ISRAA UNIVERSITY JOURNAL OF APPLIED SCIENCES ISSN : 2523- 0522
Volume 2 : issue 1 , October , 2018

Evaluation of Indoor Air Quality at Engineering Campus Library at the University Sains Malaysia

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Received Feb 2018; accepted April 2018

Abstract: *The indoor air quality (IAQ) in micro-environments is extremely important due to its impact on health and productivity of students. This study presents the findings of indoor air quality (IAQ) investigations in engineering campus library at the University Sains Malaysia. Four levels of the library were investigated during May 2015. Measurements were carried out by using electrochemical analyzer and hand-held particulate matter (PM) instrument. The results showed that Formaldehyde, carbon monoxide (CO), Ozone, and total volatile organic compounds (TVOC) levels were found below Malaysian guideline values. Temperature ranged between 18.9–28.4 °C and relative humidity (RH) ranged between 49%–73% with an average of 62.2%. The indoor concentration $PM_{2.5}$ level was 5.73±4.93μg/m3. All the monitoring pollutants' levels were found below Malaysian guideline values in the ground floor, and the 1st and 2nd floors. However, several exceedances occurred in the 3rd floor. Inadequate introduction and/or distribution of fresh air may be the main problem in the left side of the building and in the 3rd floor. Thus, evaluation of the HVAC (Heating, Ventilation, and Air Conditioning) system should be examined.*

Keywords: *Indoor Air Quality, Thermal Comfort, HVAC, Ventilation, Student Health.*

1. Introduction

Indoor air pollution has been ranked as the second biggest environmental provider to ill health after unsafe water and sanitation (Keraka *et al.*, 2013; Salem 2017) . Considering people spend an estimated 90% of their time indoors, the air quality is an important factor related to occupant comfort and health (USEPA, 2012; Salem 2017) . The most common health problems that indoor pollutants may contribute are sick building syndrome (SBS) and building-related symptoms (BRS). The quality of indoor air has emerged into a relevant field of study and has received significant public attention since the energy crisis experienced in the early 1970s.

Various trade organizations and public agencies have developed recommendations and regulations to minimize exposure to air contaminants; however, most of these exposure levels are established for industrial environments. Mindful that non-industrial facilities do not use chemicals in frequency and volume that is common at industrial establishments, the concentrations of indoor air contaminants in the former facilities are “rarely present in levels known to be harmful” (Conrad and Soule, 1997). Despite the media attention and academic research focused on chronic exposures to relatively low concentrations of indoor contaminants, the adverse effects of poor indoor air quality (IAQ) at non-industrial facilities remains ambiguous to the environmental and medical professional (Salem 2017).

Malaysia currently is experiencing rapid urbanization and economic growth due to the development of industrial estates. The clear phenomenon of rural to urban migration has brought as a consequence greater emissions into the atmosphere, which has predominantly been produced by the increase in traffic. In addition, the expansion of suburbs into closer proximity with industrial plants in certain areas has led to the problem of air pollution (Azmi et al., 2010) . As a tropical country, the lower ventilation rates combining with increasing the outdoor pollutants may affect the indoor air quality. Further, the high humidity and high temperatures experienced increase the risk of thermal discomfort and moisture problems indoor (Hamimah et al., 2010).

Several IAQ studies in Malaysia reported that IAQ, thermal comfort and SBS has become a common issue in Malaysia buildings (Mustapha *et al.*, 2008; Juliana *et al.*, 2009; Makhtar *et al.*, 2010; Kamaruzzaman and Razak, 2011; Norhidayah *et al.*, 2013). Moreover, till now no mandatory regulations to be advised on IAQ in school buildings were established, where the regulations and standards have been set to industrial building during the last 10 years (DOSH, 2010; PWDM, 2013). The purpose of this study is to examine indoor air quality (IAQ) levels, and thermal comfort within the four floor of the University Sains Malaysia’s (USM) Engineering library.

2. Methodology

Overview

An industrial hygiene air sampling investigation has been conducted in the library in the USM's Engineering campus. Data collected during this investigation included fine particulate matter ($PM_{2.5}$), ground level ozone (O_3), volatile organic compounds (TVOC), formaldehyde (CH_2O), CO, CO_2, temperature (Temp), relative humidity (RH), and dew point temperature (Tdp). All monitoring parameters were collected during one week, i.e. from 23-April 2015 through 30-April 2015.

