INDOOR AIR QUALITY ASSESSMENT FOR A MULTI-STOREY UNIVERSITY OFFICE BUILDING IN MALAYSIA

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ABSTRACT

The indoor air quality (IAQ) in office buildings should be assessed for public health concerns as it relates to work performance and productivity. Therefore, this paper aims to assess the IAQ in a university office building. From this investigation, the level of contaminated indoor air is examined, the significant causes and contributing factors of contaminated indoor air are determined and a recommendation to improve the existing condition has been proposed. The physical parameters measured include air temperature, air velocity, relative humidity, and concentrations of carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), and also air particles. It was found that the number of air particles of 0.5 µm in diameter is about 197,748 particles/m^3, while air particles of 5.0 µm in diameter is around 534 particles/m^3. The collected data were then compared with a questionnaire and IAQ standards. In conclusion, the indoor air quality within the multi-storey central office building of Universiti Tun Hussein Onn Malaysia (UTHM) is acceptable and suitable for occupation even though there were countable symptoms of Sick Building Syndrome (SBS) among its occupants.

KEYWORDS

air particles, indoor air quality, university office building, Sick Building Syndrome, carbon dioxide, carbon monoxide, sulphur dioxide

1.0 INTRODUCTION

Recently, there has been a rapid growth in urbanisation and industrialization in Malaysia. This has led to a dramatic rise in the number of residences, office buildings and manufacturing facilities, together with increases in both the number and density of motor vehicles and population. Outdoor air quality has been widely examined since pollution would directly cause many adverse health effects to the population (Zhang, 2004). However, Fisk et al. (1987) claimed that

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most people spend 10% to 15% of their time outdoors and the remaining time is in indoor environment, which means the indoor air quality is predominant in daily life. Besides that, the industrialization/urbanization process also exhibits both positive and negative effects on indoor air quality (Baek et al., 1997).

As a result, acceptable indoor air quality (IAQ) is one of the critical components of green building design (Xiong et al., 2015). The topic of green building has been expanded outside the environmental community and has become a critical issue among mainstream building industry professionals to counter the negative health impacts brought about by IAQ problems in buildings. As referenced in the Green Building Index in Malaysia, IAQ has been included as one of the default elements in green building assessment and certification. Green buildings require indoor air quality measures that are in compliance with minimum indoor air quality (IAQ) performance to enhance indoor air quality indoors, thus contributing to the comfort and well-being of the occupants. Previous studies have indicated that the majority of available measurements in green buildings do show that IAQ, as perceived by green building occupants, is improved as compared to the responses from occupants in conventional buildings (Stenemann et al., 2017). However, the relationship between energy consumption and IAQ, and tenant education on the pollutant levels and exposures towards health effects, as well as the thermal condition may need more attention in IAQ investigations in green buildings. Therefore, there is a clear need for studies evaluating IAQ in buildings for public health and indoor environment quality as it impacts workplace performance and productivity.

Environmental quality for residential buildings has been calculated using measured data for air temperatures, relative humidity and carbon dioxide concentration (Laskari et al., 2017). According to the Environmental Protection Agency (EPA) (EPA, 1997), pollutant levels are two to five times higher inside the home than outside. These pollutants include airborne particles and particulate matters such as allergens, lung irritants, gases, toxic chemicals and volatile organic compounds (VOCs). However, indoor air quality (IAQ) problems are not limited to homes. In fact, many office buildings have significant sources of air pollution, possibly due to inadequate provision of the ventilation system. Research also focuses on computing acceptability limits for IAQ at workplace (Freda et al., 2017).

The findings discussed earlier have demonstrated that indoor air has a tendency to be more polluted than outdoor air (albeit with different pollutants) although it might not affect the common understanding of air pollution. This may be due to how indoor air pollutant levels reflect the sum of contributions from indoor sources as well as from outdoor pollutants that enter a building through openings and ventilation air (Nazaroff, 2013). In fact, indoor air generally provides a greater health hazard than the corresponding outdoor setting. IAQ is the most important issue in the occupation of office buildings, as a poor IAQ in the office space will affect the work performance of occupants and loss of productivity. Measuring workers' productivity is important in a workplace where performance measures provide detailed information about worker productivity. Based on the studies by both Clements-Croome (2008) and Wyon (2004), the performance of simulated office work would increase by removing the common sources of indoor air pollution. In contrast, the performance in carrying out or accomplishing an action, task, or function in office work would deteriorate when occupants in the office are suffering from Sick Building syndrome (SBS) due to the impacts of poor IAQ. This may reduce the ability of workers to accomplish the expectations of the company. Besides that, the occupants in offices may also be affected by the illness related to SBS, such as a headache, which may cause difficulty in thinking. Thus, this would indirectly lead to low performance of the occupants and their output or productivity per hour of work done would decline due to health problems.

IAQ problems commonly occur in an office building when the quantity of fresh air ventilation being provided is inadequate for the amount of air contaminants present. Air contaminants such as dust, mists, fumes, vapours and gases can be found in almost every workplace. Some employees may acquire sick building syndromes due to the air pollutants. As a result, they may also have to be on sick leave for several days; thus, losing their time and money as well as lowering their productivity (Wyon, 2004). The decision to perform air monitoring is significant as the IAQ assessment is based on either regulatory requirements or hazard evaluations for quantifying the exposures. A statistical model was proposed by Wong *et al*. (2006), which is an easy tool for performing IAQ monitoring to characterize the air pollutants in office buildings and will be useful for determining appropriate mitigation measures.

