ORIGINAL ARTICLE

Indoor Air Quality Assessment in the Office of the Transformer Manufacturing Factory in Selangor, Malaysia

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ABSTRACT

Introduction: As humans spend 90% of their time inside, indoor air quality (IAQ) is critical for occupant health. The primary concern associated with low IAQ is its impact on employees' health, comfort, and productivity. In accordance with the Industry Code of Practice on Indoor Air Quality 2010 (ICOP IAQ 2010), a ten-parameter assessment was conducted in the office of the transformer manufacturing factory in Selangor, Malaysia. **Methods:** The measured parameters are temperature, air movement, relative humidity, carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (CH_2O), particulate matter (PM10), total volatile organic compounds (TVOCs), total fungal count (TFC), and total bacterial count (TBC). This study employed both qualitative and quantitative approaches by distributing questionnaires (N = 42), and measuring the indoor air quality parameters with integrated equipment at selected stations and comparing them to the ICOP IAQ 2010 standard. **Results**: A majority of the measures, with the exception of air movement, CO_2, and TBC, complied with the ICOP IAQ 2010 standards. The one-way ANOVA test showed that there were significant differences ($p < 0.05$) for the parameters of temperature, PM10, and TVOCs. The Chi-Square test revealed that sleepiness was a symptom of the sick building syndrome, affecting both male and female employees the most frequently and significantly. **Conclusion:** Air movement, CO_2, and TBC values that did not meet ICOP IAQ 2010 requirements revealed poor IAQ at the study site, which could have a negative influence on the employees' health. To cut down on air pollution, the improvement on the ventilation system should be done to reduce the risks to the employees' health.
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Keywords: Indoor air quality, air pollutants, office, ICOP IAQ, transformer

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INTRODUCTION

Occupational health problems mainly occur due to poor indoor air quality (IAQ) in the workplace. Employers are responsible for preparing a safe working environment as prescribed under Section 15 of the Occupational Safety and Health Act of 1994 (OSHA 1994) to ensure the protection of employees and other building occupants from poor IAQ (1). Exposure to poor IAQ can affect their health and well-being as well as indirectly reduce their productivity (2). The Malaysia Ministry of Human Resources has approved a set of guidelines, the Industry Code of Practice on Indoor Air Quality 2010 (ICOP IAQ 2010), that can be used in monitoring the IAQ in the workplace (3). In the ICOP IAQ 2010, IAQ is stated as a condition where the indoor air in a room or building can affect the occupants' health, comfort, and ability to work. Meanwhile, the United States Environmental Protection Agency (USEPA) stated that indoor air quality is the air quality in buildings like schools, houses, offices, and other enclosed structures that is related to occupants' health and comfort (4).

Polluted indoor air has become a global issue because exposure to indoor air pollutants causes occupant health problems. In addition, people mostly spend 90% of their time inside a building, whether for working or living (5-8), and this increases their chances of being exposed to indoor air pollutants. Based on the USEPA, pollutants in indoor air are two to five and can be more than 100 times higher than in outdoor air (4). Therefore, a building's mechanical ventilation is crucial for maintaining a low level of air contaminants by providing sufficient air flow (6, 9).

Occupants who have been exposed to pollutants such as particulate matter and carbon dioxide can experience headaches, eye irritation, and skin inflammation (10-11). These indoor pollutants exacerbate irritation to the respiratory system of an already susceptible person and can affect their neurological, reproductive, and cardiovascular systems (12-13). Other than that, biological pollutants such as bacteria, yeast, and fungus can cause asthma and allergy reactions (3). The occurrence of sick building syndrome (SBS) is one of the health effects that can be used as an indicator for assessing the IAQ within a building (14-15). SBS symptoms such as dizziness and nausea occur without a clear cause and usually resolve themselves after the occupants leave the building (16). SBS can also cause lower productivity by reducing work performance (2). This will lead to company losses as more employees take sick leaves and become more demotivated at work. Therefore, this study was undertaken to examine the indoor air quality of the office at the transformer manufacturing factory in Selangor. The outcomes of the study may promote improvement on the air quality for a safe working environment for the employees.

