ASSESSMENT OF INDOOR PARTICULATE MATTER ($PM_{2.5}$) IN NEWLY RENOVATED ROOMS AT SCHOOL OF CIVIL ENGINEERING BUILDING , USM

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2022

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering
Universiti Sains Malaysia

August 2022

Appendix A8

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2021/2022

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Assessment of Indoor Particulate Matter ($PM_{2.5}$) in Newly Renovated Rooms at School of Civil Engineering Building, USM

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ACKNOWLEDGEMENT

In the steadfast and merciful name of Allah. All compliments to Allah for providing the ability and blessing to finish my thesis. In every circumstance I encountered while finishing my course,. He always gave me hope and courage. I want to express my gratitude to everyone who helped make my thesis achievable and encouraged me.

I want to express my sincere gratitude to Prof. Madya Dr. Noor Faizah Fitri Bt Md Yusof for her supervision, counsel, and unwavering support. She made significant contributions to the accomplishment of this study by making helpful suggestions and remarks.

In completing my thesis, my family and friends have been a huge support, encouraging me despite my own small venture into writings. My sincere gratitude to my friend Auji Aseela Bt Anuar for helping me with the monitoring and sharing ideas for my research.

Finally, I want to extend my sincere gratitude to everyone of my friends who have supported me in some way while I was writing my thesis. Without their committed participation and assistance, this thesis could not have been completed.

ABSTRAK

Kualiti udara dalaman dianggap sebagai salah satu kebimbangan terhadap kesihatan manusia terutamanya semasa pandemik Covid-19 kerana orang ramai lebih kerap berada di dalam bangunan berbanding di luar. Empat bilik yang baru diubah suai di bangunan Pusat Pengajian Kejuruteraan Awam, USM, Pulau Pinang telah dipilih sebagai kawasan kajian dalam penyelidikan ini. Ia dijangka tercemar dengan pencemaran dan bahan zarahan akibat kerja-kerja pengubahsuaian dan sumber pencemar daripada penghuni. Oleh itu, pemantauan diperlukan untuk mengenal pasti kepekatan bahan zarahan di dalam bilik dan membandingkan tahap dengan garis panduan kualiti udara daripada WHO. Pemantauan dijalankan bermula 22 Mac 2022 sehingga 19 Mei 2022 melibatkan dua sesi pemantauan bagi setiap bilik iaitu pada cuti semester dan semester berterusan. Kepekatan data $PM_{2.5}$, suhu dan kelembapan relatif diperoleh menggunakan peralatan monitor bacaan terus optik (ODRM) model E-Sampler 9800 dan dianalisis menggunakan perisian SPSS dan Microsoft Excel. Didapati purata kepekatan $PM_{2.5}$bagi setiap sesi pemantauan adalah antara 3.038 $\mu g/m^3$ hingga 22.731 $\mu g/m^3$. Hasil kajian menunjukkan terdapat peningkatan kepekatan $PM_{2.5}$ apabila bilangan penghunian meningkat. Kepekatan $PM_{2.5}$ di semua bilik adalah dalam garis panduan WHO iaitu 15$\mu g/m^3$ kecuali Tetupai Lounge semasa cuti semester. Memandangkan bilik tersebut masih dalam proses pengubahsuaian semasa pemantauan, maka kualiti udara di dalam bilik tersebut masih dalam keadaan baik. Berdasarkan analisis menggunakan Korelasi Pearson, suhu dan kelembapan relatif adalah berkorelasi terhadap kepekatan $PM_{2.5}$. Kesimpulannya, penghunian dan jenis aktiviti mempengaruhi kepekatan $PM_{2.5}$. Di samping itu, kualiti udara dalaman di dalam bilik yang baru diubah suai dianggap dalam keadaan baik dan selamat untuk kesihatan manusia.

ABSTRACT

Indoor air quality is considered as one of the main concern for the human's health especially during Covid-19 pandemic since people stay indoor more often compare to outdoor. Four newly renovated rooms in School of Civil Engineering buildings, USM, Penang were selected as a study area in this research. It is expected to be contaminated with pollutions and particulate matter due to the renovation works and contaminant sources from occupants. Hence, a monitoring is required to identify the $PM_{2.5}$ concentration in the rooms and compare the level with air quality guideline from WHO. The monitoring was carried out involving two monitoring sessions for each room which was during semester break and ongoing semester. Concentration of $PM_{2.5}$, temperature and relative humidity data were obtained using optical direct-reading monitor (ODRM) equipment of E-Sampler 9800 model and analyzed using SPSS software and Microsoft Excel. It was found that the average $PM_{2.5}$ concentration for each monitoring session conducted at all selected rooms were between 3.038 $\mu g/m^3$ to 22.731 $\mu g/m^3$. The result showed that there were increase of $PM_{2.5}$ concentration when the number of occupancy increase. $PM_{2.5}$ concentration in all rooms were within the guideline from WHO which is 15$\mu g/m^3$ except for Tetupai Lounge during semester break. Considering that the room was still under renovation during the monitoring, so the air quality in the room is still in good condition. Based on the result analysed using Pearson Correlation, the contribution of the meteorological sources such as temperature and relative humidity have a correlation with $PM_{2.5}$ concentration. In conclusion, the occupancy and type of activities effects $PM_{2.5}$ concentration. In addition, the indoor air quality in the newly renovated rooms were considered in good condition and safe to human's health.

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LIST OF ABBREVIATIONS

API	Air Pollution Index
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Ca	Calcium
CO	Carbon Monoxide
DOE	Department of Environment
DOSH	Department of Safety and Health
Fe	Ferum
IAQ	Indoor Air Quality
NO_2	Nitrogen Dioxide
O	Oxygen
O_3	Ozone
ODRM	Optical Direct-Reading Monitor
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter 2.5
PM_{10}	Particulate Matter 10
SO_2	Sulphur Dioxide
SPSS	Statistical Packages for Social Science
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Environmental issue have become a significant aspect that needed to be considered especially during Covid-19 pandemic because human are more likely to stay indoor due to restrictions of travelling, outdoor activities and works. Since there is frequently a higher concentration of viral particles indoors than outside, where there is generally little to no air flow, humans are more prone to contract the disease indoors than outdoors (Morawska et al., 2020).

Indoor air is the air inside a building that has occupied such as workplaces, schools, hostels, retail malls, hospitals, and private dwellings. Most of the indoor buildings especially that was equipped with air conditioner use Heating Ventilation and Air-Conditioning (HVAC) system. This system use to offer thermal comfort while maintaining acceptable indoor air quality through appropriate ventilation with filtration (USEPA, 2021a).

