INDOOR AIR QUALITY ISSUES FOR NON-INDUSTRIAL WORK PLACE

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ABSTRACT

Indoor air quality (IAQ) issues are not new in Malaysia. However, lack of study, data and local regulation become one of the major contributions towards this problem especially with the non-industrial sector. This study are focusing on the application of related legal requirement, identify source of problem contribute to the IAQ, occupational exposure and control measure required to mitigate the issue in future. It have been perform specifically at the office area facilitate with centralized air conditioning system. A total of 125 samples were performed against the floor area (5000m²) and specific activities perform within the building. It has been divided into two stages which are based on quantitative and qualitative approach. Walk through survey were conducted and the area sampling were selected for data collection. It shows that 77 % of the IAQ issue comes from inadequate ventilation supply into the building against number of air change rate per occupant range 20 cfm per person. These findings also lead to the identification of high carbon dioxide at the area sampled; microorganism, Total Volatile Organic Compound (TVOC) and relative humidity levels exceed the allowable limit. Carbon dioxide, detected with mod reading at 1300ppm against the ceiling limit of 1000ppm by Code of Practice on IAQ (CoP-IAQ). This situation can be related to 80% of bacterial and fungal count perform exceed the 500 cfu/m³ limit by World Health Organization (WHO). Issue of uncontrolled renovation and lack of awareness among occupant are main contribution toward the IAQ problem as well. TVOC for 8TWA exceed the stipulate value of 3ppm. The CoP-IAQ only covered five common chemical in the indoor setting. However, the study have shown other parameters like microorganism, ventilation rate or physical parameter like temperature and humidity also play a major role as an indoor contaminant agent. This study are believe to help the researcher, occupational practitioner and management to use as baseline toward the management and control of the Indoor Air Quality in indoor settings in terms of pollutant and control measures to minimized the exposure among the occupant.

Keywords: *Indoor air quality (IAQ), Workplace, Occupational exposure, office building.*

1. INTRODUCTION

Fundamental changes in the way of live and work have had significant impact on IAQ. There is a shift in commercial building construction toward lighter, synthetic construction materials, centralized sophisticated maintenance and energy efficient. It is important, therefore, to develop standards for air quality that render the indoor environment at least as safe as the outdoors and within the comfort range for most individuals. ASHRAE (American Society for Heating, Refrigerating and Air- Conditioning Engineers) defines acceptable Indoor Air Quality (IAQ) as "air in which there are no known contaminants at harmful concentrations and with which a substantial majority (usually 80%) of the people exposed do not express dissatisfaction"(ASHRAE 62.1 2007)[8].The problem with this definition is that in nonindustrial environments measurable contaminants are rarely present in levels known to be harmful, even where complaints of discomfort and adverse health effects are considerably in exceed of the "acceptable" 20 %. [13-14][46-47]

In Malaysia specifically, a Code of Practice on Indoor Air Quality have been launch in July 2005 by The Department of Occupational Safety and Health (DOSH) to chatter for these requirement at a place of work. However , the scope of this code only apply to all non- industrial places of work in industries listed under Schedule 1 of the Occupational Safety and Health Act 1994 (Act 514) [24].

2. NATURE OF THE PROBLEM ON IAQ

Issues of occupational and health in the office have received tremendous attention from the management since the SARS and H1N1 outbreak in Malaysia. A lot of unidentified complain from tenant and staff in the commercial building was recorded by the health and safety group. These especially in terms of thermal comfort and humidifier fever have affected the absenteeism and productivity indirectly. Lack of space and renovation from private office to open space cubicle in the office environment have become a main pattern to the facilities management or building owner to maximized number of occupant per area. Issue of energy efficient led to decreased ventilation rates for most interiors, with increased potential for build-up pollutant Also, lower levels of potentially harmful pollutants might be expected to have greater effect indoor because of longer exposure times (Spengler & Sexton 1983)[46]. Previous study by other researcher shown Americans, especially in urban environments, spends nearly 90% of their time indoors [33]. Contributing to the increase in IAQ complaints, office workers today expect a clean, comfortable working environment. This is compounded by the public health concerns about the chemical and biological contaminants in air, water and food [4]. There are many sources of indoor air pollutants and among the common ones are environmental tobacco smoke (ETS) emitted due to burning of tobacco products; various chemical substances such as formaldehyde emitted from furnishings; volatile organic compounds emitted from the use and application of solvents; and ozone emitted from photocopiers and laser printers (DOSH 2005)[24]. It should be noted here that ETS has been recognized as a human carcinogen by the International Agency for Research on cancer and exposure to it will increase the risk of coronary heart disease[16].

