Indoor Air Quality in UAE Office Buildings and Their Effects on occupants' Health, Comfort, Productivity and Performance

نوعية الهواء الداخلي في مكاتب مباني دولة الإمارات العربية المتحدة
و تأثيرها على صحة، راحة ، إنتاجية ، و أداء العاملين

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May 2015

Acknowledgment

I would like to express my sincere gratitude to Dr. Hasim Altan, my thesis advisor, for his continuous support, motivation and patience during the dissertation process. Dr. Hasim Altan provided helpful feedback and encouraged me to complete this dissertation, which is one of the most significant achievements in my life. I would also like thanks my mom and my husband, for their continuous courage and motivation.

Lastly, I would also like to thank my sisters, friends, and colleagues for all the encouragement and the support.

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Abstract

Indoor air quality has become one of the most important aspects that environmentalists, academics and even the general public is taking consideration on. Given the fact that humans spends majority of their daily hours indoors, good indoor air quality and comfort is of high criticality. In particular, Dubai has grown to be one of the busiest and fast-growing cities in the Middle East and in the world. With its population on continued rise, rapid urbanization and industrialization has consequences to the environment, especially to indoor air quality/environment. This research study aimed to explore and assess the various indoor air quality pollutants in office spaces in Dubai, and these pollutants might contribute to the negative health risks as well as the productivity of the occupants. It seeks to address some questions that guided the research study relating to the concentration levels of specific indoor air quality indicators (e.g. TVOC, Ozone, Carbon Monoxide, Carbon Dioxide, Relative Humidity and Temperature).

The research study used convergent parallel design of mixed methodology, which includes conducting quantitative measurement of the concentration levels of the above-noted IAQ indicators and qualitative-oriented survey for occupants. The spot measurement phase was done in a total of 17 office spaces in Ajman University of Science and Technology. An indoor air quality monitoring instrument called Direct Sense-IAQ was used to measure the concentration levels of IAQ indicators for an 8-hour observation period. A survey was used to collect data from 80 occupants of these 17 office spaces.

Findings showed that majority of the office spaces have average concentration levels of TVOC which are within the acceptable range of concentration based on international and Dubai building requirements and standards. Similarly, all monitored office spaces had average concentration levels of Carbon monoxide which

were within the acceptable range set by ASHRAE and Dubai Building standards, as well as other international standards including NAAQS and WHO. Average concentration levels of ozone in all office spaces were lower than the standard values designated by international and local standards. Few office spaces have higher carbon dioxide concentration levels, which were above the acceptable concentration limit. The potential cause of this was the lack of open windows in these office spaces. Relative humidity and temperature levels at the office spaces were also within the acceptable range based on international and local standards for both the indicators.

Abstract (Arabic)

تعتبر نوعية الهواء الداخلي أحد أهم المواضيع التي يهتم بها كل من خبراء البيئة، الأكاديميون وكذلك عامة الناس آخذين بعين الاعتبار المدة التي يقضيها الناس في أماكن مغلقة وبالتالي أهمية الحصول على تكييف جيد وذو نوعية عالية الجودة. تعتبر دبي خاصة من المدن التي تنمو وتتطور بشكل سريع في الشرق الأوسط كما أن عدد الناس بازدياد مستمر مما يترتب على ذلك نمو الصناعة بما يؤثر على البيئة خاصة نوعية الهواء الداخلى أو البيئة.

تهدف هذه الدراسة استكشاف وتقييم أنواع مختلفة من نوعية الهواء الملوث في المكاتب في دبي وما قد يؤثره هذا على الصحة وانتاجية العمل. تسعى هذه الدراسة إلى الإجابة عن بعض الأسئلة التي قادت إلى هذه الدراسة من حيث مستوى التركيز لبعض الملوثات ومؤشرات النوعية لها مثلاً: مجموع المركبات العضوية المتطايرة ، اوزون، كربون، مونوكسيد، كاربون دايوكسايد، الرطوبة النسبية ودرجات الحرارة.

اعتمدت الدراسة اسلوب البحث بطريقتين وتضمنت القياس العددي لمستويات تركيز الهواء الداخلي وقياس نوعي باستخدام الاستبيان للإنتاجية العمل. قامت الدراسة على مكتب في جامعة عجمان للعلوم والتكنولوجيا. واستخدمت تقنية قياس مستوى التركيز عن طريق مراقبة نوعية الهواء الداخلي .استخدمت تقنية نوعية الهواء الداخلي لقياس مستويات التركيز لمدة ٨ ساعات من المراقبة، ثم استخدم الاستبيان لجمع البيانات من ٨٠ موظف يعملون في هذه المكاتب.

أظهرت النتائج أن أغلبية المساحة داخل المكاتب لديها معدل توكيز مجموع المركبات العضوية المتطايرة بنسبة معقولة من التركيز بحسب المقاييس والمتطلبات الدولية لمباني دبي. من جهة أخرى مشابهة، وجد أن مشاحات المكاتب التي تمت مراقبتها لديها معدل مقبول من الكاربون مونوكسايد بمعدل مقبول من قبل معايير ASHARE ومقاييس المباني في دبي. كان معدل تركيز الاوزون في جميع المكاتب أقل من القيم الموضوعة من قبل المعايير المحلية والدولية. قليل من المكاتب لديها مستوى تركيز أعلى من مستويات الكاربون دايوكساید والتي كانت أعلى من حد الركيز المقبول. والسبب الرئيسي لذلك كان قلة النوافذ المفتوحة في هذه المكاتب. كما كانت نسبة الرطوبة ودرجات الحرارة ضمن المعدل المقبول بالاعتما›د أو بحسب المعايير المحلية والدولية.

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Chapter 1

Introduction

1.1. Background of the Study

The UAE, which consist of the seven Emirates (e.g. Abu Dhabi, Dubai, Sharjah, Umm Al Quwain, Fujairah, Ajman and Ras Al Khaimah), is one of the fastest-growing economies in the UAE and has witnessed rapid urbanization across all the Emirates, especially Dubai and Abu Dhabi. The UAE has experienced an annual rate of urbanization of about 2.87% since 2010, with 85.3% of the total population living in urban areas (CIA World Factbook, 2014). Accordingly, the population of the country has grown from over 2 million in 1997 to 9.4 million in 2013. Population density of the country is about 27 persons per square kilometer. Out of the total UAE population, about 15% to 20% are citizens of the UAE, while the rest are immigrants including Egyptians, Palestinians, Yemenis, Jordanians, Omani, Indians, Afghans, Iranians, Europeans and Filipinos. The rapid urbanization, booming economy and the growing population of the country have an impact on a wide range of environmental issues and challenges for the country (Maps of the World, 2015).

To support the rapid urbanization, some industries and economic sectors have also made some significant progress, but this has come with a price for the environment. For example, the construction industry expanded following the rapid expansion of the population in the country. As a matter of fact, an average increase of 5% of the total population annually has led to the expansion of real estate and infrastructure (Gorgenländer, 2010). Yet, the construction industry that maintains the expansion of real estate and infrastructure presented significant effects on the environment. All construction sites produce considerable amount of dust from a wide range of sources such as concrete, cement, wood, stone and silica most of these substances are fine particles invisible to the naked eye. These fine particles of dust could lead to an increased risk of various health problems such as respiratory illnesses, asthma, bronchitis and even cancer. In addition to dust, engine exhausts of vehicles as well as heavy equipment could increase harmful particles and gasses emitted to the atmosphere, including carbon monoxide, soot, hydrocarbons, nitrogen oxides and carbon dioxide (Construction Week, 2011). Construction sites are just fraction of the wide spectrum of air and water quality problems in the country.

According to the United Nations, there are numerous types of pollution sources in UAE. Considering that the UAE lies in a desert region of the world, dust storms and sand storms are very common types of pollution sources. Other sources include greenhouse gas emissions and other gases emitted by various industries including construction industries. Local sources also includes the rapid urban growth, transportation systems, industrialization and the lack of awareness as well as the lack of institutional capabilities, which have contributed to the low air quality in the country and poor IAQ control (UN, 2014).

1.2. IAQ in United Arab Emirates

By definition, indoor air quality is the term used to describe the various characteristics of the air inside a house, buildings or indoor spaces and is considered as an important indicator in relation to the comfort levels of occupants as well as to the health status. Indoor air quality has been considered as a critical safety and health issue for the past few years now. Key factors that influence the level of indoor air quality include humidity, temperature, chemical pollutants and sources, ventilation, and biological sources (e.g. dust mites, mold, pollen, etc) (Healthy Home, n.d.).

Indoor air quality has been a primary concern for UAE residents, considering that they spend about 90% of their time indoors. Farther so, the Middle East has an environment that supports a good breeding environment for various indoor contaminations, primarily because of extreme temperatures and humidity, continuous use of air conditions, poor ventilation and frequent sand storms and surrounding construction dust (Healthy Home, n.d.). Few research studies have explored the current condition of indoor air quality of the country.

The study by Funk et al (2014) attempted to measure the air quality in residential spaces across UAE. The study measured weekly average concentrations of a wide range of indoor air quality pollutants and indicators including carbon monoxide, formaldehyde, hydrogen sulfide, nitrogen dioxide, sulfur dioxide and particulates (e.g. $PM_{2.5}$, PM_c and PM_{10}). In addition to that, the study also measured outdoor air quality. Sampling devices were used to measure all these indicators of indoor air quality on subject locations. Based on their findings, concentrations of all indoor air quality pollutants and indicators demonstrated similar concentration ranges found by various indoor air studies being conducted in developing countries. Additional, the study also noted that indoor levels of carbon monoxide were significantly related to the common pollutant sources including air conditioning, smoking and attached kitchens. Also, indoor concentrations of particulates such as $PM_{2.5}$ and PM_{10} significantly with the vehicles parked within five meters of the home, as well as with the central air condition and attached kitchens (Funk, et al., 2014, p. 709).

An early study by Yeatts et al (2012) assessed the health risks associated with various indoor air pollutants in the UAE. Using an interview methodology, the research found out that those who lived in houses with quantified concentrations of sulfur dioxide, nitrogen dioxide, and hydrogen sulfide were more likely susceptible to asthma as well as increasing the risk of developing wheezing symptoms. Quantified formaldehyde is positively related to neurologic symptoms while burning incense on a daily basis will increase the risk of frequent headaches, poor or difficulty in concentrating and forgetfulness (Yeatts, et al., 2012). a

1.3. Motivation

1.3.1. Energy Consumption, Life Style, and Ecological Footprint in the UAE

The discovery of the expansive oil resources in the UAE marked a new wave of progress for the country for the past 5 decades, from a “semi-nomadic existence in a harsh desert environment to a thriving lifestyle with vast, ultra-modern facilities and infrastructure (Funk, et al., 2014, p. 710)”. Apparently, following the influx of drastic development and economic progress because of the exploitation of these vast oil resources, the entire population of the country enjoys a ridiculous GDP per capita. The UAE’s geographical environment encompasses desert ecosystem and limited natural resources; however its consumption of natural resources is rising drastically. Because the country has a hot, dry climate, it needs extensive amounts of energy for cooling as well as for desalination of sea water that caters to household and domestic water needs of the country (Ministry of Environment and Water , 2010).

Subsequently, the increased energy spending of the country has lead to greater capacity and demand for products and natural resources being imported into the UAE from foreign nations. This has led to a staggering 9.5 hectares per capita footprint, which is the highest per capital ecological footprint (EF) in the world (see Figure 1). The term ecological footprint is a type of measurement that calculates the consumption of natural resources of a country, a city, or even an individual. This measurement takes into consideration six land types, which are used for various purposes to cater human consumption and activities (Emirates Wildlife Society, 2014). These include:

- Cropland - productive land used to grow crops for human consumption and livestock, fiber and oils.

- Grazing land -land required for feeding livestock for human consumption of meat, dairy, hide and wool products

- Fishing grounds -the surface area required to support the harvesting of fish and marine products for human consumption

- Forest land -land that provides time and fuel wood for human consumption

- Carbon uptake land -the amount of forest land needed to assimilate the carbon dioxide emitted in the atmosphere as a result of human activities

- Built up land - land covered by human infrastructure for transportation, housing and industrial development (Emirates Wildlife Society, 2014).

Based on the Figure 1.1, the UAE's EF has contributed to the high energy consumption, as expressed in the carbon uptake land component of the EF measurement. Commercial and residential infrastructures and properties across the country are using substantial amount of energy which is 225% more energy than European countries (Khawaja, 2012).

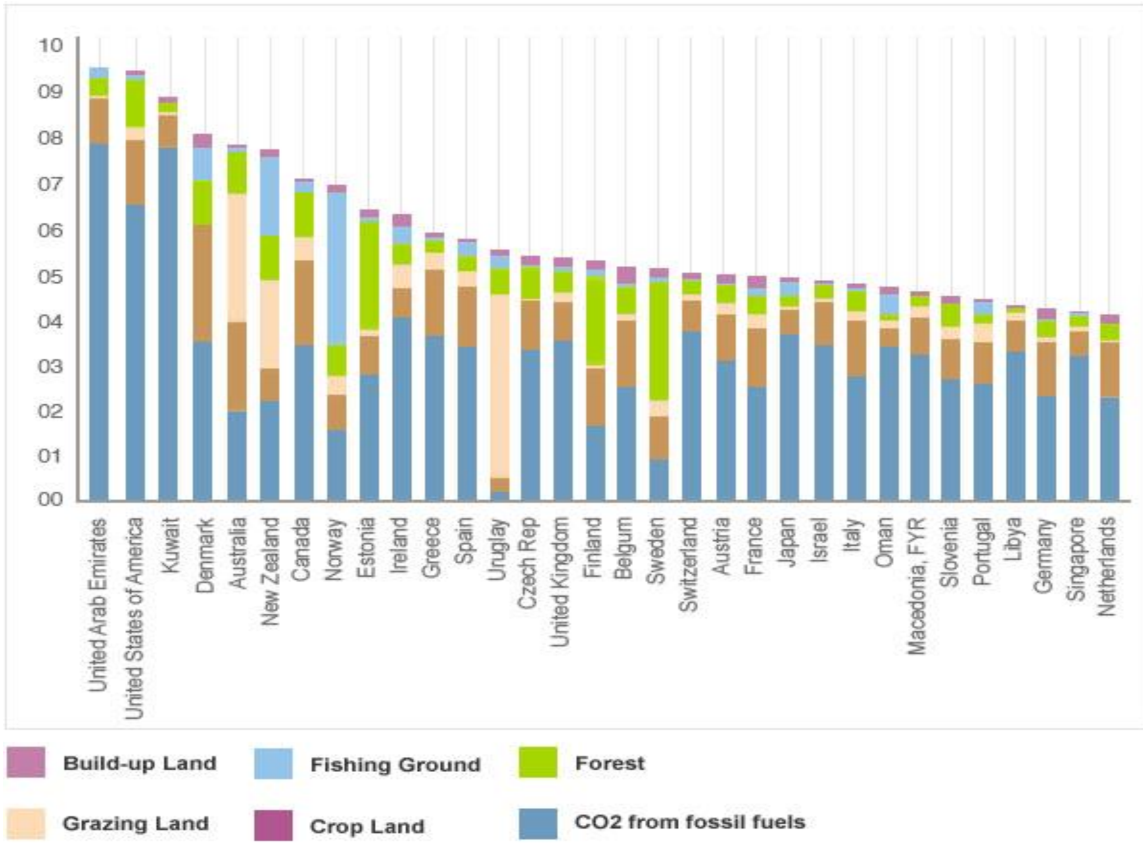

Figure 1.1 : UAE's Ecological Footprint

(Emirates Wildlife Society ,2014)

Because of the alarming ecological footprint of the country, the national government of the UAE, in partnership with various non-government organizations, has launched its Ecological Footprint Initiative, which enables the country to encourage sustainable lifestyles and ultimately minimizing the county's EF. The primary goals of this initiative were to increase awareness with regards to what a Footprint is, to identify the various sectors that fuel the high footprint of the country and to develop and design strategies to effectively manage the UAE's EF. Through this initiative, the UAE becomes the third country in the world that makes use of in-depth science and research in managing its ecological footprint (Ministry of Environment and Water , 2010).

1.4. Research Aim and Objectives

The primary aim of this research study is to measure the various indoor air quality pollutants and investigate the impact of indoor air quality on the occupant's health and productivity in office spaces.

Guided by such an aim, the specific objectives of this current research study include:

- To measure and assess the indoor air quality (IAQ) parameter levels inside office spaces

- To measure and evaluate the sources of indoor air quality (IAQ) inside office buildings

- To assess the effects of the indoor air quality (IAQ) condition on the occupant's health

- To measure and evaluate the impact of indoor air quality (IAQ) on occupant's productivity and performance.

1.5. Research Questions

Drawing from the research objectives, the research questions that are to be answered upon the completion of this current research study include (1) what are the concentration levels of specific indoor air quality (IAQ) indicators in a typical office building in UAE, and (2) what would be the possible occupant health risks/effects and productivity impacts of indoor air quality inside office buildings?

1.6. Significance of the Study

Upon the completion of this current research study, its significance would lie on the fact that the data gathered and analyzed from this study would be used for future studies exploring the relationship between indoor air quality (IAQ) and building design, human health, occupants' behaviour and comfort zones. Further, the research study will provide findings and conclusions that will trigger the need for assessing local policies and implicate new policies to control indoor air pollution. Furthermore, the study's significance also lies on the expansion of public awareness and knowledge regarding the topic of indoor air quality, and further increases their comprehension regarding the need for appropriate monitoring of indoor air quality in this region. The relative importance of public awareness to indoor air quality monitoring and management would implicate key regulatory actions for key, rapidly-developing sectors such as the construction industry, real estate, transportation and many others in the reduction of their contribution to air pollution.

1.7. Thesis Outline

The current research study is organized into 5 chapters, each having subsections. The organization of this study is described below:

Chapter 1: Introduction

This section of the research study presents a discussion that sets out the background of the study as well as motivation for this research. As noted, the research study's aim is to understand the indoor air quality of office buildings in Dubai, and assessing its impacts to occupants' health and productivity. The objectives and scope of the research were also defined. In addition, the research questions that guide the research study were also identified, as well as the significance of the research study. More so, this section also provides a narrative on the current indoor air quality conditions in UAE, as well as the country's climate conditions, lifestyle and economic footprint that influences the indoor air quality or environment.

Chapter 2: Literature Review

This chapter points out the current concerns regarding indoor air quality, in general, and in office spaces in particular. Then, this section reviews the fundamental theories, previous literature on works in IAQ assessment, as well as the international guidelines or standards for IAQ assessment.

Chapter 3: Methodology

This section of the research study provides a discussion on the framework and methodology that the study used. It specifically describes the sampling times and locations, as well as the procedures that were utilized for the data collection and data analysis of the study.

