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Indoor Environmental Quality in Micro & Nanoelectronics Laboratories at IMEN, Research Complex, UKM

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ABSTRACT

The National University of Malaysia's Micro and Nanoelectronics laboratories were examined to ascertain their comfort levels. Eight laboratories were chosen as the study locations. This study aims to assess the interior air quality at six locations by measuring CO_2, formaldehyde CHOH, total volatile organic compound TVOC, PM2.5, indoor temperature, and relative humidity. The thermal comfort evaluation for labs 1, 2, 3, 4, 5, and 7 is between 20.45 and 22.47 °C, which is below the range of DOSH and Ashrae. While the average readings in laboratories 6 and 8 are within the limits allowed at 23,21 °C and 23,75 °C, respectively. Five laboratories were exceeding the upper limit of RH (30–60%) but only three laboratories were still within the maximum level mentioned by the Ashrae standard. RH exceeded the ICOP limit (60%) at 70.3%, 63.7%, 75.4%, 60.6%, 62.8% and 65.5%, at Lab 1, 2,3,6,7 and 8, respectively, whereas temperature exceeded it (22.5- 26 °C) at 20.45, 22.2, 21.9, 22.43, 21.58 and 22.47 at Lab 1, 2, 3, 4, 5, 7 and 8, respectively. While the average air velocities for all laboratories are 0.17, 0.13, 0.10, 0.16, 0.12, 0.14, 0.15 and 0.09 ms^{-1}, respectively. All the data that has been measured is found to be below the maximum level as recommended by the ASHRAE Standard 55 (2004) of 0.25 ms^{-1}. The indoor air contaminants (CO, CHOH, TVOC, PM2.5, and PM10) met the standard level of ICOP and DOSH except for CHOH approaches ICOP (0.1ppm) at 0.1 and 0.09, at Point 9 and Point 10 for laboratory 3 compared to other laboratories where the concentration obtained is lower. The highest laboratories average concentration of PM2.5 was 13 $\mu g/m^3$ determined in Lab 3, which was the most actively utilized one because the research activity in this laboratory was working more intensively than the others. As in the study of PM2.5, the highest average PM10 concentration was evaluated in Lab 3 as 36 $\mu g/m^3$. Based on observations and studies, we find that fresh outdoor air with a complete and good purifier/filter should be used to reduce the concentration of indoor pollutants.

Keywords:
Relative humidity; total volatile organic compound; indoor air quality; particle matter; thermal comfort

1. Introduction

Air quality in indoor environments, such as offices, schools, universities, and hospitals attract even greater attention because a combination of high concentration pollution rates over a long

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period in a building can result in higher exposures and adverse health effects. Dionova *et al.,* [1] reported that IAQ has four main elements which are the concentration of CO, CO_2, NO_2 and O_3. Meanwhile, VOCs, particulate matter (PM2.5), temperature and humidity are the four elements of thermal comfort. There are many health hazard places related to many kinds of air pollution such as CO, CO_2, NO_2, O_3, particulate matter, volatile organic compounds (VOCs), temperature and humidity reported over the last two decades. This air pollution has caused dizziness, fatigue, respiratory and cardiovascular diseases. In more serious cases, it even could cause cancer [1,2].

University students spend more than 80% of their lives indoors, such as in the office, student room or laboratory environment [3,4]. Good indoor air quality (IAQ) can provide an impact related to health and comfort to occupants. This IAQ study can be obtained by making characterization against particles, chemistry, and biological elements in atmosphere and on surfaces close to the air in space. along with advanced development, people spend more time of the 80% are indoors, and exposure to low indoor air quality can result in health effects such as chronic-toxic symptoms and carcinogenic effects [5].

Several factors can significantly affect the IAQ of a laboratory building such as the type of heating, ventilation, and air conditioning (HVAC) system, building materials, electronic equipment in the building and the type of air filter used [6,7]. The development of buildings nowadays needs to be balanced to ensure the next generation's needs will be more secure. To achieve a dynamic development of buildings, IAQ needs to be considered. According to the statistics of a study conducted by the International Facility Managers Association, IAQ, and terms comfort is a major operational issue in all types of buildings [8,9]. All IAQ studies in clean environments must follow the limit levels recognized by ASHRAE.

