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Original Article

Linking laboratory air quality to workers' psychological performance in Malaysian university laboratories

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ABSTRACT

Introduction: Poor indoor air quality (IAQ) in laboratories can negatively impact worker comfort and psychological well-being. This study investigates the relationship between IAQ and psychological performance among laboratory workers in Malaysia.

Methods: This cross-sectional study was conducted from October to November 2023 in six university laboratories categorized as chemical and non-chemical. A total of 52 workers, aged 20-49 years, participated. IAQ was measured in real-time for 8 hours during weekdays using instruments to monitor particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), total volatile organic compounds (TVOC), airborne microorganisms, carbon dioxide (CO_2), temperature (°C), relative humidity (RH), and air movement. Psychological distress was assessed using the General Health Questionnaire (GHQ-12). Data were analyzed using Kruskal-Wallis, One-Way ANOVA, and Chi-Square tests.

Results: Significant differences in IAQ parameters were found across laboratories, with elevated $PM_{2.5}$ (p=0.007) and PM_{10} (p=0.020), as well as CO levels (p=0.042). Over 51.9% of workers experienced psychological distress, particularly those exposed to high CO levels (≥2.5 ppm) and temperatures above 23.3°C. Workers in these conditions were 6.5 times more likely to report discomfort (p=0.042).

Conclusion: High CO levels and elevated temperatures are significantly associated with psychological distress among laboratory workers. Improving ventilation and maintaining optimal temperatures could enhance comfort and psychological performance in laboratory environments. External stressors may also influence psychological performance, but were not fully controlled.

Keywords: Indoor air quality, Indoor environmental quality, Laboratory, Psychological performance, Workers

Introduction

In contemporary society, individuals spend approximately 87% of their time in indoor environments, including residences, offices, and laboratories, with an additional 6% spent inside vehicles.[1–3] This underscores the critical need to understand the factors influencing indoor environmental quality (IEQ). The complex and interconnected nature of these factors directly impacts well-being and productivity. Research has shown that imbalanced IEQ, such as poor indoor air quality (IAQ), can significantly impair cognitive function and mental health, contributing to conditions like "presenteeism," where workers attend work but experience reduced productivity due to health issues or distractions.[4–6]

Previous studies highlight that IEQ comprises multiple indoor conditions, including IAQ, thermal comfort, and visual and odor comfort, significantly affecting occupants.[7,8] These interrelated factors involve parameters such as temperature, relative humidity, air velocity, volatile organic compounds (VOCs), carbon dioxide (CO_2), carbon monoxide (CO), particulate matter ($PM_{2.5}$, PM_{10}), and biological contaminants, all of which have been shown to influence individual health and well-being.[9,10] The heightened awareness during the COVID-19 pandemic has further emphasized the adverse effects of poor IAQ on psychological performance, linking exposure to air pollutants with serious neurocognitive and mental health issues.

This study focuses on laboratory workers at a university in Malaysia, aiming to examine the relationship between specific IAQ parameters and psychological outcomes such as comfort and stress. The objective is to comprehensively understand how IEQ influences workers' well-being in laboratory environments. Prior research indicates that occupational stress in Malaysia is prevalent, with rates as high as 28.5%, particularly among specific job categories.[11] However, university laboratory settings have been understudied, despite their unique micro-environments where pollutant concentrations may be elevated due to the nature of experimental work and the number of individuals operating in these spaces.[12–14]

Methods

This cross-sectional study was conducted across six laboratories within a Malaysian university faculty. Given Malaysia's hot and humid climate, these laboratories, equipped with both local and central air conditioning systems, were selected due to their high utilization by workers. They provided a suitable environment for assessing IAQ and its impact on workers' well-being.

The laboratories were classified into chemical and non-chemical categories to investigate potential differences in IAQ and its effects on psychological performance. Chemical laboratories handle chemicals and biological materials, while non-chemical laboratories primarily focus on computational and theoretical work. Monitoring efforts were evenly distributed between the two types to provide a comprehensive overview of IAQ across different laboratory environments.

The study population consisted of laboratory workers aged 20 to 49, selected randomly from faculty administration records. Both male and female workers actively engaged in laboratory work were included in the study.

The study employed Cochran's formula to determine the appropriate sample size for hypothesis testing in a finite population. Based on an expected stress prevalence of 21.7% and a 80% confidence interval, the required sample size was initially estimated at 47 respondents.[15] The final target sample was increased to 52 respondents to account for potential dropouts. Eligible participants were laboratory workers aged 20 to 59 who had been employed for at least one year, ensuring adequate exposure assessment. Exclusion criteria included pregnant women and individuals with chronic illnesses, as their conditions could influence psychological performance assessments.

The study followed a systematic process, beginning with obtaining ethical and faculty approvals, distributing questionnaires, and conducting IAQ assessments using specific instruments over a month. The initial two weeks were allocated for distributing questionnaires, followed by a week of continuous IAQ monitoring in selected laboratories.

A thorough walkthrough inspection was conducted in all six laboratories, considering factors such as ventilation type, combustion activities, window openings, ongoing activities, instruments, machines, and occupancy levels. Sampling points were strategically placed based on each laboratory's design and total area to ensure representative IAQ measurements.

Psychosocial and physical risk factors affecting mental health among workers were assessed using standardized questionnaires from the General Health Questionnaire (GHQ-12) and Post Occupancy Evaluation (POE).[16,17] These questionnaires were translated into Malay, pilot-tested, and verbally explained by the researcher to ensure clarity. Data collection was conducted online using Google Forms, with completed questionnaires kept confidential. Only participants meeting the inclusion criteria were included in the study. Informed consent was obtained from all participants, with a witness countersigning the consent form to uphold ethical principles.