2.1. Inadequate Ventilation or Air Movement

According to Milton et al.(2000),the prevalence of short-term sick leave by office workers was 50% higher with a lower ventilation rate of 12 L / s per person than it was with 24 L/s . In addition to the rate of ventilation, the occupant density seems to affect the incidence of respiratory diseases. All occupied buildings require a supply of outdoor air. Depending on outdoor conditions, the air may need to be heated or cooled before it is distributed into the occupied space. As outdoor air is drawn into the building, indoor air is exhausted or allowed to escape (passive relief), thus removing air contaminants. According to Saari et al.(2005), without adequate ventilation and cooling, an excessive increase in the efficient use of given space may reduce the quality of its indoor climate to the extent that it affects the people using it, leading to reduced performance and even to an increase in morbidity[6]. As a result, deterioration in productivity may involve losses that offset any financial benefit of a more efficient use of space.

2.2. IAQ Parameter Contributed

2.2. 1. Temperature and Relative Humidity

ASHRAE 55(2004), defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal comfort environment"[9]. The perception of thermal comfort is affected by body temperature that is interactively influenced by personal activity, clothing, and the environmental factors of air temperature, air movement, and RH. ASHRAE 55(2004) standard for relative humidity of 30-60% and Temperature of 20-26°C. [10]According to ASHRAE 62 (2007) humidity is not a major concern in ventilation system design [8]. Humidity has only a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy, however, long-term high-humidity indoors may cause microbial growth, and very low humidity (15-20 per cent) with increase temperature may cause dryness and irritation of eyes and airways (Cheong et al.2005)[10].

2.2.2. Carbon Dioxide (CO_2)

A study carried out by Mui et al.(2005) shown a correlation determining the average concentration in the occupied period for a ventilated space could be significantly increased with increasing number of sampling points in the space[40]. The results shown of the spatial mean indoor CO2 concentration in the office, it was found that when the number of sampling points required for IAQ measurement was reduced by 50%, the probability of obtaining the sample-spatial average concentration at the same confidence level would be decreased by 10%.It can be conclude that the selection of the sampling location in a space allows relatively expedient evaluations of IAQ.

2.2.3. Carbon Monoxide, CO

A survey on the status of indoor air pollution in residential buildings using different fuels in China (Z.Wang et al.2004) indicate that the concentrations of four indoor pollutants resulting from gas combustion were less than those resulting from coal combustion [25]. This can be conclude as combustion issue in the indoor environment is not significant in this office area as the sources only comes from the ambient air environment supply to the AHU system.

2.2.4. Respirable Particulate

Respirable particulate can be classified into Environmental tobacco smoke, chemical and biological origin (EPA 1987)[35]. EPA (1993) showed IAQ measurements for airborne dust will be well below occupational and ambient air guidelines except under the most extreme conditions [36].

2.2.5. Total Volatile Organic Compound (TVOC) and Formaldehyde (HCHO)

Sources of VOC and HCHO in the building could be from the painting, furniture, glue or air refresher. Indoor pollution caused by VOCs is an important aspect of IAQ which raises particular concern since many organic indoor pollutants are either known, or are suspected to be allergic, carcinogenic, neurotoxin, immunotoxic, irritant or indicative of SBS. It may derive from the human activities and interior building materials in tight building design

Study found that off-gassing chemicals would adsorb onto another building material and re-emit at a later time (AIHA 1993) [3]. Formaldehyde (HCHO) is a VOC that has been studied extensively. Small amounts of formaldehyde are present in most indoor environments. Itching of the eyes, nose, or throat may indicate an elevated concentration. 0.1ppm as guidance by DOSH (2005) provides reasonable protection against irritational effects in the normal population. Hypersensitivity reactions may occur at lower levels of exposure. Worst-case conditions are created by minimum ventilation, maximum temperatures, and high source loadings [36][48]. Study by Lundgren (1994) show the chemical pollutant emissions may affect the indoor environment in several ways: affect health and well-beings, give rise to troublesome odors, contaminate other materials, result in discoloration of adjacent materials, and condense on electronic equipment and result in mal-operation[22].

2.2.6. Microbiological

Interpreting microbial sampling data is challenging because there may occur in buildings a diversity of contaminant, including many different culturable and non-culturable fungi and bacteria. The few studies related to actinomycetes in indoor environments are very specific, such as toxin production by a single isolated strain, or studies concerning pathogen. For this study a Total bacteria & Total Fungi Results were collected as indicator of area overcrowding, humidity and filter efficiency. Sampling approach was based on the qualitative information of operation of HVAC, humidity level, overcrowding, construction of the building envelope and occupant susceptibility. The results shows 80% of the bacteria count exceed the WHO level 500 cfu/m³. This have been support by Nevalainen et al.(1993) findings where most often there are more bacteria count than fungi in a air-conditioned office[41]. Sarikanth et al.(2008) shown microbial growth affected by physical characteristic like size, shape or droplet of particles,enviromental factors include magnitude of air currents, relative humidity and temperature[42]. This can be conclude presence of fungi indicates problems with water penetration or high humidity. However Lima et al.(2006) study shown present in many of the examined points, the frequency of *actinomycetes* was very low when compared to fungal and bacterial counts, this might due to sampling method and equipment used which can be a variable factor to the microbial sampling in indoor environment apart of sources from ambient air supply into the building[14] .