Walk-through Survey

A walk-through survey was utilized to document the materials, design, condition and cleanliness of the library, and the heating, ventilation, and air conditioning (HVAC) system. Data were collected to characterize the materials and conditions of the ceiling, floor, interior walls, exterior walls, HVAC equipment, library contents, environmental modifiers, and the indoor environment. Among the specific items inspected were water stains, mould, air fresheners, pesticides, odours, general cleanliness, and lighting quality.

Sampling Sites

Sampling was performed in the building during the hours of normal operation. The library building utilizes HVAC unit to circulate the outdoor air with indoor air. In general, natural ventilation was limited as windows and doors were closed throughout the study. Four floors of the library building were selected to be monitored. In each floor two locations were chosen from the right and left sides of the building. For every selected site in every floor 8 hours of continuous sampling was occurred.

Equipment and Supplies

A summary of the sampling equipment's is provided in Table 1. The mass concentration of particles ($PM_{2.5}$) has been monitored using E-bam. The monitor performs particulate size measurements by using laser light scattering method. GrayWolf IAQ monitor Model IQ-610 were used for TVOC, O_3, CO, CO_2, Temp, RH and Tdp measurements. For formaldehyde measurement was used Formaldemeter htV-m meter.

ISRAA UNIVERSITY JOURNAL OF APPLIED SCIENCES ISSN : 2523-0522
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Table 1 Specifications of equipment's used for data collection

Data Collected	Range	Company	Model	Uncertainty / Detection Limit	Method
$PM_{2.5}$	Size Range: 0.1-100 µm	Met One Inc.	E-BAM-9800 REV L	0.003 mg/m3 or 2% Reading	90° light scattering, laser diode with flow rate 16.7 l/m
CO	0.0-500 ppm	GrayWolf Sensing Solutions	IAQ monitor Model IQ-610	±2ppm <50ppm, ±3%rdg >50ppm	Electro-chemical
TVOC	5-20000 ppb			1 ppb	Photo-Ionization Detection (PID)
O_3	-			-	Electro-chemical
CO_2	0~10000 ppm			Accuracy: ± 3% rdg ± 50 ppm	NDIR (Non-dispersive Infrared)
Temp	-25° to +70°C			±0.3°C	Platinum temperature (resistive element)
RH	0 to 100 %			±2%RH <80%RH (±3%RH>80%RH	Electrostatic capacity
CH_2O	0-10 ppm	PPM Technology	Formaldemeter htV-m	Accuracy 10% at 2ppm	Electro-chemical

Sample Collection

Sampling was conducted in the selected locations during the study activities by using previous mentioned samplers. The samplers were placed at least 1.5 m height from the floor as shown in Figure 1. Samples were collected for 1 min over 8 hours.

Data Analysis

The data were analyzed using descriptive statistics and parametric statistical tests. The mean, median, minimum, maximum and standard deviation of the data were determined. To compare the between locations and floor data, the parametric t test and ANOVA were used, with a significance value of 0.05, to determine if a statistically significant difference existed.

3. Results and Discussion

Overview

This study was designed to measure and evaluate the concentration of fine particulates, TVOC, O_3, CO, CO_2, as well as the temperature and relative humidity within the investigated area at the four floor's library. The airborne contaminants are ubiquitous in the environment, and therefore are expected at some measurable concentration in the indoor air. Temperature and relative humidity were included in the study due to their influence on the building occupant's comfort level and overall perception of the IAQ.

Summary of Results

More than 3,800 data points were collected during this study. The data were analyzed to identify the mean, median, minimum and maximum measurement and standard deviation for each contaminant and comfort parameter. Summary statistics from the study are organized in Table 2.


