# STUDY ON INDOOR PARTICULATE MATTER ($PM_{2.5}$) IN HOSTEL ROOMS OF UNIVERSITI SAINS MALAYSIA ENGINEERING CAMPUS

By

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# ABSTRAK

Kualiti udara dalaman yang baik mempengaruhi kesihatan dan keselesaan penghuni. Satu kajian telah dijalankan untuk menyiasat hubungan antara bahan zarah dengan diameter kurang daripada 2.5 mikron ($PM_{2.5}$), suhu persekitaran, kelembapan relatif dan kelajuan angin. Objektif kajian adalah untuk menentukan tahap kepekatan semasa $PM_{2.5}$, menilai pengaruh jumlah penghuni dan aktiviti manusia terhadap tahap kepekatan $PM_{2.5}$ dan mengkaji hubungan antara parameter menggunakan korelasi Pearson. Empat bilik asrama di Kampus Kejuruteraan USM telah dipilih dalam kajian ini. Penyumbang bahan pencemar adalah daripada aktiviti manusia di dalam bilik yang ditetapkan dan kawasan sekitarnya. Sesi pemantauan dibahagikan kepada dua tempoh: cuti semester (SB) dan sesi akademik (AS). Met One E-sampler (ODRM) digunakan untuk mengumpul data 24 jam secara berterusan dan data yang dikumpul dianalisis menggunakan perisian SPSS dan Microsoft Excel untuk mencapai objektif kajian. Bilik asrama A, B dan C mempunyai tahap kepekatan $PM_{2.5}$ yang lebih tinggi semasa pemantauan AS berbanding pemantauan SB. Sebaliknya, bilik D menunjukkan tahap kepekatan $PM_{2.5}$ lebih tinggi semasa pemantauan SB berbanding pemantauan AS. Bilik B boleh dianggap sebagai bilik yang paling tercemar kerana tahap kepekatan (purata setiap jam 8.41 $\mu g/m^3$) di dalam bilik adalah yang paling tinggi. Aktiviti manusia di dalam dan di luar bilik menyumbang kepada perubahan tahap kepekatan $PM_{2.5}$. Sumber luar $PM_{2.5}$ seperti habuk dari pengubahsuaian rumah berhampiran juga telah dipertimbangkan dalam kajian ini. Menurut korelasi Pearson, parameter meteorologi utama yang mempengaruhi kepekatan $PM_{2.5}$ ialah suhu persekitaran. Kajian mendapati aktiviti manusia merupakan penyumbang utama kepada tahap kepekatan $PM_{2.5}$ di bilik asrama Kampus Kejuruteraan USM.

# ABSTRACT

Good indoor air quality influenced the health and comfortability of the occupants. A study was conducted to investigate the relationship between the indoor particulate matter with a diameter less than 2.5 micron ($PM_{2.5}$), ambient temperature, relative humidity and wind speed. The objectives of the study were to determine the current concentration level of $PM_{2.5}$, evaluate the influence of occupancy and human activity on $PM_{2.5}$ concentration level and discover the association between parameters using Pearson correlation. Four hostel rooms in USM Engineering Campus were selected in this study. The pollutant contributors were from the human activities inside the designated rooms and the surrounding area. The monitoring sessions were divided into two periods: semester break (SB) and academic session (AS). The Met One E-sampler (ODRM) was used to collect 24-hour data continuously and the collected data was analysed using SPSS software and Microsoft Excel to achieve the objectives of the study. Hostel rooms A, B and C had higher $PM_{2.5}$ concentration levels during the AS monitoring than the SB monitoring. On the contrary, room D showed greater $PM_{2.5}$ concentration level during the SB monitoring than the AS monitoring. Room B can be considered as the most polluted room because the concentration level (mean hourly average 8.41 $\mu g/m^3$) in the room was the highest. Indoor and outdoor human activities contributed to the changes of $PM_{2.5}$ concentration level. The outdoor sources of $PM_{2.5}$ such as dust from nearby house renovation also have been considered in this study. According to the Pearson correlations, the key meteorological parameter that influenced the $PM_{2.5}$ concentrations was ambient temperature. The study discovered that human activity was the major contributor to the $PM_{2.5}$ concentration level in the USM Engineering Campus hostel rooms.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| API | Air Pollutant Index |
| APIMS | Air Pollutant Index of Malaysia |
| AS | Academic session |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| AT | Ambient Temperature |
| CO | Carbon Monoxide |
| COVID-19 | Coronavirus Disease 2019 |
| DOE | Department of Environment |
| DOSH | Department Occupational Safety and Health |
| HCs | Hydrocarbons |
| IAQ | Indoor Air Quality |
| ICOP 2010 | Industry Code of Practice 2010 |
| MCO | Movement Control Order |
| MCS | Multi chemical sensitivity |
| NIOSH | National Institute of Occupational Safety and Health |
| $NO_2$ | Nitrogen Dioxide |
| $O_3$ | Ozone |
| ODRM | Optical Direct Reading Monitor |
| PAQ | Perceived air quality |
| PM | Particulate Matter |
| $PM_{10}$ | Particulate Matter (particles with an aerodynamic diameter less 10 µm) |
| $PM_{2.5}$ | Particulate Matter (particles with an aerodynamic diameter less 2.5 µm) |
| RH | Relative Humidity |
| SB | Semester break |
| SBS | Sick building syndrome |
| SEM | Scanning electron microscope |
| $SO_2$ | Sulphur Dioxide |
| SPSS | Statistical Package for the Social Sciences |
| TSP | Total Suspended Particulate |
| TVOC | Total volatile organic compounds |

| | |
|---|---|
| USEPA | United States Environmental Protection Agency |
| USM | Universiti Sains Malaysia |
| WHO | World Health Organization |
| WS | Wind speed |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background Study

Indoor air quality (IAQ) describes the air quality within and outside of buildings, and it affects the health, comfort, and productivity of building occupants. Poor IAQ has been attributed to the symptoms like headaches, fatigue, trouble concentrating, and irritation of the eyes, nose, throat and lungs. Furthermore, some specific chronic diseases have been linked to specific air contaminants or indoor environments, like lung, heart diseases and aggravated asthma.