3. METHODOLOGY

The method will concentrate on the qualitative approach known as Walk-through survey while the second phase concentrate on site sampling based on the quantitative approach [12].The studies focused on the potential pollutant, ventilation system and occupant activities contribute to poor indoor air quality in the office environment [1-2][7]. The researcher emphasized on the building design, indoor air climate and the general symptom indicate the Sick Building Symptom (SBS) among the occupant [31][43]. The study framework and design activity are elaborated in figure 1 below.

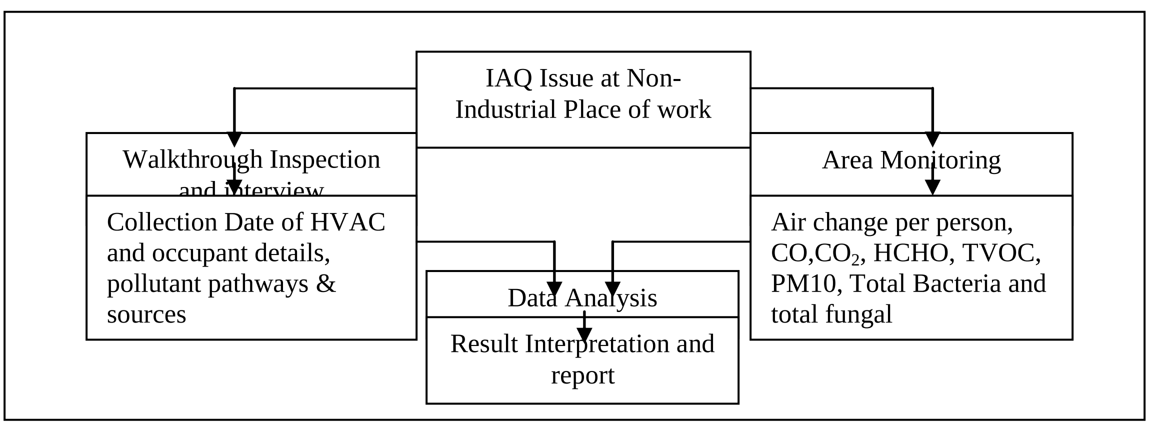


Figure 1: Study Framework

3.1. Subject Selection

Two high raised building were selected for this study. Both building are used as multipurpose building like hotel, offices and also cafeteria. The ventilation systems are centralized and have been operated for more than 10 years. It located at heavily traffic area and operated seven days a week during 8.00am to 5.30pm daily except for the hotel which is 24 operating hours. However, this study only specified the office area and cafeteria as a control area. Two company were selected with total number of occupancy are more than 500 person estimated per floor space.

3.2. Walk Through Survey and Interview

The assessment was first conducted qualitatively whereby a walk through survey was carried out for Company A and Company B Offices located. Observations were also made at other level of the tower where the public cafeteria is located. The purpose of walk through survey is to identify any potential indicators of IAQ issues which include:

- Visual evidence of moisture problems or microbiological contamination.
- The presence of unusual odors.
- Potential and locations of specific pollutant sources.
- Pollutant pathways and pressure differentials.
- Review of the ventilation air condition system
- Excessive settled dust.

During the walk through survey, areas that require further investigation were identified where quantitative assessment through IAQ sampling and analysis will be conducted. A total of ninety (90) representative sampling locations were identified distributed over 9 levels of Company A office areas and outside the office. Another thirty seven (37) areas sampling collected from Company B itself. Total of 127 sampling locations including outside samples were performed on two stages from March to June 2009.

3.3. Review of Ventilation System

Several sessions of discussion were held with the facilities supervisor of to obtain information on the operations and maintenance of the ventilation systems in particular those serving the offices. To evaluate air distribution in a particular room or area, air flow measurements were carried out at supply air diffusers and return/grilles using air velocity meter. Smoke tubes were also used to observe air flow patterns that provide some indication of the flow pattern of air coming from the HVAC system. This information was then calculated and translated into air exchange to determine whether the ventilation rate is sufficient for occupants within a particular room according based on ASHRAE 62(2007) [8-9].