In university faculty buildings, students and staff estimately spend their time at least 8 hours daily based on the working hours timing. Rooms in university buildings are usually equipped with mechanical ventilation which can affect the result of transporting outdoor air particles to the indoor space. In mechanical ventilation, the filters unable to entirely remove all of the particles from outdoors. Therefore, the air from outside which typically contain outdoor-originated particles enter the indoor area. Indoor air quality has become main concern especially during Covid-19 pandemic since the poor indoor air quality can result to potential spread of the viruses and other health issues. Other than that, sick building syndromme (SBS) is the most common health issue occur due to the poor indoor air quality and have a strong connection with the amount of time spent in the building. This symptom usually occur when occupants spend much time in poor air condition indoor buildings.

1.2 Particulate Matter

According to (Eljarrat et al., 2020), particulate matter, often known as PM, is the aggregate of all solid and liquid particles that are suspended in air. A significant number of these particles are harmful. Particulate matter has asymmetrical shapes, and the behaviour of its aerodynamics is measured in terms of the diameter of an idealized sphere. Acids such as nitrates and sulphates, organic compounds, metals, and soil or dust particles are some of the constituents of particle pollution (USEPA, 2021d). Primary particulate matter and secondary particle matter, which are produced in the gaseous precursors such as sulphur dioxide, ammonia, nitrogen oxide, and non-methane volatile organic compounds, can both be directly released into the atmosphere (WHO, 2021a).

Aside from describing the particles based on their diameter or size, the size of the particles also indicates how long they can stay in the atmosphere. $PM_{2.5}$ can stay in the atmosphere for days to a few weeks (de Jesus et al., 2019). Due to the growing population, there is a strong possibility for an increase in traffic, construction, and industrial activities, all of which have an impact on the creation of ambient air pollution, including particulate matter (Abdul Salim, 2019).

The direct absorption of harmful air particles through the skin as well as the intake of contaminated food and water that has been exposed to excessively dangerous air particles are additional potential causes of adverse health effects in (Mohd Zahid et al., 2018).

1.3 Problem Statement

Maintaining the good indoor quality is the main concern for students in university especially in preventing the spread of Covid-19 virus. The biggest environmental health concern in the world may be air pollution and hence it is important to monitor particulate matters in the indoor environment (Liu et al., 2020).

Since the rooms in School of Civil Engineering, USM are newly renovated, it is believed that possible pollutants such as dust, mists, fumes, vapours, and gases can be sense in the rooms. A study in renovated office buildings in Manchester found that there were negative impact of high pollutants in renovated buildings towards the occupant's health and comfortability (Alomirah & Moda, 2020). Despite of the pollutants may result in many health problems such as respiratory problems, (Hayes et al., 2020) mentioned that $PM_{2.5}$ can cause cardiovascular disease. The pollutants may result in sick building syndrome (SBS) towards the students which will effect their productivity and health. The variety of human activities become the main contributor to the indoor air quality level such as renovation or construction activities increase the possibility and potential for poor indoor air quality in the buildings (Rosman et al., 2019).

Measuring $PM_{2.5}$ levels in newly renovated rooms can assist in determining the potential exposure of students to indoor air pollutants based on their daily and typical activities. Understanding the particulate matter levels may allow identification of controls to decrease particulate matter levels and reduce potential health effects of occupants exposed to indoor air pollutants.

1.4 Objectives

This study focuses on the assessment of Indoor Air Quality with a measurement of $PM_{2.5}$ concentration and other physical parameters. There are several objectives that have been set for this study which includes :

i. To determine the concentration of $PM_{2.5}$ of selected rooms in School of Civil Engineering, USM and compare to the air quality guideline by World Health Organization (WHO).

ii. To investigate the effect of occupancy numbers and activities towards the concentration of $PM_{2.5}$.

iii. To investigate the relationship between the temperature and relative humidity with particulate matter $PM_{2.5}$ concentration using Pearson Correlation.

1.5 Scope of Study

This study focuses on rooms in School of Civil Engineering, USM buildings. There are four rooms selected which are based on the accessibility and activities of the students and staff. In other hand, all rooms selected are newly renovated which might contribute to particulate matter pollution due to the renovations.

The monitoring of $PM_{2.5}$ concentration takes about 3 months from 22 Mac 2022 to 19 May 2022 to be completed since it requires two monitoring session (during semester break and ongoing semester). In this case, the lecture room and tutorial room are being used for physical classes and chosen based on the few characteristics such as number of occupants, with or without mechanical ventilation and activities carried out. Tetupai Lounge is a typical workplace and leisure room for students which were still under renovation during the monitoring. Data was taken in each rooms for 24 hours in a specific time set starting from 10:00 am until 10:00 am the next day. This study intended to observe the difference of the IAQ level of the room with and without occupant; hence, the monitoring process is taken once during semester break where it was expected to be unoccupied and once during ongoing semester which the rooms will be occupied with students for classes. The conditions of the surroundings environment and number of occupant were taken into account and calculated manually.

1.6 Dissertation Outline

In order to obtain better understanding of the study, this thesis has been categorized into five specific chapters. In Chapter 1, an introduction of the thesis including problem statement, objectives, scope of work and dissertation outline were provided. This chapter provides an overview of the entire study and explains why it was conducted in order to establish the desired work goals. Chapter 2 is a literature review that discuss informations based on previous researches and were used as a references for this study so that the clear and strong findings can be used to support this study. In Chapter 3, the details of methodology used are explained step by step from beginning of the study until the analysis. Every methods used in this study were discussed including site selection, type of instrument used, monitoring procedures and software used for analysis. Chapter 4 discusses the results obtained and analysis from the study. This chapter used graphs, tables, and figures to illustrate the findings. Discussion were made on the basis of the software-based analysis and comparison with the previous findings. Last chapter of the thesis is conclusion and recommendations where conclusions are made based on the study objectives and the outcomes. On the basis of the findings and observations, recommendations were made for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor Air Quality

The Environmental Protection Agency (USEPA, 2021c) describes Indoor Air Quality (IAQ) as the air quality within and around buildings and structures, particularly as it concerns to occupant health and comfort . The indoor places include classrooms, hostels, workplace, shopping malls, private residents and public indoor places.