MATERIALS AND METHODS

Study Location

The IAQ assessment was conducted in the office of the transformer manufacturing factory. The office is an open space without walls and is divided by partitions for different departments. Five sampling stations were chosen in the office, designated as S1 to S5. S1 is the Quality Check/Quality Assurance department, S2 is the Engineering department, S3 is the Operational department, S4 is the Finance and Human Resources department, and S5 is the photocopy and printing area.

Walkthrough Survey

A walkthrough survey adopted from the ICOP IAQ 2010 guidelines (3) was conducted prior to sampling the indoor air quality parameters. This survey was conducted during working hours to identify potential sources of indoor air pollutants. The conditions of the office, such as the workspace area, the type of ventilation system, and the total number of employees, were taken into account. At this stage, the employees' complaints were also reviewed from interviews conducted with them.

Questionnaire

An indoor air quality questionnaire was used to assist in identifying the potential sources of indoor air pollutants and adverse health effects experienced by employees at work. The questionnaire used in this study was adopted from the Industry Code of Practice on Indoor Air Quality 2010 (3). The questionnaires were distributed to all office employees in order to obtain their demographic information and any SBS symptoms that they experienced. Based on the G*Power version 3.1 software calculation, this study needed a total sample size of 42 (17). This study employed a convenience sampling (non-probability sampling) method by recruiting 42 employees who were available without disrupting their work routines.

Measurement of IAQ Parameters

The sampling was conducted for 8 working hours, from 0800 to 1700, continuously except during the lunch hour, representing the regular working hours. Parametric readings were taken every 10 to 15 minutes. The instruments were placed at the selected sampling stations and measured at least one meter from the walls and windows, two meters from the doors, and were not placed directly under the fans or air-conditioning units, as recommended by the ICOP IAQ 2010 guidelines (3).

IAQ measurements at five sampling locations were conducted at two different phases which were in the morning and afternoon. Measurement was conducted at four time slots evenly distributed over the business hours. Sampling slots 1 and 2 were conducted in the morning, while sampling slots 3 and 4 were conducted after the lunch hour. The physical and chemical parameters were measured using a direct reading method. Meanwhile, the biological parameters were determined by using a media exposure method.

The NIOSH Manual Analytical Method (NMAM 0800) was used to measure the total bacterial count (TBC) and total fungal count (TFC) (18). Two types of media were used: trypticase soy agar (TSA) was used for detecting bacteria, while sabouraud dextrose agar (SDA) was used for detecting fungi. The sampling was done in the morning and afternoon, in accordance with the aim of comparing the TBC and TFC during the morning and afternoon sessions. Prior to the bacterial count, the prepared plate was incubated for 48 hours at 37 °C, while for the fungal count, the plate was incubated for 5 days at 25 °C (30,31). The observed colonies were counted and referred to the Feller statistical conversion table in order to obtain the Pr value (19). Then, the total colony of fungi or bacteria (X) was calculated according to the following formula: $X = Pr \times 1000/V$. Table I shows the instruments used for each measured parameter.

Statistical Analysis

The data obtained were analysed with the Statistical Package for Social Sciences (SPSS) version 23 software. A descriptive analysis was performed to describe the sociodemographic respondents, working conditions, the prevalence of sick building syndrome (SBS), and IAQ measure readings. The Chi-Square test was used to determine the prevalence of SBS among the employees based on the answered questionnaires. Meanwhile, a one-way ANOVA test was used to compare the concentration of indoor air quality parameters between the stations inside the office. The significance level in the study was set at $p < 0.05$.

Ethical Clearance

This study was approved by the Research Ethics Committee of Universiti Kebangsaan Malaysia with reference number: UKM PPI/111/8/JEP-2019-039, dated 24th January 2019. All information pertaining to the participants and the company was kept confidential.