The study conducted is to study and analyze the risk assessment for several laboratories at IMEN UKM. Furthermore, until now no specific IAQ studies have been carried out in the micro and nanoelectronics laboratory at the UKM research complex. Note that, there has not been any study organized on Research Complex in Malaysia. The HVAC system is an existing facility and it plays an important role in the control of the IAQ system and comfort for the building occupants. Therefore, this ideal IAQ can create a good working environment for staff and researchers. The IAQ analysis study considers several things such as building characteristics that include building type, building location, period of construction, type of ventilation systems and building materials, interior source of pollutants, external pollutants resources, water intrusion, maintenance and occupant activity [10,11]. Generally, indoor environmental pollution consists of benzene, toluene, formaldehyde (CHOH), xylene, total volatile organic compounds (TVOC), hydrazine, ammonia, etc. TVOC and BTEX are the main organic pollutant [12,13]. A building can be categorized as Sick Building Syndrome (SBS) when it contains high concentrations of formaldehyde (CHPH) and TVOC [14-17].

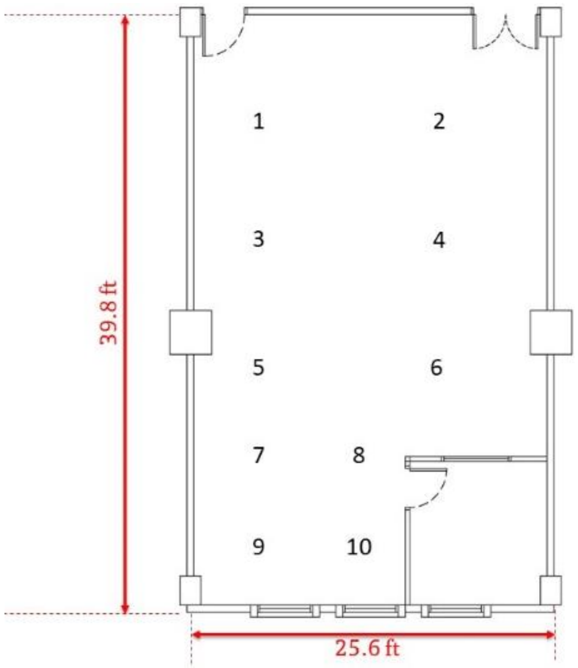
The interpretation of the IAQ air quality index is the air quality inside the building that provides comfort and health to the occupants. This IAQ can be affected by several factors such as chemicals, gases, fungi, microbes or particles and others that can lead to illness. Several causes contribute to poor IAQ concentration levels. There are main factors which are physical factors, chemical factors, and biological factors. In general, physical factors include temperature, humidity, air movement, dust, noise and lighting. While the chemical factors are pollutants from paint, new furniture, carpets, tobacco smoke, cosmetics and insecticides. As for biological factors, it consists of microorganisms such as bacteria, fungi and microalgae spores that can cause allergic reaction problems. Good IAQ is necessary for a healthy indoor work environment. But poor IAQ in a workplace can affect health either from short-term effects or long-term effects to health such as allergic reactions, respiratory problems, allergic reactions, respiratory problems, eye irritation, sinusitis, bronchitis and pneumonia.

Indoor chemicals and varying concentrations in the building or laboratory have increased according to the needs of the current activity. Therefore, continuous monitoring of indoor air quality for facilities or laboratories with chemicals and the development of guidelines for IAQ is essential for materials that have a high health risk to protect the interests of the occupants [18,19]. Therefore, this study aims to define the concentrations of selected IAQ parameters in selected laboratories in Research Complex, UKM and, to evaluate IAQ trends and compare them with existing IAQ guidelines and standards.

2. Methodology

The sampling had been accomplished in the IMEN micro and nanoelectronics laboratory at Research Complex, University Kebangsaan Malaysia (UKM), Bangi Selangor, which is located at latitude 2° 55' 12.594'' N and longitude 101° 46' 9.3144'' E. Eight laboratories in IMEN were selected. These were MEMS & NEMS, Lab on Chip (LOC), organic printed emitting light (OPEL), Semiconductor & Nanoelectronics and Biomimetic & Nanostructure laboratories which were denoted as Lab 1, Lab 2, Lab 3, Lab 4 and Lab 5 at level 4, IMEN Research Complex. In addition, artificial kidney, c-electronics, and microfluidic laboratories which labelled as Lab 6, Lab 7 and Lab 8 at level 3, IMEN, Research Complex. Measurements were carried out for 10 minutes for each sampling.