Humans averagely spend 80–90% of their time indoor making the indoor air quality to be the main concern in terms of health, comfort and productivity due to the huge amount of exposure time (Saini et al., 2020). Recent studies found that IAQ has become one of the main concern problems in the period of school construction or higher education and an exposure to numerous contaminants due to poor IAQ increases risk of developing both short- and long-term health issues (Ismail et al., 2020). Air quality in educational buildings is significant not just because of the length of time spent there, but also because of the high occupant density (Aziz et al., 2015). This study focusses the chemical sources of particulate matter 2.5 and the comfort parameters of temperature and relative humidity. In a recent study of indoor air quality in university libraries by (Güneş et al., 2022) found that the most significant source of particulate matter in the indoor environment was found to be an indoor seconder blowing dust.

During the pandemic of Covid-19, good ventilation system in indoor spaces is very significant compared to outside air since good ventilation can help minimise the concentration of airborne pollutants, such as viruses and remove unwanted particles (USEPA, 2021b). Sometimes, limiting the number of occupants in the buildings or rooms can help to increase the effective rate of ventilation especially during the pandemic.

Environmetal Protection Agency, EPA suggested that maintaining good ventilation during cleaning of the rooms can be done by opening windows or doors during and after cleaning which can help to minimise the possibility of particles resuspended during cleaning especially those that could transit the SARS CoV-2 virus (USEPA, 2021b). Authorities encouraged public to limit room occupancy in order to reduce risks from SARS CoV-2.

2.2 Particulate Matter 2.5

According to EPA, $PM_{2.5}$ are particles that inhalable and have a diameter of 2.5 micrometres or less. These particulate matter mostly directly come from a construction sites, unpaved roads, fields, smokestacks or fires and due to the chemical reactions such sulphur dioxide and nitrogen oxides (USEPA, 2021d). $PM_{2.5}$ has an aerodynamic diameter of $\leq$ 2.5 µm which absorb various chemical contaminants such metals, organic compounds and toxins. PM has a variety of elements, including nitrates, sulphates, elemental and organic carbon, and causes more harm than any other major air contaminant. Between and within parts of the world, ambient $PM_{2.5}$ concentrations differ significantly. In 2019, more than 90% of the world's population resided in regions where concentrations were higher than the 10 g/m^3 WHO air quality guideline from 2005 (WHO, 2021a). According to WHO, the updated guidelines state that annual average concentrations of $PM_{2.5}$ should not exceed 5 $\mu g/m^3$, while 24-hour average exposures should not exceed 15 $\mu g/m^3$ more than 3 - 4 days per year (WHO, 2021b). $PM_{2.5}$ concentration in aA study in university library at different level of the building in

Nibong Tebal found that the mean concentration of $PM_{2.5}$ was 5.73 µm/m^3 (Elbayoumi et al., 2018).

These particles are likely to be high outdoor due to high pollution compared to indoor. Department of Health of New York State (DOH) mentioned that due to the micro size of the particle, it can penetrate into the respiratory and blood system that could lead to short term health effect. Figure 2.1 shows the approximate size of a particulate matter compared to human hair.

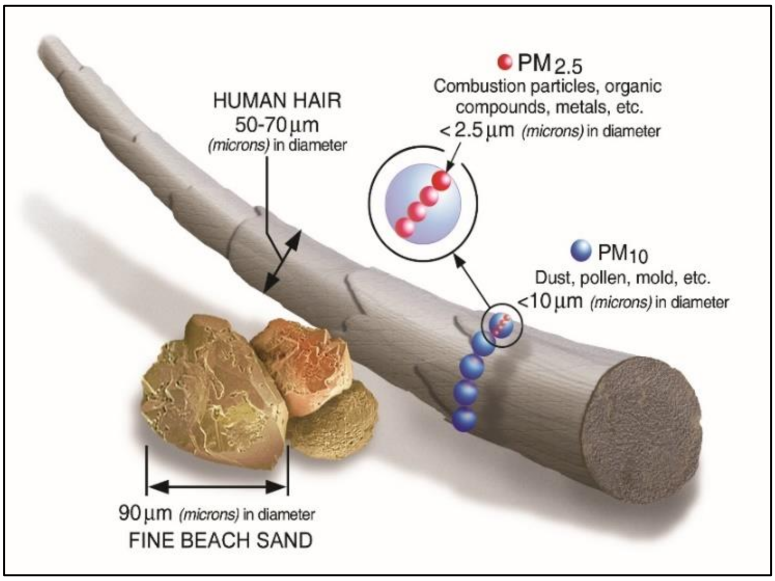


Figure 2.1: Approximate size of particulate matter (Source: USEPA, 2021c)

Based on the statistic made by World Health Organisation (WHO) in 2016, 58% of outdoor air pollution-related deaths are due to heart disease, 18% of the death are due to respiratory infections and another 6% of deaths are due to lung cancer (WHO, 2021a). The amount of outside $PM_{2.5}$ that enters a building is determined by the structure's design and operation. However, $PM_{2.5}$ may be removed from outdoor air by air filters in building ventilation systems before it is supplied to inhabited area (Rosman et al., 2019).

2.2.1 Indoor Particulate Matter Sources

There are many natural sources of PM and the most common sources are from the indoor combustion and daily activities such cleaning, burning of fuels, and cooking. Besides, some particles that can be seen with naked eyes such dust,dirt, smoke and soot can also be a contributor to indoor PM sources (Irankunda, 2018).

Most sources of outdoor air pollution are beyond the control of individuals for a sector such transportations, energy, agriculture and wastes. Recent study found that indoor air pollutants such as cooking and cigarette smokes given greater influences than pollutants from outdoors (Kim et al., 2020). Sources of $PM_{2.5}$ due to human activities such as walking, dressing, and sweeping contribute $PM_{2.5}$ concentration about 33% (Zhou et al., 2016).

Ca-rich particles had a large contribution of Ca, Fe, and Ti, which might be attributed to deteriorated cement, interior dry wall and dust from the furniture in the room which have not been used for quite a long period (Carrion-Matta et al., 2019).

2.3 Ventilation

Ventilation system in a building can be in two types which are mechanical ventilation and natural ventilation. In mechanical ventilation, fans are used to ventilate the confined space while natural ventilation is determined by natural sources and depending on the outdoor environment (Carrion-Matta et al., 2019). Building ventilation systems are intended to provide adequate levels of outdoor air, remove contaminants generated within the space, and provide a thermally comfortable environment for the building's occupants. In minimizing exposure of pollutants and transportation of outdoor air into indoor, sealing windows and doors is significant

(Zhou et al., 2016). Indoor $PM_{2.5}$ concentration can be impacted by outdoor $PM_{2.5}$ concentration through open window and even in a low velocity wind.

