UMT PRESS

Journal of Sustainability Science and Management
Journal Homepage: https://jssm.umt.edu.my
eISSN: 2672-7226
DOI: http://doi.org/10.46754/jssm.2026.05.008

INDOOR AIR QUALITY AND RISK ASSESSMENT IN UNIVERSITY CAFETERIA ENVIRONMENT

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ARTICLE INFO

Article History:
Received: 7 September 2024
Revised: 7 April 2025
Accepted: 14 January 2026
Published: 15 May 2026

Keywords:
Cafeteria, health risk, indoor air quality, risk assessment, health symptoms.

ABSTRACT

Indoor air quality is essential to sustainability because of its impact on human health, environmental stability, and economic outcomes. This study examines Indoor Air Quality (IAQ) and related health risks in a university cafeteria experiencing increased occupancy and reported discomfort. A comprehensive assessment was conducted, measuring physical (temperature and relative humidity), chemical (formaldehyde, ozone, carbon monoxide, total volatile organic compounds, carbon dioxide, and PM_{10}), and biological (total fungi and bacteria counts) parameters. Risk analysis followed ISO 31000 guidelines and health risk assessment protocols, evaluating both carcinogenic and non-carcinogenic risks. Most parameters complied with acceptable standards, except for elevated temperature, PM_{10}, and total bacteria counts. A questionnaire survey identified dust, odour, unstable temperature, and inadequate ventilation as primary stressors associated with symptoms such as headaches, dizziness, and throat irritation. The moderate risk score of 9 indicated a need for planned and temporary interventions. PM_{10} exposure resulted in a carcinogenic risk of 0.164, surpassing USEPA (2023) and WHO (2021) thresholds (1×10^{-6}), and a non-carcinogenic hazard quotient of 1.047, indicating significant health concerns. These findings highlight the necessity for targeted mitigation strategies and support the development of a comprehensive IAQ monitoring and risk management framework to inform future policy and research initiatives.

Introduction

Indoor air quality is a critical component of sustainability, impacting human health, environmental preservation, and long-term economic stability, particularly in enclosed spaces such as university cafeterias, where it significantly affects the well-being of occupants. University cafeterias serve as a central hub, often visited by students and staff for daily activities such as eating, socialising, and studying. Hence, air quality in cafeterias is a growing concern, as inadequate indoor air quality poses health risks. Health issues range from minor irritation to serious respiratory conditions, impacting the productivity, health and comfort of occupants.

Recent research has identified particulate matter (PM_{10}), volatile organic compounds, and carbon dioxide as the primary pollutants in indoor environments, and temperature is also a key factor. Alves *et al*. (2020) emphasised that indoor air quality in a cafeteria showed higher concentrations of particulate matter, metals, and volatile organic compounds, and poorer ventilation than in outdoor environments, but the circumstances did not pose a cancer risk. Liang *et al*. (2021) also highlighted that indoor pollution was exacerbated when outdoor contaminants from high-pollution metropolitan regions entered interior spaces. Furthermore, Javed *et al*. (2020) reported that cooking activities in cafeterias were major sources of particulate matter and volatile organic compounds emissions, especially during peak meal times. In addition, the use of cleaning agents significantly increases volatile organic compound concentrations and persists long after the cleaning process. Likewise, occupancy rate directly influences carbon dioxide concentrations and indoor temperature, as greater numbers of occupants increase both through human respiration and body heat.

Prolonged exposure and high levels of particulate matter and volatile organic compounds caused respiratory issues, headaches and decreased cognitive function (Ramos *et al*., 2019). Xie *et al*. (2022) elaborated on the health risks, noting that moderate levels of indoor pollutants exacerbated asthma and allergy conditions. Consequently, regular monitoring and immediate remediation measures were highlighted. Wu *et al*. (2023) proposed a comprehensive risk assessment model tailored for the dynamic environment of university cafeterias, where occupant behaviour and fluctuations in chemical pollutant levels during daily operations were considered. Indoor environments that are safe and conducive to learning and social interactions ensure the health and well-being of students and staff.

This study focuses on a university cafeteria due to its high occupancy and recurrent complaints from occupants regarding thermal comfort. The research objectives are to investigate indoor air quality by analysing physical, chemical, and biological parameters, and to conduct risk and health risk assessments of the university cafeteria. The findings are vital for evidence-based mitigation strategies and management practices to address identified risks. Therefore, it safeguards the well-being and academic performance of the university community by improving indoor air quality.

Materials and Methods

Assessment Preparation

Initially, the research ethics was approved by the Research Ethics Committee, Universiti Teknologi MARA (Appendix 1). The study was conducted in the cafeteria at Universiti Teknologi MARA, with the approval of the cafeteria operator. Through the complaints and complaint procedure surveys, discomfort with indoor air quality and high occupancy were recorded (Appendix 2). The total area of 426.29 m^2, with a volume of 1184.38 m^3, was spanned by the cafeteria. The five sampling points were determined in accordance with Appendix 4 of the Industry Code of Practice Indoor Air Quality 2010 (ICOP IAQ 2010), as shown in Figure 1 (Department of Occupational Safety and Health, Ministry of Human Resources Malaysia, 2010).

Indoor Air Quality Assessment

A walkthrough inspection was conducted in accordance with Appendix 3-A of ICOP IAQ 2010 (Department of Occupational Safety and Health, Ministry of Human Resources, Malaysia, 2010). Physical, chemical and biological parameters assessments were conducted using appropriate instruments. The physical chemical parameters were temperature and relative humidity. Formaldehyde, ozone, carbon monoxide, total volatile organic compounds, carbon dioxide, and particulate matter (PM_{10}) were the assessed chemical parameters. For biological parameters, total bacterial and total fungal counts were examined. For full-period, consecutive, long-term direct sampling, four cycles of physical and chemical parameters were measured over eight hours from 8 a.m. to 4 p.m., with each sampling duration around 20 minutes. Meanwhile, only one cycle of biological parameter measurements was performed. Samples were prepared in duplicates.