In general, university offices contain relatively high pollutants due to routinely massive printing activities, overly dense occupation and low-quality ventilation. Field measurements were conducted at the Czech Technical University in Prague (Kolarik et al., 2015), and it was found that demand-controlled ventilation (DCV) did not statistically improve the office's indoor air quality. Thermal comfort has been critically discussed (Sekhar, 2016) in meeting sustainable characteristics without sacrificing human health. Therefore, as a result of having less information on the performance of IAQ within university office buildings, this study addresses the investigation of IAQ in a multi-storey central office building located at the Universiti Tun Hussein Onn Malaysia (UTHM) by utilizing both physical and subjective measurements. Physical measurements cover the commonly used IAQ parameters, such as air temperature, relative humidity, air velocity, concentrations of carbon dioxide (CO_2), carbon monoxide (CO) and sulphur dioxide (SO_2) gases, as well as air particles (Putra, 2015). The consideration for investigating such IAQ parameters in this study was based on their consideration by a number of previous studies on IAQ and SBS symptom in office buildings (Fadilah and Juliana, 2012; Norhidayah et al., 2013). The study has revealed that among all the parameters measured, CO_2 is highly associated with SBS as well as the impacts of poor ventilation and accumulation of possible contaminants within the indoor environment (Aizat et al., 2009; Norhidayah et al., 2013). Meanwhile, a questionnaire survey is used for the subjective measurement. The results from these two measurements are then compared with the ASHRAE standard (ASHRAE, 2004a; ASHRAE, 2004b), Malaysian standard of MS 1525 (Department of Standards Malaysia, 2014), DOSH standard (Ministry of Human Resources Malaysia, 2010) and ISO 14664-1 standard (ISO, 1999) to determine the level of IAQ within the office building.

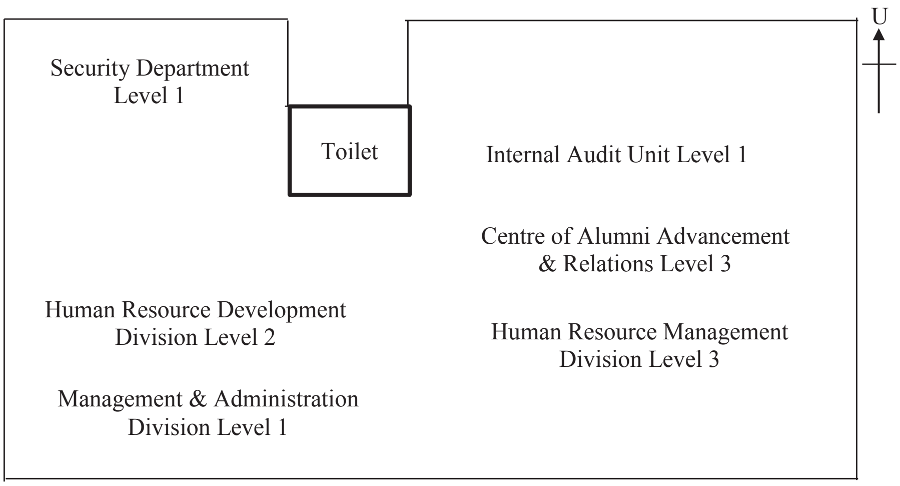
2.0 FIELD MEASUREMENTS

2.1 Location of Field Investigation

The university's population is around 16,000. The Central Office Building at UTHM (as shown in Figure 1), which was officially occupied in 2010, had been selected for field measurement. The typical layout of the building is shown in Figure 2. This building is located about 1 km from an industrial area, and the nearest factory, which operates 24 hours, intermittently releases gases and various kinds of substances into the surrounding environment. In addition, a large number of vehicles entering the university produce sound, gas and substances. The office layout design is basically the combination of open plan offices and cellular offices for each department or unit. Table 1 describes the locations for site investigation.

FIGURE 1. Central office building, UTHM.

FIGURE 2. Typical layout of the building.



2.2 Investigation Procedures

The purpose of this IAQ study is to understand the perceptions of air quality inside the office spaces. In parallel, a field protocol was developed and tested in a pilot study to quantify IAQ for office buildings. Field measurement tests were carried out for each investigated location to measure the indoor physical parameters such as temperature, relative humidity (RH), air velocity, and the gaseous pollutants SO_2, CO_2 and CO.

The concentration of SO_2 in this study is assumed to be related to the building's proximity to the industrial area and factory. The readings of air particles had also been recorded where the

TABLE 1. Description of location for field investigation.