The lab work schedule is typically from 8.00 a.m. to 6.00 p.m., but the research working time is flexible. The layout of the sampling point for Lab 1, 2 and 3 is shown in Figure 1. Moreover, the sampling point for Labs 4, 5, 6, 7 and 8 are shown in Figure 2. This study was performed to identify the potential factors influencing the IAQ for each laboratory. All IAQ data from indoor air consists of temperature, RH, CO_2 HCOH, TVOC and PM2.5.



No.	Laboratory Name	MEASUREMENT		
		ft	ft^2	m^2
Lab 1	MEMS & NEMS	39.8 X 25.6	1018	95
Lab 2	Lab on Chip (LOC)	39.8 X 25.6	1018	95
Lab 3	Organic Printed Emitting Light (OPEL)	39.8 X 25.6	1018	95

Point 1-10:
The layout of the sampling points.

Fig. 1. The Layout of the Sampling Points for Lab 1, 2 and Lab 3

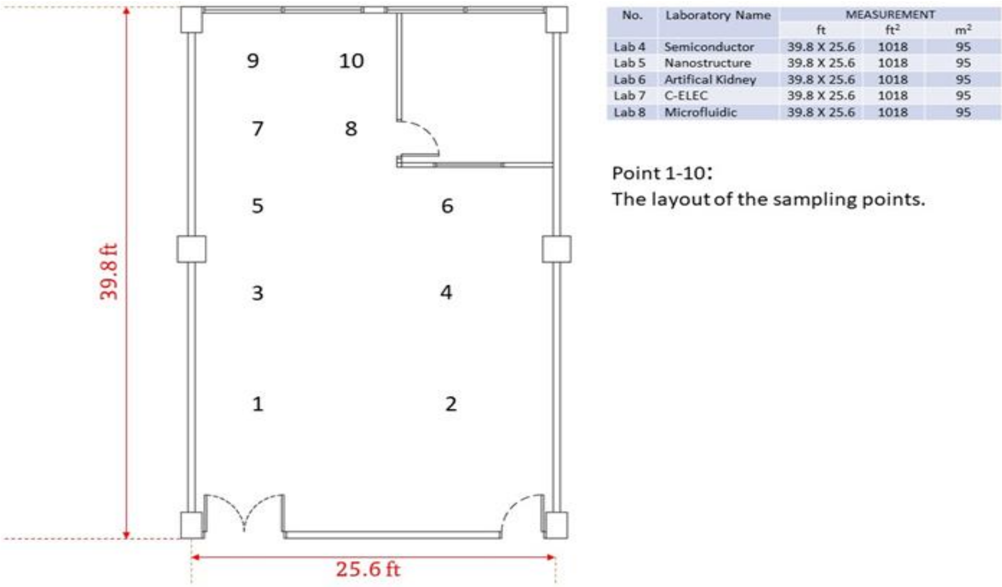


Fig. 2. The Layout of the Sampling Points for Lab 4, 5, 6, 7 and Lab 8

Meanwhile, the list of equipment currently used, and the accuracy of the measurement is shown in Table 1. All data obtained will refer to the Ashrae standard for further evaluation. The measurement of Indoor Air Quality using Air Quality Monitor Bramc BR- Smart -128SE was prepared to measure the levels of carbon monoxide (CO_2), the total volatile organic compound (TVOC), particulate matter (PM2.5) and formaldehyde (CHOH). Meanwhile, air temperature (T) and relative humidity (RH) were monitored using Fluke 971.

Table 1
List of Instruments for IAQ measurement

Type of Instruments	Measurement Parameters	Accuracy
Temperature Humidity Meter (Model Fluke 971)	Temperature Relative Humidity	*Operating range* Temperature: -20 - 60°C RH: 5 - 95% *Accuracy* Temperature: ±0.5°C RH: ±2.5% *Resolution* Temperature: 0.1°C RH: 0.1%
Air Quality Monitor (Bramc BR- Smart - 128SE)	PM2.5/ PM10 Formaldehyde (HCHO) CO_2 TVOC	*Operating range* PM2.5/PM10: 0 - 999µg /m³ HCHO: 0 - 3.000mg /m³ CO_2: 400 - 5000ppm TVOC: 0 - 9.999mg /m³ *Accuracy* PM2.5/PM10: ± 10% HCHO: ± 10% CO_2: ± 45ppm+3% TVOC: ± 10% *Resolution* PM2.5/PM10: 1µg /m³ HCHO: CO_2: 1ppm TVOC: 0.001mg/m³

Besides that, the Handled Particle Counter (Kanomax 3889) Model was used for the particulate counter. All equipment was mounted using a tripod and readings are recorded on the SD card. Measurement parameters are obtained after 10 minutes to 20 minutes for stabilization purposes. Then, the location of the laboratory was set according to the current time and date for the monitoring. The measurement data is set with a real-time average of one minute (100% logging data). Meanwhile, sampling points are taken with positions more than 1 meter from walls, corners, fume hood and windows. In addition, analyses are made more than 2 meters from central air conditioning systems, floor fans, exhaust fan systems and main doors.

