Investigation of Indoor Particulate Matter (PM) Level in Office Buildings in the UAE

البحث في مستوى الجسيمات الدقيقة في المكاتب في الامارات العربية المتحدة

by

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ABSTRACT

The air around us is a mixture of many elements from different states. The particulate matters are suspended particles in the air, which are in liquid or solid state. These particulate matters have a major impact on human health. Due to their size, they can be inhaled and penetrate through the respiratory system, causing allergies, diseases or in extreme cases, it can cause death.

This study focuses on investigating the concentration of indoor particulate matter in office buildings in the United Arab Emirates. Two offices in Dubai, the heart of the industrial hub, had been selected for the study. An online questionnaire had been distributed to the office workers, to collect information about the space. Participants from office A had shown some symptoms of difficulty in concentration, running nose, burning of eyes, dizziness, and difficulty in sleeping. Whereas in office B, the results of the questionnaire had indicated a rise in the symptoms experienced than in office A. The PM concentration had been measured at morning, noon and afternoon for each office, for two consecutive days. These results were compared with the international standard levels set by the World Health Organization. In office A, the $PM_{2.5}$ concentrations were 4.292 µg/m^3 (morning), 4.690 µg/m^3 (noon) and 3.735 µg/m^3 (evening). Whereas in office B, the $PM_{2.5}$ concentrations were 82.619 µg/m^3 (morning), 75.634 µg/m^3 (noon) and 56.851 µg/m^3 (evening). Unlike office B, office A were within the recommended 24-hour air quality guideline (AQG) level stated by the WHO for $PM_{2.5}$ which is 15 µg/m^3. For PM_{10} concentration in office A, it was 32.78 µg/m^3 (morning), 19.71 µg/m^3 (noon) and 8.63 µg/m^3 (evening). While in office B, the PM_{10} concentration were 133.083 µg/m^3 (morning), 100.661 µg/m^3 (noon) and 59.490 µg/m^3 (evening). Based on the results, PM_{10} concentration in office A were within the recommended 24-hour AQG level for PM10 which is 45 µg/m^3. There were many factors that had led the PM concentration in office B to be high, including the office building being located in an

industrial district and the use of split system air conditioning which cools only the air without exhausting the air pollutants in the space. The author had further investigated the particle count emitted by the common sources of air pollutants in an office space, which are the human and the computer. Based on the measurements and calculations, the $PM_{2.5}$ particle count emitted by the human is 35 particles per minute as an approximate. While for the computer, a total of 10 particles of $PM_{2.5}$ is emitted per minute. For particles which are larger in size (PM_{10}) they were emitted by the human with a total of 1 particle per 2 minutes and 18 seconds.

ملخص البحث

الهواء المحيط بنا عبارة عن مزيج من العديد من العناصر من حالات مختلفة. الهباء الجوي ، أو المعروف أيضًا باسم المواد الجسيمية ، عبارة عن جسيمات معلقة في الهواء ، تكون في حالة سائلة أو صلبة. هذه الجسيمات لها تأثير كبير على صحة الإنسان. نظرًا لحجمها ، يمكن استنشاقها واختراقها عبر الجهاز التنفسي ، مما يسبب الحساسية أو الأمراض أو في الحالات القصوى ، يمكن أن تسبب الوفاة.

تركز هذه الدراسة على التحقيق في تركيز الجسيمات الداخلية في مباني المكاتب في دولة الإمارات العربية المتحدة. تم اختيار مكتبين في دبي ، قلب المركز الصناعي ، للدراسة. تم توزيع استبيان عبر الإنترنت على العاملين بالمكتب لجمع معلومات عن المكان. أظهر المشاركون من المكتب (أ) بعض أعراض صعوبة التركيز وسيلان الأنف وحرق العين والدوخة وصعوبة النوم. بينما في المكتب (ب) ، أشارت نتائج الاستبيان إلى ارتفاع في الأعراض التي ظهرت في المكتب (أ). تم قياس تركيز الجسيمات في الصباح والظهيرة وبعد الظهر لكل مكتب لمدة يومين متتاليين. تمت مقارنة هذه النتائج مع المستويات القياسية الدولية التي وضعتها منظمة الصحة العالمية. في المكتب (أ) ، كان تركيز 4.292 PM2.5 ميكروغرام / متر مكعب (صباحًا) ، 4.690 ميكروغرام / متر مكعب (ظهرًا) و 3.735 ميكروغرام / متر مكعب (مساءً). بينما في المكتب (ب) ، كان تركيز PM2.5 82.619 ميكروغرام / متر مكعب (صباحًا) ، 75.634 ميكروغرام / متر مكعب (ظهرًا) و 56.851 ميكروغرام / متر مكعب (مساءً). على عكس المكتب (ب) ، كان المكتب (أ) ضمن مستوى إرشادات جودة الهواء الموصى به على مدار 24 ساعة الذي حددته منظمة الصحة العالمية لـ PM2.5 وهو 15 ميكروغرام / م 3. بالنسبة لتركيز PM10 في المكتب (أ) ، كان 32.78 ميكروغرام / متر مكعب (صباحًا) ، 19.71 ميكروغرام / متر مكعب (ظهرًا) و 8.63 ميكروغرام / متر مكعب (مساءً). أثناء التواجد في المكتب (ب) ، كان تركيز PM10 133.083 ميكروغرام / متر مكعب (صباحًا) ، و 100.661 ميكروغرام / متر مكعب (ظهرًا) و 59.490 ميكروغرام / متر مكعب (مساءً). بناءً على النتائج ، كان تركيز PM10 في المكتب (أ) ضمن مستوى إرشادات جودة الهواء الموصى به على مدار 24 ساعة لـ PM10 وهو 45 ميكروغرام / متر مكعب. كانت هناك العديد من العوامل التي أدت إلى ارتفاع تركيز تركيز الجسيمات الداخلية في المكتب (ب) ، بما في ذلك تواجد المبنى في منطقة صناعية واستخدام نظام تكييف (split system) الذي يبرد الهواء فقط دون استخراج ملوثات الهواء في الفضاء. قام المؤلف أيضًا بالتحقيق في عدد الجسيمات المنبعثة من

المصادر الشائعة لملوثات الهواء في المساحات المكتبية ، وهي الإنسان والكمبيوتر. بناءً على القياسات والحسابات ، يبلغ عدد الجسيمات PM2.5 المنبعثة من الإنسان 35 جسيمًا في الدقيقة كتقريبي. بينما بالنسبة للكمبيوتر ، ينبعث ما مجموعه 10 جسيمات من PM2.5 في الدقيقة. بالنسبة للجسيمات الأكبر حجمًا (PM10) ، تم إطلاقها بواسطة الإنسان بإجمالي جسيم واحد لكل دقيقتين و 18 ثانية.

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CHAPTER 1: INTRODUCTION

During the last century, there had been a dramatic enhancement in the technological field which had transformed our daily lifestyle. People who are living in towns and cities are spending around 90% of our time indoors, either at home or in a workspace. All this comes with a price, which have raised the emissions of air pollution in our surrounding atmosphere and consequently, increased the importance of indoor air quality (IAQ). Indoor activities such as cooking, smoking and use of electronic machines emits air pollutants (Kishi, Norback and Araki, 2020).

The World Health Organization (WHO) had considered the air pollution as the single biggest environmental threat to human health. This could be measured from its impact on the burden of disease (World Health Organization, 2021).

Due to the lack of awareness about the topic and its impact on the human health, there are minimal research papers had investigated the indoor particulate matter concentration in office buildings in hot and humid climatic countries, and absence of papers in the United Arab Emirates. Many papers have looked into the indoor air quality in general with the concentration of each pollutant.

This paper will study the PM10 and PM2.5 concentrations in two office spaces in Dubai, one in a well-designed office which is located in a commercial district, while the other office is in a poorly-designed building in an industrial district. The results will be compared with the World Health Organization (WHO) standards. In addition, will look into the health symptoms felt by the office users by distributing a questionnaire. Finally, will propose several solutions to have a better indoor air quality with minimal or controlled PM concentrations.

1.1. Motivation of the study

The number of deaths caused from indoor air pollution is considered as one of the world's largest environmental problems. (Ritchie and Roser, 2022) Socio-demographic index (SDI) is a measure in which identifies the level of development for each country. Low and Low-middle SDI countries suffer with the largest rates of death, resulted from inaccessibility to clean fuels for daily-life usage (Ritchie and Roser, 2022).

The Lancet is an international medical journal with a trusted source of public health, clinical and global health knowledge. The journal publishes the Global Burden of Disease (GBD) study which is led by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington, Seattle (USA). It assesses the mortality and morbidity caused by diseases, injuries and other risk factors in more than 200 countries. One of the findings for the 2019 GBD study is that there is an increase in risk exposure for the ambient particulate matter pollution (Murray et al., 2020). In 1990s, the summary exposure value (SEV) of the global population exposed to maximum risk of particulate matter is 44.22%. This value had declined reaching to 37.56% in 2010 and 33.94% in 2019. Based on these values, a total of 2.68 billion people worldwide being exposed to maximum risk of particulate matter in 2019. Figure 1 shows the total population being exposed to the maximum risk of particulate matter in 1990, 2010 and 2019 (Ritchie and Roser, 2022).

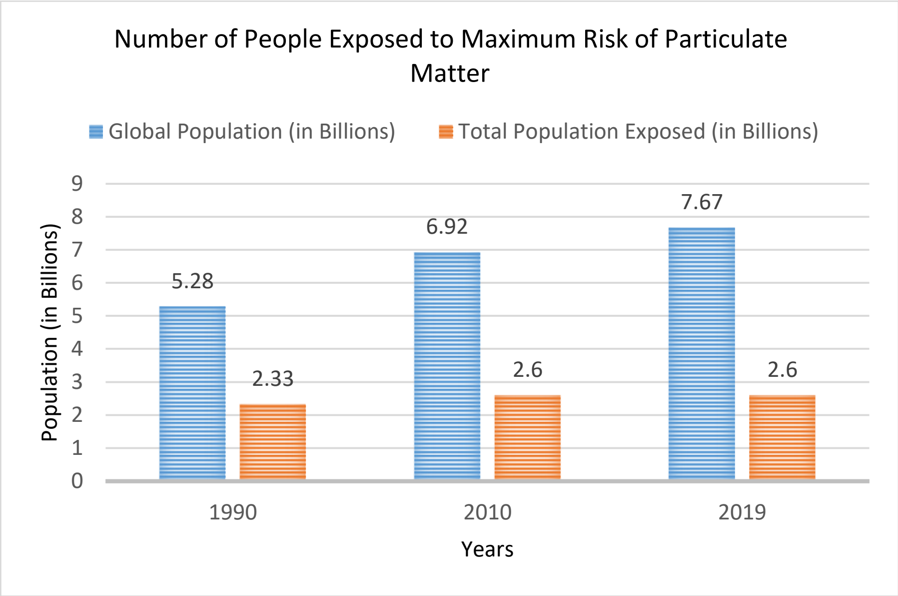


Figure 1: The total number of people being exposed to the maximum risk of particulate matter in 1990, 2010 and 2019. (Ritchie and Roser, 2022)

Besides, the World Bank Group which is a global partnership between five institutions: The International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), the International Finance Corporation (IFC), the Multilateral Investment Guarantee Agency (MIGA) and the International Centre for Settlement of Investment Disputes (ICSID). The main purpose of this partnership is to look into the sustainable solutions for the rise of the developing countries and to reduce poverty. (Who we are, n.d.)

The World Bank Group had published a report in 2020 which uses the GBD 2016 estimates. The $PM_{2.5}$ exposures in the Middle East and North Africa (MNA) has the highest $PM_{2.5}$ exposures with a total of 79 μg/m^3, followed by South Asia (SA) with 77 μg/m^3, Sub-Saharan African (SSA) regions with 68 μg/m^3, East-Asia and Pacific (EAP) regions with 43μg/m^3, Europe and Central Asia (ECA) with 19 μg/m^3, Latin America and the Caribbean (LAC) with 17 μg/m^3 and the North America (NA) having the lowest exposure of 9 μg/m^3.

Compared to the WHO's annual air quality guideline (AQG) all these values are above the AQG level which is 5 µg/m³ as shown in figure 2 (World Bank Group, 2020).

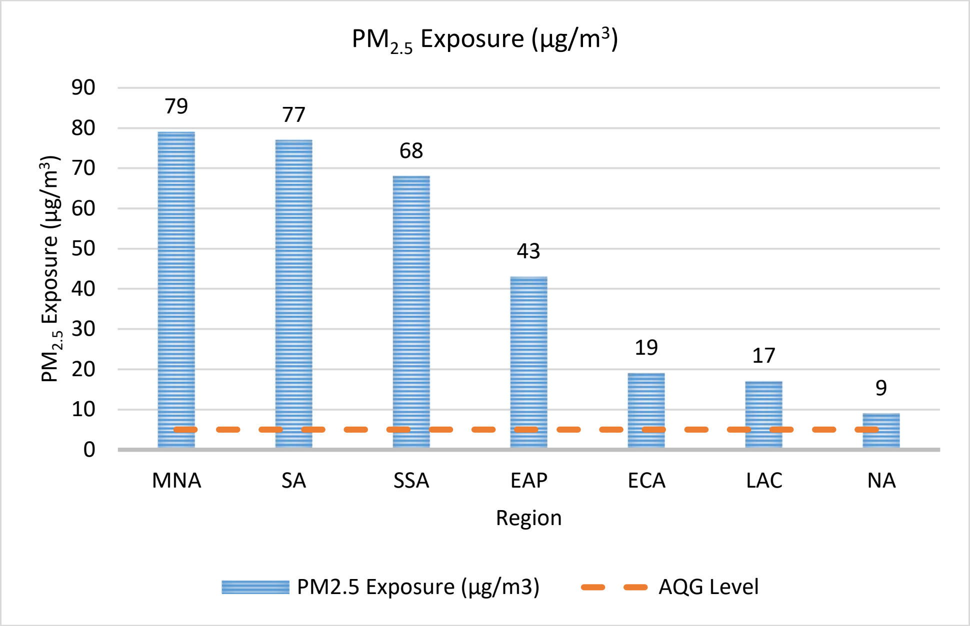


Figure 2: The regional $PM_{2.5}$ exposure in 2016 compared with the AQG annual level (World Bank Group, 2020)

Figure 3 and 4 illustrates the number and share of deaths for the most fatal respiratory illnesses caused from PM2.5 exposures in 2016. The ischemic health disease had the highest mortality rate with a total death of 1,576,105 deaths and shares about 39% of the total deaths. Followed by the cerebrovascular and COPD diseases with a 19% each of the global deaths. Then the lower respiratory infections with a 16% share and then the lung cancer with a 7% (World Bank Group, 2020).

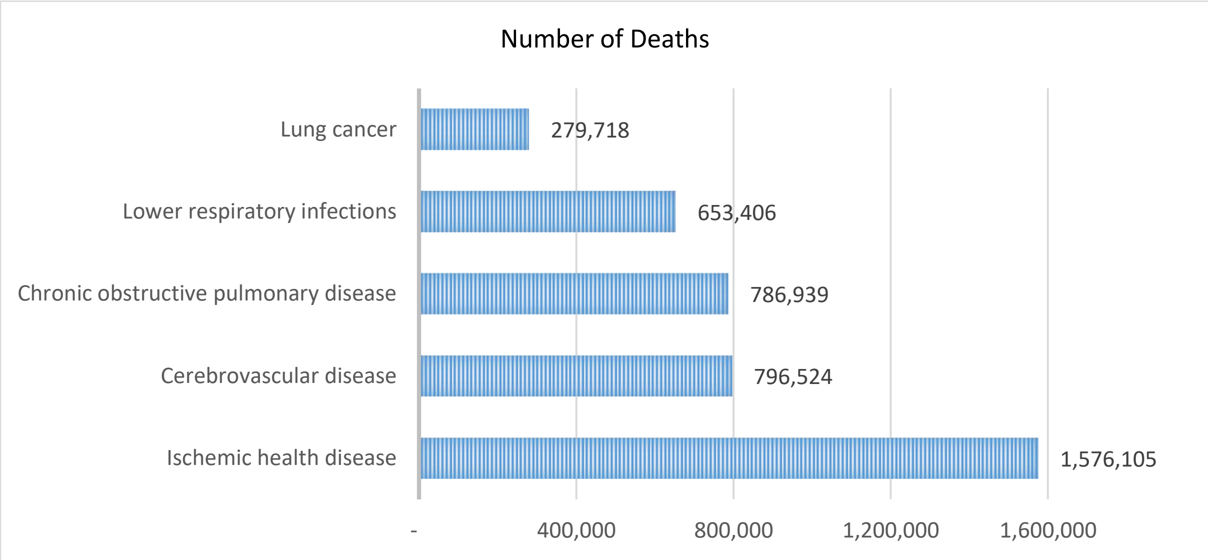


Figure 3: Number of deaths caused by PM2.5 exposure-related diseases in 2016 (World Bank Group, 2020).

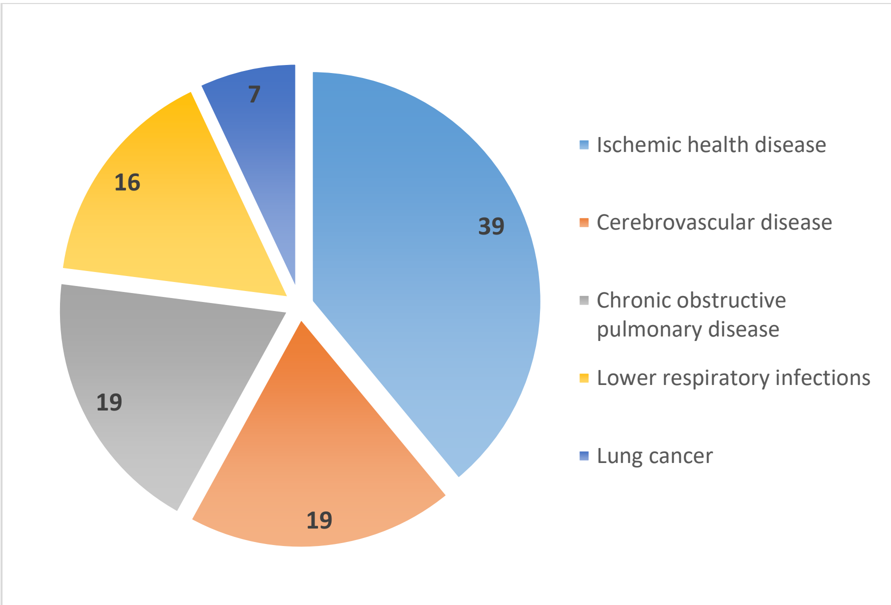


Figure 4: Share of deaths caused by PM2.5 exposure-related diseases in 2016 (World Bank Group, 2020).

To avoid the increasing number of deaths due to respiratory diseases worldwide, the WHO had recommended to minimize the ambient and indoor air pollution in all countries, by adopting WHO standards, which will be discussed later in Chapter 3.6.

The roadmap of a research design should follow the following steps; (1) selecting a topic of the research, (2) develop a research questions generated from the research topic, (3) reviewing of previous studies published, (4) selecting the methodology to be used, (5) data collection and analysis, and finally (6) the conclusion.

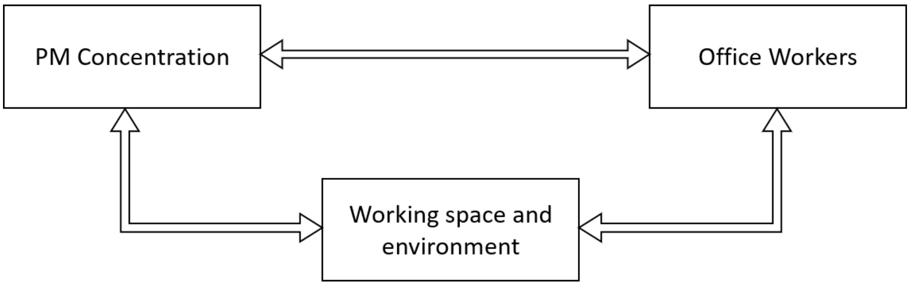
1.1. Research Question

Ibrahim (2015) had looked into the indoor air quality of office buildings in the UAE. However, the author here had focused on other indoor air quality parameters other than the particulate matter concentration in office spaces.

In this study, there was a need to investigate the particulate matter concentration in office buildings in the UAE and based on the inclined risk and symptoms associated with exposure, the research question had been formulated.

1.2. Aims and objectives

The main goal of the research paper is to investigate the particulate matter concentration in office spaces in the United Arab Emirates. However, to identify the standard of working in an office environment, the PM concentration will be measured for a well-designed office space and a poorly designed. The results to be compared with the World Health Organization (WHO) guidelines for the PM concentration. It’s impact on health to be studied by distributing a questionnaire to the office users. Finally, to look into the emissions extracted from commonly used equipment in an office space, such as computers and printers.


PM Concentration
Office Workers
Working space and environment

CHAPTER 2: LITERATURE REVIEW

2.1. Indoor Air Quality (IAQ)

2.1.1. What is Indoor Air Quality (IAQ)

The Environmental Protection Agency in the United States (US EPA) had described the indoor air quality (IAQ) as the air quality of an indoor space in which has a direct impact on the human's health and comfort (Introduction to Indoor Air Quality | US EPA, n.d.). The indoor air quality is a subset of the broader, indoor environmental quality (IEQ). There are many factors affecting the air quality of an indoor space. These factors are the air temperature, relative humidity, air exchange rate, concentration of air pollutants, outdoor climate, and the activity of the occupants (Dorgan and Dorgan, 2006).

The air quality can be controlled early from the design stage. For instance, ensuring a proper ventilation of the structure, to avoid contamination and the selection of finishing materials with minimal emissions. While during the construction phase, a proper construction of the joints avoiding the infiltration of outdoor air pollutants to the indoor spaces (Introduction to Indoor Air Quality | US EPA, n.d.).

The indoor air quality is altered by the sources of air pollutants in a given space. The known pollutants which had been stated by the US EPA includes the asbestos, biological pollutants, pesticides, carbon monoxide, formaldehyde, lead, nitrogen dioxide, radon, volatile organic compounds and particulate matters (Indoor Pollutants and Sources | US EPA, n.d.). These contaminants are released from various interior materials. Radon gas is emitted from construction materials such as sand, concrete, cement and masonry units, gypsum board and marble. Whereas materials like wood, paint, adhesives, rubber and synthetic resin emits formaldehyde and volatile organic compounds (VOC) to the air

(Panagopoulos, Karayannis, Kassomenos and Aravossis, 2011). Figure 5 highlights the potential air pollutants emitted in an office space.

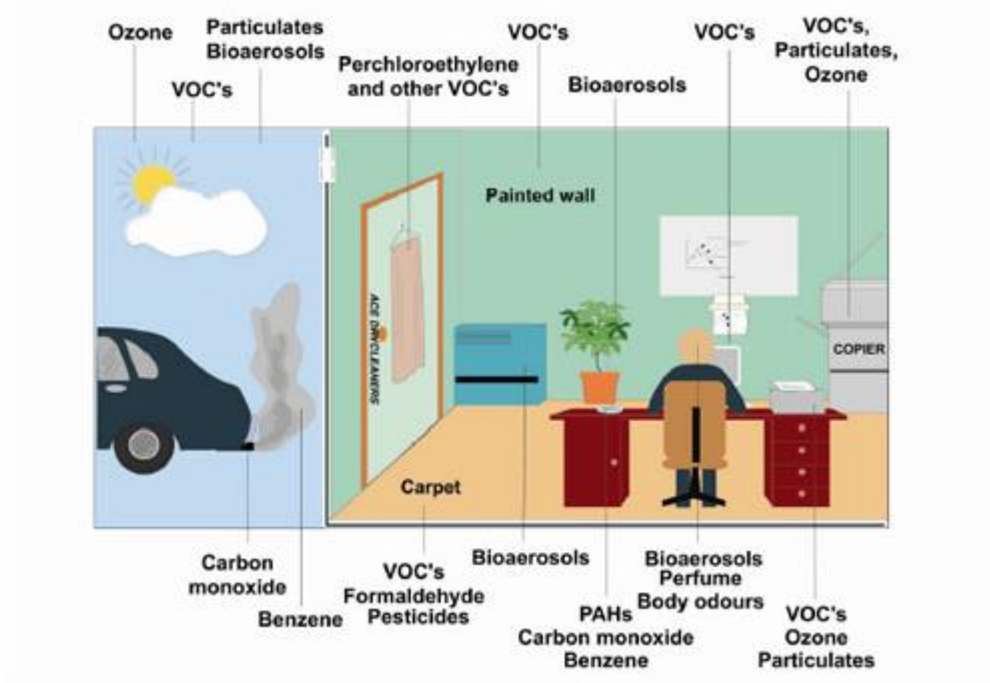


Figure 5: Common sources of indoor air pollutants in an office (Indoor air quality estimator, n.d.).

The importance of breathing fresh air relies on understanding how the human lungs work. As described by the American Lung Organization, the lungs are the essential organs of the respiratory system. Its function is to provide the body with fresh air while extracts waste gases. Air pollutants have a negative impact on the respiratory system and organs (How Lungs Work, 2021). Pramitha and Haryanto (2019) had assessed 109 adults being exposed to indoor particulate matter (PM) in an industrial area east of Jakarta, Indonesia. The results had shown that more than 38% of the participants had lung function impairment (Pramitha and Haryanto, 2019).

Exhaled air from human beings, building materials, indoor activities, infiltration are common sources of indoor air pollutants. On top of all, burning of fossil fuel for cooking and heating is considered as the main cause of indoor air pollutants, especially in the developing countries (Sundell, 2004).

2.1.2. Impact of Poor Indoor Air Quality

Building-related illnesses (BRI), sick building syndrome (SBS), allergies and acute exposure are symptoms of poor IAQ. Sick building syndrome are symptoms of acute health effects and discomfort feeling felt by the occupants of a space. These symptoms are such as headache, irritation of nose, eyes or throat, dry cough, dizziness, difficulty in concentration. The SBS are symptoms without knowing the main reason or cause, unlike the building-related illnesses, were the main cause is defined (Indoor Air Facts No. 4 Sick Building Syndrome, 1991).

Prolonged exposure to air pollutants deteriorates the human's health. Diseases such as acute lower respiratory infections for children under 5 years old, lung cancer, stroke and cardiovascular diseases in adults are consequences of this exposure. Duration of exposure and the sensitivity of the inhaler are the factors that determines the impact of air pollutants on health. For instance, people who are suffering from asthma or heart disease may notice severe health impacts (Frequently Asked Questions about Air Pollution, n.d.).