Mental health scores were calculated using the GHQ-12, a 12-item unidimensional measure of mental health. Higher scores indicate higher levels of psychological distress. The GHQ-12 was graded on a four-point Likert scale, with scores ranging from 0 to 36, and scores above 12 were classified as cases.

Psychological performance indicators were assessed using the POE, which consists of six questions rated on a seven-point Likert scale. These questions measure various aspects of psychological performance, including environmental satisfaction, comfort, stress levels, mood impact, and productivity. The aggregated scores provided a comprehensive overview of the workers' overall psychological well-being.

Real-time IAQ measurements were conducted at each sampling location over 8 hours during regular working hours, from 8 a.m. to 5 p.m., with a 1-hour break from 1 p.m. to 2 p.m. Measurements were taken at a height of 1 meter above the floor and positioned at least 1 meter away from walls and doors, to maintain accuracy and consistency in temperature readings. Data were recorded at 1-hour intervals to capture variations in IAQ parameters throughout the day. Instruments used included the DustTrak II Aerosol Monitor (TSI, USA; model 8532) for particulate matter ($PM_{2.5}$ and PM_{10}), Q-Trak IAQ Monitor (TSI, USA; model 7565) for temperature, relative humidity, carbon dioxide (CO_2), and carbon monoxide (CO), VelociCalc Multi-function Ventilation Meter (TSI, USA; model 9565) for air velocity, handheld VOC Monitor (RAE Systems, USA; model PpbRAE 3000) for total volatile organic compounds (TVOC), and Duo SAS High Volume Microbial Air Sampler (International PBI, Italy; model 360) for airborne microorganisms.

Data analysis was performed using SPSS Version 29. The Shapiro-Wilk test was used to assess data normality. Sociodemographic information was analyzed using frequency and percentage distributions. As the data did not follow a normal distribution, the Kruskal-Wallis test was applied to determine significant differences in IAQ parameters between the two types of laboratories. The psychological performance of the workers was evaluated using frequency and percentage distributions. The Chi-Square Test of Independence was employed to explore the association between IAQ parameters and workers' psychological performance, identifying potential links between environmental factors and worker well-being.

A pilot test involving 10% of the intended sample size was conducted to validate the questionnaire's effectiveness. The internal consistency reliability was evaluated using Cronbach's alpha, which was 0.75. This indicated that the questionnaire items were consistent and reliable for measuring psychosocial and physical risk factors.

All instruments used for IAQ measurements were calibrated before air sampling to ensure accuracy and reliability. IAQ assessments followed the Malaysia Industrial Code of Practice on Indoor Air Quality (ICOP), 2010, ensuring that measurements aligned with national guidelines. These quality control measures ensured that the data collected were valid, reliable, and reflective of actual IAQ conditions and their impact on workers' psychological performance.

Ethical Clearance

Ethical approval was obtained from the Ethics Committee for Research Involving Human Subjects at the university (Ref. No.: JKEUPM-2023-394). Permission for data collection was also secured from the faculty dean. Participants were fully informed about the study's purpose, and informed consent was obtained from all participants, ensuring their understanding of the study procedures and their rights. The consent process included detailed information about the study's objectives, the nature of their participation, and assurances regarding the confidentiality and anonymity of their responses.

Results

The general characteristics of workers in chemical and non-chemical laboratories were analyzed to determine demographic and occupational similarities between the two groups. Table 1 summarizes these characteristics, showing no statistically significant differences in gender distribution, age range, or employment duration between laboratory types. Most workers are mid-career professionals aged 30-49 years, spending less than 8 hours per day in the laboratory. Additionally, a slightly higher proportion of workers in chemical laboratories reported knowing IAQ; however, this difference was not statistically significant.

Table 1: General characteristics of workers at each selected laboratory

Characteristics	Chemical Laboratory (N=41)				Non-Chemical Laboratory (N=11)		χ^2	p
	Number (%)							
	A	B	C	D	E	F		
§Gender							7.80	0.167
Male	1 (6.7)	5 (33.3)	6 (40.0)	2 (13.3)	0 (0.0)	1 (6.7)		
Female	7 (18.9)	7 (18.9)	7 (18.9)	6 (16.2)	5 (13.5)	5 (13.5)		
§Age							3.81	0.956
20 – 29 Years	2 (18.2)	2 (18.2)	2 (18.2)	2 (18.2)	2 (18.2)	1 (9.1)		
30 – 39 Years	3 (14.3)	7 (33.3)	5 (23.8)	3 (14.3)	1 (4.8)	2 (9.5)		
40 – 49 Years	3 (15.0)	3 (15.0)	6 (30.0)	3 (15.0)	2 (10.0)	3 (15.0)		
§Employment Years in Laboratories							3.60	0.609
< 10 Years	4 (16.0)	6 (24.0)	5 (20.0)	6 (24.0)	2 (8.0)	2 (8.0)		
≥ 10 Years	4 (14.8)	6 (22.2)	8 (29.6)	2 (7.4)	3 (11.1)	4 (14.8)		
§Average Hour in Laboratory Per Day							0.62	0.988
< 8 Hours	6 (14.3)	10 (23.8)	10 (23.8)	7 (16.7)	4 (9.5)	5 (11.9)		
≥ 8 Hours	2 (20.0)	3 (30.0)	3 (30.0)	1 (10.0)	1 (10.0)	1 (10.0)		
§Knowledge of IAQ							8.67	0.123
Yes	8 (19.5)	8 (19.5)	9 (22.0)	7 (17.1)	5 (12.2)	4 (9.8)		
No	0 (0.0)	4 (36.4)	4 (36.4)	1 (9.1)	0 (0.0)	2 (18.2)		

*N = 52; *Significant at $p<0.05$; §By χ^2 test with Yates' correction for expected values <5*

Indoor air quality (IAQ) parameters in the laboratories

The assessment of IAQ across six laboratories (A to F) was conducted to examine variations in key environmental parameters throughout the day. The measurements were taken at multiple time points over a single day, providing a time-resolved view of the IAQ in these environments (Figure 1).