3.4. Sampling Mechanism for Total Bacteria & Fungi

Generally there are two methods of IAQ sampling and measurement: direct-reading and integrated sampling. The former provides immediate and fast feedback in terms of sampling result while the latter involved drawing of air through a collector known as sampling medium [29-30]. In the case of this project, most parameters were measured using direct reading except for microbiological sampling. The equipment used for microbiological samples is (used Anderson Single Stage Sampler) as Two types of media were used specifically for Total Bacteria known as Tryptone Soy Agar and Total Fungi media used Sabroud Dextrose Agar. All samples were sent to the lab for analysis 48 hour for Total bacteria and 5 days for fungal [38-39].

3.5. Sampling Method

The IAQ monitoring was carried out in strict conformance to internationally accepted methods of sampling and analysis. All sampling were perform within the business hours from 0800 am to 0530pm to represent the real time environment. The reference for sampling and analytical techniques and well as equipment used are given in Table 3.3. CO_2 , CO readings can be taken at supply outlets or air handlers to estimate the percentage of outdoor air in the supply air stream using the direct reading meters[42]. The results are usually presented in parts per million (ppm). A photo ionization detector and direct-reading instrument used as a screening tool for measuring TVOCs and HCHO. Both equipment support with accuracy value of ± 25% and accepted by DOSH (2005)[24]. The sampling probe will be located between 75 and 120 cm from the floor at the centre of the room or an occupied zone.

Table 1: Summary of IAQ Parameters, Reference Method and Equipment Used

Item	Parameter	Reference Method	Equipment
1	CO, CO_2, TVOC, RH and Temperature.	Direct Reading	IAQ Rae Multi-gas detector c/w RH and Temperature sensors.
2	Formaldehyde	Direct Reading	Formaldemeter
3	Respirable particulates (PM10)	NMAM 0600	Dust Track Meter
4	Air Flow and Ventilation Rate	ASHRAE 62-2007	Flow meter Velocycal CFM
5	Microbial; Total bacteria and Total fungi	NIOSH BIOLOGICAL SAMPLING NMAM 0800	SKC Microbiological Sampler

Legend

- ***NMAM;*** *NIOSH Manual Analytical Method*
- ***USEPA;*** *United States Environmental Protection Agency*
- ***ASHRAE:*** *American Society of Heating, Refrigeration, and Air Conditioning Engineering*

3.6. Data Analysis and Comparison with Standard Regulation

The data obtained was analyzed using Microsoft Excel for obtaining the appropriate the mean ± SD of the test conducted. All data are presented in a control chart in order to be differentiated and plot the control limits. The purpose of control chart is to allowed simple detection of events that indicative to actual process change [28].

After data collection and sampling are performed, all the data will be compared according to the related regulation. Code of Practice for Indoor Air Quality 2005 and ASHRAE Standard 62.1 (2007): Ventilation and Acceptable Indoor Air Quality has stipulated details of minimum requirement with maximum limit for potential Indoor Air pollutant.

4. RESULT AND DISCUSSION

Measurement was conducted at several locations for both companies in order to measure the percent of fresh air supplied into the building. For Company A, Temperature against floor method were used and for Company B using Carbon dioxide with indication of ventilation rate adequacy at each monitored room/area in comparison with ASHRAE Standards 62(2007) which required 15-20 cfm per person. This due to the different ventilation design applies at both companies .It was found that:

i. Results show that outside air percentage for all measured area do not meet the minimum standard.

ii. This may be related due to overcrowding whereby during renovation partition and officers rooms without considering the air supply and total number of occupants per area. Other potential causes are blockage of supply diffuser by the occupant and closing of outdoor air intake from the system.

iii. 77 % of the ventilation rate was detected less than the ASHRAE standard requirement for Company A & B area

4.1. Temperature and Relative Humidity

Figure 2 provides the results of temperature and figure 3 for Relative Humidity monitoring between Company A and B. It indicates, with the exception of the area L11, Finance, L52, Receptionist, L54; Area 1 and L13; area 3 and 6 of reading detected were 76-78 % at Company B, other area readings complied with the ASHRAE 55(2004). Average temperature detected were 24.4°C.Two area exceed the temperature value represent the ambient air temperature from the intake point. There a few potential of high humidity at Company B where the thermostat setting was very low and a lot of opening through the louver within the building envelope. Standing water issue from the flower pot and leakage also contribute to this problem. Relative humidity show mean of 50% for most of the areas tested. Table 4.8 illustrate correlation between the temperature and Sick Building Syndrome.