The impact can be either short-term effect or long-term effect. Some of the short-term symptoms may include a headache, eye irritation, throat irritation, dizziness and feeling tired (Introduction to Indoor Air Quality | US EPA, n.d.). Besides, long-term symptoms can be respiratory diseases, heart disease or even cancer. In extreme cases, it can lead to death. Based on the estimates of the Institute for Health Metrics and Evaluation (IHME), the number of people died due to indoor air pollution in 2017 was around 1.6 million, which was 3 percent of the total recorded deaths at this year (Ritchie and Roser, 2022). Lately, the

WHO had published in September 2021, that the number of deaths due to indoor air pollution had reached to 3.8 million annually, which had crossed the double number of deaths in 4 years. Deaths were caused by pneumonia, ischaemic heart disease, chronic obstructive pulmonary disease (COPD), stroke and lung cancer (Household air pollution and health, 2021).

Figure 6 shows the share of deaths related to indoor air pollution across the world. The majority of deaths caused by the indoor air pollutants are found in the low-income countries, especially in the African continent. This is due to three main factors; the infiltration of outdoor pollutants, the human activity inside the building and the building materials used to include the furniture and equipment. Lack of knowledge, awareness and resources maximizes the risk of being exposed to harmful pollutants (Ritchie and Roser, 2022).

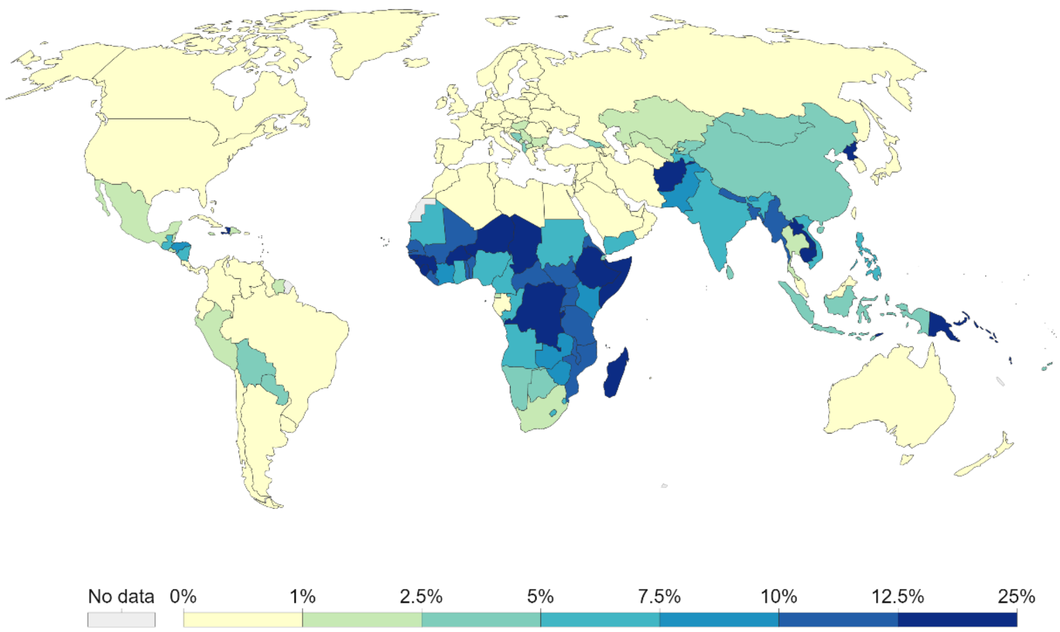


Figure 6: Global share of deaths from indoor air pollution in 2019 (Ritchie and Roser, 2022).

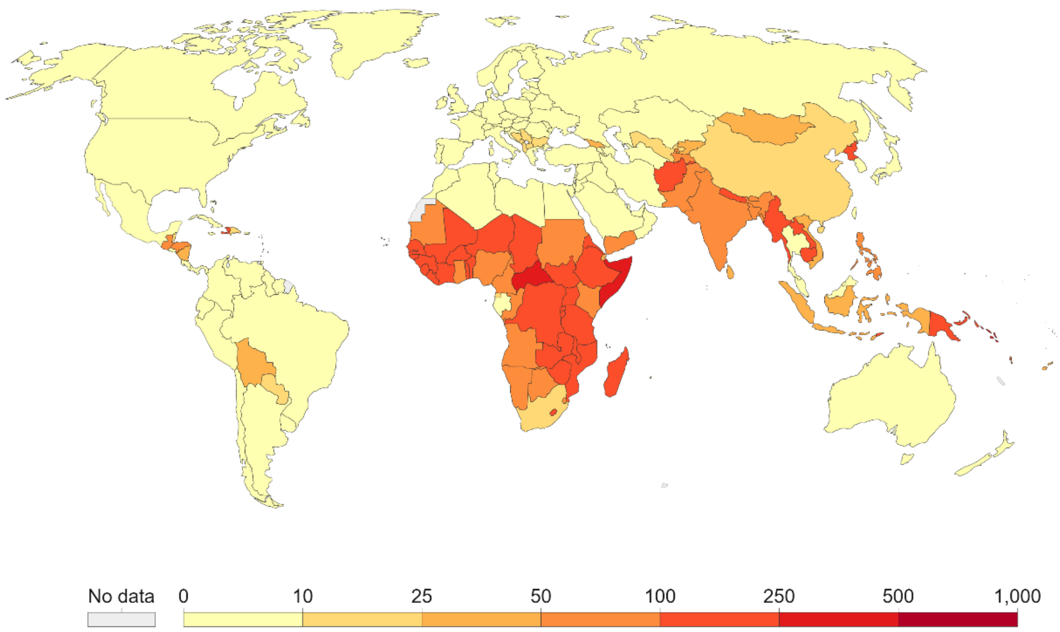


Figure 7: The death rates from indoor air pollution in 2019 (Ritchie and Roser, 2022).

It was noticed that the islands have the largest share of deaths. The country with the highest number of deaths is the Solomon Islands. It is an islands in the South Pacific Ocean, with almost 400,000 recorded deaths (20.69% death rates) of their total population in 2019. Figure 8 illustrates the lifestyle and dilapidated houses in the Solomon Islands. Papua New Guinea, Vanuatu and Kiribati are islands near to the Solomon Islands, which are facing a huge risk with the highest number of deaths. Madagascar, an island in the African continent is facing the same threat. Somalia, Central African Republic, Niger, Guinea-Bissau, Chad, Burundi, Mozambique and Guinea are the African countries with the largest share of deaths. Afghanistan is the first Asian country with a total recorded death of 179,000 in the year of 2019.

Figure 8: Streets and houses in Solomon Islands. (Solomon Islands PM blames violent anti-government protests on foreign interference, 2021)

In 1990s, the number of deaths caused by indoor air pollution exceeded the 4 million deaths (Figure 9). This had dropped and reached to around 2.3 million deaths in 2019. In terms of age groups, the largest were for the children under the age of 5 years. With a total death of almost 1.5 million in 1990, it had declined to less than 500,000 deaths in 2019, with being the third largest group. For the 70+ years age group, the number of deaths remain high with minimal drop in the past 3 decades, from 1.42 million in 1990 to 977,000 deaths in 2019.

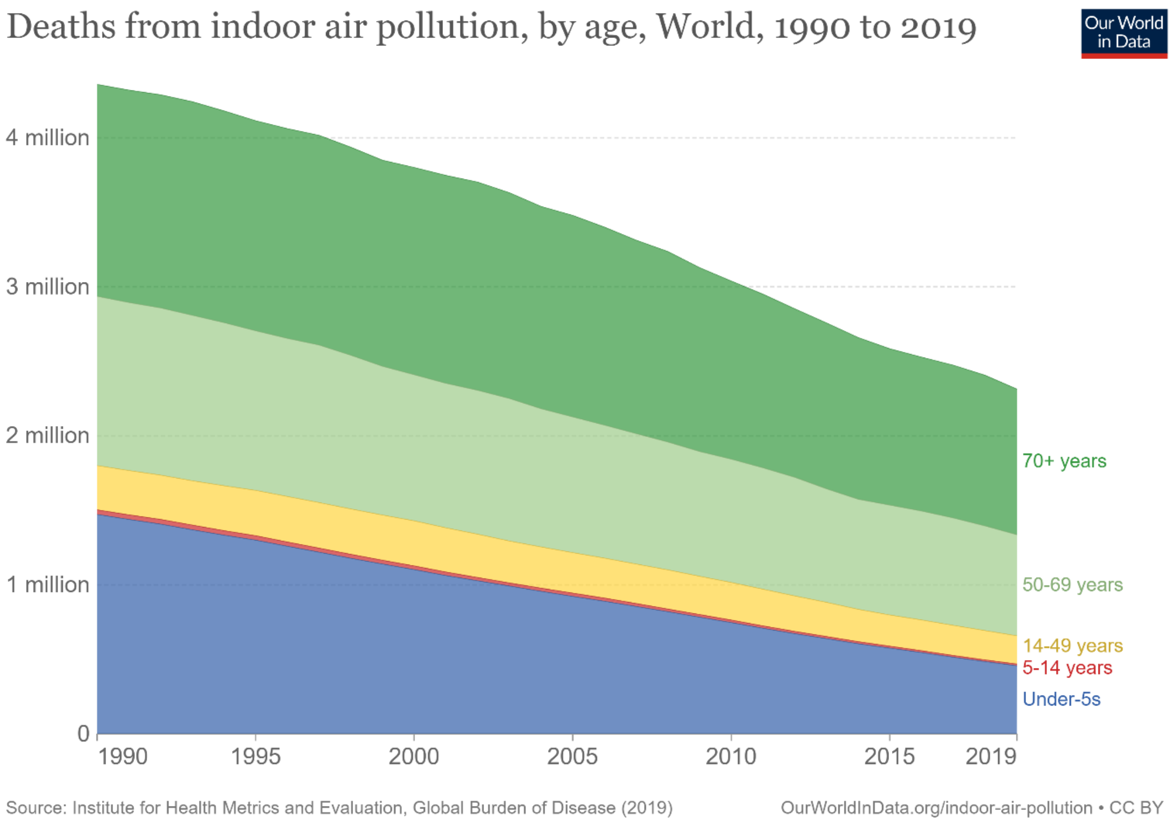


Figure 9: The number of deaths caused from indoor air pollution split into different age groups.

Poor indoor air quality has a negative impact on the human health and their activity. Figure 10 highlights the common health effects caused by the indoor air pollutants. A building in Mashhad, Iran had been investigated. Results had shown that staff working in poor IAQ complains from headache, tiredness and a dusty air (Atarodi et al., 2018). Despite that it does not stimulate a specific symptom, it can affect the respiratory, neurological, or even the cardiovascular system (Azuma et al., 2020).

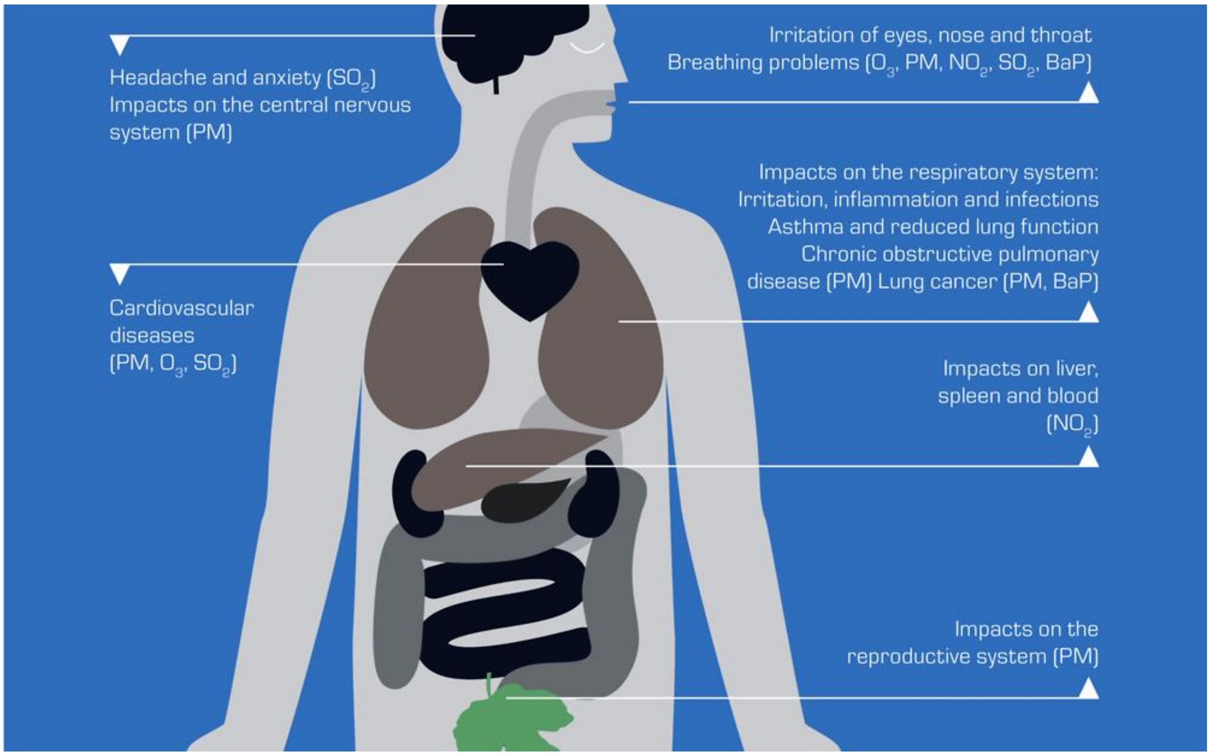


Figure 10: The common human health effects caused by indoor air pollutants (Health impacts of air pollution, 2014).

2.1.3. Sources of Air Pollutants

Our daily activities eventually cause the discharge of indoor air pollutants, creating a favourable atmosphere for the growth of mold, fungus, viruses, pollen, dust mites and roaches. These contaminants degrade the indoor air quality of a given space.

There are various sources of air pollutants in an office building. Emissions from the building materials are one of the main sources which includes asbestos, formaldehyde, organics, paints, adhesives, cleaning materials, carpets and furnishings. Electronics such as computers, copying machines, printers and other office machines releases pollutants. In addition, poor airtightness may result in transportation of air pollutants from outdoors to indoors. Biological contaminants, pesticides and other chemicals can be sources of office pollutants (Do You Suspect Your Office Has an Indoor Air Problem? 2022). Rasli et al.

(2021) had claimed that the indoor air quality is highly influenced by the ventilation within the building.

2.2. Particulate Matter (PM)

2.2.1. What is a Particulate Matter?

Indoor Particulate Matter (PM) is an indoor air pollutant. The air around us, has a mixture of solid particles mixed with water droplets, is commonly known as the particulate matter. The PM is divided into two groups in terms of particle size. Particles with a diameter of 10 micrometer or less is known as PM_{10} or coarse particles, whereas particle sizes with a diameter of 2.5 micrometer or less is known as $PM_{2.5}$ or fine particles. The comparison between the particle sizes is shown in figure 11. Coarse particles found in the atmosphere cannot enter into the respiratory system, hence, their health impact is limited. However, the fine particles are most often respirable and accumulate in the respiratory system, causing serious complications.

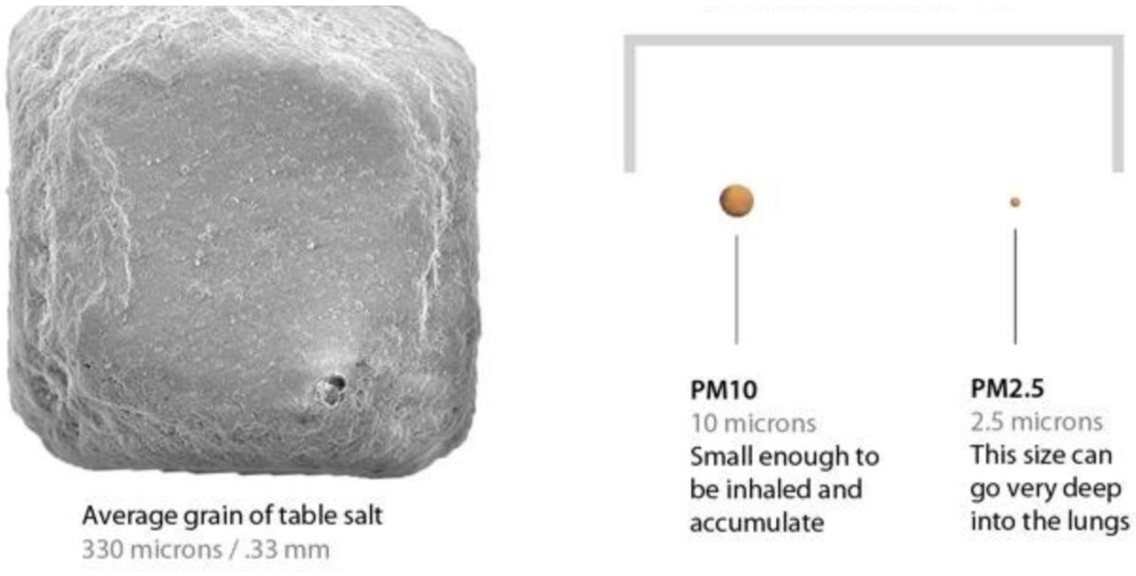


Figure 11: Size comparison between particulate matters and a grain of table salt. (Fine particle pollution, n.d.)

The particulate matter is a combination of inorganic salts (figure 12) such as ammonium nitrate, sodium chloride and ammonium sulphate along with biological materials, elemental and organic carbon, minerals extracted from rocks and trace metals (Zeb et al., 2018). Zeb et al. (2018) in their study had investigated the composition of the outdoor particulate matters in Pakistan. A total of 14 elements; oxygen, carbon, nitrogen, silicon, calcium, iron, aluminium, chlorine, potassium, magnesium, sulphur, sodium, titanium and zinc. Activities such as biomass burning, vehicular traffic, fossil fuel generators, emissions from industries and other anthropogenic activities increases the carbon percentage in the air. Inhaling black carbon causes many diseases including lung cancer. Figure 13 shows the shape and size of a particle, which had been taken under an electron microscope (to be explained later at chapter 2.4).

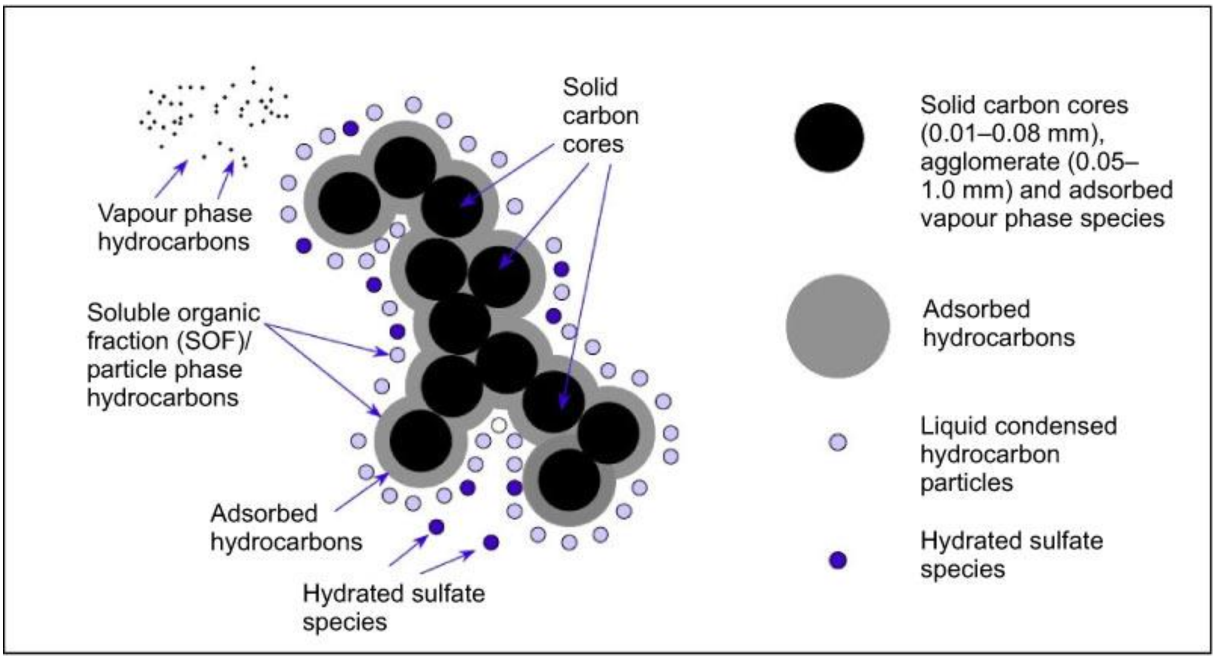


Figure 12: The composition of a particulate matter (Mohankumar and Senthilkumar, 2017).

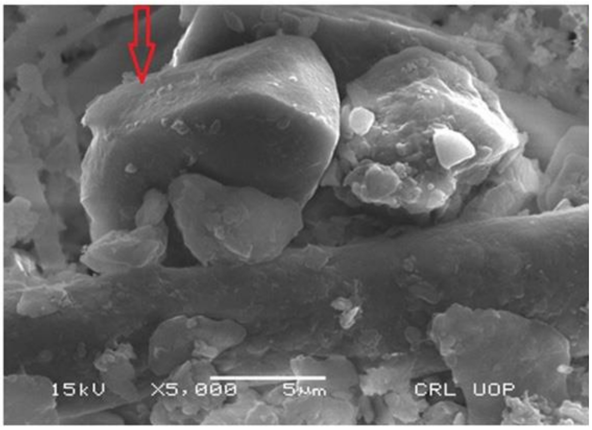


Figure 13: The morphology of a particle with a size of 26 µm (Zeb et al., 2018).

Sources of the particulate matters are either natural or a secondary source. The natural sources include windblown dust, volcanic eruption, sea salt, crustal materials. These sources tend to emit large-sized particles. On the other hand, processes such as stemming from man-made or natural emissions, and gas-to-particle conversion are examples of secondary processes. Some pollutants are locally emitted, while others are travel along with winds.

As Kyung and Jeong (2020) from the Department of Allergy in the Gachon University Gil Medical Center in Korea, had stated that being exposed to high PM concentration leads to oxidation stress and direct toxic injury. Consequently, an increase in pulmonary inflammation and respiratory symptoms aggravation, causing critical situation especially to those who are allergic or with a respiratory disease. As the pulmonary function indicates the respiratory health, prolonged exposure to high PM concentration increases the risk of chronic obstructive pulmonary disease (COPD) and even lung cancer being spread among adults. In addition, the authors had studied and concluded that the number of patients with COPD admitting to a hospital increases simultaneously along with the exposure duration. In Korea, the patients with COPD admitting to a hospital had increased by around 2.7% as the PM_{10} concentration had increased by 10 $\mu g/m^3$. Figure 14 shows a comparison between the healthy lungs with many room-like air sacs and a lung with COPD were the walls of the alveoli are destroyed and filled with mucus. The symptoms include shortage of breath, wheezing, blueness of the fingernails and the lips and cough with phlegm (Kyung and Jeong, 2020). Figure 15 indicates the penetration of the particulate matters, in terms of size, into the human lungs. The smaller particles in size, the deeper it reaches into the respiratory system (Chest Diseases, 2018).

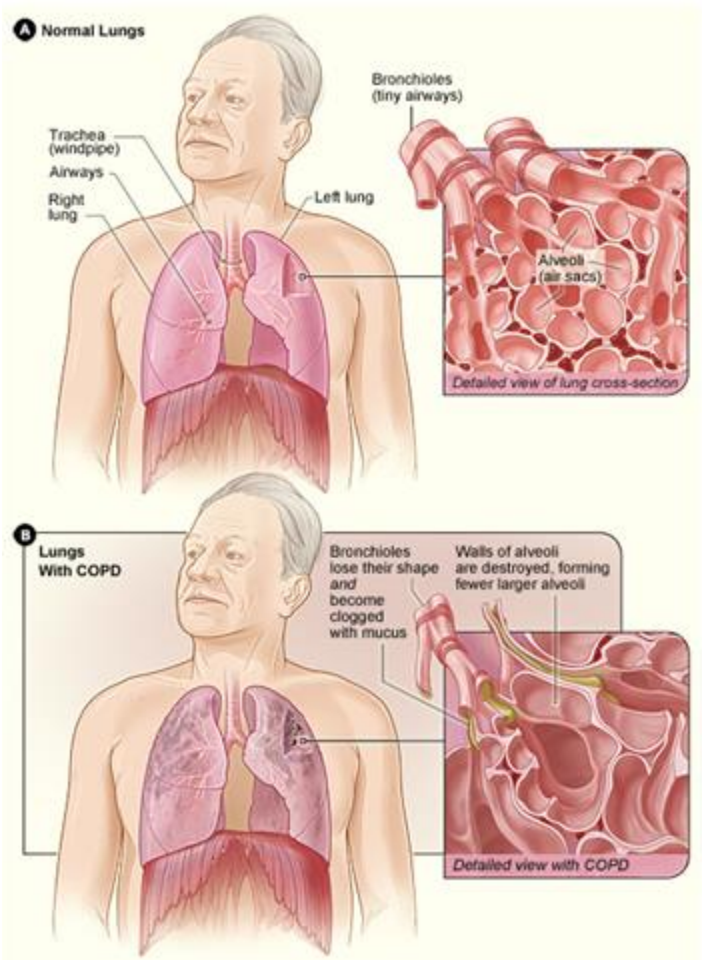


Figure 14: Comparison between a healthy lungs and lungs with COPD (Chest Diseases, 2018).

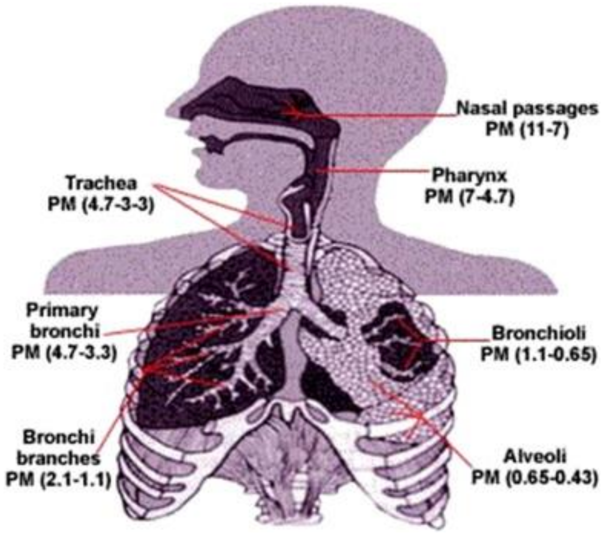


Figure 15: Penetration of PM into the respiratory system (Chest Diseases, 2018).

2.2.2. Sources of Indoor Particulate Matter

The NCBI has divided the sources of particulate matters in indoor spaces into three groups: primary, secondary and re-emission sources. A primary source emits directly the air pollutant into the atmosphere. A secondary source occurs due to the reaction of air pollutants in the atmosphere to form another pollutant. The re-emission source results from the deposition of primary or secondary pollutants on the terrestrial or aquatic surfaces (Outdoor air pollution, 2016).