EVM Environmental Monitors (Quest EVM-7) were used to record the physical parameters of temperature and relative humidity. The formaldehyde and ozone concentrations

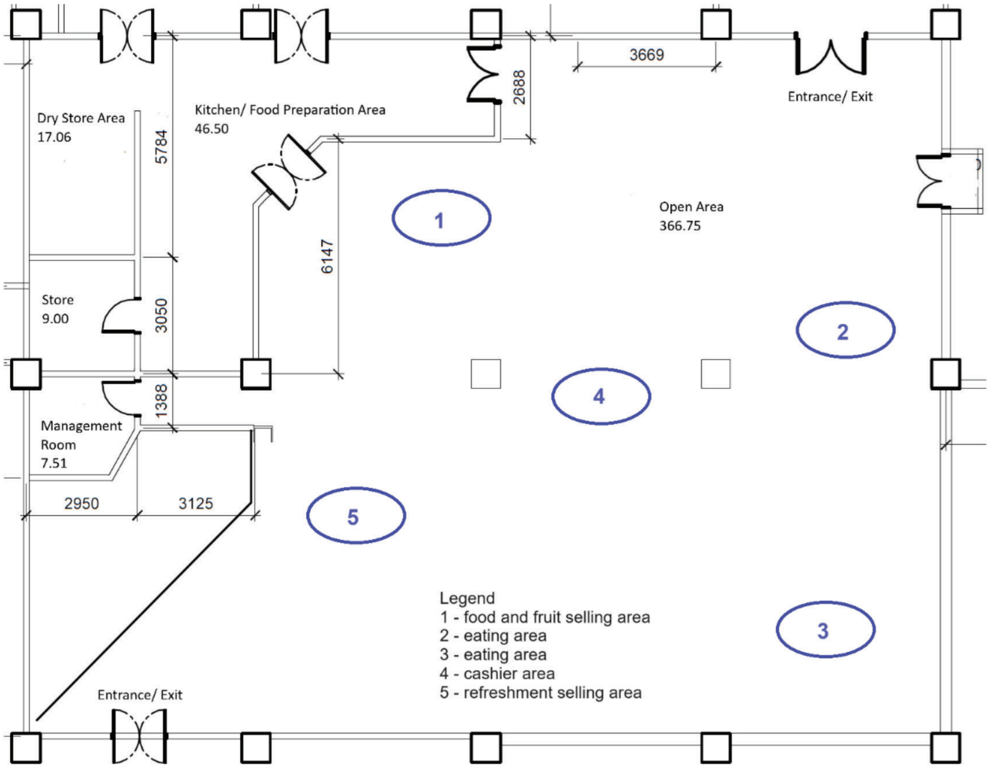

Figure 1: Five sampling points at the cafeteria (Sampling point 1 represented the food and fruit selling area, sampling points 2 and 3 were located at the eating area, sampling point 4 was at the cashier area, and sampling point 5 was at the refreshment selling area)

were measured using a Handheld Formaldehyde Meter (HAL-HFX205) and an Aeroqual Ozone Meter (Series-500), respectively. Carbon monoxide, total volatile organic compounds, carbon dioxide, and particulate matter (PM_{10}) concentrations were recorded using EVM Environmental Monitors. For biological assessment, a single biostage standard impactor and a pump with a calibrated flow rate of 28.3 L/min were used to conduct biological sampling. Tryptone Soya Agar and Malt Extract Agar were used for total bacterial and total fungal counts, respectively. In the laboratory, the tryptone soya agar plates were incubated at 30–35 ºC for two days. Meanwhile, the malt extract agar plates were incubated at 20–25 ºC for four days (Sandle, 2023). The hole correction was conducted for the colony count.

Statistical Analysis

Data were analysed in Microsoft Excel to calculate the average and standard deviation. In addition, a single-factor Analysis of Variance (ANOVA) was conducted to identify significant differences between sampling points and cycles.

Questionnaire Survey

A set of symptom questionnaires based on Appendix 3-B of the ICOP IAQ 2010 was adopted. The questionnaire included general information, nature of occupation, environmental conditions, and present symptoms and diseases. A Google Forms QR code was distributed to cafeteria occupants. 60 respondents voluntarily participated in a questionnaire survey on environmental conditions and symptoms.

Risk Assessment

The ISO 31000:2018 risk management guideline was adopted (ISO 31000, 2018). The risk assessment was calculated based on the risk assessment matrix. It was calculated numerically by multiplying the likelihood of indoor air quality parameters exceeding the acceptable limit (*L*) by the severity of symptoms among occupants due to poor indoor air quality at the workplace (*S*) (Equation 1).

Risk score = likelihood (*L*) x severity (*S*) (1)

Health Risk Assessment

Carcinogenic (Equations 2 and 3) and non-carcinogenic (Equations 4 and 5) risks were calculated and evaluated according to Khaslan *et al*. (2024). The average concentration of particulate matter in indoor air was 0.22 mg/ m^3, exposure frequency was 260 days/ year (5 working days/ week x 52 weeks = 260 days) and the reference concentration is 0.15 mg/m^3 (Department of Occupational Safety and Health, Ministry of Human Resources Malaysia, 2010).

$$CR = LADD \times CSF \quad (2)$$

$$CSF = IUR \times \left(\frac{BW}{InhR}\right) \quad (3)$$

$$HQ = \frac{ADD}{RfD} \quad (4)$$

$$RfD = RfC \times \left(\frac{InhR}{BW}\right) \quad (5)$$

where *CR* = the cancer risk, *LADD* = the lifetime average daily dose, *CSF* = the cancer slope factor, *IUR* = the inhalation unit risk, *BW* = the body weight, *InhR* = the inhalation rate, *HQ* = the hazard quotient, *ADD* = the average daily dose level, *RfC* = the reference concentration and *RfD* = the reference dose.

Results and Discussion

Walkthrough Inspection

The uneven, high temperatures that caused thermal comfort issues were observed during the walkthrough inspection. In addition, observations from the walkthrough inspection also recorded odour problems. The uneven temperature was attributed to poor air circulation and the mechanical ventilation and air conditioning system's efficiency, as well as the high occupancy of the cafeteria. Chen *et al*. (2022) reported that poor mechanical ventilation and high occupancy led to thermal comfort issues, including elevated and uneven temperatures. On the other hand, the observed odour in the cafeteria originated from food and refreshment preparation. The poor ventilation conditions of the cafeteria trapped the odour in the area. Sundell *et al*. (2011) supported the findings where ventilation plays an important role in influencing human exposures to indoor pollutants and odours. Further investigation through indoor air quality parameters assessment is crucial to confirm the observed issues.