Figures 1(a) – 1(d) show the studied chemical contaminants. Figure 1a shows that $PM_{2.5}$ levels are highest in Laboratory B, peaking at approximately 45 µg/m³ at 1 p.m., exceeding the permissible exposure limit (PEL) of 35 µg/m³. Similarly, Figure 1b displays that PM_{10} concentrations also peak in Laboratory B around 1 p.m. at approximately 45 µg/m³, with Laboratories C and F showing moderate afternoon increases. Figure 1c reveals that CO levels peak in Laboratory F at 2.5 ppm at 12 p.m., while other laboratories maintain lower, stable levels. Meanwhile, Figure 1d shows that TVOC levels spike in Laboratories A and B during the morning, with Laboratory B reaching over 500 ppb at 9 a.m., then rapidly decreasing.

As for the biological contaminants, Figure 1(e) shows that bacterial counts are highest in Laboratory E at 8 a.m. (140 CFU/m³), shifting to Laboratory F by 1 p.m. (130 CFU/m³). Additionally, Figure 1(f) reveals that fungal counts peak in Laboratory F at 8 a.m. (120 CFU/m³) but decrease by 1 p.m.

CO_2 as a ventilation performance indicator, as shown in Figure 1g, peaks in Laboratory E at around 1000 ppm at noon, with Laboratories A, C, D, and F remaining below the 1000 ppm threshold. The studied physical parameters are shown in Figures 1h – 1j. Air temperatures in Figure 1(h) generally remain within the comfort range (23°C to 26°C), with Laboratory F consistently slightly above 26°C. Figure 1(i) shows that the highest relative humidity in Laboratory E reaches nearly 80% at midday, while other laboratories maintain lower levels. Figure 1(j) shows air movement peaks in Laboratory C around 2 p.m., with Laboratory F showing lower movement, especially at midday.

Perceptions of workers on indoor environmental quality (IEQ) in the laboratories

Understanding workers' perceptions of IEQ is crucial in assessing potential workplace discomfort and its implications for well-being and productivity. Figure 2 illustrates workers' perceptions of various IEQ factors across six laboratories (A-F), with data presented as the number and percentage of respondents in each category. Responses for each question were categorized into two groups based on the median response value, which served as the cut-off point. Responses below the median were classified as 'positive' perceptions, while those equal to or above the median were classified as 'negative' perceptions.

Figure 2(a) assesses, "Is the air fresh or stale?" (scored from 1 for stale to 7 for fresh). Laboratories A, B, and C have a higher percentage of workers reporting fresh air than Laboratories D, E, and F, where a significant portion find the air stale.

Figure 2(b) evaluates, "Is the air humid or dry?" (scored from 1 for humid to 7 for dry). In most laboratories, most workers perceive the air as too humid, with Laboratory B having the highest percentage of workers reporting this.

Figure 2(c) assesses, "Does the air smell?" (scored from 1 for smelly to 7 for not smelly). In most laboratories, most workers perceive the air as smelly, particularly in Laboratory F, where this perception is most prevalent.

Figure 2(d) examines, "Is the air movement still or good circulation?" (scored from 1 for still to 7 for good circulation). The perception of air being still is more dominant in most laboratories, except for Laboratory E, where most workers report good air circulation.

Figure 2(e) evaluates, "Do you have control over ventilation?" (scored from 1 for full control to 7 for no control). Most laboratory workers perceive no control over ventilation, particularly in Laboratories A and B, where the perception of having no control is dominant.

Figure 2(f) assesses, "Is the temperature too cold or too hot?" (scored from 1 for too cold to 7 for too hot). Most workers across most laboratories perceive the temperature as being too cold, except in Laboratory E, where more workers reported the temperature as too hot.

Figure 2(g) evaluates, "Is the design of the building envelope effective in blocking out the natural heat?" (scored from 1 for not effective to 7 for very effective). Laboratories B and C have a higher percentage of workers perceiving the design as ineffective. In contrast, Laboratories E and F have a more balanced view of the effectiveness of the building design.

Psychological performance among workers

Understanding the psychological well-being of laboratory workers is crucial in assessing the impact of occupational and environmental factors on mental health. Table 2 summarizes the psychological well-being of workers based on the GHQ-12. Most items have a median score of 0, indicating minimal psychological distress for most respondents, such as "Lost much sleep over worry". Items like "Felt you could not overcome your difficulties" have slightly higher median scores of 1.0, suggesting moderate distress. It also shows the number and percentage of workers classified as experiencing psychological distress according to predefined thresholds, with scores above 12 considered as cases. Notably, 51.9% of respondents exceeded the GHQ-12 threshold (>12), categorizing them as experiencing psychological distress.