RESULTS

Description of Office

Based on the walkthrough survey, it was found that this factory has been in operation for three years. The office, located on the first floor, is equipped with an air conditioning system. There are four main departments in the office, namely Quality Check/Quality Assurance, Finance and Human Resources, Engineering, and Operational Departments. There are two bathrooms, each for males and females, a separate office room for the top management, and a server room. The floor is carpeted, and all employees must take off their shoes before entering the office. Most of the employees wear company-provided slippers inside the office. Smoking is strictly prohibited inside the building, but there is a specific smoking area outside the building. The housekeeping chores are done twice daily by cleaners in the morning and late afternoon before office hours end.

Table I: List of parameters and instruments

No.	Parameter	Instruments
1	Temperature, Air Movement and Relative Humidity	TSI 9565 meter with TSI 966 articulate probe
2	PM_{10}	TSI Quest EVM-7
3	Formaldehyde	Formaldehyde Meter
4	TVOC	Aeroqual Series 500
5	CO and CO_2	TSI 9565 meter with TSI 982 articulate probe
6	Total fungal count and total bacterial count	MAS-100 Eco Microbial Air Sampler

Sociodemographic data of Respondents, Office Conditions, and the Prevalence of Sick Building Syndrome

Table II shows the socio-demographics of the 42 respondents. The office employees consist of 48% males and 52% females. 57% of the employees are below 40 years old, while the remaining 43% are 40 years old and above. Most of the respondents (90%) are non-smokers and the remaining (10%) are smokers. Out of the 42 respondents, 93% have been working in the study location for more than two years, and the other 7% have only been working for less than two years. Regular working hours per day are 8 hours, for a total of 40 hours per week, but 79% of employees work overtime.

Table III shows the three most reported office conditions were dust and dirt (19%), varying room temperatures (14.3%), and draught and dry air (11.9%). Many respondents indicated that they were unsure about the potential impact that the office environment may have on their work performance and well-being.

The prevalence of sick building syndrome (SBS) experienced by the respondents is shown in Table

Table II: Socio-demographic of respondents

Socio-demographic characteristic	% (N=42)
Gender	
Male	48
Female	52
Age	
<40 years old	57
≥40 years old	43
Smoking status	
Yes	10
No	90
Service period	
<2 years	7
≥2 years	93
Average hour works per week	
<40 hours	21
≥40 hours	79

Table III: Office condition based on respondent's experience

Variables	Respondent (%)			p-value
	Yes, often	Yes, sometimes	No, never	
Draught	11.9	31.0	57.1	0.61
Room temperature too high	7.1	52.4	40.5	0.29
Varying room temperature	14.3	59.5	26.2	0.73
Room temperature too low	7.1	45.2	47.6	0.80
Stuffy air	4.8	42.9	52.4	0.26
Dry air	11.9	45.2	42.9	0.43
Unpleasant odour	9.5	42.9	47.6	0.50
Passive smoking	7.1	21.4	71.4	0.17
Dust and dirt	19.0	52.4	28.6	0.61

IV. Sleepiness was the highest prevalence of SBS symptoms reported by employees, with a value of 70% for males and 90.5% for females. Female employees significantly experienced more sleepiness compared to male. Employees are considered to have SBS if they have encountered the onset of two or more SBS symptoms once or twice a week for four weeks and their condition will only improve after leaving the workplace (11, 16). The results indicated that both male and female employees experienced headaches, sleepiness, dizziness, dry throat, stuffy nose, coughing, a general feeling of being sick, and heavy head.

Physical, Chemical, and Biological Parametric Readings

Comparison of the Physical Parameters Between the Sampling Stations

Table V shows the results of the evaluation of indoor air temperature, relative humidity, and air movement at each sampling station. Based on the table, the temperature for each sampling station was between the ranges of 24.01 ± 0.34°C and 24.56 ± 0.32°C, which was within the recommended range (23–26°C) set up by ICOP IAQ 2010 guidelines. There was a significant difference ($p < 0.05$) between station one and stations two and three in the office. It can be seen at all stations that the relative humidity readings were within acceptable ranges (40–70%), with ranges between 56.43 ± 1.35% and 57.83 ±

Table IV: Percentage of prevalence of sick building syndrome (SBS) among male and female respondents