Chapter 4: Results and Discussion

This section of the research study the findings derived from the data analyzed. This chapter has two sub-sections. The first is the presentation of results which encompassed the findings derived from the spot measurements and the survey results. Spot measurements were presented for six key indicators of indoor air quality including TVOC, carbon dioxide, carbon monoxide, ozone, relative humidity and temperature. Spot measurements were conducted at 17 offices spaces at two building locations at Ajman University of Science and Technology. Discussion and interpretation of the findings were also presented.

Chapter 5: Conclusion and Recommendations

The final section of the research study draws conclusion for the research study, summarizing the key findings, recommendations, and points the future research implications.

Chapter 2

Literature Review

2.1. Indoor Air Quality and Pollution

It is common that indoor areas of significant spaces to people, considering that is where people typically spend most of their time at. As a matter of fact, 90 per cent of human life is spent indoors (Zhang and Smith (2003). Accordingly, indoor air is considered as one of the most basic elements for human subsistence. It plays a role for human health because of long exposer time. Similarly, the fact that humans tend to spend most of their time indoors, means that indoor air pollution is unavoidable. Indoor air pollution, which is produced by both indoor and outdoor sources, such as HVAC system, furniture's, computers, scanners and materials, represents greater exposure to health risk amongst individuals as compared to outdoor air pollution. According to Balakrishnan and Bruce (2006, p. 190), "the extent and magnitude of consequent health risks, however remain poorly understood". There are diverse causal aspects that explain why there is some difficulty in generating accurate monitoring and estimations of health consequences of indoor air pollution, as identified by Balakrishnan and Bruce (2006). These include:

- There are wide range of indoor air pollutants;
- Influence of the nature and location of the pollutants/pollution sources; and

- Influences of the air exchange and interaction between the indoor/outdoor environments and individual behavior.

In addition to such reasons, Hall and Tilley (1995) have identified wide range of factors that influence the levels of indoor air pollution. These include maintenance activities, the existence of pollutant sources, levels of outdoor contamination, seasonal changes, indoor humidity and temperature and ventilation rates.

Evidences has stressed that indoor air pollution sources are manifold. Table 2.1 below shows the summary of the sources of indoor air pollution including their respective pollutants, as based on the findings from the study by Zhang and Smith (2003) and Seltzer (1984). Sources consist of combustion and burning of solid fuel indoors, tobacco smoking, outdoor air pollutants, emissions from construction materials and furnishings, and improper maintenance of ventilation and air conditioning systems. Yet, differences in the significance of these diverse sources are present in various parts of the world, drawing from the basis of socio-economic development levels of these areas (Balakrishnan & Bruce, 2006).

Although those quite clean sources of energy used for residential and commercial (e.g. office) activities dominate in most areas situated in developed countries, improvements in energy efficiency have produced major effects. For instance, improvements in the energy efficiency that caused homes to become fairly airtight have contributed to the decrease in the amount of indoor air circulating in and out of the building. This inability of the establishment to extract indoor air has caused increases in the levels of indoor pollutants (Zhang and Smith , 2003). More so, even those considered as minor pollution sources (e.g. furnishings and household materials) increase the chance of indoor air pollution exposure, as well as increased risks of health illnesses. In developed countries, there is an increasing concern with regards to the combination of different kinds of pollutants that present in the air, which include tobacco smoke, nitrogen dioxide and bio-aerosols. There is also a growing concern and attention on the volatile organic compounds and semi-volatile organic compounds that are produced and emitted by household materials and products.

Pollutant	**Major indoor sources**
Volatile organic compounds	Perfumes, hairsprays, furniture polish, cleaning solvents, carpet fibers, adhesives, sealants, air fresheners, contaminated water, plastics, wood preservatives, paints, varnishes, stored fuels and automotive products and others.
Formaldehyde	Particle board, interior grade plywood, cabinetry, furniture, urea formaldehyde foam insulation, carpet, fabrics
Pesticides	Insecticides, disinfectants, consumer products, dust from outside
Sulfur dioxide	Combustion of sulfur-containing fuels
Nitrogen dioxide	Improper operation of gas furnaces, tobacco smoke, vehicle exhaust and others
Aldehydes	Furnishings, construction materials
Asbestos	Remodelling/demolition of construction materials
Lead	Remodelling/demolition of painted surfaces

Biological pollutants	Damp materials/furnishings, components of climate control systems, occupants, outdoor air, humidifiers
Radon	Soil under buildings, construction materials
Free radicals and other short-lived, highly reactive compounds	Indoor chemistry

Table 2.1: Potential sources of selected indoor air contaminants common in various types of buildings

(Zhang and Smith, 2003, and Seltzer ,1984)

As noted, there has been a growing concern about air quality in indoor office spaces and buildings. Accordingly, office spaces and environments have significantly changed due to the introduction and adoption of a wide range of electronic technologies, especially printing machines (e.g. laser-jet printers and ink-jet printers). Office technologies in today's modern and technology-driven era have now becoming a key facet of office activities in daily basis. Various kinds of office printers have been used almost every minute since their commercialization in the market. However, the increasing usage of these office machines has resulted in an office environment that has higher health risks which are detrimental for office employees. Health risks include frequent experiences of headaches, dryness in the eyes, nose and throat, dry and tight facial skin and many others (Lee, Sanches, & Ho, 2001). Past literatures have expressed the negative consequences of operation of office machines to the health of exposed employees.

Studies have concluded that office machines and equipment do not only contribute to the concentration of air pollution in office spaces, but has been extensively linked with increasing complaints regarding employees' health (Wolkoff, Johnsen, Franck, Wilhardt, & Albrechtsen, 1992; Wolkoff, Wikins, Clausen, & Larsen, 1993). Operation of printing machines and other office equipment also emit substantial amounts of a wide range of pollutants that are detrimental to the health of those employee who have been exposed. These include ozone gas, volatile organic compounds (VOC) and particulates (Lee, Sanches, & Ho, 2001). Other office pollutants include carbon dioxide, carbon monoxide, nitrogen dioxide, formaldehyde, radon and airborne bacteria (Wong, Mui, & Hui, 2006).

For office equipment like laser jet printers, there are some studies that expressed the view that these equipment emit a fairly substantial amount of particulate matter. By definition, particulate matter is a "complex mixture with components that have diverse chemical and physical characteristics (Samet, Brauer, & Schlesinger, 2006, p. 218)". There are various types of particulate matter, based on their aerodynamic diameter. For instance, particulate matter has an aerodynamic diameter of 2.5 μm is known as PM_{10}, while those having an aerodynamic diameter of 2.5 μm are called $PM_{2.5}$. Relating to particulate matter emission of office equipment such as laser printers, Morawska and colleagues (2008) found out that a laser printer increases particle concentration in the air during its operation state. Likely, the highest concentration of particulate matter peaked in the tunnel of about 8×10^4 particles cm^{-3}. Super-micrometer particle concentration displayed a somewhat different trend, with sharp increase in concentration immediately after commencement of printing (sharper and earlier than for sub-micrometer particles), followed by a rapid decrease in concentration about 40 seconds later, and then by another increase, not always to as high values as before (Morawska, et al., 2008).

2.2. Health-Related Effects of Indoor Air Pollution on Occupants

It is evident that poor indoor air quality causes indoor air pollution which stems out on the environment of buildings and spaces characteristics of meeting thermal comfort and acceptable levels of gas concentrations for respirations (Kamaruzzaman & Sabrini, 2011). As noted earlier, there is a wide range of sources of pollutants in indoor office spaces and buildings, which emits different kinds of contaminants into the air, therefore exposing office occupants to diverse health risks. Below are some of the different health risks and effects of poor indoor air quality.

2.2.1 Sick Building Syndrome

The term ‘sick building syndrome’ was first introduced and coined during the late 1970s, describing a certain situation wherein building occupants experience acute health problems a broad range of labels covering an assortment of symptoms triggered by long exposure to building environments (Babatsikou, 2011). Despite its increasing prevalence, there is no single, unanimously-accepted definition of SBS as well as there being an absence of an adequate theory for SBS. SBS characteristics are often non-specific symptoms that occur in certain buildings or office spaces, and are not rooted in particular illnesses like hypersensitivity pneumonitis or infection (Redich, Sparer, & Cullen, 1997). Table 2.2 shows some of the symptoms and their effects on individuals experiencing sick building syndrome.

Organ Involved	Symptoms	Effects
Eyes	Irritated, dry/watering	Itching, redness, burning, or has difficulty in wearing contact lenses
Nose	Irritated, runny/blocked	nosebleeds, itchy or stuffy

		nose
Throat	Dry or sore	Irritation, or pharyngeal symptoms, upper airway irritation or difficulty swallowing
Skin	Dryness, itching or irritation	Rash or specific clinical terms such as erythema, rosacea, urticaria, pruritis, xerodermia
Others	Headache, irritability, lethargy, and poor concentration	

Table 2.2 : Most common symptoms and effects of sick building syndrome

(Raw (1992; cited in Kamaruzzaman & Sabrini, 2011)

In most cases, sick building syndrome generally occurs only in certain types of buildings that have automated heating, air-conditioning and systems ventilation; however it may also occur and prevale in other public buildings and spaces such hospitals, schools, apartment buildings and educational institutes. Despite the fact that the specific causes of SBS are still vague and unknown, most research studies and health experts proposed that the symptoms of SBS are expected to be the result of a combination of factors, which might include:

- Combustion pollutants (e.g. Nitrogen dioxide, carbon monoxide)
- Chemical pollutants from indoor sources (e.g. volatile organic compounds, formaldehyde from dust, carpeting, upholstery)

- Heavy metals (e.g. lead and mercury)
- Ozone emitted by office machines like printers and photocopiers
- Electromagnetic radiation (e.g. computers, microwaves)
- Biological pollutants (e.g. viruses, dust mites, pollen, bacteria)
- Inadequate ventilation (e.g. defective heating systems, malfunctioning ventilation and air-conditioning systems) ,(Babatsikou, 2011).

There are past research studies that explore SBS and its implications to occupants' health. For example, the study by Zamani ,et al (2013) investigated the relationship between indoor air quality and the prevalence of SBS in two different offices in Selangor, Malaysia. Based on their findings, there is an increased risk of experiencing SBS in buildings having substantial concentrations of various pollutants such as carbon monoxide, carbon dioxide, total volatile organic compound, and particulates (PM_{10} and $PM_{2.5}$). It was concluded that proper ventilation in buildings that increases ventilation rates per person in office buildings would considerably reduce the occurrence of SBS (Zamani, Jalaludin, & Shaharom, 2013). The negative correlation between ventilation rates and the prevalence of SBS evidenced by Zamani , et al (2013) was supported by other scientific studies such as (Jaakkola & Miettinen, 1995; Fisk, Mirer, & Mednell, 2009; Lee & Sohn, 2014).

2.2.2 Building Related Illnesses and Symptoms

Apparently, indoor air quality issues have become a major issue in recent decades, especially pointing to newly-constructed or re-modeled buildings. Technically, there are two building issues that have been identified. One of which is the sick building syndrome and the building-related symptoms and illnesses. The primary difference between the two is that the former refers non-specific symptoms that occur in certain building or office spaces while the latter is frank illnesses or symptoms with etiology, such as hypersensitivity pneumonitis and humidifier fever. In sick building syndrome, as discussed earlier, occupants of the building often complain symptoms that are caused by acute discomfort but for which no consistent etiology has been identified. Symptoms include headache, fatigue, eye irritation and lethargy (Bauer, et al., 1992).

In the review by Menzies and Bourbeau (1997), the term specific building-related illnesses is an umbrella term that describes a group of illnesses with a relative homogeneous clinical picture, objective abnormalities on clinical or laboratory evaluation, and one or more identifiable sources or agents. These agents are said to cause either infection, immunologic or allergic diseases. Menzies and Bourbeau also identified a wide range of specific building-related illnesses from their review on secondary data sources, as summarized in Table 2.3 below. Menzies and Bourbeau and other studies (Salvaggio, 1994; Page & Trout, 2001; Crook & Burton, 2010; Gerardi, 2010) have established evidence regarding the concept of building-related illnesses.

There are a lot of primary specific building-related illnesses that have been explored for the past decades and the summarized in Table 3 are the most common illnesses prevalent in commercial, non-industrial work buildings and spaces including office buildings. The transmission of specific respiratory pathogens could be increased through crowding or limited outdoor-air exchange rate. The single causal agent could result in building-related outbreaks, having different symptoms. As an example, the Legionella pneumophilia could result in Legionnairies' Dsease – a pneumonia with a case fatality rate of 10 to 15 per cent. It could also result in Pontiac fever, which is a milder, flue-like illness (Frase, Tsai, & Orenstein, 1977; Kaufmann, McDade, & Patton, 1981).

Disease	Types of Buildings	Indoor source	Agent or exposure
Infectious Legionnaires' disease and Pontiac fever	Large buildings (e.g. hospitals, offices, hotels)	Cooling Tower, air conditioning or humidifier, potable water	Legionella pneumophilia
Flu-like illness and common cold	Office Buildings, Military barracks	Human source	Respiratory virus
Tuberculosis	Office buildings	Humidifier	Mycobacterium tuberculosis
Immunologic Hypersensitivity pneumonitis and humidifier fever	Office buildings, factory	Humidifier, air conditioning, ventilation unit	Multiple bacteria, fungus, actinomycetes, penicillium, Aspergillus, multiple organisms
Allergic dermatitis, rhinitis and asthma	Office buildings, factories	Surface dust, carpet, clothing, humidifier	Dust mites, plant products, animal allergens, fungus
Rhinitis contact urticaria, laryngeal ederma	Office buildings	Carbonless copy paper	Alkylphenol novolac resin

Irritation dermatitis, upper and lower respiratory tract irritation	Office buildings	Ceiling boards, tobacco smoke, vehicle axhaust, any combustion process	Glass fibers, combustion products like carbon monoxide and nitrogen dioxide

Table 2.3: Specific illnesses known or suspected to be related to buildings

Menzies & Bourbeau (1997), data gathered from review of secondary sources like case studies, journal articles, etc.

Similarly, hypersensitivity pneumonitis and humidifier fever were first characterized as separate disorders but could co-exist and be caused by the same immunologic responses to fungi, bacteria or protozoa that contaminate humidifiers or ventilation systems. Symptoms of both the hypersensitivity pneumonitis and humidifier fever could include fever, chills, malaise, and the presence of specific antibodies to microbial agent. In addition, hypersensitivity pneumonitis also manifest symptoms such as cough, chest tightness, dyspnea, lung-function abnormalities and occasionally radiographic abnormalities (Welch, 1991). On the other hand, outbreaks of asthma that is related to the exposure in office buildings have been widely reported. Exposure to common indoor allergens like dust mites, plant products, and passively-transported allergens may happen in any occupied building, including office spaces (Boechat, Rios, Ramos, Luiz, Neto, & Silva, 2010). Dermatitis, conjunctivitis, and upper and lower respiratory tract symptoms could also manifest irritant responses resulting from the exposure to non-allergenic agents such as man-made vitreous fibers and glass fibers (Menzies & Bourbeau, 1997).

2.3. Effects of IAQ on Office Occupants' Performance and Productivity

Besides the health effects of poor indoor air quality in commercial, non-industrial buildings such as office buildings, there has been a lot of evidences that points to the impacts of poor indoor air quality to occupants' performance and productivity. According to Antikainen and colleagues (2008), indoor air issues the are results of the interactions of various factors can impact building occupants' health, comfort, and performance, and, ultimately impacts the entire function of the organization.

The experimental study by Wyon (2004) aimed to justify the relationship between the indoor air quality and performance and productivity. Wyon highlighted that ventilation is an important component of a good and healthy indoor work environment. This is because ventilation gets rid of air pollutants that were emitted or produced originally from inside the building. Based on his findings, performance of occupants in office buildings could be significantly increased through removing indoor air pollution sources which include floor coverings, used and old supply air filters and computers/machines/equipment. It is also noted to be useful that these pollutants have to be placed in clean and ordered spaces which could help in increasing the ventilation rate, by which clean outdoor air could be supplied from 3 to 10 to 30 l s^{-1} per person. (Wyon, 2004)

Unlike the experimental and simulated procedures used by Wyon in studying indoor air quality's impact on occupants' working performance and productivity, others studies have used survey questionnaires that allow them to calculate or measure occupants' perception of indoor air quality. Survey questionnaires facilitated different by past research are considered as subjective assessments of the quality of indoor air. For example, a study performed by the Indoor Environment Department of the Lawrence Berkeley National Laboratory showed findings pointing out that an improved satisfaction with regards to the indoor air quality of work environments is positively associated with the improvement of work performance. Specifically, work performance of occupants would most likely to increase up to 1 per cent with a 10 per cent reduction of occupants' discontent with indoor air quality.

Similarly, Fisk and Seppanen (2006) presented evidence and justifications that improved indoor air quality at workstations would help in the improvement of work performance, and therefore productivity. According to this particular study, sources of indoor pollutions like surface materials, equipment and furnishings could impact the level of work performance amongst employees. Employees would most likely demonstrate poor working performance in various work activities and aspects such as proof-reading of text documents, typing and inputting, speed and accuracy of activities. On the other hand, Bakó-Biró & Olesen (2005) concluded that:

1. Indoor air quality could significantly enhance the performance of people;

2. Improved indoor air quality through fewer improved sources and higher ventilation rates could extensively enhance work performance and productivity, and

3. Improved indoor air quality would be of great help in financial terms for the organization/firm, considering that it allows savings in health care costs due to fewer instances and occurrences of sick building syndrome, sick leaves and others (Bakó-Biró & Olesen, 2005).

2.4. Common IAQ Contaminants in Offices

Indoor air contaminants can originate within the building or can be drawn in from outdoor sources. If these contaminants are not dealt with, indoor air quality issues could emerge, even though HVAC systems are properly designed and well-maintained. There are 5 common indoor air contaminants in offices , as discussed below:

- Carbon dioxide: carbon dioxide levels should be maintained through assessing the efficiency of ventilation in buildings. Increase carbon dioxide levels increases in office spaces due to inadequate ventilation. Outside sources include vehicle exhaust fumes and other exhausts.
- Carbon monoxide: combustion often causes or emits carbon monoxide, which includes tobacco smoking. Major source of carbon monoxide is vehicle exhaust.

- Formaldehyde: this is a colorless gas having a strong odor. It is most commonly found in various products such as insulation products, ceiling tiles, particle board, plywood, office furniture and many others.
- Ozone: ozone contaminants are emitted by electrical discharges in various office equipment such as photocopiers and electrostatic precipitator devices.
- VOCs – volatile organic compounds are those chemically contain carbon atoms and often being evaporated at room temperature. VOCs are mostly found and emitted from building materials, furnishings, carpets, printers and photocopiers, adhesives and many others (Government of Hong Kong, 2003; BCA , 2010).