Figure 1 indoor air sampling in the USM's Engineering library

Table 2. Descriptive Statistics of measured environmental parameters

Parameter	Minimum	Maximum	Mean	Std. Deviation
TVOC (ppm)	0.300	1.720	0.180	0.310
CO_2 (ppm)	372.50	517.93	436.77	32.19
O_3 (ppm)	0.00	0.00	0.00	0.00
CO (ppm)	0.00	1.36	0.59	0.32
CH_2OH (ppm)	0.01	0.04	0.02	0.01
$PM_{2.5}$ (µg/m3)	0.00	22.00	5.73	4.93
Temp (° c)	18.90	28.40	23.74	2.21
RH (%)	49.00	73.00	62.26	5.28
Tdp (° c)	12.28	21.92	15.60	2.35

Particulate Matter ($PM_{2.5}$)

Particulate matter, or PM, refers to a mixture of solid and liquid atmospheric particles with an aerodynamic diameter (d10) less than 10 micrometres. It arises mainly from anthropogenic sources, such as fossil fuel combustion by electric utilities and motor vehicles, wood burning, and the smelting or other processing of metals. Several population based studies have established a strong

ISRAA UNIVERSITY JOURNAL OF APPLIED SCIENCES
ISSN: 2523-0522
Volume 2: issue 1, October, 2018

correlation between exposures to particulate matter (PM) and increasing rates of mortality, morbidity, respiratory and cardiovascular problems especially among children. The average concentration of indoor $PM_{2.5}$ during the study period was 5.73±4.93µg/m^3 which is below the values set by WHO guideline (25 µg/m^3 for $PM_{2.5}$). As illustrated in Figure 2 the trend of $PM_{2.5}$ concentrations was the same during the sampling hours. When comparing the mean $PM_{2.5}$ concentrations by the floors, a statistical difference was noted only between the 3rd floor (8.13 µg/m^3) and 2nd, 1st and ground floors (6.19 µg/m^3, 5.69 µg/m^3 and 2.94 µg/m^3, respectively) as shown in Table 3. In addition by comparing between locations in the same floor (left and right sides), the t-test showed the mean $PM_{2.5}$ concentration was statistically different between locations only in 3rd floor ($p<0.001$).

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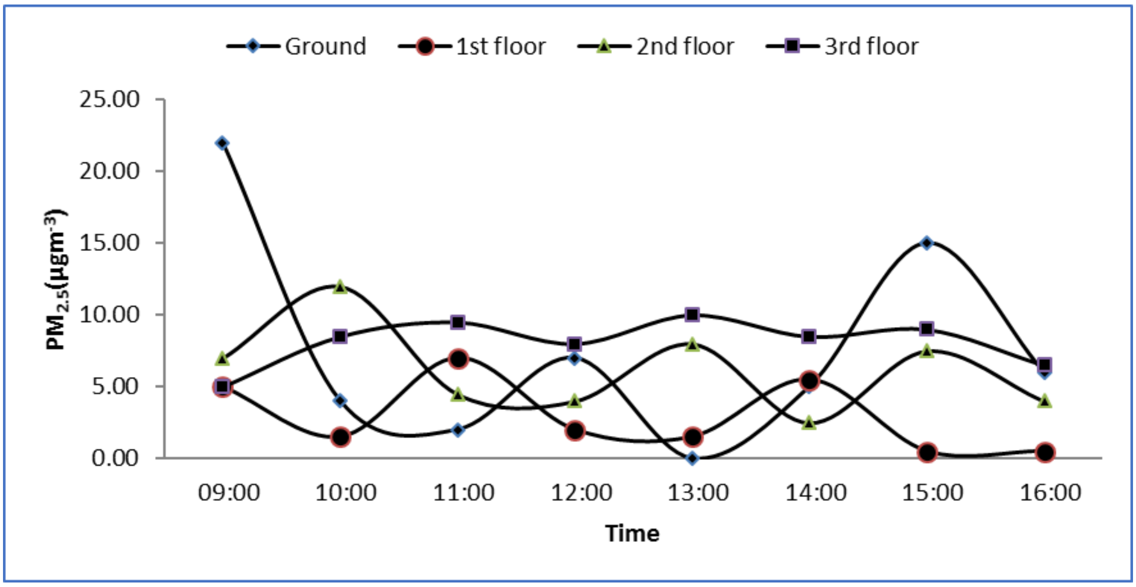

Figure 2 Temporal variation of indoor $PM_{2.5}$

Table 3 Analysis of variance (ANOVA)

	Sum of Squares	**Mean Square**		**Sig.**
Between Groups	219.92	73.30		**0.02**
Within Groups	1310.56	21.84		
Total	1530.48			