Zone	Description	Level	Area, m^2	No. of occupants
A	Management & Administration Division	1	395	19
B	Internal Audit Unit	1	265	13
C	Security Department	1	109	10
D	Human Resource Development Division	2	364	16
E	Centre of Alumni Advancement & Relations	3	198	7
F	Human Resource Management Division	3	438	23
	Total		**1769**	**88**

minimum required number of measuring points for each office space was determined based on floor area and application of Equation 1. The investigation measured the air particles within the diameter range of 0.5 to 5 µm. The concentration of the particles was then classified according to ISO 14644-1 (ISO, 1999). The measurements were taken for two consecutive days for air particles and six consecutive days for other identified physical parameters. Time intervals of 60 seconds for each data collection point for all parameters were kept the same. All the data were collected during office working hours from 8.00 am to 5.00 pm.

$$N_L = \sqrt{A} \tag{1}$$

where,

N_L = the minimum number of sampling locations

A = the area of the cleanroom or clean zone in square metres.

The results obtained from the field measurement were then compared with different standards which include ASHRAE 62-2004, MS 1525, OSHA and ISO 14644-1. The ASHRAE 62-2004 was used to compare the existing environmental parameters such as air temperature, relative humidity, air velocity, and concentrations of CO_2 and CO gases. Furthermore, the concentration of SO_2 was also discussed and compared with OSHA standards. ISO 14644-1 was utilised to compare the number of air particles in ISO Class 7. The results of the present study were also compared with the findings of previous relevant researches.

Subjective measurements were carried out using a questionnaire survey to define the occupants' sensation towards the air quality inside the Central Office Building. The questionnaire was distributed to all 88 staff working in the office spaces. The survey was conducted in parallel with the field measurement. The questionnaire has four sections, including the background of respondents, workplace information, health information and well-being in the office, and also the description of workplace conditions. Initially, the questionnaire survey items had been verified by experts. The results from this subjective measurement were used to define the physiology and psychology perception of occupants in the office in relation to IAQ conditions.

3.0 RESULTS AND DISCUSSIONS

3.1 Field Measurement

IAQ is a constantly changing interaction of complex factors that affect the types, levels, and importance of pollutants in indoor environments. These factors include sources of pollutants or odours, design, maintenance and operation of building ventilation systems, moisture and humidity, and occupants' perceptions and susceptibilities. In addition, there are many other factors that affect the indoor thermal comfort or perception of IAQ.

Figure 3 shows the results of average physical parameters data measured for three consecutive days from the field measurements. The average recorded relative humidity was in the range of 58% to 74%, while the average indoor air temperature was in the range of 23.7°C to 26.1°C. The average reading for air velocity was between 0.14 m/s and 0.26 m/s. Meanwhile, the average concentrations of SO_2, CO_2, and CO were in a safe range with reference to the relevant standards.

For air particles measurement, the average numbers of air particles with diameters of 0.5 μm and 5.0 μm and above are shown in Figures 4 and 5 respectively. Based on the findings, it was found that there were higher number of air particles with a diameter of 0.5 μm as compared to that of diameter 5.0 μm as more particles could be captured per unit volume due to smaller particle sizes. This can be seen from both bar charts showing the results where there are higher number of air particles with a diameter of 0.5 μm ranging between 150,103 particles/m^3 to 258,519 particles/m^3 as compared to that of air particles with a diameter of 5.0 μm which range between 382 particles/m^3 to 869 particle/m^3 in all locations.

3.1.1 Analysis with IAQ Standards

Figure 3 shows the comparison of results of the present study with the different IAQ standards as set by ASHRAE Standard 62-2004, OSHA and ISO 14644-1 in order to assess whether the measured IAQ parameters and the number of air particles in the central office building are in compliance with the relevant standards.

Even though IAQ levels in the Central Office Building are acceptable to be occupied, countable SBS cases have been found. This may be due to other contaminant sources such as volatile organic compounds (VOCs) emitted from paint, chemical contaminants, and biological contaminants that contribute to SBS but are not assessed due to the limitation of this study.

For overall ASHRAE and OSHA recommendations, only relative humidity was not within the suggested values, possibly due to the geographical location. Therefore, the obtained results should be free from SBS symptoms. However, there is a small number of occupants who exhibited SBS symptoms. It is possible that in warm and hot countries, relatively high air temperature differences between indoor and outdoor may cause symptoms like fever, nose irritation, etc., or perhaps in humid countries, skin dryness due to the building cooling system is common. Consequently, the mentioned symptoms should be not be reliable indicators for SBS in hot and humid countries.

3.1.2 Comparison with Previous Studies

Table 2 shows the comparison of results from previous research and the measured field data. The comparison of results obtained from the current study was made with those of previous investigations of IAQ parameters and air particles within the same office building carried out by Abdullah (2003), Mamat (2005), and Handayani (2008).

FIGURE 3. Comparison of the average data of (a) air temperature, (b) relative humidity, (c) air velocity, (d) SO_2 content, (e) CO_2 content and (f) CO content.