The concentration of air pollutant varies in these groups or categories. Emissions from the primary sources are controlled by the physical processes. The main source categories are further divided into three sub-categories: point source, mobile source and area source (Figure 16). Point sources are fixed or non-movable source, that emits the pollutant, while the mobile source is a source which can travel from one place to another. Sources which are dispersed over a large area are called an area source. Lowther et al. (2019) had illustrated that the source of indoor particulates from emissions, scavenging, nucleation, accumulation or any other physical process (Lowther et al., 2019).

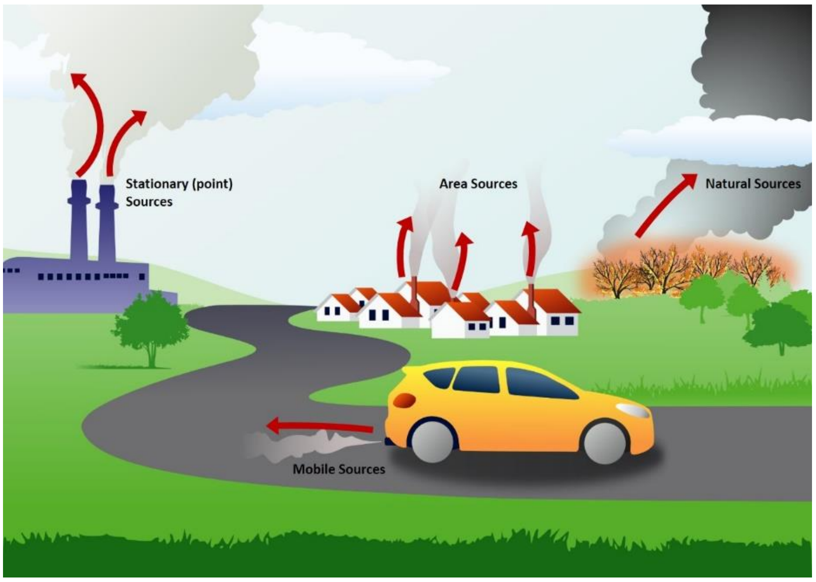


Figure 16: Point, area, and mobile source of air pollutants (EPA EcoBox Tools by Exposure Pathways - Air, 2021)

2.2.3. Particulate Matter in the United Arab Emirates

The sources of air pollutants in the United Arab Emirates (UAE) are either natural or man-made. Natural pollutants such as dust and sandstorms are commonly known in the region due to the geographic location and the arid climate of the country. Whereas man-made pollutants which are emitted from stationary sources such as industries and mobile sources such as moving cars and vehicles (Phanikumar et al., 2020). Due to the rise of man-made pollutants for the past few decades because of the industrial revolution and technological enhancements in the region, resulted in unbalanced and rise of air pollutants' concentration. Phanikumar et al. (2020) had noticed that the PM2.5 concentration reaches its peak during daytime in winter and spring.

2.3. Office Buildings

2.3.1. Indoor Air Quality of office buildings

Many activities emit pollutants including building maintenance and renovation, housekeeping and pest removal services. There are three main categories of air pollutants found in office buildings; biological containments, chemical pollutants and particulate matters.

The productivity in an office building is an indicator of the air quality in an office. It can be measured from the sales or profit achieved and the number of errors occurred by the employees. Nevertheless, the productivity of the employees can be estimated from their satisfaction and personal evaluation. Other indicators that might interfere with measuring the employees' productivity in an office includes the salary, relationship with the management, training and experience, workload and stress (Dorgan and Dorgan, 2006). Therefore, for the past few decades, office buildings were mechanically ventilated with no operable windows. (US EPA, 1990)

2.3.2. Dubai Building Code for office buildings

The Dubai Building Code (DBC) had stated that the occupant's load factor should be not less than 9.3 m^2 per person for an enclosed office and 4.6 m^2 per person for an open office. The minimum length or width dimension for an enclosed office is 2.4 m, while for the minimum clear height should be 2.5 meters (Government of Dubai, 2021).

Referring to chapter H.4.6.3 in the DBC, the dry bulb temperature inside the office rooms should be 24 ºC (± 1.5ºC) and the relative humidity to be around 50% (± 5%). The HVAC system used should be capable of achieving the thermal comfort needed within the space as mentioned in table 2 for about 95% of the year (Government of Dubai, 2021).

Table 1: The Lower and the upper limits for achieving the thermal comfort of a space (Government of Dubai, 2021).

Variable	Lower Limit	Upper Limit
Dry bulb-temperature	22.5 ºC	25.5 ºC
Relative humidity	30%	60%
Average air velocity	0.2 m/s	0.3 m/s

In addition, supplying fresh air to indoor spaces facilitates in controlling the concentration of indoor pollutants and achieving a better indoor environment. The air pressurization of a space shall be maintained to reduce the contamination of occupied rooms and to avoid any undesired condensation and mould growth. To withdraw an air pollutant from an indoor space, mechanical exhaust ventilation system is used (figure 17), to achieve the requirements of ASHRAE fundamental handbook and ASHRAE 62.1. The system should ensure that the exhausted air neither causes any inconvenience to the surrounding premises and nor being drawn back into the ventilation system of the building (Government of Dubai, 2021). In section 6.1.4 in the ASHRAE 62.1, it was stated that whenever the outdoor PM concentration exceeds the guidelines, a particle filter should be used to clean the outdoor air before being supplied to the interior spaces. While based on Table 6-1 in the same document, the minimum ventilation rate for the workspaces in office buildings is 5 cfm/person.

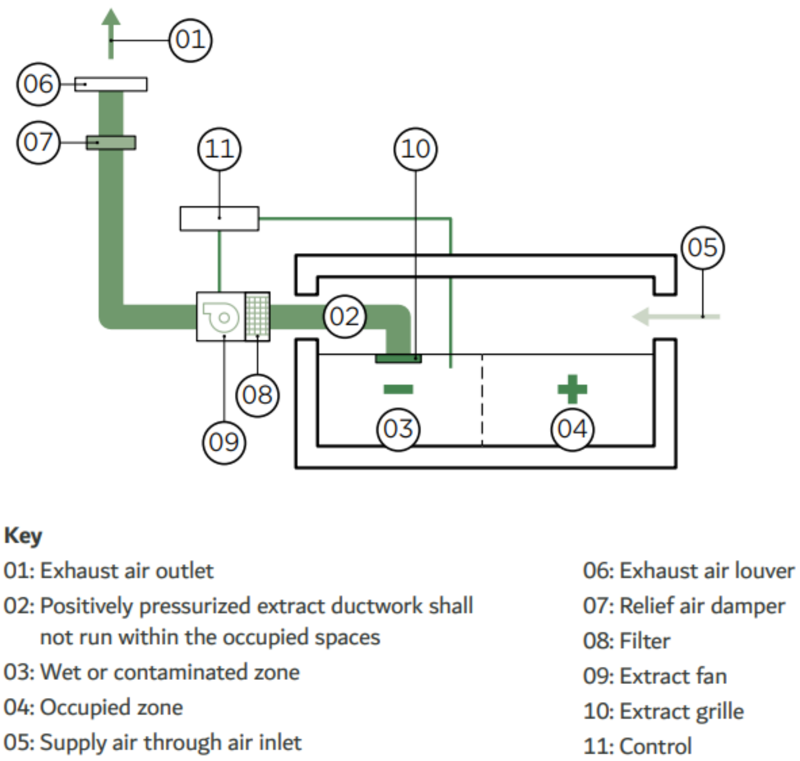


Figure 17: The components of mechanical exhaust ventilation system by the DBC (Government of Dubai, 2021).

Interior building materials and finishes (such as paints, adhesives, sealants, carpet flooring) should not exceed the allowed limit specified by the Dubai Central Laboratory.

2.4. Measurement Approaches of PM Concentration

The particles emitted from physical reaction in the atmosphere are categorized into three main groups; the fine or nuclei mode (<0.1 μm), the accumulation mode (0.1 – 2.5 μm) and the coarse mode (>2.5 μm). On the other hand, the total suspended particles (TSP) technique is measuring the mass of all particles in the atmosphere. Lowther et al. (2019) had outlined the methods and the metrics used to measure the particulate matter. Particle mass, particle number and particle size distribution were three different metrics used. The measuring methods had included the gravimetric, optical and electrical methods (Lowther et al., 2019).

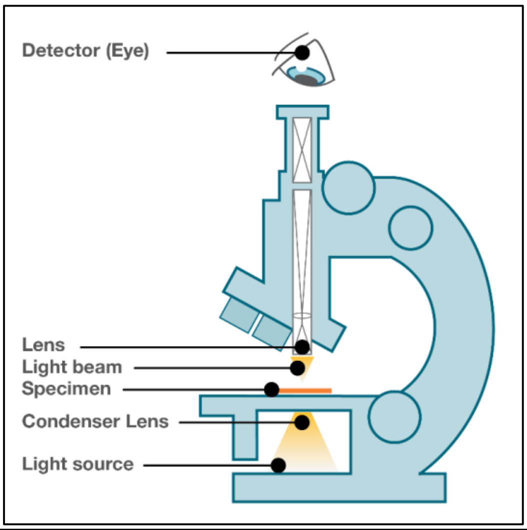
2.4.1. Particle Mass

Being the most prominent metric used to measure the particulate matter, the particle mass is easy to use and at low cost with respect to other metrics. The particles are categorized into three groups; PM10, PM2.5 and PM1. Based on this categorization, the results can be compared easily (Lowther et al., 2019).

The particle mass can be measured by two different techniques; the gravimetric or optical method. In the gravimetric method, a filtered sample is weighted before and after a sampling period. The difference in weight would be the Particle mass. The sample is either actively or passively collected. Active sampling is whenever an air is mechanically pumped through the filter at a certain flow rate. Particles are deposited on the filters via collection substrate. Despite the filters are cheap, portable and can be deployed easily in indoor spaces, the process is highly time consuming. The pump-free passive sampling is lighter, smaller and causes less noise. However, it is affected by the wind speed and the particle size (Lowther et al., 2019).

The filtered sample is then examined using an optical or electron microscope. Figure 18 shows a diagram of the optical microscope, while figure 19 shows a sample of particles examined under electron microscope. The microscope is used to find out the number of particles in the examined sample, the size, the shape and the structure of the particle. Nevertheless, the ultra-fine particles (UFP) cannot be determined using the gravimetric method (Lowther et al., 2019).

Whereas in the optical method, the particle mass is measured by emitting laser beams on the sample. Light when falls on the particle's surface, it is either scattered or absorbed. The particle concentration is then determined by measuring the scattered and absorbed light by a photometer detector. The sampler is also known as scattering laser photometer (SLP) (Lowther et al., 2019).



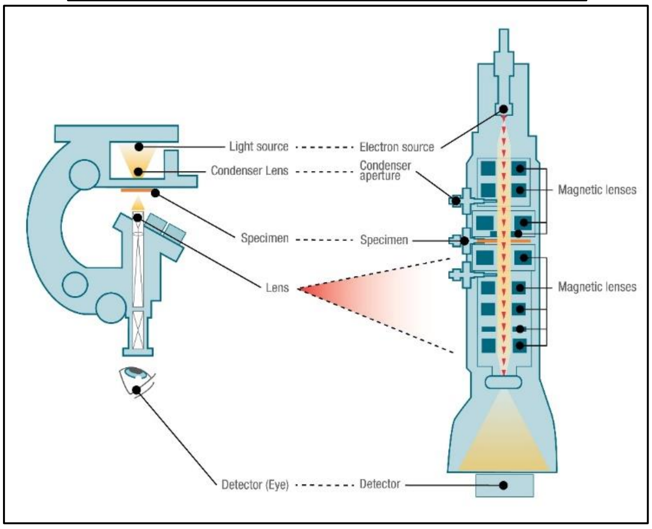


Figure 18: Diagrams of optical microscope (on the left) and electron microscope (on the right) (Ilitchev, 2020).

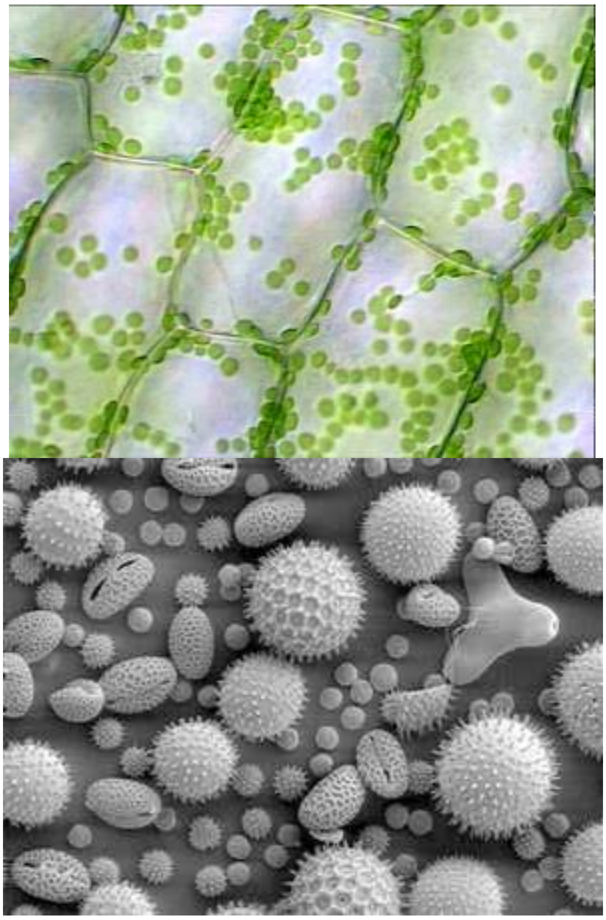


Figure 19: Image formation in optical microscope (on the left) and electron microscope (on the right) (Barras, 2008).

Lowther et al. (2019) stated that the combined intensity of the scattered light is directly proportional to the volume concentration of the particles in the sample. The photometers are commonly used as they are light, portable and robust units. In addition, they provide real time and accurate measurements of particle concentration, with a frequency of 1 second. However, the efficiency drops for the smaller-sized particles, which can detect from 100nm to 10μm particle size and a detection limit of 0.001 to 200mg/m^3 (Lowther et al., 2019).

2.4.2. Particle Number

Optical and current methods are used for particle counting. Similar to Scattering Laser Photometer (SLP), the Optical Particle Counter (OPC) emits a laser beam which is then collected by a photodetector (Figure 20). Unlike photometers, photodetectors are used in which each particle is illuminated at once, and the scattered flash is converted into an electric current. Each electric current is equivalent to a single particle. Hence, the number of particles are counted. In terms of size, the larger the particle, the higher the electrical current generated. One of the main disadvantages of these devices is the inability to count particles less than 300nm in size. For counting particles which are smaller in size (<300nm), a Condensation Particle Counter (CPC) are used. In CPC, a solvent is condensed on the particle's surface. This process would increase the particle's size to be counted, after being passed through the laser beam (Lowther et al., 2019).

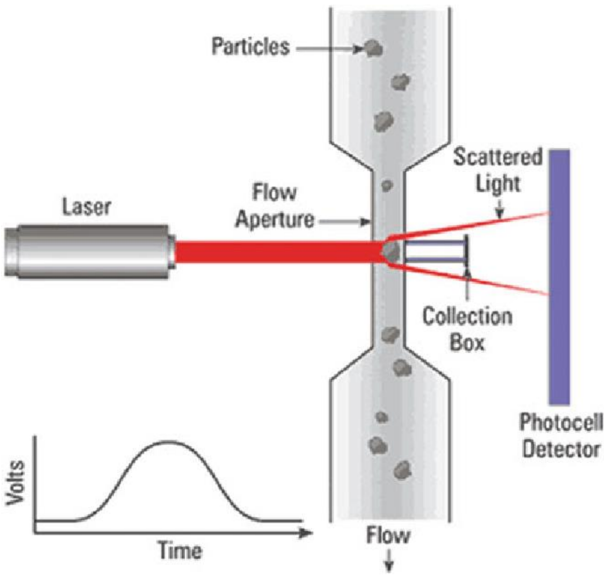


Figure 20: Diagram of optical particle counter (OPC) (Dambruoso et al., 2013).

CHAPTER 3: RESEARCH METHODOLOGY

To research about a certain topic, a strategy needs to be adopted to investigate and select the most appropriate method for a specific topic (Faryadi, 2019). The selection of the method is from the author's point of view, based on the reviewal of previous studies about the same topic. Finding an answer to the research question derives the type of data to be collected, the methodology to be used, and how the data will be analysed. The selected method to be applied to gather the required information should achieve certain guidelines such as selecting the suitable instrument to provide a meaningful outcome, the instrument provides a valid and reliable results and the results should not be biased under any mean of pressure (Faryadi, 2019).

Throughout the years, many papers had investigated the particulate matters of an indoor space. Each had adopted a methodology, from the researcher's point of view. In this chapter, the author had reviewed the common methods used by previous scholars to investigate the PM concentration of an indoor space in general, or an office in specific. Papers published within the past 5 years had been filtered and reviewed. The inclusion criteria considered were: 1) The papers published in a scientific journal, 2) focused on the particulate matters and 3) focused on the indoor spaces.

3.1. Types of Research Approaches Used

3.1.1. Literature Review

A piece of academic writing, where a topic is critically evaluated and analysed. It presents an up-to-date researches with relevant theories and any knowledge gap, to give a clear picture of the selected topic. Any research would require conducting a literature review, to find out the current state of knowledge. Reviewing a literature is very beneficial, as a general overview of the subject would be gained, avoid wastage of time by repeating the work already done by others, and to find out what are the drawbacks or any knowledge gaps in which you can start from.

Nezis, Biskos, Eleftheriadis and Kalantzi, (2019) had reviewed scientific papers published during the last 16 years. They have considered several criteria for the selection of the references, which are that the papers are published in a scientific journal, the topic is related to indoor air quality in office spaces, they were written in English, they highlight the duration of exposure during the working hours, and finally, they exclude the staff members who were partially working in the office. The common online scientific databases referred to were the Science Direct, Scopus, PubMed and Web of Science. The information gathered from the papers includes the sampling period, the location of the study, the measured pollutants, the quantity of offices and the staff workers, the duration of the sample, the instruments used and the type of ventilation used. They had found out that the factors affecting the concentration of indoor pollutants are the office location, the age of the building, the air-tightness of the fenestration, the design of the space, the ventilation rate, the activities performed in the space, the concentration of outdoor air pollutants, the outdoor air temperature and relative humidity.

Cheriyan and Choi (2020) had reviewed the studies focusing on the particulate matters emitted from the construction sites, and their impact on the human health. The studies had been selected from online databases such as Science Direct, Scopus, Web of Science and Google Scholar. The factors used for the selection of the papers included the study focused on the PM exposure in the construction sites, the health of the workers exposed to PM and field measurements taken from construction sites. Based on these factors, they had selected and reviewed 48 scientific papers, published since 1999. They have noticed a rising in the number of papers since 2014, which is a sign of increase in awareness of the subject. They have grouped the papers into five categories; the PM generated from construction equipment, PM generated from construction activities, the control measures for the PM, the health impacts of PM, and the PM monitoring. The authors had highlighted that the construction activities have a major impact on the human's health. They mentioned that the United States and South Korea are considering the results from these scientific studies to minimize and control the PM concentration being generated from the construction field.

Junaid et al. (2018) had looked into the scientific studies on the indoor PM emissions and their impact on health in the southern Asian countries. The online databases that had been used were the Science Direct, PubMed, Google Scholar and Web of Science. A total of 136 studies had been collected and reviewed since 1990.

3.1.2. Questionnaire

A questionnaire is a list of questions to collect information from respondents. Their responds depend mainly on their point of view, experience and attitudes. It can be used to collect quantitative information, qualitative information, or even both. Questionnaire helps to gather data in an efficient way than other opinion-related methods such as interviews and telephone calls. Respondents has a stress-free choice, as the data are administered anonymously, controlling the risk of errors (Faryadi, 2019).

Zhang et al. (2018) had conducted a cross-sectional survey with children from two primary schools. They had obtained written consent from the parent or guardian of each participant. The survey was used to collect general information of the participants, the living condition and their lifestyle. The authors had measured the $PM_{2.5}$ concentration inside the school campus using TSI DUST-TRAKTM DRX (Model 8533, TSI Inc. Paul, MN, USA) apparatus. The apparatus was placed from 8 a.m. to 4 p.m. for 6 days, at a distance of 1 meter away from the adjacent walls and at a height of 1.2 meters from the floor to achieve a better accuracy by placing the apparatus at the beathing zone of the children. The samples were collected at a rate of 3 l/m and the values were recorded every 8 hours with a time interval of 1 minute. The collected concentration values were rounded up to 1 $\mu g/m^3$, whereas the limit of detection were kept at 1 $\mu g/m^3$.

A research paper done by Pantavou et al. (2018) to collect data using a mobile weather station. The station had a TSI Dust Track 8520 aerosol monitor set, a Rotronic S3CO3 thermo-hygrometer, a Second Wind C3 anemometer, a Kipp & Zonen CM3 pyranometer, and a gray globe thermometer. The station were kept at a height of 1.1 meter to measure the following parameters: PM10 concentration, air temperature, relative humidity, average wind speed, globe temperature and total solar radiation on a horizontal plane. These parameters were supported by the responses gathered from the pedestrians visiting the selected sites. They were interviewed to assess the air quality, by scaling the air dust perception and the air pollution perception. The clothing insulation, the metabolic rate and their activity in the last 30 minutes before the interview were considered in the data processing. Other variables such as the medical health and the smoking status were also included.

Rasli et al. (2021) had assessed the indoor air quality of an air-conditioned office in Pulau Pinang, Malaysia. The office were occupied by 11 workers. A survey had been distributed to be filled by the office workers to find out the source of indoor air pollutant in the office and it’s impact on the workers. The questionnaire were divided into six sections; general information, background factors, nature of occupation, environmental conditions, previous and current disease symptoms. The results had included the duration of usage of equipment (display unit, fax machines, photocopier, typewriter) in the office by the workers. The air quality were monitored using an IAQ probe (IQ-610) to measure the carbon monoxide, total volatile organic compounds, ozone, carbon dioxide, air temperature and relative humidity. The air movement were detected using the AS-201 whereas for the particulate matter, Airborne Particle Counter were used (Rasli et al., 2021).

3.1.3. Interviews

Interviewing with the participants is performed by having a face-to-face or a phone discussion. The main benefit of an interview is that you can ask open-ended question and get the opinion of the respondents freely and not like the questionnaire. It is usually conducted in a friendly manner. There are two types of an interview; a structured and an unstructured interview. A structured interview is when the questions are previously prepared and asked to the participants. The results are uniform as all the participants are asked the same questions, which is then can be compared. Whereas the unstructured interview is when the questioned asked are not previously prepared. The interviewer has the freedom in framing the questions and the sequence of the interview. However, the results might not be comparable, as some of the questions might be missed out or understood by the participants in another manner (Faryadi, 2019).

Tamire et al. (2021) had measured the PM concentration in the rural households in Ethiopia and their impact on the human health. 150 households had been randomly selected to have a face-to-face interview. The authors had asked questions about the number of family members, the housing characteristics, the type of stove and fuel being used, and the cooking duration and frequency. After that, the PM concentration were monitored using a Particle and Temperature Sensor instrument, which has a built-in photometer. The measurement took place for 24 hours with a one-minute logging intervals. The association between the results and the time of cooking were investigated. The precautions taken were that the instrument is placed at the height of a standing-mother which is 1.5 meters. The instrument were located away from any fenestration and an unobstructed airflow to avoid misleading results. In addition, it was placed away from the stove by at least 1 meter to avoid the effect of point source from the stove.

Pantavou et al. (2018) had carried out a face-to-face interview with the pedestrians at two central urban sites in the city of Athens, Greece. The structured interview took place for 5 days with previously prepared questions. The authors had asked questions to the participants about their personal characteristics including their gender, age, weight and height, type of clothing they wear and the last activity they performed during the last 30 minutes. They asked them questions about the time spent at each site, their smoking status and if they have any medical condition. Moreover, the participants were asked to assess the air quality of the site, for the overall pollution and the dust concentration, using a 5-point bipolar scale, from "very dusty" to "very good". The authors had conducted a total of 387 interviews with the pedestrians. A total of 215 interviews were conducted at site 1, while 172 interviews at site 2. Most of the interviews were done during the day-time. 207 of the participants were male aged from 18 to 34 years old. The majority did not have any medical history and did not smoke. Most of the participants had responded that the air was "fairly clean". There was a variation in the perception of air quality depending on the age group, duration of exposure and the smoking condition of the participant. The responses of the participants to the questions related to the signs of headache, dizziness, difficulty in breathing or fatigue, were associated to the poor air quality perception.

3.1.4. Field Measurement

Field measurement is a methodology to collect data of a specific parameter. One or more independent parameters are manipulated to measure their impact on other dependent variables. Research papers had looked into the impact of each variable on the PM concentration of an indoor space.

Othman et al. (2020) had investigated five office buildings in the Bangi town, which is 38 km from the capital city of Kuala Lumpur. All the buildings are mechanically ventilated with central air conditioning and windows were kept closed always. Air conditioning systems were switched on and off at the same time. To measure the particulate matters, an optical PM2.5 sensor were used. The measuring equipment were placed at a height of 1 meter above the ground and located in the center of the room. The data were measured at 1 minute interval for 9 hours. The data of the outdoor PM2.5 concentration were obtained from the nearest Air Quality Monitoring Station, 17 km away from the sampling sites.

Whereas, Ren and his colleagues had conducted a field measurement in seven high schools in Texas, from which, four to eight classes were monitored in each school. They recorded the factors that might affect the results, such as the site condition, ventilation system in the school, floor finishes, ceiling height, and the floor area. Other factors including the ambient temperature, humidity and wind speed were collected from the weather station. The windows were kept closed and the HVAC system is operating throughout the year. The particle number concentration were measured by using eight particle counters. The instruments were placed at a height of 1.5 meter to 1.8 meter. The results collected from the instruments were then converted to mass concentration. The converted mass concentration were analyzed using the statistical software “SPSS”, to find out if the PM concentration is normally distributed. Moreover, the correlation between indoor and outdoor concentrations were analyzed (Ren, Wade, Corsi and Novoselac, 2020).

Zhang et al. (2020) had measured the impact of short-term exposure to PM2.5 on the blood pressure of employees working in an office based in Beijing, China. More than 4500 employees had participated and performed health check-up at the Beijing Xiaotangshan Hospital Medical Center for 5 years since 2013. The participants had been selected based on factors including, the age should be between 18 and 60 years old, their office should be located within 10 km from the nearest weather monitoring station and finally, had performed their health check-up during the five years. Participants with any missing information or experienced any infection in their respiratory system for more than two weeks were excluded from the study. A questionnaire had been distributed to collect their demographic and physical information including the gender, age, the smoking status, any dietary habit, height, body mass and blood pressure. The participants were allowed to relax for 5 minutes before measuring the blood pressure with the hands being at the level of the heart. Using mercury sphygmomanometer, it was measured three times with an interval of 30 seconds and then averaged. With the help of 35 monitoring stations, the daily concentration of air pollutants, including the PM concentration, were gathered. The medical results had shown that the rise in blood pressure were associated with the increased PM concentration.