2.5. Factors Affecting IAQ

According to the Centers for Disease Prevention and Control (2014), indoor air environment is a manifestion of the interaction of different factors, which often contribute in the development of indoor air quality issues:

2.5.1 Pollutant Sources

Factor refers to the source of contamination or discomfort indoors, outdoors or within the mechanical systems of the building. Common outside soruces in the building include contaminated outdoor air (e.g. pollen, dust), emissions from nearby sources (e.g. odors from dumpsters, vehicle exhausts) and soild gas (e.g. radon, pesticides).

Pollutants can be produced by the outdoor or indoor sources which include maintenance activities in the building, pest control, housekeeping, renovation or remodeling, new furnishings or finishes, and occupant activities in the building. Minimizing the people's exposure to pollutants from these sources is an important goal of an indoor air quality program. Some of the key pollutant categories include: Biological contaminants where the excessive concentrations of bacteria, viruses, fungi, dust mite allergen, animal dander, and pollen may result from insufficient maintenance and housekeeping, water spills, poor humidity control, condensation, or may be brought into the building by occupants, infiltration, or ventilation air. Too much exposure in indoor biological pollutants can cause symptoms in allergic individuals and can trigger asthma episodes. Another category is chemical pollutants which are generated by smoking tobacco, emissions from products used in the building, accidental spill of chemicals, and gases that can cause combustion. And lastly, particles, solid or liquid substances that are light enough to be suspended in the air, represent the largest of which is visible in sunbeams streaming into a room. However, particles that are invisible to the naked eye are likely to be more harmful to human health (EPA, 1997).

2.5.2 Pathways

There are one or more pollutant pathways that connect the pollutant source into the office spaces in the building. One of which is the HVAC system, where the pollutant sources emitting contaminants outside the building flows in the HVAC system into the office.

2.5.3 Occupants

Human activities are critical factors that contribute to the development of IAQ issues. Human activities such as personal activities, housekeeping activities, maintenance activities and others are common aspects in contributing to indoor air quality problems in both residential and commercial buildings.

2.5.4 Moisture and Humidity

The presence of moisture and dirt causes molds and other biological contaminants to grow, so it is important to control moisture and relative humidity in occupied spaces. Relative humidity levels that are too high can contribute to the growth and spread of unhealthy biological pollutants while humidity levels that are too low may contribute to irritated mucous membranes, dry eyes, and sinus discomfort (EPA, 1997).

2.6. HVAC Systems

Heating, Ventilating and Air Conditioning (HVAC) systems are widely used in various parts of the world (Lin & Chen, 2014). Commonly, the term HVAC system refers to the equipment installed in buildings that provides heating, cooling, filtered outdoor air and humidity control that establishes a comforting environment within the building. However, not all HVAC systems are intended to perform all these functions, as some buildings could make use of natural ventilation instead of using HVAC systems (CDC, 2014). These systems carry out processes that are designed to control the air conditions necessary for achieving comfort and safety of occupants (TSI, 2013). Its function of providing comfort and safety within an indoor environment is achieved through responding to the loads required by the building's envelope design, lighting system design and occupant activities (US Department of Energy, 2013).

Accordingly, there are different variables or factors that have to be taken into consideration when it comes to designing HVAC systems. These include the age of the design, climate, building codes, budget, planned use of the building, HVAC user's and designers' preferences and successive modifications (CDC, 2014). HVAC systems installed at buildings are diverse in terms of its complexity. Typically, large, modern office establishments that present an increase in heat due to lighting, people activities and equipment operation require cooling for a year-round basis. Similarly, some interior spaces need to be heated and/or cooled depending on the changes in the outdoor weather conditions. The basic components of an HVAC system that function in maintaining thermal comfort as well as indoor air quality include outdoor air intake, mixed-air plenum and outdoor air control, air filter, heating and cooling coils, humidification and/or de-humidification equipment, supply fan, ducts, terminal device, return air system, exhaust or relief fans and air outlet, self-contained heating or cooling unit, control, boiler, cooling tower and water chiller (CDC, 2014, pp. 123-124). These components are illustrated in the figure 2.1 below.

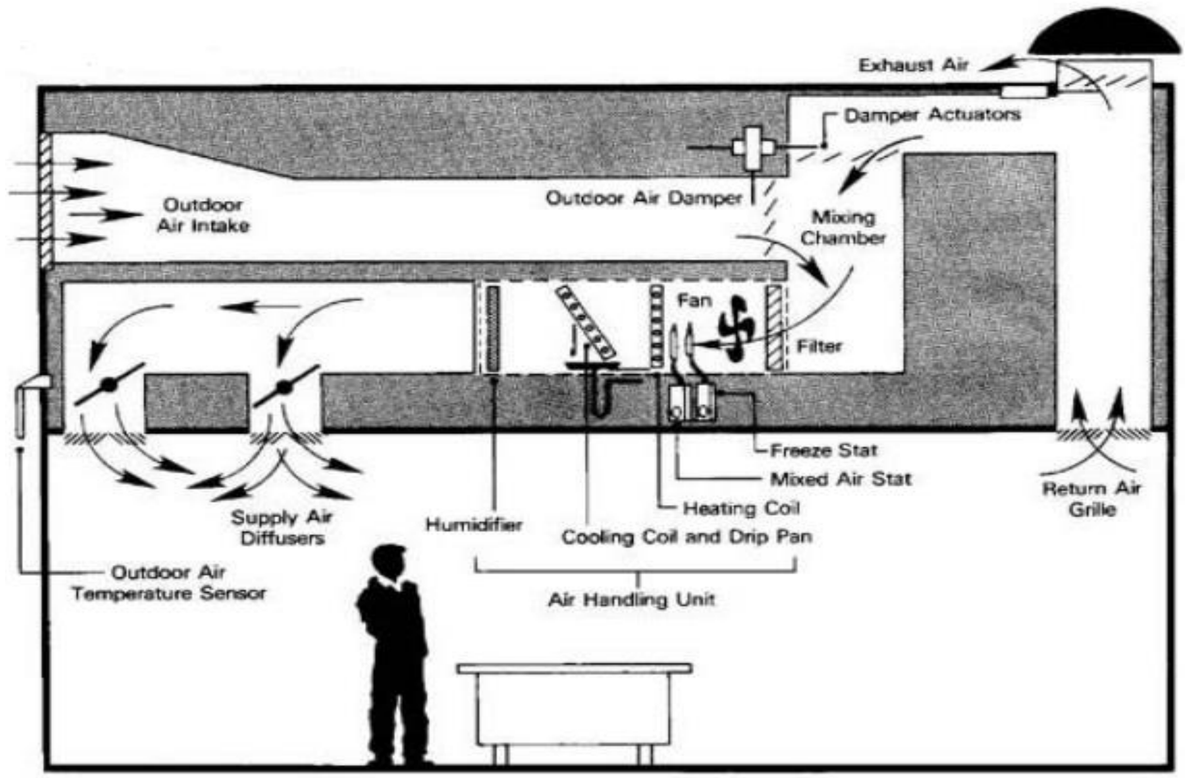

Figure 2.1 : Typical layout of HVAC system components

(CDC 2014, p. 124)

There are various types of HVAC systems that are available and installed in buildings. Below are some of the most common types:

- Single-zone system – this HVAC system functions as a single, temperature-controlled zone, these are often installed and found in small shops or computer rooms where the indoor environment and usage remains the same.
- Multi-zone system – This HVAC system provides conditioned air to different zones from a single, central air-handling unit. This is much more common in

office buildings and classrooms where the zones have the same thermal load requirements. Temperature controllers in each of the zones in the indoor space maintain the zone's conditions, therefore varying the amount of delivered heated or cooled air.

- Constant volume system – This type of HVAC system does not alter or change the air volume being delivered to the indoor space. The temperature controller control the volume of air delivered to the zone, activating the heating and/or cooling coils.
- VAV (Variable Air Volume) System – this HVAC system uses the damper to regulate air volume into the zone, by which the damper responds to the zone's thermostat controlling heating and cooling coils. VAV boxes are installed in the multi-zone system duct runs.
- Heat pumps – this type of HVAC system is a refrigeration system that pumps out heated indoor air in order to keep the indoor space cool. Likewise, in times of cold weather, the system draws in heat from outdoor air and then moves it into the indoor, occupied space.
- Unit ventilator – this HVAC system is a single, self-contained system that is commonly installed in hotels/motel rooms, schools, garages, and other indoor spaces where individual room environments are maintained separately (TSI, 2013).

2.6.1 HVAC and Indoor Air Quality

Making available a comfortable and healthy indoor air quality for both residential and commercial buildings (e.g. office buildings) that have HVAC systems has been a major focus of concern amongst HVAC engineers. This is because exposure to indoor pollutants could pose a more serious effect especially to health of occupants due to higher concentrations of pollutants in indoor spaces as compared to its outdoor counterparts (Vedavarz, Kumar, & Hussain, 2007). Reduction of indoor air quality in office buildings and other buildings that have HVAC systems could be due to the failure of the HVAC system to control the existing air contaminants that further decrease thermal comfort of an indoor space. As above, pollutants deriving from HVAC systems include dust or dirt in ductwork, microbiological growth in drip pans, improper use of sealants/cleaning compounds, refrigerant leakage and improper venting of combustion products (Centers for Disease Prevention and Control, 2014).

One of the major aspects that are critical for HVAC engineers and designers to place great emphasis on is that airflow patterns in buildings are caused by the combined interaction between different factors such as mechanical ventilation systems, human activity and natural forces. Pressure disparities created by these factors typically transfer airborne contaminants high-pressured zones/areas into those low-pressured rooms by passing through any available pathways and openings. The HVAC system is often considered as the predominant pathway and driving force for air movement in buildings. All components of the buildings along with HVAC equipment (e.g. walls, ceilings, occupants) could interact with each other and therefore affect contaminant or pollutant distribution in indoor spaces (Centers for Disease Prevention and Control, 2014).

HVAC systems as a source or cause of indoor air pollution or contaminant distribution in indoor spaces have been extensively explored and investigated in indoor air quality research and literature. According to Bearg (1993), HVAC systems could contribute to biological contamination problems in indoor spaces either by being a host, an incubator or propagator, or transporter of the contaminant. For example, viable fungi deposited in HVAC systems can multiply if adequate nutrients are available and temperature and humidity conditions are conducive to growth. Because fungal fragments and spores are continually entering the HVAC system, the system filters can potentially be used as a record of fungal exposure (Kemp, Keuhn, & Pui, 1995). Supporting this finding, the study by Chang et al. (1996) measured the fungal bio-contamination in HVAC ducts. Based on their findings, fibrous glass ductboard and galvanized steel duct were more susceptible to high fungal (P.

chrysogenum) growth compared to the insulated flexible duct. Moreover, accumulation of dust in both fibrous glass ductboard and flexible duct increased the growth level of fungi as compared to galvanized steel. Consequently, dust accumulation as well as high humidity should be controlled in HVAC ducts in order to prevent fungal (P. chrysogenum) growth, therefore decreasing the risk of fungal contamination that reduces indoor air quality (Chang, Foarde, & Van Osdell, 1996).

Similarly, the study by Mendell et al. (2008) explored the building-related symptoms of office workers caused by contaminants associated with HVAC systems. Based on their findings, humidification systems which are in poor condition were related to the significant increase in risks of upper respiratory symptoms, eye symptoms, fatigue, difficulty in concentrating and skin symptoms. Additional so, less frequent maintenance and cleaning of cooling coils and drain pans were related with the substantial increase in experiencing eye symptoms and headache (Mendell, Lei-Gomez, Mirer, Seppänen, & Brunner, 2008).

2.6.2 Air Filtration in HVAC and IAQ

Air filters function in capturing particles and therefore preventing them from entering and passing through the conditioned air stream. Air filters are commercially available in different sizes and configurations depending on their application. There are various filter media used in most HVAC systems including paper, sponge foam, spun glass and pleated woven bags. Other common air filters are electrostatic particle arresting types which allow a more effective drawing in and capturing of particle due to its electrically-charged filter media. Activated charcoal filters are also common that are applied to get rid of unpleasant odors caused by gases. Filters are mostly found in various locations in the HVAC system, depending on its application. However, it is placed in front of a key HVAC component in order to extend the use, reduce maintenance costs and avoid damage from dirt and other air pollutants. Further, a secondary function of filter is to avoid contaminants from scattering throughout the ventilation system and ultimately into the indoor spaces and areas (TSI, 2013).

Typically, filters are rated and evaluated through various standards and test approaches such as dust spot and arrestance for measuring performance of filters (see Table 2. 4). Low efficiency filters or those with ASHRAE Dust Spot rating of 10% to 20% or less are commonly utilized to keep lint and dust from clogging the heating and cooling coils of a system. To prevent contamination of air in indoor spaces, filters should have the capability to remove bacteria, pollens, insects, soot, dust and dirt that meets the required efficiency of use in buildings. On the other hand, those filters having ASHRAE Dust Spot rating of 20% to 60% or medium efficiency filters are more effective in terms of providing better filtration. In other words, selection of filters should be based on the ability of filters in protecting both the HVAC system components and the indoor air quality. Most of the buildings use medium efficiency, pleated filter mainly because of its higher removal efficiency (CDC, 2014).

Dust Spot Efficiency	**Application**
10% – 20%	Window air conditioners, packaged air conditioners, domestic furnaces. Effective on lint, some pollen. Ineffective on smoke.
20% - 40%	Air conditioners, domestic furnaces, central systems. Effective as prefilter for clean room filters. Removes some smoke and staining particulate materials
40% - 60%	Reciculating AHUs, central AHUs, prefilters for HEPA filters. Effective on pollen, dust,

	some bacteria. Slightly effective on fume and smoke. Ineffective on tobacco smoke, virus
60% - 80%	Hospital AHUs, new building construction. Effective on pollen, some building criteria, smudge and staining particles, coal and oil smoke

Table 2.4: ASHRAE Standard 52.1 – Dust Spot Efficiency for Filters

(Burton (1997, p. 40)

Indoor air pollution encompasses high levels of pollutant concentrations in the air, and air filters are critical to trap dust particles that carry different kinds of pollutants. It is important to note that air filters are key components in a HVAC system since it somehow filters out dust from entering the ventilation system. There are various research studies that explored how air filters could even contribute to indoor air quality problems. For example, the study by Hyttinen ,et al (2007) found out different kinds of chemical compounds such as terpenes, carboxylic acids, hydrocarbon organic compounds and others were the chief emission products found in filter dust. As above, many of these compounds have low odor threshold values and thus add to the unpleasant odor emitted from the filters (Hyttinen, Pasanen, Björkroth, & Kalliokoski, 2007).

Similarly, there were various studies that explored bio-contamination in air filters in HVAC systems. A number of studies have examined fungal survival and growth on HVAC filters. In one such study Maus ,et al (2001) studied the survival of mold spores in new and used air filter media such as polyester fiber, polypropylene fiber and glass fiber. HVAC filters were placed in an environmental chamber where relative humidity was controlled. These filters were then exposed to a known concentration of A. niger spores while a constant flow of clean air was drawn through them for about 1 hour to 5 days. For new filter media, viability was not affected a relative humidity was below 35%. At relative humidity of greater than 85% *A. niger* showed a slight decline in viability in a glass fiber medium and a more pronounced decline in polyester and polypropylene fiber.

In addition, Maus et al (2001) noted that the results for the used glass fiber medium were similar to the new glass fiber medium. However the decline in viability did not occur in the two other fibers. The results from this study indicate that although relative humidity was high enough to support growth, there was no increase in viability on either the new or used filter media. This result is not surprising when considering the new filter media. In the case of the used filter media however, the filter cake most likely contained some material that could have served as fungal nutrients. The lack of growth under these conditions indicates that fungal colonization of HVAC filters is not always a definite occurrence, even under apparently ideal conditions. Other research studies that supported the fact that air filters could contribute to bio-contamination of indoor air quality include Simmons et al (1995), Kemp et al (1995), Martikainen et al (1990), and Moritz, Schleibinger and Ruden (1998).

2.6.3 Maintenance of HVAC Systems

Maintenance of HVAC systems is critical to prevent future problems and unnecessary costs. There is a wide range of aspects that should be considered in a typical maintenance check-up. Maintenance check-up should include (1) checking thermostat settings in order to guarantee optimal cooling and heating purposes, (2) tightening all electrical connections to ensure safe operation of the system and therefore increasing the life of HVAC major components, (3) lubricating all moving components or parts of the system, (4) checking and inspecting the condensate drain in the central air conditioner, furnace and/or heat pump; and (5) checking the controls of the system in order to guarantee safe and proper operation (Energy Star, 2015).

Cooling specific maintenance also covers cleaning the evaporator and condenser air conditioning coils, checking the central air conditioner's refrigerant level and cleaning and adjusting blower components. On the other hand, heating-specific maintenance involves checking all gas and/or oil connections, gas pressure, burner combustion and heat exchanger in order to make sure that the heater system operates safely and efficiently (Energy Star, 2015).

2.6.4 Importance of HVAC Maintenance

It is considered that HVAC maintenance is one of the most important tasks in order to reduce the problems and risks involving poor indoor air quality. Besides the common pollutants and sources of pollutants present in the building like cleaning products, copy machines and printers, vehicle exhaust and others, HVAC systems could also contribute as a source of pollutants. If HVAC systems are not properly maintained, ventilation air filters could be a breeding ground for microorganisms and odor. Microbial growth could be the result of stagnant water in drain pans or from uncontrolled moisture inside of air ducts and cooling coils (CDC, 2015).

2.7. How Ventilation Impacts IAQ

Ventilation in buildings refers to the circulation of air throughout the building. Proper ventilation in indoor is important to achieve since it influences indoor air quality within the building. The relationship between ventilation and indoor air quality is mediated on the process of moving in fresh air into the indoor area that further reduces contaminant concentrations. As noted earlier, ventilation or HVAC systems do not only function as a mechanism to control contaminants in indoor areas, but also provide a comfortable environment for occupants. Even a subtle discomfort of indoor environment could stem to different complaints regarding indoor air quality (American Industrial Hygiene Association, 2015). Discomfort, as well as indoor air pollution, has been widely noted to be the outcome of poor ventilation, by which proper ventilation rates in indoor buildings, including office buildings, are not properly achieved. Table 2.5 below shows the ASHRAE Standard 62-1989 ventilation rates, outlining the appropriate air requirements for ventilation in commercial facilities including office buildings.