One of the main concerns is creating suitable thermal settings for the inhabitants. The combined impacts of physical dimensions of indoor settings, human variables such as clothing insulation and activity, as well as physiological and psychological aspects, may be used to assess perceived comfort levels and their variation. According to ASHRAE, standard ventilation level recommended for classrooms is 50 people/1000 ft2 and 15 cubic feet per minute (CFM)/person (ASHRAE, 2020).

2.4 Health Issues Regarding Indoor Air Pollution

Typically, exposure of indoor air pollution is likely to increased respiratory-related symptoms such as sneezing, coughing, wheezing and difficulty to breath. These symptoms may be mild and only effect in a short term, however in some cases the symptoms get worsen and lead to chronic respiratory problems.

Indoor air pollutions can give effect to human health both in short term effect and also long term effect. Short term exposure to the air pollution have been linked to many health issues such as lung disease, severe bronchitis and asthma attacks, and infections in respiratory system. Long term exposure can be lead to failure of lung function and development of chronic bronchitis since the particulate matter is inhalable as shown in Figure 2.2.

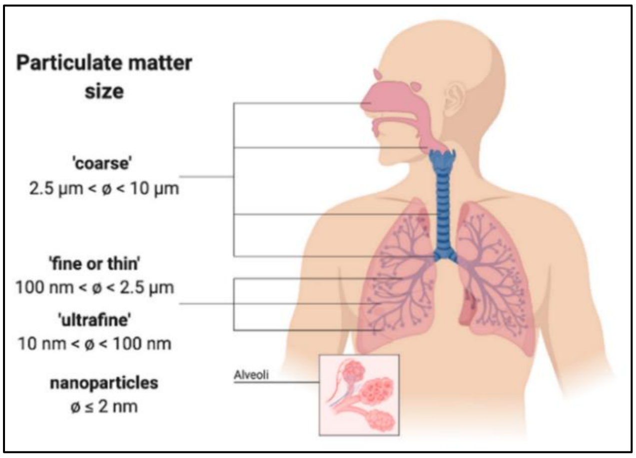


Figure 2.2: Potential Location of Particulate Matter in the Respiratory System (Source : (WHO, 2021a)

The health effect can be different depending on the individuals including the factors of age, condition of health, and gender. Individuals with higher risk to be effected are more likely to suffer negative health impacts as a result of air pollution. Biological variables, non-biological factors, greater exposure, and/or increased dosage at a given concentration can all put these individuals at risk (USEPA, 2021e). Hence, the risk of health effect can be different especially in factor of age. For instance, children are likely to have asthma compared to adults and senior citizen are likely to have high risk of heart attack or stroke due to their condition of health. Some studies found that there is a relationship between genetic characteristics of individuals and their response to air particle pollution (Manisalidis et al., 2020; Rider & Carlsten, 2019).

2.5 Humidity and Temperature

Other than $PM_{2.5}$, parameters of humidity and temperature are also taken onto consideration to determine the level of thermal comfort and these parameters are linked to the productivity of the occupancy. Temperature is significant factor that influence the productivity and thermal comfort by maintaining the comfortable environment. An extremely dry or hot air can cause dry skin to the occupants, not only that, it can effect the structure buildings. For instance, high temperature can lead to shrinkage and fading of the paints on wooden structures. A study in China found that a workstation under moderate humidity condition and moderate temperature was more comfortable than under high humidity condition (He et al., 2017). Generally, humidity is the amount of water vapour in the air that has an effect to the human thermal comfort because when the humidity is high, the wetter is the surroundings environments (Hong, 2020). However, extreme humid air condition is not a good sign as it can cause corrosion, decay and moisture deteroriation (Morse et al., 2017). In a study carried out in South American city, it is found that there is a positive correlation of $PM_{2.5}$ concentration and relative humidity in a residential areas. Regardless of the intensity of the rain event, a correlation between high RH and a general decrease in $PM_{2.5}$ concentrations was found (Zalakeviciute et al., 2018). Relative humidity impacts the way that PM naturally deposits itself by adhering to moisture particles, which raises the quantity of PM in the atmosphere. As humidity rises, moisture particles gradually enlarge to the point of "dry deposition," which lowers the atmospheric concentrations of $PM_{2.5}$ (Zhang et al., 2017).

2.6 Air Quality Status

Based on Department of Environment (DOE, 2020), The Air Pollutant Index (API) reflects the current state of the air quality. Six primary air pollutants—ground level ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter less than 10 microns in size (PM_{10}), and particulate matter less than 2.5 microns in size—are used to calculate the API ($PM_{2.5}$). The air pollutant index (API) is presented in Table 2.1.

Table 2. 1: Air Quality Status (API) by (DOE, 2020)

API	AIR QUALITY STATUS	HEALTH EFFECT
0 – 50	Good	Low pollution without any bad effect on health
51 – 100	Moderate	Moderate pollution does not pose any bad effect on health
101 – 200	Unhealthy	Worsen the health condition of high-risk people with heart and lung complications.
201 – 300	Very Unhealthy	Worsen the health condition and low tolerance of physical exercises to people with heart and lung complications. Affect public health
> 300	Hazardous	Hazardous to high-risk people and public health

In 2020, restricted movement control order (MCO) was ordered by the Government causing the significant increase in air quality which the air quality level were at good and moderate level compared to in 2019. The increase in air quality was due to the limited industrial and social activities during the MCO as proved by the daily $PM_{2.5}$ concentration in Klang area, the largest contributor to industrial air pollution where in 2020, Klang recorded lower API readings compared to the previous years as shown in Figure 2.3.