Fine particulate matter ($PM_{2.5}$) is an airborne pollutant with an aerodynamic diameter of less than 2.5 micrometres that has been associated with negative acute and chronic human health outcomes. Despite the fact that the majority of $PM_{2.5}$ research has focused on outdoor exposures, people spend more time indoors, where $PM_{2.5}$ can penetrate. Hence, the concentration of $PM_{2.5}$ indoors must be controlled to protect the comfort and health of the occupants of the building.

Indoor particulate matter (PM) includes particles from the outside that migrate indoors and particles that originate from indoor sources. According to the United States Environmental Protection Agency (USEPA), indoor PM can be generated through cooking, combustion activities (candles, fuel burning equipment, and smoking), and some hobbies. PM can also be produced from biological sources in the building environment, such as bacteria and mould derived from building materials. Pet dander, chemicals from cleaning products, and emission from kilns and copy machines were also among the potential contributors for indoor $PM_{2.5}$.

## 1.2 Problem Statement

The Malaysian National Institute of Occupational Safety and Health (NIOSH) has consistently emphasised that indoor air quality (IAQ) should not be taken lightly because it has significant impacts on buildings occupants, particularly negative impacts. IAQ refers to the air quality inside buildings, which should be in a good condition because people live there. As previously stated, the negative effects are connected to poor IAQ. Poor IAQ was discovered in approximately 30 percent of new and renovated buildings according to the United States Consumer Product Safety Commission (2022). Poor IAQ are synonymous with the building diseases such as sick building syndrome (SBS) and multi chemical sensitivity (MCS) (NIOSH, 2015). These illnesses frequently have a long-term impact on people's health.

Throat irritation, coughing, difficulty of breathing, and itchy skin rashes are the most common health symptoms associated with poor IAQ. All of the health problems listed are related to the respiratory system. According to Health Informatics Centre Planning Division (2021) by the Ministry of Health Malaysia, diseases of the respiratory system are the second greatest cause of hospitalisation, with 9.67% of all hospitalisation. This demonstrates the importance of controlling air quality in Malaysia.

Fine particulate matter ($PM_{2.5}$) is an air contaminant that is a concern for people's health when the level is high. $PM_{2.5}$ particles that have an aerodynamic diameter of less than 2.5 micrometres can penetrate the human body via the respiratory system (Health Effects Institute, 2020). Therefore, the concentration of $PM_{2.5}$ inside buildings should be monitored and controlled because people spend the majority of their time indoors.

## 1.3 Objectives

The objectives of the study are:

1. To determine the current concentration of Particulate Matter 2.5 ($PM_{2.5}$) in selected hostel rooms of USM Engineering Campus.
2. To investigate the effect of the occupancy and human activities on $PM_{2.5}$ concentration level in hostel rooms of USM Engineering Campus.
3. To identify the influence of relative humidity, ambient temperature and wind speed on $PM_{2.5}$ concentration using Pearson correlation.

## 1.4 Scope of Study

The assessments of the $PM_{2.5}$ monitoring were conducted in four hostel rooms of USM Engineering Campus, Nibong Tebal, Penang. The monitoring was carried out twice for each room starting from 16$^{th}$ March 2022 until 22$^{nd}$ April 2022. The concentration of $PM_{2.5}$, temperature, relative humidity and wind speed of the room were recorded by using an E-sampler (ODRM). Continuous one-minute reading intervals for 24-hour data collection were recorded at monitoring locations. All the collected data were analysed by using SPSS software and Microsoft Excel to get the desired result.

## 1.5 Dissertation Outline

The structure of the research project dissertation consists of five chapters including introduction, literature review, methodology, results and discussion, and ended with conclusion and recommendation. First chapter (Chapter 1) describes a summary of the study, followed by the problem statements that can be used to investigate and understand why the study was conducted. The objectives of the study were clearly stated in order to determine the scope of work that needed to be completed. Literature review (Chapter 2) is to extract any previous related research to the study that could be used as a source of information for the study. The third chapter (Chapter 3) explains the methodology that is being used to complete the study. The methodology includes experiment procedures, instrument used, site selection, etc. Chapter 4 provides the data collection that being analysed and discussed from the research methodology. All the results will be presented in a variety of forms such as graphs, tables etc for better interpretation. Last chapter (Chapter 5) concludes the outcomes of the study and justify whether or not the objectives of the study have been achieved. Recommendation might be made for future reference on the subject.

# CHAPTER 2

# LITERATURE REVIEW

Indoor air pollution is just as detrimental as ambient air pollution because people spend the majority of their time inside buildings. Indoor air quality of each building should be examined on a regular basis to ensure the occupants' health and comfort.

## 2.1 Air Pollution in Malaysia

The World Health Organization (WHO) defines that air pollution is a contamination of the indoor or outdoor environment by any chemical, physical or biological agent that alters the natural characteristics of the atmosphere. The clean atmosphere began to be affected by human activities, and became polluted. This is referred to as anthropogenic air pollution. For the past decades, the major sources of air pollution in Malaysia are power plants (85%), motor vehicles (10%), industry activity (3%), and other sources (2%) (Sentian et al., 2019). Though most researchers generally focus on anthropogenic air pollution, it is essential to consider that nature also contributes to atmospheric pollution, as instances, volcanoes, forest fires, plant and animal decomposition, pollen pores, volatile hydrocarbons (HCs) emitted by vegetation, etc (Godish, 2004). However, in Malaysia, there are only a few natural disasters related to the atmosphere such as volcanic activity because there is only one active volcano in Malaysia, which is Bombalai volcano. This volcano is located in north-east Borneo, close to the border of Indonesia (Tahir et al., 2010). In addition, airborne volcanic ash transported from neighbouring countries with active volcanoes, such as Indonesia, might be the contributor to the natural air pollution in Malaysia.

Air pollution has generally been regarded as a serious environmental concern worldwide. In 2019, air pollution rose from the fifth to the fourth leading risk factor of death globally (Health Effects Institute, 2020). Consequently, it has become the greatest environmental threat to human health. According to WHO standards, the air quality in Malaysia is moderately unsafe. However, overall air pollution in Malaysia decreased in 2020 as a result of the Movement Control Order (MCO) given by the government (Health Informatics Centre Planning Division, 2021). The COVID-19 virus pandemic is influencing the reduction of emissions, particularly from mobile road sources and biomass burning.