A paper by Mandin et al. (2017) had investigated a total of 148 mechanically ventilated rooms from 35 office buildings in 8 different European countries. Data from the field measurements had been collected in five days from summer and winter seasons. The samplers were placed in the center of each room and at a height of 110cm. They have avoided heating sources, ventilation channels and sunlight, to avoid any misleading results. The data collection and analysis had followed the EN 12341: 2014 standard. The PM2.5 concentration ranged from 2.7 µg/m3 in Finland to 17 µg/m3 in Hungary in summer. While in winter, the concentration were 3.4 µg/m3 in Finland and 32 µg/m3 in Hungary. The results were evaluated using the WHO air quality guidelines. During the period of the research, the WHO had considered the AQG of the PM2.5 concentration to be 25 µg/m3 (24-hour mean) and 10 µg/m3 (annual mean). The results collected showed that PM concentration were below the 24-hour limit in summer, while in winter, Hungary had exceeded. On the other hand, the annual limit were exceeded in Hungary (Mandin et al., 2017).

3.1.5. Simulation

Yu et al. (2020) had studied the air tightness of two office buildings in Shenyang, China. They have conducted a field measurement on 3 points, one of them is in the meeting room facing the northern main façade (Point A), the second is in the electrical room looking towards the southern façade (Point B) and the third one was placed outside the building (Point C). The authors took several precautions such as keeping the instrument away from any point source and absence of any activity within the range of measurement. In addition, all the windows were kept closed and the air conditioning were switched off. The main purpose of the study is to measure the infiltration rate of particulate matters from outside to inside the office building through the gaps within the building. The gravimetric method is utilized to measure the average PM mass concentration inside and outside the building. Two instruments were used for the measurements, the COMDE DERENDA particle sampler and the Lao ying 2030 intelligent TSP sampler. The results had shown that the infiltration rate at point A is lower than at point B. The authors had looked into the type of gaps in the façade of the building. Based on the results and analysis, they had simulated the different relations between the mass concentration of the indoor and outdoor particulate matter with the gap size and shape at the façade. The gaps were divided into three types, the square-shaped, the L-shaped and the U-shaped gaps. The gambit software were used to model and mesh. All the parameters for the modelled samples were kept the same except for the gap height, to find out it's association with the infiltration rate. Three different variation of heights were simulated; 1mm, 0.5mm and 0.1mm. Based on the simulation, the highest infiltration rate were for the particles with a size of between 0.25 µm and 0.75 µm, and this rate decreases with the increase of the particle size. They estimated that this is due to two main forces, the brownian diffusion and the gravitational force. The simulation had illustrated that whenever the height of the gap is 1mm, the infiltration rate is almost 95% for particles sizes 0.01 to 10 µm, and with a height of 0.5mm, the rate is 90% for the particle sizes ranging from 0.25 to 2.5 µm, and finally whenever the gap height is 0.1 mm, the rate of particle penetration is 50 % for a particle size of 0.4 µm.

Hong, Liao and Liu (2019) in their scientific paper wanted to find out the distribution characteristics and the optimal location to monitor the PM concentration in an office room in Chongqing University in China. A field measurement is taken place using a laser sensor to measure the PM concentration in the space. The temperature and the wind speed data were collected using the Agilent 34980A Multifunction Intelligent Data Collector and the Swema 3000 anemometer respectively. The authors had stated that the source of the air pollution in the space is the incense, with an emission rate of 5.33 $\mu g/m^3$ for $PM_{2.5}$. A total of 10 points had been monitored using the instruments, five of them were evenly distributed within the space at a height of 1.2 m, whereas the remaining five were near the ceiling. With the help of Microsoft Excel, the correlation, regression, t-test and the robust statistical analysis were performed. Then, the authors had analysed the PM distribution within the room via ANSYS 15.0 simulation software. To track the motion of the particulate matters, the authors had adopted the Euler-Lagrange model. The results of the simulation illustrated that the optimal level for monitoring the PM concentration is at the breathing zone.

3.2. Selected Methodologies

In the previous chapter, the author had mentioned various papers using different methodologies. However, to find out the impact of high PM concentration and it's relation on health, the process is divided into two steps. The first step is to perform an actual site measurement. These values will be investigated and compared with international standards or guidelines, to find out the quality of the air in a given space. The second step is to collect a quantitative data in the form of questionnaires from the office users, to investigate and understand the impact of the collected values on the user's health.

3.2.1. Field Measurement

Based on chapter 2.4 in the literature review, the required information to be gathered the particle mass and count to find out the PM concentration of a given space. In addition, the temperature and relative humidity of each space will be measured. The TSI Optical Particle Sizer (Model 3330) had been selected to measure the PM concentration (figure 21). The company has an experience of more than 60 years in machines and instruments.

As shown in Figure 22, the sampled air is pumped through a maximum of 16 channels to measure the particle mass and number. It measures a particle size range of 0.3 to 10 µm.

Due to the addition of sheath flow around the sample, the size resolution of the sample is improved and the surface is kept clean, which minimizes the maintenance rate. Once the instrument starts measuring, the sample air is pumped straight to the measurement region. This is to control the particle losses due to the transportation. The particle concentration and size are measured in the optical chamber. Then the particles are filtered for a gravimetric analysis.

Figure 21: The TSI Optical Particle Sizer - Model 3330. (Optical Particle Sizer (OPS) 3330, n.d.)

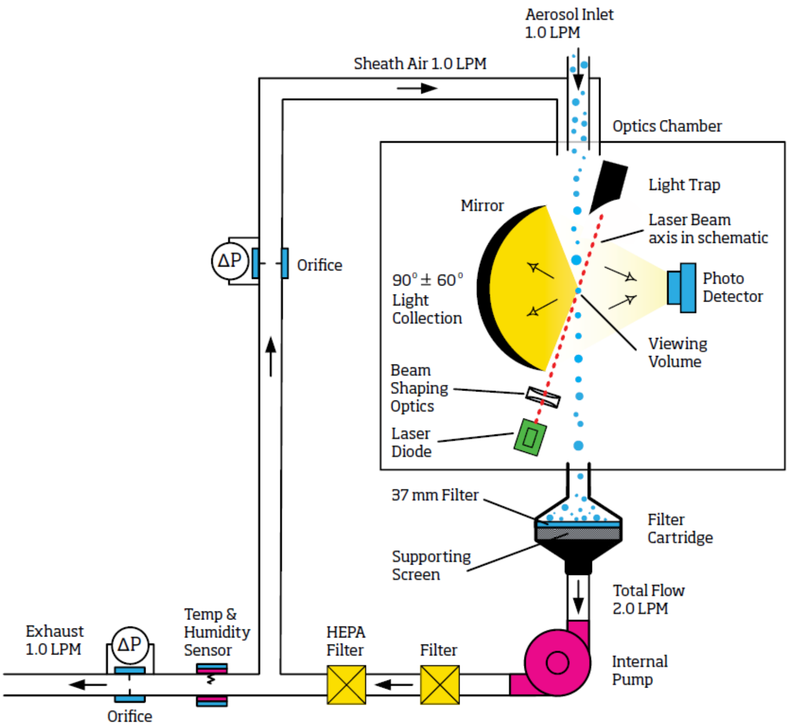


Figure 22: The inner components of TSI Optical Particle Sizer - Model 3330 (Optical Particle Sizer | Model 3330, n.d.)

The instrument were tested several times in the author's personal room and in Office A as mentioned in the coming chapter. This was done to understand more about the instrument. The particles are filtered based on their particle size into different channels. With a total of 16 channels in the instrument, the author has found out to use only 12 channels based on the tests performed. The author had noticed that the concentration of smaller-sized particles were much higher than the larger-sized particles. Therefore, the particle sizes were grouped as following (figure 23); 0.300 – 0.400 µm, 0.400 – 0.550 µm, 0.550 – 0.700 µm, 0.700 – 1.000 µm, 1.000 – 1.300 µm, 1.300 – 1.600 µm, 1.600 – 2.200 µm, 2.200 – 3.000 µm, 3.000 – 4.000 µm, 4.000 – 5.500 µm, 5.500 – 7.000 µm and 7.000 – 10.000 µm.

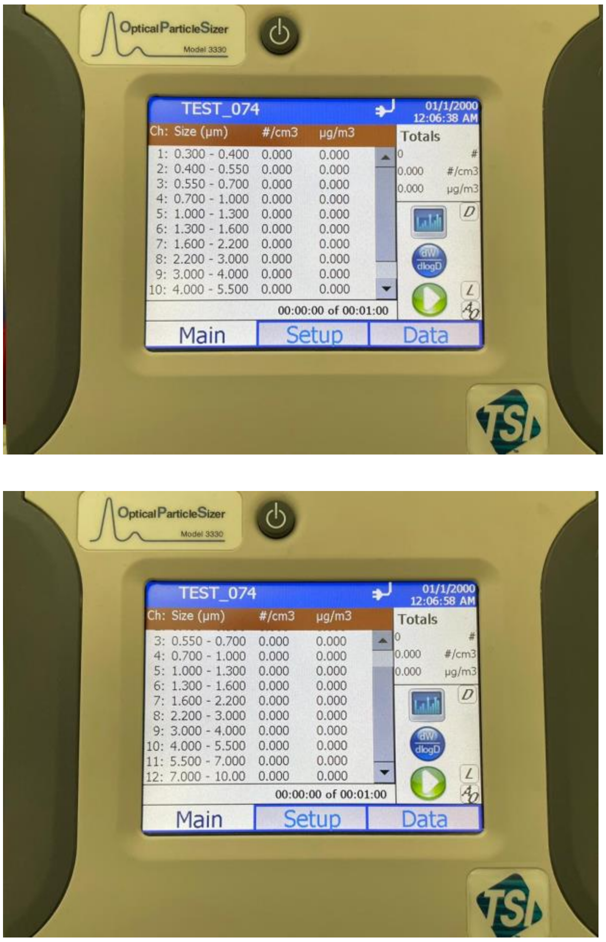


Figure 23: Grouping of particle sizes to 12 channels. (Author, n.d.)

Besides, the Thermo Scientific Personal DataRAM pDR-1500 (figure 24) were used to measure the PM concentration, the real-time room temperature and the relative humidity. It is a portable and with high precision of real-time aerosol concentration measurement. It has a sample filter for post-gravimetric validation. However, it was not used in this research. The instrument is with a concentration measurement range of 0.001 to 400 µg/m^3. It's precision is 0.005 µg/m^3 for 1 second averaging time or 0.0005 µg/m^3 for 60 seconds averaging time. It measures a particle size range of 0.1 to 10 µm.

Figure 24: The Thermo Scientific Personal DataRAM pDR-1500 aerosol monitor (pDR-1500, n.d.)

3.2.2. Questionnaire

A questionnaire is structured similar to writing an essay, divided into three main sections; the introduction, the main issue and the conclusion. Any questionnaire needs an to be introduced explaining the main subject and the it's purpose. In addition, it may include a brief introduction about the researcher and the expected time duration to answer the questionnaire. The confidentiality of the respondents should be clearly highlighted, to minimize the pressure on them and to avoid any biased responses. The questionnaire is usually concluded by expressing gratitude of the author. The author should ensure that the questions are clear, understandable and simple. The type of questions that are preferred to be used are multiple-choice questions, dichotomous questions with a "Yes" or "No" responses and Questions with ranking or sliding scales. Open-ended questions are not commonly desired (Faryadi, 2019).

There are many techniques to distribute a questionnaire. It can be written-based or an online-based questionnaire. Sending it via an email, or by using an online platform such as Google Forms or Survey Monkey, are examples of an online-based questionnaire. On the other hand, the written-based is a form distributed to the participants (Faryadi, 2019).

In this research, the questionnaire that had been distributed were an online-based. The main reason is to avoid any physical contact due to the spread of the global pandemic, Covid-19. Survey Monkey platform had been used to create the questionnaire, and it had been distributed to the participants via a link in an email. This had helped to control and avoid any physical contact, to ensure the safety of the respondents. The introduction about the research were performed face-to-face to the respondents, as well as mentioned in the email. Some of the respondents did not have access to a computer, the questionnaire were shared via scanning a bar code. Figure 25 shows the bar code that had been used to access the questionnaire.

Figure 25: The bar code that had been used to access the questionnaire. (Author, n.d.)

First of all, questionnaires from previous scientific papers about a similar topic had been reviewed to understand the typology of questions to be asked. Then, began to structure the questions that would have a direct or indirect effect on the participants, in addition to the symptoms felt after prolonged exposure to the atmosphere in the office. The questionnaire were divided into four sections; the surrounding context or region, the building's section, the workspace and the working environment. The surrounding context section focused on the broad-scale question, looking into any outdoor activity nearby the office building, that might affect the measured results. Questions in the building's section focused on the location of the working space in the building, in terms of floor-wise and any nearby industrial or service rooms, that might affect the results due to the emissions from the space. The service rooms mentioned including toilets, garbage rooms, industrial kitchen. while the workspace focused mainly on the interior working space and it's direct affect on the users.

A pilot study had been shared with two participants to ensure the clarity of the questions. The questionnaire had been updated based on their comments, which is then after that had been distributed to the remaining participants.

3.3. Justification

Based on the extensive review, to widen the understanding of a current situation, a field measurement is taken. Many scholars had measured the actual condition, and then had built up either a simulation of different variables or had looked into the possible solutions and recommendation. The main purpose of this study is to investigate and compare the PM concentration between different office workspaces. Hence, the expected results are the particle mass and count of each office, which is then compared with the WHO standards. Based on the reviewal of previous research papers, the majority of the scholars had applied the field measurements to identify the PM concentration of an indoor space. Nevertheless, the questionnaire is a complementary method, which helps to understand the impact of the PM concentration and the sick building syndrome experienced by the office users and participants. adding to the goal of the paper to find out the impact of these results on the participants and users of the office, a questionnaire would give us their feedback and opinions about each space.

3.4. Variables' List

The variables are parameters that are not consistent but are expected to change and would have an impact on the result of the measurements taken (Faryadi, 2019). They are categorized into three groups; independent, dependent and controlled variables. Independent variables are variables that would cause the impact on the dependent variables. On the other hand, the controlled parameters are kept constant to avoid any influence on the outcome of the measurements.

The aim of the research is to measure the PM concentration in the selected office and to investigate the impact on the occupants' health. The PM concentration is affected by many variables. The independent variables that had been considered are the interior finishes, building age, ambient temperature, relative humidity, room size, number of occupants in the space, active and passive ventilation systems and the ventilation rate (if available). The dependent variable that had been looked into were the occupants' health and health symptoms. Nevertheless, the controlled variables were the measurement timing, season, function of the building and the duration of the measurement. Other variables that might had affected the results such as if the occupants had any allergy, the outdoor activities and their impact on the indoor measurements and any weather disorder.

3.5. Precautions taken

The precautions taken is to make sure that the instruments are away from any localized air flow from fans, ducts or any nearby equipment, at a height of 1 meter above the floor. The instruments are placed at the center of each room to perform the test. The measurements are taken at the morning (8:00 am), noon (12:00 pm) and evening times (6:00

pm). The morning test is taken one hour after the start of the office timing, to make sure that everyone had reached to the office. The noon timing is the peak of the workload, and the evening timing is when the majority of the employees had left the office. Each PM concentration measurement had included 3 samples with 1 minute interval.

3.6. Air Quality Guidelines (AQG)

The WHO had recently published guidelines for the air pollutants and their critical health outcomes in terms of duration and scale of exposure. This guideline is applicable for indoor and outdoor spaces (World Health Organization, 2021).

The WHO had indicated that the long-term exposure to high PM concentration had negative impacts to human health including all-cause mortality, cardiovascular mortality, respiratory mortality and lung cancer mortality. Nevertheless, short-term exposure results in all-cause mortality, cardiovascular mortality and respiratory mortality (World Health Organization, 2021).

The Air Quality Guideline (AQG) is used as a reference to find out the recommended concentration values to avoid adverse health effects due to the exposure to air pollutants. The guidelines are developed by performing observational studies. Interim target is a gradual step towards reduction of air pollutant's concentration. By achieving these targets, will have a reduction in risks for acute and chronic human health effects. The recommended interim targets and AQG level of $PM_{2.5}$ and PM_{10} are mentioned in tables 2 and 3.

Table 2: Recommended 24-hour AQG level and interim targets for PM2.5 (World Health Organization, 2021).

Recommendation	$PM_{2.5}$ (µg/m3)
Interim target 1	75
Interim target 2	50
Interim target 3	37.5
Interim target 4	25
AQG level	15

Table 3: Recommended 24-hour AQG level and interim targets for PM10 (World Health Organization, 2021).

Recommendation	PM_{10} (µg/m3)
Interim target 1	150
Interim target 2	100
Interim target 3	75
Interim target 4	50
AQG level	45

Based on the WHO publications, table 4 shows that the largest number of deaths in 2016, are in the Western Pacific countries with a total of more than 1.2 million deaths and South-East Asian countries exceeding 1.35 million deaths. The United Arab Emirates is an Eastern Mediterranean country, with a total number of deaths less than 350,000. To achieve the AQG level, the number of deaths would drop to 64,000 and a total percentage reduction of around 80%.

Table 4: Number of regional deaths and percentage reduction that can be achieved at the interim targets and AQG level (World Health Organization, 2021).

WHO region	**Global / regional deaths and percentage reduction through achievement of interim target or AQG level**					
	Air pollution level, 2016	**Interim target 1**	**Interim target 2**	**Interim target 3**	**Interim target 4**	**AQG level**
African Region						
Number of deaths (in thousands)	474	403	349	255	188	60
Percentage of Reduction	-	14.5	26.2	45.9	60.4	87.3
Region of the Americas						
Number of deaths (in thousands)	249	249	247	230	203	89
Percentage of Reduction	-	0	0.6	7.4	18.2	64.1
South-East Asian Region						
Number of deaths (in thousands)	1351	1078	948	742	580	223
Percentage of Reduction	-	19.7	29.5	44.6	56.8	83.3
European Region						
Number of deaths (in thousands)	464	463	457	436	385	157
Percentage of Reduction	-	0.2	1.5	6.2	17.1	65.9
Eastern Mediterranean Region						
Number of deaths (in thousands)	336	289	253	199	158	64
Percentage of Reduction	-	13.8	24.3	40.4	52.6	80.7
Western Pacific Region						

Number of deaths (in thousands)	1278	1160	1024	818	643	248
Percentage of Reduction	-	9.2	19.8	36.1	49.7	80.6
Global						
Number of deaths (in thousands)	4155	3646	3276	2677	2155	848
Percentage of Reduction	-	12	20.8	35.2	47.8	79.5

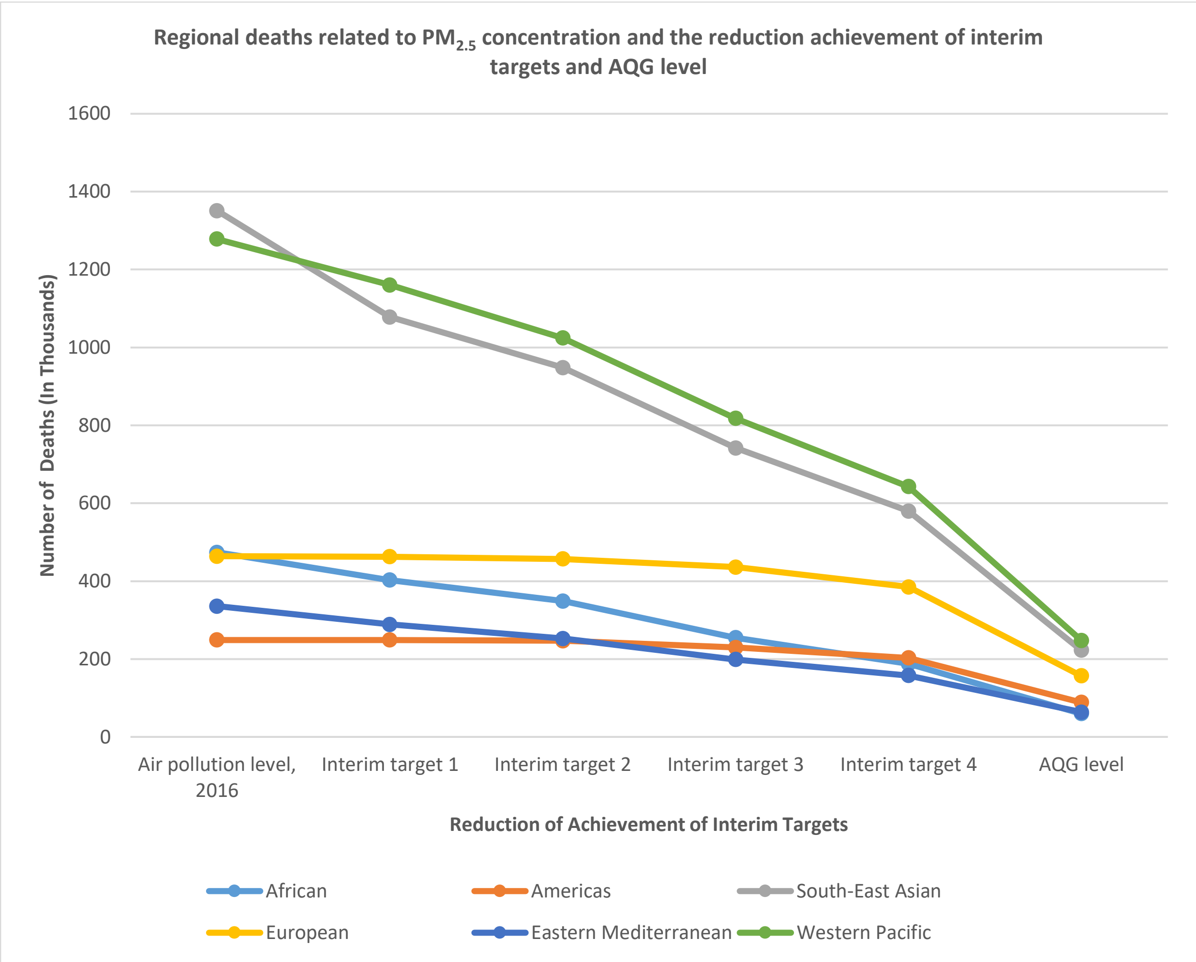


Figure 26: Number of regional deaths and percentage reduction that can be achieved at the interim targets and AQG level (World Health Organization, 2021).

3.7. Weather Analysis

The United Arab Emirates (UAE) is one of the Gulf Cooperation Council (GCC) countries. Being located in the middle east, on the southern coast of the Persian Gulf, it is sharing borders with Saudi Arabia and Oman (Figure 27).

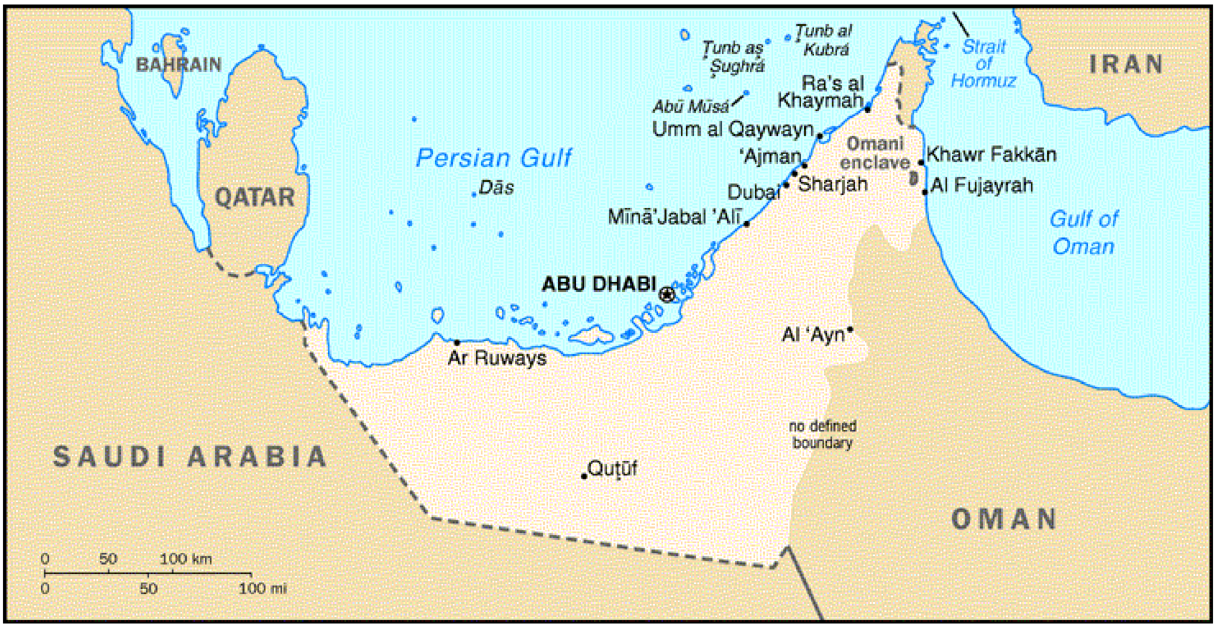


Figure 27: The map of United Arab Emirates and it's borders (Schrenk et al., 2022).

The climate in the United Arab Emirates is hot and humid. Figure 28 illustrates the temperature ranges from 47 Celsius in the summer season and drops to 5 degree Celsius in the Winter. The mean temperature from June to August is 34 degree Celsius, whereas from December to February the mean temperature is 19 degree Celsius. The mean temperature remains higher than the comfort zone for around 7 months, from April to October. Therefore, the citizens stay in an air-conditioned indoor space, to avoid the heat of the sun. In terms of wind speed, it is considered as a gentle breeze throughout the year, with a mean wind speed of 4 m/s as shown in Figure 29. The relation between the relative humidity and the dry bulb temperature is shown in Figure 30. The humidity remains high (around 80%) during the morning and the evening times and drops in the noon time.