Carbon Monoxide (CO)

Carbon monoxide is a by-product of incomplete combustion of organic matter (e.g, gasoline, wood and tobacco). Exposure to carbon monoxide can produce immediate and acute health effects. Several air quality standards have been established to address carbon monoxide and prevent symptoms from exposure to these substances. The average indoor and outdoor CO concentration for the library during the study period was very small and negligible (0.59±0.32 ppm). This value is below the Malaysian Code of Practice (10 ppm) (DOSH 2010). This lower concentration may be due to the University's location as a suburban area, where CO is considered as a scale pollutant which generated by road traffic. The natural ventilation was limited as windows and doors were closed throughout the office hours of the library. As illustrated in Figure 3, CO concentrations was slightly high in the morning (8:00-9:00) then decreased in the 1st ,2nd, and 3rd floors. When comparing the mean CO concentrations by the floors, a statistical difference was noted only between the 2nd, 3rd floors and 1st and ground floors. In addition by comparing between locations in the same floor (left and right sides), the t-test showed the mean CO concentration in the left side of the library was statistically different from the right side in all floors ($p < 0.001$).

Volatile Organic Compounds (TVOC)

Indoor air concentrations can be greatly impacted by the use of products containing volatile organic compounds (VOCs). VOCs are carbon-containing substances that have the ability to evaporate at room temperature. Frequently, exposure to low levels of total VOCs (TVOCs) may produce eye, nose, throat and/or respiratory irritation in some sensitive individuals. Table 2 shows the daily 8-hours average indoor-outdoor concentration levels of TVOC in the monitoring library. The indoor concentration of TVOC ranged from 0.003 ppm to 1.72 ppm. Moreover, TVOC concentrations indoor and outdoor were below the values set by the Malaysian Department of Safety and Health for TVOC (3 ppm). As illustrated in Figure 4 TVOC concentrations was low and stable during the monitoring hours. A unimodal pattern displayed with peaks at 1:00 PM in the 3rd floor then decreased. When comparing the mean TVOC concentrations by floor, a statistical difference was noted only between the 3rd floor and the remaining floors. In addition by comparing between locations in the same floor (left and right sides), the t-test showed the mean TVOC concentration in the left side of the library was statistically different from the right side in all floors ($p<0.001$).

