivotal factor influencing the relationship between IAQ and psychological performance; hence, the students may have different experiences and perceptions of the indoor environment. These students who spend more hours in potentially hazardous environments might experience more psychological stress and discomfort, as proven in an earlier study (21,26-27). Therefore, it is crucial to consider time spent in these environments when assessing the impacts of IAQ on students.

Indoor Air Quality (IAQ) Parameters in the Laboratories

The results from Table 2 indicate significant disparities in IAQ parameters between six laboratories, with significant differences for $PM_{2.5}$, PM_{10}, CO_2 and RH. Factors contributing to high indoor air pollutant levels included laboratory activities (28), poor ventilation, laboratory location, furniture, paints, computers, and the influence of outdoor pollutants (29). Prolonged exposure to elevated particulate matter can pose serious health risks, including respiratory and cardiovascular issues (7), emphasising the need for effective particulate control measures in these environments.

Conversely, the lower CO_2 levels in chemical laboratories (B, C and D) suggest adequate ventilation, resulting in more effective dilution and removal of indoor air contaminants (30). Adequate ventilation is crucial for maintaining IAQ by reducing the concentration of indoor pollutants and ensuring a continuous supply of fresh air. E potentially needs improved ventilation to reduce CO_2 accumulation. High RH in E could contribute to discomfort and biological growth, indicating enhanced humidity control is necessary (31). Moreover, most laboratories maintained AT within or close to the recommended range of 23-26°C, providing a thermally comfortable environment for occupants (31). The AM of most laboratories were within the recommended range of 0.15-0.50 m/s, although some were slightly below this range, suggesting a need for minor adjustments to ensure adequate air circulation.

The lack of significant differences in other chemical and biological contaminants indicates that while some aspects of IAQ are well-managed across laboratories, specific pollutants like particulates require targeted intervention in the laboratories. While CO and TVOC levels varied, they were consistently safe across all laboratory types, indicating effective control of these compounds within all laboratory settings. The significant difference in RH between the laboratories further suggests that environmental controls differ, impacting overall IAQ and potentially affecting the occupants' comfort and health (31). Our findings show that while certain IAQ parameters are elevated in the laboratories, all measured parameters remained within safe limits as per DOSH (32) and DOE Malaysia (33) standards. On the contrary, a similar IAQ assessment study conducted in practical laboratories at a university in Spain reported some parameters exceeding recommended limits by the Spanish Standardisation Association (UNE) (34).

Perceptions of Students on Indoor Environmental Quality (IEQ) in the Laboratories

The results from Figure 1 highlight nuanced perceptions of IEQ among students across different laboratory settings. The generally neutral to slightly positive perceptions of air freshness, humidity, and smell suggest that, while not ideal, the IEQ in these laboratories is acceptable to most students. This finding contradicts a previous study which reported that lecturers and students encounter poor thermal, lighting, acoustic, and IAQ conditions, which may adversely affect their teaching and learning effectiveness (35). However, the notable perception of dryness in air humidity and the tendency to find the temperature slightly cold point towards specific areas needing improvement. Moreover, a previous study discovered that students were generally uncomfortable in high humidity, but their performance was worse in low humidity (36). Low humidity caused dryness in their eyes and airways, reducing their learning performance.

The perceived lack of control over ventilation in most laboratories, except for one chemical laboratory (C), suggests a potential area for intervention to improve student satisfaction and psychological comfort. It is important to prioritise IEQ in educational settings by implementing solid measures, such as effective ventilation systems. While students may not directly control the central air-conditioning system, opening windows and doors during appropriate outdoor air quality and temperature conditions promotes natural ventilation and air circulation (37). Additionally, the relatively positive perception of building design effectiveness in blocking out natural heat indicates that structural aspects of the laboratories are performing adequately in this regard. This finding is supported by a previous finding that revealed thermal comfort as the main problem that impairs students' attention spans and general health due to insufficient building insulation and outdated technical equipment (38).

These insights are crucial for informing targeted improvements in IAQ and IEQ, which can enhance students' overall learning environment and psychological well-being in university laboratories. Addressing issues such as air dryness, temperature control, and ventilation could significantly improve students' comfort and performance, offering a more conducive educational environment (35).