### 2.1.1 Air Quality Status

In Malaysia, the Air Pollutant Index (API) is used as an indicator to measure ambient air quality instead of the term pollutant concentration since it is easier to understand. According to the Air Pollutant Index of Malaysia (APIMS), the API is calculated using 24-hour data retrieved from the Air Quality Monitoring Network throughout the country and updated hourly. The API value is determined based on average concentration of air pollutants such as Sulphur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Carbon Monoxide (CO), Ozone ($O_3$), and particulate matter ($PM_{2.5}$ and $PM_{10}$). Each pollutant produces its sub-index, and the highest relative sub-index will be considered as API reading. The APIMS stated that $PM_{2.5}$ is the most prevalent pollutant and hence defines the API value. The API value and status are listed in Table 2.1.

Table 2.1: API Range and its Impact on Health (APIMS, 2022)

| API | Status | Health Effect | Health Advice |
|---|---|---|---|
| 0-50 | Good | Low pollution without any bad effect on health | No restriction for outdoor activities to the public. Maintain healthy lifestyle. |
| 51-100 | Moderate | Moderate pollution that does not pose any bad effect on health | No restriction for outdoor activities to the public. Maintain healthy lifestyle. |
| 101-200 | Unhealthy | Worsen the health condition of high risk people who is the people with heart and lung complications | Limited outdoor activities for the high risk people. |
| 201-300 | Very Unhealthy | Worsen the health condition and low tolerance of physical exercises to people with heart and lung complications. Affect public health | Old and high risk people are advised to stay indoors and reduce physical activities. People with health complications are advised to see doctor. |
| > 300 | Hazardous | Hazardous to high risk people and public health | Old and high risk people are prohibited for outdoor activities. Public are advised to prevent from outdoor activities. |
| >500 | Emergency | Hazardous to high risk people and public health. | Public are advised to follow orders from National Security Council and always follow the announcement in mass media. |

## 2.2 Indoor Air Quality

The air quality within any closed building environment should be in a healthy condition because people inhale about 10 $m^3$ of air daily. As a matter of fact, people spend the majority of their time indoors, whether at home, office or institutions. Therefore, each person is desired to live in a healthy indoor environment. Good indoor air quality (IAQ) is described when there are no known contaminants at harmful concentrations inside the building, and its occupants do not complain about their living conditions (ASHRAE Standard, 2003). There are some health problems associated with poor IAQ such as sick building syndrome (SBS), multi chemical sensitivity (MCS) and building related illnesses (NIOSH, 2015). In addition, the chronic health problems such as cardiovascular disease, chronic obstructive and pulmonary disease, and lung cancer also can increased due to the poor IAQ (Carrer and Wolkoff, 2018). All these related health problems are possible to affect human health in both short-term and long-term periods. The characteristics of poor IAQ are stuffiness, undesirable odours, and presence of organism, bacteria, toxic chemical substance, moulds, and spores. In addition, if the building is too hot, cold, dry, and humid also considered as poor IAQ.

### 2.2.1 Industry Code of Practice in Indoor Air Quality 2010 (ICOP 2010)

The purpose of this industry code of practice is to provide guidance on improving the IAQ and to establish a minimum standard for selected parameters that will avoid discomfort and/or adverse health effects among employees and other occupants of an indoor or enclosed environment. The employer and an occupier including building owner and building management have a general duty under the Occupational Safety and Health Act 1994 (Act 514) to provide a safe workplace for their employees or other persons than his employees (occupant). Most IAQ assessments will comply with this code practice. The assessments should be monitored whether the parameters observed are in the acceptable criteria as provided in Table 2.2 and Table 2.3.

Table 2.2: Acceptable Range for Specific Physical Parameters (DOSH, 2010)

| Parameter | Acceptable Range |
|---|---|
| Air Temperature | 23 - 26 °C |
| Relative Humidity | 40 - 70 % |
| Air Movement | 0.15 – 0.50 m/s |

Table 2.3: List of Indoor Air Contaminants and The Acceptable Limits (DOSH, 2010)

| Indoor Air Contaminants | Acceptable Limits | | |
|---|---|---|---|
| | ppm | $mg/m^3$ | $cfu/m^3$ |
| Chemical contaminants | | | |
| (a) Carbon monoxide | 10 | - | - |
| (b) Formaldehyde | 0.1 | - | - |
| (c) Ozone | 0.05 | - | - |
| (d) Respirable particulates | - | 0.15 | - |
| (e) Total volatile organic compunds (TVOC) | 3 | - | - |
| Biological contaminants | | | |
| (a) Total bacterial counts | - | - | 500* |
| (b) Total fungal counts | - | - | 1000* |
| Ventilation performance indicator | | | |
| (a) Carbon dioxide | C1000 | - | - |

## 2.3 Malaysia Ambient Air Quality Standard 2020

The Malaysian Department of Environment established the New Malaysia Ambient Air Quality Standard in 2020 to replace the Malaysian Ambient Air Quality Standard of 2013. This guideline standard contains six air pollutants criteria which are particulate matter less than 10 micron ($PM_{10}$), particulate matter less than 2.5 micron ($PM_{2.5}$), sulphur dioxide ($SO_2$) carbon monoxide (CO), nitrogen dioxide ($NO_2$), and ground level ozone ($O_3$). Table 2.4 listed the air pollutants with its standard to be referred.

Table 2.4: Malaysia Ambient Air Quality Standard (DOE, 2020)

| Pollutants | Averaging Time | Malaysia Ambient Air Quality Standard (2020) |
|---|---|---|
| $PM_{2.5}$ (µg/$m^3$) | 1 Year | 15 |
| | 24 Hour | 35 |
| $PM_{10}$ (µg/$m^3$) | 1 Year | 40 |
| | 24 Hour | 100 |
| $SO_2$ (µg/$m^3$) | 1 Year | 250 |
| | 24 Hour | 80 |
| $NO_2$ (µg/$m^3$) | 1 Hour | 280 |
| | 24 Hour | 70 |
| $O_3$ (µg/$m^3$) | 1 Hour | 180 |
| | 8 Hour | 100 |
| CO (mg/$m^3$) | 1 Hour | 30 |
| | 8 Hour | 10 |

## 2.4 WHO Air Pollution Guideline 2021

Air pollution is one of the most serious environmental hazards to human health and climate change. Therefore, the World Health Organization (WHO) publishes guidelines to preserve public health by reducing the levels of air pollutants, which also contribute to climate change. Following a systematic review of the available evidence, WHO revised the guidelines level downwards, cautioning that exceeding the new air quality guideline levels is linked with significant health risks (WHO, 2021).

