A Study of Indoor Air Quality Issues for Non-Industrial Work Place

Baba Md Deros, Siti Hamimah Ismail, Nor Kamaliana Khamis, Mohd Yusri Yusof and Ahmad Rasdan Ismail

Department of Mechanical & Materials Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, 43600 Bandar Baru Bangi, Selangor, Malaysia.

ABSTRACT

In non-industrial sector, two major issues that led to fungal growth, outbreak of disease like SARS and H1N1 are lack of research and health regulations. This study has three main objectives: to identify major complaints; to verify these complaints; and to determine their effects towards employees’ productivity. It focused on related legal requirement, identify source of problem, occupational exposure and control measures required to mitigate Indoor Air Quality (IAQ) issues. Quantitative and qualitative IAQ studies were performed in Company A and Company B office areas equipped with centralized air conditioning system. The purpose is to investigate whether they complied with Malaysian Department of Occupational Safety and Health (DOSH) IAQ Code of Practice. A total of 125 subjects performing specific activities within the building took part in the study against a 5000m² of floor area. It was found that 77% of IAQ issues are due to inadequate ventilation supply in the building, high level of carbon dioxide, microorganism, Total Volatile Organic Compound (TVOC) and humidity that exceeded ceiling limit set by DOSH and World Health Organization. In conclusion, major factors that contribute towards IAQ problems are uncontrolled renovation, lack of awareness among occupants, micro organism, ventilation rate, temperature and humidity.

Key words: Carbon dioxide, Humidity, Indoor air quality, Micro organism, Total volatile organic compound.

Introduction

Indoor Air Quality (IAQ) affects human well-being and productivity, increase risks for diverse diseases because we spend most of our time indoors (Samet and Spengler, 2003). Generally, indoor environmental quality and health study focuses on the relationship of building environment to common health symptoms: for example, asthma and hypersensitivity (Milton et al., 2000). Generally, air pollutants are inhaled and their initial impacts are on the respiratory tract. They may also be absorbed; some are stored in body tissues creating adverse health effect (Lebowitz, 1983). The terminology used associated with comfort and health effects of Indoor Air Quality (IAQ) are becoming more confusing. The terms “sick building syndrome (SBS),” “tight building syndrome,” “building-related illness,” and “building-related disease” have been used interchangeably (Samet and Spengler, 2003; Samet et al., 1987). American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines acceptable IAQ as “air in which there are no known contaminants at harmful level and with which a substantial majority (i.e. about 80%) of the people exposed do not express dissatisfaction” (ASHRAE, 2007). In most large cities, it has become a fact of life that the indoor environment is considered as a refuge not only from the weather, wildlife and unrestricted contact with other people, but also from the air pollution. In fact, many past literatures indicate that environmental insults during young ages have long lasting influences on human health and productivity (Almond, 2006).

In Malaysia, the Department of Occupational Safety and Health (DOSH, 2005) had launched a Code of Practice on Indoor Air Quality to cater for these requirements at work place. 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). A study by Dockery & Spengler (Dockery and Spengler, 1981) showed most Americans, especially in urban environments, spends nearly 90% of their time indoors. Energy efficiency issues had led to decreased ventilation rates, which resulted to higher potential for harmful pollutant build-up in
building interiors due to longer exposure times, which in-turn might have greater effect indoors (Spengler and Sexton, 1983).

The main problem with non-industrial environments, measurable contaminants are rarely present in levels known to be harmful, even where complaints of discomfort and adverse health effects exceed the normal 20 % “acceptable” limit (Gammage and Kaye, 1985). There are many sources of indoor air pollutants, such as: environmental tobacco smoke (ETS) emitted from burning of tobacco products; formaldehyde emitted from furnishings; volatile organic compounds emitted from solvent usage and application; and ozone emitted from photocopiers and laser printers (DOSH 2005; Samet and Yang, 2001).