Physical Parameters Assessment

Figure 2 shows indoor air temperatures at five sampling points over four cycles in the cafeteria. The temperature ranged from 28–31°C with an average temperature of 30 ± 0.99°C. Findings showed that all collected sampling data were above the maximum acceptable limit of the ICOP IAQ 2010 at 26°C and the ANSI/ASHRAE Standard 55 – 2022 at 27 ºC, indicating a thermal comfort issue focused on temperature. In the ANOVA analysis, a significant temperature difference across cycles is observed ($p < 0.05$), but no significant difference among sampling points is observed. High and uneven temperatures may be due to the mechanical ventilation system's inefficiency, which could not support the high number of occupants in the cafeteria (Yusup *et al*., 2014). The average number of occupants observed was 60–80, exceeding the cafeteria's maximum designed capacity of 50, coinciding with inadequate mechanical ventilation (Zhang *et al*., 2024). High occupancy increased heat due to occupants' respiration rates and heat accumulation. Hence, an increase in temperature was observed over time. Ameen *et al*. (2023) supported these findings, noting that the mechanical ventilation and air conditioning system plays a major role in achieving thermal comfort in indoor air. Fans were found to increase ventilation in the cafeteria; however, this caused uneven temperatures.

In addition, it was observed that the cafeteria doors were opened during lunch hours and during high-occupancy periods to facilitate the movement of occupants. The open doors in the afternoon and evening brought in high-temperature outdoor air, increased indoor air temperatures, and worsened the condition. Liang *et al*. (2021) is consistent with this study, in which outdoor air impacts indoor air quality. Various temperature readings also supported the uneven temperature observed during the walkthrough inspection. High indoor temperature led to health symptoms and effects. Occupants, especially those with preexisting health issues, experienced headaches, fatigue and reduced cognitive function due to thermal discomfort (Zuo *et al*., 2020). Furthermore, elevated temperatures increased the likelihood of symptoms of sick building syndrome, such as respiratory distress and irritation (Hou *et al*., 2021). Reynolds *et al*. (2021) also stressed that adequate ventilation was crucial to maintaining health and comfort in high-traffic, high-occupancy environments.

Relative humidity for five sampling points across four cycles is shown in Figure 3. The measured relative humidity showed variability between 60–69% across sampling locations, with an average of 64 ± 2.36%. All recorded data were within the acceptable range of the ICOP IAQ 2010 for relative humidity (40–70%). The ANOVA analysis shows that relative humidity is significantly different among cycles at 0.0025 ($p<0.05$); however, the differences among sampling points at 0.7548 are not statistically significant ($p>0.05$). A well-scheduled housekeeping and management operation kept the relative humidity within acceptable limits and promoted a sustainable, healthy indoor environment and a low risk of illness. Chang *et al*. (2021) highlighted that proper cleaning and housekeeping contributed to good indoor air quality. On the other hand, all sampling points, except for cycles 1 and 2, were below the 65 % ANSI/ASHRAE Standard 55-2019 acceptable limit for fungi prevention. High relative humidity in the morning (cycles 1 and 2) resulted from overnight moisture buildup, poor overnight ventilation, and the cooling-induced effect; condensation occurred, thereby increasing relative humidity in the morning. Waterson and Hunt (2024) also reported that a saving-building policy with no ventilation during the nighttime increased relative

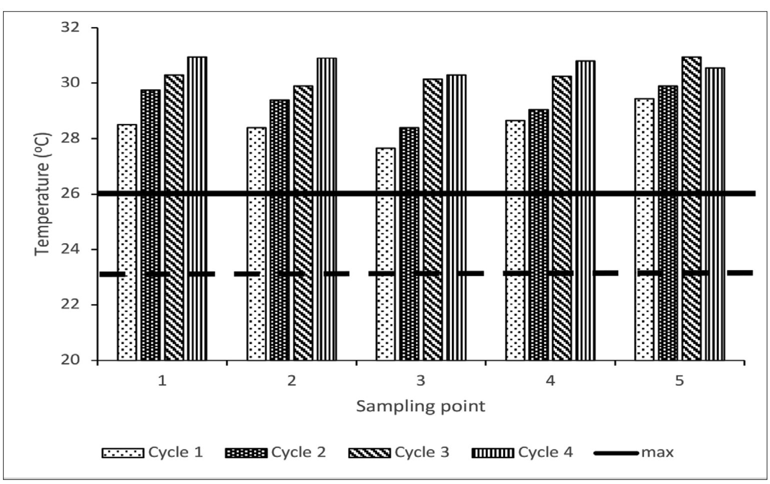

Figure 2: Temperature in the cafeteria for five sampling points over four cycles. The lines are the specified temperature range of the ICOP IAQ 2010 at 23–26°C

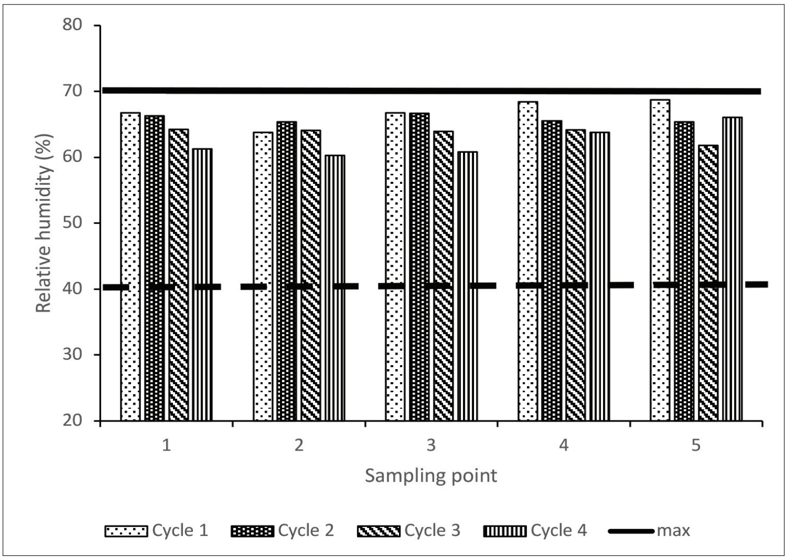

Figure 3: Relative humidity in the cafeteria for five sampling points over four cycles. The lines are the specified relative humidity range of the ICOP IAQ 2010 at 40–70 %

humidity, especially in the morning. Low humidity can lead to symptoms such as dry skin and respiratory irritations, while high humidity promotes fungi growth and illness (Torriani *et al*., 2024). Overall, ideal relative humidity levels improved thermal comfort, thereby enhancing cognitive performance and occupant well-being.