The WHO's new standards set air quality levels for six air pollutants. The selected pollutants are the most harmful to human health. The air pollutants are particulate matter less than 10 micron ($PM_{10}$), particulate matter less than 2.5 micron ($PM_{2.5}$), sulphur dioxide ($SO_2$) carbon monoxide (CO), nitrogen dioxide ($NO_2$), and ground level ozone ($O_3$). The guideline is shown in Table 2.5.

Table 2.5: WHO Air Pollution Guideline (WHO, 2021)

| Pollutants | Averaging Time | WHO 2021 Air Quality Guideline |
|---|---|---|
| $PM_{2.5}$ (µg/m$^3$) | 1 Year | 5 |
| | 24 Hour | 15 |
| $PM_{10}$ (µg/m$^3$) | 1 Year | 15 |
| | 24 Hour | 45 |
| $SO_2$ (µg/m$^3$) | 24 Hour | 40 |
| | 10 Minute | 500 |
| $NO_2$ (µg/m$^3$) | 1 Year | 10 |
| | 24 Hour | 25 |
| | 1 Hour | 200 |
| $O_3$ (µg/m$^3$) | Peak Season | 60 |
| | 8 Hour | 100 |
| CO (mg/m$^3$) | 24 Hour | 4 |
| | 8 Hour | 10 |
| | 1 Hour | 35 |
| | 15 Minute | 100 |

## 2.5 Indoor Particulate Matter 2.5

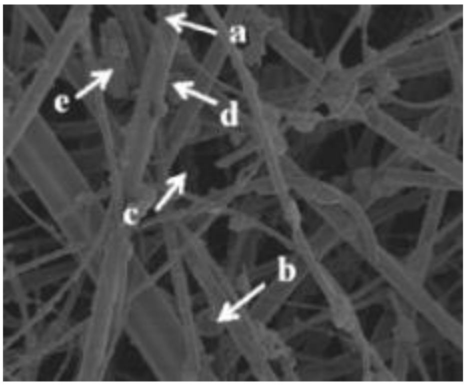
Fine particulate matter ($PM_{2.5}$) is one of the main pollutants that leads to health problems. $PM_{2.5}$ are airborne particles measuring less than 2.5 micrometres in aerodynamic diameter and less than a 30th of the diameter of human hair (Health Effects Institute, 2020). The unit measurement for this pollutant concentration is micrograms of particulate matter per cubic meter of air, or µg/m$^3$. Since $PM_{2.5}$ is the most frequent air pollutant that affects both short and long term health, its concentration is an essential air quality indicator. These fine particles are harmful due to their small size that allows them to travel deeper into the cardiopulmonary system.

According to the United States Environmental Protection Agency (USEPA), indoor PM levels are dependent on several factors. The factors are the outdoor levels, infiltration, types of ventilation and filtration systems used, indoor sources, and personal activities of occupants. It is stated that activities of occupants are included as one of the pollutant sources (Prihatmanti and Bahauddin, 2014). Therefore, occupant activity also should be considered as a contributor to pollution because $PM_{2.5}$ may be produced.

### 2.5.1 Physical Characteristics and Sources of $PM_{2.5}$

Airborne particulate matter (PM) is a complex mixture of solids and aerosols made up of tiny droplets of liquid, dry solid fragments, and solid cores with liquid coatings. Particles with a diameter of 10 microns or less ($PM_{10}$) are inhalable into the lungs and can cause negative health effects, implying that fine particulate matter ($PM_{2.5}$) is included (California Air Resources Board, 2022). $PM_{2.5}$ can be seen in a variety of morphologies.

In 2018, Zhang et al. conducted a research on the physical and chemical characteristics of $PM_{2.5}$ during the summer and winter seasons. A scanning electron microscope (SEM) was used to examine the morphology of particles. SEM images are commonly used in the study of atmospheric particle morphology because they directly display particle size, shape, aggregation characteristics, composition, and particle origins (McMurry, 2000). Zhang et al. (2018) discovered that the morphological characteristics of $PM_{2.5}$ for the different seasons do not alter much. The fine particulate matters were found in the form of agglomerate irregularly shaped, spherical, elongated, and flocculent particles, as illustrated in the Figure 2.1. It is proven that $PM_{2.5}$ particles come in a range of shapes and sizes.




SU8010 10KV 9.3mmx3.00k SE(UL) 10.0µm

Figure 2.1: Shapes of $PM_{2.5}$; (a) flocculent particles (b) spherical particles (c) deformation of spherical particles (d) irregularly shaped agglomerate (e) elongated particles (Zhang et al., 2018)

Referring to Figure 2.1, irregularly shaped agglomerate particles (d) could be large particles that absorbed various substances and whose source was dirt or construction dust. Spherical substances and disproportionate spherical particles (b) could be coal fly ash, which is mostly produced by coal burning (Du et al., 2015). Spongy spherical particles were most likely spongy carbon particles (Masiol, 2013). Mineral particles were said to form in the form of elongated particles (e) with a regular shape and smooth surface. $PM_{2.5}$ from automobile exhaust might be flocculent particles (a) that were fluffy and had a soot aggregate (Du et al., 2015). It is suspected that the spherical particles and soot aggregates in $PM_{2.5}$ allow fine particles to easily absorb toxic and harmful substances (Zhang et al., 2018).

## 2.6 Ambient Temperature, Relative Humidity and Wind Speed

Temperature and relative humidity were mainly recognized as indirect factors influencing perceived air quality due to their impact on indoor air pollution sources (Fang et al., 2000). The temperature of the surrounding air is measured in degrees Celsius (°C), whereas relative humidity (RH) is the moisture content of the environment expressed in percentage. Perceived air quality (PAQ) is defined as evaluation of indoor air satisfaction and comfortable sensory perception by occupants (Woo et al., 2011).

According to the ICOP 2010, the recommended average relative humidity indoors is 40-70 %. If the indoor relative humidity exceeds the provided range, biological contaminants begin to accumulate which can lead to odour problems and health risks. On the other hand, health issues such as skin irritation and dry eyes may occur in rooms with relative humidity below the required range (General Filters Inc, 2022).

The air was evaluated as less acceptable with increasing temperature and humidity, and this impact was more evident with decreasing levels of air pollution (Fang et al., 2000). It can be concluded that lower temperature and relative humidity of the room improves the perceived air quality. Thus, the IAQ of the building improves with the good PAQ.