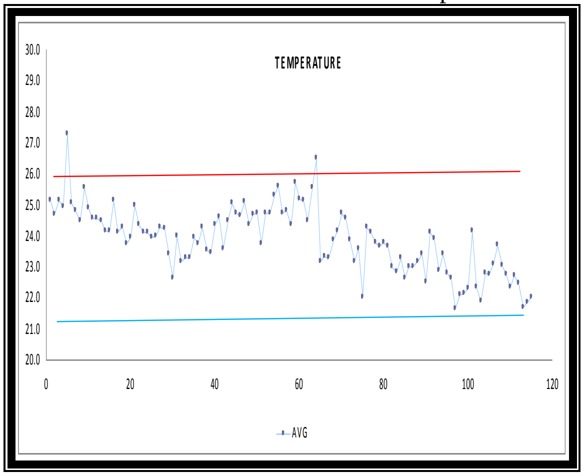


Figure 2: Summary of Temperature result between Company A & B

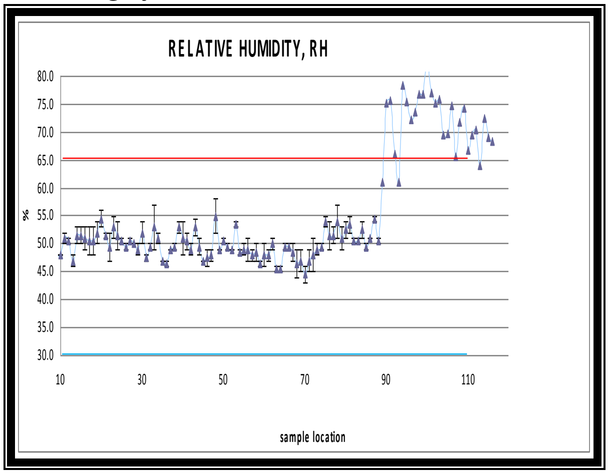


Figure 3: Summary of RH result between Company A & B

4.2. Carbon Dioxide (CO_2)

Carbon Dioxide was measured at all selected points for area and supply diffusers. The results by floor level are graphically illustrated in figure 4 and 5. While not usually considered a pollutant, CO2 is easily measured and is often used as a surrogate for measurement of ventilation rates in indoor air quality investigations. The CO_2 concentrations at Company B offices were found below the COP ceiling limit of 1000ppm where most of the area detected with mean range of 584ppm compare than Company A where the mean reading shown the range of 1300ppm which is above the ceiling limit of 1000ppm. With the exception L36 and AHU at L39, the CO_2 concentrations at Company A offices were found exceeded the COP ceiling limit of 1000ppm. Company A area were identify with high number of occupant against the air supply per area. This might be due to the design of the VAC system and design o workplace for private offices does not consider the location of air supply and return damper.

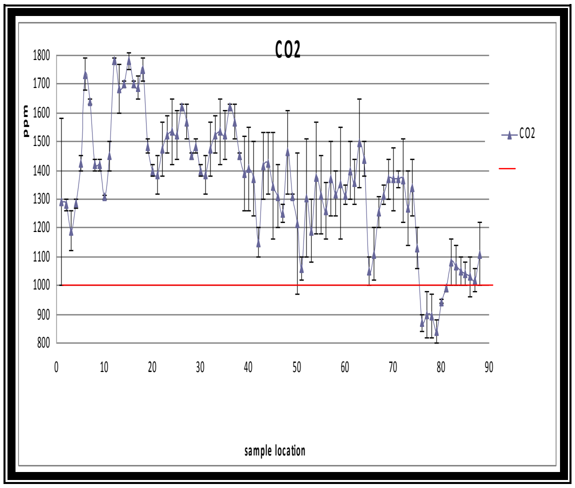


Figure 4: Summary of CO_2 level at Company A.

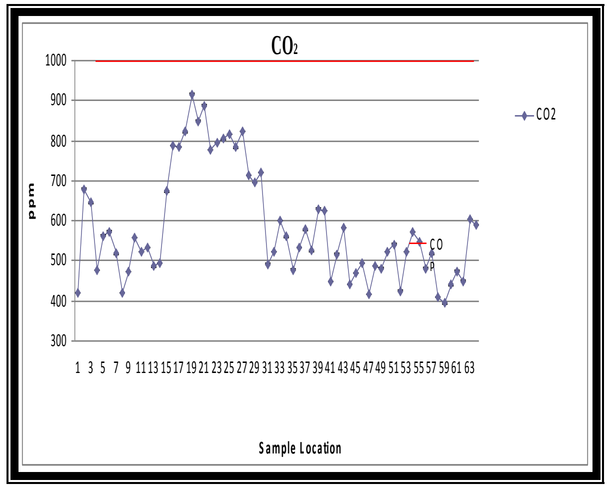
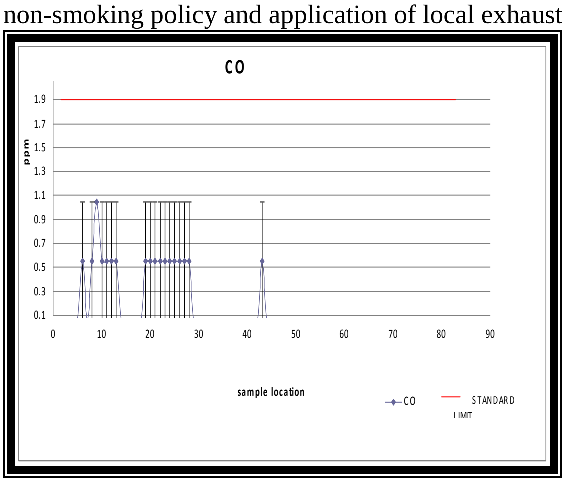


Figure 5: Summary of CO2 level at Company B.