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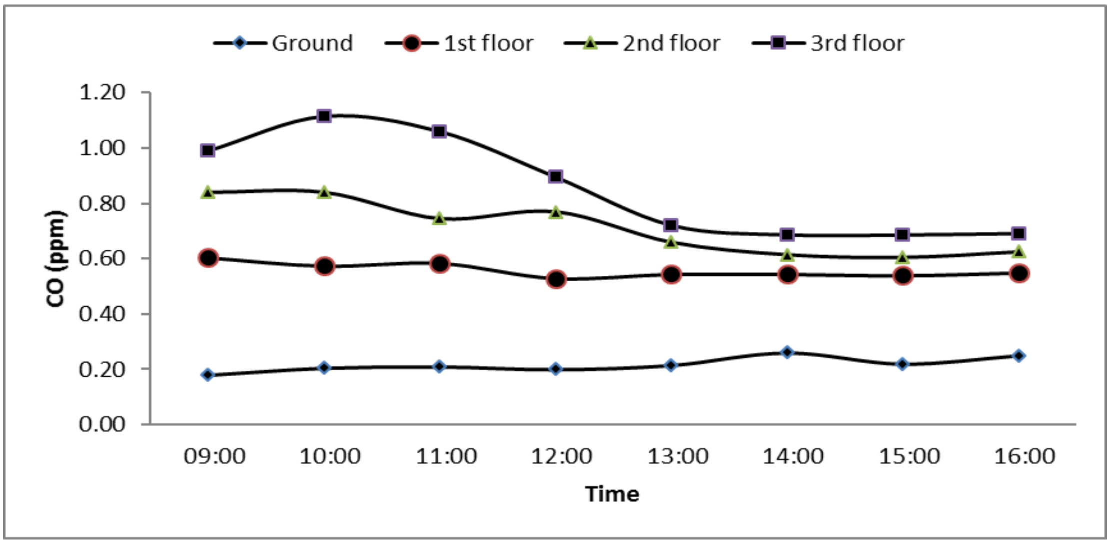
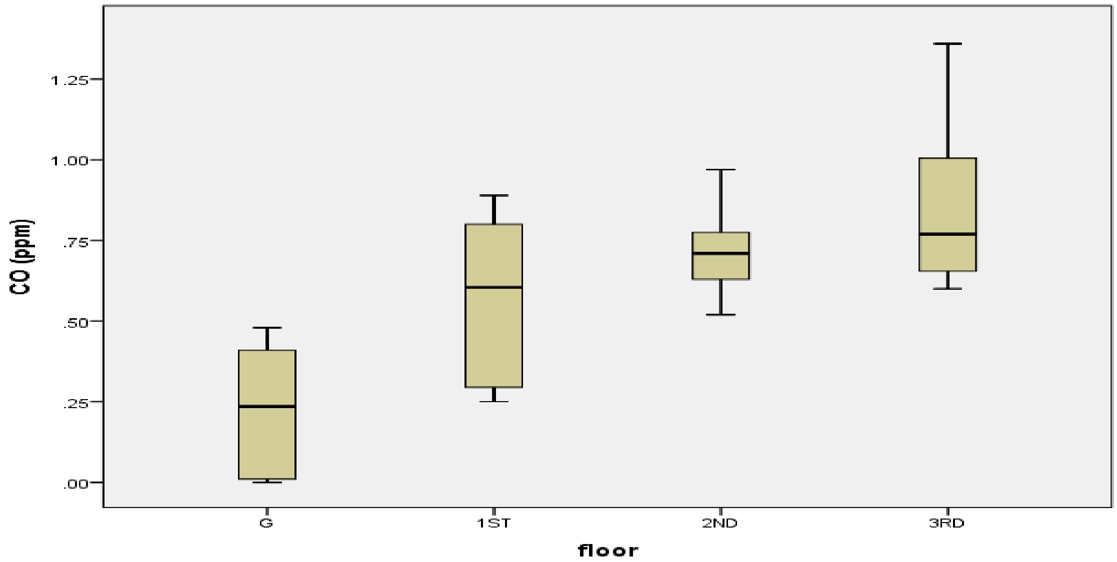


(a)



(b)

Figure 3(a) Temporal variation and (b) indoor CO concentration in library building

Formaldehyde (CH_2OH)

The average level of formaldehyde during the sampling period was 0.02 ±0.01, which is below the values set by the Malaysian Department of Safety and Health for CH2OH (0.1 ppm). As shown in Figure 5 the concentrations in the fourth floor were small and stable.