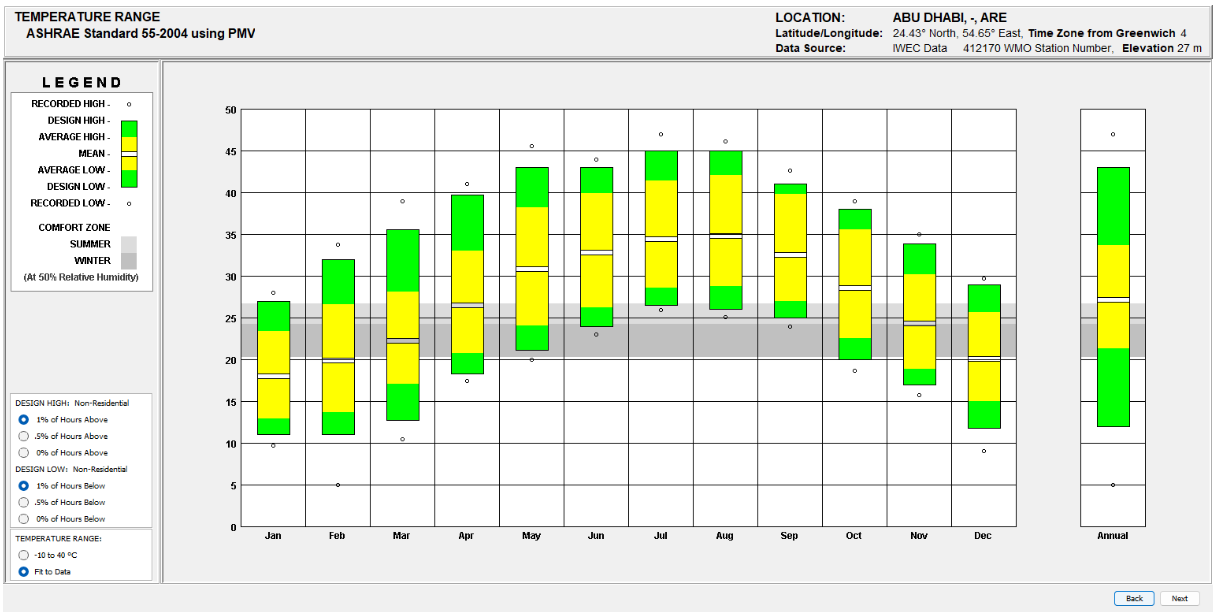


Figure 28: Monthly temperature range in the United Arab Emirates (Climate Consultant, 2022).

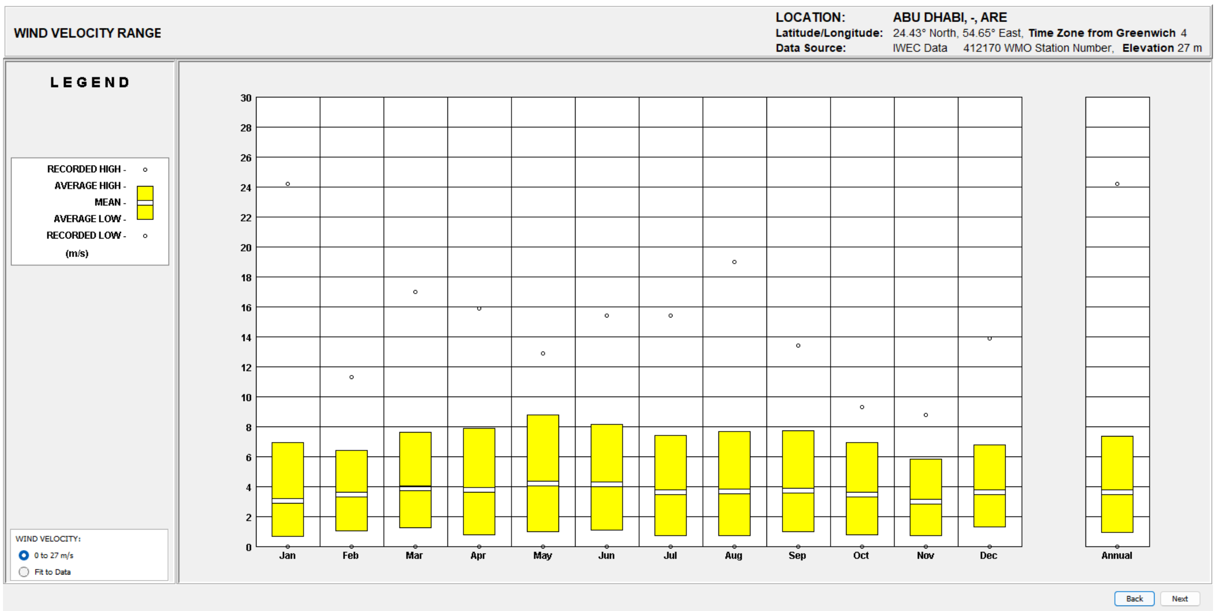


Figure 29: Monthly wind speed range in the United Arab Emirates (Climate Consultant, 2022).

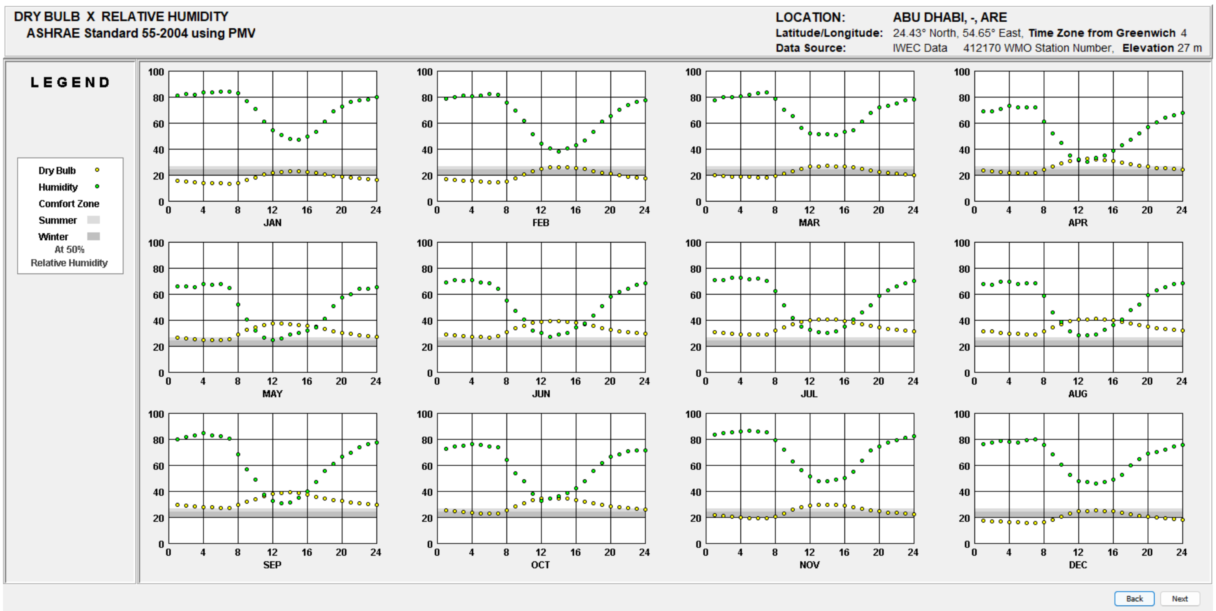


Figure 30: Hourly dry bulb temperature and relative humidity each month throughout the year in the United Arab Emirates (Climate Consultant, 2022).

CHAPTER 4: CASE STUDY

Due to the time frame of the research, the available manpower and the Covid-19 global pandemic which had limited the accessibility to the office buildings, the research was limited to two types of offices in the UAE, a well-designed office in a planned urban space and an office in an industrial zone with poor interior design and layout. The selected case studies are located in Dubai.

The data that had been collected from the investigated office rooms are the number of occupants, building materials (floor, wall and ceiling), building age, windows or openings, air conditioning system, furniture and equipment (computers, printers, etc.).

4.1. Case Study: Office A

Office A had been selected from one of the office buildings in Bay Square community. Figure 32 presents the masterplan of the Bay Square and with it's pedestrian-friendly outdoor space. The Bay Square is located in Dubai's Business Bay district which is 1.2km away from the downtown. The complex project was launched in 2007 and the construction were completed in 2014. The 4-billion dirhams project, spans over an area of 5 million square foot. It comprises of three residential buildings, eight commercial buildings and two hotel buildings, with a total of 13 mid-rise buildings. With more than 500 office spaces are leased, the field measurements had been taken in one of the offices and compared with the WHO standards.

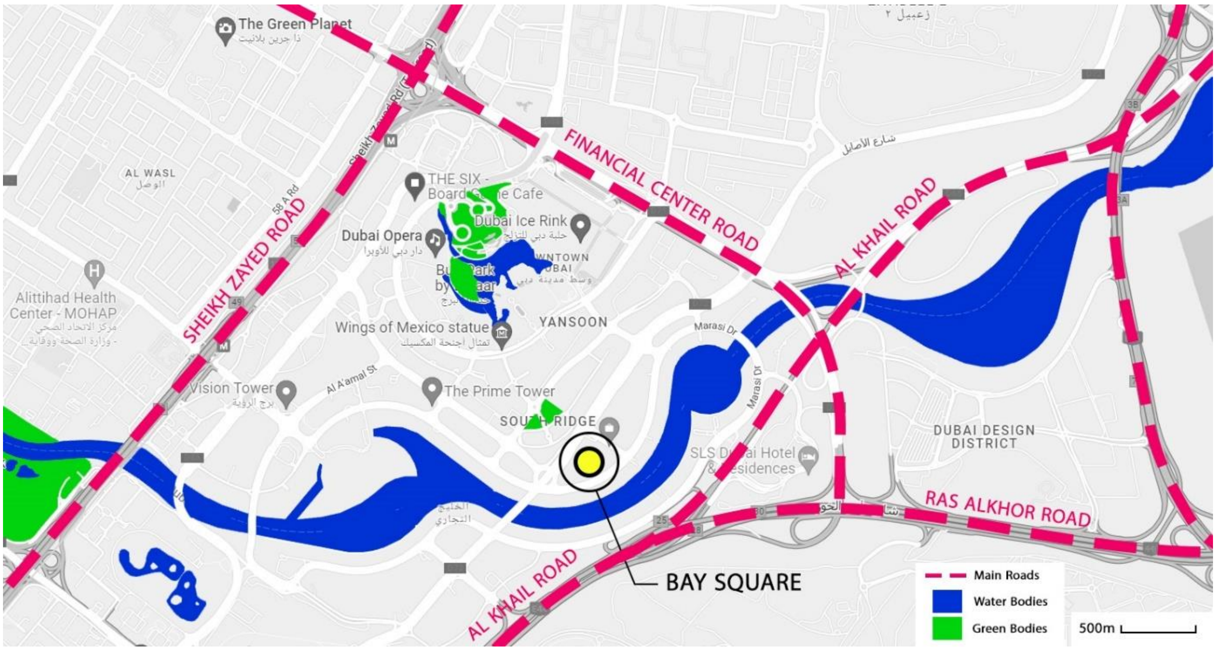


Figure 31: Location of Bay Square and it's relation with the nearest water bodies, green bodies and main roads. (Author, 2022)

Figure 32: Masterplan of Bay Square (JLL Property, n.d.)

Figure 33: Office buildings at Bay Square (Author, 2022)

The office is occupied with a total of 60 employees; 44 of them are in the main space (Room A.1), 8 in office A.2, and one in each office from rooms A.3 to A.10. Except for the employees staying in office rooms A.6 and A.10, all of them are staying inside their offices from 8:00 am in the morning to 5:00 pm in the evening. Figure 34 illustrates the office rooms layout and their respective sizes, varying from 11 m^2 to 208 m^2. The occupancy density of room A.1 is within the acceptable range stated by the DBC, which is greater than or equal to 25 occupants per 100 m^2.

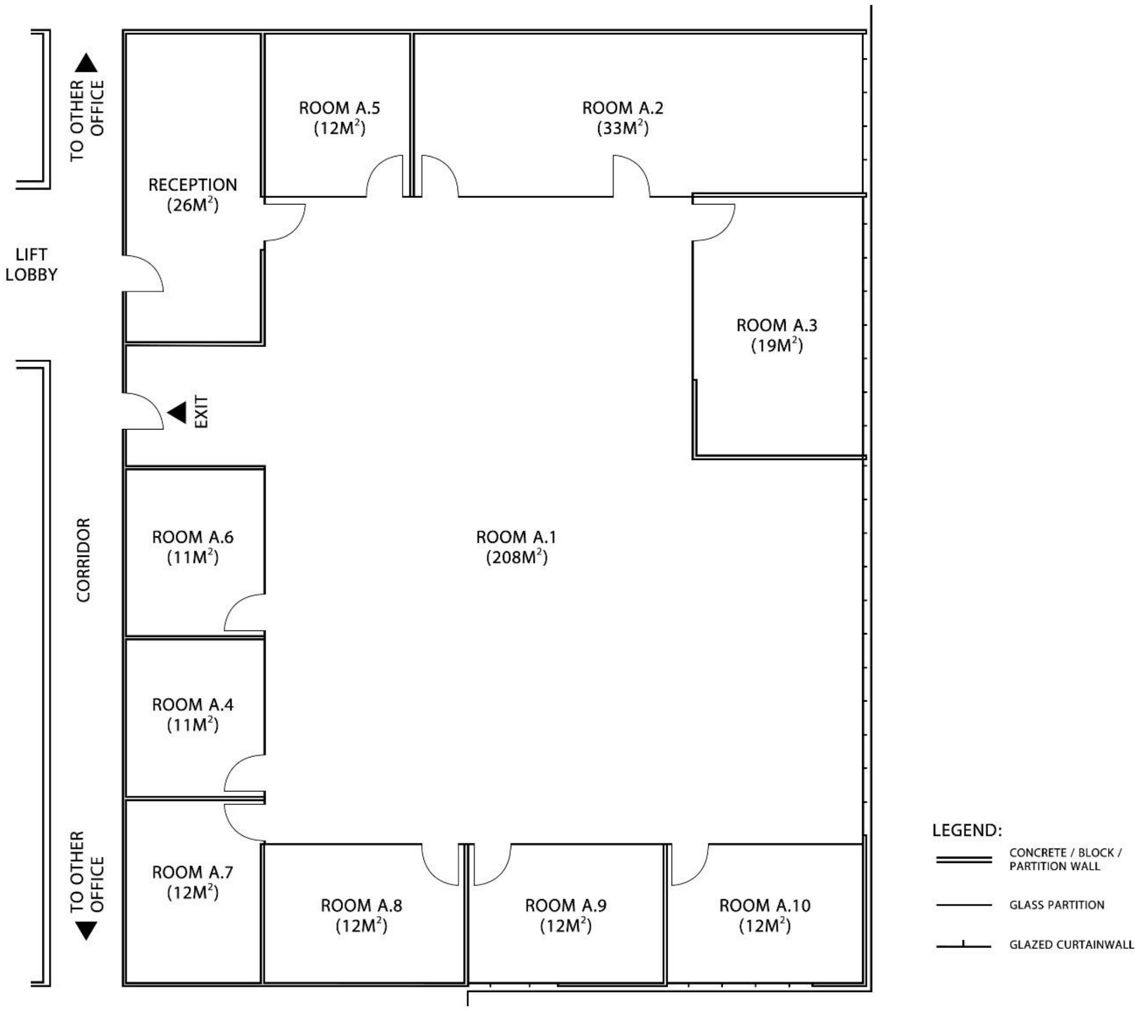


Figure 34: Layout of rooms in Office A (Author, 2022)

The interior finishes of the office are carpet tiles flooring on raised floor, emulsion paint on drywall partitions, and painted structural slab soffit. The exposed mechanical ducts, electrical conduits and fire-fighting pipes and sprinklers are painted, with no false ceiling (Figure 35). The office does not have an operable window, with fresh air being supplied only by the HVAC system. The air conditioning system consists of fan coil units, air handling units, pumping units, chilled water piping network connected to a district cooling and sheet metal ducting. The fresh air is pumped through fresh air handling units with energy recovery wheels, which is transported to the fan coil units and then supplied to the office. The toilets and the pantry are ventilated with fans in fresh air units.

Figure 35: Mechanical ducts, electrical conduits and fire-fighting pipes in Office A. (Author, 2022)

The carpet tiles are cleaned in the weekends on a monthly-basis, using a vacuum cleaner. The management of the office decided to keep the vacuuming activities during the weekends to minimize the negative impact on the staff, in terms of noise pollution or high PM concentration in the space. Rohadi et al. (2020) had illustrated in their study that vacuuming activities arises the PM concentration due to the resuspension of particles. They investigated that the PM_{10} concentration caused by the vacuum cleaning in the office were 420 µg/m3, which is 9 times higher than the AQG level, whereas the $PM_{2.5}$ concentration were 270 µg/m3 which is 18 times higher. They estimated that the particulate matter stays in the air for a period of 1 to 4 days, before resting on a surface (Rohadi, Jaafar, Ismail and Ibrahim, 2020).

4.2. Case Study: Office B

Office B is in Al Quoz district, which is an industrial district located in Bur Dubai between two main roads, Al Sheikh Zayed Road and Al Khail Road. The office is situated 7km away from the downtown. It is divided into two major zones, Al Quoz residential and Al Quoz industrial zones (Figure 37). The major zones are further divided into 4 minor zones. The district has few green parks near to the main roads and a cemetery. The date of construction is unavailable; however, it had been constructed for more than 13 years. The office is at the second floor in a three-storey building, with only a security desk in the ground floor.

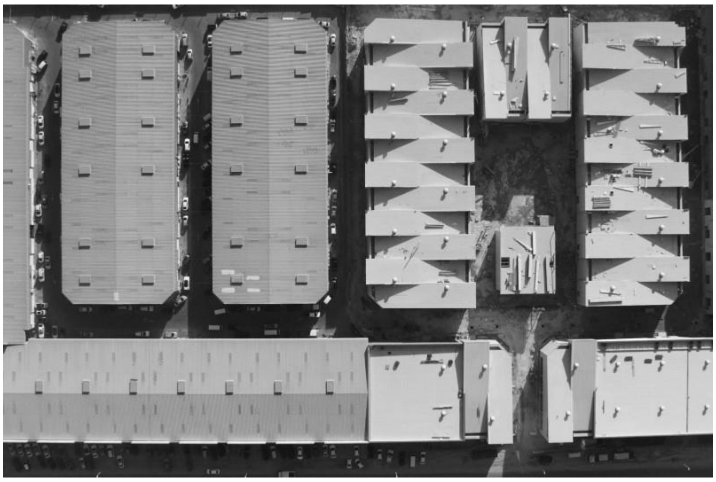


Figure 36: Top view of Al Quoz industrial area (Al Quoz Area Guide, 2018)

Figure 37: Al Quoz district is divided into to major zones, Al Quoz residential and Al Quoz industrial zones. Each major zone is further divided into 4 minor zones. (Google maps, 2022)

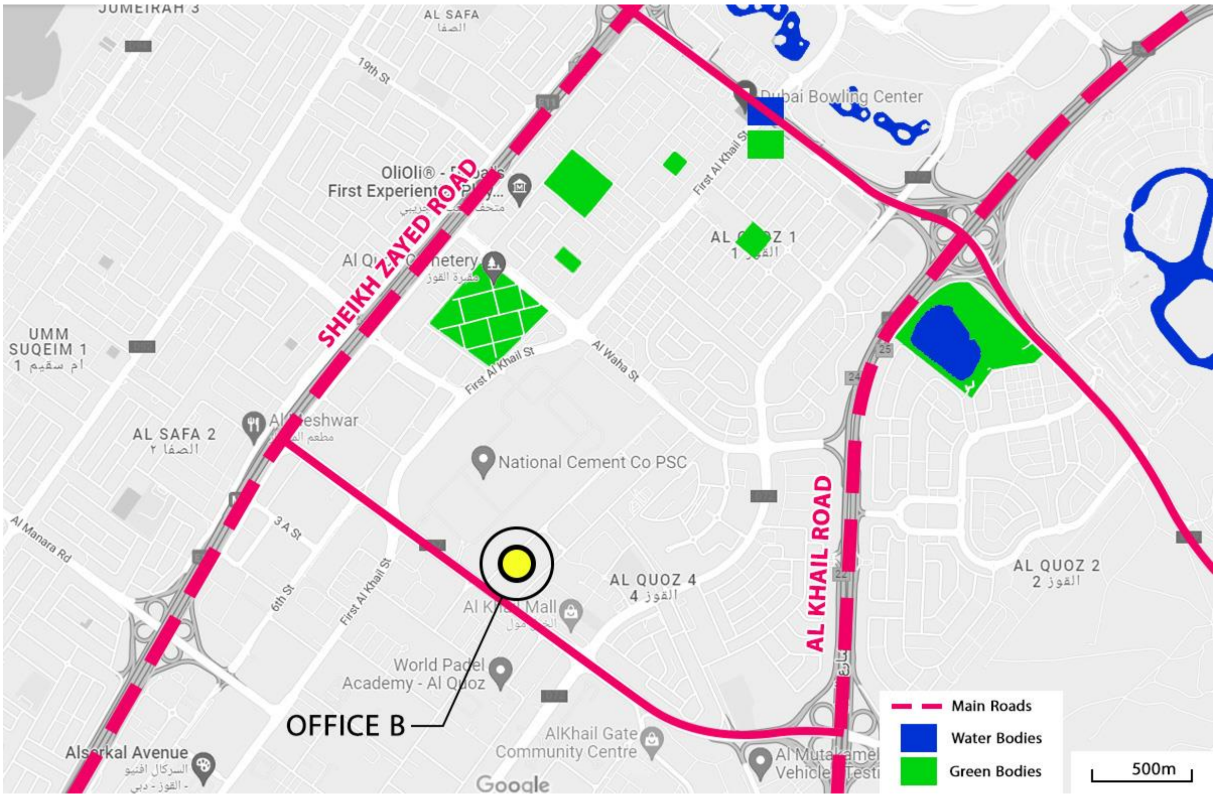


Figure 38: Office B is located in Al Quoz residential zone 4 (Google maps, 2022)

Office B was designed as an open-plan office with a total of 14 staff members are sitting in the same space including their manager. The office is divided into 3 spaces; the manager's space, the workspace and the storage space. Each staff had their own computer and printer, which was used extensively.

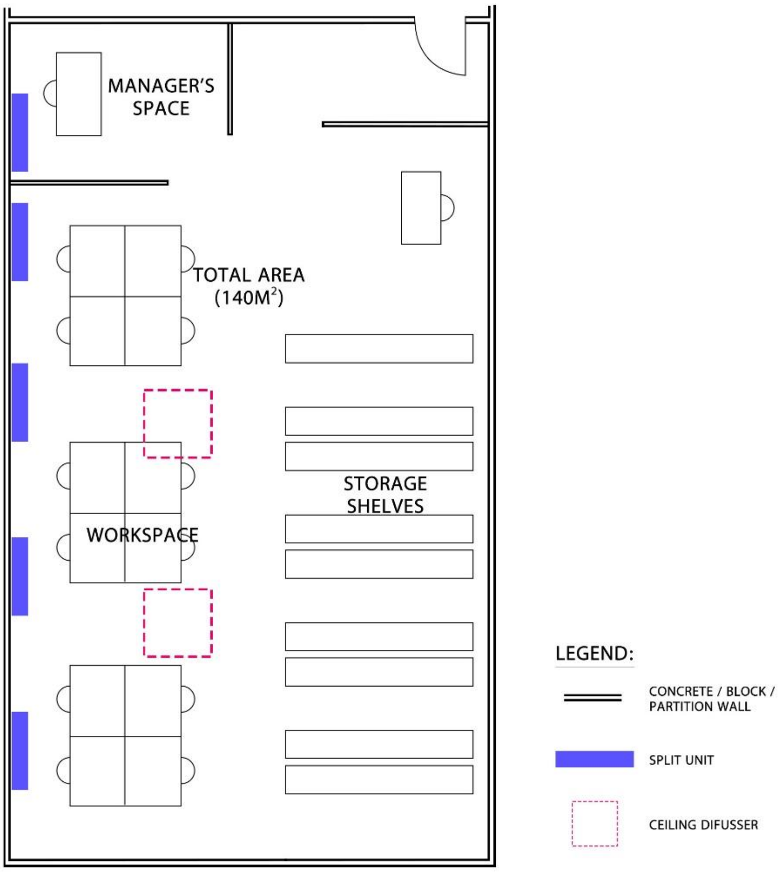


Figure 39: Layout of spaces in Office B along with ventilation layout. (Author, 2022)

The interior finish of the office is ceramic flooring, emulsion painted plaster on blockwalls and false ceiling tiles. The mechanical ducts, electrical conduits and fire-fighting pipes are hidden by the false ceiling. There is a ceiling-mounted supply and return diffusers which are not working. However, they have fixed 5 wall-mounted split units in the office, 4 of them are constantly working while 1 is switched off all the time. There are two operable windows which are used to passively ventilate the office whenever needed.

CHAPTER 5: RESULTS, FINDING AND DISCUSSION

5.1. Office A: Data Collection, Results and Discussion

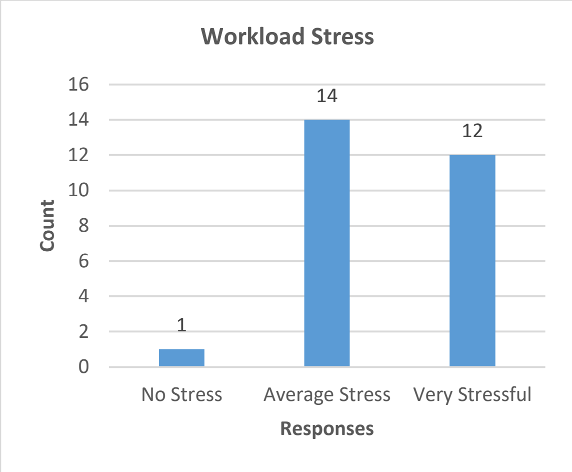
5.1.1. Questionnaire Distribution, Results and Discussion

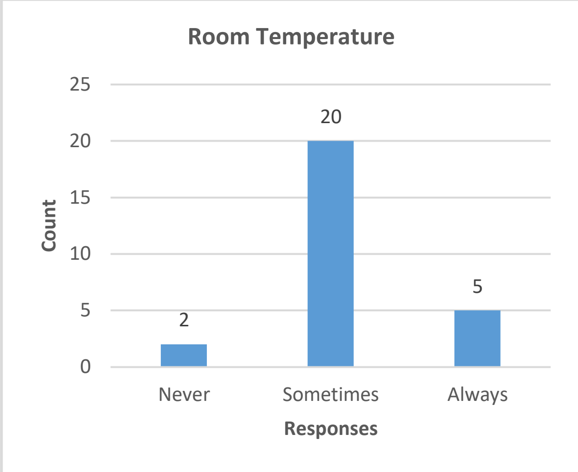
The pilot sample were distributed via a link to 4 participants from the company's technical department in Office A. It was filled on the 22nd, 24th and 25th of January, 2022. The questionnaire was updated based on the comments given by the participants in the pilot sample. Then, it was distributed to the remaining participants from the same department in Office A on the 2nd of February, 2022. An official email was sent with an introduction about the questionnaire and its purpose, along with the link being attached in the email. A total of 10 had responded on the same day, and on the following two days. The questionnaire was then distributed to the HR department on the 11th of February, 2022 and 4 participants had responded from a total of 6 members. A reminder was sent to the Technical department on the 15th of February with an additional explanation and a visit to the office to ensure that everything is clear. A total of 9 participants had responded on that day. The questionnaire was filled by a total of 27 out of 45 participants from Office A. Three of them were sitting in Rooms (A.3), (A.4) and (A.5). 2 are sitting together in Room (A.2) and the remaining 22 are in Room (A.1). The remaining rooms were for the managers which did not participate in the questionnaire and was not counted.