Chemical Parameters Assessment

The measured chemical parameter concentrations of formaldehyde, ozone, and carbon monoxide were reported as 0 ± 0.0000 mg/L, respectively, and were below the acceptable limits of the ICOP IAQ 2010, where formaldehyde at 0.1 ppm, ozone at 0.05 ppm, and carbon monoxide at 10 ppm. Findings also showed levels below the acceptable limits of the ANSI/ASHRAE Standard 62.1-2022 for formaldehyde, ozone, and carbon monoxide at 0.027 ppm, 0.05 ppm, and 9 ppm, respectively. Minimal combustion sources and proper hood maintenance contributed to effective pollutant removal, maintaining clean air (Salthammer *et al*., 2020; Ghani *et al*., 2024). High formaldehyde concentrations lead to respiratory issues and cognitive impairment; high ozone levels cause throat irritation and respiratory distress; high carbon monoxide levels pose risks of headache, dizziness, and impaired cognitive function. Hence, minimum and low pollutant levels safeguarded human health (Surawattanasakul *et al*., 2022).

Figure 4 presents total volatile organic compounds at low concentrations, below the 3 ppm acceptable limit set by the ICOP IAQ 2010. The total volatile organic compounds in the cafeteria ranged from 0.0850 to 0.5900 ppm, with a mean of 0.2713 ± 0.1339 ppm. The ANOVA analysis shows that there is no statistically significant difference in total volatile organic compound concentration across cycles (0.0758) or sampling points (0.0896; $p>0.05$). The observed odour in the cafeteria may mostly originate from the food and the food preparation process. These revealed that the odour problem in the cafeteria is non-hazardous and has a low risk of illness (Zhou *et al*., 2023). Volatile organic compounds (VOCs) in university cafeterias may originate from building materials, cleaning products, and furnishings (Vardoulakis *et al*., 2020). Symptoms of VOC exposure can include respiratory issues, headaches, skin irritations, asthma and sick building syndrome (Horvat *et al*., 2025; Yin

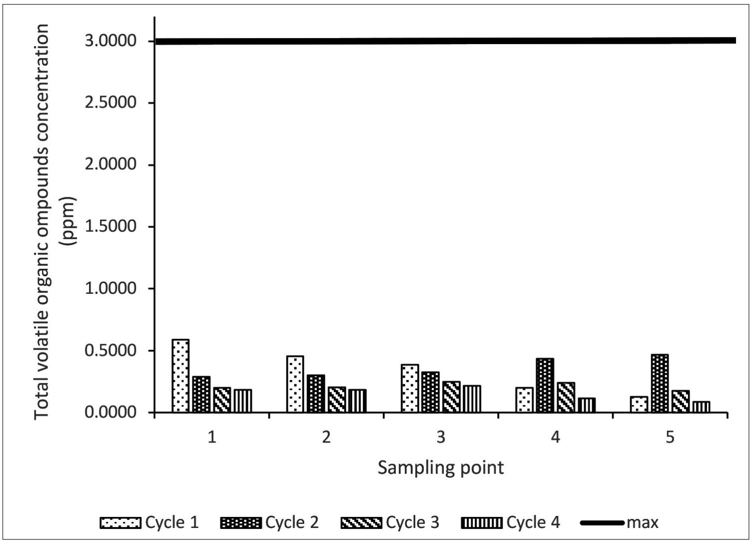

Figure 4: Total volatile organic compounds concentration in the cafeteria for five sampling points over four cycles. The line is the specified total volatile compounds range of the ICOP IAQ 2010 at 3 ppm

et al., 2024). Long-term exposure to elevated VOC levels has been associated with serious health effects, including certain cancers and organ damage. Implementing effective indoor air quality management, regular housekeeping, and ventilation strategies significantly reduced indoor VOC concentrations, thereby promoting a healthier university cafeteria environment.

Figure 5 shows that the carbon dioxide concentrations at five sampling points across four cycles were below the maximum acceptable limit of the ICOP IAQ 2010 at 1000 ppm. For ANOVA analysis, carbon dioxide concentration is significant across cycles at 0.0395 ($p<0.05$), but not among sampling points at 0.1950, indicating no statistically significant differences ($p>0.05$). The range and mean of carbon dioxide were 379–958 ppm and 595 ± 164 ppm, respectively. The activities of occupants, overcrowding, and the conditions at sampling points play a major role in carbon dioxide concentration (Ateş & Khameneh, 2023). High carbon dioxide concentrations were observed at cycle 1 sampling points 1, 2, and 3 due to a large number of occupants queued for food selection at sampling point 1 and the activity of eating together at sampling points 2 and 3.

The brunch habit between 9 and 11 a.m. was popular among students and favoured heavy food in dining areas. Findings from Ali *et al*. (2020) are consistent with this study, in which activities and the functionality of dining areas at sampling points contributed to carbon dioxide generation and concentrations in the cafeteria. Furthermore, the open door also reduced carbon dioxide concentration in the cafeteria by increasing fresh air intake, thereby increasing air exchange (Alves *et al*., 2020). Symptoms of elevated carbon dioxide include headaches, dizziness, fatigue, and impaired cognitive function, especially when concentrations exceed 1000 ppm (Lyu, 2024). Chronic exposure to high carbon dioxide levels can lead to respiratory issues and decrease overall health (Krismanuel, 2024). Inadequate air exchange often results in discomfort and dissatisfaction, thus affecting their comfort experience (Budiawan *et al*., 2023).