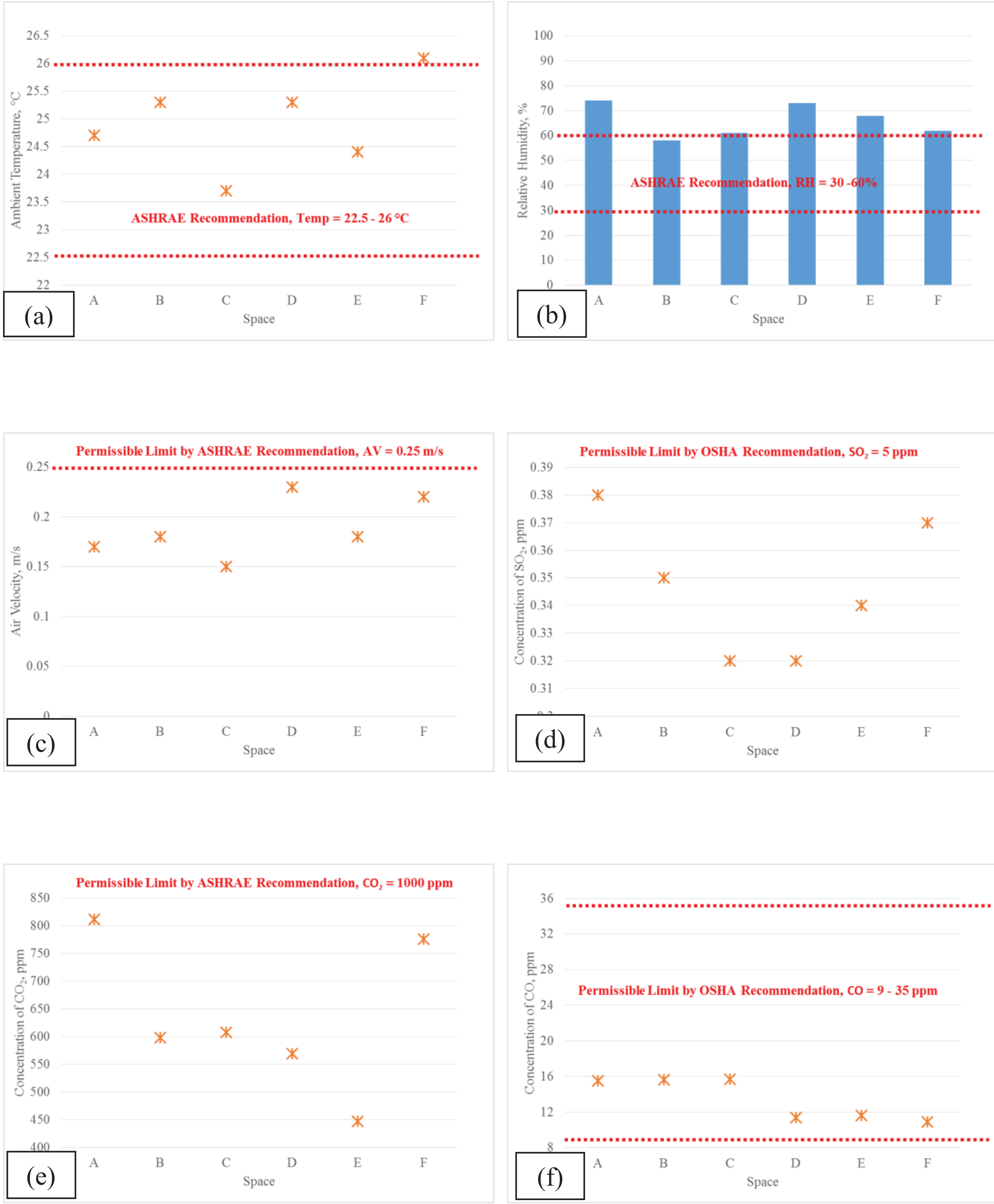


FIGURE 4. Air particles of greater than 5.0 μm in diameter.