Table 2: Distribution of general health questionnaire (GHQ-12) results among the respondents

Items	**Median (IQR)**
Lost much sleep over worry	0.0 (1)
Felt constantly under strain	0.0 (1)
Felt you could not overcome your difficulties	1.0 (2)
Been feeling unhappy or depressed	1.0 (2)
Been losing confidence in yourself	1.0 (2)
Been thinking of yourself as a worthless person	0.5 (2)
Been able to concentrate on what you are doing	2.0 (1)
Felt that you are playing a useful part in things	2.0 (1)
Been able to face up to your problem	1.5 (1)
Felt capable of making decisions about things	2.0 (1)
Been feeling reasonably happy, all things considered	2.0 (1)
Been able to enjoy your normal day-to-day activities	2.0 (1)
Scale Total	13.5 (6)
Presence of Psychological Distress	**N (%)**
Yes	27 (51.9)
No	25 (48.1)

IQR = Interquartile Range

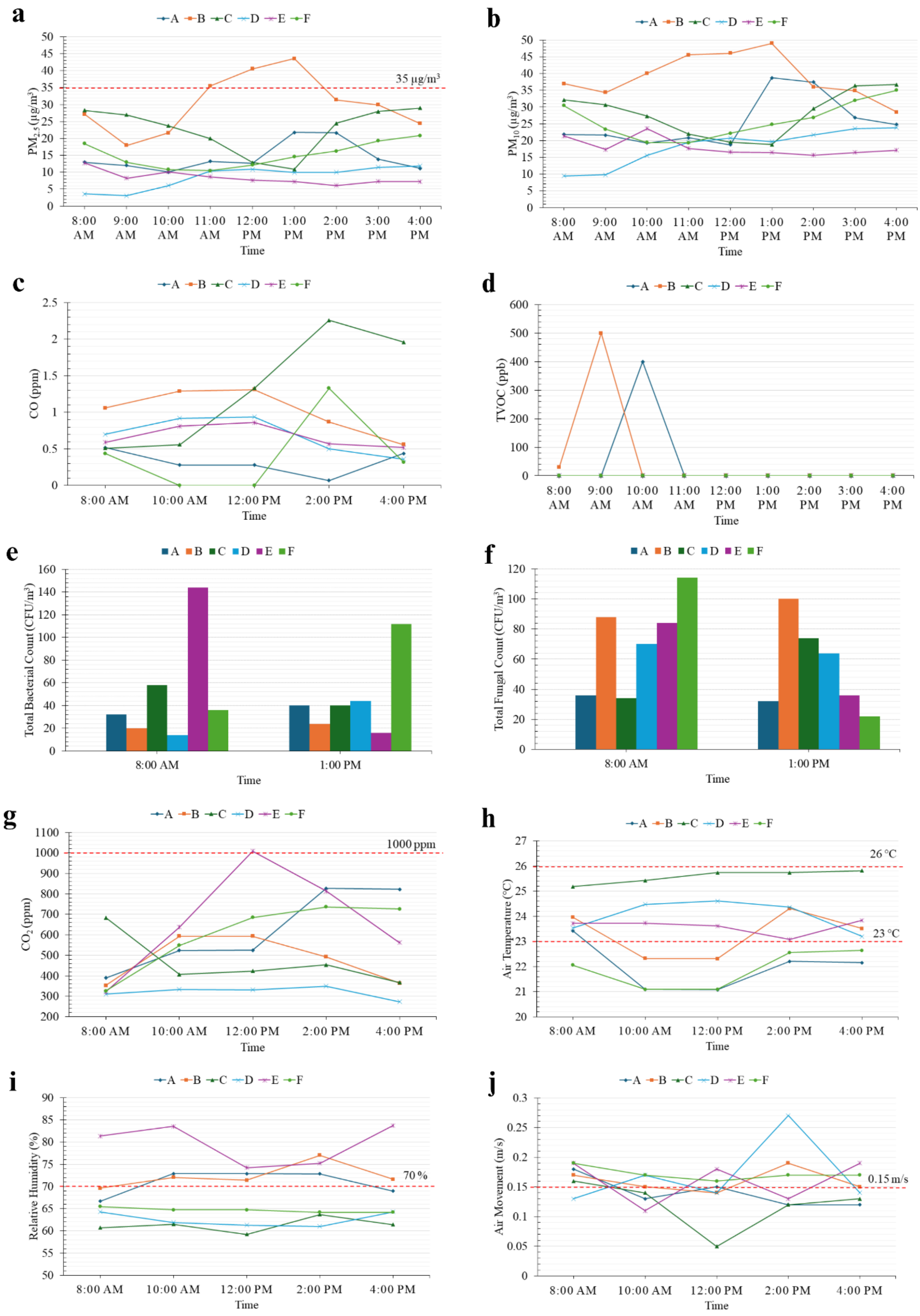

Figure 1: Indoor air quality parameters in the laboratories

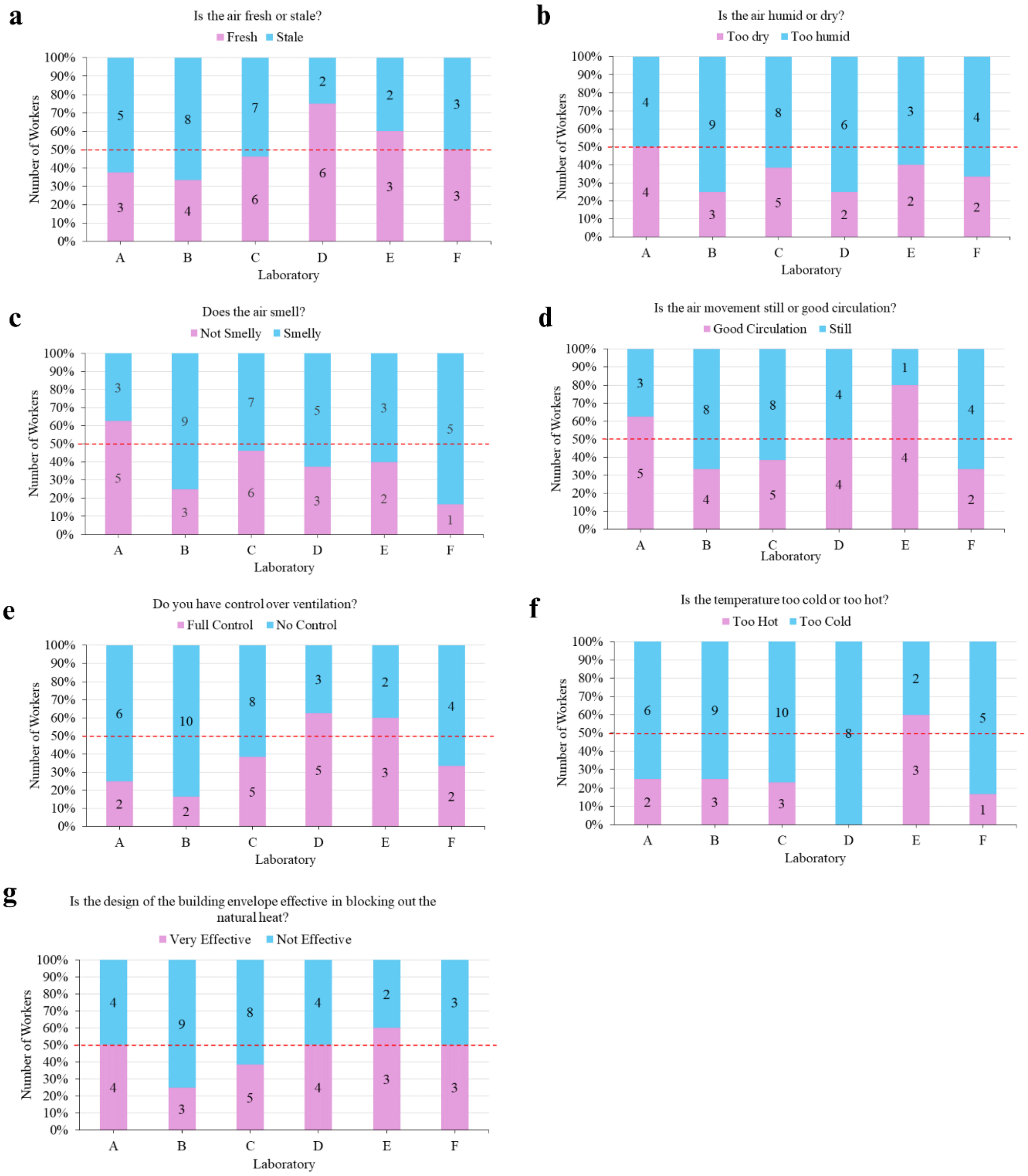

Figure 2: Perceptions of indoor environmental quality parameters in the laboratories

Psychological performance indicators of the laboratory workers

Assessing psychological performance is crucial in understanding the impact of IAQ and indoor environmental conditions on laboratory workers. Psychological factors such as air quality perception, comfort, stress, mood, and productivity significantly affect workplace satisfaction and efficiency. Figure 3 compares workers' perceptions of various psychological performance factors across six laboratories (A-F). Responses are grouped into positive and negative perceptions, with the cutoff point based on the median response value.

The first question, "Does the air quality in your working space have a negative effect on your work performance?" assesses how workers perceive air quality to impact their productivity, as illustrated in Figure 3(a). Across all laboratories, perceptions of an adverse effect on performance are generally low. However, Laboratory E stands out, with 80% of workers believing that air quality negatively affects their performance.

The second question, "Are you satisfied with the indoor air quality of this laboratory building?" gauges overall satisfaction with IAQ, as shown in Figure 3(b). Most workers across all laboratories reported dissatisfaction, except for Laboratory A.

The third question, "What is your comfort level in the laboratory?" assesses comfort, as displayed in Figure 3(c). Workers in all laboratories generally reported being uncomfortable.