Office Areas	**Estimated max occupancy/1000 ft^2 or 100m^2**	**Air Requirements**	
		Cfm/person	**L/s person**
Office space	7	20	10
Reception areas	60	15	8
Telecommunication centers and data entry areas	60	20	10
Conference Rooms	50	20	10

Table 2.5 : ASHRAE Standard 62-1989 ventilation rates for Office buildings

(Vedavarz, Kumar, & Hussain (2007, p. 4.2)

Multiple research studies have expressed the importance of proper ventilation and its role in affecting indoor air quality and human health. For example, various studies (Hedge, Burge, & Robertson, 1989; Wargockin, Sundell, & Bischof, 2002) quantitatively measured the association between the prevalence of sick building symptoms (SBS) and ventilation rates of office buildings. Based on these findings, the greatest number of SBS is recorded in buildings with ventilation types such as buildings with air conditioning, with mechanical ventilation and with natural ventilation. Similarly, many studies also concluded that ventilation rates that is below 10 Ls-1 person -1 are associated with an increased prevalence of SBS symptoms, suggesting that increase of ventilation rate would decrease the likelihood or risks of experiencing SBS (Wargockin, Sundell, & Bischof, 2002; Godish & Spengler, 1996).

2.8. Effect of Climatic Condition on IAQ

Few research studies have justified the relationship between climate change and indoor climate/air environment. As a matter of fact, the link between the two is relatively strong and deserves utmost attention, given the fact that policy makers even overlooked this connection more often. According to Nazaroff (2013), climate change could pose impacts and effects to indoor air pollution in various ways. Accordingly, he noted that it will influence the concentration of air pollutants in buildings. He further noted that the resulting changes in human exposure to these air pollutants could impact public health. Changes could be expected through the altered outdoor pollution as well the changes in buildings being affected in response to the changing climate. Nazaroff also highlighted that there are three classes of factors that explain the indoor pollutant levels in indoor spaces – properties of pollutants, building factors such as ventilation rate and occupant behavior. The divergences and changes in indoor conditions likely influence the public health significance of climate change (Nazaroff, 2013).

The review by the Built Environment Research Group (2014), supported and expanded the findings of Nazaroff (2013) and discussed on the categories that explains the relationship between climate change and indoor air quality and health. These include:

- Climate change is anticipated to result to various changes in outdoor pollutant concentrations, especially for ozone and particulate matter, which will also reflect as the shifts and changes in the level of concentrations of various indoor pollutant.

Such changes are due to the outdoor pollutants infiltrating into the buildings with differing efficiencies.

- Climate change is anticipated to result to various changes in the meteorological conditions that certainly will influence and effect existing performance of the building, as well as building operations. In addition to that, such changes in the meteorological conditions will also have impacts on human behaviors. Building performance, operations and human behaviors could include changes in air infiltration rates, air-conditioner operation, and window opening patterns, which have competing effects on indoor pollutant concentrations.

- Climate change is also anticipated to result to extensive policy responses that might influence the approaches in which humans tend to design and construct buildings, including improving energy efficiency across the building stock by implementing energy efficient building practices in new construction and widespread application of weatherization retrofits in existing buildings (Built Environment Research Group, 2014).

Similarly, the study by Levin (2008) pointed out that the changes in yearly and episodic precipitation totals as well as changing water table levels, flooding and storms will increase the number of structures threatened by mould and other moisture-dependent organizations. Levin further noted that climate change will affect the internal temperatures and comfort of buildings. He noted that the average temperatures will likely increase improving winter comfort conditions but cause problems with overheating in summer. More so, the use of air conditioning and warmer and more humid internal environments would result to the increased risk of Legionella problems (Levin, 2008).

2.9. Dubai Weather Condition

Dubai is one of the most populated emirates in the UAE. This well-known city has been a tourist destination year round despite its temperatures that will reach up to over 40 degrees. The climate condition of Dubai is desert-like and likely could be described as an arid subtropical climate. During the summer, Dubai's temperature is very hot, with June to September as the hottest months and could record a temperature of up to 45 degree Celsius. Average temperature in the summer would be low to mid 30 degrees Celsius. In addition, rainfall is extremely low between June and September and rainfall occurs primarily on winter.

Winter in Dubai provides more comfortable temperatures, with December to February as the coolest months averaging about 20 degrees Celsius. Annual rainfall is only about 150mm. Likely, late spring and early autumn are very hot. Autumn is commonly warm and dry while early springs have rapidly hot days and still has potential for rainfall.

2.10. Knowledge Gap

This section presents a discussion relating to the literature review knowledge gap that aided the research study in establishing its study framework. It also highlighted the urgent call for the taking serious actions in controlling the sources or causes of poor indoor air quality.

Following the comprehensive review of past research studies conducted for exploring the IAQ of office environments in UAE, there are various knowledge gaps that were identified and determined. These include:

- Lack of awareness and understanding the various sources or causes of indoor air pollution. It is critical that people had to be get of better understanding in relation to selecting materials used in indoor environment, considering that these materials could be potential contributors to poor indoor air quality which could affect occupants' health, productivity, performance and many others.

- There is limited information and evidences regarding the office environment. Most of the research studies in the past were focused primarily on the sustainability of buildings, but lack on the focus of indoor air environment. This means that available evidences were focused more on sustainability actions such as saving energy, green buildings and many others.
- There is lack of policies and regulations related to office health conditions as well as lack of regular assessments relating to office indoor environment.

Chapter 3

Methodology

3.1. Overview of Research Methodology

Research methodology, by definition is the systematic approach to resolve an issue or research problem. It is the science of studying how the proposed research is to be performed. Principally, research methodology refers to the procedures that the researchers carry out entailing the procedures of describing, explaining and predicting a phenomenon. A research study takes into consideration to design or develop a methodology for the subject topic or problem that is to be explored. Similarly, it is important that the researchers should design a proper research methodology and research methods required and appropriate for the research. Often, the terms research methods and research methodology is used interchangeable; however, there are different. Research methods, by definition are the various procedures, schemes and algorithms utilized in the research, while the research methodology is the logical way in solving the problem. There are various points to take in to consideration in developing the research methodology. Some of these include:

- Suitable method for the chosen problem
- The order of accuracy of the result of a method
- Efficiency of the method (Rajasekar, Philominathan, & Chinnathambi, 2006)

The importance of understanding and designing appropriate research methodology summarized wide range of benefits including increased confidence in the researcher's ability to evaluate and use of research results, increased ability to make intelligent decisions concerning the issues and problems that researcher is attempting to explore or solve, a more developed disciplined thinking in observing the field in an objective manner (Kothari, 2004).

3.1.1 Case Study Methodology

There are different types of research approach or methodology. One of which is case study methodology. Basically, the definition of case study revolves around the in-depth, comprehensive understanding of a complex problem in its real-life perspective. It is an integrated research design that is adapted to wide range of disciplines, especially the social sciences. Case studies could be utilized for the purpose of explaining, describing or exploring events or phenomena in the everyday context in which they exist or emerge. They could be used to understand and investigate causal connections and pathways resulting from the event or phenomena. Unlike the experimental design which aims to assess and test identified hypotheses through deliberate manipulation of the environment, case study approaches are more focused on capturing information on a more explanatory way. This means, it concentrates on the 'how', 'what' and 'why' inquires (Crowe, Cresswell, Roberson, Huby, Avery, & Sheikh, 2011).

The case study methodology could be approached in different manners, depending on the epistemological perspective of the researcher. These include:

- Critical – focuses on questioning one's own and other's assumptions
- Interpretivist – attempting to understand individual and shared social meanings
- Positivist – orientating towards the criteria of natural sciences (Crowe, Cresswell, Roberson, Huby, Avery, & Sheikh, 2011)

Advantages of adopting the case study methodology are reflected from its characteristic of being very flexible. Here, case study research methodology support exploratory investigation in order to achieve a better understanding of specific situations or to create ideas and concepts for the use in follow-up work. It could also be used in order to achieve a detailed description of certain experiences while allowing the investigation of the 'how', 'why' and 'what explanatory questions, therefore supporting the analytic generalization via cross-case analysis. In addition, it is very flexible in a way that it could be used as a study approach in an emancipator work (e.g. action research, participatory inquiry, etc) (Gilson, 2006).

3.1.2 Laboratory Methodology

The Laboratory-based methodology is categorized as a controlled experimental research method, which uses a laboratory to conduct the experimental study from where the measurements are taken. It is an appropriate approach in testing specific parameters such as the behavior of materials. In this approach, certain conditions can be managed and controlled like the variables to be tested, exposure of the sample materials to different environments such as moisture, wind, and sunlight. This method will have its restrictions to examine the full scenario that is happening in its natural condition. Further to that, the provision of a test laboratory with all the necessary test equipment and accessories such as sensors and test probes and sensors for measurement purposes will entail a significantly high cost, in addition to the limited time frame allotted to complete this research study (Kothari, 2004).

3.1.3 Literature Review Methodology

Literature review is an evaluative report of studies found in literature related to your selected areas (Boote & Beile, 2005). It is the identification, summarization, and evaluation of previously published articles, reports, books, or even Internet entries of a particular topic. Sometimes the review also encompasses unpublished documents such as dissertations, manuals, or personal correspondence (Marrelli, 2005). At first we can say that without literature review you will not acquire an understanding of your topic, of what has already been done on it, how it is been researched, and what are the key issues.

The literature review is important because it describes the proposed research is related to prior research in statistics, it shows the originality and relevance of your research problem, the proposed methodology justifies, and it demonstrates your preparedness to complete the research. Thus, comprehensive review of literature provides you an up-to-date understanding of the subject and its significance to practice and it provides comparisons of your own research findings. However, literature review is not matched by a common understanding of how a review of related literature can be done, how it can be used in research, or why it needs to be done in the first place. Literature reviews encourage deep learning, assess different cognitive levels, time and cost efficient to look for resources, and enhance analytical skills through identifying differences in previous work and their work. Literature reviews are also versatile, relatively in expensive and efficient, no scheduling or coordination involved, a good library or online database and competent reviewer are the only resources needed, and it is an excellent first step in a project because they provide a conceptual framework for further planning and study (Marelli, 2005).

3.2. Selected Research Methods

To address the research question at hand necessitates some evidence, which calls for an empirical research. Empirical research method is centered on measured and observed event and collects knowledge from the actual happening or experience rather than from the belief or theoretical concepts. Empirical research approach is more concerned with the collection of data through observation. Some of the observations are performed in the field or in-situ measurements. Other observations are conducted by using survey methodology.

3.2.1 Survey Methodology

McBurney and White (2009) pointed out that Survey methodology is a research method that is used by a researcher who would like to collect descriptive data or information. The survey method allows the researcher to gather data about different variables by conducting interviews and using questionnaires. Once the data is gathered, the researcher uses data analysis technique to draw interpretations or conclusions among the variables. Survey methodology was selected amongst the various research methodologies that were studied in this report for the reason that the researcher will be able to collect many types of data or information. One advantage of using the survey method approach is one is able to gather a significant amount of information in a less given time. Survey method approach is easily conducted through mails, emails, fax, or online on the internet. Bryman and Bell (2009) emphasized that survey method approach requires less time perform and is much more easy to manage as compared to other research techniques like the case study and Laboratory research methodologies.

The survey methodology, the most common research methodology used by researchers, involves information gathering regarding the characteristics of interest in a more systematic and organized manner. Here, well-identified and defined concepts, methods and procedures are utilized and collected data are compiled and analyzed into a summary format. The survey methodology involves 11 key steps, which are:

1. Formulating the statement of objective of the survey - Developing the survey's information needs as well as identifying operational definitions. Basically, it involves information that is included in the survey and what is excluded.

2. Selecting the survey frame - Determining and contacting the sample respondents from the survey population.

3. Identifying the sampling design – involves determining the kind of survey to be adopted (e.g. sample surveys or census survey)

4. Designing the survey questionnaire – entails the designing of questionnaire, which is a group, or sequence of questions designed to capture information from the respondents. This involves tasks such as deciding on what questions will be ask, how to assemble and organize the questions and many others.

5. Collecting the data – involves collecting the required information for the selected participants of the survey. It could be done through survey sheets or computer-assisted survey.

6. Data capture and coding – involves assigning numerical value to the responses made by the respondents in order to facilitate data capture and processing in general.

7. Editing and imputation – entails evaluating or checking the responses in order to identify missing or invalid responses through follow ups with the respondents or manual review of the survey questionnaire.

8. Estimation – involves obtaining values for the population of interest in order to establish conclusions about the population based on the gathered information form only a sample of the population.

9. Analyzing the data – involves the summarization of the data and interpretation of the data's meaning in such a manner that in endows the researcher with clear answers to the research questions that is identified in the survey.

10. Data dissemination – involves distribution of the survey data to the users in various media like press releases, electronic media and others.

11. Documentation – involves creating a report on the overall procedures, findings and conclusions in the survey (Minister of Industry, 2010).

There are different types of surveys, which include face-to-face interview surveys, telephone surveys, postal surveys, web surveys, flow samples, business surveys, and many others. Face-to-face interview surveys include researchers or surveyors to conduct surveys at respondent's own home (e.g. household surveys). Here, participants will be provided first with an advance letter to notify participants that an interviewer will conduct a survey and do face-to-face interview sessions with them. Telephone surveys are those surveys that are carried out or administered via telephone. Postal surveys are those types of surveys that make use of self-completion questionnaires administered by mail, wherein the answered questionnaire will be sent back through email or any other submission procedure. Web surveys are conducted via the Internet, wherein survey participants will be asked to answer the questionnaire hosted online through online survey platform provider (e.g. Survey Monkey). Flow samples involve surveys wherein the sampling and gathering of data were done simultaneously from a mobile population that is identified by time and location. Lastly, business surveys are those surveys that involve respondents answering on behalf of the business (de Leeuw, Hox, & Dillman, 2008).

3.2.2 Field Measurement Methodology

Field research methodology, by definition, refers to a broad approach to qualitative research or a method of collecting qualitative data. The primary aspect of field research methodology is that the researcher basically goes 'into the field' in order to observe the phenomenon in-situ. This particular approach of research is often associated with the methodology of participant observation, wherein the field researcher is required to make field notes in order to document the observed data. The data written in the researcher's field notes are then coded and analyzed in different approach. In the participant observation, the researcher goes into the research methodology as a participant in the culture or context being observed. It often require long period of time mainly because this type of research involves guaranteeing that observations being made are drawn from the natural phenomenon (LaBonte, n.d.).

Field research methodology could present a wide range of benefits. First of all, this methodology enables researcher to achieve a first-hand experience and understanding about the subject being explored by their study. This means that the close-up observation of the subject would allow researchers to obtain in-depth and very detailed information and data with regards to the people and the processes that the subject event or phenomenon is demonstrating. Secondly, the field research is the most appropriate approach in understanding the functions of social context that impacts the lives and experiences of subjects. Lastly, it provides a way for researcher to explore social fact that might not be directly visible or of which research participants may be unconscious or unaware of (Blackstone, 2014).

3.3. Advantages of Mixed-Method Approach

Combining both qualitative and quantitative research methodologies have been a common design chosen by most researchers in conducting their studies. The mixed-method research approach presents more insightful findings and conclusions, given the fact that numeric and text-based resources are amalgamated together. From its basic definition, mixed –method design involves utilizing at least one quantitative method and one qualitative method, wherein neither forms of approach is intrinsically related to any certain investigative paradigm (Creswell & Clark, 2011).

Advantages of utilizing mixed method approach or combining two approaches (e.g. qualitative and quantitative) are quite apparent. One of the advantages is that mixed methods approach allows the researcher to gather more evidence to investigate a research problem than either quantitative or qualitative approach alone could provide. In addition to that, it also endows the researcher the opportunity to address the weaknesses of using either quantitative or qualitative alone. This means that combining both research approaches offers strengths that compensate the limitations of both the approaches. Similarly, mixed methods research provides a way for researchers to address the research questions that could not be addressed or answered by quantitative or qualitative approaches alone (Creswell & Clark, 2011). In a nutshell, mixed methods provide advantages that boil down to the ability of the researcher to explore comprehensively a research problem through integration of numeric and text-based sources. Comprehensive investigation is obtained in a sense that the investigation is leaned towards using qualitative and quantitative perspectives supporting each other's obtained findings and analyses.

3.4. Subjective Study

To gather data from occupants relating to their perceptions about indoor air quality of their offices and their impacts to their health and productivity, survey was used and facilitated to 80 participants. The utilization of survey design was chosen because they provide measurements that are standardized. This means that the same information is collected from all respondents. In this research, the questionnaire was purposively-designed to capture relevant data to address the research questions from the occupants' perception on IAQ. Hard and soft copies of the survey were available for the participants. The administration of the survey involves giving participants a 5-minute orientation of the requirement, survey structure, study objective and the answering format. All the results of the survey were recorded in excel sheet.

The survey questionnaire administered by the researcher was written in Arabic, though questionnaire written in English were also available for those participants who preferred to answer the questionnaire written in English. As noted, the participants were selected based on convenience sampling, where participation in the survey is voluntary. In addition, upon survey questionnaire administration, the research respondents' ethical considerations and rights were exercised. This will basically take form in the option wherein the respondent can either provide their names or not; while ensuring that the rest of the personal preferences such as age, gender, number of years in the University and race will be provided.

3.5. Objective Study

To gather data regarding the IAQ indicators, the research study utilized a monitoring instrument called Direct Sense-IAQ. This allowed the researcher to measure and identify any IAQ issue that could impact occupants. The use of the Direct Sense-IAQ is advanced while user-friendly, which makes it convenient for the researcher. More so, this is a portable device that allowed the researcher to conduct any needed measurement for the given area more simply. It is most appropriate not just for the walk-through investigation but also constant long-term measurements, as it classified the exact ratio/amount of the related air components in such a way that it affords a pure picture of the IAQ status. The table 3.1 below shows some of the specifications of the device, which presents justification of using it in this current research study.

Feature	**Description**
Data Logging	By using the device manually can be taken a snapshots
Back-lit color display	This tool provides the client accurate figures with Visuals and diffrents graphics
Intelligent user interface	Very user-friendly interface with drop down menus.
Reporting	The client can simply download the notes and the informations to WolfSense® PC software, and then take the results directly for the reporting
Accessories	Hard-shell security case can be used to save the tool through transport and long-term measurements. Additional ,option

	camera or other devices and software can be added with the main tool for a hugee measurements

Table 3.1 : Multi-functional features of Direct Sense-IAQ

3.6. Case Study -Office Buildings

One of the primary objectives of the research study is to assess the indoor air quality of office spaces, with focus on six key IAQ indicators including TVOC, Ozone, Carbon Dioxide, Carbon Monoxide, Relative Humidity and Temperature. These indicators were measured in 17 office spaces at two buildings as Ajman University of Science and Technology.

3.6.1 Building A

Building A is a 3-storey building comprised of office spaces, classrooms and studios. This building was first established in 2003, with three main entrances. Spot measurements were conducted at 11 office spaces. These office spaces have different flooring materials (e.g. marble and carpet flooring), number of occupants, furniture arrangements, number of office desks, number of office equipment (e.g. printers, scanners, and photocopiers), windows, natural ventilation and lighting and others. Table below shows some of the observations in 11 offices at Building A based on the above-noted office features. The figures below show the floor plans of Building A.