Each laboratory has several different research equipment such as a vacuum pump system, fume hood, furnace, wet bench, and exhaust fan system. Table 2 shows a list of laboratories that have several equipment facilities and research equipment. Each laboratory has one entrance door, one emergency door and one window in Lab 2, 4, 5, 7 and 8. Two windows in Lab 3 were kept closed during the sampling operation. Equipment presents in the laboratories differed by number and type because different types of research were performed. Both doors remain closed except for students coming in and out. Each laboratory is furnished with one ducted fume hood except for Lab 8. Hoods were run only, if necessary, by the experiment performed. The type and number of other equipment were different due to differences in areas of research such as deposition pump, etching system and characterization equipment shown in Table 2. Lab 3 had the highest number of researchers(six), while Lab 8 was the smallest frequently used laboratory by two researchers.

Table 2
Facilities and Research Equipment

No.	Lab Name	Facilities and research equipment
Lab 1	MEMS & NEMS	Fume hood, centralized & split air conditioning system, vacuum pump and window.
Lab 2	Lab On Chip (LOC)	Fume hood, wet bench, vacuum pump, exhaust fan system, air conditioning centralized unit
Lab 3	Organic Printed Emitting Light (OPEL)	Fume hood, wet bench, vacuum pump, exhaust fan system, centralized & cassette type air conditioning system
Lab 4	Semiconductor & Nanoelectronics	Centralized & split unit air conditioning system
Lab 5	Biomimetic & Nanostructure	Fume hood, vacuum pump, exhaust fan system, furnace, centralized air conditioning system
Lab 6	Artificial Kidney	Fume hood, centralized air conditioning system
Lab 7	C-Electronics	Fume hood, vacuum pump, exhaust fan system, furnace, centralized air conditioning system
Lab 8	Microfluidics	Centralized air conditioning system

The laboratories have an area of 95 m^2 and a volume of 274.55 m^3. The selection of the reading point is based on the total area of the laboratory floor according to the daily activities of the research and during the peak hours of the highest number of laboratory users.

This evaluation reading is measured by measuring for 10 minutes where each point is for one minute for 10 different points.

3. Results and Discussion

3.1 Indoor Environmental Comfort

In general, there are three main elements in conducting studies on indoor air quality, especially for laboratories that have air-conditioning systems such as air movement, humidity and temperature. (ANSI/ASHRAE Standard 55, 2004). Table 3 shows the reading parameters of temperature and relative humidity for all 8 laboratories. From Table 3, lab 1,2,3,4,5 and 7 show the average temperature reading below the range of DOSH and Ashare with an average reading from 20.45 to 22.47 °C. While lab 6 and 8 show an average reading in the acceptable range of 23.21 °C and 23.75 °C, respectively.

Table 3
Result of temperature, humidity and air velocity in Laboratory 1 to 8

Laboratory	Temperature (°C)	Air Velocity (ms^{-1})	RH (%)
Laboratory 1	20.45	0.17	70.3
Laboratory 2	22.20	0.13	63.7
Laboratory 3	21.9	0.10	75.4
Laboratory 4	22.43	0.16	56.4
Laboratory 5	21.58	0.12	55.6
Laboratory 6	23.21	0.14	60.6
Laboratory 7	22.47	0.15	62.8
Laboratory 8	23.75	0.09	65.5
ASHRAE Standard	22.5- 26	<0.25	30-60
ICOP Limit	23-26	0.15-0.5	40-70

For this IAQ study, the average RH was calculated as 70.3 % in Lab 1, 63.7 in Lab 2, 75.4 % in Lab 3, 60.6% in Lab 6, 62.8% in Lab7 and 65.5% in Lab 8. The data shows that the humidity at six laboratories has exceeded the maximum limit suggested by ASHARE Standard 55(2004). This is due to the tropical climate in Malaysia. As the study reported by Zuraimi and Tham *et al.,* [20] shows that the outdoor temperature is 30 °C while humid (90%) for the average tropical climate. However, overall, the humidity for all laboratories is within an acceptable range.