The presence of visible moisture and mould associated with condensation, leaks or other moisture into the interior or envelopes is consistently associated with increased risk of respiratory symptoms and asthma (Bornehag et al., 2001). In an office building, Kilburn (2000) and Duflö et al. (2008) agreed that the effect of a redesigned floor plan, occupant density and quality of indoor climate are interrelated with human health (i.e. sick leave) and performance (i.e. productivity), which has become a major concern for more than three decades. This result is in-line with Milton et al. (2000) finding, prevalence of short-term sick leave by office workers was 50% higher at a lower ventilation rate of 12 litres/second compared with 24 litres/second. In short, sick leave is an outcome that could be used as an indicator of respiratory diseases with respect to the indoor air quality environment.

Occupants of office buildings with central ventilation of cooling air consistently report health symptoms, such as asmucus membrane irritation, breathing difficulties, irritated skin, headache and fatigue, which may due to contaminants disseminated by air conditioning into the indoor air (Mendell, 2004; Cheong et al., 2006). According to Mendell et al. (2002) and Fisk (2000) building with inadequate ventilation may increase the transmission of infectious respiratory diseases or sinus infections among occupants. In an office working environment dissatisfied employees believe IAQ issues caused higher mental productivity loss compared to manual office tasks (i.e. typing) productivity loss (Kogonen and Tan, 2004). Normally, in an office environment pollution loads, fresh airflow rate and ventilation efficiency can be easily estimated. In other words, it can be concluded that IAQ issues are not limited to the Heat and Ventilating and Air Conditioning (HVAC) system and design but it may also due to occupant activities and quality of outdoor air. It should also be noted that the IAQ study have many limitations due to climatic differences from one country to another, building design, effect of different pollutants and ventilation efficiency on perceived air quality. Therefore, more detailed work is needed for estimating the contaminant levels in the breathing zone with different ventilation systems.

This study has three main objectives, they are: to identify the type of major complaints; to verify these complaints; and to determine their effects towards employees’ productivity. It focused on the application of related legal requirement, identify source of safety and health problem, occupational exposure and control measures required to mitigate the IAQ issues.

Material and Method

This study was done as part of the evaluation on occupational and environmental health program at Company A and Company B. It focused on the potential pollutant, ventilation system and occupant activities that contribute to poor indoor air quality in the office environment. It had investigated the building design; indoor air quality and general symptoms that indicate the Sick Building Symptom (SBS) among the occupants. Company A and Company B are located in high rise building (i.e. more than 250 meters) above the ground level were selected for this study. At present, both buildings are used as multipurpose building such as: hotel, offices and cafeteria. They have been occupied for more than 10 years and are using centralized ventilation systems. Both companies are located at a busy traffic area and operate seven days a week from 8.00 am to 5.30 pm except for the hotel division which operates 24 hours. A total of 125 subjects took part in the study against a 5000 m² floor area and performing specific activities within the building. This study only covers the office and cafeteria as a control area. Both companies have total number of occupancy more than 500 persons per floor space. Milton et al. (2000) defined crowding less than 9.3 m² per employee. The sampling points for each parameter were determined according to the type of activities and based on the air condition design with respect to floor spaces (DOSH, 2005). At least one sample was taken from each floor or from each area serviced by a separate air-handling unit. Visual inspection and in-situ readings for pollutant gases such as Carbon Dioxide (CO₂) and Total Volatile Compound (TVOC), flow measurement of air intakes, return air and supply air were taken during walk through at the office areas. To evaluate air distribution in a particular room or area, air flow measurements were carried out at supply air diffusers and return/grilles using a Velocity Air test instrument (Velocycal CFM). 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 to ASHRAE (2007).
In this study, most parameters were measured using direct reading except for microbiological sampling. Referring to Figure 1, the equipment used for conducting microbiological sampling is Anderson Single Stage Sampler and the two types of media used are: Tryptone Soy Agar for investigating Total Bacteria and Sabroud Dextrose Agar for investigating Total Fungi. All samples were sent to the laboratory for analysis: 48 hour analysis for Total bacteria and 5 days analysis for fungal.