The PM_{10} concentration at five sampling points across four cycles is illustrated in Figure 6. Results ranged from 0.1655–0.2985 mg/m^3, with a mean of 0.2194 ± 0.0357 mg/m^3. Findings showed that particulate matter concentrations were above the acceptable limit of the ICOP IAQ

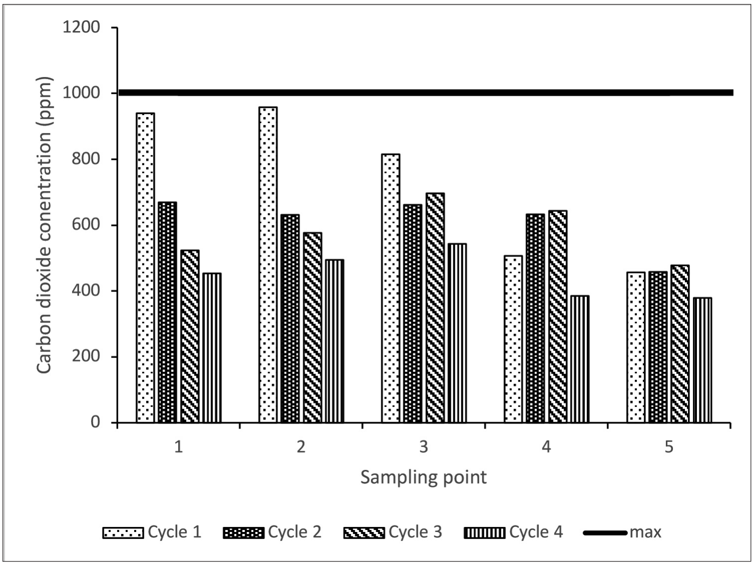

Figure 5: Carbon dioxide concentration in the cafeteria for five sampling points over four cycles. The line is the specified carbon dioxide range of the ICOP IAQ 2010 at 1000 ppm

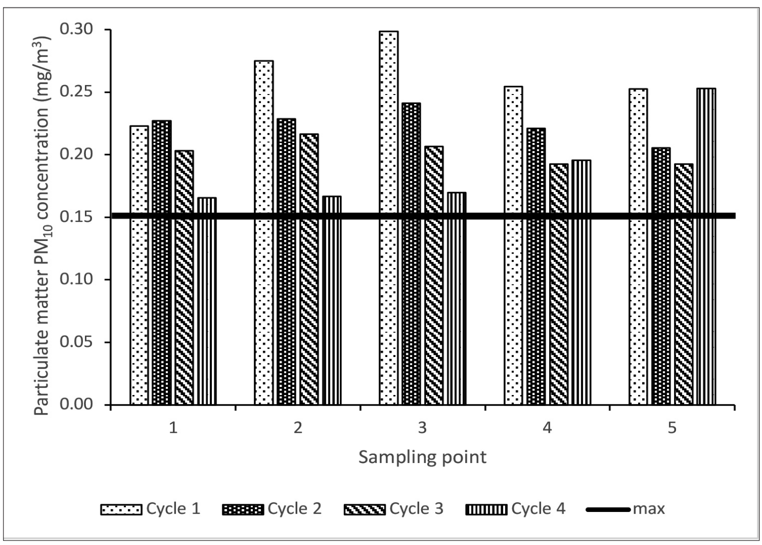

Figure 6: Particulate matter PM_{10} concentration in the cafeteria for five sampling points over four cycles. The line is the specified carbon dioxide range of the ICOP IAQ 2010 and the ANSI/ASHRAE Standard 62.1-2022 at 0.15 mg/m^3

2010 and the ANSI/ASHRAE Standard 62.1-2022 at 0.15 mg/m^3. A statistically significant difference in particulate matter concentration is observed across cycles at 0.0019 ($p<0.05$), whereas no significant difference at 0.9103 is detected at the various sampling points ($p>0.05$). High-frequency occupant movement introduced particulate matter into the cafeteria via dust and soil carried on shoes and clothing (Pakpahan *et al*., 2019; Yusup *et al*., 2014).

Additionally, wind transported dust and pollen from outside through open doors, penetrating indoors and remaining suspended, thus raising particulate matter levels (Othman *et al*., 2019). Emissions from food and its preparation also contributed to increased particulate matter levels, particularly due to spillage. High levels of particulate matter are detrimental to respiratory health (Chang *et al*., 2021). Elevated PM_{10} levels caused symptoms such as respiratory discomfort, headaches, asthma or other chronic respiratory conditions (Rojas-Rueda *et al*., 2021). Severe health issues, including cardiovascular diseases and increased mortality rates related to respiratory illnesses, were attributed to long-term exposure (Wang *et al*., 2019). Maintaining PM_{10} levels below the acceptable limit is essential to ensure a safe cafe environment.

Biological Parameters Assessment

Table 1 summarises the findings for total fungal and total bacterial counts for the biological parameters in the cafeteria. Measured total fungi counts varied from 0–230 CFU/m³ with a mean of 124 ± 45 CFU/m³. On the other hand, the average total bacterial count was 586 ± 90 CFU/m³, with a range of 301–1466 CFU/m³. The total fungi counts were within the acceptable limit of 1000 CFU/m³ as specified by the ICOP IAQ 2010. The total bacteria and fungi counts at sampling points 1–4 complied with the acceptable limit of the ICOP IAQ 2010 of 1000 CFU/m³, except sampling point 5, which recorded elevated levels of 1466 CFU/m³, nearly three times the acceptable limit. However, it shows significant differences among sampling points for total bacteria and total fungi counts at 0.0003 and 0.0395, respectively ($p<0.05$). Contaminated surfaces and airborne microbes in the refreshment area were the sources of the elevated total bacteria counts. Practices and activities such as the preparation, cleaning, handling, and sale of refreshments enhanced bacterial growth. Furthermore, the high temperature and humidity also created a conducive environment for microbial growth (Stetzenbach *et al*., 2004; Qiu *et al*., 2022). Asif *et al*. (2019) reported that long operational hours and in-house cooking and washing activities at the food court recorded a similar trend of high total bacteria counts. The elevated bacterial counts at sampling point 5 suggest a potential health risk to cafeteria users, including symptoms such as respiratory issues, allergic reactions, headaches, and gastrointestinal disturbances, particularly foodborne illnesses such as salmonellosis and *E. coli* infections (Yuan *et al*., 2022). Long-term exposure to high levels of microbes resulted in serious health effects, including chronic respiratory diseases and increased susceptibility to infections.