In this study, the air velocity has been measured in eight research laboratories that have several staff and students. Table 3 shows the level of air velocity in Lab 1 can vary from 0.15 ms-1 to a maximum of 0.18 ms^{-1}, at Lab 2 can vary from 0.12 ms^{-1} to a maximum of 0.15ms^{-1}, in Lab 3 can vary from 0.09 ms^{-1} to maximum of 0.18ms^{-1}, at Lab 4 can vary from 0.15 ms^{-1} to maximum of 0.18 ms^{-1}, at Lab 5 can vary from 0.08 ms^{-1} to maximum of 0.11 ms^{-1}, at Lab 6 can vary from 0.12 ms^{-1} to maximum of 0.16 ms^{-1}, at Lab 7 can vary from 0.15 ms^{-1} to maximum of 0.18ms^{-1} and 0.07 to 0.14 $ms\text{-}^{1}$ at Lab 8. The average air velocities for all laboratories is 0.17, 0.13, 0.10, 0.16, 0.12, 0.14, 0.15 and 0.09 ms-1, respectively. all the data that has been measured is found to be below the maximum level as recommended by the ASHRAE Standard 55 (2004) of 0.25 ms^{-1}. The results show that all laboratory areas can be considered as having system inadequate ventilation and still low below the standards suggested by ASHRAE. The relative humidity levels at the Organic & Printed Electronics (Lab 3) are very high exceeding ICOP 2010 upper limit of 70% most of the times with average value of 80.3 during logging time. The relative humidity level reach it peaks at 96% at one point during night-time. The MVAC system is not able to maintain relative humidity level below 70% during normal operation hours. Combination of low wall surface temperature level and high relative humidity level during night-time cause condensation whenever building surfaces reach the dew point temperature.

This provides conducive environment for mold and microbial growth especially on wet wall surface due to condensation. Combination of low wall surface temperature level and high relative humidity level during nighttime cause condensation whenever wall surfaces reach the dew point temperature. This explained the formation of mold growth on wall column surfaces due to its higher thermal conductivity property.

The position of the laboratory which has a lot of equipment and laboratory tables is one of the factors of the limited air circulation system. Al-Awadi *et al.,* [21] found that air circulation is crucial for a building to ensure that air pollution can be reduced. In addition, the studies by Chow *et al.,* [22] found that the internal wind circulation of buildings is very important and consistent air movement can improve thermal comfort.

For the other laboratories during normal operation hours (morning, noon and afternoon), the MVAC system can control the relative humidity level well below 65% most of the times. This can be considered as a good range to prevent mould growth within the indoor environment.

3.2 Indoor Air Quality

Table 4 shows the descriptive Indoor air quality statistics follow ICOP limit standards. Indoor air quality is separated into biological contaminants contain of (TBC and TFC), chemical contaminants (CO, CHOH, O_3, PM10, and TVOC), while and ventilation performance indicator (CO_2). In this study, the indoor air quality assessment only focuses on (CH2O, PM2.5, PM10, and TVOC) and ventilation performance indicator (CO_2). The results show that all indoor air quality concentrations (CO_2, CHOH, PM2.5, PM10, and TVOC) for all laboratories were within acceptable range limits as recommended by ICOP.

Table 4
Descriptive statistics of indoor air quality with acceptable limit from DOSH

Indoor Air Contaminant	Descriptive Statistical	Laboratory								Limit
		Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	
TVOC	N	10	10	10	10	10	10	10	10	3 ppm
	Mean	0.032	0.027	0.097	0.031	0.052	0.036	0.046	0.044	
	Std. Dev	0.003	0.004	0.069	0.002	0.003	0.004	0.002	0.001	
	Min	0.029	0.026	0.050	0.028	0.046	0.027	0.043	0.042	
	Max.	0.036	0.038	0.256	0.035	0.057	0.041	0.049	0.046	
CO_2	N	10	10	10	10	10	10	10	10	1000 ppm
	Mean	563.2	588.5	595.8	605	622	603.8	651	651.5	
	Std. Dev	23.09	1.72	5.63	13.45	6	5.33	3.46	5.28	
	Min	523	586	588	590	607	596	646	645	
	Max.	581	591	604	625	629	611	658	658	
CH_2O	N	10	10	10	10	10	10	10	10	0.1 ppm
	Mean	0.006	0.003	0.041	0.004	0.039	0.004	0.006	0.012	
	Std. Dev	0.002	0.001	0.029	0.006	0.003	0.001	0.003	0.001	
	Min	0.002	0.002	0.005	0.001	0.003	0.003	0.002	0.011	
	Max.	0.01	0.005	0.1	0.018	0.041	0.006	0.014	0.013	
$PM_{2.5}$	N	10	10	10	10	10	10	10	10	25µg/m^3
	Mean	6	7	11	7	5	11	5	11	
	Std. Dev	2	1	2	1	1	1	1	1	
	Min	2	5	7	5	2	9	3	9	
	Max.	9	8	13	8	6	12	8	12	
PM_{10}	N	10	10	10	10	10	10	10	10	150 µg/m^3
	Mean	4	9	15	13	10	5	9	16	
	Std. Dev	3	3	5	12	6	3	6	8	
	Min	2	5	10	3	4	2	2	7	
	Max.	8	12	36	24	17	10	19	27	