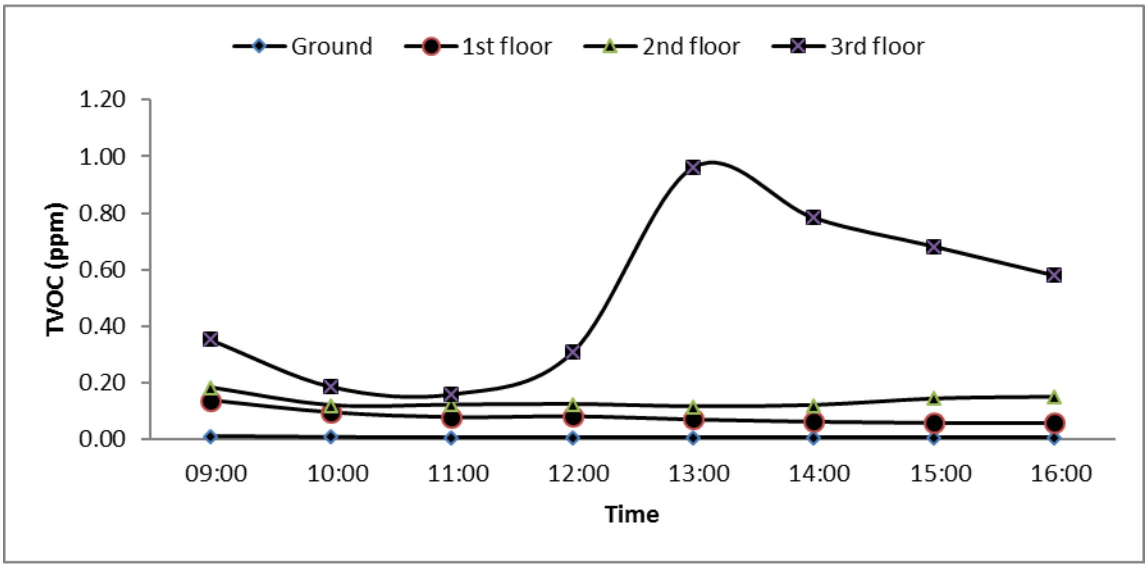


Figure 4 Temporal variation of indoor TVOC

Ozone (O_3)

It was assumed that the likely source of indoor O_3 would be attributed to the presence of copy machine. In general, the frequency of machine operation was minimal and most samples were collected while the machine was idle. Regardless of whether the copy machine was in use, the indoor concentration of O_3 in the library was not detected during the study's period. Therefore, no further analyses were conducted.

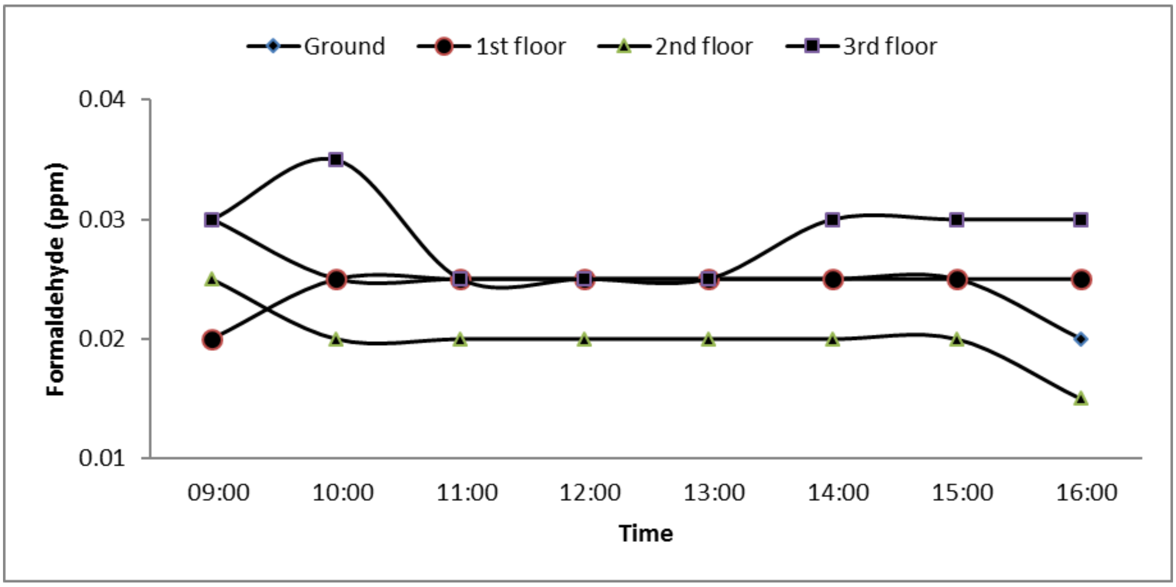


Figure 5 Temporal variation of indoor formaldehyde

ISRAA UNIVERSITY JOURNAL OF APPLIED SCIENCES ISSN: 2523-0522
Volume 2 : issue 1 , October , 2018

Carbon Dioxide (CO_2)

Of the all measurements collected, a narrow range of CO_2 levels were seen. The concentrations f the four locations ranged from 372.5 ppm to 517.9 ppm. The mean CO_2 reading for each locati was well below ASHRAE's recommended level of 1,000 ppm. As illustrated in Figure 6, the C concentration decreased as the day progressed from 517 ppm to 372 ppm during monitoring hou The four floors also displayed statistical differences in mean CO_2 concentration with high concentration in the ground floor. The area at the ground floor is adjacent to the entrance doors. T periodic opening of the doors could influence the mixing of the indoor and outdoor air, and, therefo offset significant differences CO_2 in this area. Moreover, comparing the right and lift sides detect statistical difference in CO_2 in all floors ($p < 0.001$) .