3.6.1.1 Floor Plans of Building A

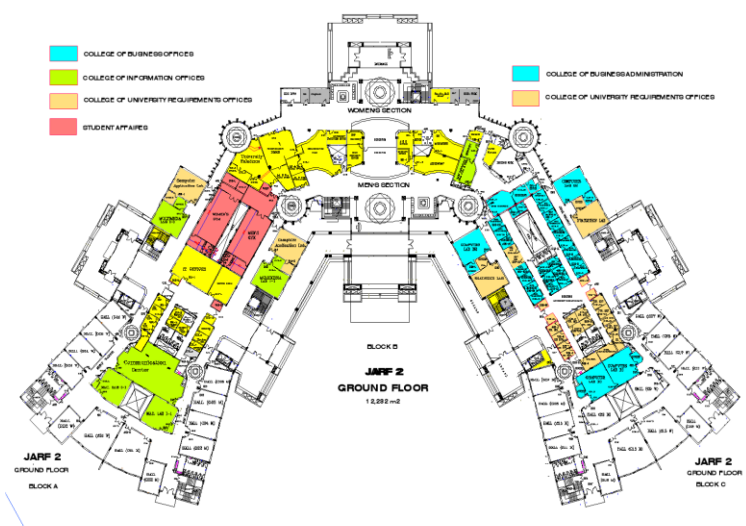

Figure 3.1 : Building A -Ground floor plan

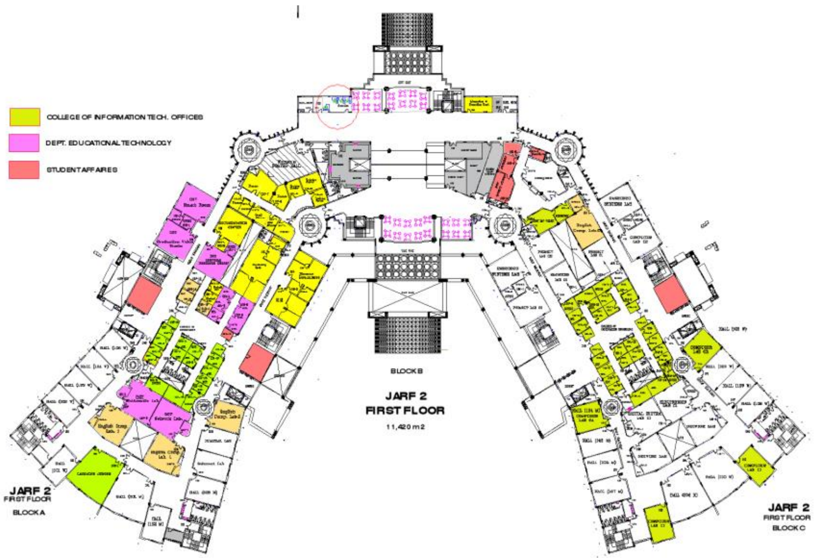

Figure 3.2: Building A -First floor plan

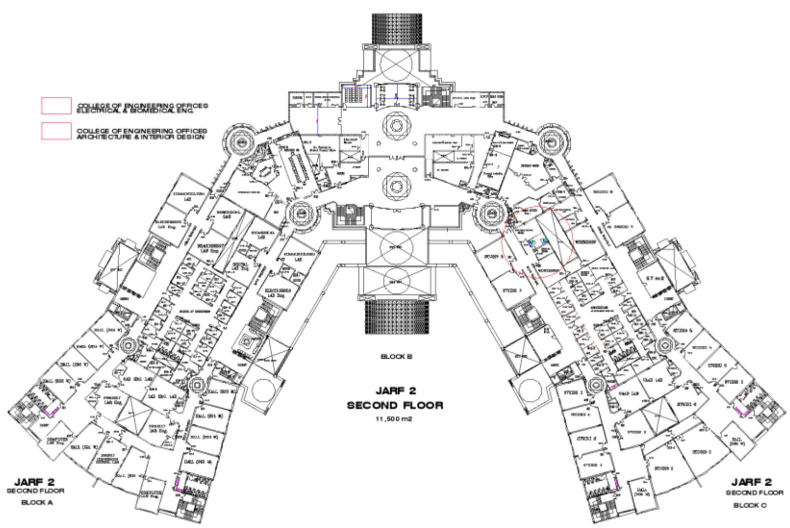

Figure 3.3: Building A -Second floor plan

3.6.1.2 Observations of Offices -Building A

Office 1

Occupants: 7 persons

Materials: paint for walls, marble tiles for flooring, and tiles for ceiling.

Furniture's: 7 offices disk, 7 chairs, and big storage.

Opening: no windows.

Equipment's: 7 computers, 2 printers and scanners.

Office 2

Occupants: 3 persons

Materials: paint for walls, carpet for flooring, and gypsum board for ceiling.

Furniture's: 3 offices disk, 5 chairs, storage, and 1 meeting table.

Opening: no windows.

Equipment's: 3 computers, 3 printers and scanners.

Office 3

Occupants: 4 persons

Materials: paint for walls, carpet for flooring, and gypsum board for ceiling.

Furniture's: 4 offices disk, 11 chairs, 1 storage cabinet, and 1 meeting table.

Opening: windows, but not open.

Equipment's: 4 computers, 4 printers and scanners.

Office 4

Occupants: 3 persons

Materials: paint for walls, carpet for flooring, and gypsum board for ceiling.

Furniture's: 3 offices disk, 5 chairs, 2 storage cabinets, and 1 meeting table.

Opening: no windows

Equipment's: 3 computers, 3printers and scanners.

Office 5

Occupants: 6 persons

Materials: paint for walls, marble for flooring, and tiles for ceiling.

Furniture’s: 6 offices disk, 9 chairs, 2 storage cabinets, and 1 meeting table.

Opening: 1 window

Equipment’s: 6 computers, 6 printers and scanners.

Office 6

Occupants: 3 persons

Materials: paint for walls, carpet for flooring, and gypsum bored for ceiling.

Furniture’s: 3 offices disk, 10 chairs, 1 storage cabinet, and 1 meeting table.

Opening: wall to wall window, not open

Equipment’s: 3 computers, 3 printers and scanners

Office 7

Occupants: 3 persons

Materials: paint for walls, marble for flooring, curtains, and gypsum bored for ceiling.

Furniture’s: 3 offices disk, 10 chairs, 1 storage cabinet, and 1 meeting table.

Opening: 1 window

Equipment’s: 3 computers, 3 printers and scanners.

Office 8

Occupants: 5 persons

Materials: wallpaper for walls, carpet flooring, and tiles for ceiling.

Furniture’s: 5 offices disk, 8 chairs, 1 storage cabinet, and 1 meeting table.

Opening: no window

Equipment’s: 5 computers, 5 printers and scanners.

Office 9

Occupants: 5 persons

Materials: paint for walls, marble flooring, and tiles for ceiling.

Furniture’s: 5 offices disk, 7 chairs, and 2 storage cabinets

Opening: no window

Equipment’s: 7 computers, 5 printers and scanners.

Office 10

Occupants: 6 persons

Materials: paint for walls, marble and carpet flooring, and tiles for ceiling.

Furniture's: 6 offices disk, 9 chairs, 2 storage cabinets, and 1 meeting table

Opening: no window

Equipment's: 6 computers, 6 printers and scanners.

Office 11

Occupants: 5 persons

Materials: paint for walls, marble flooring, and tiles for ceiling.

Furniture's: 5 offices disk, 7 chairs, 1 storage cabinet, and 1 meeting table

Opening: no window

Equipment's: 5 computers, 5 printers and scanners.

3.6.2 Building B

Building B is one of the blocks of Ajman University of Science and technology, and has office spaces and a big library for students in its 2-story architecture. Built in 2005, the office spaces and the library had carpet flooring. Spot measurements were conducted in 6 office spaces in this building. These office spaces have different flooring materials (e.g. marble and carpet flooring), number of occupants, furniture arrangements, number of office desks, number of office equipment (e.g. printers, scanners, and photocopiers), windows, natural ventilation and lighting and others. The sub-section below show the some of the observations in 6 offices at Building B based on the above-noted office features.

3.6.2.1 Floor Plans of Building B

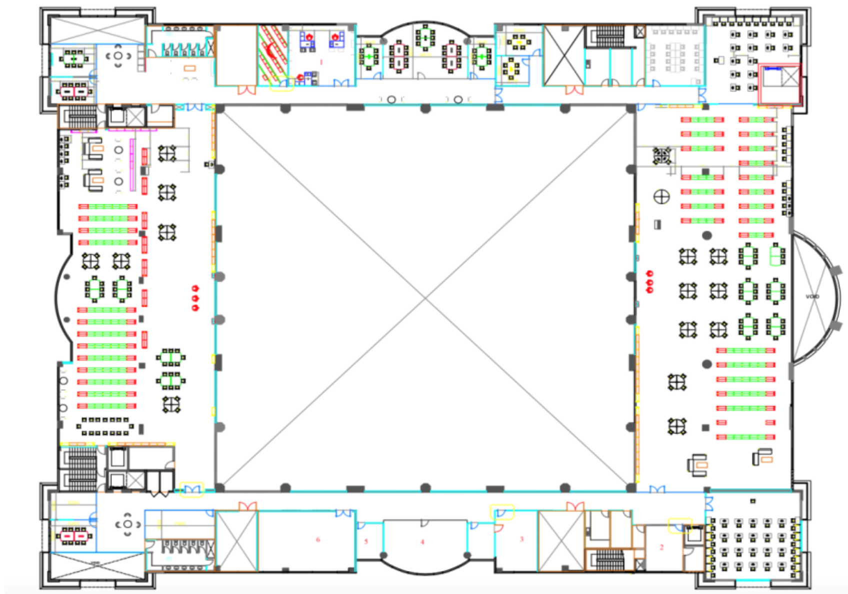

Figure 3.4: Building B -First floor plan

3.6.2.2 Observations of Offices -Building B

Office 1

Occupants: 4 persons

Materials: paint for walls, carpet flooring, curtains, and gypsum bored ceiling.

Furniture's: 4 offices disk, 7 chairs, 1 storage cabinet, and 1 meeting table

Opening: 3 windows

Equipment's: 4 computers, 4 printers and scanners.

Office 2

Occupants: 2 persons

Materials: paint for walls, carpet flooring, curtains, and gypsum bored ceiling.

Furniture's: 2 offices disk, 8 chairs, 1 storage cabinet, and 1 meeting table

Opening: 3 windows

Equipment's: 2 computers, 2 printers and scanners.

Office 3

Occupants: 2 persons

Materials: paint for walls, carpet flooring, curtains, and gypsum bored ceiling.

Furniture's: 3 offices disk, 7 chairs, and 2 bookcases

Opening: 3 windows

Equipment's: 2 computers, 3 printers and scanners.

Office 4

Occupants: 2 persons

Materials: paint for walls, carpet flooring, curtains, and gypsum bored ceiling.

Furniture's: 3 offices disk, 7 chairs, and 2 bookcases

Opening: 3 windows

Equipment's: 3 computers, 3 printers and scanners.

Office 5

Occupants: 2 persons

Materials: paint for walls, carpet flooring, curtains, and gypsum bored ceiling.

Furniture's: 2 offices disk, 8 chairs, 1 storage cabinet, and 1 meeting table

Opening: 3 windows

Equipment's: 2 computers, 2 printers and scanners.

Office 6

Occupants: 3 persons

Materials: paint for walls, carpet flooring, curtains, and gypsum bored ceiling.

Furniture's: 3 offices disk, 7 chairs, and 2 bookcases

Opening: 3 windows

3.7 Limitation of the Study: There are many limits and barriers during the study, especially during field measurements method by using instrument called Direct Sense-IAQ. One of these obstacles was changing the weather conditions during the day, which has helped to change the readings, the condition of device that some times it is need regular maintenance or changing or cleaning the filter continuously, also it was some security issues in the university.

Chapter 4

Result and Discussion

4.1. Introduction

This chapter of the dissertation presents the results of the data collected and analyzed relative to the indoor air quality of two office buildings at Ajman University of Science and Technology. Just to reiterate, the aim of this dissertation is to measure indoor air quality in office buildings, which includes measuring 6 key indoor air quality indicators including TVOCs, Carbon Dioxide, Carbon Monoxide, Ozone, Temperature and Relative Humidity (%). This section first presents the results gathered from the actual spot measurement procedures using the monitoring instrument – Direct Sense-IAQ. Here, descriptive statistics are used to present and analyze the results, which include summary tables showing the minimum, maximum and average concentrations of TVOCs, Carbon Dioxide (ppm), Ozone (ppm) and Carbon Monoxide (ppm). These tables also show the minimum, maximum and average temperature and relative humidity during an 8-hour observation for each office space in the two buildings.

Survey results are also presented, as well as the discussion of results. The discussion section entails combining the survey results and on-site measurement results of the key indicators and presenting an overall interpretation of the findings. Claims and interpretation of the findings will be supported by existing research studies exploring the same subject topic being investigated by the current research.

This chapter will conclude a chapter summary, which presents the key points covered by the entire chapter.

4.2. Presentation of Results

This section of the chapter presents the key findings and results without applying the researcher's interpretation of the results. Simply, this section only presents the actual findings and results gathered from the data collected. This section is divided into three sub-sections – (1) findings observed in Building A, (2) at Building B, and (3) survey results.

4.2.1. Building A

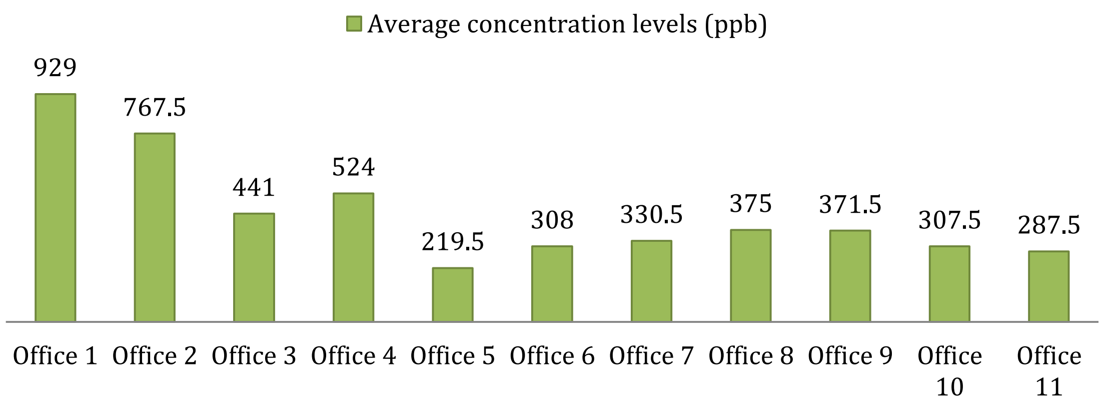

Figure 4.1: Average concentration levels of TVOCs in Building A office spaces

Figure 4.1 shows the average concentration levels of TVOCs (Total Volatile Organic Compounds) in 11 offices located in Building A. The data shows that concentration levels, as per average values, of TVOCs are very high on Offices 1 and 2 with 929ppb and 767.5ppb, respectively. It is within the Office 1 that concentration levels of TVOC peaked at its highest concentration value of 986ppm. Office 5 has the smallest average concentration levels of the IAQ indicator, with only 219.5ppm. Offices 6 to 11 shows some relatively small values relative to the other offices in the building, with average TVOCs concentration levels ranging between 287ppm and

375ppm. Detailed maximum and minimum concentration levels of TVOCs by Office number can be found in Appendix A.

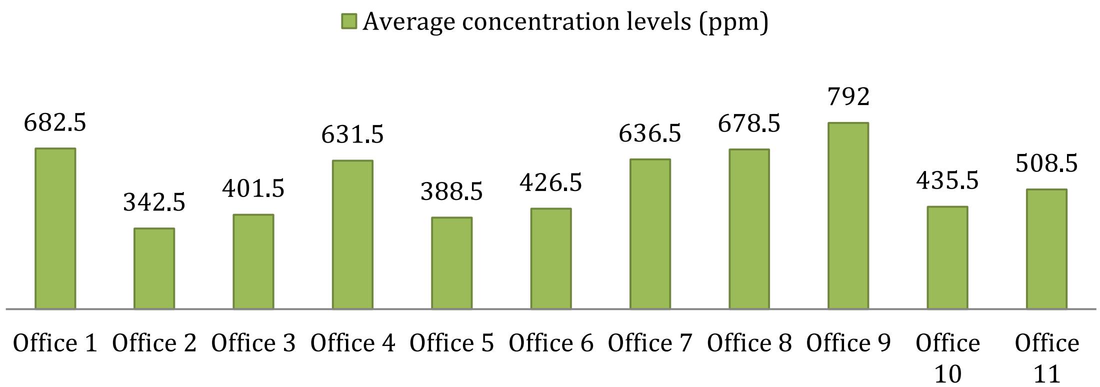

Figure 4.2: Average concentration levels of Carbon Dioxide in Building A office spaces

Figure 4.2 shows the average concentration levels of carbon dioxide observed in 11 office spaces in the building. Based on the data, Office 9 has the highest average CO_2 concentration level amongst the 11 office spaces, with concentration level of 792ppm. Office numbers 1, 4, 7 and 8 also have relatively-high average CO_2 concentration levels, ranging between 631ppm and 683ppm. Detailed maximum and minimum concentration levels of CO_2 by Office number can be found in Appendix A.

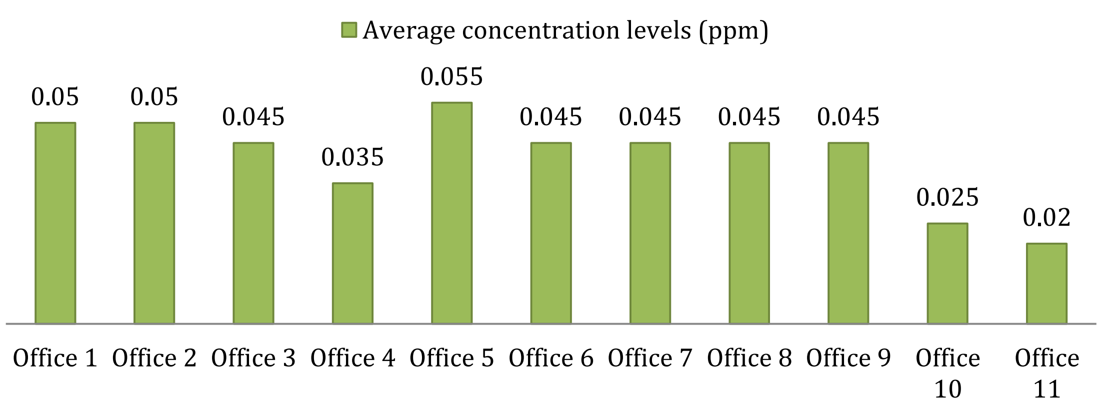

Figure 4.3: Average concentration levels of Ozone in Building A office spaces

Figure 4.3 shows the average concentration levels of ozone pollutant in office spaces in Building A. Based on the measured levels, all office spaces receive low concentrations of ozone, with Office 5 having an observed 0.055ppm of the said pollutant. The only office spaces having significantly lower ozone concentration levels are Office 10 and 11. Detailed maximum and minimum concentration levels of ozone by Office number can be found in Appendix A.