3.2.1 Carbon dioxide

In indoor environment, carbon dioxide gas is mainly generated from human respiration. Indoor carbon dioxide levels indicate the adequacy of fresh air introduction in the building and the effectiveness of the building ventilation system. Table 4 shows the levels of carbon dioxide recorded at the sampling areas. The acceptable level of CO_2 for ASHRAE and ICOP Dosh standards is below 1000ppm for continuous exposure for 8 hours. In this study, all the research laboratories presented CO_2 concentration in the range of 523 to 658 ppm as shown in Table 4. In general, this concentration rate of CO_2 is still in safe condition for all laboratory residents, which shows that automated ventilation was well functioning. The level of CO_2 in this laboratory results from human breathing activity.

The concentration rate of CO_2 will be higher at the position of 1.6 m from the ground level compared to other levels. Table 3 shown the CO_2 data presented here as a mean over the data measured. Fan *et al.,* [23] found that the high CO_2 concentrations level in the laboratory or office space indicated poor air quality, lack of ventilation and the indoor air is not refreshed adequate within the laboratory and office building. An office and laboratory in a building space should have adequate air exchange in addition to cooling. Evaluation of the CO_2 concentration record shows that laboratory 8 has the highest concentration, while the air circulation record in the laboratory is also among the lowest compared to other laboratories. This phenomenon can lead to the growth of bacteria [24].

3.2.2 Total volatile organic compound (TVOC)

Based on the data obtained from the TVOC measurement in each laboratory, all laboratories show that the TVOC reading is below 0.05 ppm. Data reading from Table 4 shows the lowest value of TVOC is 0.026 ppm in lab 2. As observed, the average TVOC reading is between 0.027 to 0.097 ppm. Laboratory 3 showed the highest TVOC concentration reading with a reading of 0.256 ppm. In this study, the results shown do not show the actual concentration readings in the laboratory. For example, in laboratory 3, the average concentration of TVOC only reached a reading of 0.256 ppm because the reading range is between 0.050 to 0.115 ppm for reading points 1 to 8. For points 9 and 10 there is a significant increase in the concentration of TVOC because this laboratory handles a lot of chemicals that exist in a lot of chemical compounds that are very volatile under normal conditions. The concentration of TVOC in the Opel laboratory (Lab 3) showed a higher value than the other laboratories but is still safe and below the standard as recommended by Schulz *et al.,* [25]. This situation may be due to laboratory 3 having a density of laboratory equipment, many chemicals and the frequency of handling chemicals and gases in two fume hoods to conduct experiments. While for TVOC concentration studies in other laboratories, it was found that there were 11 VOC compounds in the gas content in the laboratory building as reported by Park *et al.,* [26] within the range of 85 to 393 μm^3 (37ppb- 171ppb).

In general, the results for the TVOC concentration level in each laboratory are still below the safe limit, thus there is no cause for concern regarding this TVOC concentration. Compared to other laboratories that utilise fewer chemicals, laboratories that handle chemicals have higher TVOC concentration levels. All laboratories demonstrate no concern about TVOC concentration, even though the DOSH (2005) recommended TVOC concentration level is 3ppm. There were no resources available during the research phase, such as carpets or new furniture. During the inspection process, no construction or painting is done. The construction of this research complex was officially finished in 2012, and the lab activities began to run at the end of the same year. The low TVOC concentration levels in each laboratory relative to the exposure limit may be attributed to all the aforementioned factors.