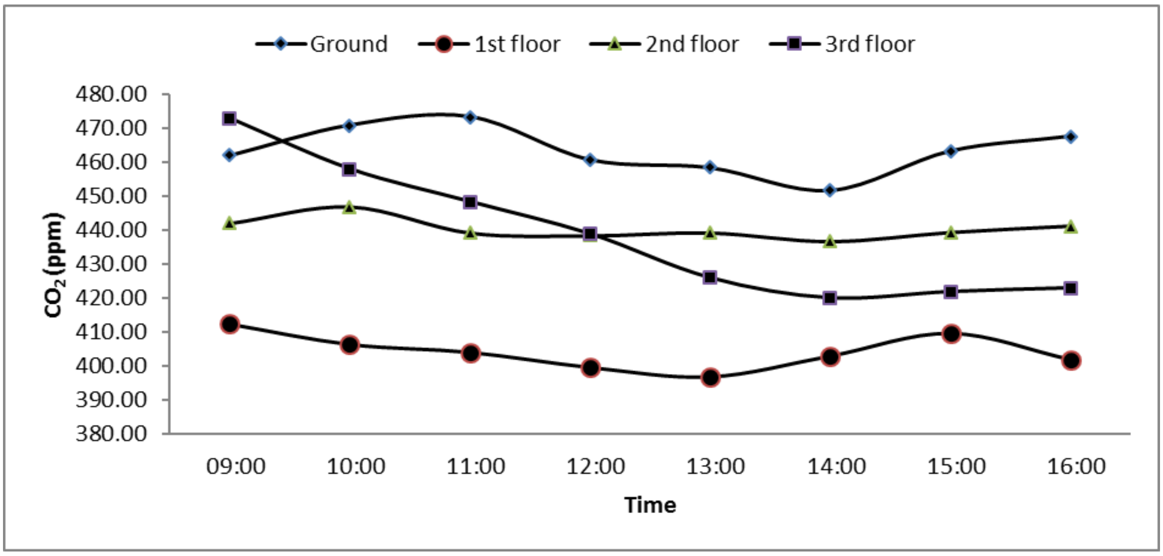


Figure 6 Temporal variation of indoor CO_2

Thermal Comfort Parameters

The mean temperature for all four locations was 23.74ºC, ranging from 18.9 ºC to 28.40 ºC with a standard deviation of 2.21ºC. The total measurements for relative humidity were logged with a range from 49% to 73%. The mean relative humidity for all four locations was 62.2%. Both temperature and relative humidity are within optimum comfort the levels 23 and 26 ° C and 55% and 70% for temperature and humidity, respectively, in the ground level, 1st and 2nd floors and exceeded the guideline occasionally in the 3rd floor. Figure 7 display the temporal variation of indoor temperature in the 4th floors. As shown in the figure the temperature in the 3rd floor (26.5ºC) was significantly higher than the remaining floors ($p < 0.001$). A comparison of the temperature within the individual floors revealed statistical differences in the ground level,

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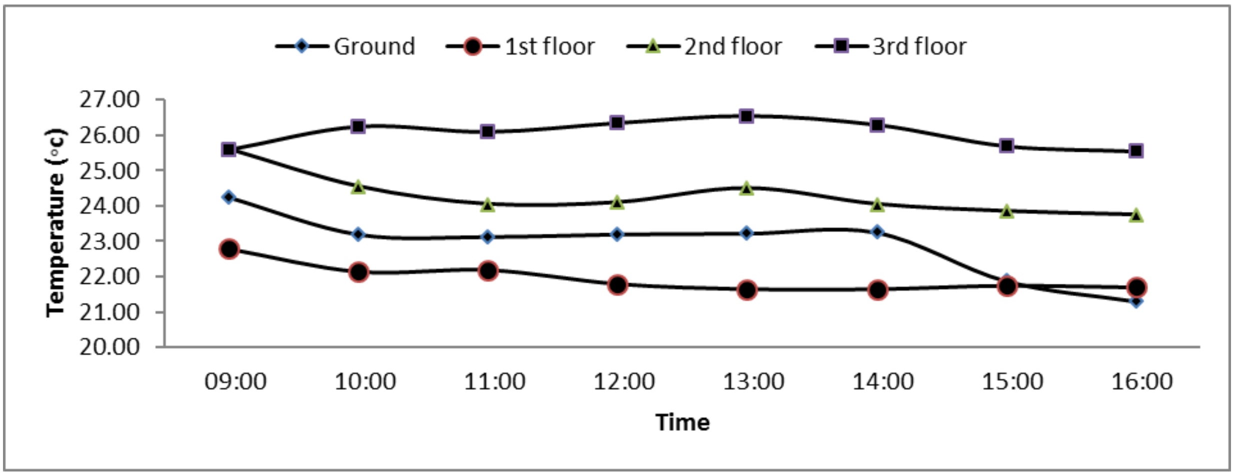
and the 2nd and 3rd floors in the right and left sides. Additionally, in comparing individual locations, RH was statistically different in the left side than all the right side in all floors except in the 3rd floor.