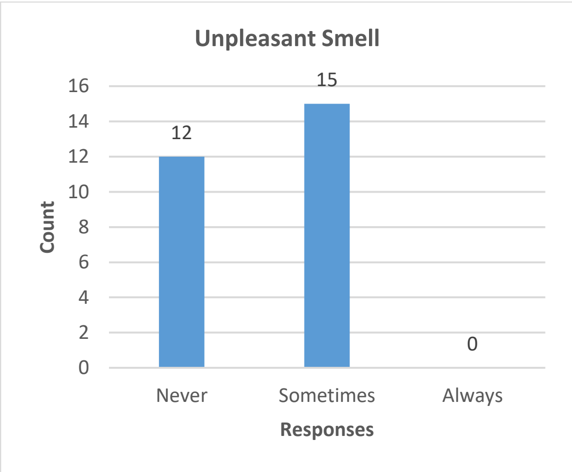
Table 5: Number of people responded to the questionnaire in Office A. (Author, 2022)

Office A			
	Number of workers in the office (per person)	Number of people responded (per person)	Area of the working space (m^2)
Room A.1	43	22	250
Room A.2	3	2	28
Room A.3	1	1	20
Room A.4	1	1	11
Room A.5	1	1	11

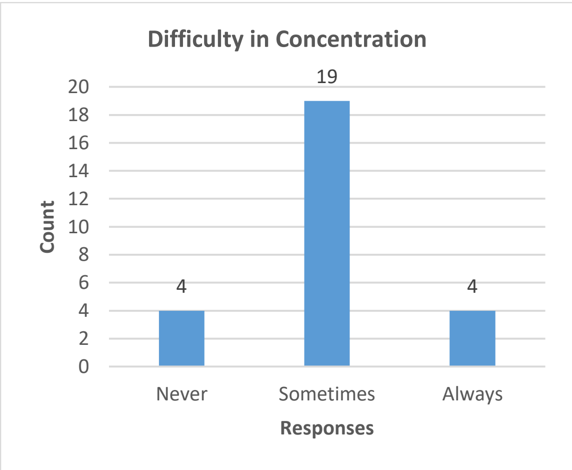
The charts in Figure 40 indicate the symptoms felt by the Office A participants. Based on the responses, the workload stress is between average to very stressful as 14 had responded “average stress” while 12 had responded “very stressful”. Working in a stressful environment for a long period of time would increase the risk of facing a difficulty in concentration at work as well as in sleeping. This would result in an unbalanced process in the human organs, and specifically in the respiratory system. Therefore, around 70% of the total responses are facing difficulty in concentrating at work; 19 of them are complaining sometimes while 4 are always facing difficulty. Similarly, for sleeping, 19 participants are sometimes having a difficulty in sleeping whereas 3 participants are always unable to sleep properly. Running nose might be another symptom for those people who are allergic to dust particles, were 40% of the total responses had never noticed this symptom.

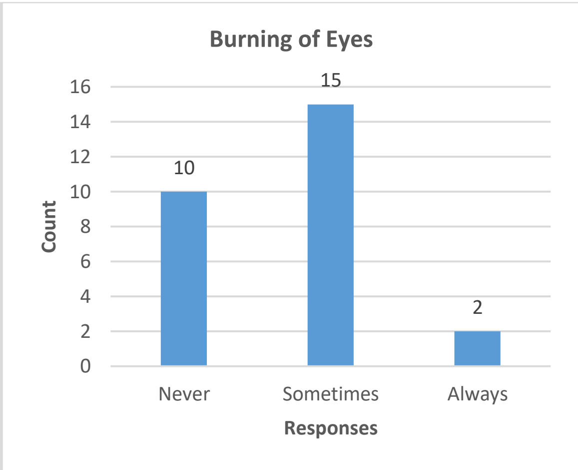

Workload Stress
Count
16
14
12
10
8
6
4
2
0
1
14
12
No Stress
Average Stress
Very Stressful
Responses

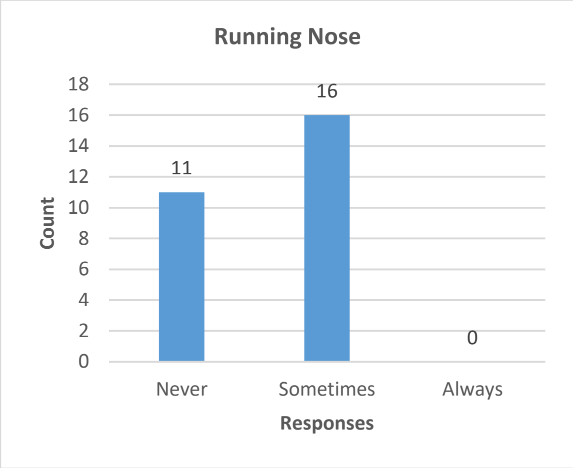

Room Temperature
Count
25
20
15
10
5
0
2
20
5
Never
Sometimes
Always
Responses


Unpleasant Smell
Count
16
14
12
10
8
6
4
2
0
12
15
0
Never
Sometimes
Always
Responses


Dizziness
Count
16
14
12
10
8
6
4
2
0
12
14
1
Never
Sometimes
Always
Responses


Difficulty in Concentration
Count
20
18
16
14
12
10
8
6
4
2
0
4
19
4
Never
Sometimes
Always
Responses


Burning of Eyes
Count
16
14
12
10
8
6
4
2
0
10
15
2
Never
Sometimes
Always
Responses



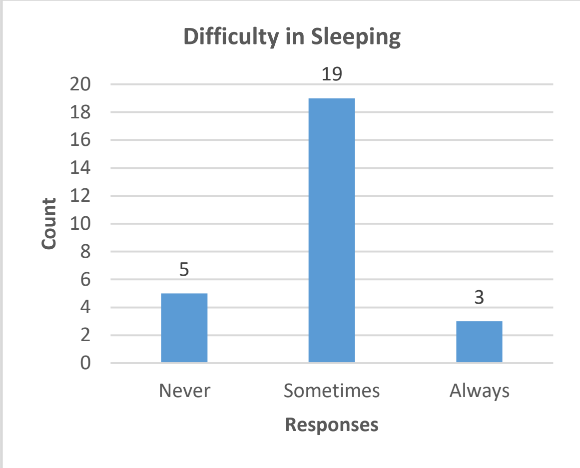


Figure 40: Responses of the questionnaire distributed in Office A. (Author, 2022)

5.1.2. Field Measurements

After collecting the data from the questionnaires distributed, and due to a long process of getting the approval from the management of each department and the top management for both offices, the field measurements began in the month of April, 2022.

The measurements were taken for rooms A.1 and A.4 as shown in Figure 27. The test in Office A were conducted on 28th and 29th of April, 2022. The room temperature, relative humidity and the PM concentration inside the rooms were collected. The extracted values were divided into two groups, PM2.5 and PM10. For PM2.5 includes all particle size range from 2.5 µm in diameter or less, while PM10 includes particle size range from 2.5 µm to 10 µm. The results are then compared with the WHO standards as highlighted in Chapter 3.

The rooms temperature was kept at 21°C and around 60% relative humidity as indicated by the Thermo Scientific Personal DataRAM pDR-1500 (check the Appendix for pictures from the instrument). For the PM concentration, the below charts highlight the measurements taken for Office A. Based on the measurements of the particle count indicates that the majority of the particles are with a diameter less than or equal to 2.5 µm, which penetrates the human's respiratory system and causing more health complications as mentioned in chapter 2. In room A.1, the particle counts for $PM_{2.5}$ were at 23,736 particles in the morning, which had dropped in the noon time to 19,009 particles and then a negligible rise to 19,148 in the evening time. The PM2.5 concentrations were 4.292 µg/m^3 in the morning time, then raised to 4.690 µg/m^3 during noon time then dropped again to 3.735 µg/m^3. While for PM10, the particle counted in the morning time were 298 particles, which had dropped to 242 particles in the noon time and then 89 particles in the evening time. The PM10 concentration were 32.78 µg/m^3 in the morning, then dropped to 19.71 µg/m^3 in the noon and then further dropped to 8.63 µg/m^3 in the evening time. Switching off the air conditioning in the morning time before the workers reaching the office is the main cause behind the rise of the particle count and the PM concentration in the office, especially for the PM10 with a concentration of 32.78 µg/m^3 which indicates the accumulation of particles with a diameter size greater than 2.5 µm in diameter into the atmosphere of the office.

Based on the results, the presence of the users in the office had a major impact on the PM10 particle count, as by the end of the day the particle count had dropped by 63% (153 particles) from the noon time. Unlike PM10, the extraction of PM2.5 from the office atmosphere were relatively harder than PM10. Despite the presence of the air pollutant's sources (people, computers and printers), the PM2.5 particle count were kept constant. This indicates that the air conditioning in the space is extracting the PM2.5 particles at the same rate of being supplied by the sources.

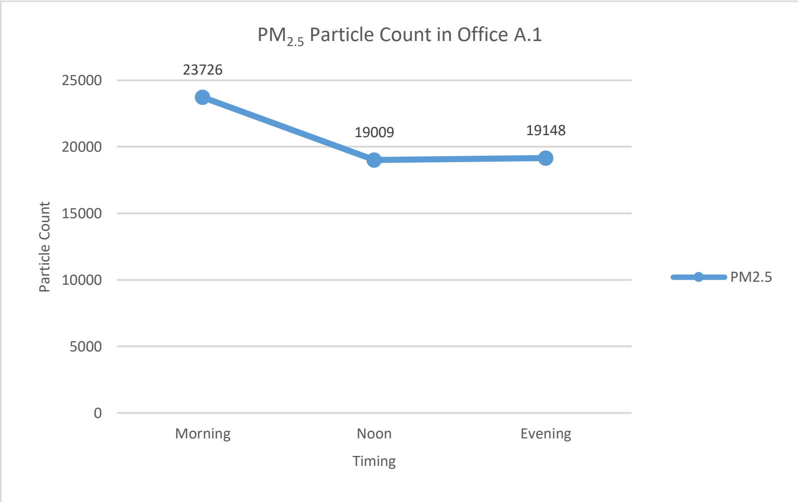


Figure 41: $PM_{2.5}$ particle count in room A.1 at Office A. (Author, 2022)

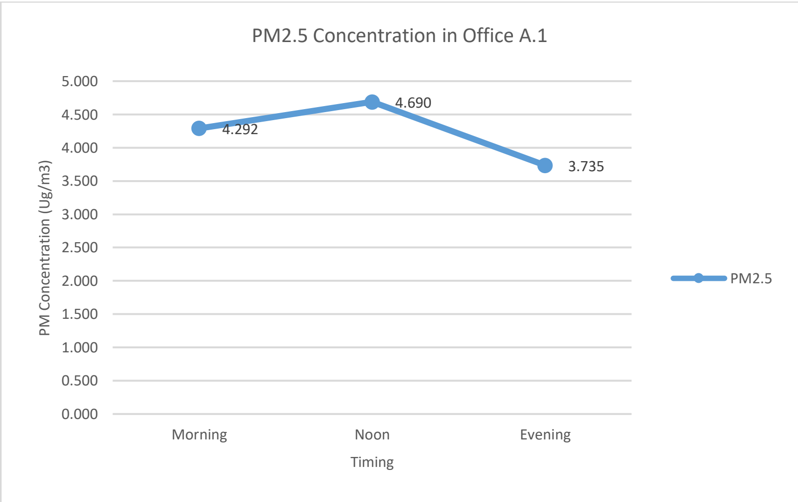


Figure 42: $PM_{2.5}$ concentration in room A.1 at Office A. (Author, 2022)

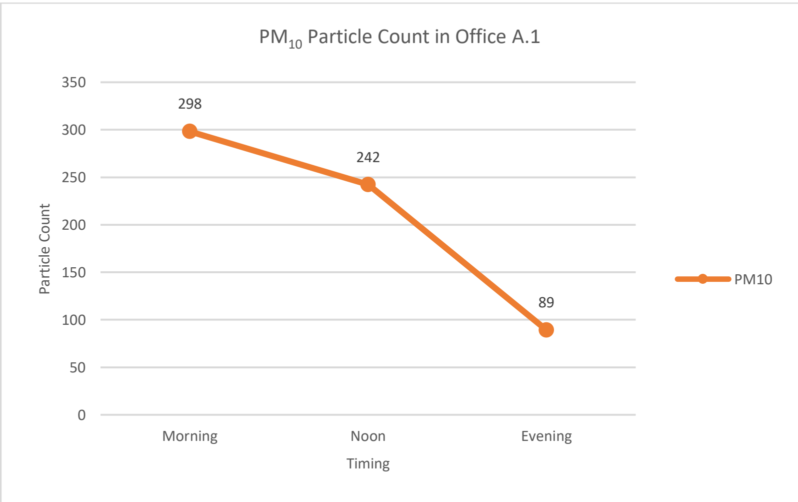


Figure 43: PM_{10} particle count in room A.1 at Office A. (Author, 2022)

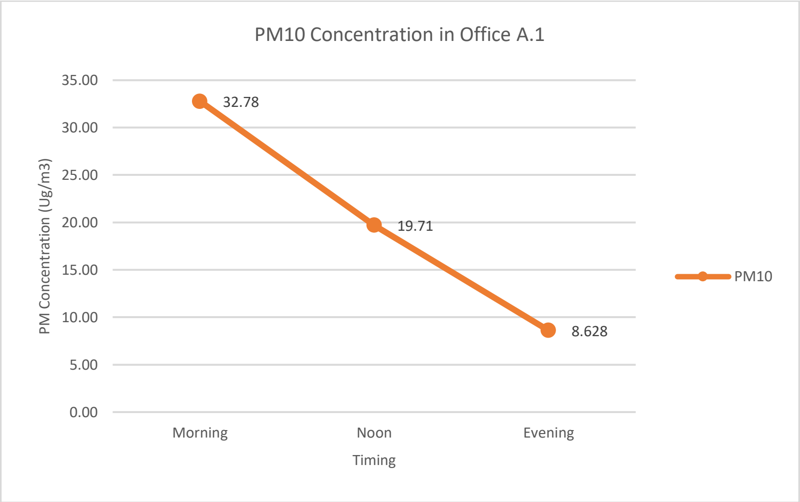


Figure 44: PM_{10} concentration in room A.1 at Office A. (Author, 2022)

Whereas in room A.4, the particle counts for $PM_{2.5}$ were 20,038 particles with a concentration of 2.765 µg/m^3. The particle count had raised more than 10,000 particles from the morning in the noon time, reaching to 30735 particles with a concentration of 10.31 µg/m^3. In the evening time, the particle count had dropped to 16,109 particles with a concentration of 2.464 µg/m^3. On the other hand, the PM_{10} particle count were 81 particles in the morning with a concentration of 7.622 µg/m^3. During the noon time, the particle count had raised to 184 particles with a total concentration of 9.202 µg/m^3. The particle count is then dropped to 72 particles in the evening, with a concentration of 8.478 µg/m^3. The sources of air pollutants in room A.4 were the user and his computer. However, the sharp decline in the evening measurement due to the user had left on both days of the measurement at 1pm, taking his computer along with him.

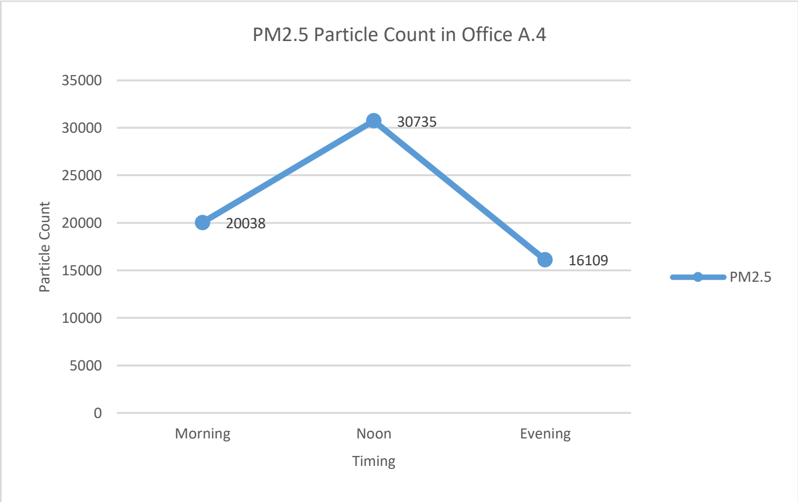


Figure 45: $PM_{2.5}$ particle count in room A.4 at Office A. (Author, 2022)

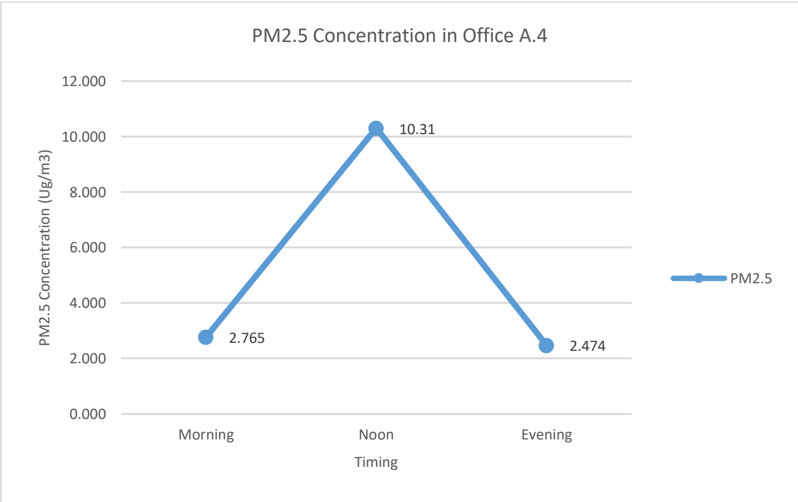


Figure 46: $PM_{2.5}$ concentration in room A.4 at Office A. (Author, 2022)

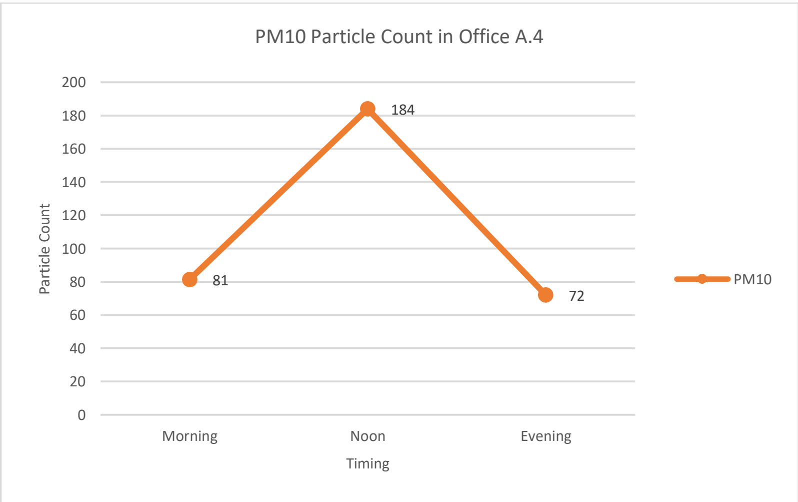


Figure 47: PM_{10} particle count in room A.4 at Office A. (Author, 2022)

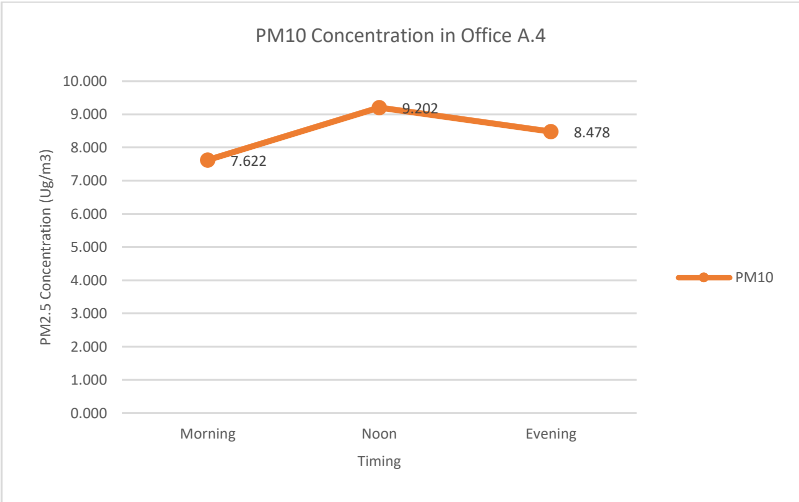


Figure 48: PM_{10} concentration in room A.4 at Office A. (Author, 2022)

As an overall, the $PM_{2.5}$ and PM_{10} concentrations for both rooms, Rooms A.1 and A.4, is within the range of AQG level. The PM_{10} concentration is not exceeding the AQG level which is 45µg/m^3. However, it is noticed that the morning's concentration in Room A.1 is the highest with 30µg/m^3. On the other hand, the $PM_{2.5}$ concentration is not exceeding the AQG level which is 15µg/m^3. The highest concentration of $PM_{2.5}$ were in the noon time for Room A.4, due to the relatively smaller area of the room, in which the number of particles is spread over a smaller area.

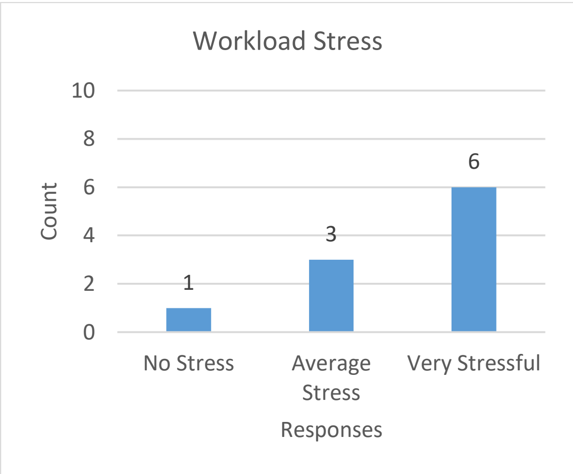
5.2. Office B: Data Collection, Results and Discussion

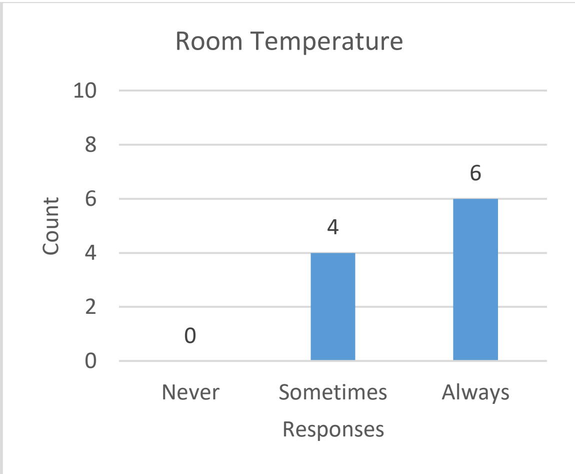
5.2.1. Questionnaire Distribution, Results and Discussion

Following to the same steps applied in office A, the questionnaire were distributed to the staff at Office B via a link. Unfortunately, due to Covid-19 pandemic, the workload at the office was always high as some office workers did not attend. Thus, it was filled by 10 participants out of 14 staff members in Office B. Based on the responses, 6 out of 10 had responded that the workload is very stressful, while 3 had responded an average stress. For the room temperature, 6 participants are always complaining as the air conditioning split units are very close to the them, while the rest are sometimes. The majority are not complaining of an unpleasant smell, which might indicate that the source of air pollutant does not have an odour. 40% of the participants are complaining of dizziness while the rest are not complaining at all. In terms of concentration during work, 50% are not complaining and 50% are sometimes facing difficulty. The burning of eyes and the running nose are major symptoms felt by 90% of the participants, which might indicate a high level of PM concentration. 6 participants are sometimes facing difficulty in sleeping, while 2 are always facing a difficulty.

Table 6: Number of people responded to the questionnaire in Office B. (Author, 2022)

Office B			
	Number of workers in the office (per person)	Number of people responded (per person)	Area of the working space (m^2)
Office B	14	10	250





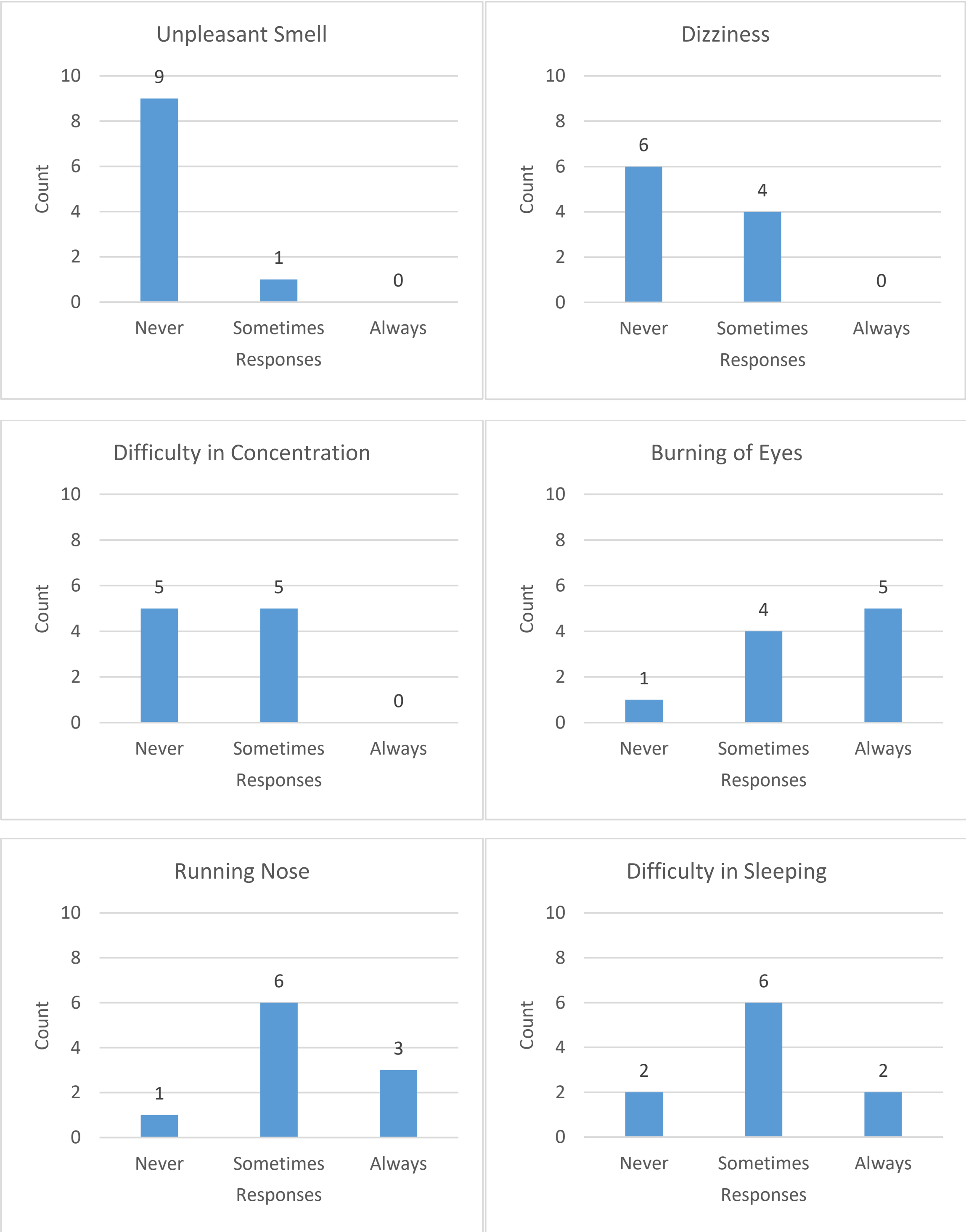


Figure 49: Responses of the questionnaire distributed in Office B. (Author, 2022)

5.2.2. Field Measurements

At office B, the measurements were taken on the 1st and 2nd of May, 2022. The two devices were kept in the middle of the workspace at a height of 1 meter from the floor. The samples were taken at morning, noon and evening times. (Refer to Appendix for the pictures) The charts below illustrate the results from office B. The $PM_{2.5}$ particle count were 24,688 particles in the morning with a concentration of 82.619 µg/m^3. During the noon time, the particle count were 25913 particles with a concentration of 75.634 µg/m^3. The end of the day, the particle count had dropped to 23,308 particles with a concentration of 56.851 µg/m^3. On the other hand, the PM_{10} particles count in the morning time were 354 particles with a concentration of 133.083 µg/m^3. The particles count had declined to 275 particles in the noon time with a total concentration of 100.661 µg/m^3. In the evening, the particle count had further dropped to 181 particles with a concentration of 59.490 µg/m^3.