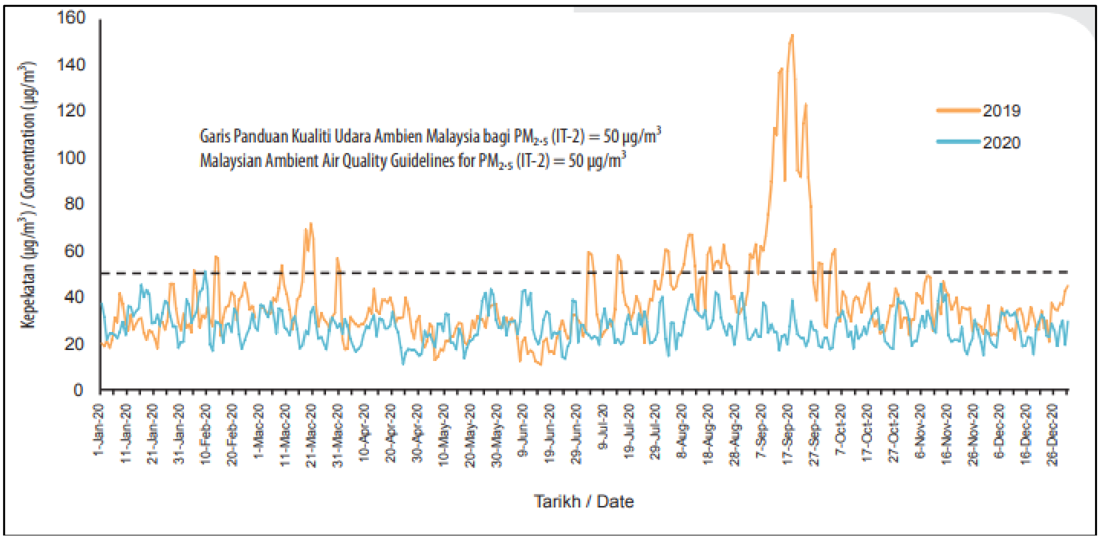


Figure 2.3: Trend of 24-hour Concentration of Particulate Matter ($PM_{2.5}$), Klang 2019 and 2020. (Source: DOE, 2020)

The $PM_{2.5}$ concentration in 2020 was much lower compared to in the previous year due to humid weather conditions, reduction of forest and bush fire cases. In the previous year, there were bad haze incidents and various industrial activities that contributed to the high $PM_{2.5}$ level as shown in the Figure 2.4. However, the $PM_{2.5}$ level still under the acceptable range of Malaysian Ambient Air Quality Guideline for $PM_{2.5}$.

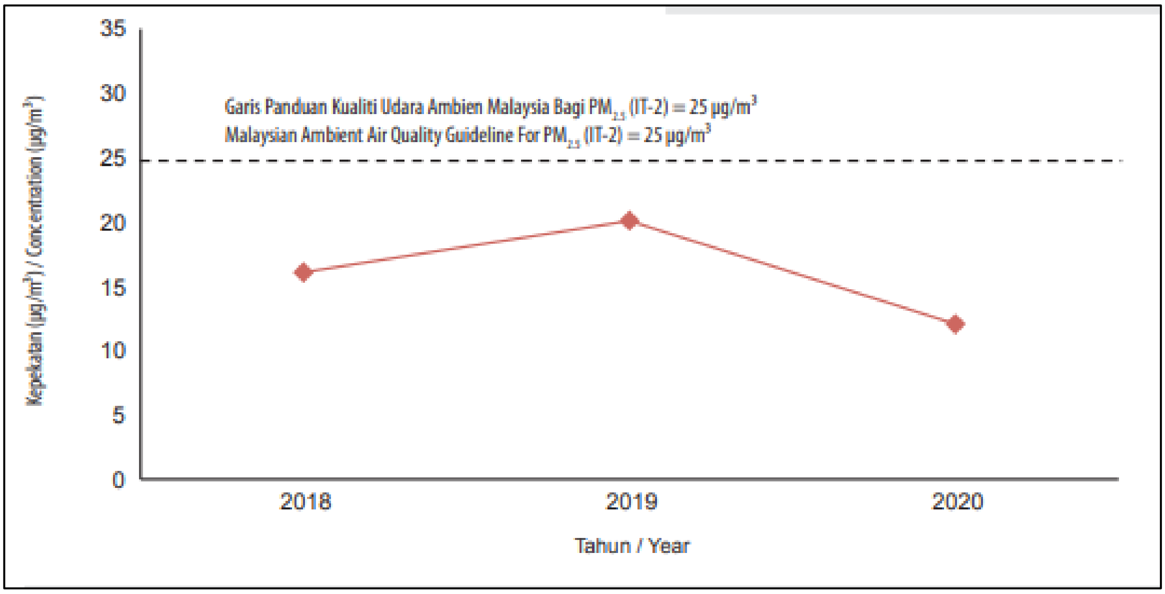


Figure 2.4: Annual Average Concentration of Particulate Matter ($PM_{2.5}$), 2018-2020 (Source :DOE, 2020)

2.7 Sick Building Syndrome (SBS)

Sick building syndrome mainly causes by temperature, humidity, volatile organic compounds (VOC) cleanliness, ventilation and physcological factors. The symptoms typically linked to amount of time spent indoor and enclosed space, activities and furnishing in the buildings. The term "sick building syndrome" (SBS) was used in the mid-1970s to characterise a structure where health issues are more prevalent than predicted (Fu et al., 2021). SBS can occur in spaces that are:

1. Mechanically ventilated

2. Improper furnishings and building fabrics
3. Poor plan layout
4. Poor maintenance arrangements

In mechanically ventilated space such offices or enclosed air-conditioner room, it has been proven that products emitting volatile organic chemicals (VOSs) such plastic boards, dry wall, computers, printers, synthetic carpets and acoustic tiles increase risks of SBS (Zainal et al., 2019).

In a survey conducted involving office workers of academic institution in Malaysia with age range of 18 to 60 years old found that the occurrence of SBS was higher among female compared to males (Zainal et al., 2019). Hence, it is significant to maintain good cleaning and housekeeping in the workplace and in institution buildings.

2.8 Summary

Based on the past studies, it can be found that the concentration of particulate matter effected by the other physical parameters such as temperature and humidity. The activity and existence of occupant become the main sources of the increasing in level of indoor particulate matter. There were significant correlation between physical parameters such as temperature, relative humidity and concentration of $PM_{2.5}$ and eventually affect the indoor air quality. The relationship between the physical parameters such as temperature, relative humidity and concentration of $PM_{2.5}$ can be visualized and interpreted using Pearson Correlation (Ma et al., 2022; Mopa Wambebe & Duan, 2020; Qiu et al., 2017; Yang et al., 2020).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describe the research methodology involved in site selection, data collection using optical direct-reading monitor (ODRM) equipment and the use of Comet 2 Software to assess the concentration of $PM_{2.5}$, temperature and relative humidity in selected rooms at School of Civil Engineering buildings, USM, Penang. The schematic flow of methodology in achieving objectives of this study is shown in Figure 3.1. All the data were interpreted and analyzed using Microsoft Excel and IBM SPSS.