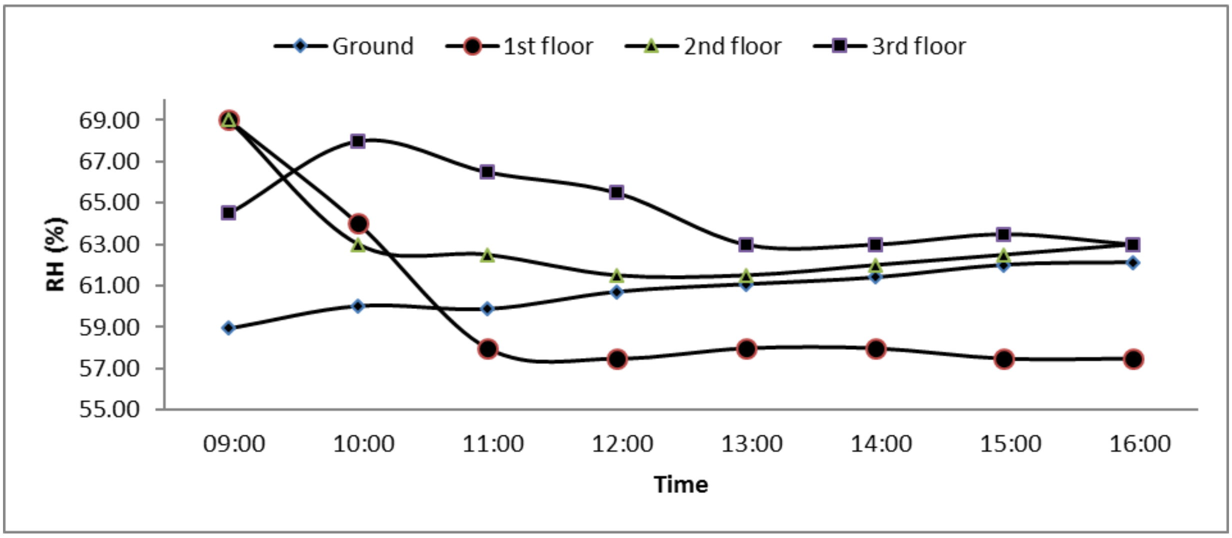


Figure 7 Temporal variation of indoor temperature and relative humidity

4. CONCLUSION

It is generally accepted among environment health and medical professionals alike, that poor ventilation as well as contaminated indoor air can lead to complaints from building occupants. The purpose of this study was to assess and evaluate the variability of $PM_{2.5}$, O_3, CO_2, CO, TVOC, formaldehyde, relative humidity, and temperature in the USM's Engineering library. The result showed that all environmental pollutants were below the Malaysian guideline of indoor air quality. However, parametric data analysis indicated statistical differences of the chemical contaminants and thermal comfort variables between the right side andthe left side of the building, where the left side has significant chemical contaminants and thermal comfort variables, comparing with the right side which may be due to pressure differentials between the two sides of the building that may account for influx of contaminants. Further, by comparing the measured pollutants among the 4th floor, the 3rd floor had higher pollutants concentrations and a higher temperature. Inadequate introduction and/or distributions of fresh air may be the main problem. Investigators may need to discuss the operation of the ventilation system with buildings' engineers and perform ventilation testing to determine proper fresh air intake. Measurements should be made under maximum and minimum airflow conditions to determine the range of fresh air intake.

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