On the other hand, Figure 4.4 showed below the average concentration levels of carbon monoxide in 11 office spaces at building A. Based on the data, Office 9 had the highest recorded average concentration levels amongst all the offices, with concentration levels of 0.95ppm at an average within the 8-hour observation period. Those other offices showed only small concentration levels, ranging from 0.1ppm to 0.45ppm. Detailed maximum and minimum concentration levels of carbon monoxide by Office number can be found in Appendix A.

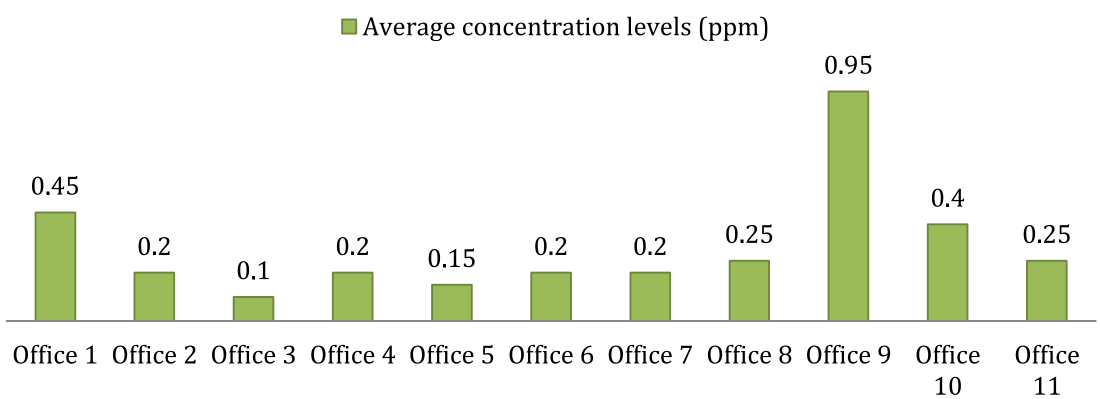

Figure 4.4: Average concentration levels of Carbon Monoxide in Building A office spaces

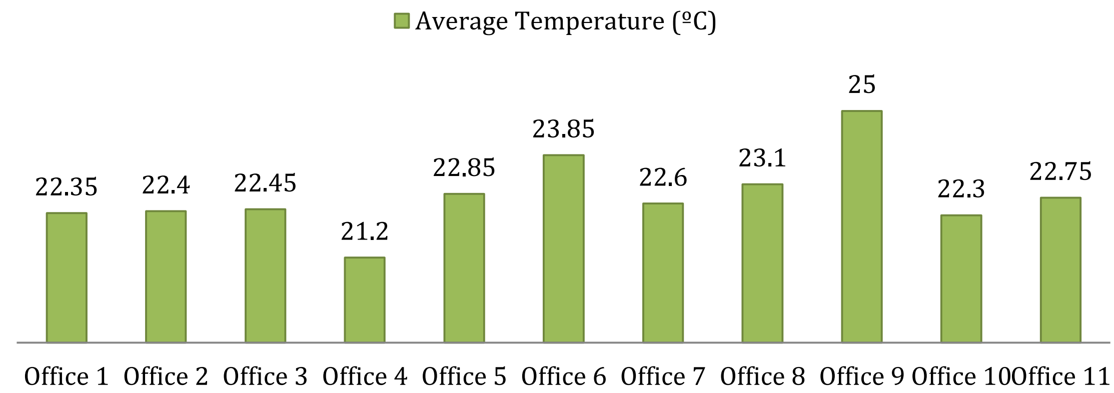

Figure 4.5: Average Temperature levels in Building A office spaces

Figure 4.5 shows the average temperature levels in office spaces located in Building A. Based on the data above, Office 9 has an average temperature of 25 degrees Celsius, which is the only office having warmer temperatures. Detailed maximum and minimum temperature levels by Office number can be found in Appendix A.

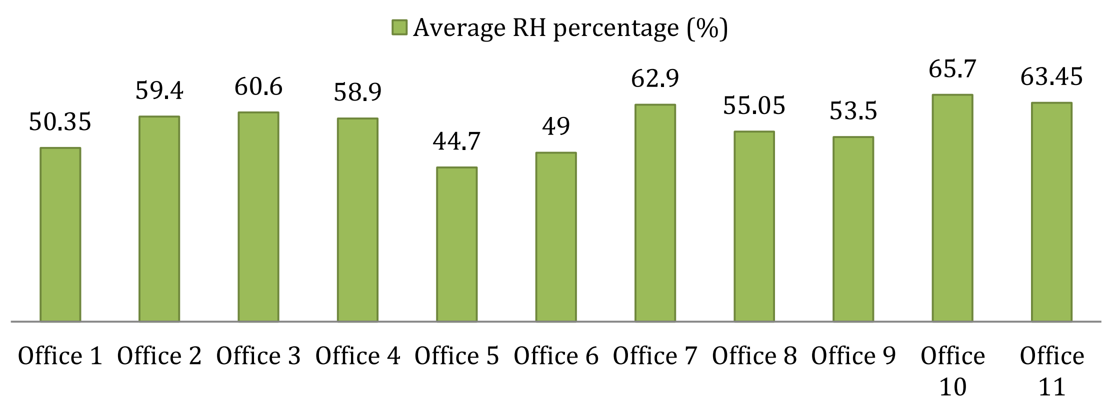

Figure 4.6: Average Relative Humidity percentage in Building A office spaces

Further, Figure 4.6 below shows the observed average relative humidity percentage in the different office spaces at building A. Accordingly, Office 3, 7, 10 and 11 have higher RH percentage, meaning that these offices contained higher amount of moisture in the air compared to what the air could hold at their respective temperature levels. Detailed maximum and minimum RH percentage levels by Office number can be found in Appendix A.

4.2.2. Building B

This sub-section presents the measurements of the 6 indoor air quality indicators in 6 different office spaces in Building B. To start with, Figure 4.7 shows the average concentration levels of TVOCs the office spaces, wherein Office 1 recorded the highest average concentration levels of 381.5ppb. Office 3 also shows some relatively high concentration, measuring an average of 330ppb at the 8-hour measurement period. Other offices have average concentration levels ranging from 219ppb to 309ppb. Office 1 and 3's observed concentration levels peaked to its highest value of 390ppb and 330ppb, respectively. Detailed maximum and minimum concentration levels of TVOCs by Office number can be found in Appendix A.

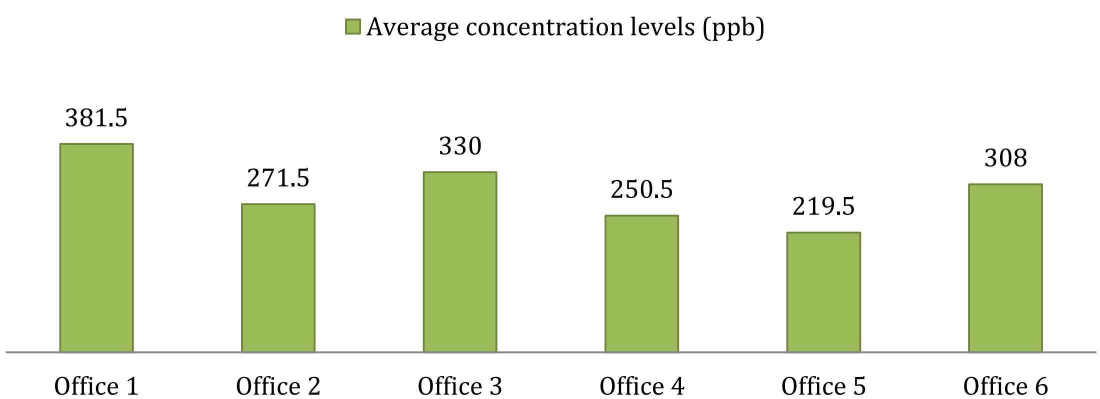

Figure 4.7: Average concentration levels of TVOCs in Building B office spaces

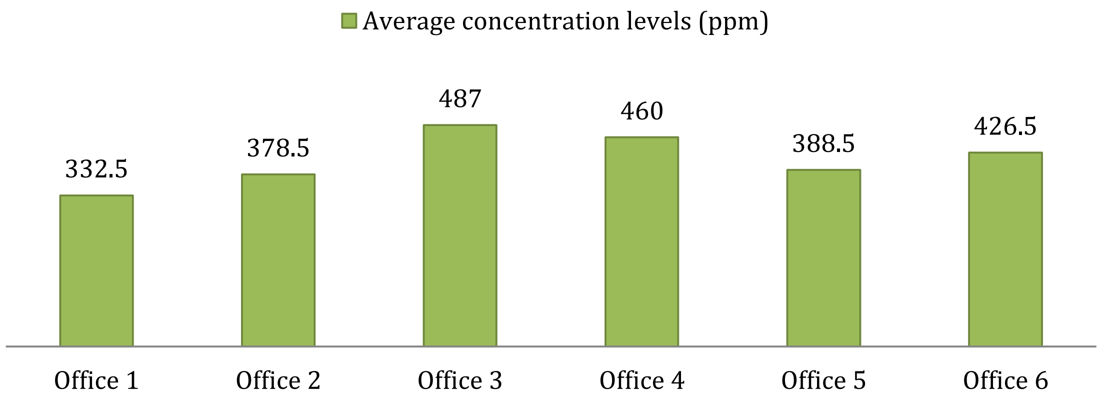

Figure 4.8: Average concentration levels of Carbon Dioxide in Building B office spaces

Figure 4.8 shows the average concentration levels of carbon dioxide in 6 office spaces in Building B. Accordingly, Office 3 observed the highest concentration levels with an average of 487ppm, compared to other office spaces. Office 4 also shows some high concentration levels with an average of 460ppm. Detailed maximum and minimum concentration levels of CO_2 by Office number can be found in Appendix A.

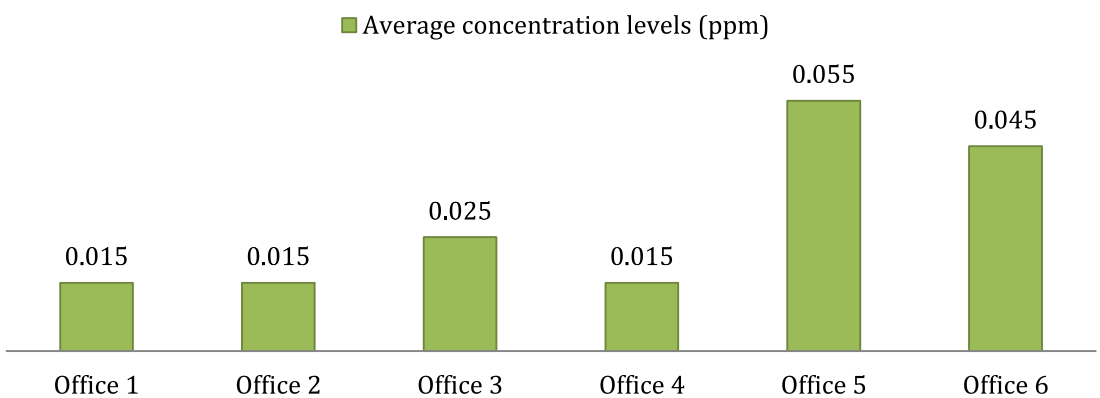

Figure 4.9: Average concentration levels of Ozone in Building B office spaces

Figure 4.9 showed the average concentration levels of ozone in 6 different office spaces in Building B. Drawing from the data, both Office 5 and 6 had observed concentration levels higher than that other offices, with average ozone levels of 0.055ppm and 0.045ppm for an 8-hour measurement period. Other offices' average concentration levels ranged from 0.015ppm to 0.025ppm. Detailed maximum and minimum concentration levels of ozone by Office number can be found in Appendix A.

Figure 4.10 shows the average concentration levels of carbon monoxide in 6 different office spaces located in Building B. Accordingly, the only offices that had high average concentration levels recorded for this indicator is Office 3 and Office 4 with 0.075ppm and 0.55ppm average concentration levels, respectively. Other offices only recorded some average concentration levels ranging from 0.15ppm to 0.3ppm. Detailed maximum and minimum concentration levels of carbon monoxide by Office number can be found in Appendix A.

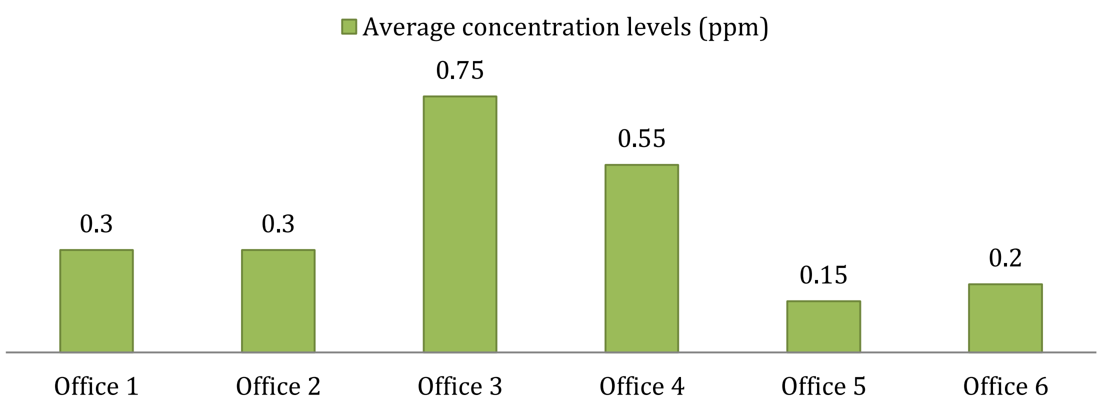

Figure 4.10: Average concentration levels of Carbon Monoxide in Building B office spaces

Figure 4.11 shows the average temperature levels in 6 different offices spaces located in Building B. According to the data, observed temperature at Office 6 is much higher compared to other average temperature levels at other offices, with an observed average temperature of 23.85 degrees Celsius. Detailed maximum and minimum temperature by Office number can be found in Appendix A.

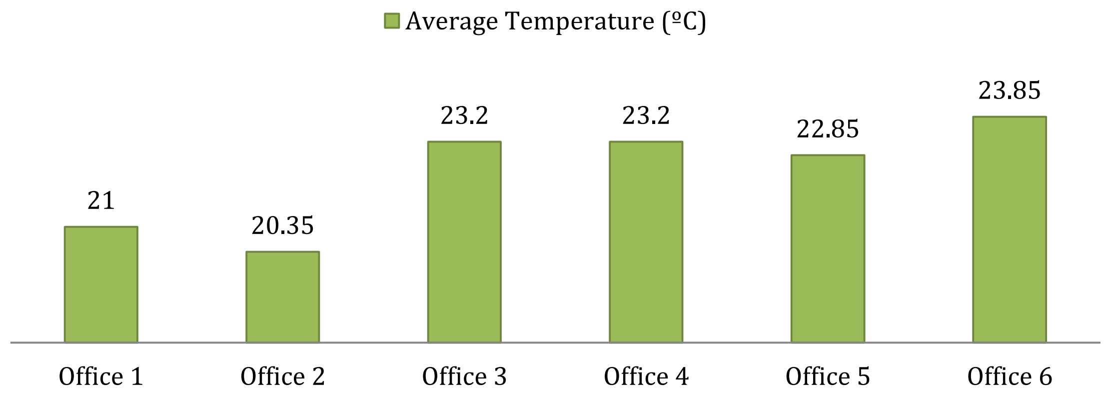

Figure 4.11: Average Temperature levels in Building B office spaces

Figure 4.12 shows the observed average relative humidity at office spaces in Building B, wherein Office 1, 2, 3, and 4 have higher RH percentage. These offices have RH ranging from 59 to 60. On the other hand, Office 5 and 6 showed some lower RH, compared to the other 4 offices, with 44.7 and 49, respectively. Detailed maximum and minimum RH levels by Office number can be found in Appendix A.

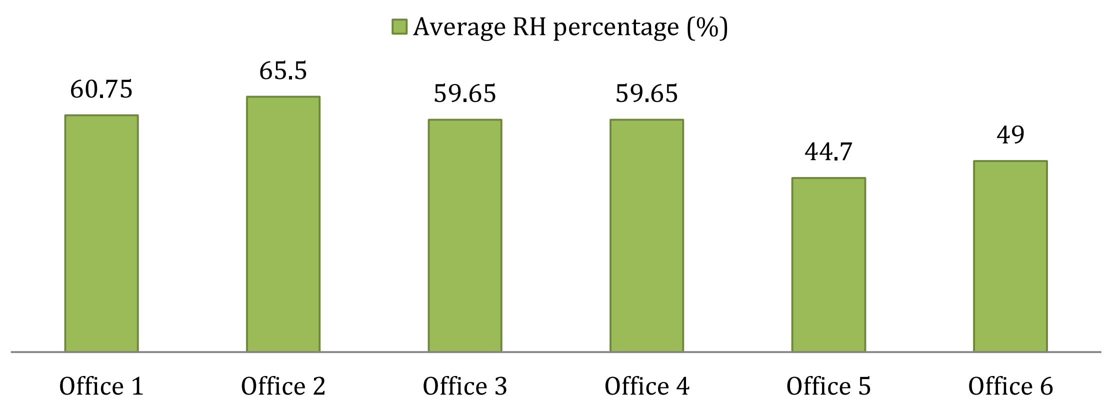

Figure 4.12: Average Relative Humidity percentage in Building B office spaces

4.2.3. Survey Results

This section presents the survey findings from the collected responses of 80 participants who worked at Buildings A and B. To start with, Table 4.1 shows the participants gender and age. Majority of the participants from both buildings were female, accounting about 53% out of 60 and 40% out of 20 in Building A and B, respectively. A total of 40 were male participants. On the other hand, majority of the participants belong to 20 - 30 age group, accounting about 37 out of 80. 29 were in 31 – 40 age group, while only 9 and 5 belong to 41-50 and 51-60 age groups.

	Building A (n=60)		**Building B (n=20)**	
	Frequency	**Percentage**	**Frequency**	**Percentage**
Gender				
Female	32	53%	8	40%
Male	28	47%	12	60%
Age Group				
20 – 30	27	45%	10	50%
31 – 40	22	36%	7	35%
41 – 50	7	12%	2	10%
51 – 60	4	7%	1	5%
61 and older	0	0	0	0

Table 4.1: Participant demographics by gender and age

Table 4.2 below shows the number of hours occupants spent working at their designated offices. Majority of the participants surveyed worked more than 7 hours at offices – 48 out of 60 in Building A and 16 out of 20 in Building B.