4.3. Carbon Monoxide, CO

Carbon monoxide is part of combustion product and indicates the infiltration issue in the indoor environment.The results of CO measurements is summarized graphically in figure 6 and 7. It was found that all locations were detected with low concentration of CO complied with the COP ceiling limit of 10ppm. This indicates that there was no infiltration of combustion gas from the traffic, cafeteria and car park into the office space. The concentration of CO in the outside air at the time of assessment was 8ppm. Mean reading for both company detected between 0.1 to 2.3ppm.It was noted that reading at Company B slightly higher than Company A. This might due to the VAC system design where Company B used the AFU that located underneath the occupant .Location of fresh air intake of the system also contribute to this issue, where Company A the intake point located on top of the building and Company B was facing the heavy traffic .Potential from other sources like cooking, car park and Environmental tobacco smoke were very low due to the design and best practice applied in both building. Both of the building implement non-smoking policy and application of local exhaust were install at both car parks and cafeteria area.



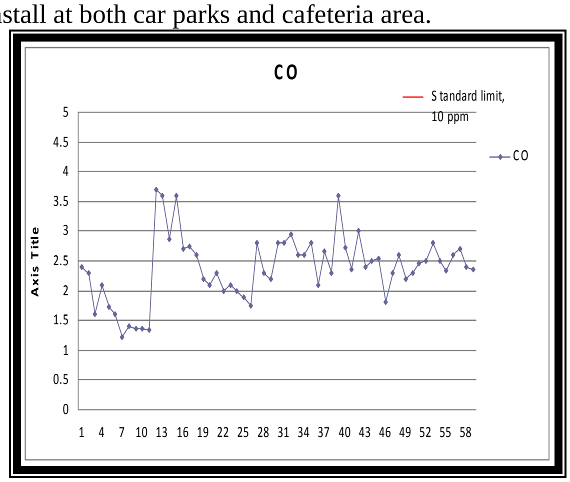


Figure 6: Summary of CO level at Company A

Figure 7: Summary of CO level at Company B

4.4. Particulate Matter

Respirable particulate matter is an indicator which directly contributes to the IAQ problem at workplace. Code of Practice on Indoor Air Quality (IAQ) published by Department of Occupational Safety and Health Malaysia has set the maximum standard for the particulate at 0.15 mg/m³ for 8-hours. The results in figure 8 and 9 show that the readings at all locations complied with COP Standard Limit except level 11, finance and south area. Mean of detection at Company B is 0.0036 mg/m³ and A was 0.01 mg/m³ . This may due to the occupant activities like improper storage at Company A contribute to the detection of particulate within the area .All results detected were less than the COP limit less than 0.15 mg/m³.This can be related to the practice and humidity level detects within the buildings itself.