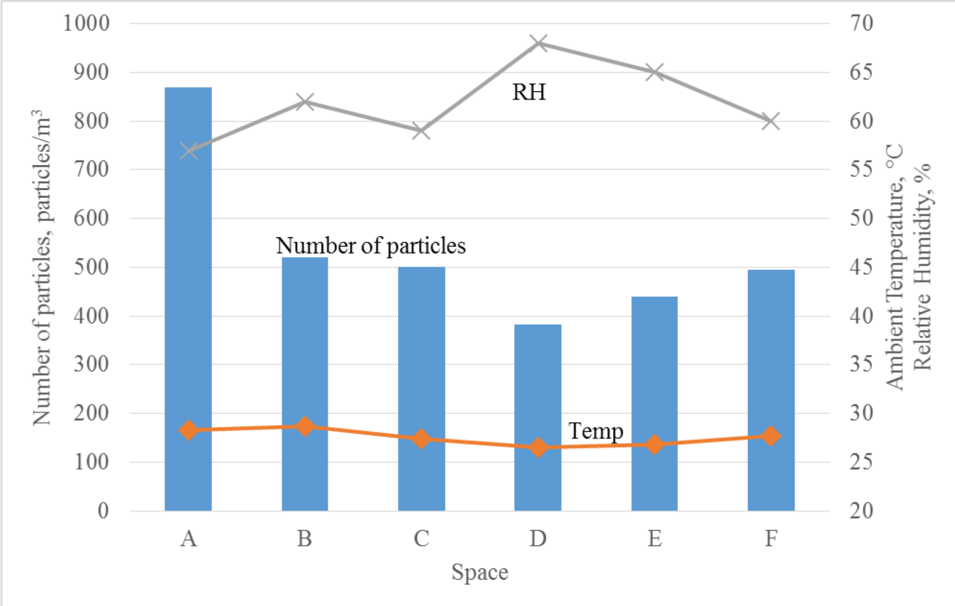
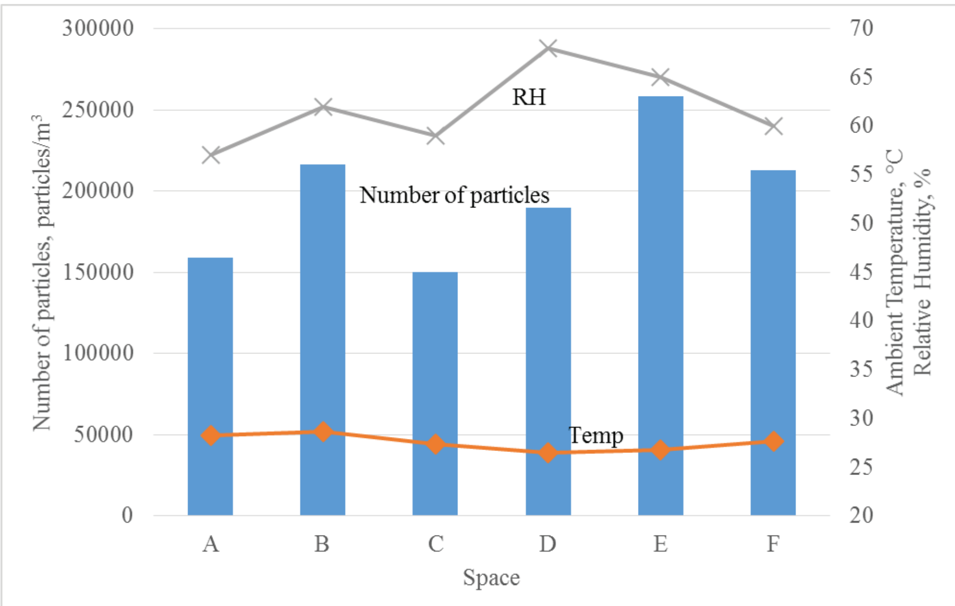


FIGURE 5. Air particles of greater than 0.5 μm in diameter.



The measured average air temperature values from previous studies were in the range of 22.5°C and 24.7°C. The measured average air temperature value of the current study was 24.9°C, which is higher than the previous data with a percentage difference of 0.8 %. Similarly, the measured average relative humidity percentage of the current study is higher as compared to those of previous studies with the highest percentage difference of 18.55 %. Table 2 shows that the average relative humidity value of 66% measured in the current study was closest to that obtained by Abdullah (2003). The recorded average air velocity values from previous studies were in the range of 0.065 m/s to 0.40 m/s, and the measured average air velocity of this study was 0.19 m/s, which is lower than those of Mamat (2005) and Handayani (2008).

The average concentration level of CO gas obtained from the current study is also higher than the previous data recorded by Abdullah (2003) and Handayani (2008). The recorded concentration level of CO gas for the present study was 13.5 ppm, while the level of CO gas measured by Abdullah (2003) and Handayani (2008) were 0.2 ppm and 12.2 ppm, respectively. The main reason for the large difference in the readings obtained from the present study with that of Abdullah (2003) is possibly due the office building being located nearby the car park. Furthermore, the office spaces were always busy with visitors. The frequent openings of the office doors by staff and visitors may indirectly contribute to polluted outdoor air and CO gas being brought into the building, thus increasing the existing amount of CO gas inside the office spaces.

The allowable concentration level of CO_2 gas as recommended by the Standard is below 1000 ppm. For the current study, the measured concentration level of CO_2 was 635 ppm, which is also below the maximum permissible level. In previous studies, Handayani (2008) recorded the highest concentration of CO_2 gas at 721.5 ppm, while Abdullah (2003) measured the lowest at 478.5 ppm. The factor that affects the concentration of CO_2 gas is the total number of occupants in the office spaces. CO_2 gas concentration that is significantly beyond the allowable level would indicate poor ventilation.

3.2 Subjective Measurement

It is possible to get a 10% response rate (Denscombe, 2010) that can still be accepted. Other than by figures, it is more productive to evaluate the response rate by several justifications (Denscombe, 2010), which include measurement of non-response rate and its relevant fashion. In this study, the response rate of 63% was achieved. From Table 3, it can be assumed that the

TABLE 2. Comparison of current results with that of previous studies.

Sources		Current test [30]	Previous Studies [29]	[28]	
Air Temperature (°C)		24.9	24.7	23.3	22.5
Relative Humidity (%)		66	53.76	60	64.5
Air Velocity (m/s)		0.19	0.36	0.4	0.065
SO2 (ppm)		0.35	—	—	—
CO (ppm)		13.5	12.2	—	0.2
CO2 (ppm)		635	721.5	609	478.5
Air Particle (number/m^3)	0.5 μm	197748	—	—	—
	5.0 μm	534			
Dust (mg/m^3)		—	0.03	0.06	—

lowest response rate would be the security department where its officers have to be regularly on daily routine operations around the campus. Out of 56 occupants in total, the response rate of 63% (i.e. 35 respondents) is therefore reasonably sufficient for the survey.