Symptoms	Gender (%)		p-value
	Male	Female	
Headache	65	71.4	0.808
Heavy head	55	12.8	0.734
Malaise	50	52.4	0.614
Sleepy	70	90.5	0.022*
Dizziness	55	70	0.327
Nausea	10	15.8	0.589
Cough	50	60	0.438
Stuffed nose	55	66.7	0.498
Dry throat	55	60	0.349
Skin itchiness	35	45	0.798
Eye irritation	25	33.3	0.572
Head itchiness	30	20	0.460

* Significant at p <0.05
N = 42

Table V: Physical parameter of indoor air quality in the office

Parameter	Station	Mean ± Standard deviation	ICOP acceptable limit
Temperature	S1	24.01 ± 0.34	23-26 °C
	S2	24.56 ± 0.32 [a]	
	S3	24.53 ± 0.15 [a]	
	S4	24.39 ± 0.13	
	S5	24.37 ± 0.45	
Relative Humidity	S1	57.83 ± 1.61	40-70 %
	S2	56.43 ± 1.35	
	S3	56.78 ± 0.62	
	S4	57.08 ± 0.85	
	S5	56.85 ± 1.48	
Air movement	S1	0.07 ± 0.04	0.15-0.5 m/s
	S2	0.08 ± 0.02	
	S3	0.08 ± 0.02	
	S4	0.09 ± 0.03	
	S5	0.07 ± 0.05	

a. Has significant difference (p<0.05) with station 1
b. Has significant difference (p<0.05) with station 2
c. Has significant difference (p<0.05) with station 3
d. Has significant difference (p<0.05) with station 4
e. Has significant difference (p<0.05) with station 5

1.61%, respectively. There was no significant difference (p > 0.05) between the sampling stations. The average air movement reading was very low and not within the range of the acceptable limit, which is 0.15 m/s to 0.5 m/s at all sampling stations as shown in the table. The mean reading of air movement in the office was only between 0.07 ± 0.04 m/s and 0.09 ± 0.03 m/s, which was below the minimum acceptable limit of 0.15 m/s. There was no significant difference (p > 0.05) between stations.

Comparison of the chemical parameters between the sampling stations

Table VI indicates the average reading for five chemical parameters measured for indoor air quality at every

Table VI: Chemical parameters of indoor air quality in the office

Parameter	Station	Mean ± Standard deviation	ICOP acceptable limit
Carbon monoxide	S1	0.750 ± 0.14	10 ppm
	S2	0.730 ± 0.17	
	S3	0.680 ± 0.20	
	S4	0.740 ± 0.28	
	S5	0.720 ± 0.29	
Carbon dioxide	S1	1676 ± 76	1000 ppm
	S2	1679 ± 97	
	S3	1699 ± 133	
	S4	1696 ± 135	
	S5	1642 ± 184	
Particulate matter	S1	0.088 ± 0.01	0.15 mg/m^3
	S2	0.071 ± 0.02	
	S3	0.083 ± 0.01	
	S4	0.062 ± 0.01 [a, c]	
	S5	0.065 ± 0.01 [a, c]	
Total volatile organic compound	S1	1.290 ± 0.21 [b]	3 ppm
	S2	1.720 ± 0.70	
	S3	0.770 ± 0.05 [b]	
	S4	0.250 ± 0.14 [b]	
	S5	0.190 ± 0.08 [b]	
Formaldehyde	S1	0.073 ± 0.03	0.1 ppm
	S2	0.073 ± 0.01	
	S3	0.067 ± 0.01	
	S4	0.068 ± 0.01	
	S5	0.064 ± 0.01	

a. Has significant difference (p<0.05) with station 1
b. Has significant difference (p<0.05) with station 2
c. Has significant difference (p<0.05) with station 3
d. Has significant difference (p<0.05) with station 4
e. Has significant difference (p<0.05) with station 5

sampling station. From the table, the carbon monoxide (CO) concentration at all stations did not exceed ICOP IAQ 2010's limit of 10 ppm. There was also no significant difference (p > 0.05) between sampling stations. Station one had the highest reading, 0.75 ± 0.14 ppm, while the CO reading at station two was 0.73 ± 0.17 ppm. The average reading at station three was the lowest, at 0.68 ± 0.20 ppm. Meanwhile, the mean reading at station four was the second highest, at 0.74 ± 0.28 ppm, whereas the mean reading at station five was 0.72 ± 0.27 ppm.