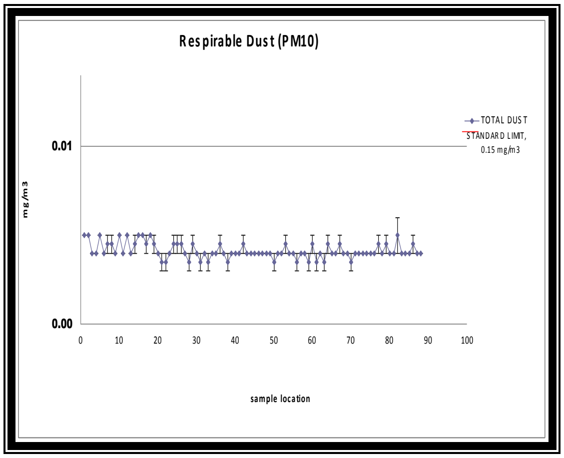


Figure 8 : Summary of Respirable Dust at Company A

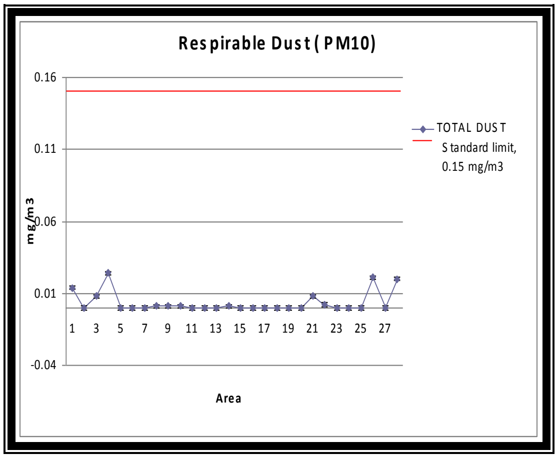


Figure 9 : Summary of Respirable Dust result at Company B

4.5. Total Volatile Organic Compound (TVOC) and Formaldehyde (HCHO)

The results of VOC monitoring are summarized graphically in figure 10 and 11 respectively. High TVOC at the areas of Company B due to new carpet install and the air conditioning system where most of the return points were block by the occupant. Its show that the level of TVOC complied with the COP limits of 3ppm (DOSH 2005) respectively for company A. Results HCHO was detail in Figure 12 and 13. Company A show low result except for area 72 and 81 due to blockage of the return point and storage of paper within the area. Company B all the result detected below 0.1ppm.Standard error of mean reading shown 0.33 ppm. This may contribute from the humidity level and phenol contain within the area itself. It has been note that the reading can be interfere by the high humidity level and phenol sources within the area.