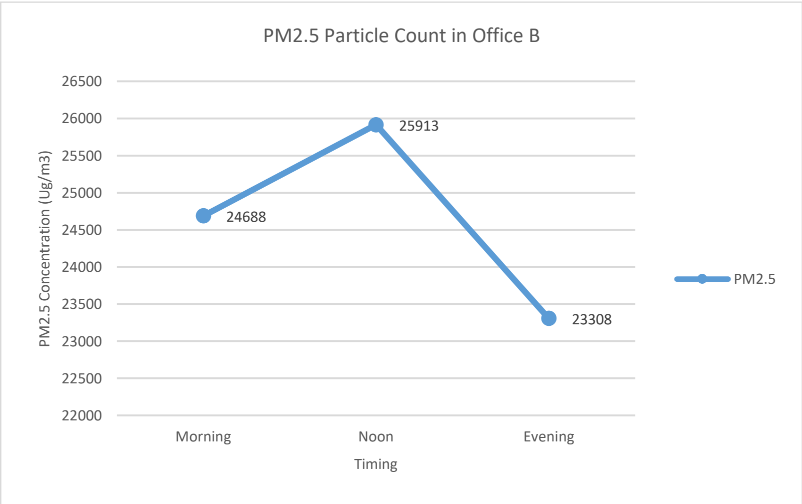


Figure 50: PM2.5 Particle count in Office B. (Author, 2022)

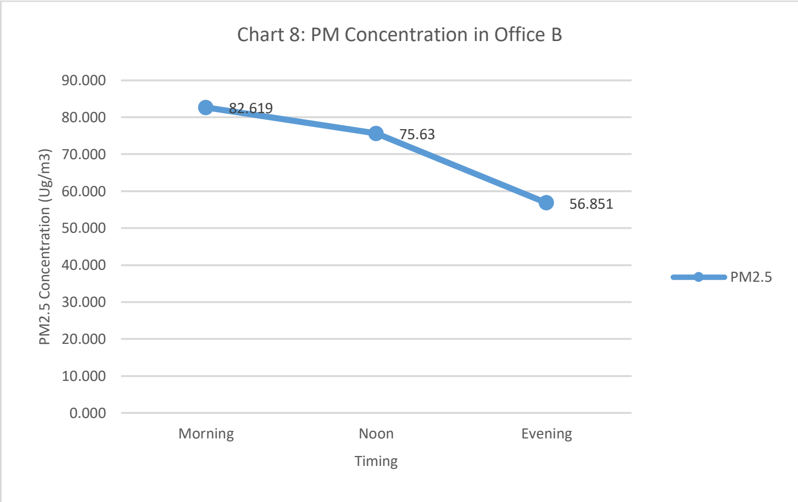


Figure 51: PM2.5 concentration in Office B. (Author, 2022)

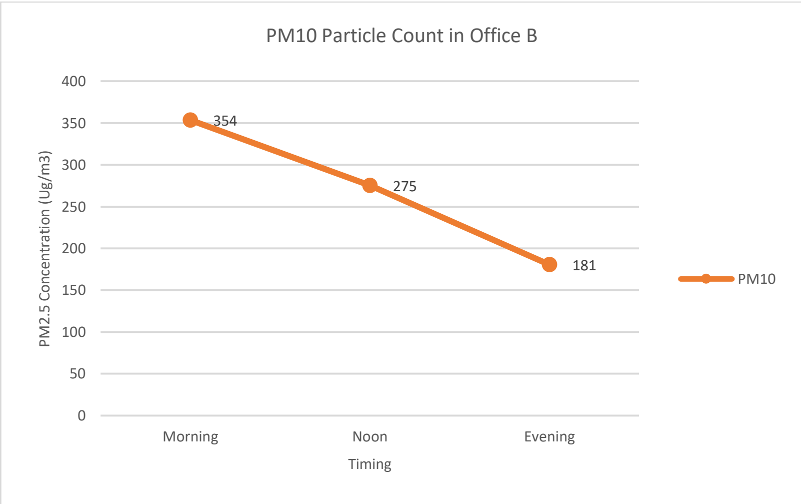


Figure 52: PM10 Particle count in Office B. (Author, 2022)

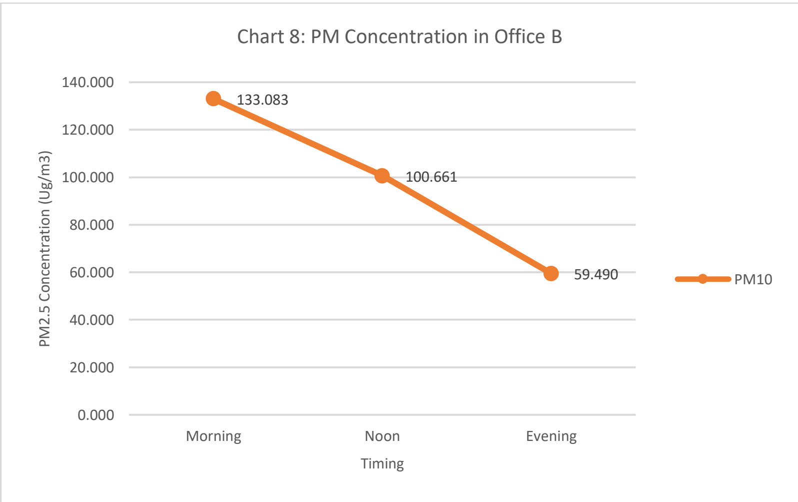


Figure 53: PM10 concentration in Office B. (Author, 2022)

5.3. Pollutant Sources Measurements

To find out the impact of source pollutants in an office, the PM concentration were measured for offices A.6 (without a desktop computer) and A.4 (with a desktop computer). Both offices were selected for this comparison, as they have the same floor, wall and ceiling finishes, same layout and room size. The author made sure that there was no other sources of air pollutants in the rooms and the HVAC system were switched off. The measurements were taken for 2 hours.

The $PM_{2.5}$ particle count after the first 30 minutes of field measurement were at 4,221 particles per minute and with a concentration of 17.718 µg/m^3. The particle count had dropped to 4,178 particles per minute at the first hour with a concentration of 15.899 µg/m^3. At 1 hour and 30 minutes mark, the particle count had raised to 4,501 particles counted per minute with a concentration of 15.561 µg/m^3. At the end of the measurement, the particle count had reached to 4,791 particles per minute and with a total concentration of 15.696 µg/m^3.

The PM_{10} particle count at the 30 minutes-mark were at 15 particles per minute and with a concentration of 43.809 µg/m^3. There was a drop at the 1 hour-mark to 5 particles per minute and with a concentration of 7.417 µg/m^3. Then, further dropped to 3 particles per minute at the 1 hour and 30 minutes mark with a concentration of 2.452 µg/m^3. At the end of the two-hour measurement, the particle count had reached to 2 particles per minute and with a concentration of 2.139 µg/m^3.

Based on the author’s investigation, the rise in the $PM_{2.5}$ particle counts in the second hour (from 1 hour-mark to 2 hour-mark) is estimated to be from the desktop computer. With a simple equation, the rise of 613 particles in the second hour were divided to find out the number of particles emitted by the computer only. Based on the equation, the average number of particles emitted by the computer were 10 particles per minute. The drop in the $PM_{2.5}$ concentration were due to the spreading of particles from the main source, reaching to almost a constant 15.719 µg/m^3 as an average in the second hour.

$$\frac{613\ particles}{60\ minutes} \equiv 10\ particles\ per\ minute$$

On the other hand, there was a drop of 10 particles per minute in the first hour, before reaching a constant of between 2 to 3 particles per minute being counted. The high particle count at the beginning of the measurement is estimated to be due to the interference of the author to place and prepare the instrument. However, the PM_{10} concentration seems to have a similar decline in the first hour, reaching to a constant level at 4.003 µg/m^3 as an average in the second hour.

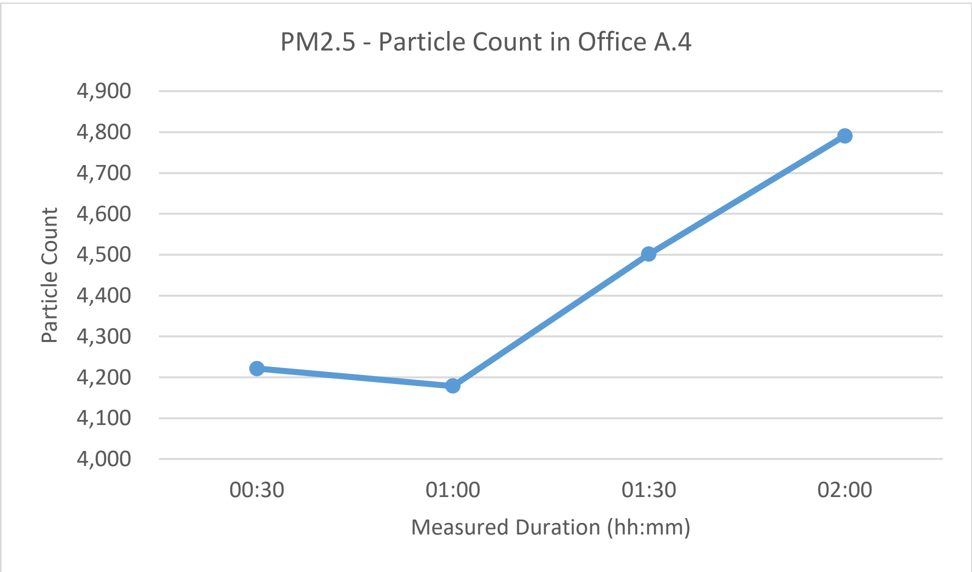


Figure 54: $PM_{2.5}$ Particle count in office A.4 with a pollutant source. (Author, 2022)

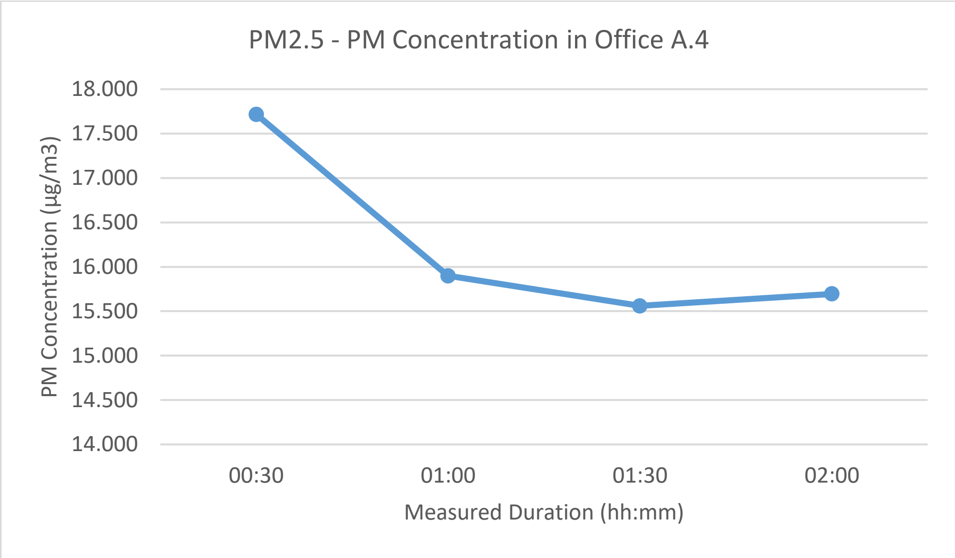


Figure 55: $PM_{2.5}$ concentration in office A.4 with a pollutant source. (Author, 2022)

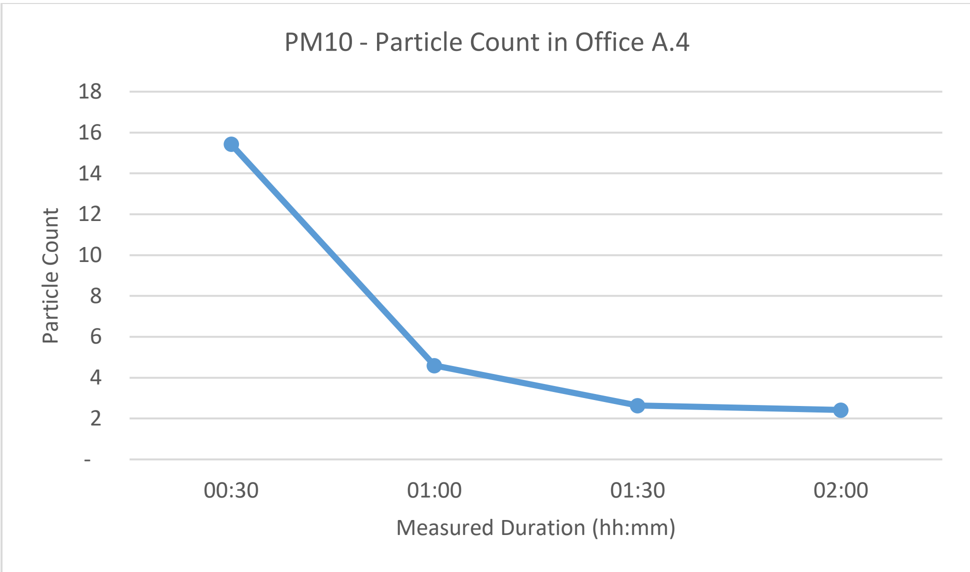


Figure 56: PM_{10} Particle count in office A.4 with a pollutant source. (Author, 2022)

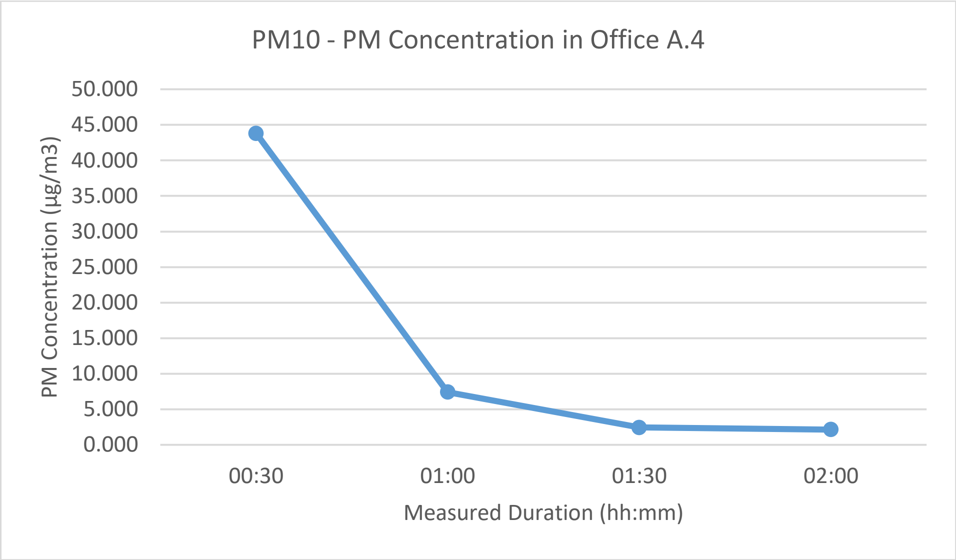


Figure 57: PM_{10} concentration in office A.4 with a pollutant source. (Author, 2022)

To have a clearer vision, the particle count and the PM concentration were measured for room A.6 with the absence of the computer as a source of air pollution. The room kept empty and without the interference of any source of pollutant during the measurement. Based on the measurements, the $PM_{2.5}$ particle count after the first 30 minutes from the beginning of the measurement were 6,303 particles per minute with a concentration of 3.047 µg/m^3. At the 1-hour mark, the particle count had dropped to 5,983 particles per minute with a concentration of 2.703 µg/m^3. The particle count had further dropped to 5,464 particles per minute at the 1 hour 30 minutes mark with a total concentration of 2.360 µg/m^3. At the end of the two-hour measurement, the particle count had dropped to 4,638 particles per minute, with a concentration of 2.005 µg/m^3. Whereas the PM_{10} particle count were 6 particles per minute in the first 30 minutes, with a concentration of 0.880 µg/m^3. The particle count had dropped to 4 particles per minute with a total concentration of 0.436 µg/m^3. At the 1-hour-and-30-minutes mark the particle count were almost at a constant state at 3 particles per minute with a concentration of 0.480 µg/m^3. At the end of the measurement, the particle count were 4 particles per minute with a concentration of 0.501 µg/m^3.

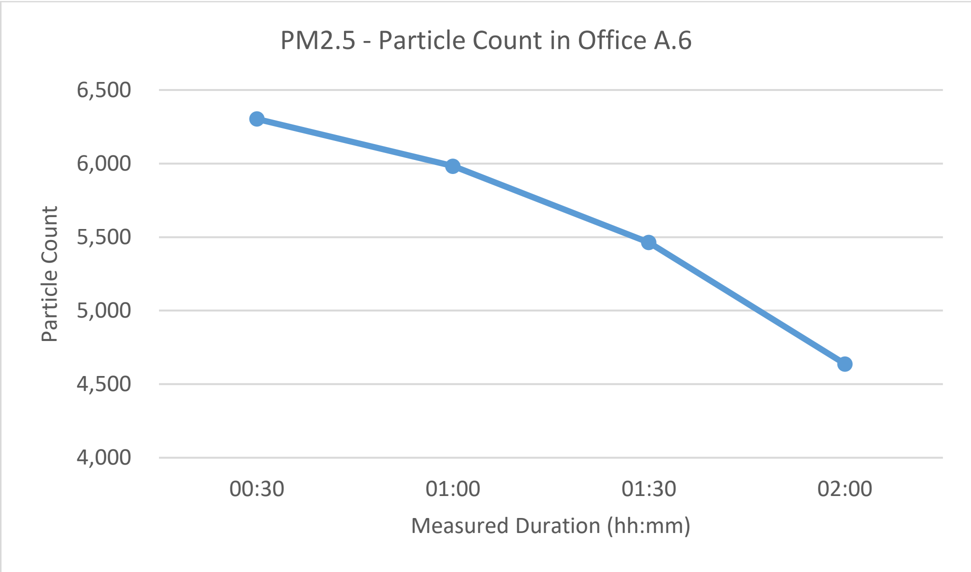


Figure 58: $PM_{2.5}$ particle count in office A.6. (Author, 2022)

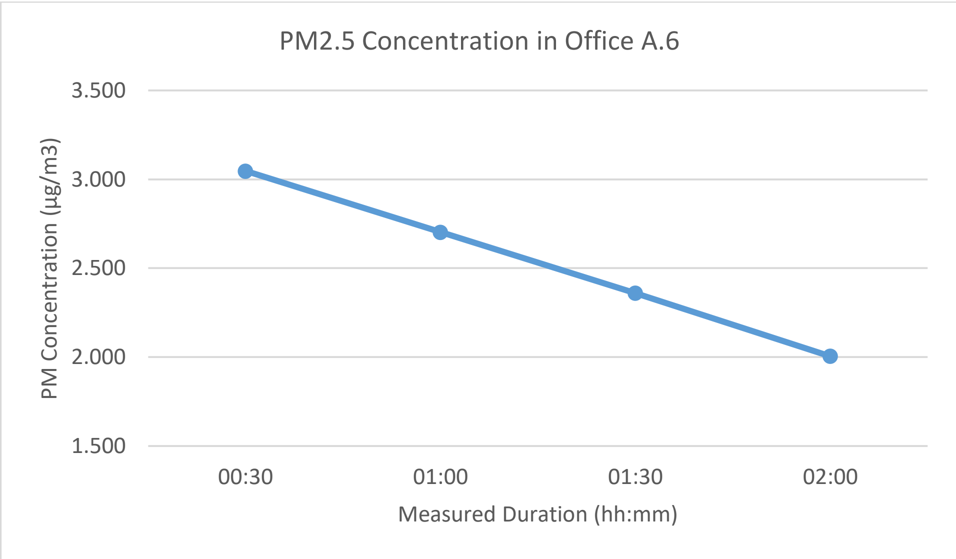


Figure 59: $PM_{2.5}$ concentration in office A.6. (Author, 2022)

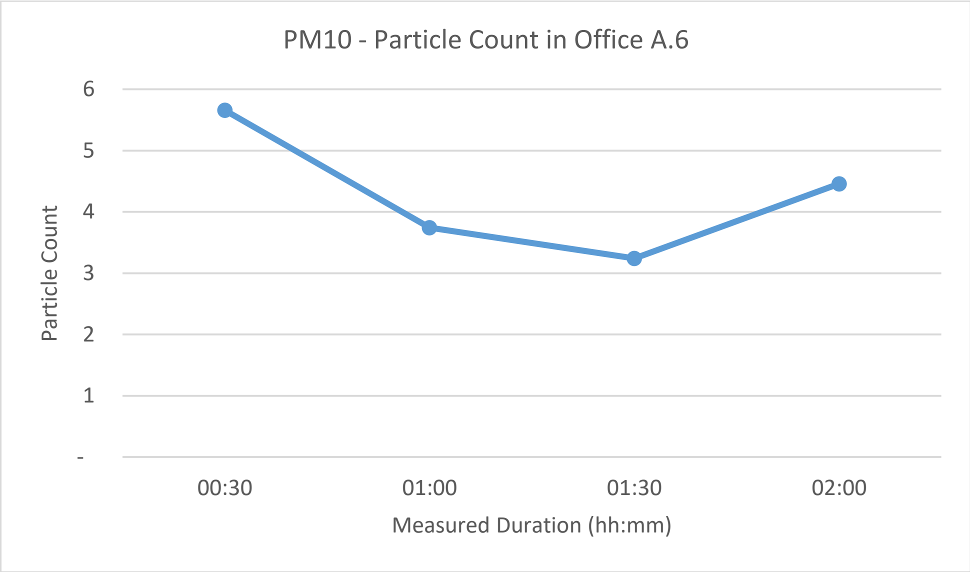


Figure 60: PM_{10} particle count in office A.6. (Author, 2022)

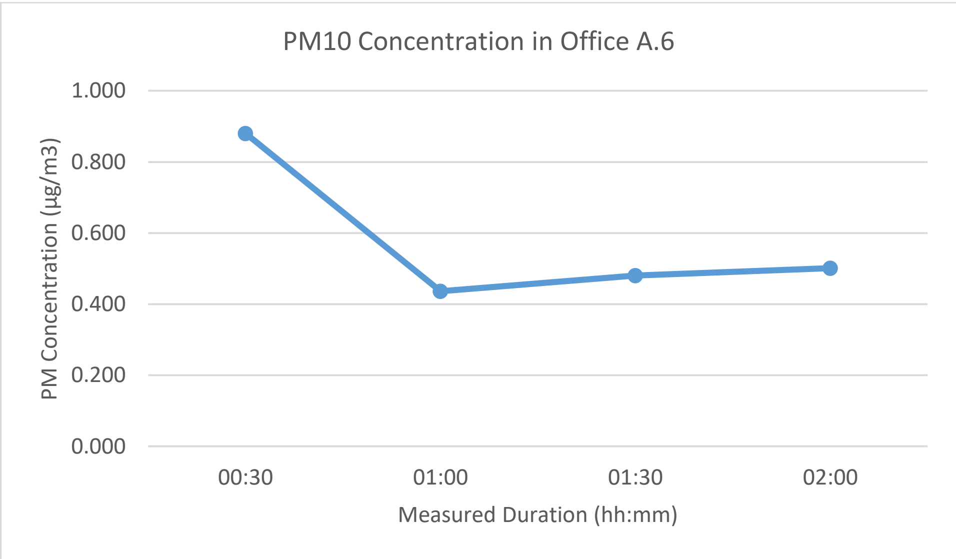


Figure 61: PM_{10} concentration in office A.6. (Author, 2022)

Compared with the results taken for office A.4 in the presence of the user and his computer, which had an increase in the PM2.5 particle count of 10,697 particles from the morning to the noon time. Then there was a sharp decline in the particle count of 14,626 particles from the noon to the evening time. With a simple equation, the particle count emitted by the user were 35 particles per minute and his computer were 10 particles per minute.

$$Particle\ count\ (per\ minute) for\ the\ user\ and\ his\ computer:$$

$$\frac{10{,}697}{(4\ hours \times 60\ minutes)} = 45\ particles\ per\ minute$$

$$\frac{14{,}626}{(6\ hours\ \times 60\ minutes)} = 41\ particles\ per\ minute$$

$$Particle\ count\ (per\ minute) for\ the\ user\ only:$$

$$45\ particles\ per\ minute - 10\ particles\ per\ minute = 35\ particles\ per\ minute$$

Whereas for the PM10 particle count, the results from the computer only had indicated that there is no or minimal PM10 particles emitted by the computer. This indicates that the impact on the PM10 particle count were from the office user. Based on the measurements for the PM10 particle count, there was a rise of 103 particles from morning to noon time and then declined by 112 particles from noon to evening time. Hence, a PM10 particle is emitted by the user every 2 minutes and 18 seconds as an approximate.

$$\frac{103}{(4\ hours \times 60\ minutes)} = 0.43\ particles\ per\ minute$$

$$= 1\ particle\ every\ 2.3\ minutes$$

$$\frac{112}{(6\ hours \times 60\ minutes)} = 0.31\ particles\ per\ minute$$

$$= 1\ particle\ every\ 3.2\ minutes$$

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

In this study, the main factors associated with the PM concentration in office buildings in the United Arab Emirates, in Dubai exactly, were highlighted and the concentration were measured in two different offices and compared. The results were used to study and analyse the impact of each factor on the PM concentration. The HVAC system plays an important role in the indoor air quality. It’s main purpose not only limited to conditioning the indoor air to reach the desired room temperature and relative humidity, but also to extract the pollutants from the space. Therefore, the selection of the HVAC system and it’s design are very critical.