Based on the table, the carbon dioxide (CO_2) concentration readings at all five sampling stations were quite similar, ranging between 1642 ± 184 ppm and 1699 ± 133 ppm. All readings at all stations were more than 1000 ppm, in violation of the acceptable ICOP IAQ 2010 limit. However, there was no significant difference (p > 0.05) between sampling stations.

As for the reading of particulate matter (PM_{10}) at all five sampling stations in Table VI, all stations did not exceed the ICOP IAQ 2010 limit of 0.15 mg/m^3. Both stations one and three had the highest PM10 concentrations (0.088 ± 0.01 mg/m^3 and 0.083 ± 0.01 mg/m^3), while station four had the lowest PM10 concentrations (0.062 ± 0.01 mg/m^3). The PM10 concentration of station four has a significant difference ($p < 0.05$) with station one and station three.

TVOCs average reading at all stations did not exceed the ICOP IAQ 2010 limit of 3 ppm as shown in Table VI. The highest TVOCs reading was 1.720 ± 0.70 ppm at station two, followed by the reading of 1.290 ± 0.21 ppm at station one. Readings at stations three and four were 0.770 ± 0.05 ppm and 0.250 ± 0.14 ppm, and the lowest TVOCs reading was 0.190 ± 0.08 ppm at station five, respectively. There was a significant difference ($p < 0.05$) between station two and the other stations.

Based on Table VI, the formaldehyde concentrations at all sampling stations were within the acceptable range of less than 0.1 ppm. The highest reading was at station one (0.073 ± 0.03 ppm) and station two (0.073 ± 0.01 ppm), while the lowest reading (0.064 ± 0.01 ppm) was recorded at station five. There was no significant difference ($p > 0.05$) between all stations.

Comparison of Biological Parameters between the Sampling Stations

Table VII indicates the average reading of the total fungal count and total bacterial count in the transformer manufacturing factory's office. The total fungal count (TFC) readings at every station did not exceed the ICOP IAQ 2010 limit of 1000 cfu/m^3. However, station three's total bacterial count (TBC) reading at noon was 586 cfu/m^3, which exceeded the acceptable limit, while the TBC readings of other sampling stations did not exceed the ICOP IAQ 2010 limit of 500 cfu/m^3 as shown in Table VII.

DISCUSSION

This study aimed to provide a preliminary study for monitoring indoor air quality (IAQ) in an industrial office in Malaysia. In this study, both readings of temperature and relative humidity were stable, with not much difference in values. The temperature readings varied in the office as the air conditioning would be switched off if there were fewer employees in the office. It also might be influenced by the number of employees at each sampling station and the heat released by humans in response to the cold air in the environment (12, 20). The relative humidity readings were within the limit as basically influenced by temperature (5, 14). As for the air movement parameter, it has been shown that readings were very low at all sampling stations. The potential cause might be attributed to insufficient ventilation as the air-conditioning was switched off and all windows were shut. Low air movement can cause discomfort to the occupants, such as headaches, difficulty breathing, and sleepiness due to build up of indoor pollutants (21). The mechanical ventilation and air-conditioning (MVAC) system in the office building failed to provide sufficient ventilation in enclosed spaces. Therefore, external exhaust fans can be installed on office walls to increase air circulation. Instead of blowing air outward, it should draw air and moisture inward (15).

Five chemical indoor air parameters were measured in this study: carbon monoxide; carbon dioxide; particulate matter; TVOCs; and formaldehyde. The first chemical parameter measured was carbon monoxide (CO), which is normally produced by incomplete combustion like vehicle exhaust, tobacco smoke, and stoves (22) CO inhalation can cause dizziness, headaches, nausea, and vomiting (1, 22-23). In the worst case, death may occur due to high CO exposure (21-22).