The fourth question, "What is your stress level in the laboratory?" evaluates stress experienced by workers, as illustrated in Figure 3(d). Most laboratory workers showed relatively lower stress levels, except for Laboratories A and D.

The fifth question, "Rate the impact of the laboratory building on your mood," measures how the environment affects workers' moods, as shown in Figure 3(e). Across all laboratories, most workers reported that the laboratory building had a negative impact on their mood, particularly in Laboratory B, where over 80% of workers rated the impact as poor.

The sixth question, "What is your work productivity in the laboratory?" measures perceived changes in productivity due to the laboratory environment, as displayed in Figure 3(f). Most workers reported a decrease in productivity across all laboratories, particularly in Laboratories B and D.

Association between indoor air quality (IAQ) parameters and psychological performance

Understanding the relationship between sociodemographic factors and psychological distress is crucial in identifying key risk factors affecting laboratory workers. Table 3 reports the relationship between various sociodemographic factors and the presence of psychological distress among laboratory workers. The table uses odds ratios (OR) and Chi-Square (χ^2) tests to determine whether factors such as type of laboratory, gender, age, years of employment, and hours spent in the laboratory per day are associated with psychological distress.

The amount of time spent in the laboratory each day shows a strong and statistically significant association with psychological distress ($p=0.007$). Workers who spend more than 8 hours per day in the laboratory are far more likely to experience psychological distress (OR=0.08). Conversely, the type of laboratory, gender, age of workers, and the length of time workers have been employed in laboratories do not show a significant correlation with psychological distress.

In addition, the results revealed no significant associations between the IAQ parameters studied and the presence of psychological distress among laboratory workers. Although some parameters, such as high levels of particulate matter and relative humidity, showed trends towards increased odds of distress, these findings were not statistically significant.