6.1. Recommendations:

6.1.1. Corporate scale

The most effective ways that had been stated to mitigate the amount of air pollutants emitted into a space is to mitigate the pollutant from the source. However, this method is not always possible or practical. Natural or mechanical ventilation is the second most effective method to control the indoor air pollutants. The ventilation process had been described by US EPA as the supply and extraction of air from a space, a room or a building. In a mechanical ventilation, the supply and extraction are performed via a combination of processes. These processes are supplying fresh air from outside, cooling or heating the air and mixing the supplied fresh air with the returned air from inside. The air is mixed in a certain ratio, which is then distributed and supplied to the rooms and spaces. A certain ratio of the returned air is then exhausted outside the building, to allow the intrusion of fresh air. These processes are designed based on many factors such as the area of the space, the number of users, and ceiling height. If any process performed inadequately based on these factors, air pollution will accumulate within the space. Hence, having a proper design, operation and maintenance of the HVAC system is essential to achieve a proper indoor air quality within the space (US EPA, 1990).

The ventilation rate needed in an office building is usually indicated in the building code and is expressed in units of cubic feet per minute per person (cfm/person). Based on ASHRAE standard for having an acceptable ventilated indoor air quality, the ventilation rate that needs to be considered for an office space is 5 cfm/person as shown in the snapshot below. Nevertheless, being aware of the main sources of air pollutant in an office building is essential. A point source might require a localized exhaust system such as chemical fume hood to exhaust air pollutants emitted from a strong pollutant source. The addition of this system would minimize the energy wasted in extracting the air pollutants in the building, which thus, cuts down the running cost. Besides, the period of operating the HVAC system in an office building should be turned on before the arrival of the occupants and turned off after their departure. Failure to ventilate the building during the presence of the occupants, will lead to accumulation of air pollutants inside the space. Nonetheless, if the HVAC system is not properly maintained, it will not only reduce or eliminate the airflow, but it will become a source of contamination. Filters must be cleaned in a regular basis, to ensure optimum level of air quality is achieved (US EPA, 1990).

During any sort of maintenance or renovation, it is always recommended that the ventilation rates are higher during these activities to control and minimize the impact on the indoor air quality of the space (US EPA, 1990).

Air cleaners may help to minimize the effect on human health, as it can filter out particulate matters from being disposed into an indoor space. A pollutant being in a solid or liquid state can be removed using these air cleaners. However, to remove gaseous pollutants, a special media needs to be embedded into the air cleaners, such as an alumina or activated carbon (Will air cleaners reduce health risks?, 2022).

6.1.2. Individual scale

The usage of smart integrated systems with various sensors to monitor and control the indoor air quality of a given space (Tran, Park and Lee, 2020). Kyung and Jeong (2020) from the department of allergy in Gachon University Gil Medical Center, had recommended to wear a face mask whenever exposed to high PM concentration, as it is an easy and simple way to control and avoid exposure to various air pollutants.

Some minor actions and decisions could save us from being exposed to a high concentration of air pollutants. For instance, staying away from newly applied materials by air conditioning and leaving the space. Allowing the intrusion of fresh air into a space and exhausting the old, polluted air is a simple and easy way to stay safe from the air pollutants in a space.

6.2. Limitations and Recommendations

Due to Covid-19 pandemic, getting approval on accessing office spaces and buildings were very complicated. Therefore, the research needs to be performed on wider range of office buildings and in different geographical locations and cities in the United Arab Emirates and the Middle East. Moreover, the research to be done in different seasons to check it's impact on the indoor PM concentration in office buildings. Nevertheless, a simulation of different air conditioning systems in a single office space can be performed to select the most suitable system in an office space. Another limitation is that the unavailability of sufficient number of instruments to perform the measurements at the same day.

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APPENDIX A: FIELD MEASUREMENT RESULTS

Results of Office A.1:

Particle Size Range	Particle Count		
	Morning	Noon	Evening
0.300 - 0.400	18839	13514	14248
0.400 - 0.550	2993	2973	2849
0.550 - 0.700	662	867	775
0.700 - 1.000	648	905	744
1.000 - 1.300	255	368	268
1.300 - 1.600	78	112	72
1.600 - 2.200	251	269	193
2.200 - 3.000	136	117	46
3.000 - 4.000	71	64	19
4.000 - 5.500	47	40	13
5.500 - 7.000	19	10	5
7.000 - 10.00	25	11	6
PM2.5	**23726**	**19009**	**19148**
PM10	**298**	**242**	**89**

Particle Size Range	Microgram Per Cubic Meter		
	Morning	Noon	Evening
0.300 - 0.400	0.857	0.615	0.648
0.400 - 0.550	0.342	0.339	0.325
0.550 - 0.700	0.171	0.223	0.200
0.700 - 1.000	0.427	0.596	0.490
1.000 - 1.300	0.410	0.591	0.432
1.300 - 1.600	0.250	0.360	0.230
1.600 - 2.200	1.835	1.966	1.411
2.200 - 3.000	2.539	2.182	0.854
3.000 - 4.000	3.246	2.926	0.879
4.000 - 5.500	5.332	4.568	1.523
5.500 - 7.000	4.980	2.575	1.202
7.000 - 10.00	16.69	7.462	4.170
PM2.5	**4.292**	**4.690**	**3.735**
PM10	**32.78**	**19.71**	**8.628**

Results of Office A.4:

Particle Size Range	Particle Count		
	Morning	Noon	Evening
0.300 - 0.400	16239	18723	12336
0.400 - 0.550	2476	6554	2359
0.550 - 0.700	527	2095	600
0.700 - 1.000	450	1717	496
1.000 - 1.300	176	716	175
1.300 - 1.600	51	225	41
1.600 - 2.200	119	704	103
2.200 - 3.000	38	131	28
3.000 - 4.000	22	32	18
4.000 - 5.500	12	13	15

Particle Size Range	Microgram Per Cubic Meter		
	Morning	Noon	Evening
0.300 - 0.400	0.739	0.853	0.56
0.400 - 0.550	0.283	0.750	0.269
0.550 - 0.700	0.136	0.540	0.154
0.700 - 1.000	0.296	1.133	0.326
1.000 - 1.300	0.282	1.154	0.281
1.300 - 1.600	0.162	0.723	0.131
1.600 - 2.200	0.867	5.154	0.750
2.200 - 3.000	0.711	2.454	0.530
3.000 - 4.000	1.001	1.458	0.819
4.000 - 5.500	1.370	1.487	1.712

5.500 - 7.000	4	4	4
7.000 - 10.00	5	4	7
PM2.5	**20038**	**30735**	**16109**
PM10	**81**	**184**	**72**

5.500 - 7.000	1.030	0.946	1.030
7.000 - 10.00	3.511	2.857	4.388
PM2.5	**2.765**	**10.31**	**2.474**
PM10	**7.622**	**9.202**	**8.478**

Results of Office B:

Particle Size Range	Particle Count		
	Morning	Noon	Evening
0.300 - 0.400	14985	17341	16709
0.400 - 0.550	4334	3774	3031
0.550 - 0.700	1708	1423	1106
0.700 - 1.000	1774	1640	1206
1.000 - 1.300	860	821	586
1.300 - 1.600	269	242	192
1.600 - 2.200	758	671	479
2.200 - 3.000	233	193	134
3.000 - 4.000	73	50	32
4.000 - 5.500	34	21	9
5.500 - 7.000	6	8	1
7.000 - 10.00	7	5	4
PM2.5	**24688**	**25913**	**23308**
PM10	**354**	**275**	**181**

Particle Size Range	Microgram Per Cubic Meter		
	Morning	Noon	Evening
0.300 - 0.400	5.460	6.318	6.086
0.400 - 0.550	3.582	3.119	2.504
0.550 - 0.700	4.202	3.501	2.720
0.700 - 1.000	7.547	6.976	5.127
1.000 - 1.300	12.15	11.60	8.275
1.300 - 1.600	9.565	8.616	6.812
1.600 - 2.200	40.11	35.51	25.33
2.200 - 3.000	32.43	26.78	18.57
3.000 - 4.000	26.60	18.09	11.78
4.000 - 5.500	28.10	17.08	7.436
5.500 - 7.000	14.76	18.86	3.280
7.000 - 10.00	31.20	19.85	18.43
PM2.5	**82.619**	**75.63**	**56.851**
PM10	**133.083**	**100.661**	**59.490**

Results of Office A.4 (with a computer as a source pollutant):

From 0 to 30 minutes:

Particle Size Range	Particle Count
0.300 - 0.400	416721
0.400 - 0.550	56111
0.550 - 0.700	13932
0.700 - 1.000	11379
1.000 - 1.300	4452
1.300 - 1.600	1168
1.600 - 2.200	2777
2.200 - 3.000	926
3.000 - 4.000	403
4.000 - 5.500	292
5.500 - 7.000	100
7.000 - 10.00	130
PM2.5	**506,540**
PM10	**1,851**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	5.055
0.400 - 0.550	1.544
0.550 - 0.700	1.141
0.700 - 1.000	1.611
1.000 - 1.300	2.094
1.300 - 1.600	1.383
1.600 - 2.200	4.890
2.200 - 3.000	4.285
3.000 - 4.000	4.889
4.000 - 5.500	8.034
5.500 - 7.000	8.191
7.000 - 10.00	18.410
PM2.5	**17.718**
PM10	**43.809**

From 30 minutes to 1 hour:

Particle Size Range	Particle Count
0.300 - 0.400	415,733
0.400 - 0.550	54,230
0.550 - 0.700	13,388
0.700 - 1.000	10,881
1.000 - 1.300	4,113
1.300 - 1.600	1,039
1.600 - 2.200	2,023
2.200 - 3.000	397
3.000 - 4.000	89
4.000 - 5.500	36
5.500 - 7.000	10
7.000 - 10.00	19
PM2.5	**501,407**
PM10	**551**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	5.043
0.400 - 0.550	1.492
0.550 - 0.700	1.097
0.700 - 1.000	1.541
1.000 - 1.300	1.934
1.300 - 1.600	1.230
1.600 - 2.200	3.562
2.200 - 3.000	1.837
3.000 - 4.000	1.080
4.000 - 5.500	0.990
5.500 - 7.000	0.819
7.000 - 10.00	2.691
PM2.5	**15.899**
PM10	**7.417**

From 1 hour to 1 hour and 30 minutes:

Particle Size Range	Particle Count
0.300 - 0.400	453,730
0.400 - 0.550	56,152
0.550 - 0.700	13,336
0.700 - 1.000	10,510
1.000 - 1.300	3,767
1.300 - 1.600	902
1.600 - 2.200	1,754
2.200 - 3.000	258
3.000 - 4.000	40
4.000 - 5.500	14
5.500 - 7.000	3
7.000 - 10.00	1
PM2.5	**540,151**
PM10	**316**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	5.505
0.400 - 0.550	1.545
0.550 - 0.700	1.093
0.700 - 1.000	1.489
1.000 - 1.300	1.772
1.300 - 1.600	1.068
1.600 - 2.200	3.089
2.200 - 3.000	1.194
3.000 - 4.000	0.485
4.000 - 5.500	0.385
5.500 - 7.000	0.246
7.000 - 10.00	0.142
PM2.5	**15.561**
PM10	**2.452**

From 1 hour and 30 minutes to 2 hours:

Particle Size Range	Particle Count
0.300 - 0.400	488034
0.400 - 0.550	57181
0.550 - 0.700	13211
0.700 - 1.000	10337
1.000 - 1.300	3584
1.300 - 1.600	886
1.600 - 2.200	1657
2.200 - 3.000	232
3.000 - 4.000	42
4.000 - 5.500	15
5.500 - 7.000	0
7.000 - 10.00	1
PM2.5	**574,890**
PM10	**290**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	5.922
0.400 - 0.550	1.574
0.550 - 0.700	1.082
0.700 - 1.000	1.464
1.000 - 1.300	1.686
1.300 - 1.600	1.049
1.600 - 2.200	2.919
2.200 - 3.000	1.074
3.000 - 4.000	0.510
4.000 - 5.500	0.413
5.500 - 7.000	0.000
7.000 - 10.00	0.142
PM2.5	**15.696**
PM10	**2.139**

Results for Office A.6 (without any source pollutants):

From 0 to 30 minutes:

Particle Size Range	Particle Count
0.300 - 0.400	594031
0.400 - 0.550	108131
0.550 - 0.700	25448
0.700 - 1.000	19385
1.000 - 1.300	5351
1.300 - 1.600	1293
1.600 - 2.200	2725
2.200 - 3.000	505
3.000 - 4.000	123
4.000 - 5.500	35
5.500 - 7.000	8
7.000 - 10.00	8
PM2.5	**756,364**
PM10	**679**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	0.901
0.400 - 0.550	0.412
0.550 - 0.700	0.219
0.700 - 1.000	0.426
1.000 - 1.300	0.287
1.300 - 1.600	0.138
1.600 - 2.200	0.664
2.200 - 3.000	0.315
3.000 - 4.000	0.187
4.000 - 5.500	0.133
5.500 - 7.000	0.069
7.000 - 10.00	0.176
PM2.5	**3.047**
PM10	**0.880**

From 30 minutes to 1 hour:

Particle Size Range	Particle Count
0.300 - 0.400	569405
0.400 - 0.550	100561
0.550 - 0.700	22982
0.700 - 1.000	17290
1.000 - 1.300	4472
1.300 - 1.600	1029
1.600 - 2.200	2169
2.200 - 3.000	361
3.000 - 4.000	65
4.000 - 5.500	18
5.500 - 7.000	5
7.000 - 10.00	0
PM2.5	**717,908**
PM10	**449**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	0.864
0.400 - 0.550	0.383
0.550 - 0.700	0.197
0.700 - 1.000	0.380
1.000 - 1.300	0.240
1.300 - 1.600	0.110
1.600 - 2.200	0.529
2.200 - 3.000	0.225
3.000 - 4.000	0.099
4.000 - 5.500	0.069
5.500 - 7.000	0.043
7.000 - 10.00	0.000
PM2.5	**2.703**
PM10	**0.436**

From 1 hour to 1 hour and 30 minutes:

Particle Size Range	Particle Count
0.300 - 0.400	525790
0.400 - 0.550	88661
0.550 - 0.700	19938
0.700 - 1.000	14779
1.000 - 1.300	3830
1.300 - 1.600	911
1.600 - 2.200	1758
2.200 - 3.000	294
3.000 - 4.000	56
4.000 - 5.500	34
5.500 - 7.000	2
7.000 - 10.00	3
PM2.5	**655,667**
PM10	**389**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	0.797
0.400 - 0.550	0.338
0.550 - 0.700	0.171
0.700 - 1.000	0.324
1.000 - 1.300	0.205
1.300 - 1.600	0.097
1.600 - 2.200	0.428
2.200 - 3.000	0.183
3.000 - 4.000	0.085
4.000 - 5.500	0.129
5.500 - 7.000	0.017
7.000 - 10.00	0.066
PM2.5	**2.360**
PM10	**0.480**

From 1 hour and 30 minutes to 2 hours:

Particle Size Range	Particle Count
0.300 - 0.400	453222
0.400 - 0.550	70834
0.550 - 0.700	15563
0.700 - 1.000	11240
1.000 - 1.300	3252
1.300 - 1.600	773
1.600 - 2.200	1681
2.200 - 3.000	328
3.000 - 4.000	104
4.000 - 5.500	50
5.500 - 7.000	25
7.000 - 10.00	28
PM2.5	**556,565**
PM10	**535**

Particle Size Range	Microgram Per Cubic Meter
0.300 - 0.400	0.687
0.400 - 0.550	0.270
0.550 - 0.700	0.134
0.700 - 1.000	0.247
1.000 - 1.300	0.174
1.300 - 1.600	0.083
1.600 - 2.200	0.410
2.200 - 3.000	0.204
3.000 - 4.000	0.085
4.000 - 5.500	0.129
5.500 - 7.000	0.017
7.000 - 10.00	0.066
PM2.5	**2.005**
PM10	**0.501**

Appendix B: Calibration Certificate

CERTIFICATE OF CALIBRATION AND TESTING

ENVIRONMENT CONDITIONS		
TEMPERATURE	20.3	°C
RELATIVE HUMIDITY	37.23	%RH
BAROMETRIC PRESSURE	1004.1	hPa

MODEL	3330
SERIAL NUMBER	3330115301

☒ AS LEFT
☐ AS FOUND

☒ IN TOLERANCE
☐ OUT OF TOLERANCE

– CALIBRATION VERIFICATION RESULTS –

OPS COUNTING EFFICIENCY TEST @ 0.3 µM AND 0.5 µM — *Unit: %*

#	MEASURED	ALLOWABLE RANGE
1	49.00	40.00~60.00
2	107.00	90.00~110.00

OPS RESOLUTION CHECK @ 0.5 µM — *Unit: %*

#	MEASURED	ALLOWABLE RANGE
1	4.34	0.00~5.00

OPS INLET FLOW CALIBRATION — *Unit: LPM*

#	MEASURED	ALLOWABLE RANGE
1	0.97	0.95~1.05

OPS ZERO COUNT (5 MINUTE TEST) — *Unit: Counts*

#	MEASURED	ALLOWABLE RANGE
1	2	0~5

OPS SIZING OF 1µM PARTICLES (% BETWEEN 0.7 µM AND 1.3 µM PER ASHRAE 52.2) — *Unit: %*

#	MEASURED	ALLOWABLE RANGE
1	98.67	90.00~100.00

Measurement Variable	System ID	Last Cal.	Cal. Due
Classifier	UK70804080	16-06-16	16-06-17
0.296 / 0.006 (PSL)	45164	Expiration Date:	30-11-18
0.994 / 0.015 (PSL)	169240	Expiration Date:	31-05-19
5.02 / 0.030 (PSL)	173759	Expiration Date:	30-09-19
1.361 / 0.015 (PSL)	170632	Expiration Date:	30-06-19

Measurement Variable	System ID	Last Cal.	Cal. Due
CPC	UK3772132904	29-07-16	29-07-17
0.508 / 0.008 (PSL)	44867	Expiration Date:	31-08-18
9.85 / 0.08 (PSL)	178837	Expiration Date:	31-12-19
0.707 / 0.009 (PSL)	44582	Expiration Date:	31-05-18

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DATE

Doc ID: CERT_OPS_03

Appendix C: Office A Questionnaire Responses

Respondent No.	Number of hours spent in the office	Rate how stressful the work is at your office?	Room Temperature	Unpleasant smell	Passive smoking	Fatigue	Headache	Dizziness	Difficulty in concentrating	Burning of the eyes	Running nose	Cough	Difficulty in sleeping
	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response
1	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
2	Full day (6+ hours)	Very stressful	Always	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes
3	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Never	Never	Sometimes
4	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
5	Full day (6+ hours)	Average stress	Sometimes	Never	Never	Never	Sometimes	Never	Never	Never	Never	Never	Never
6	Full day (6+ hours)	Average stress	Sometimes	Never	Never	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
7	Full day (6+ hours)	Average stress	Sometimes	Never	Never	Sometimes	Sometimes	Never	Sometimes	Never	Sometimes	Sometimes	Sometimes
8	Full day (6+ hours)	Very stressful	Sometimes	Never	Never	Sometimes	Sometimes	Never	Sometimes	Never	Never	Sometimes	Sometimes
9	Full day (6+ hours)	Very stressful	Always	Sometimes	Never	Sometimes	Always	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Always
10	Full day (6+ hours)	No stress	Sometimes	Never	Never	Sometimes	Sometimes	Never	Never	Never	Sometimes	Sometimes	Sometimes
11	Full day (6+ hours)	Average stress	Never	Never	Never	Sometimes	Never	Never	Sometimes	Never	Never	Never	Sometimes
12	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Always	Never	Never	Sometimes	Never
13	Full day (6+ hours)	Very stressful	Always	Sometimes	Never	Sometimes	Sometimes	Sometimes	Always	Never	Sometimes	Never	Never
14	Full day (6+ hours)	Very stressful	Always	Never	Never	Sometimes	Sometimes	Sometimes	Sometimes	Never	Never	Never	Sometimes
15	Full day (6+ hours)	Average stress	Sometimes	Never	Sometimes	Never	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes

16	Full day (6+ hours)	Very stressful	Sometimes	Sometimes	Never	Always	Never	Never	Sometimes	Sometimes	Never	Never	Sometimes
17	Full day (6+ hours)	Very stressful	Sometimes	Sometimes	Never	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
18	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
19	Full day (6+ hours)	Very stressful	Never	Never	Never	Sometimes	Sometimes	Never	Never	Sometimes	Never	Never	Sometimes
20	Full day (6+ hours)	Very stressful	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Never	Sometimes	Always
21	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Never	Never
22	Full day (6+ hours)	Very stressful	Sometimes	Sometimes	Never	Always	Always	Always	Always	Always	Never	Sometimes	Sometimes
23	Full day (6+ hours)	Very stressful	Sometimes	Never	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
24	Full day (6+ hours)	Average stress	Sometimes	Sometimes	Never	Sometimes	Sometimes	Never	Never	Sometimes	Sometimes	Sometimes	Always
25	Full day (6+ hours)	Very stressful	Always	Sometimes	Never	Sometimes	Sometimes	Sometimes	Always	Always	Never	Sometimes	Sometimes
26	Full day (6+ hours)	Average stress	Sometimes	Never	Never	Sometimes	Sometimes	Never	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
27	Full day (6+ hours)	Average stress	Sometimes	Never	Never	Sometimes	Sometimes	Never	Sometimes	Never	Sometimes	Sometimes	Never

Appendix D: Office B Questionnaire Responses

Respondent No.	Number of hours spent in the office	Rate how stressful the work is at your office?	Room Temperature	Unpleasant smell	Passive smoking	Fatigue	Headache	Dizziness	Difficulty in concentrating	Burning of the eyes	Running nose	Cough	Difficulty in sleeping
	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response	Response
1	Full day (6+ hours)	Average stress	Always	Never	Never	Never	Always	Sometimes	Sometimes	Always	Sometimes	Sometimes	Sometimes
2	Full day (6+ hours)	Very stressful	Sometimes	Never	Never	Sometimes	Sometimes	Never	Never	Sometimes	Never	Sometimes	Always
3	Full day (6+ hours)	Average stress	Always	Never	Never	Never	Always	Never	Sometimes	Always	Sometimes	Never	Sometimes
4	Full day (6+ hours)	Very stressful	Always	Never	Never	Never	Always	Sometimes	Sometimes	Always	Sometimes	Never	Never
5	Full day (6+ hours)	Average stress	Always	Sometimes	Sometimes	Sometimes	Always	Sometimes	Sometimes	Sometimes	Always	Never	Sometimes
6	Full day (6+ hours)	Very stressful	Sometimes	Never	Never	Sometimes	Sometimes	Never	Never	Sometimes	Always	Sometimes	Sometimes
7	Full day (6+ hours)	Very stressful	Sometimes	Never	Never	Sometimes	Sometimes	Sometimes	Never	Always	Always	Sometimes	Always
8	Full day (6+ hours)	Very stressful	Always	Never	Never	Never	Always	Never	Sometimes	Sometimes	Sometimes	Never	Sometimes
9	Full day (6+ hours)	Very stressful	Always	Never	Never	Never	Sometimes	Never	Never	Always	Sometimes	Never	Sometimes
10	Full day (6+ hours)	No stress	Sometimes	Never	Never	Never	Never	Never	Never	Never	Sometimes	Never	Never

Appendix E: Questionnaire sample screenshots

Questionnaire: Indoor Air Quality in Office Buildings

* 1. Company Name:

2. Department:

3. Which office building you are staying in?

- ○ Bay Square - Building 13
- ○ Al Qouz 3 - ASGC PRO Office

AREA / REGION

4. Which of the following is found near to the office building? (Range of 500 meters)

- ☐ Green areas (Parks or Gardens)
- ☐ Water Body (Sea or lakes)
- ☐ Construction Site
- ☐ Factory
- ☐ Other (please specify)
- ☐ None of the above

BUILDING INFORMATION

5. The workplace is located at which floor?

- ○ Basement Floors
- ○ Ground or Street Level
- ○ Upper Floors
- ○ Top Floor/Level

6. Which of the following rooms are found near to the workplace?

- ☐ Toilets & Restrooms
- ☐ Garbage Room
- ☐ Industrial Kitchen
- ☐ Other (please specify)
- ☐ None of the above

7. Operable windows are available in the workplace?

- ○ Yes
- ○ No

WORKPLACE INFORMATION

8. Number of employees in the workplace

- ○ Only me
- ○ Less than 5 persons
- ○ 5 - 10 persons
- ○ 10+ persons

9. Which of the following machines/equipment are available in the workplace?

- [ ] Printers & Plotters
- [ ] Refrigerators & Freezers
- [ ] Computers
- [ ] Other (please specify)

WORKING ENVIRONMENT

10. Number of hours spent in the office

- ○ 0 - 3 hours
- ○ 3 - 6 hours
- ○ Full day (6+ hours)

11. Rate how stressful the work is at your office?

- ○ No stress
- ○ Average stress
- ○ Very stressful
- ○ Extremely stressful

12. Overtime work (Hours per week)

- ○ 0 Hours
- ○ 1 - 3 Hours
- ○ 4 - 6 Hours
- ○ 7+ Hours

13. For how long have you been working at your current office?

- ○ Less than 1 year
- ○ 1 - 3 Years
- ○ 4 - 6 Years
- ○ 7+ Years

Have you been bothered by any of the following?

14. Room Temperature

- ○ Always
- ○ Sometimes
- ○ Never

15. Unpleasant smell

- ○ Always
- ○ Sometimes
- ○ Never

16. Passive smoking

- ○ Always
- ○ Sometimes
- ○ Never

How often do you feel the following?

17. Fatigue

- ○ Always
- ○ Sometimes
- ○ Never

18. Headache

- Always
- Sometimes
- Never

19. Dizziness

- Always
- Sometimes
- Never

20. Difficulty in concentrating

- Always
- Sometimes
- Never

21. Burning of the eyes

- Always
- Sometimes
- Never

22. Running nose

- Always
- Sometimes
- Never

23. Cough

- Always
- Sometimes
- Never

24. Difficulty in sleeping

- Always
- Sometimes
- Never

25. How often do you visit the doctor for the past 6 months, based on the previous symptoms?

- 0 - 2 Times
- 3 - 5 Times
- 6 - 10 Times
- 10+ Times