	Building A (n=60)		**Building B (n=20)**	
	Frequency	**Percentage**	**Frequency**	**Percentage**
Number of work hours				
0-1	0	0	0	0
2-3	0	10	0	0
4-5	2	3%	0	0
6-7	10	17%	4	20%
More than 7	48	80%	16	80%

Table 4.2: Number of hours spent in offices

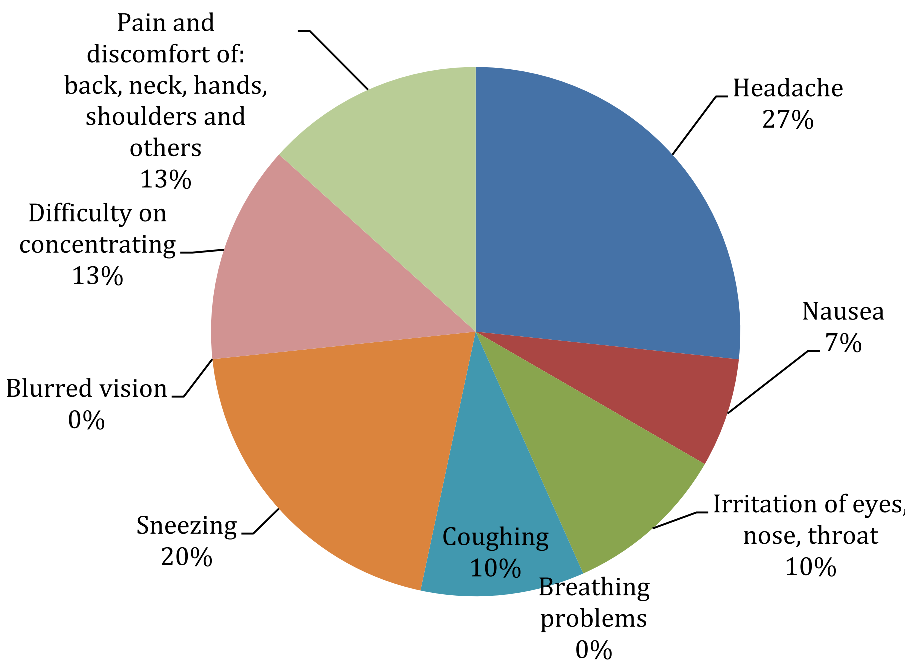

Figure 4.13: Symptoms and discomfort experienced by occupants

Figure 4.13 below shows the percentage of responses indicating the variety of symptoms and discomfort experienced by occupants within work hours at their offices. Based on the data, majority of the participants experienced headaches during their stay at their offices, accounting about (27 %) of the total responses. On the other hand, (20 %) of the participants also identified that they sometimes sneeze during their time spent at the office. Other noted symptoms include nausea (7%), irritation in the eyes, nose or throat (10%), difficulty in concentrating (13%), and pain and discomfort of back, neck, etc. (13%).

Perceptions	Yes	No
Does the temperature vary from room to room?	72	8
Are there any unusual odors?	68	12

Is the air dry?	66	14
Is the work area too warm?	45	35
Does the air seem stuffy?	51	29
Is it dusty?	50	30
Other unpleasant odors (food, perfume, etc.)?	47	33
Too little air movement?	47	33
Is the work area too cool?	44	36
Too much air movement?	29	51
Is the workspace humid?	52	28
There are any unpleasant chemical odors?	49	31

Table 4.3 : Perceptions about office environment

Table 4.3: shows the responses made by the participants regarding their office environment, with participants choosing the applicable statements. Based on their responses, many of the participants agreed that their respective offices vary in terms of temperature. Additional, the majority also noted that there were some unusual odors in their work spaces, and they tended to notice that air in the office is dry. Temperature at work area was also noted to be too warm and air seemed to be stuffy and dusty. Most of them also noted that they often spell other unpleasant odors like food, perfume and others.

4.3. Discussion

4.3.1. TVOCs Concentration

According to the ASHRAE Standard 62-1989R, the recommended concentration levels of TVOCs should not be higher than 1.0 mg/m^3. Basically, TVOC concentrations could be managed to be less than the no-effects level of 0.2 mg/m3. Converting the measurement into ppb, the recommended indoor air TVOCs concentrations should not go over 500ppb, with acceptable concentrations between 50 ppb to 325ppb OSHA (2011). Current research findings of the average concentrations of all offices spaces in Building A demonstrated that there were a lot of office spaces within the building having observed concentration levels of TVOCs exceeding such acceptable range. For example, it could be shown that all office spaces except Office 5, 6, 10 and 11 have concentration levels of TVOCs that are above the recommended range, and three of which (Office 1, 2, and 4) is much higher than the maximum level of 500ppb. On the other hand, majority of the office spaces observed by this research located in Building B are within the acceptable range set forth by the ASHRAE standards.

Further, comparing the findings of all office spaces in Building A and B regarding their average TVOCs concentration levels with the building standards and regulations set forth by the Dubai Government (n.d., 2015), all office spaces have failed to contain an acceptable minimum level of 300 mg/m^3 or approximately 75pbb. According to the building standards and regulations by the Dubai Government, the maximum acceptable limit for TVOCs in an 8-hour continuous monitoring should be less than 300 mg/m^3.

The literature has provided evidence pointing to the wide range of sources of VOC. For example, OSHA (2011) highlighted that VOCs are emitted by various products and other sources including paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids, and carbon less copy paper (p. 16). There is some equipment and office furnishings that were observed in all of the office spaces in Buildings A and B that might emit VOCs and contribute to the average TVOCs concentration levels in each of the office spaces. For example, all of the office spaces in Building A have at least 2 printing machines and office furnishings like office chairs and tables, and others. This equipment and office furnishings might have contributed to the total emission of VOCs in the office. However, because of the fact that the spot measurement did not actually measure the emissions of VOCs from this office equipment and furniture, it is inconclusive to state that these did influence the low or high concentration levels of TVOCs at the office spaces in Building A.

4.3.2. Carbon Dioxide Concentration

Carbon dioxide (CO_2) is a major product of human respiration and is utilized as an important indictor to evaluate indoor air quality, as well as the performance of ventilation systems. By generally-accepted standards set forth by the ASHRAE, the accepted level for carbon dioxide should be below 1000ppm. The findings of the concentration levels of carbon dioxide at office spaces in Building A showed that there is adequate air circulation for all the office spaces, wherein all offices have below-800ppm concentration levels. The same goes to office spaces located at Building B, in which all office spaces in this building has more air circulation compared to the majority of the offices in Building A. All offices in Buildings A and B passed the recommended level established by other standards such as the OSHA, in which the current OSHA standard for carbon dioxide is 5000 ppm as an 8-hour time-weighted average concentration (Mallinger, 2015).

On the other hand, the maximum acceptable level of carbon dioxide based on the Dubai Government's building air quality requirements and regulation is 800 ppm (Dubai Government, 2015). Office spaces at Building A had average concentration levels ranging from 342ppm to 792ppm, which means that all of them passed the Dubai standards for the maximum level of carbon dioxide concentration for an 8-hour observation period. Conversely, all of the office spaces located at Building B also had average concentration levels that are below the maximum limit or acceptance level for CO_2 concentration levels for an 8-hour monitoring period.

Reiterating the literature, a higher concentration levels of carbon dioxide within buildings is a great indicator that there is no adequate ventilation in the office

(Greiner, 1991). The findings showed average concentration levels of carbon dioxide in office spaces at Buildings A having an open window (e.g. Office 5) tend to have low levels of Carbon dioxide concentration compared to those having no windows (e.g. Offices 1, 2, 4, 8, 9, 10, and 11) or at least windows but not open (e.g. Office 3, 6, and 7). The same goes to office space at Building B, wherein all have one window left open which potentially contributed to their low average levels of carbon dioxide concentration.

4.3.3. Carbon Monoxide Concentration

Carbon monoxide (CO) is an odorless and tasteless gas that could have negative health impacts if not detected early. There are a lot of standards that set recommended and acceptable levels of concentration for carbon monoxide appropriate for office buildings as well as other indoor spaces. For example, the National Ambient Air Quality Standards or NAAQS (2008) set a standard value of 9ppm for an 8-hour average exposure time. ASHRAE Standard also followed the same standard with NAAQS, with 9 ppm for 8-hour average observation. The World Health Organization also limits based on exposure time ranging from 90 ppm for 15-minute exposure and 10 ppm for 8-hour exposure (ASHRAE, 2014). The concentration levels of all offices at Building A and B were within the acceptable concentration levels set by the standards of NAAQS, WHO and ASHRAE.

On the other hand, the maximum acceptable level for carbon monoxide for an 8-hour continuous monitoring period stipulated by the building requirement and specifications for air quality in Dubai is 9ppm or 10 microgram/m^3 (Dubai Government, 2015). This Dubai requirement of 9ppm value for the acceptable levels of ozone in building is similar to the ASREAE and NAAQS standards. This, therefore, concludes that all office spaces located at both Buildings A and B were within the concentration levels set by the standards by the Dubai Government in relation to carbon monoxide concentration levels.

Literature noted that there are various sources of carbon monoxide emissions in indoor spaces. For example, tobacco smoke, gasoline-powered equipment, gas water heaters, generators, and others. Auto, truck, or bus exhaust form garages, nearby roads or parking areas could also be a source (EPA, 2015). Considering the absence of these sources at the office spaces located in Building A and B, it could be potential that the carbon monoxide could be caused by other sources that were not observed by the current research. The low average levels of carbon monoxide concentrations observed during the 8-hour spot measurements could be caused by carbon dioxide from outside sources, but such a statement is inconclusive.

4.3.4. Ozone Concentration

Ozone (O3) is a colorless gas with a noticeable odor, which is naturally produced in the atmosphere. A wide range of standards and guidelines were created by various organizations to enforce regulatory levels relating to the ozone concentrations. For example, the NAAQS and the Canadian standards identified below 0.12 ppm as the acceptable ozone concentration, while the OSHA, WHO, NIOSH and ACGIH placed below 0.1ppm as the acceptable concentration levels of Ozone (ASHRAE Standards, 2007). The findings of the current study showed that all offices in Buildings A and B has low ozone concentrations that are below the standard values designated by the above mentioned standard organizations. This means that there is no problem in the indoor air quality at the selected sites at the University.

Conversely, the standards identified by the Dubai Government stipulating 0.06 ppm as the maximum acceptable level of concentration for ozone is much lower compared to other international standards including OSHA, NAAQS, and ASHRAE (Dubai Government, 2015). Considering the average concentration levels of ozone observed in all office spaces at both Building A and B, all of them passed the standards set by the Dubai Standards.

According to the World Health Organization, ozone is created in the atmosphere through the photochemical reactions in the presence of sunlight and other pollutants including nitrogen oxides and volatile organic compounds (WHO, 2005). Although, the concentration levels of ozone in office spaces at Buildings A and B are low, it could be potentially noted that the presence of VOCs at the office spaces might have an effect to the presence of ozone at these building spaces.

4.3.5. Temperature and Relative Humidity

According to ASHRAE standards, acceptable temperature and relative humidity ranges for indoor environments is 20-27°C and 30-60%. Findings showed that all office spaces at Building A and B have temperatures within the ASHRAE standard range. However, 3 offices at Building A have higher percentage of RH, which are above the standard level. Other offices at the same building, though within the specified range, are close to surpassing the acceptable RH percentage. The same goes to office spaces at Building B where 2 offices have higher RH percentage than the ASHRAE standards, and the other 4 are almost in the recommended upper limit of the RH percentage range.

Drawing from the Dubai Government standards and requirements for building's thermal comfort, HVAC systems must be capable of complying with the range of conditions for both temperature and relative humidity. Accordingly, it was noted that the temperature levels must be between 22.5°C to 25.5°C, while relatively humidity must range between 30% and 60% (Dubai Government, 2015). The average temperature levels at office spaces located in Building A were within the range for the acceptable temperature range, as per Dubai standards. The same goes for all office spaces in Building B, where temperature levels reached within the acceptable range. Conversely, only 7 office spaces in Building A were within the acceptable range in terms of relative humidity, whilst the other 4 spaces exceeded the acceptable range with Office 3 having 60.6% RH, Office 7 having 62.9% RH, Office 10 having 65.7% RH and Office 11 having 63.45% RH. Four office spaces in

Building B have average RH within the acceptable range of RH while the other three exceeded the limit RH percentage. Often, the principal cause of higher relative humidity in indoor office spaces is basically the breathing of occupants, wherein a person's breathing creates ¼ cup of water an hour (Energy, 2006). Though this has not been justified by the current research findings, there is still this possibility that the relative humidity levels in the office spaces in Buildings A and B could be caused by the occupants' breathing.

4.3.6. Ventilation, Natural Lighting and Occupants' Health and Productivity

To reiterate, a well-ventilated office space has noted to be a contributor to the reduced concentration levels of carbon dioxide (See section 4.3.2.). Ventilation has been sufficient in Building B, where all of the of the office spaces in this building have open windows, unlike those offices in Building A where majority of them do not have windows or have closed windows. This makes office spaces in Building B more appropriate for occupants who are in need of proper ventilation during work, therefore increasing their productivity and reducing ventilation-related health risks such as headaches, loss of focus and other issues.

Besides ventilation, natural lighting is a key indicator for a good working environment in indoor office spaces, according to the responses by the survey participants. One stated that his office is a well-lit environment, which allowed him to work properly. Surveyed office workers also recognized the value of windows in providing not just proper ventilation but also daylight. Extensive literature has supported the relationship between natural lighting and occupant's health and productivity at work. For example, the report by Edwards and Torcellini (2002) present a review of literature that acknowledged the importance of windows. The lack of windows is one of the biggest challenges in office spaces, wherein reasons for disliking windowless offices include no daylight, poor ventilation, inability to know the weather, inability to see out and have a view outside, feelings of being cooped-up, feelings of isolation and feelings of depression and tension (p. 14). Additional, natural lighting in office spaces could also have the ability to reduce the prevalence of headaches, Sad and Eyestrain, which might explain inconclusively the various health issues and workplace problems faced by the surveyed participants (see Figure 4.13) (Edwards & Torcellini, 2002).

Chapter 5

Conclusion and Recommendations

5.1. Conclusion

To repeat, the primary objective of this study was to measure the indoor air quality indicators (e.g. TVOC, Ozone, Carbon Monoxide, Carbon Dioxide, Relative Humidity and Temperature) in office spaces at Ajman University of Science and Technology. The findings showed that the majority of the office spaces at the University have average concentration levels of TVOC which were within the acceptable range based on international and local standards such as the ASHRAE, NAAQS and Dubai Building Requirement and Specifications. Although not conclusive, it could be suggested that the primary cause of the higher concentration levels of contaminates at some of the offices are the office equipment and furniture present at these spaces. Also, the lack of open windows could be the cause of higher carbon dioxide concentration levels in some of the offices, however, such causal relationship is not conclusive since the findings were only limited to measuring the TVOC and Carbon Dioxide concentration levels in office spaces and not on the measuring emissions of these potential causes.

Another important conclusion of this research study is that all office spaces have concentration levels of ozone and carbon monoxide which were within the acceptable concentration range set forth by the international and local IAQ standards. Similarly, it was also concluded that temperature levels and relative humidity in all office spaces were within the acceptable range as per international and local IAQ standards. In addition to this, it could be concluded that proper ventilation in office buildings contribute to the lower concentration levels of four indoor air quality indicators, TVOC, Ozone, Carbon Monoxide and Carbon Dioxide.

The findings and conclusions drawn from the research could provide important data for the School administration of Ajman University of Science and Technology, implicating recommendations for school indoor air quality policies which might include limiting the presence of pollutants in offices and maintaining proper ventilation through HVAC systems or simply through an open window. To note, the primary limitation of this research is that it did not explore the causal relationship between pollutant sources present in office spaces and the total concentration levels of key IAQ indicators. This could present future research implications.

5.2. Recommendations

The quality of the air depends on the people who are share the same air zone. The great ambiance of the nature of the air depends on how people control it. Everyone contributes to the air quality. Poor quality of the air is due to the lack of building management and maintenance quality. In an office setting, toxic products and unhealthy habits contribute towards the unhealthy air. Consequently, this affects not only people's health, but also performance and productivity of work.

From the findings from the case studies, the literature review provides evidence of the air quality issues in the buildings. Further investigation has shown a clear indication of the building problems in Dubai. There is a research gap in terms of the required actions to help resolve the problem for better office environment for people who work. This research will provide a set of recommendations for the indoor environment and IAQ.

5.2.1 Dubai Municipality

Dubai Municipality (DM) initiatives and objectives are essential in the overall strategy. A great amount of effort towards standards for construction contractors and consultants was implemented. To get the word out, e-publishing was introduced by Dubai Municipality to support the development of any construction. It included the following regulations regarding: green building, specifications, and an advisory note on building material specifications and safety practices.

5.2.1.1 The Compliance in Indoor Air Quality - Existing Buildings

Other buildings are subject to inspections by Dubai Municipality such as religious buildings, theatres, public health care facilities, offices, cinemas and others that may come up. The air quality should be followed by the regulations based on the technical guidelines. The buildings, which abide by these regulations will be awarded indoor air quality certificate by Dubai Municipality.

Sampling Schedule	Type of Samples	Maximum Acceptable	Sampling Duration
Initial test completed by 31 December 2011. Further testing within 5 years of last compliant test.	Formaldehyde	< 0.08 ppm	8- hour continuous monitoring (8 hour time-weighted average [TWA])
	Total Volatile Organic Compound (TVOC)	< 300 micrograms/ m³	
	Respirable Dust (<10 microns)	< 150 micrograms/ m³	
	Ozone	0.06 ppm (120 micrograms/ m³)	
	Carbon Dioxide	800 ppm (1440 microgram/ m³)	
	Carbon Monoxide	9 ppm (10 micrograms/ m³)	
	Bacteria	500 CFU/ m³ (Algar plate)	
	Fungi	500 CFU/ m³ (Algar plate)	

Figure 5.1 : Illustrates the contaminants listed
(Dubai Municipality, 2015)

A. Which should make sure that the building is suitable for occupation.
B. All air quality testing should be done through a licensed accredited company approved by Dubai Municipality. Complaints should be submitted to the DM.
C. The air quality testing equipment should come with certificates, which are approved by the DM and required by the manufacturer. In addition, these certificates can come from calibration facilities and have at least an annual calibration certificate. They are to be inspected and checked by the DM in order to ensure the authenticity of any renewal (Dubai Municipality, 2015).

5.2.1.2 HVAC Equipment Cleaning and Inspection

The HVAC equipment and systems must be maintained and all its parts must be inspected and cleaned based on the specifications approved by Dubai Municipality. Dubai Municipality must provide the evidence about the building operator as a qualified professional to handle the equipment for the job for cleaning or general inspections. The technical guidelines are an important aspect in being able to have good clean air. The maintenance must follow these guidelines (Dubai Municipality, 2015).