Table 3: Associations between sociodemographic information and presence of psychological distress among laboratory workers

Variables	Presence of Psychological Distress: Yes N (%)	Presence of Psychological Distress: No N (%)	OR (95% CI)	χ^2	p
Type of Laboratory					
Chemical	5 (18.5)	22 (81.5)	0.72 (0.19 – 2.74)	0.2	0.629
Non-Chemical	6 (24.0)	19 (75.0)			
Gender					
Male	7 (25.9)	20 (74.1)	0.74 (0.22 – 2.48)	0.2	0.629
Female	8 (32.0)	17 (68.0)			
Age					
20 – 39 Years	16 (59.3)	11 (40.7)	0.82 (0.27 – 2.51)	0.1	0.726
40 – 49 Years	16 (64.0)	9 (36.0)			
Employment Years in Laboratories					
< 10 Years	11 (40.7)	16 (59.3)	0.54 (0.18 – 1.63)	1.2	0.271
≥ 10 Years	14 (56.0)	11 (44.0)			
Average Hour in the Laboratory Per Day					
< 8 Hours	18 (66.7)	9 (33.3)	0.08 (0.01 – 0.72)	**7.2**	**0.007***
≥ 8 Hours	24 (96.0)	1 (4.0)			

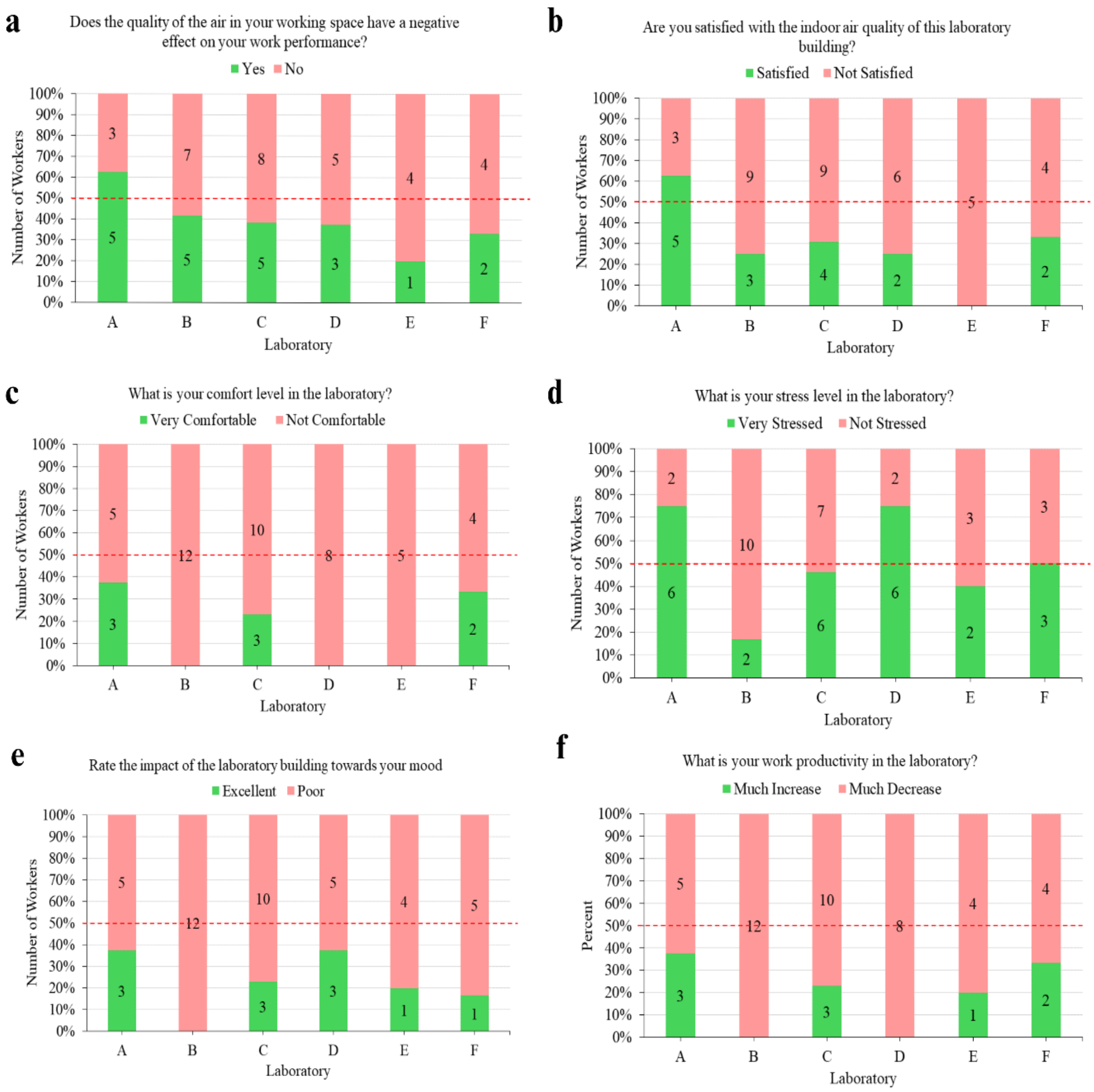

Figure 3: Psychological performance indicators of the laboratory workers

The relationship between IAQ parameters and psychological performance needs to be determined to discover the critical role of IAQ in workplace comfort and stress management. The findings from Tables 4 and 5 highlight key associations between specific IAQ parameters and psychological performance, particularly regarding discomfort and stress levels among laboratory workers. There is a statistically significant association between CO levels and discomfort among laboratory workers (p=0.042). Workers exposed to high CO levels are 6.5 times more likely to report feeling uncomfortable than those exposed to lower CO levels. Additionally, air temperature was significantly associated with discomfort (p=0.042). Workers exposed to temperatures above 23.3°C were 6.5 times more likely to feel uncomfortable than those in cooler conditions. Conversely, other IAQ parameters did not show statistically significant associations with comfort levels.