Strikingly, CO_2 concentrations in this study were high, recording more than 1000 ppm, and were above the ICOP IAQ 2010 recommendation. High concentrations of CO_2 are related to SBS symptoms due to inadequate air movement, causing stuffy air and the accumulation of other indoor air pollutants (23, 35). To add to that, CO_2 is also continuously produced by occupants as a by-product of respiration (22). Based on the SBS symptoms that they experienced, exposure to excessive CO_2 could have caused headaches, dizziness, and dyspnoea for the employees in this study. It may also cause hypercapnia, which can be serious and fatal (20, 24).

Regarding the PM10 concentration reading, the result was within the acceptable range. The potential source of PM10 might be due to the accumulated dust from surfaces such as furniture, carpeting, and curtains (21) inside the office. Other than that, particulate matter like dust and dirt can attach to occupants' clothes and then get re-suspended in the air in the course of the occupants' daily activities (22).

The measured TVOCs concentrations were at an acceptable limit, indicating that this air pollutant might not be harmful to the employees. Air fresheners, perfumes, furniture, and photocopy machines are typical

Tables VII: Reading of total fungal count and total fungal bacteria in the office of the transformer manufacturing factory

Paramater	ICOP acceptable limit	Station Phase	1	2	3	4	5
Fungi	1000 cfu/m^3	Morning	8	10	12	36	64
		Afternoon	22	48	38	24	24
Bacteria	500 cfu/m^3	Morning	388	354	238	418	280
		Afternoon	382	248	**586**	100	274

sources of TVOCs (25-28). There were air fresheners and wood products at station two, which might have been the main source of TVOCs inside the office. Besides air fresheners and wood products, stations one and two are located near a newly painted wall, whereby the paint can emit TVOCs that contributed to the higher readings than those of other stations (28, 36). Even though station five is the photocopy and printing area, it recorded the lowest TVOCs reading due to its proximity to the office front door. Also, one machine was not in operation during the sampling session.

The low formaldehyde concentration in this study did not harm the employees, as the highest concentration was only 0.07 ppm. The potential sources of formaldehyde inside the office include urea-formaldehyde resins used in the assembly of wood-based products, paints, varnishes, and detergents (26-27, 29). Prolonged exposure to high levels of formaldehyde can cause eye, nose, and throat irritation, as well as asthma, bronchitis, and possibly cancer (10).

Only one total bacterial count reading exceeded the acceptable limit range, while no total fungal count reading exceeded the acceptable limit. People, animals, ventilation, air-conditioning, mould, and re-suspension of settled dust can all be the sources of microbial contaminants in the building (30, 34). The total bacterial count that exceeded the acceptable limit at station three might be influenced by the large number of employees at noon compared to other stations. Airborne microorganisms can be released from the human respiratory system through talking, coughing, and sneezing (31). In addition, the human skin can also be a significant source of airborne microbial contaminants (30, 32). A study by Adams et al. found that the most crucial factor affecting the presence of microbial contaminants is human occupancy, particularly in poorly ventilated or heavily occupied buildings (33).

The present study investigated the perceptions and experiences of respondents, which may have been influenced by other circumstances during the sampling session. In addition, since this study was done in a factory, there was a time constraint during the sampling session, which limited the number of participants.

CONCLUSION

Based on the results of this study, it was determined that the office at the research location has poor indoor air quality and thus does not comply with ICOP IAQ 2010 standards for air movement, CO_2, and total bacterial count. It may explain why employees have reported experiencing more than two SBS symptoms at work. Therefore, it is recommended to install an exhaust fan to prevent the accumulation of indoor air pollutants and to promote ventilation within the office, which may reduce employees' health issues. In addition to maintenance, the MVAC system should be inspected at least twice a year. Furthermore, this study might be enhanced by combining personal air sampling of selected IAQ parameters with health assessment, such as lung function test, to determine the correlation between exposure levels and employees' lung health.

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