5.2.1.3 Environmental Tobacco Smoke

- According to the Local Order No 11- 2003, smoking is prohibited in all public areas such as: commercial buildings, hospitals, hotels, restaurants, government buildings, healthcare facilities, amusement or entertainment areas, coffee shops, and shopping centers. Dubai Municipality may mandate other places in the future.
- Areas where smoking is permitted are authorized if the area meets the criteria listed according to the Manual of Regulating Smoking in Public Places. It is issued by the DM by stature resolution no 92 -2009. Certain places prohibit smoking, but other areas allow smoking depending on the type case. Decisions are made by case-by-case basis.

- There must be a distance of 25 feet from the building of entrances of the building, doors, windows, and ventilation systems where air can enter. This rule applies to designated areas only.
- A permit is issued from the Public Health and Safety Department of Dubai Municipality every year for all places, which have the permission for smoking, is allowed. All documents and guidelines must be met along with the layouts (Dubai Municipality, 2015).

5.2.1.4 Avoid Using The High Pollutants Materials

- Low Emission Material: In Coatings and Paints: All buildings must follow the rules regarding the limits of Volatile Organic Compound (VOC). These would include not only current buildings, but also the new applications of all paints and coatings applied in buildings. These paints and coatings must be approved and certified by the Dubai Central Lab or approved by Dubai Municipality.

- Low Emission Material: In Sealants and Adhesives: The rules are similar for building adhesives, adhesive bonding primers, adhesive primers, and adhesive bonding primers, sealants, and sealant primers used in the buildings. The usage should not go beyond the guidelines of the Volatile Organic Compound (VOC). The Dubai Municipality or Dubai Central Lab must approve these materials.

- Carpet Systems: Every carpet system used must be approved and certified by the Dubai Municipality or the Dubai Central Lab for commercial buildings or public areas. However, these commercial carpets are not allowed for labor accommodation, educational facilities or any other places (Dubai Municipality, 2015).

5.2.1.5 Ventilation Systems and The Indoor Air Quality

There are minimum ventilation requirements for proper indoor air quality. These standers are provided by the ASHRAE Standard .62-2007. Occupancy density is measured by the type of activity of that area and found under that structure from the government. All of the current and new buildings must have a mechanical or mixed mode of ventilation. The requirements can be found from Dubai Municipality. In buildings, which produce toxic fumes or chemicals, there must be a separate space with special extraction systems to create a negative pressure to remove the fumes or chemicals to avoid them to diffuse in to other rooms. There must be proper storage of these products based on Dubai Municipality Requirements. Operable windows: all windows should be operable and easy to open unless there is a safety hazard and follow the Dubai Municipality Building Regulations (Dubai Municipality, 2015).

5.2.1.6 Facilitation of IAQ Throughout Construction, Operation & Maintenance Practices, and Good Design

IAQ is important and easy to achieve during building construction, but also during the entire lifespan of the building if people pay attention to the source of the VOC. The designer may select building products, which do not produce noxious or irritating odors. The entry way may be built with systems, which catch and hold dirt particles. During maintenance, the cleaning staff can also avoid creating IAQ issues by using products, which are less toxic or avoid them if possible. HVAC systems separate the kitchen and other operations from the people inhabiting the place. The Operations and Maintenance will make sure they can control the level of contaminants floating from one air space to another (Dubai Healthcare City, 2013)**.**

5.2.1.7 Prevent and Block Airborne Mold, Bacteria, and Other Fungi

- An HVAC and building design can prevent mold and fungi
- Interior humidity conditions should be managed based on needs by the HVAC

regardless of the wide range of outdoor conditions

- The HVAC must be able to dehumidify at 1%. Humidity Ratio should be able to be managed in extreme or below average conditions
- It is important for every building to consider how to prevent moisture infiltration
- Monitor the moisture condition from a leak or floor (Dubai Healthcare City, 2013).

5.2.1.8 Assure The Comfort and Acoustic Privacy

Contaminant isolation is the key for the controlling odors that unruly and proper product selection could help avoid these issues. It is essential to minimize the noise through the use of sound absorbing materials, high and sound transmission, ceilings, and equipment sound isolation. The sound masking systems are an effective tool in reducing the interference from distracting office noise from the surrounding environment. Some HVAC systems produce a white noise, which helps in reducing the distracting sounds. As a result, there is no need for sound masking systems. Furthermore, when installing ventilation systems, it is important to avoid using small diameter ducts with high velocity airflow, as it is ineffective (Dubai Healthcare City, 2013).

5.2.2. Renovation in Work Space

Serious renovation work should commence only after working hours to reduce the negative impact on the people who are working. The work that is being done should be isolated if this is not possible. For example, during construction, plastic sheeting to avoid cross contamination is minimized. The air supply should also be separated along with the use of toxic substances. The use of toxic substances should be used only after people have gone home. Temporary exhaust systems may be necessary until the work is completed. These unhealthy particles should be blocked so they do not enter the rooms next door. Air filters of the MVAC system need to be inspected on a regular basis and changed if necessary. In fact, they should be changed often to avoid over load of dust (Dubai Healthcare City, 2013).

5.2.3 Office Equipment Selection

Built in gas filtration should be a priority when it comes to selection of office equipment. For example, installing photographic processing equipment and gas appliances should have a specific pollution control with the built in gas filters and comply with the right emission standards. The Environmental Protection Agency (EPA) recommends the following approaches:

- Examine data on emissions of the products from the manufacturers
- Obtain a manufacturer testing report regarding the emissions for the five major VOCs. They should have a toxicity of 5mg/m3 in the chamber testing conditions
- Obtain the procedures of handling and storing the product
- Obtain the information on ozone emission rates for office equipment
- Equipment's with VOC concentrations by 500 µg/m3 or more should be discarded.
- Office machinery which increases ozone concentrations by more than 19.6 µg/m3 (0.01 ppmv) should be discarded or avoided in purchase (Dubai Healthcare City, 2013).

5.2.4 Air Quality is A Mutual Responsibility

Poor air quality is always due to inadequate HVAC design in buildings. It is the building management responsibility. Building may experience poor air quality due to the breakdown of equipment , therefore maintenance is required. The building occupants may be also the reason for the poor air quality or equipment maintenance needs. These air quality issues are usually coinciding with comfort problems. Factors such as humidity, temperature, or air movement in the space, which is not enough, may contribute to the problem. However, when people suffer from other symptoms that appear to be from VOCs, it is not always the case like headaches (EPA, 1997).

5.2.5 Future Recommendations

The research provides a comprehensive detailed report of the indoor air quality condition in UAE office buildings. There have been certain variables laid out to test and examine the conditions of the indoor environment. The health condition of the office spaces is an important part of the research apart from the already known facts about the building locations, human activities, and environmental surroundings. Indoor air quality is an important part of the research area, which should incorporate the age of the space users and sensitivity to the pollutants concentrations. Other commercial industries should be given more attention to make sure that the environment is a positive productive one for all employees as it should be safe and healthy.

It is important to take the data that is collected and utilize it to do the analysis using measurements, surveys, or interviews to get a clear picture of the situation. The reason for great detail is the fact that some conditions that people suffer from can be exposure to pollutants from other spaces such as visiting clinics, hospitals, or other residences. These symptoms occur even after the person leaves an indoor environment. Therefore, an intensive study of Dubai's indoor environment could help shed the light on the conditions of industrial, commercial and residential spaces.

Other studies can be arranged to focus on the offices in specific areas in Dubai, in order to build a database in regards to the pollution level in commercial areas. The data would asset in helping setting rules and regulations for any new business in the area. Also, the weather condition is an important part in design to help in making sure there is a sustainable indoor space, which is healthy for people.

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Appendix A

Spot Measurements for Offices Building A

Office .1	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 2nd floor	Min:890	Min:500	Min:.05	Min:0.4	Min:22.1	Min:49.5
	Max:968	Max:757	Max:.05	Max:0.5	Max:22.6	Max:51.2
	Ave:929	Ave:682.5	Ave:.05	Ave:0.45	Ave:22.35	Ave:50.35

Office.2	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 2nd floor	Min:646	Min:141	Min: .05	Min:0.1	Min:22.2	Min:56.7
	Max:889	Max:544	Max: .05	Max:0.3	Max:22.6	Max:62.1
	Ave:767.5	Ave:342.5	Ave: .05	Ave:0.2	Ave:22.4	Ave:59.4

Office.3	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 2nd floor	Min:340	Min:368	Min: .04	Min:0.1	Min:22	Min:58.8
	Max:542	Max:435	Max: .05	Max:0.1	Max:22.9	Max:62.4
	Ave:441	Ave:401.5	Ave:.045	Ave:0.1	Ave:22.45	Ave: 60.6

Office.4	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 2nd floor	Min: 438	Min: 542	Min:0.03	Min:01	Min: 20.9	Min: 54.7
	Max: 610	Max: 721	Max: .04	Max: 0.3	Max: 21.5	Max:63.1
	Ave: 524	Av: 631.5	Av: .035	Ave: 0.2	Ave: 21.2	Ave: 58.9

Office.5	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 172	Min: 277	Min:0.05	Min: 0.1	Min: 21.6	Min: 39.3
	Max: 267	Max: 500	Max: .06	Max: 0.2	Max: 24.1	Max: 50.1
	Ave: 219.5	Av: 388.5	Ave:.055	Ave: 0.15	Ave: 22.85	Ave: 44.7

Office.6	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 2nd floor	Min: 206	Min: 404	Min:0.04	Min: 0.1	Min: 23	Min: 44.9
	Max: 410	Max: 449	Max: .05	Max: 0.3	Max: 24.7	Max: 53.1
	Av:e 308	Av: 426.5	Ave:.045	Ave: 0.2	Ave: 23.85	Ave: 49

Office.7	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 309	Min: 544	Min:0.04	Min: 0.1	Min: 21.7	Min: 61.2
	Max: 352	Max: 729	Max: .05	Max: 0.3	Max: 23.5	Max: 64.6
	Ave: 330.5	Av: 636.5	Av: .045	Av: 0.2	Av: 22.6	Av: 62.9

Office.8	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 300	Min: 600	Min:0.04	Min: 0.2	Min: 22.5	Min: 52.4
	Max: 450	Max: 757	Max: .05	Max: 0.3	Max: 23.7	Max: 57.7
	Ave: 375	Av: 678.5	Ave:.045	Ave: 0.25	Ave: 23.1	Ave: 55.05

Office.9	**TVOCs (ppb)**	**Carbon Dioxide (ppm)**	**Ozone (ppm)**	**Carbon Monoxide (ppm)**	**Temperature (Celsius)**	**Relative Humidity %**
AUSTN Ground floor	Min: 306	Min: 682	Min:0.04	Min: 0.9	Min: 24.7	Min: 53.2
	Max: 437	Max: 902	Max: .05	Max: 1	Max: 25.3	Max: 53.8
	Ave: 371.5	Ave: 792	Ave:.045	Ave: 0.95	Ave: 25	Ave: 53.5

Office.10	**TVOCs (ppb)**	**Carbon Dioxide (ppm)**	**Ozone (ppm)**	**Carbon Monoxide (ppm)**	**Temperature (Celsius)**	**Relative Humidity %**
AUSTN Ground floor	Min: 249	Min: 338	Min:0.01	Min: 0.1	Min: 21.6	Min: 63
	Max: 366	Max: 533	Max: .04	Max: 0.7	Max: 23	Max: 68.4
	Ave: 307.5	Av: 435.5	Ave:.025	Ave: 0.4	Ave: 22.3	Ave: 65.7

Office.11	**TVOCs (ppb)**	**Carbon Dioxide (ppm)**	**Ozone (ppm)**	**Carbon Monoxide (ppm)**	**Temperature (Celsius)**	**Relative Humidity %**
AUSTN Ground floor	Min: 233	Min: 402	Min:0.01	Min: 0.1	Min: 22.6	Min: 62.8
	Max: 342	Max: 615	Max: .03	Max: 0.4	Max: 22.9	Max: 64.1
	Ave: 287.5	Av: 508.5	Ave: .02	Ave: 0.25	Ave: 22.75	Ave: 63.45

Spot Measurements for Offices Building B

Office.1	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 247	Min: 260	Min: .01	Min: 0.2	Min: 20.8	Min: 58.6
	Max: 390	Max:405	Max: .02	Max: 0.4	Max: 21.2	Max: 62.9
	Ave: 381.5	Av:332.5	Ave: .015	Ave: 0.3	Ave: 21	Ave: 60.75

Office.2	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 200	Min: 282	Min: 0.01	Min: 0.2	Min: 19.8	Min: 62.7
	Max: 343	Max: 475	Max: .02	Max: 0.4	Max: 20.9	Max: 68.3
	Ave: 271.5	Av: 378.5	Ave: .015	Ave: 0.3	Ave: 20.35	Ave: 65.5

Office.3	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 272	Min: 417	Min: 0.01	Min: 0.5	Min: 22.8	Min: 57.7
	Max: 388	Max: 557	Max: .04	Max: 1	Max: 23.6	Max: 61.6
	Ave: 330	Ave: 487	Ave: .025	Ave: .75	Ave: 23.2	Ave : 59.6

Office.4	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 200	Min: 400	Min: .01	Min: 0.5	Min: 22.8	Min: 57.7
	Max: 301	Max: 520	Max: .02	Max: .6	Max: 23.6	Max: 61.6
	Ave: 250.5	Ave: 460	Ave: .015	Ave: 0.55	Ave: 23.2	Ave: 59.65

Office.5	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 172	Min: 277	Min: .05	Min: 0.1	Min: 21.6	Min: 39.3
	Max: 267	Max: 500	Max: .06	Max: 0.2	Max: 24.1	Max: 50.1
	Ave: 219.5	Av: 388.5	Ave: .055	Ave: .15	Ave: 22.85	Ave: 44.7

Office.6	TVOCs (ppb)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Temperature (Celsius)	Relative Humidity %
AUSTN 1st floor	Min: 206	Min: 404	Min: .04	Min: 0.1	Min: 23	Min: 44.9
	Max: 410	Max: 449	Max: .05	Max: 0.3	Max: 24.7	Max: 53.1
	Ave: 308	Av: 426.5	Ave: .045	Ave: 0.2	Ave: 23.85	Ave: 49

Appendix B

According to the survey, this questionnaire has been gathered by using different sources such as ASHRAE and literature review from different papers.

INDOOR ENVIRONMENTAL QUALITY SURVEY

(ALL OF YOUR ANSWERS WILL BE TREATED IN TH STRICTEST CONFIDENCE)

Work Place Information

Name(Optional): …………………

Survey Date: …………………....

Birthdate: …………………………..…

Building Name: …………………..

Job title: ……………………………..…

Floor (G/1st /other): ……………..

1. Gender?

- Female
- Male

2. How long have you been in the building?

- Years --------------
- Months ------------

3. How many hours do you stay at the office?

- 0-1
- 2-3
- 4-5
- 6-7
- More than 7

4. In a typical week, how many days do you work in this building?

- 5 days a week
- More than 5 days a week

5. How many Colleagues work at the location where you work?

- ----------------------

6. What is the flooring material in your workstation?

- Carpet tiles

- Marble
- Other material

7. Overall, how clean is your workspace?

- Extremely clean – Cleaned every day
- Moderately clean – Cleaned twice a week
- Slightly clean – Cleaned every month
- Not at all clean – Cleaned 4 times a year

8. Please describe the light level in your workstation area?

- ----------------------------

9. Within your workspace, is there any glare (light reflection):

- Nothing – no glare at all
- Sometimes – morning time or Evening time
- Very often - morning time and Evening time

10. Overall, how comfortable did you find the furniture (table and chair) in your workspace?

- Extremely comfortable
- Slightly comfortable
- Not at all comfortable

11. Do you use computer? If yes how many hours per day?

- None
- 1 to 3 hours
- 4 to 6 hours
- 7 to 9 hours
- 10 hours or more

12. Do you wear glasses when you use the computer?

- Yes
- No

13. Do you use a glare screen on your computer?

- Yes
- No

14. Do you have a window in your office? If yes how many?

- Yes, ------------
- No

15. If there is a window in your workspace, how far (in feet) is the closest window from your desk chair?

- Feet
- No window

16. How many of the following equipment's (photocopier, printer and scanners) do you have it in your work space ?

- Less than 5
- 5 to 10
- More than 10

17. Have there been any alterations in your workspace recently? E.g: new location, renovation, cleaning?

- Yes
- No

18. Are you satisfied with your office arrangements?

- Extremely satisfied
- Slightly satisfied
- No at all

Information About Health and Well-Being

Symptoms and patterns
1.Check all the symptoms or discomfort you are experiencing:

- Headache
- Nausea
- Irritation of eyes, nose, throat
- Breathing problems
- Coughing
- Sneezing
- Blurred vision
- Difficulty on concentrating
- Pain and discomfort of: back, neck, hands, shoulders and others

2. When do you notice these and how often do they occur?

- ---------------------------

3. On average, when you notice the symptoms, how long have you been at work?

- Less than 1 hour
- 2 to 4 hours
- More than 4 hours
- 1 day
- After ------days

4. When do the symptoms go a way?

- Over night
- After a week away
- Rarely/never

5. Has the pain or discomfort caused you to take time off work?

- Yes
- No

6. Do you IAQ (Indoor Air Quality) symptoms occur only when you are at work?

- Yes
- No

7. Are you a smoker?

- Never Smoked
- Former Smoker
- Current Smoker

8. How do you define the air in your workspace?

- Fresh
- Stuffy
- Dusty
- Moldy

9. Suspected and potential causes:

Check any of the following that are true:

- Are there any unusual odors?
- Does the air seem stuffy?
- Is the air dry?
- Is it dusty?
- Is the work area too warm?
- Is the work area too cool?
- Is the workspace humid?
- Too much air movement?
- Too little air movement?
- Does the temperature vary from room to room?
- There are any unpleasant chemical odors?
- Other unpleasant odors (food, perfume, etc.)?

10. What is your satisfaction with the indoor air quality in this office?

- Very satisfaction
- Satisfied
- Slightly satisfied
- Dissatisfied
- Very dis satisfied

11. What do you believe may be the cusses of your IAQ problem?

- ---

12. Have you already tried seeking medical help? For instance, going to the doctors?

- Yes
- No

13.If yes, what were your most usual complaints? Please specify:

- ______________________________

14.Did the doctor say anything negative about your health condition?

- Yes, please specify: ____________________
- No

15.Was there any particular medical diagnosis that alarmed you?

- Yes, please specify: __________________
- No

16.What did you do after visiting the doctor and talking about your health complaint?

- Rest and take prescribed medication
- Take more laboratory tests
- Seek second opinion from other health physician
- Others, please specify: _______________________