The wind transports air pollutants away from their source, where they disperse. Generally, the higher the wind speed, the greater the dispersion of the pollutant and lower their concentration. A study found that the level of particulate matter appeared to be higher with low wind speeds and vice versa (Cichowicz et al., 2020).

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter explains the methodology used to accomplish the study in detail. Figure 3.1 demonstrates the systematic process that must be followed in order to reach the objectives of the study. Data collection began on March 16, 2022 until April 22, 2022 in four selected hostel rooms at Desasiswa Lembaran, USM Engineering Campus. The indoor monitorings were conducted for two sessions for each room. The Optical Direct Reading Monitor (ODRM) called E-sampler-9800 from Met One Instruments, Inc. was used in this study, and the parameters that were highlighted were fine particulate matter ($PM_{2.5}$), ambient temperature, relative humidity and wind speed. The recorded data were analysed by using SPSS software and Microsoft Excel to investigate the relationship and pattern of the collected data.

## 3.2 Study Area

The study was carried out in four selected hostel rooms in SH2, Desasiswa Lembaran, USM Engineering Campus. All of the rooms are on the ground floor of the same building. Room A and B are located on the building side facing the east, while room C and D are built on the building side that face west as indicated in Figure 3.2 and Figure 3.7. The rooms facing the east receive morning sunlight, and the rooms facing the west are excessively exposed to sunlight in the evening. As a result, the indoor temperature for each room was slightly different depending on the exposure of the sunlight received during the day. Figures 3.3, 3.4, 3.5 and 3.6 showed the room layout for each room respectively.