3.2.3 Formaldehyde

The measurement of formaldehyde concentration in each laboratory presented below 0.1ppm and fluctuates from 0.002 to 0.012 ppm, 0.002 to 0.005 ppm, 0.033 to 0.041 ppm, 0.001 to 0.018 ppm, 0.007 to 0.100 ppm, 0.002 to 0.014 ppm, 0.003 to 0.006 ppm, 0.011 to 0.013 ppm for laboratories 1 to 8, respectively. Meanwhile, all laboratories have an average reading of HCOH in the range of 0.006 ppm, 0.003 ppm, 0.041 ppm, 0.004 ppm, 0.039 ppm, 0.004 ppm, 0.006 ppm and 0.012 ppm, respectively, as shown in Table 3. In summary for HCOH, no reading exceeds 0.1 ppm as suggested by DOSH Standard level. However, laboratory 3 shows a maximum reading of 0.1 ppm at point 10, but still in the acceptable range as recommended by Dosh. This situation is caused by the condition of the laboratory which has a higher number of chemicals uses compared to other laboratories. In addition, chemical waste is also stored near points 8, 9 and 10.

Formaldehyde is an organic compound found in the air with the formula HCOH, especially widely used in the manufacturing sector. According to standard regulations, occupational exposure to HCOH that exceeds the level of 0.1 ppm can cause several respiratory symptoms such as difficulty breathing, sore throat, headache and asthma. HCOH is classified as a human carcinogen by the United States Environmental Protection Agency. Therefore, for healthy and safe occupational safety, ensuring that all occupants maintain HCOH exposure below 0.1 ppm and keep stay in an air-conditioned space is important thing. In general, this formaldehyde is also contained in food either naturally or because of air pollution [27].

3.2.4 Particle Matter 2.5

The highest laboratories average concentration of PM2.5 was 13 µg/m^3 determined in Lab 3, which was the most actively utilized one because the research activity in this laboratory was working more intensively than the others. The lowest concentration was found in Lab 1 which was the least actively used, so the PM2.5 concentration was categorized from high to low in proportion to the level of movement in the laboratory. Therefore, it can be surmised that the main cause of PM2.5 was the resuspension of remained dust on the floor by the movement of students or researchers who working in the laboratory and their research activity with the chemicals. The limits by Dosh values listed in Table 4 have averaged 1 hour for this study. In this study for PM2.5 concentration, all laboratories do not exceed any limit values as recommended by Dosh standard.

3.2.5 Particle Matter 10

As in the study of PM2.5, the highest average PM10 concentration was evaluated in Lab 3 as 36 µg/m^3. However, the lowest concentration was evaluated in Lab 2, 6 and Lab 7 as 2 µg/m^3, so the monitoring and sampling results accept in finding the highest concentration laboratory, about both PM2.5 and PM10. It can be considered that some other sources, such as cleaning of dusty surfaces or outdoor air due to windows being opened, may have changed the PM10 concentration in Lab 1 and Lab 3. All determined PM10 concentrations were above the detailed limits in Table 4.

Generally, the assessment of eight laboratories for air temperature and air velocity is below the maximum acceptable value of 22.5 to 26 °C according to ASHRAE standard and the air velocities in these laboratories are within the limit of 0.25 ms^{-1} as recommended by ASHRAE. However, for the RH parameter, laboratory 1 (70.3%), laboratory 2 (63.7%), laboratory 3 (75.4%), laboratory 6 (60.6%), laboratory 7 (62.8%) and laboratory 8 (65.5%) are not within the recommended limit for acceptable indoor room humidity of below than 60% as in the ASHRAE standard. While for the evaluation of the

IAQ, TVOC for laboratory 3 (0.097 ppm) shows the highest reading compared to other laboratories. Nevertheless, the assessment of TVOC for this laboratory is still within the acceptable range and below the ASHRAE standard. Meanwhile, the assessment of CO_2, HCOH and concentration for eight laboratories is within the recommended by the ASHRAE standard. However, HCOH concentration in lab 3 (0.041ppm) shows the highest average compared to other labs but is still within the acceptable range. Therefore, laboratory 3 needs more attention for the next action plan to reduce HCOH concentration to balance the measurement range with the other labs.

The high concentration in this laboratory may be caused mostly by the building materials as well as the many kinds of chemicals that are kept here, in addition to the chemical waste that is also kept here. As a result of this, it is recommended to separate the chemical waste to improve the ventilation system in the laboratory and obtain greater air movement. This lends credence to the hypothesis that the cause of the greater concentrations is most likely connected to the level of activity that takes place within the laboratory. In addition, the overall particle pollutant concentration in laboratory 3 is much greater when compared to the concentrations found in the other laboratories. The purpose of this assessment is to study thermal comfort and IAQ evaluation in 8 laboratories that have their management of chemical substances shown in Table 5. As the concentration of HCOH, TVOC and RH in OPEL laboratories (laboratories 3) are found to be higher concentration compared to other laboratories, it is recommended to increase the ventilation frequency for better reduction purposes to keep it below the acceptable boundary.