Table 5 reveals that only air movement had a significant association with stress levels among laboratory workers (p=0.023). Workers exposed to low air movement conditions are 3.7 times more likely to report being stressed than those with higher air movement. This finding suggests that insufficient air circulation may increase stress in laboratory environments. Other IAQ parameters, while potentially influential, did not show statistically significant associations with stress levels.

Table 4: Associations between IAQ parameters and comfort level among laboratory workers

Variables	Comfort Level		OR (95% CI)	χ^2	p
	Not Comfortable N (%)	Very Comfortable N (%)			
§Chemical Contaminants					
High CO (≥ 0.67 ppm)	35 (92.1)	3 (7.9)	6.5 (1.30 – 32.36)	4.13	**0.042***
Low CO (< 0.67 ppm)	9 (64.3)	5 (35.7)			
High $PM_{2.5}$ (≥ 15.08 μg/m³)	31 (79.5)	8 (20.5)	0.8 (0.68 – 0.93)	1.77	0.183
Low $PM_{2.5}$ (< 15.08 μg/m³)	13 (100)	0 (0.0)			
High PM_{10} (≥ 25.92 μg/m³)	31 (79.5)	8 (20.5)	0.8 (0.68 – 0.93)	1.77	0.183
Low PM_{10} (< 25.92 μg/m³)	13 (100)	0 (0.0)			
High TVOC (≥ 113 ppb)	17 (85.0)	3 (15.0)	1.0 (0.22 – 4.97)	0.01	0.952
Low TVOC (< 113 ppb)	27 (84.4)	5 (15.6)			
§Biological Contaminants					
High Total Bacterial Count (≥ 49 CFU/m³)	19 (79.2)	5 (20.8)	0.5 (0.10 – 2.15)	0.39	0.533
Low Total Bacterial Count (< 49 CFU/m³)	25 (89.3)	3 (10.7)			
High Total Fungal Count (≥ 60 CFU/m³)	29 (93.5)	2 (6.5)	5.8 (1.04 – 32.31)	3.16	0.075
Low Total Fungal Count (< 60 CFU/m³)	15 (71.4)	6 (28.6)			
§Ventilation Performance Indicator					
High CO_2 (≥ 602.24 ppm)	14 (73.7)	5 (26.3)	0.3 (0.06 – 1.34)	1.58	0.208
Low CO_2 (< 602.24 ppm)	30 (90.9)	3 (9.1)			
§Physical Parameters					
High Air Temperature (≥ 23.3 °C)	35 (92.1)	3 (7.9)	6.5 (1.30 – 32.36)	4.13	**0.042***
Low Air Temperature (< 23.3 °C)	9 (64.3)	5 (35.7)			
High Relative Humidity (≥ 70.84 %)	22 (88.0)	3 (12.0)	1.7 (0.35 – 7.84)	0.07	0.790
Low Relative Humidity (< 70.84 %)	22 (81.5)	5 (18.5)			
High Air Movement (≥ 0.16 m/s)	21 (91.3)	2 (8.7)	2.7 (0.50 – 15.09)	0.65	0.422
Low Air Movement (< 0.16 m/s)	23 (79.3)	6 (20.7)			

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

Table 5: Associations between IAQ parameters and stress level among laboratory workers

Variables	Stress Level		OR (95% CI)	χ^2	p
	Not Stressed N (%)	Very Stressed N (%)			
Chemical Contaminants					
High CO (≥ 0.67 ppm)	22 (57.9)	16 (42.1)	2.5 (0.70 – 8.80)	2.02	0.156
Low CO (< 0.67 ppm)	5 (35.7)	9 (64.3)			
High $PM_{2.5}$ (≥ 15.08 μg/m³)	22 (56.4)	17 (43.6)	2.1 (0.57 – 7.48)	1.26	0.262
Low $PM_{2.5}$ (< 15.08 μg/m³)	5 (38.5)	8 (61.5)			
High PM_{10} (≥ 25.92 μg/m³)	22 (56.4)	17 (43.6)	2.1 (0.57 – 7.48)	1.26	0.262
Low PM_{10} (< 25.92 μg/m³)	5 (38.5)	8 (61.5)			
High TVOC (≥ 113 ppb)	12 (60.0)	8 (40.0)	1.7 (0.55 – 5.28)	0.85	0.357
Low TVOC (< 113 ppb)	15 (46.9)	17 (53.1)			

Biological Contaminants					
High Total Bacterial Count (≥ 49 CFU/m^3)	13 (54.2)	11 (45.8)	1.1 (0.40 – 3.52)	0.10	0.764
Low Total Bacterial Count (< 49 CFU/m^3)	14 (50.0)	14 (50.0)			
High Total Fungal Count (≥ 60 CFU/m^3)	18 (58.1)	13 (41.9)	1.8 (0.60 – 5.66)	1.20	0.282
Low Total Fungal Count (< 60 CFU/m^3)	9 (42.9)	12 (57.1)			
Ventilation Performance Indicator					
High CO_2 (≥ 602.24 ppm)	8 (42.1)	11 (57.9)	0.5 (0.17 – 1.68)	1.2	0.282
Low CO_2 (< 602.24 ppm)	19 (57.6)	14 (42.4)			
Physical Parameters					
High Air Temperature (≥ 23.28 °C)	22 (57.9)	16 (42.1)	2.5 (0.70 – 8.80)	2.00	0.156
Low Air Temperature (< 23.28 °C)	5 (35.7)	9 (64.3)			
High Relative Humidity (≥ 70.84 %)	15 (60.0)	10 (40.0)	1.9 (0.62 – 5.65)	1.30	0.262
Low Relative Humidity (< 70.84 %)	12 (44.4)	15 (55.6)			
High Air Movement (≥ 0.16 m/s)	16 (69.6)	7 (30.4)	3.7 (1.17 – 11.96)	5.10	**0.023***
Low Air Movement (< 0.16 m/s)	11 (37.9)	18 (62.1)			