Psychological Performance among Students

The results from Table 3 and Figure 2 provide valuable insights into the psychological performance and perceptions of IEQ among students in various laboratory settings. The GHQ-12 results indicate a significant proportion of students experiencing psychological distress, which highlights the need for further exploration of the factors contributing to this distress, including IAQ. The finding on psychological distress suggests that nearly half of the student population in these laboratory settings is experiencing substantial psychological strain. The high mean scores in items related to feelings of worthlessness and concentration difficulties may reflect the stressful nature of laboratory environments, where students are often under pressure to perform and meet academic expectations. This finding aligns with a study that discovered stress and fear of failing are known stressors for students; rigid or unsupportive laboratory environments heighten these emotions (39).

Students in this study generally perceived the negative impact of IAQ on study performance to be low, which is encouraging. However, satisfaction with IAQ, comfort, and stress levels varied across laboratories, indicating areas where improvements are necessary. Notably, some laboratories were perceived as having poor air quality, which could affect students' psychological well-being and academic performance, as shown in a previous study (29). The perceived impact of laboratory environments on mood and study productivity also varied, highlighting the importance of optimising IEQ to enhance student outcomes. These findings suggest that while some laboratory environments are conducive to student well-being and productivity, others may require targeted interventions to improve IAQ and overall psychological performance. Moreover, this view is backed by a local study highlighting the importance of understanding IAQ in less commonly studied spaces like experimental or laboratory facilities (28).

Association between Indoor Air Quality (IAQ) Parameters and Psychological Performance

The results from Table 4 highlight specific IAQ parameters that are significantly associated with psychological distress among students in laboratory environments. High CO levels and elevated air temperatures emerged as critical factors influencing students' mental health. CO, even at moderate levels, can have detrimental effects on mental health, likely due to its ability to impair oxygen delivery to the brain, leading to symptoms such as headaches, dizziness, and cognitive impairment (40). These findings suggest that maintaining CO levels well below the threshold is crucial for safeguarding students' mental health.

Furthermore, a significant relationship between AT and psychological distress among students emphasises the need for effective climate control in laboratories. Higher temperatures can cause discomfort and exacerbate stress, potentially impacting cognitive function and emotional stability (31,41-42). Thus, maintaining a comfortable temperature range is essential to enhance students' psychological well-being and overall performance.

The lack of significant associations for other IAQ parameters ($PM_{2.5}$, PM_{10}, TVOC, total bacterial counts, total fungal counts, CO_2, RH, and AM) suggests that these factors, while necessary for general IAQ, may not have a direct impact on psychological distress in the studied population. However, it is essential to continue monitoring these parameters to ensure a comprehensive approach to maintaining healthy indoor environments.

This study has several limitations that should be acknowledged. First, the cross-sectional design limits our ability to establish causality between IAQ parameters and psychological performance. Longitudinal studies are needed to understand the temporal relationship between these variables better. Second, the study was conducted in a single university, which may limit the generalisability of the findings to other educational institutions with different environmental and structural characteristics. Third, categorising laboratories into chemical and non-chemical types may not fully capture the diversity of laboratory environments and their specific IAQ challenges. Future research should include a broader range of laboratory types and consider more detailed environmental and individual factors to provide a more comprehensive understanding of the impact of IAQ on psychological performance.

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AUTHOR'S CONTRIBUTION

All authors actively participated in the research and writing of this manuscript and share responsibility for its content. All authors have read and approved the final manuscript. The specific roles of each author are as follows: MN: Conceptualization, Methodology, Data Collection, Writing—Original Draft Preparation, Statistical Analysis, Data Interpretation, Writing—Reviewing and Editing. PBMH: Data Curation, Statistical Analysis, Data Interpretation. NFS: Visualization, Validation, Data Interpretation, Supervision.

CONCLUSION

This study highlights the significant impact of indoor air quality (IAQ) on the psychological performance of university students in laboratory settings. Our findings indicate that specific IAQ parameters, such as high levels of CO and elevated air temperatures, are significantly associated with increased psychological distress among students. While other IAQ parameters did not directly correlate with psychological distress, the overall indoor environmental quality (IEQ) perception influenced students' comfort, stress levels, and study productivity. These results highlight the importance of optimal IAQ in educational laboratories to enhance student well-being and academic performance. Interventions to improve ventilation, regulate temperature, and reduce pollutant levels are essential to create a healthier and more conducive learning environment. Future research should continue to explore the complex interactions between IAQ, IEQ, and psychological performance, considering the diverse activities and environmental conditions in different laboratory settings.

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