Table 1: Total fungi counts and total bacteria counts in the cafeteria

No.	Sample Name	Total Fungi Counts (cfu/m³)	Total Bacteria Counts (cfu/m³)
1	Blank 1 - Incubator	0	0
2	Blank 2 - Icebox	0	0
3	Blank 3 - Biostage	0	0
4	1	18 ± 25	336 ± 125
5	2	195 ± 25	371 ± 75
6	3	230 ± 125	459 ± 50
7	4	0 ± 0	301 ± 125
8	5	177 ± 50	1466 ± 75
	Acceptable limit*	1000	500

Note: * The ICOP IAQ 2010

Questionnaire Survey

The top five environmental conditions affecting occupants in the cafeteria, listed in order of prevalence, were dust and dirt, unpleasant odour, varying room temperature, room temperature too high, and stuffy, bad air (Appendix 3). The unpleasant odour was consistent with the walkthrough survey and the food odour was the source of the problem. Dust and dirt were verified to cause high particulate matter measurements. Varying room temperature, a room temperature too high, and stuffy, bad air confirmed high temperatures and uneven temperature issues affecting thermal comfort in the cafeteria. In summary, the questionnaire survey results supported the findings from the walkthrough inspection and the assessment of physical and chemical parameters.

Symptoms among cafeteria occupants were related to indoor air quality (Appendix 4). 41% of occupants exhibited symptoms due to poor indoor air quality at the workplace. The five most commonly occurring work environment-related symptoms were difficulty concentrating, headache, dizziness, and a hoarse, dry throat. High, uneven temperatures in the cafeteria led to heat accumulation, particularly during high occupancy. Occupants experienced symptoms such as difficulty concentrating, headaches, and dizziness. Additionally, elevated concentrations of particulate matter and total bacteria counts irritated the airways and caused coughing (Lee *et al*., 2021).

Risk Assessment

The likelihood of poor indoor air quality parameters and the severity of symptoms are crucial for risk assessment. Table 2 and Table 3 show the likelihood that indoor air quality parameters exceed acceptable limits and the severity of symptoms associated with poor indoor air quality among occupants, respectively. The temperature, particulate matter, and total bacteria counts were found to exceed the acceptable limits of the ICOP IAQ 2010. Hence, the likelihood of poor indoor air quality parameters was assessed as level 3. The severity was rated level 3, with 41% of occupants showing symptoms due to poor indoor air quality. Based on the risk assessment matrix, Table 4 shows a calculated risk score of

Table 2: Likelihood of poor indoor air quality parameters

Likelihood	Level	Criteria to Consider
Almost certain	5	7–9 parameters exceeding the acceptable limit.
Likely	4	5–6 parameters exceeding the acceptable limit.
Possible	3	3–4 parameters exceeding the acceptable limit.
Unlikely	2	1–2 parameters exceeding the acceptable limit.
Rare	1	No parameters exceeding the acceptable limit.

Table 3: Severity of symptoms due to poor indoor air quality among occupants

Severity	Level	Criteria to Consider
Catastrophic	5	90–100% of the occupants show symptoms due to poor indoor air quality at the workplace.
Fatal	4	61–90% of workplace occupants exhibit symptoms due to poor indoor air quality.
Serious	3	31–60% of the occupants show symptoms due to poor indoor air quality at the workplace.
Minor	2	1–30% of the occupants show symptoms due to poor indoor air quality at the workplace.
Negligible	1	No symptoms were observed among the workplace occupants.

9, which falls within the moderate risk category. Such a status indicates that occupants in the university cafeteria were exposed to a moderate risk of discomfort and minor health impacts. For moderate risk, a planned strategy to manage the hazard is required, including temporary control measures. All actions taken, with the completion dates, should be recorded in the risk assessment documentation. This research aligns with the findings of Jung *et al*. (2022), who conducted a risk assessment of indoor air quality and associated symptoms among office workers in Korea.

Health Risk Assessment

Table 5 summarises the factors used to calculate exposure dose in health risk assessment. The calculated Carcinogenic Risk (CR) and non-carcinogenic Hazard Quotient (HQ) associated with particulate matter exposure for adults (18–70 years old) were 0.1164 and 1.047, respectively. The high carcinogenic risk values exceeded the threshold of 10^{-6} (CR > 1 x 10^{-6}) (USEPA, 2023; WHO, 2021), indicating a significant risk of cancer development among occupants due to particulate matter inhalation (Khaslan *et al*., 2024). Furthermore, the non-carcinogenic hazard quotient is higher than 1 (*HQ* > 1), which reveals a high potential for non-cancer adverse health effects (Pakpahan *et al*., 2019; USEPA, 1989). Such circumstances highlight the need for immediate remedial action.

Recommended Intervention

To address temperature, particulate matter (PM_{10}), and total bacteria issues in the university cafeteria, both temporary and immediate interventions should be implemented to achieve compliance with the ICOP IAQ 2010. An Installation Variable Refrigerant Flow Mechanical Ventilation Air-conditioning system with an Internet of Things thermal sensor is suggested for cooling and temperature

Table 4: Risk assessment matrix

	Severity (S)				
Likelihood (L)	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Note: Red = High risk, Yellow = Moderate risk, Green = Low risk

Table 5: Exposure factors for calculating the exposure dose in health risk assessment

Factors	Adult (18–<70 years)
Inhalation Unit Risk (IUR)	1 µg/m^3
Body Weight (BW)	66 kg
Inhalation Rate (InhR)	0.65 m^3/day
Exposure Frequency (EF)	260 days/year
Exposure Duration (ED)	52 years
Averaging Time (AT_{care})[a]	25550 days (70x365 days)
Averaging Time ($AT_{noncare}$)[b]	18980 days (EDx365days)
Reference Concentration (RfC)[c]	0.15 mg/m^3

Note: [a]fixed at 70 years of exposure; [b]average years of exposure; [c]value taken from ICOP IAQ 2010 control within 23–26°C. To effectively reduce particulate matter (PM_{10}) levels in the university cafeteria, high-efficiency air conditioning filters and an exhaust hood are being upgraded. For total bacteria counts, installing a UV air purifier in food zones, hourly disinfection of high-contact surfaces, and enforcing operational cleaning schedules minimise cross-contamination and bacterial growth.

Conclusions

The indoor air quality, risk, and health risk assessments at the university cafeteria were investigated. Through a comprehensive assessment involving sampling, indoor air quality evaluation, and risk assessment, it was found that most air quality parameters were within acceptable limits of ICOP IAQ 2010, ANSI/ASHRAE Standard 55–2022 and the ANSI/ASHRAE Standard 62.1–2022, except for temperature (ICOP IAQ 2010 and ANSI/ASHRAE Standard 55–2022), particulate matter PM_{10} (ICOP IAQ 2010 and the ANSI/ASHRAE Standard 62.1–2022) and total bacteria counts (ICOP IAQ 2010).