**Fig. 1:** Anderson Single Stage Sampler.

The IAQ monitoring was carried out in strict conformance to internationally accepted methods of sampling and analysis. All sampling were performed within normal business hours from 8.00 am to 5.30 pm to represent the real time environment. The CO₂ readings can be taken at supply outlets or air handlers to estimate percentage of outdoor air in the supply air stream using direct meters reading. Normally, the results are presented in parts per million (ppm) and calculated with the assumption that all chemicals detected are the same as the one used to calibrate the instrument. A photo ionization detector is a direct-reading instrument used as a screening tool for measuring TVOCs and chemical component of formaldehyde (HCHO). Both equipment comply with DOSH (2005) have accuracy values of ± 25%. The sampling probe was located between 75 and 120 cm from the floor at the centre of the room or an occupied zone. A collection and analytical techniques are available. Dust can be collected using a pump to draw air through a filter. The filter can then be weighed (using gravimetric analysis) or examined under a microscope. For respiratory particulates, sampling was carried out using an instrument with a size selective device having a median cut size of 4 micrometer and the following penetration characteristics shown in Table 1.

**Table 1:** Recommended filter sized to measures PM 10 (DOSH, 2005).

<table>
<thead>
<tr>
<th>Particle Aerodynamic Diameter (micrometer)</th>
<th>Respiratory Particulate Mass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>97</td>
</tr>
<tr>
<td>2</td>
<td>91</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

The data collected was analyzed using Microsoft Excel for calculating the mean ± standard deviation (SD) of the test conducted. Later, all the data were presented in the form of control limits and a control chart. The purpose of control chart is to allow simple detection of events that could indicate the actual process change. After performing the data collection and sampling process, the data was compared to the related regulation shown in Table 2. Code of Practice for Indoor Air Quality DOSH (2005) and ASHRAE (2007): Ventilation and Acceptable Indoor Air Quality has stipulated details of minimum requirement with maximum limit for potential Indoor Air pollutant.

**Table 2:** List of indoor air contaminants and the maximum limit (ASHRAE, 2007; DOSH, 2005; ASHRAE, 2004).

<table>
<thead>
<tr>
<th>Indoor Air Contaminants</th>
<th>Eight hour time-weighted average airborne concentration</th>
<th>Acceptable Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>C1000</td>
<td></td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Respirable particulates</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Total volatile organic compounds</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Temperature (Temp)</td>
<td>22 - 26 °C</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity (RH)</td>
<td>30% - 65%</td>
<td></td>
</tr>
<tr>
<td>Ventilation Rate</td>
<td>Volume of fresh air supply into building is ≥ 20cfm per person</td>
<td></td>
</tr>
<tr>
<td>Total Bacteria</td>
<td>500 cfu/m³</td>
<td></td>
</tr>
<tr>
<td>Total Fungi</td>
<td>500 cfu/m³</td>
<td></td>
</tr>
</tbody>
</table>
Results and Discussion

Study result shows that the average time workers spend per week in the building was 50 hours including overtimes and weekend call. Majority of workers are working in open space with partition type of workstation which is occupied by more than 8 persons one time. Almost the entire office areas at Company A and Company B are carpeted except for pantry and filing area. Carpet is well known as the major source of dust for indoor environment, which may also provide a suitable condition for fungi and bacteria growth. It was observed that fans were used in some part of the office areas that may cause in an imbalance condition in the area. In addition, it was found that some of the air supply diffusers were blocked with paper by the occupant.

Carbon Dioxide (CO\(_2\)) was measured at all selected points and supply diffusers. The results by floor level are illustrated graphically in Figure 2 and Figure 3. Normally, CO\(_2\) is not considered as a pollutant, it can be easily measured and is often used as a surrogate for measurement of ventilation rates in indoor air quality investigations.

![Fig. 2: Summary of CO\(_2\) level at Company A.](image1)

![Fig. 3: Summary of CO\(_2\) level at Company B.](image2)

Referring to Figure 2, Company A has average CO₂ levels 1300ppm during normal occupancy periods. This value had exceeded the ceiling limit of 1000ppm (ASHRAE, 2007; DOSH, 2005; ASHRAE, 2004). In Company A, many areas were identified with high number of occupants against the air supply per unit area. This might be due to the design of the Heating Ventilation Air Condition (HVAC) system and design workplace for private offices that does not consider the location of air supply and return damper. This finding is in-line with a study done by American Conference Government Industrial Hygiene (ACGIH, 1998), where the concentration of carbon dioxide within a space may provide a good indication of the outdoor air delivered and ventilation rates stipulated. Meanwhile, in Company B offices have CO₂ concentrations levels at 584 ppm during regular occupancy, which is lower than the Code of Practice (COP) ceiling limit of 1000ppm. However, there may be some result interference by time sampling and area density as the standard error mean of 17.1 was obtained from both companies. Mui et al. (2006) proposed a correlation for determining the average CO₂ concentration in the occupied ventilated space by increasing number of sampling points in the space.