3.2.1 Demographical Information

The distributions of respondents according to their gender and office space they served are depicted in Table 3. The distribution by gender among respondents was 29 males, with the percentage of 51.8%, and 27 females with the percentage of 48.2%. Staff of different genders and ages were considered in this study, since gender and age are among the factors that affect thermal comfort. Generally, individual differences exist in thermoregulation responses and thermal comfort among individuals of the same gender or age group in moderate thermal environments, as experienced in daily life (Yasuoka et al., 2015). Numerous studies have been conducted on gender differences with regard to thermal comfort. Men can generally tolerate a wider range of thermal comfort or acclimatize to their environment as compared to the women office staff; thus, women are likely to feel less comfortable or dissatisfied within the same office space (Schellen et al., 2012; Rupp et al., 2015). However, it also depends on the total floor area of the office where they work. It was observed that most of the respondents are in the age range of 21 to 35 years old, with most of them (i.e. a total of 15 respondents) being in the age range of 21 to 25 years old.

3.2.2 Descriptions of Workplace Information

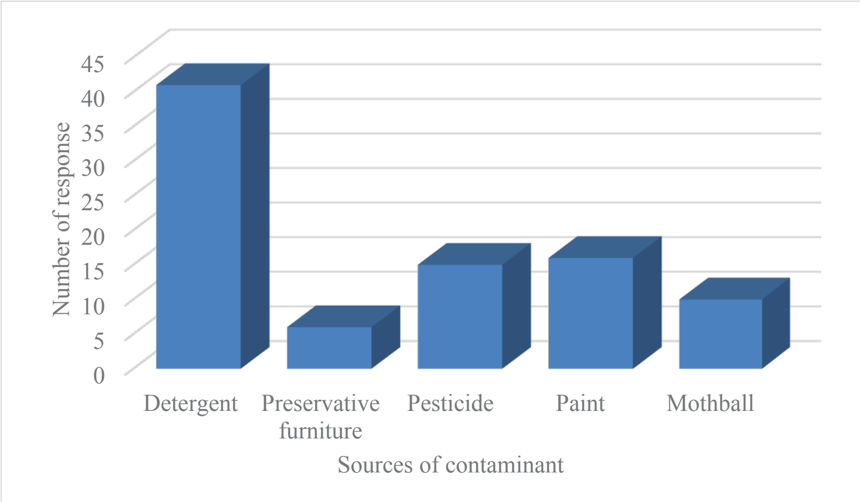
From questionnaire survey results, it is found that only 2% of the respondents felt uncomfortable with the working environment, whilst 45% of them were dissatisfied with the lighting condition within the workplace. The presence of chemical substances also affects the indoor air quality. Figure 6 illustrates the products that contained chemicals within the office spaces. The main contributor was detergent due to a cleaning process that was conducted once a day for all building areas.

Generally, all occupants were working with their computers for 7 to 9 hours per day. In the meantime, most of the office spaces had various office equipment such as photocopy machines, printers, binding machines, laminating machines and fax machines. These office

TABLE 3. Distribution of respondents based on gender.

Office Space	Gender		
	Male	Female	Total
Management & Administration Division **(A)**	3	7	10
Internal Audit Unit **(B)**	6	5	11
Security Department **(C)**	5	0	5
Human Resource Development Division **(D)**	5	5	10
Centre of Alumni Advancement & Relations **(E)**	4	1	5
Human Resource Management Division **(F)**	6	9	15
Total	**29**	**27**	**56**

FIGURE 6. Response for the sources of contaminant.



supplies produced heat and contributed to indoor pollution by releasing greenhouse gases such as CO_2. Apart from that, there are also some other pollutants emitted from printer equipment such as ozone, solvents, toner dust and VOCs (Barrese et al., 2014). The toner and paper dust from printing devices also generate particles, including ultrafine particles on the nano-scale range (Massey and Taneja, 2011). The use of liquid paper or other strong smelling chemicals such as cleanser and glue are other sources of contaminants that affect the indoor air quality.

3.2.3 Sick Building Syndrome (SBS) Symptoms

From the questionnaire survey, there are three classifications of 'not always', 'always' and 'serious' cases for each SBS symptom affecting the occupants. An assumption has been made that weighted scores of 1, 2 and 3 were assigned to each classification of 'not always', 'always' and 'serious', respectively. Therefore, the rank can be analysed from the weighted scores as shown in Table 4. It can be clearly seen from Table 4 that dizziness is the most frequent SBS symptom affecting the respondents in this building as it shows the highest ranking among the other SBS symptoms. The adverse health effects would occur as a consequence of poor IAQ issues as well as some effects due to contaminants of VOCs within the building particularly from paint and cleaning products. In general, it can be affirmed that occupants in this office building are not frequently affected by the SBS symptoms. However, a small number of occupants have shown a tendency to be affected, as they claimed to have symptoms related to skin and nose problems as well as difficulty in breathing. These are some of the initial signs that affected occupants in this office building are suffering from SBS but at a lower rate.

Generally, the problems related to eyes and skin, including itchiness and skin dryness, are mainly caused by the presence of dust or fume-producing operations within the office building. The existence of fumes and fungus are commonly caused by severe relative humidity of indoor air. Meanwhile, nose irritation is also affected by the quality of air and occupants with asthma will be the most affected group. Moreover, dizziness is commonly related to the concentrations of CO_2, SO_2, CO and also from body odours or perfume. However, from a rational perspective, contaminant source control is the most effective way to improve the IAQ in the office spaces.