The survey results further revealed that the high occupancy and inadequate ventilation in the university cafeteria resulted in elevated, uneven temperatures, creating localised heat accumulation that caused symptoms such as difficulty concentrating, headaches, and dizziness among occupants. Furthermore, elevated concentrations of particulate matter (PM_{10}) and total bacterial counts provoked upper respiratory tract irritation and, consequently, induced persistent coughing. The risk assessment, which yielded a moderate risk score of 9, suggested that both planned and temporary interventions are necessary to mitigate these issues. The findings of this study demonstrated a notable carcinogenic risk at 0.164 ($CR > 1 \times 10^{-6}$) (USEPA, 2023; WHO, 2021) and a non-carcinogenic hazard quotient at 1.047 ($HQ > 1.0$) (USEPA, 1989) for particulate matter exposure among occupants, suggesting a high health risk and immediate intervention is vital.

To achieve the ICOP IAQ 2010, immediate interventions include installing an Internet of Things-enabled Variable Refrigerant Flow Mechanical Ventilation Air-conditioning system to maintain a temperature between 23–26°C, upgrading air filters and installing a high-velocity exhaust hood to control PM_{10}, and deploying UV air purifiers with hourly surface disinfection to mitigate bacterial contamination. The study concluded that increased occupancy and reported discomfort in the cafeteria environment adversely affected indoor air quality and human health. These findings underscore the importance of maintaining stringent indoor air quality standards and highlight the need for ongoing risk assessment and health risk assessment to protect human health. Additionally, the study provides valuable data for developing an indoor air quality assessment database.

Acknowledgements

The authors would like to acknowledge Universiti Teknologi MARA for facility support.

Conflict of Interest Statement

The authors agree that this research was conducted in the absence of any self-benefit or commercial or financial conflicts, and declare that there are no conflicts of interest with the funders.

Author's Contribution

Siti Norshahira Mustafa and Nur Ijlah Wafa Abdul Rafik conducted the research and analysed the results. Nor Azura Sulong and Chia Chay Tay wrote and revised the article, conceptualised the central research idea and provided the theoretical framework. Chia Chay Tay and Zhixin Liu designed the research, and supervised the research progress; Chengjue Bi and Zhixin Liu anchored the review and revisions.

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Appendix 1

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UNIVERSITI TEKNOLOGI MARA | Fakulti Sains Gunaan

Our Reference : R1/FERC/FSG/041
Date : 2nd October 2023

[redacted]

Dear Madam

ETHICAL APPROVAL BY FERC FSG: FERC/FSG/23/041
INDOOR AIR QUALITY [redacted]

The Faculty Ethics Review Committee (FERC), Faculty of Applied Sciences UiTM has evaluated the research proposal entitled above and agreed to fully endorse and recommended as minimal risk research.

This approval is effective from **21st October 2023 – 20th December 2023.** Any changes in the procedures affecting interaction with human subjects should be reported to the Faculty Ethics Review Committee (FERC), Faculty of Applied Sciences UiTM. Significant changes will require the submission of a revised Ethics Approval Application.

Best wished for success in this research. Thank you.

"MALAYSIA MADANI"

"BERKHIDMAT UNTUK NEGARA"

Yours truly

DR. MUHD HANIS BIN MD IDRIS
Chairperson
Faculty Ethics Review Committee (FERC)

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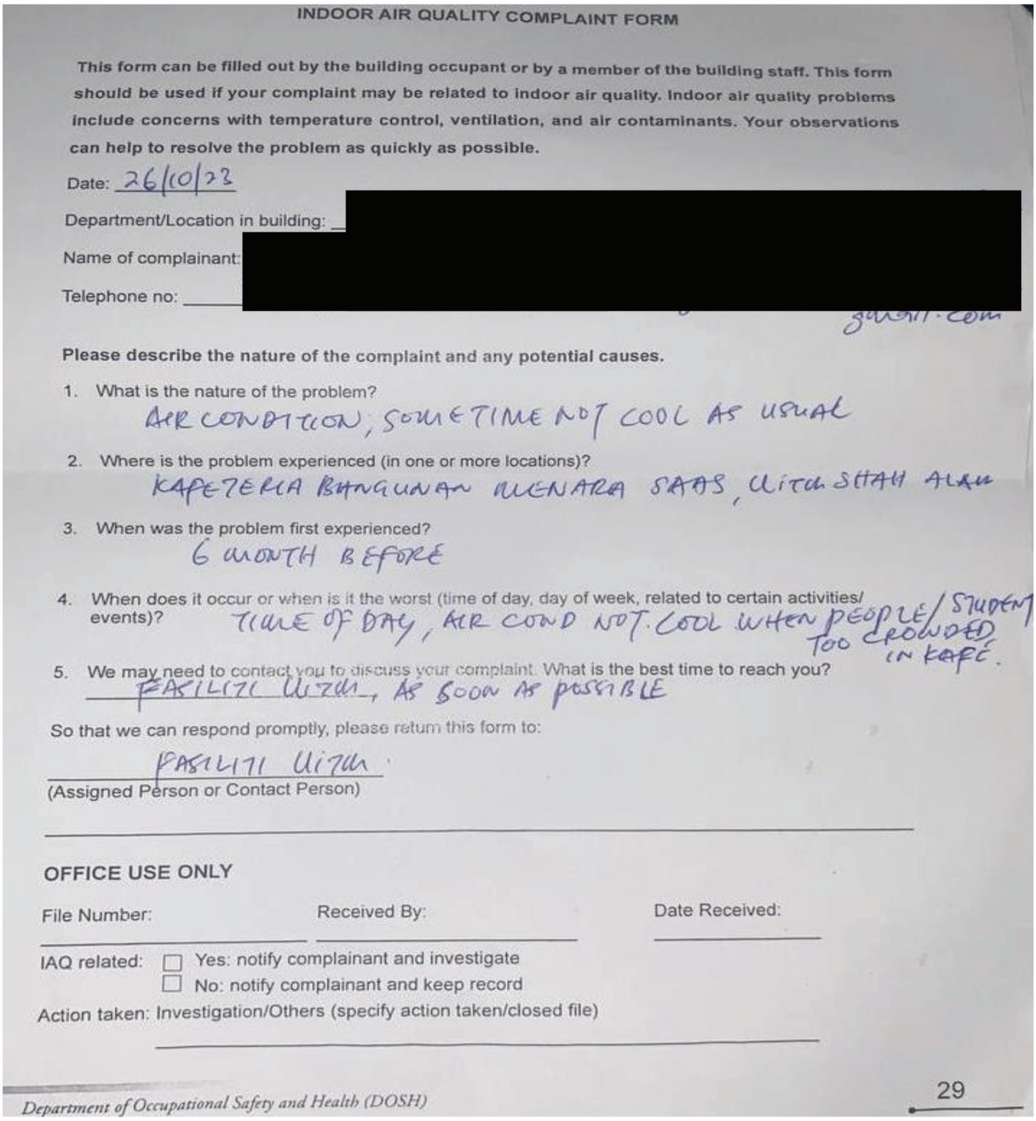
Appendix 2