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. (2006), without adequate ventilation and cooling, excessive increase in the use of a given space may reduce the quality of its indoor climate to the extent that it negatively affects the people using it, leading to reduced performance. As a result, deterioration in productivity may cause losses that offset any financial benefit of a more efficient use of space.

Further measurement was conducted at several locations at both companies to measure the percent of fresh air supplied into the buildings. In Company A and Company B measurement were made using carbon dioxide, which could be used to indicate ventilation rate adequacy at each monitored room/area compared to ASHRAE (2007) that requires 15-20 cfm per person. It was found that:

- Several air supply diffusers were found blocked by the occupants due the thermal discomfort where occupants were feeling too cold and supply diffuser is located underneath their seat.
- The blockage resulted in poor ventilation. Ventilation rate is calculated based on airflow measurement shows that 77% of the results were below recommended limits of 15 -20 cfm per person as required by ASHRAE (2007).
- This may be due to overcrowding caused by partition of office rooms during renovation without considering the air supply and total number of occupants per unit area.
- Poor ventilation was also evident by the use of fans to enhance air movement by some occupants. This situation leads to insufficient fresh air intake, which presents odour problem, high level of CO₂ and other contaminants.

Ventilation rate per person was calculated by dividing the total ventilation rate of the premises with the maximum number of persons working in the office floor. The meeting rooms were considered as a control area. It has shown the importance of good ventilation and air-conditioning to a more efficient use of space, especially in conjunction with high-value work.

In this study, Total Bacteria and 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.

Figure 4 shows very large majority of the bacteria count in Company A and B had exceeded the World Health Organization (WHO) standard limit at 500 cfu/m³. Nevalainen et al. (1992) findings, which show that there are more bacteria count than fungi in an air-conditioned office. Meanwhile, referring to Figure 5 the mean fungal count taken from 127 samples collected in Company A and Company B is higher than 500 cfu/m³. This result indicates insufficient air exchanges and overcrowding that contribute towards high Total Bacteria count. This result can be compared to Carnelly (1987) and Mountacutellu et al. (1998) studies, which found airborne bacterial and fungal count correlate positively with the number of occupants and visitors per unit area. For fungal count it is not a major issue when the relative humidity in the building can be properly control. However, result from this study in both companies shows fungi and bacteria count is a major issue. Overcrowding, standing water, humidity and HVAC filter maintenance from the building area itself have the potential to increase the microbial count within the area. Srikanth et al. (2008) showed microbial growth are affected by physical characteristic like size, shape or droplet of particles, environmental factors that include magnitude of air currents, relative humidity and temperature. Thus, it can be concluded that presence of fungi indicates problems with water penetration or high humidity.
**Conclusions:**

There are mechanisms that can be associated with ventilation and humidification with illness-related absence: irritant and allergic reactions, or increased respiratory illness due to either airborne spread infection or an increase in susceptibility. IAQ may have potentially large impacts towards health and well-being of office workers. Employees who are in good health have the tendency to be more productive, fewer days of sick leave. The results found in this study could be use to assists researchers, occupational practitioners and management as a baseline towards the management and control of IAQ in indoor settings with respect to pollutant and control measures to minimize exposure among occupants. Insufficient ventilation rate contribute towards high carbon dioxide, Bacteria Count and Total Volatile Organic compound around the office area. In addition, overcrowding can be a major issue that contributes to high bacteria count in the area. The present results emphasize the need for special care with the indoor air quality by adopting more efficient air filtration and air removing systems to lower the risk of harming the occupants’ health. Other issues that need to be considered in future studies are the effect of different pollutants on the perceived air quality. Therefore, much work is needed to better understand the most cost effective of IAQ.

**References**