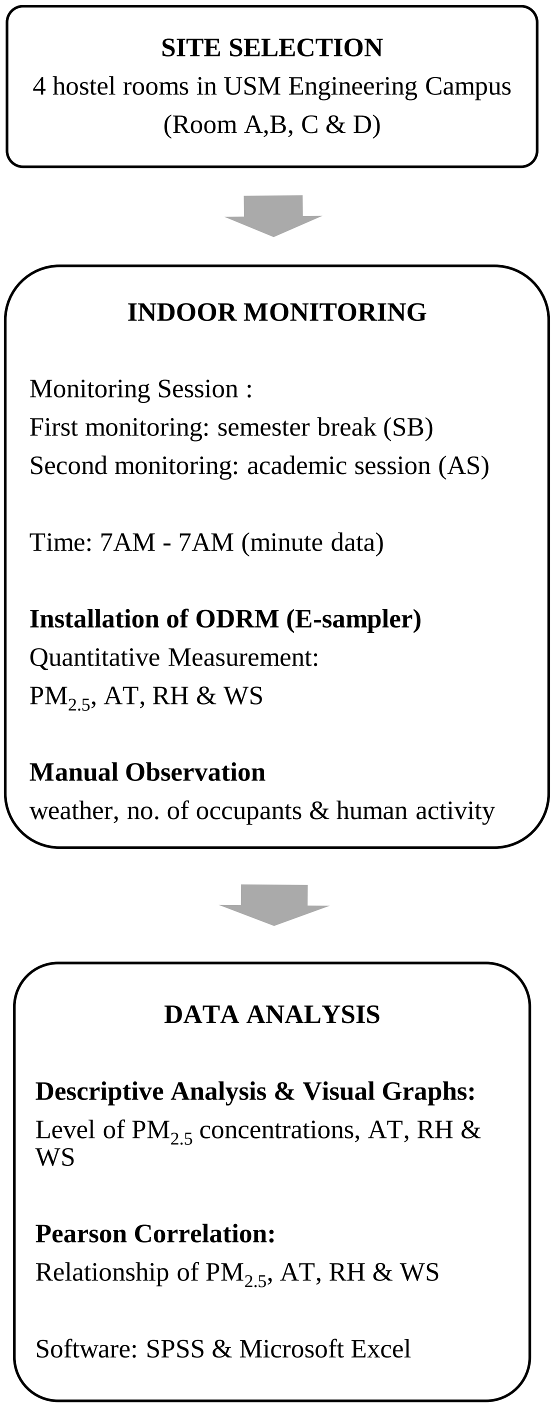



Figure 3.1: Flowchart of methodology

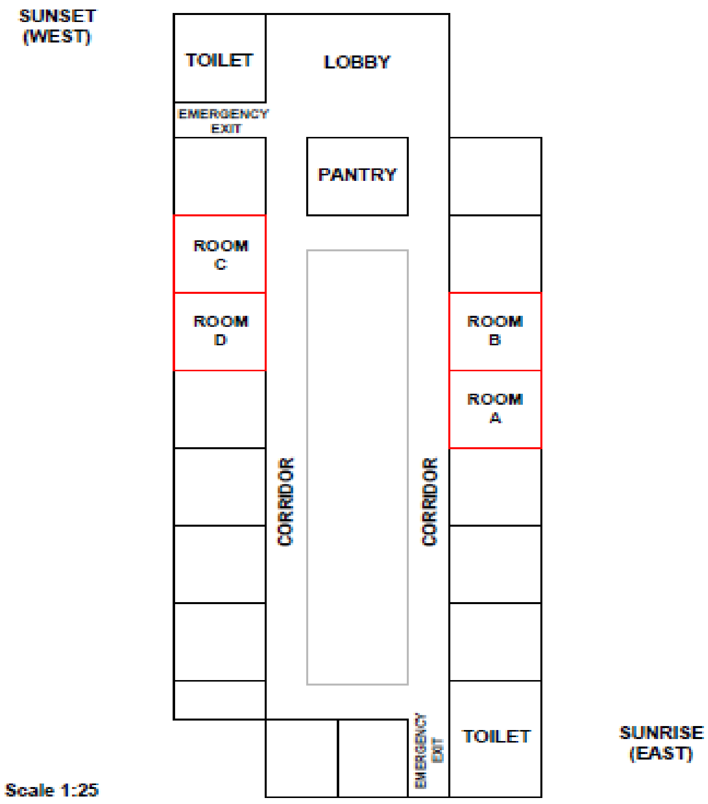



Figure 3.2: Location of the selected rooms in the hostel building

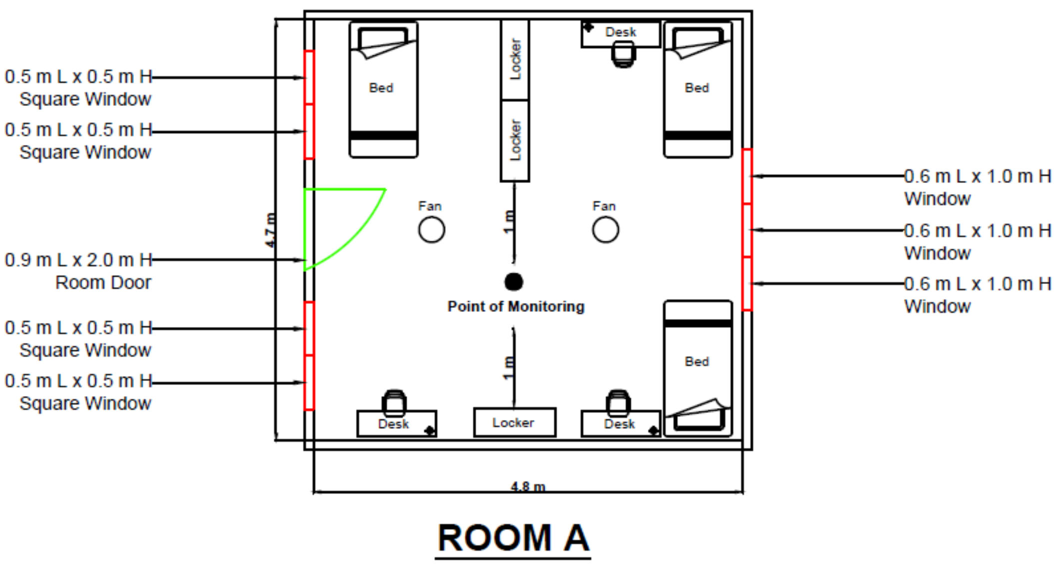



Figure 3.3: Room A layout

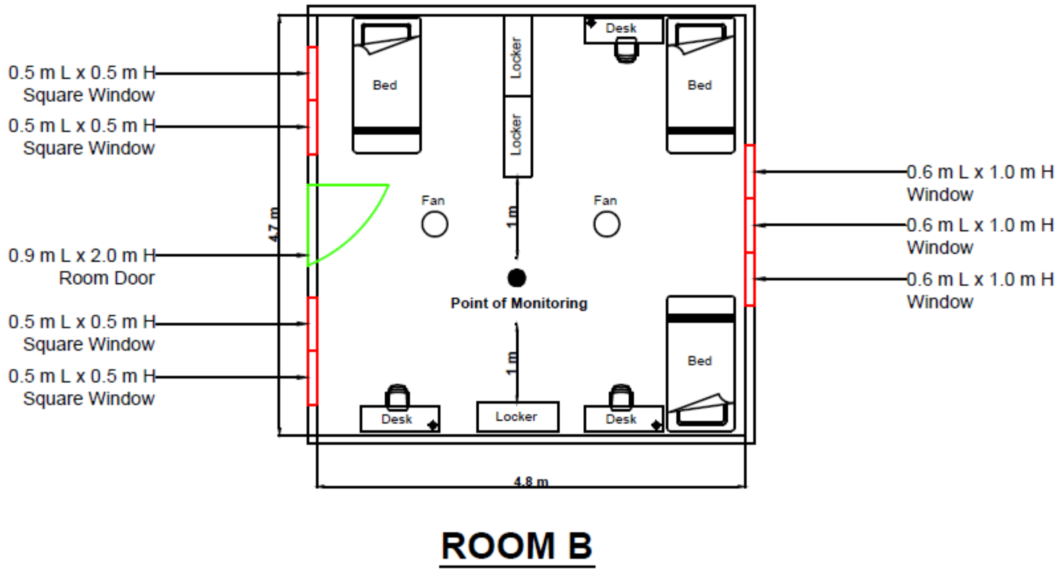



Figure 3.4: Room B layout

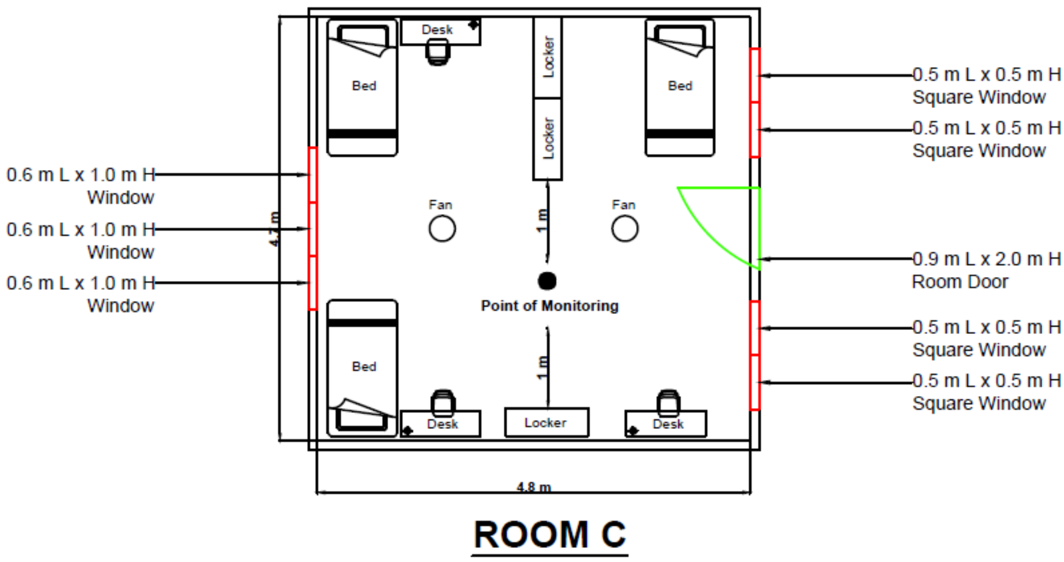



Figure 3.5: Room C layout

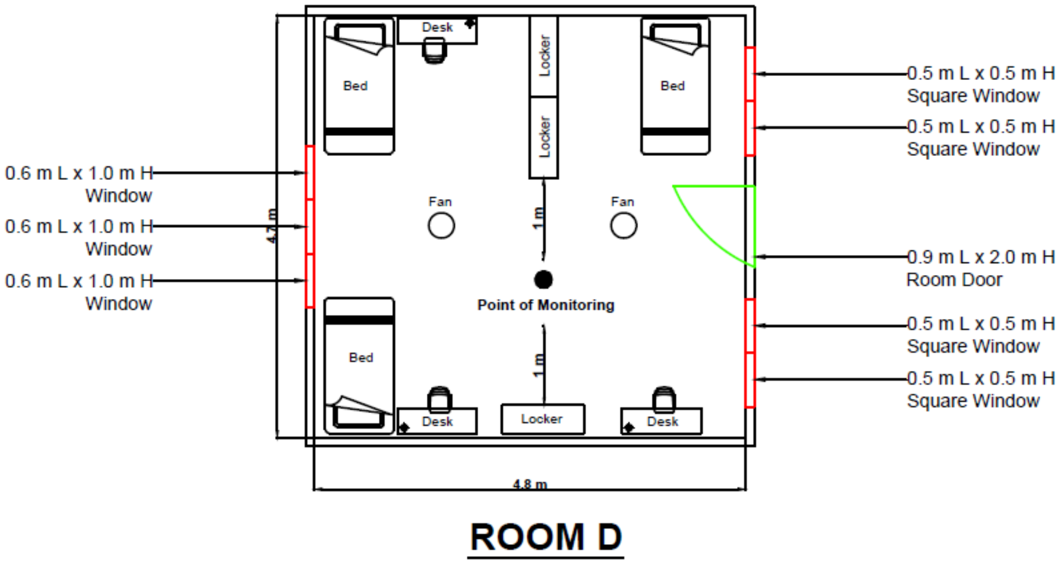



Figure 3.6: Room D layout

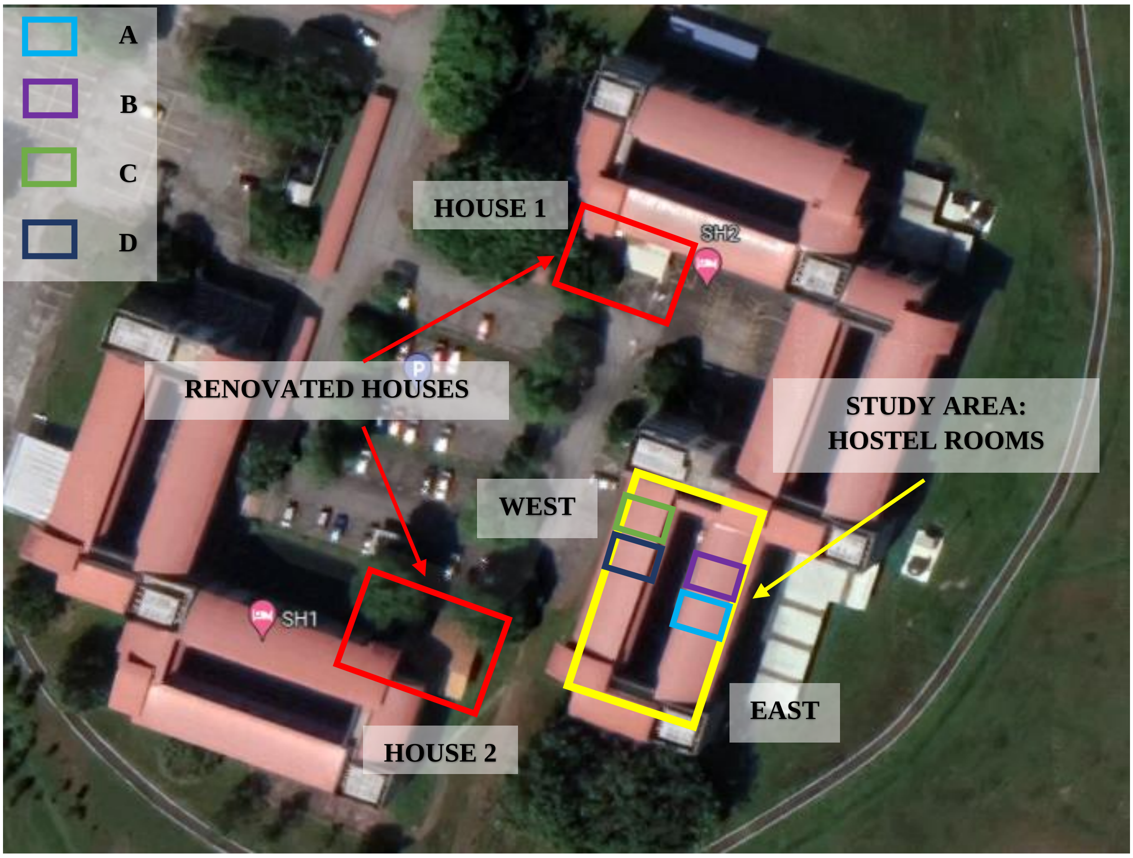



Figure 3.7: Location of renovated houses near the study area

Figure 3.8: Renovated house 1

Figure 3.9: Renovated house 2

The factors that contributed to the production of $PM_{2.5}$ in each room differed since activities done by the occupants were not the same. In this study, other contributors such as home renovation activities are also taken into account due to the location of the houses being in one kilometre radius within the study area, as shown in Figure 3.7. The renovated houses (Figure 3.8 and 3.9) are the houses of hostel officers. The administration opted to expand several spaces of the house to make the residents more comfortable.

## 3.3 Monitoring of $PM_{2.5}$

The monitoring sessions were carried out in four different hostel rooms. The monitoring period started from 16$^{th}$ March 2022 to 22$^{nd}$ April 2022 during the semester break (SB) and the academic session (AS). The two separate periods were chosen due to the students' availability at the hostel. The assessment was done by using an ODRM (E-sampler) to monitor fine particulate matter ($PM_{2.5}$) concentration and meteorological parameters such as temperature, relative humidity, and wind speed.

Each monitoring session was conducted from 7 a.m. to 7 a.m. the next morning. The data was continuously collected for a 24-hour period (minutes data). The monitoring sessions were repeated twice in each room to observe if there were any differences due to a variety of conditions. Study area characteristics are listed in Table 3.1.