The physical measurements includes of thermal comfort parameters such as temperature (C°), relative humidity (RH%), and indoor ambient particulate matter ($PM_{2.5}$). In this study, the main possible sources of the particulate matter were from the occupants, renovations activities and condition of the surroundings. Renovations of buildings can adversely affect the the occupancy of the buildings through biological contaminants, gases and particulate matters. The age range of the occupancy in the buildings are between 19 - 60 years old and based on the occupancy in each room, mostly consists of students with average age of 23 years old.

Guidelines from World Health Organisation (WHO) of air quality were used to compare the $PM_{2.5}$ concentration obtained from the study. The concentration of $PM_{2.5}$ should not exceed 15 $\mu g/m^3$ for 24-hour average exposure (WHO, 2021b).

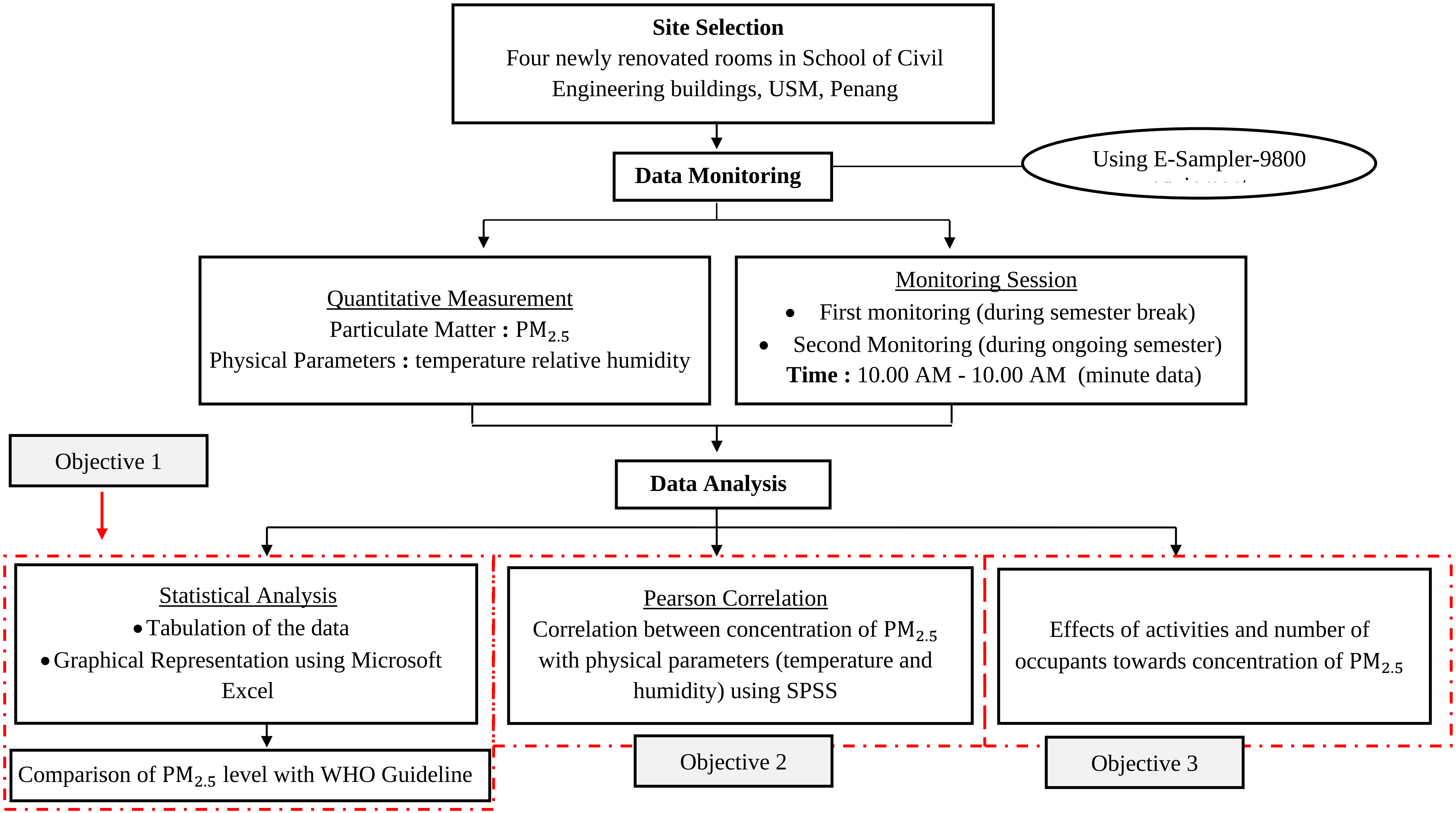


Figure 3.1: Flow of Methodology of Indoor Air Quality Assessment

3.2 Site Location Area

This study focuses on assessing the concentration of particulate Matter $PM_{2.5}$ in indoor air of a selected rooms in buildings of School of Civil Engineering, USM as shown in the Figure 3.2(a), (b), (c) and (d). There are four rooms selected that are newly renovated in 2021 which are Lecture Room, Tutorial Room 1, Tutorial Room 2 and Tetupai Lounge. The ventilation system used are mechanical and natural ventilation system where the natural ventilation was limited since the doors and windows were closed during the monitoring. Each room utilizes HVAC unit to circulate outdoor and indoor air.

(a)

(b)

(c)

(d)

Figure 3.2: Location of monitoring (a) Tetupai Lounge, (b) Lecture Room, (c) Tutorial Room 1, and (d) Tutorial Room 2

Lecture Room, Tutorial Room 1 and Tutorial Room 2 were renovated and completed in 2021, so there were no renovations activity during the first and second monitoring, only presence of occupants were taken into account. However, for Tetupai

Lounge, the room was still under finishing renovation stage during the first monitoring which on the semester break but was completely renovated during the second monitoring. Figure 3.3 and 3.4 shows the condition of Tetupai Lounge during and after renovations done.

Figure 3.3: Tetupai Lounge during renovation

Figure 3.4: Tetupai Lounge after renovation

Another outside sources can be from the occupants' clothes, shoes and their belongings. However, there is no exposure from cigarette smokes, cooking smokes or fuel smokes in the rooms since smoking is prohibited and no cooking or burning activities occur in all selected rooms.