TABLE 4. Ranking of symptoms for SBS from the multi-storey office building.

Symptom	Classification			Score (%)	Rank
	Not always	Always	Serious		
Eye redness	51	4	1	36.90	13
Itchy eyes	44	11	1	41.07	7
Watery eyes	46	10	0	39.29	10
Blurry	43	12	1	41.67	5
Itchy skin	45	8	3	41.67	5
Skin dryness	35	19	2	47.02	2
Flaky skin	46	9	1	39.88	9
Sneezing	39	14	3	45.24	3
Nose irritation	41	13	2	43.45	4
Flu	43	13	0	41.07	7
Dizziness	30	22	4	51.19	1
Fever	50	6	0	36.90	13
Cough	46	10	0	39.29	10
Breath difficulty	50	5	1	37.50	12

Environmental stressors like noise, poor lighting, vibration, overcrowding, poor workplace design can be the cause of all the symptoms and produce poor indoor air quality.

According to a literature review, it has been estimated that up to 30% of the refurbished and new buildings suffer from SBS (Sykes, 1988; Xiaoshu, 2011). This condition is defined when more than 20% of the surveyed occupants experience symptoms indicative of an IAQ problem (i.e. headaches, fatigue, nausea, eye irritation and throat irritation), and these symptoms can be alleviated by leaving the building.

According to previous research (Jafari et al., 2015; Reinikainen and Jaakola, 2001; Othman, 2003; Md Yusof, 2011), physical parameters are significantly associated with the eight common prevalent symptoms and these parameters are the air temperature with a range of 21.7°C–23.7°C, relative humidity of less than 30%, air velocity in between 0.02m/s–0.1 m/s, and the rate of outside air supply into building ranging from 0.6–15.8 cfm/person. An insufficient supply of fresh or outdoor air coupled with the poor movement of air and high humidity indoor have been defined as major causes for the prevalent SBS symptoms inside buildings. With regard to this, maintenance of HVAC system and regular building audits are some of the best practices in reducing SBS problems and a way forward is to adopt or adapt the Green Building Certification System.

3.3 Evaluation between Perception Analyses with Collected Physical Parameters

The average value of air temperature at 26.1°C in office spaces Zone F is higher than in office spaces Zone C at 23.7°C as shown in Table 5. This may be due to the office spaces in Zone F as having the greatest number of occupants as compared to that of the others. Sixty percent of the occupants in office spaces of Zone F voted for 'neutral' towards the thermal sensation of its indoor environment, although the average measured air temperature was 26.1°C. About 60% of occupants in office spaces Zone C felt 'too cold' with its indoor thermal environment as evidenced by the lower measured air temperature value of 23.7°C, while the remaining 40% of the occupants voted the indoor environment as 'too hot'. This may be due to the air temperature gradient between hot weather outside and temperature inside the building, and also the radiant heat from solar radiation affecting the occupants, particularly those sitting near the transparent windows and walls.

It also can be seen from the results in Table 5 that the average relative humidity in office spaces Zone A was too moist at 74%, as compared to that of office spaces in Zone B which was relatively dry at 58%. This may be due to the office spaces in Zone A as being located facing the sewage ponds. The level of air humidity, which is less than 30%, will affect the incidence of respiratory illnesses. Based on the occupants' responses at the Central Office Building, only 2% of subjects felt shortness of breath. However, when the air humidity level is more than 60%, it would cause mould to grow on the materials of modern office equipment (e.g., photocopiers, laser printers and computers) and cleaning products. Outdoor air pollution can also increase the level of indoor air contamination.

Air movement in occupied spaces provides a feeling of freshness by lowering the skin temperature. Based on feedback from respondents in office spaces of Zone C, 80% of them felt the air movement was normal and the other 20% felt that it was windy. Referring to the measured air velocity value of 0.15 m/s, the air movement inside office spaces of Zone C can be considered as sufficient and acceptable. However, the measured air velocity in office spaces

TABLE 5. Comparison of results between the office spaces.

Measured Parameters	Office Spaces					
	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Air Temperature (°C)	24.7	25.3	23.7	25.3	24.4	26.1
Relative Humidity (%)	74	58	61	73	68	62
Air Velocity (m/s)	0.17	0.18	0.15	0.23	0.18	0.22
SO_2 (ppm)	0.38	0.35	0.32	0.32	0.34	0.37
CO_2 (ppm)	812	598	608	569	447	776
CO (ppm)	15.5	15.6	15.7	11.4	11.6	10.9
Air Particle (number/m^3)						
diameter of 0.5 μm and above	159093	216132	150103	190013	258519	212628
diameter of 5.0 μm and above	869	520	501	382	439	495

of Zone D was relatively higher with its reading of 0.23 m/s. During the survey, at least 70% of occupants felt that there were slightly heavy air movements almost every working day, whereas about 30% of the occupants voted that they felt too much air movement within the spaces on an average of 1 to 3 days a week for about 3 consecutive weeks.