Table 3.1: Study Area Characteristics

| Room | Position of the Room | Room Size | Date of Monitoring | Monitoring Period | No. of Occupancy |
|---|---|---|---|---|---|
| A | Facing east (morning sunlight) | 15.4 ft L 15.7 ft W 9 ft H | 16th to 17th March 2022<br>9th to 10th April 2022 | SB<br>AS | 2<br>3 |
| B | | 15.4 ft L 15.7 ft W 9 ft H | 18th to 19th March 2022<br>19th to 20th April 2022 | SB<br>AS | 0<br>3 |
| C | Facing west (evening sunlight) | 15.4 ft L 15.7 ft W 9 ft H | 20th to 21st March 2022<br>21st to 22nd April 2022 | SB<br>AS | 3<br>3 |
| D | | 15.4 ft L 15.7 ft W 9 ft H | 24th to 25th March 2022<br>15th to 16th April 2022 | SB<br>AS | 0<br>3 |

L: length, W: width, H: height, SB: semester break, AS: academic session.

### 3.3.1 Optical Direct Reading Monitor (ODRM)

The E-sampler is a dual technology device that combines a laser light scatter system with a gravimetric filter sampler system. This model is a type of nephelometer that uses the principle of forward laser light scatter to measure and record real-time $PM_{2.5}$, $PM_{10}$ or TSP particulate concentration levels automatically. The gravimetric filter sampler system can be used to collect the particulate for the subsequent gravimetric mass or laboratory evaluation. However, only a laser light scatter system is used in the research as there is no filter sample taken in the experiment.

The sample air is drawn into the E-sampler and passed via the laser optical module, where the particulate in the sample air stream scatters the laser light due to its reflective and refractive properties. A photodiode detector gathered the scattered light and converted the light to an electronic signal to determine a continuous, real-time measurement of airborne particulate mass concentrations. The setup of the E-sampler instrument is shown in Figure 3.10.

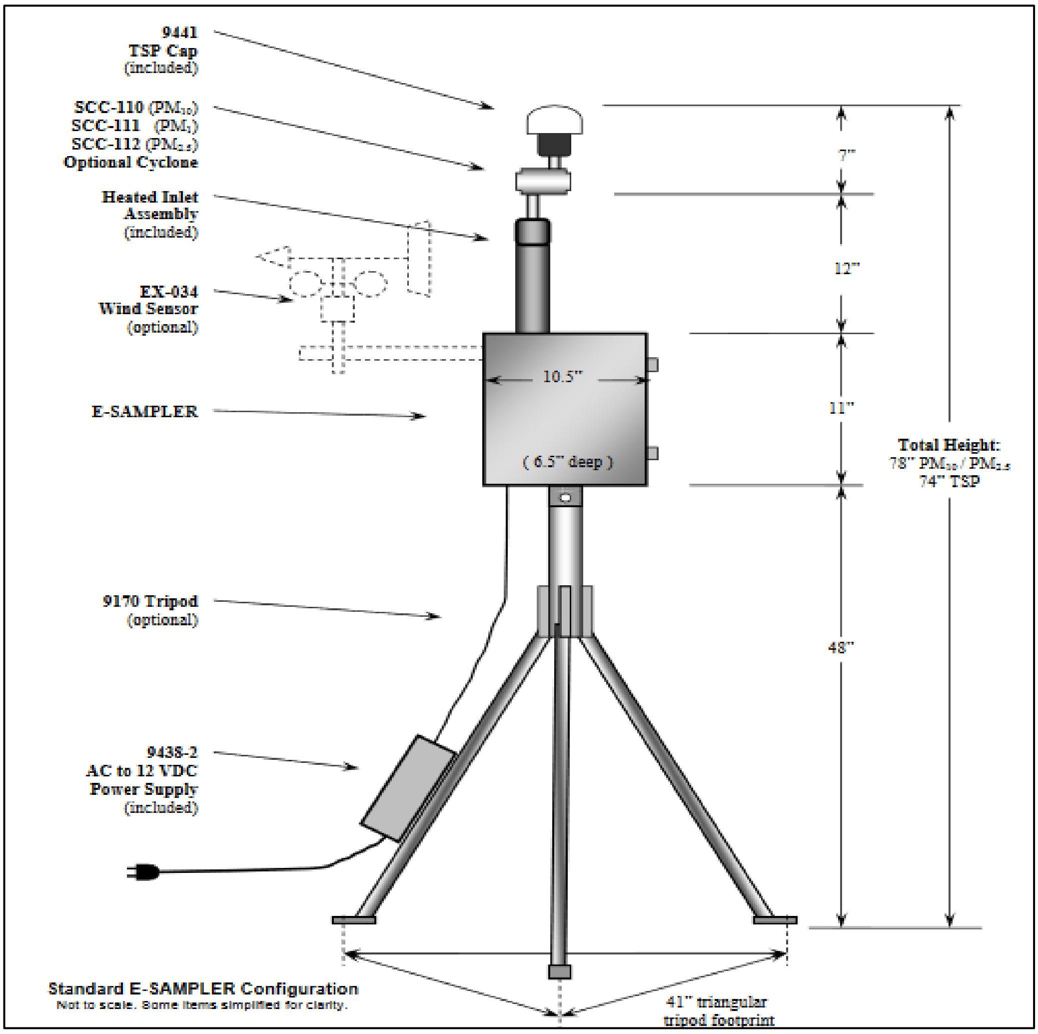



Figure 3.10: E-Sampler set up (Met One Instrument, Inc., 2009)

### 3.3.2 Physical Installation

The Met One EX-905 aluminium tripod was utilised to mount the E-sampler. The three stainless steel detent pins were removed from the tripod base by pulling the rings. The three legs were unfolded, and then the pins reinserted to secure the leg in the open position. The E-sampler control unit was installed to the tripod by sliding the slot on the back of the E-sampler over the mounting tab of the tripod. The control device was attached to the tripod with a ¼- inch bolt. The procedure was followed by the installation of a $PM_{2.5}$ sharp cut cyclone (Figure 3.11) to the inlet of the E-sampler, which was placed beneath the TSP inlet (Figure 3.11).


Figure 3.11: $PM_{2.5}$ cyclone and TSP inlet

The EX-034 wind speed/direction sensor was supplied and positioned on the end of the cross-arm, normally as far as possible from the control unit to enable the wind vane to fully rotate without hitting anything. For the collection data of ambient temperature and relative humidity, an ambient RH (EX-593) sensor was attached. All sensors were connected to the respective sensor inputs which located at the bottom of the control unit. At last, the power supply was connected to the bottom of the control unit and has been switched on. The E-sampler must be set up 1 hour before the monitoring period to allow the device to warm up. After the sampler has warmed up, the full calibration check was performed. The data from the E-sampler was retrieved