Table 5
Summary of indoor environmental comfort and the evaluation of the IAQ for Research Complex Laboratory

	Parameter	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	ASHRAE Standard 55	Malaysia DOSH Standard
Evaluation of the thermal comfort	Air temperature, °C	20.45	22.20	21.9	22.43	21.58	23.21	22.47	23.75	22.5–26.0	
	RH, %	70.3	63.7	75.4	56.4	55.6	60.6	62.8	65.5	<60	
	Air velocity, ms^{-1}	0.17	0.13	0.10	0.16	0.12	0.14	0.15		<0.25	
Evaluation of the IAQ	TVOC, ppm	0.032	0.027	0.097	0.031	0.052	0.036	0.046	0.044	<3	
	CO^2, ppm	563.2	588.5	595.8	605	622	603.8	651	651.5	<1000	<1000
	HCOH, ppm	0.006	0.003	0.041	0.004	0.039	0.004	0.006	0.012	<0.1	<0.1
	PM2.5, $\mu g/m^3$	6	7	11	7	5	11	5	11	<25	
	PM10, $\mu g/m^3$	4	9	15	13	10	5	9	16	<150	

4. Conclusion and Recommendation

This study measured the concentrations of various IAQ parameters specifically in the laboratories at UKM's Research Complex to determine IAQ trends and compare them with existing IAQ standards and guidelines. Various indoor air quality with varying concentration were detected in the laboratories of eight laboratories in the University Research Complex. Laboratory students and staff are exposed to these pollutants during their working life and research activities. Higher PM10 and PM2.5 concentration were observed in more intensively used laboratories. However, seven laboratories were lower than the respective limits. Thermal comfort evaluation for labs 1,2,3,4,5 and 7 show the average temperature reading below the range of DOSH and ASHRAE with an average reading from 20.45 to 22.47 °C. While lab 6 and 8 show an average reading in the acceptable range of 23.21 °C and 23.75 °C, respectively. Five laboratories were exceeding the upper limit of RH (30–60%) but only three laboratories were still within the maximum level mentioned by the ASHRAE standard. RH exceeded the ICOP limit (60%) at 70.3%, 63.7%, 75.4%, 60.6%, 62.8% and 65.5%, at Lab

1, 2,3,6,7 and 8, respectively, whereas temperature exceeded it (22.5- 26 °C) at 20.45, 22.2, 21.9, 22.43, 21.58 and 22.47 °C in Lab 1, 2,3,4,5,7 and 8, respectively. While the average air velocities for all laboratories is 0.17, 0.13, 0.10, 0.16, 0.12, 0.14, 0.15 and 0.09 ms^{-1}, respectively. All the data that has been measured is found to be below the maximum level as recommended by the ASHRAE Standard 55 (2004) of 0.25 ms^{-1}.

The contaminants in the indoor air (CO, CHOH, TVOC, PM2.5, and PM10) all met the acceptable level of ICOP and DOSH, except for CHOH, which approached the standard limit of ICOP (0.1ppm) at 0.1 and 0.09, respectively, at Point 9 and Point 10 for laboratory 3. This contrasts with the other laboratories, where the concentration accomplished was lower. The laboratory with the highest average concentration of PM2.5 was Lab 3, which was also the most actively employed one since the research activities in this laboratory was operating more intensively than the others. The lab's PM2.5 concentration was confirmed to be 13 g/m^3. In the same method as the investigation of PM2.5, the maximum average PM10 concentration was determined to be 36 g/m3 in Lab 3. However, the lowest quantity that was measured was 2 $\mu g/m^3$ in Laboratories 2, 6, and 7, and since this value was determined to be the case, the monitoring and sampling results accept this laboratory as having the maximum concentration of both PM2.5 and PM10. It could occur that the PM10 concentration in Lab 1 and Lab 3 may have changed by some other causes, such as cleaning the dusty surfaces or let in air from the outside because the windows were opened.

Based on our observations and investigations, we believe that fresh outdoor air combined with a comprehensive and effective purifier/filter should be utilised to lower the concentration of indoor contaminants.

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