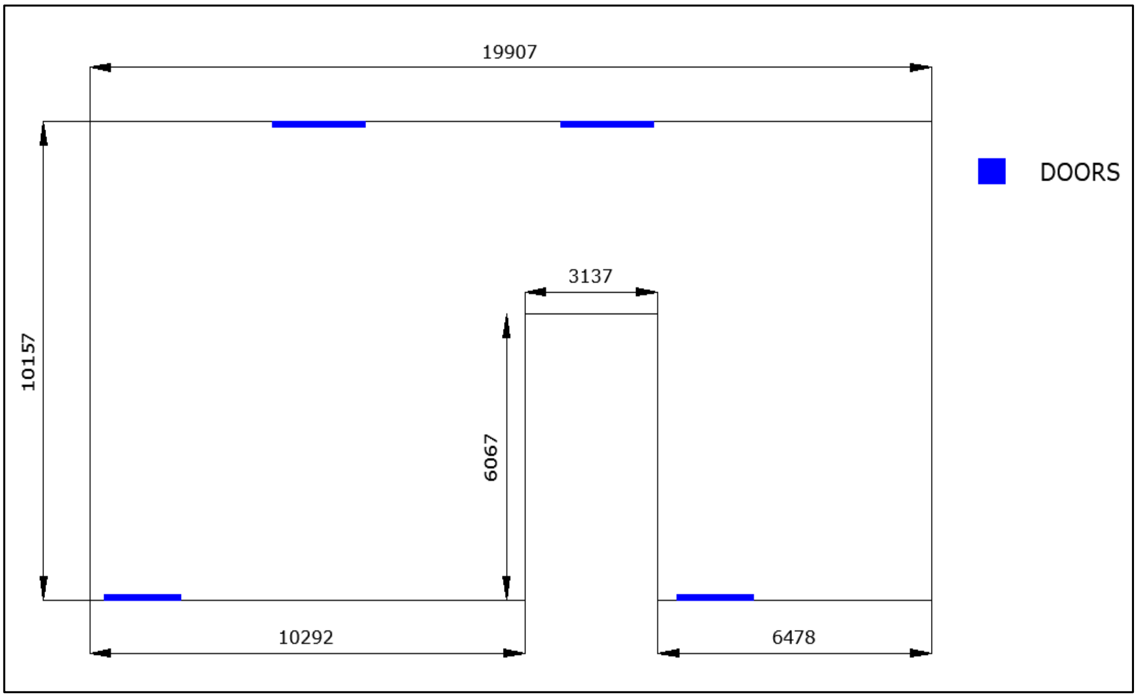
3.2.1 Building Characteristics

The renovations involved in the selected rooms mainly change in new wall paints, position of windows and furnitures in the rooms. Tetupai Lounge have no occupancy since it is newly renovated with new paint, floor furnishing, new furnitures and electronic equipments. Each area of room were measured using laser distance meter and have different size dimension as listed in Table 3.1.

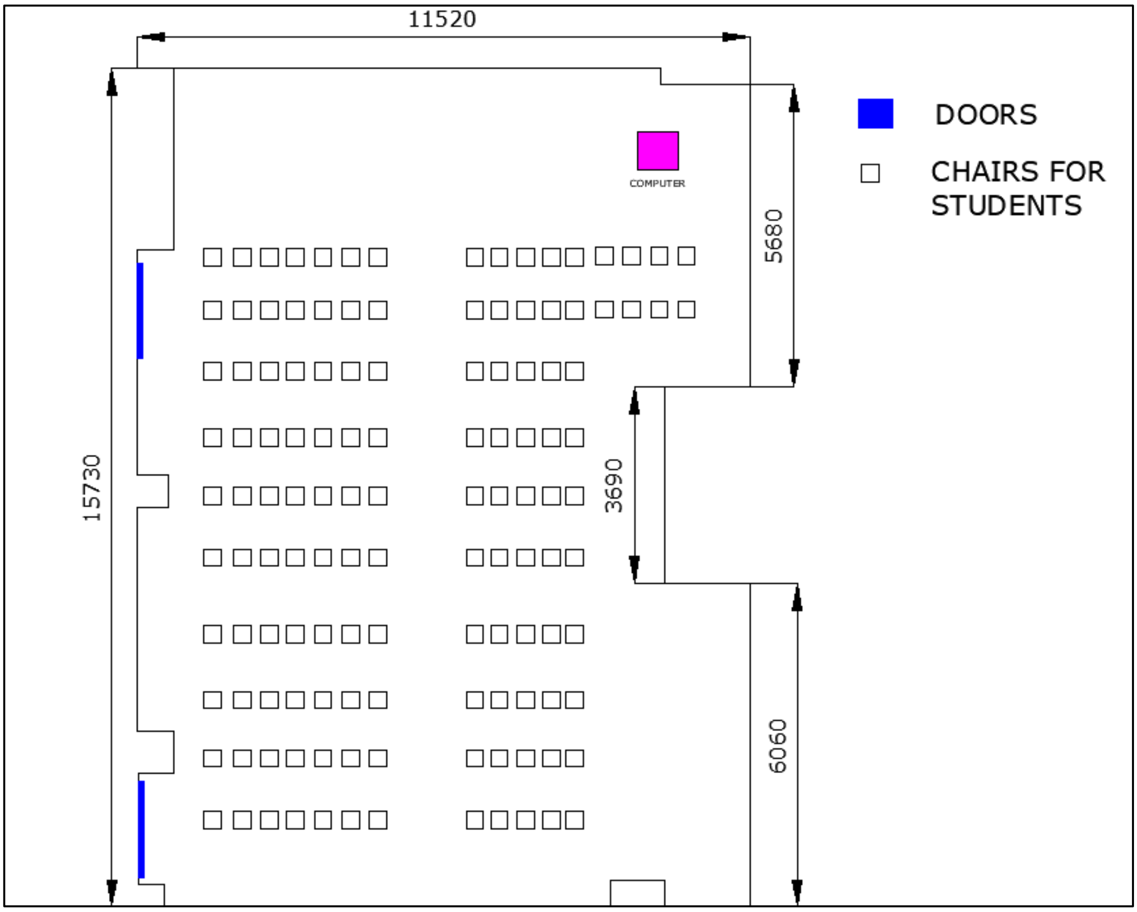
Table 3.1: Details of Selected Rooms

Room	Size Dimension	Number of doors and windows
Tetupai Lounge	10.157m (W) x 19.907m (L)	4 doors
Lecture Room	11.520m (W) x 15.730m (L)	2 doors
Tutorial Room 1	8.097m (W) x 11.520m (L)	2 doors
Tutorial Room 2	8.097m (W) x 11.520m (L)	2 doors