**Significant at p<0.05*

Discussion

The general characteristics of workers in chemical and non-chemical laboratories reveal no statistically significant differences in gender (χ^2=7.80, p=0.167), age (χ^2=3.81, p=0.956), or work experience (χ^2=3.60, p=0.609). This demographic similarity helps minimize confounding variables, ensuring that any differences in psychological and physical outcomes are more likely attributed to environmental factors, such as IAQ, rather than variations in workforce characteristics. Most workers are mid-career professionals, aged 30-49, which aligns with global trends in laboratory environments.[18]

There are critical concerns regarding IAQ, particularly in Laboratory B, where $PM_{2.5}$ and PM_{10} levels exceed permissible exposure limits (PEL), peaking at 45 μg/m³ at 1 p.m., surpassing the 35 μg/m³ threshold. These exceedances raise long-term respiratory and cardiovascular risks.[19–21] Elevated CO and TVOC levels (> 500 ppb) in Laboratories F and B and high bacterial and fungal counts indicate ventilation inefficiencies and biohazard risks in Laboratories E and F. Poor air circulation, particularly in Laboratory F, exacerbates these issues, potentially allowing contaminants to accumulate and impacting workers' comfort and health.

Subjective worker experiences reveal widespread dissatisfaction with IEQ, especially in Laboratories D, E, and F, where stale air, high humidity, and poor ventilation are prevalent. The workers' lack of control over ventilation in Laboratories A and B compounds this issue, contributing to discomfort and decreased autonomy.[22,23] These environmental stressors are likely to negatively impact worker well-being and productivity, particularly in laboratories with pronounced temperature extremes, such as the overly cold conditions in most laboratories and the excessively hot environment in Laboratory E.

More than half of the workers experience psychological distress, with symptoms such as unhappiness and difficulties in overcoming challenges being more common. This aligns with existing literature on occupational health, which suggests that poor indoor environmental conditions can contribute to mental health issues such as stress and depression.[5,6,9] The prevalence of psychological distress highlights the urgent need for interventions addressing both environmental and psychosocial factors to enhance worker well-being in laboratory settings.

The impact of poor IAQ on psychological performance was shown, particularly in Laboratory E, where 80% of workers reported that poor air quality negatively impacts their work performance. Although discomfort is widespread, stress levels remain relatively low in most laboratories except for Laboratories A and D. While discomfort may not immediately translate into stress, it can manifest in reduced productivity and mood disturbances, requiring further attention.[2,4,24]

Statistical associations between sociodemographic factors and psychological distress (Table 3) confirm that workers spending more than 8 hours daily in the laboratory are significantly more likely to experience psychological distress (p=0.007, OR=0.08, 95% CI: 0.01–0.72). This finding is consistent with occupational health research that links extended exposure to poor environmental conditions with adverse mental health outcomes.[25,26] Interestingly, factors such as gender, age, and laboratory type did not show significant associations, reinforcing the idea that environmental conditions are the primary contributors to psychological distress in these settings.

Having proper ventilation is also crucial for worker well-being.[27] High CO levels and insufficient air movement are strongly associated with discomfort and stress, highlighting the need for improved ventilation systems. Although other IAQ parameters, such as particulate matter and humidity, did not reach statistical significance, the observed trends suggest these factors may still contribute to long-term health risks if left unaddressed.

The study's cross-sectional design gave a comprehensive snapshot of IAQ and its impact on workers' psychological performance. However, this design limits the capture of seasonal variations or long-term trends in IAQ and worker health. While the study included a range of laboratories, the relatively small sample size may limit the generalizability of the findings. Additionally, GHQ-12 and psychological performance measures rely on self-reports, which may introduce recall bias. Complementary physiological stress markers, such as heart rate variability, could improve accuracy. Future studies with larger, more diverse populations and longitudinal designs would provide deeper insights into the prolonged effects of IAQ on health and productivity.

Conclusions

This study highlights the significant impact of IAQ on laboratory workers' physical comfort and psychological well-being. Key IAQ parameters contributed to discomfort, stress, and reduced productivity, including elevated particulate matter ($PM_{2.5}$, PM_{10}), CO levels, temperature, and air movement. The findings suggest that prolonged exposure to poor air quality, particularly in laboratories with inadequate ventilation and temperature control, exacerbates workers' psychological distress and physical discomfort.

We recommend implementing targeted interventions to address these issues, such as improving ventilation systems, reducing CO and particulate matter exposure, and optimizing temperature regulation. Regular IAQ assessments and increased worker education on air quality management are crucial for mitigating health risks and enhancing workplace productivity. Longitudinal studies should be conducted to further explore the long-term effects of IAQ on worker health and well-being.

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Author Contributions

All three authors have access to the manuscript's supporting data. All three authors have reviewed and accepted the manuscript and concur on the manuscript's contents. PBMH conceived the study, collected data, conducted data analysis, and wrote the first draft of the manuscript. MN and NFS were involved in project conceptualization, methodology, and validation, and they reviewed and approved the final manuscript.

Conflicts of interest

All authors declare that they have no conflicts of interest.

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