The reactions to these contaminants have led to the phenomenon of SBS. This situation tended to occur because several occupants were using electronic devices such as a photocopy machine and a laser jet printer. Based on their responses, around 17.86% and 32.14% of the occupants admitted that they would use a photocopy machine at least once a day every week, while about 73.21% of them confessed that they were using the laser printer several times a day. Electronic devices can produce CO_2, CO and other contaminant gases. The human respiration system in the office environment exhales CO_2 gas when performing light office duties. Hence, the concentrations of CO_2 and CO gases are some of the contributing sources that may cause SBS symptoms. Nevertheless, there will be considerable reduction in the sick building syndrome (SBS) as the ventilation rate per person within typical office buildings increases (Syazwan et al., 2009).

From the measured data for the concentration of SO_2 gas, there was a slightly large difference between office spaces in Zone A with its value of 0.38 ppm and in both office spaces of Zone C and Zone D at 0.32 ppm. However, the value for CO gas concentration was nearly constant in office spaces of Zone A, Zone B and Zone C which were recorded at 15.5, 15.6 and 15.7 ppm, respectively, and in office spaces of Zone D, Zone E and Zone F with their recorded values of 11.4, 11.6 and 10.9 ppm, respectively. The lowest value was recorded in office spaces of Zone F as the occupants inside these office spaces were doing fewer activities during the measurement period.

A large difference between concentrations of CO_2 gas in office spaces of Zone A with its recorded value of 812 ppm and in office spaces of Zone E which was measured at 447 ppm were recorded. From the observations, it was found that the number of occupants in office spaces of Zone A ranged from 15 to 20 occupants, as compared to only 5 occupants in office spaces of Zone E who were involved in the subjective measurement. However, an indoor CO_2 gas concentration of less than 1000 ppm does not guarantee that there is no IAQ problem. There can be other contaminant sources contributing to poor IAQ such as respirable suspended particles (RSP), VOCs, formaldehyde, and nicotine that generally tend to correlate with varying CO_2 concentrations (Md Yusof, 2011). High concentration of CO_2 gas can be an indicator of poor air circulation or under-ventilation. An indoor concentration of CO_2 gas greater than 1000 pm is indicative of a potential IAQ problem. From the questionnaire survey results, it was found that 46.43% of the occupants have developed headaches when staying in their office. Common symptoms such as headaches, loss of judgment, dizziness, drowsiness and rapid breathing are likely to occur whenever an occupant is over exposed to the CO_2 gas and some may be due to the VOCs.

Particles are solid or liquid substances that are light enough to be suspended in the air. The largest particle may be visible in sunbeams streaming into a room. However, smaller particles that cannot be seen by the visible eye are likely to be more harmful to health. Particles of dust, dirt, or other substances may be drawn into the building from outside and can also be produced by activities occurring within buildings, like sanding wood or drywall, printing, copying, operating equipment and smoking.

Based on the survey results, 63.64% of occupants in office spaces of Zone B and 80%

of occupants in office spaces of Zone E felt that the office environment was reasonably clean. Even though an office space may be clean, a lot of air particles may still exist indoors. This can be shown by the average number of air particles with a diameter of 0.5 μm and above in both office spaces of Zone B and Zone E that were measured at 216,132 particles/m^3 and 258,519 particles/m^3, respectively. Furthermore, the average number of air particles with a diameter of 5.0 μm and above recorded in both office spaces of Zone B and Zone E were significantly lower at 520 particles/m^3 and 439 particles/m^3, respectively, inside the building.

4.0 CONCLUSIONS

The IAQ in the Central Office Building at UTHM has been assessed. In conclusion, physical measurements of indoor air quality parameters for the whole central office building have led to the following conclusions:

I. The average indoor air temperature and air velocity within the office spaces are 24.9°C and 0.19 m/s, respectively, while the average concentration levels of SO_2, CO_2 and CO gases are around 0.35 ppm, 635 ppm and 3.5 ppm, respectively.
II. The number of air particles in both diameters of at least 0.5μm and 5.0μm within the office spaces are around 197,748 particles/m^3 and 534 particles/m^3 respectively.
III. Subjective assessment results generally demonstrate a good correlation with the physical parameters measured which include air temperature, relative humidity, air velocity, and concentration of contaminant gases such as SO_2, CO_2, CO and air particles.
IV. Although there are countable SBS cases affecting the occupants, IAQ within the office spaces is generally within the acceptable range.

The overall indoor environment within the office spaces is not dangerous or hazardous for occupants, and its environmental quality is generally acceptable. The measured results for air temperature, air velocity and concentrations for SO_2, CO_2 and CO are still within the range recommended by ASHRAE Standard 62-2004 as well as within the permissible exposure limit set by OSHA. The number of air particles is also within the permissible limit stated in ISO class 7. For future study, it is recommended to include the measurement of VOCs within the office spaces since organic chemicals are used in some of the office products. It is believed that VOC contaminants are the cause for the claimed SBS cases even though the IAQ inside the office building is within an acceptable level.

Maintaining a good IAQ requires attention to the building's heating, ventilation, and air conditioning (HVAC) system, the design and layout of the space, and pollutant source management. HVAC systems significantly impact how pollutants are distributed and removed. HVAC systems can even act as a source of pollutants in some cases, for example, when ventilation air filters become contaminated with dirt and/or moisture, or when microbial growth results from stagnant water in drip pans or from uncontrolled moisture inside air ducts.

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