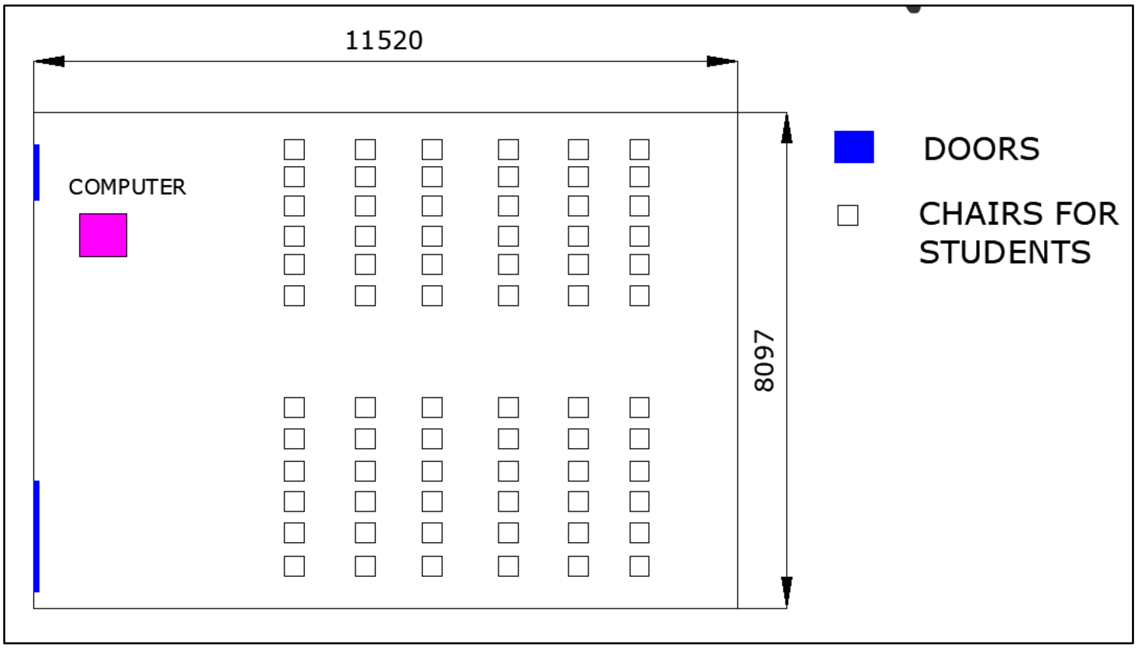
Figure 3.5 (a), (b), (c) and (d) shows the plan layout of the selected rooms. Each floor of the rooms use tiles and furniture such as chair, desk and whiteboard. Besides, the electronic devices such as computers, slide projectors, computers are also equipped in each rooms.


19907
DOORS
3137
10157
6067
10292
6478

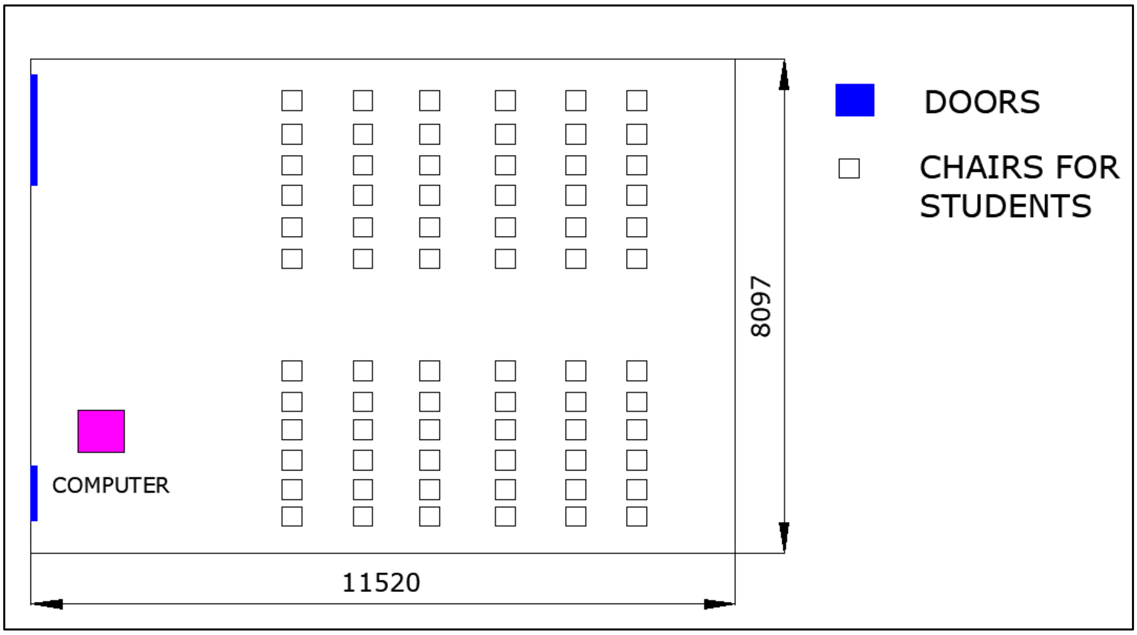
(a)


11520
DOORS
CHAIRS FOR STUDENTS
COMPUTER
5680
15730
3690
6060

(b)



(c)



(d)

Figure 3.5: Plan Layout (a) Tetupai Lounge, (b) Lecture Room, (c) Tutorial Room 1, (d) Tutorial Room 2

The type of ventilation system for all selected rooms are mechanical ventilation. All rooms are equipped with air conditioner and no fans are used. The natural ventilation in the rooms are very minimal since there is no open window and only doors. Lecture room and Tetupai Lounge use ceiling cassette air conditioner while both tutorial room 1 and 2 use ceiling suspended air conditioner with 4 air conditioner equipped in each rooms. For Tetupai Lounge, the ventilation system is equipped with heat, ventilation and air conditioning, HVAC system which provide suitable thermal climate in buildings.

3.3 Instrumentation

In this study, the monitoring instrument used was optical direct-reading monitoring (ODRM) by Met-One Instrument of model E-SAMPLER-9800 as shown in Figure 3.6. ODRM was used to measure parameters of temperature, relative humidity and concentration of $PM_{2.5}$. This instrument is a type of nephelometer that automatically measure and records real-time airborne PM_{10}, $PM_{2.5}$ or TSP particulate concentration levels by the principle of forward laser light scatter (Met One Instruments Inc, 2011).

Figure 3.6: Optical Direct Reading Monitor ; E-Sampler-9800