INDOOR AIR QUALITY COMPLAINT FORM

This form can be filled out by the building occupant or by a member of the building staff. This form should be used if your complaint may be related to indoor air quality. Indoor air quality problems include concerns with temperature control, ventilation, and air contaminants. Your observations can help to resolve the problem as quickly as possible.

Date: 26/10/23

Department/Location in building: [redacted]

gmail.com

Please describe the nature of the complaint and any potential causes.

1. What is the nature of the problem?
   AIR CONDITION; SOMETIME NOT COOL AS USUAL
2. Where is the problem experienced (in one or more locations)?
   KAFETERIA BANGUNAN MENARA SAAS, UiTM SHAH ALAM
3. When was the problem first experienced?
   6 MONTH BEFORE
4. When does it occur or when is it the worst (time of day, day of week, related to certain activities/events)? TIME OF DAY, AIR COND NOT COOL WHEN PEOPLE/STUDENT TOO CROWDED IN KAFE.
5. We may need to contact you to discuss your complaint. What is the best time to reach you?
   FASILITI UiTM, AS SOON AS POSSIBLE

So that we can respond promptly, please return this form to:

FASILITI UiTM.

(Assigned Person or Contact Person)

OFFICE USE ONLY

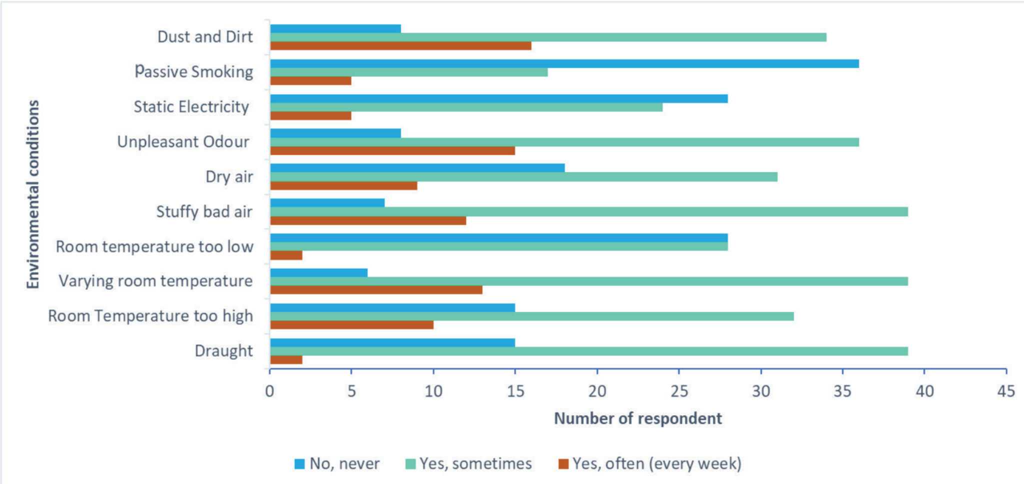
File Number: Received By: Date Received:

IAQ related: ☐ Yes: notify complainant and investigate
☐ No: notify complainant and keep record

Action taken: Investigation/Others (specify action taken/closed file)

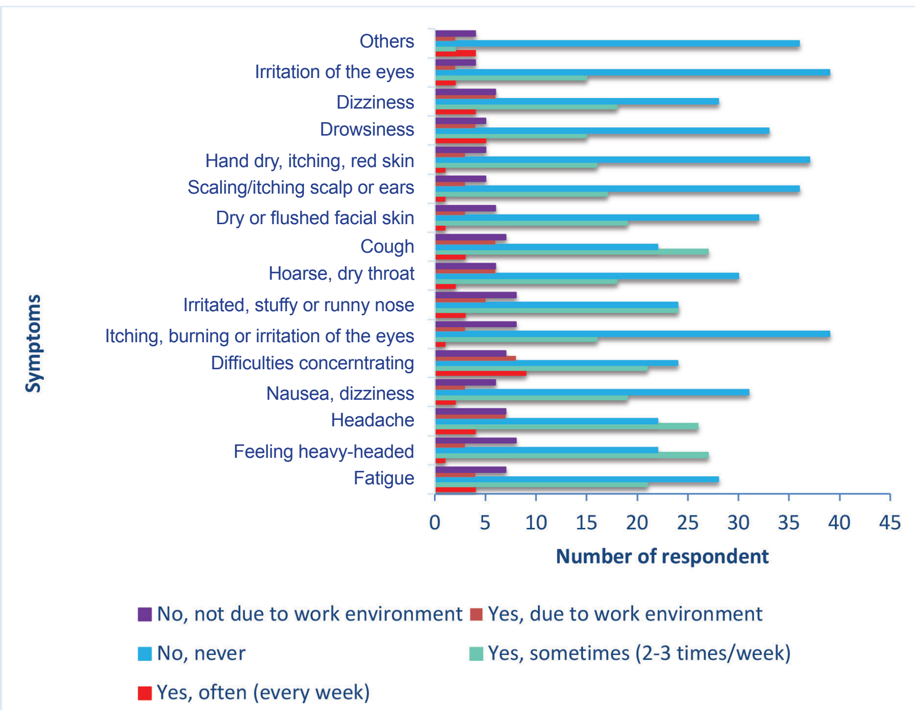
Department of Occupational Safety and Health (DOSH) 29

Appendix 3



Environmental conditions in the cafeteria that affect the occupants

Appendix 4



Symptoms of occupants in the cafeteria