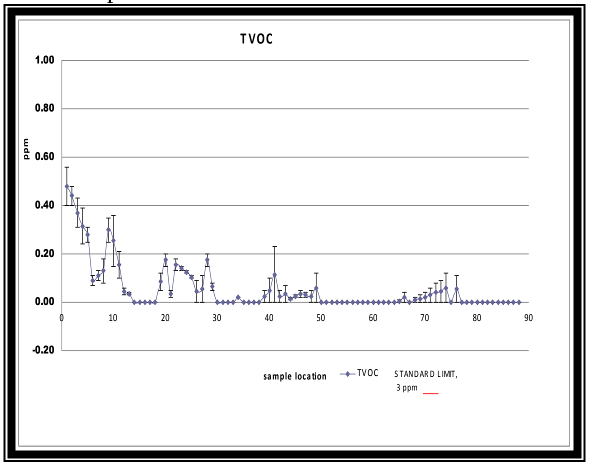


Figure 10: Summary of TVOC result for Company A

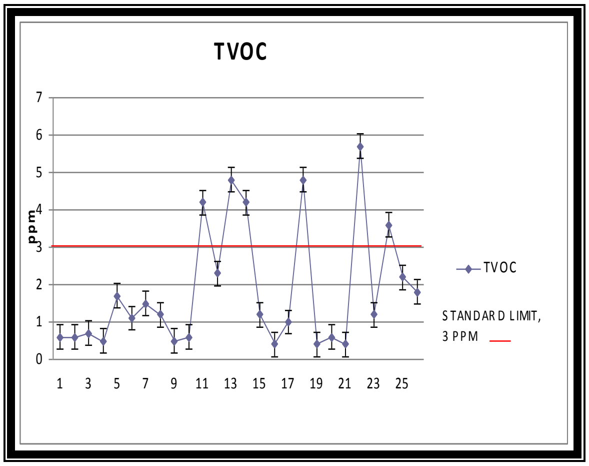


Figure 11: Summary of TVOC result for Company B

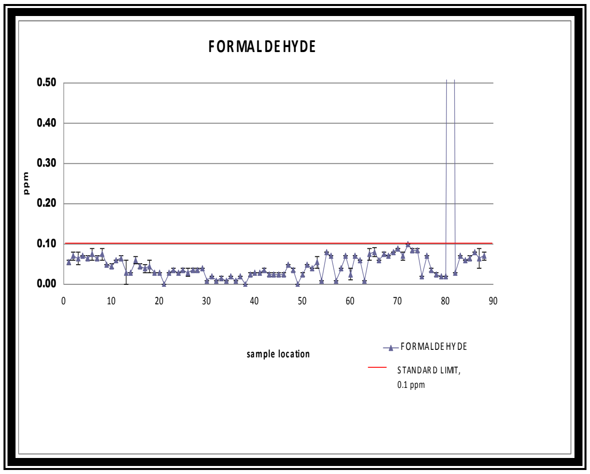


Figure 12: Summary of Formaldehyde result for Company A

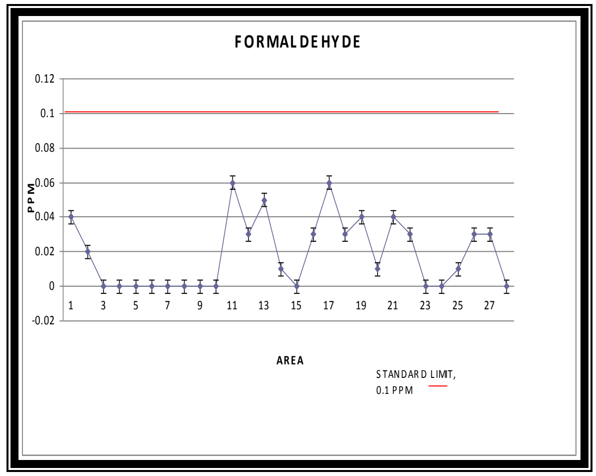


Figure 13: Summary of Formaldehyde result for Company B

4.6. Microbiological Agent

Mean of the reading shown result of 1180 cfu/m³ for the Company A. Fungal count show means of 500 cfu/m³ for 127 samples collected. This indicates insufficient air exchange and overcrowding will also contribute to high count of Total Bacteria. This can be compared by study of Carnelly (1887) and Montacutelli et al.(1998)where counts of airborne bacteria and fungal correlate positively with the numbers of occupant and visitors per area. In this study it shows the bacteria ratio to fungi 21:1 increase to 49:1 in the spacious house. As for Fungal count it can be conclude as not significant issue when the relative humidity in the building is well control. Fungi and bacteria count from both companies show significant issue. Potential with overcrowding, standing water, humidity and HVAC filter maintenance from the building area itself may increase the microbial count within the area. Results are graphically illustrated in figure 14 and 15 below.

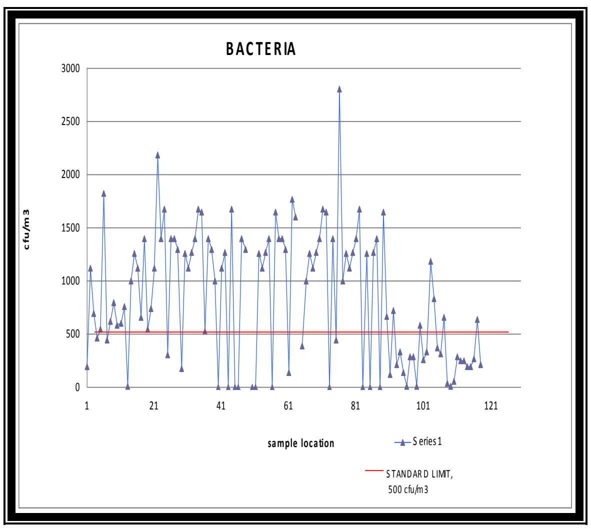


Figure 14: Summary of Bacteria count for Company A & B

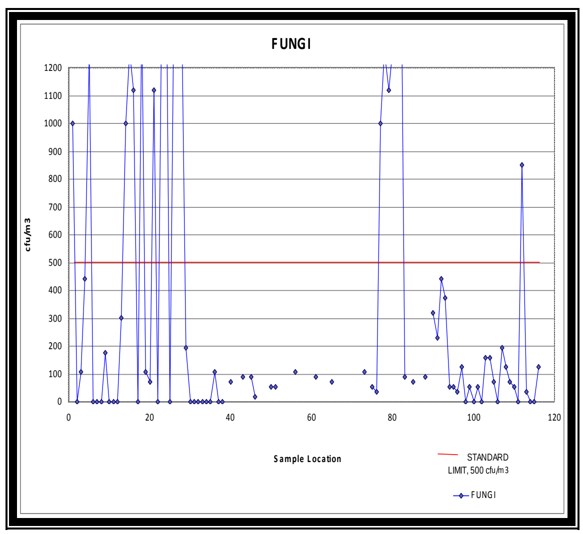


Figure 4.15: Summary of Fungi count for Company A & B

5. CONCLUSION

In general, findings from qualitative and quantitative assessment of Indoor Air Quality (IAQ) performed at Company A & B Offices indicate that there are some issues that need further attention and rectification. The following issues are found significant at both Offices:

- Inadequate Ventilation Rate

- High Carbon Dioxide level
- High bacteria and fungal count
- High TVOC for Company B
- High Humidity at Company B
- High fungal count

The above issues are interrelated. 77 % Poor ventilation rate indirectly indicate insufficient fresh air intake reflecting the weakness in the air conditioning system of Company B specifically the one serving the Office. HVAC systems in mechanically ventilated buildings control indoor air quality by providing outdoor air of suitable quality and quantity; filtering, mixing, and distributing both outdoor and indoor air to the occupied space; and providing temperature and humidity control. In addition, ventilation systems may act as sources for specific pollutants including VOCs, fibers (especially fiber glass) and other particles, and biological pollutants. Although thorough investigation of the HVAC system was unable to be conducted due poor cooperation from the building maintenance contractor for data obtain, however several factors likely to cause this problem were noted during the walk through survey. It was observed that the outdoor air dampers were not widely open during the walkthrough survey.

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