INDOOR AIR QUALITY AND POTENTIAL HEALTH RISKS IN THE FOOD REFINERY IN THE HOT-HUMID TROPICS

WONG CHIANG ANN

UNIVERSITI SAINS MALAYSIA

2018

INDOOR AIR QUALITY AND POTENTIAL HEALTH RISKS IN THE FOOD REFINERY IN THE HOT-HUMID TROPICS

by

WONG CHIANG ANN

Thesis submitted in fulfilment of the requirements

for the degree of

Master of Science

August 2018

ACKNOWLEDGEMENT

Firstly, I would like to express my deepest gratitude to my main supervisor, Dr. Mardiana Idayu Ahmad for her excellent guidance and assistance. Besides, I also wish to thank my co-supervisors, Assoc. Prof. Dr. Yusri Yusup and Dr. Sheikh Ahmad Zaki Shaikh Salim for their constructive advice.

Secondly, I would like to thank my beloved parents, siblings and my friends for their patience, understanding, continuous support and encouragement. Besides, the help from everyone involved in this study is also much appreciated including management and workers from the food refinery, lecturers, staff, postgraduate students, undergraduate students, lab assistants and others.

Last but not least, I wish to acknowledge the significant and meaningful financial assistance of MSM Fellowship from MSM Holdings Berhad and Kuok Foundation Berhad.

Thank you to all of you, I would have failed without you all and I appreciate it from the bottom of my heart.

Wong Chiang Ann, August 2018

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Air-conditioner
ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CCOHS	Canadian Centre for Occupational Health and Safety
DOSH	Department of Occupational Safety and Health
HKEPD	Hong Kong Environmental Protection Department
HKIAQO	Hong Kong Indoor Air Quality Objectives
IAQ	Indoor air quality
IARC	International Agency for Research on Cancer
ICOPIAQ	Industry Code of Practice on Indoor Air Quality
ICP-OES	Inductively coupled plasma optical emission spectrometry
MDEQ	Michigan Department of Environmental Quality
MSDS	Material Safety Data Sheets
MVAC	Mechanical ventilating and air-conditioning
NEA	National Environment Agency
NIOSH	National Institute of Occupational Safety and Health
NOAEL	No observed adverse health effects level
LOAEL	Lowest observed adverse health effects level
OSHA	Occupational Safety and Health Association
PPE	Personal protective equipment
SBS	Sick building syndrome
TSA	Trypticase soy agar

USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

LIST OF SYMBOLS

AT	Average time
C	Concentration
CR	Carcinogenic risk
EC	Exposure concentration
ED	Exposure duration
EF	Exposure frequency
ET	Exposure time
HQ	Hazard quotient
IUR	Inhalable Unit Risk
RfC	Reference concentration
UFs	Uncertainty factors

KUALITI UDARA DALAMAN DAN POTENSI RISIKO KESIHATAN DI KILANG PENAPISAN MAKANAN DI KAWASAN TROPIKA PANAS DAN LEMBAP

ABSTRAK

Kualiti udara dalaman yang buruk akan mengakibatkan masalah kesihatan maka menjejaskan produktiviti syarikat. Masalah kesihatan yang paling kerap dilaporkan dalam industri makanan ialah penyakit pernafasan yang disebabkan oleh kualiti udara dalaman yang buruk. Kajian ini bertujuan untuk mengenal pasti kualiti udara dalaman dan kepekatan elemen dalam zarahan di kilang penapisan makanan sambil menilai risiko kesihatan yang mungkin diakibatkan supaya strategi untuk meminimumkan risiko boleh dikemukakan. Satu pemantauan kualiti udara dalaman telah dijalankan di lapan lokasi dalam lingkungan kawasan kilang penapisan makanan. Sembilan parameter termasuk parameter fizikal, kimia, biologi dan penunjuk pengudaraan telah dipantau menggunakan cara pemantauan semasa, cara gravimetrik dan cara kiraan plat. Kepekatan elemen PM_{10} kemudiannya diuji menggunakan ICP-OES dan risiko kesihatan telah dikira. Keputusan menunjukkan bahawa suhu, pergerakan udara, karbon dioksida (CO_2) dan zarahan bersaiz 10 mikron (PM_{10}) di tujuh lokasi telah melebihi piawai disebabkan pengaruh daripada suhu luaran, kipas mekanikal dan angin semula jadi, kadar pengudaraan yang tidak mencukupi, penetapan sistem penyaman udara, pelepasan daripada mesin dan pelepasan daripada habuk makanan. Untuk kepekatan elemen dalam PM_{10}, Ca, Mg Ni, Zn dan Se telah dikesan. Sumber elemen yang dikesan berkemungkinan berasal daripada makanan dan aktiviti manusia termasuk trafik dan pencemaran industri. Untuk parameter yang telah melebihi piawai, impak kesihatan berkemungkinan akan timbul semasa pendedahan kepada suhu yang tinggi dan kepekatan zarahan yang

tinggi. Untuk risiko kesihatan yang berpotensi, Ni didapati boleh memberi risiko kesihatan sama ada bukan karsinogenik ataupun karsinogenik terhadap manusia di dalam bangunan. Strategi untuk meminimumkan risiko yang merangkumi tanggungjawab pihak pengurusan syarikat dan pekerja telah dikemukakan.

INDOOR AIR QUALITY AND POTENTIAL HEALTH RISKS IN THE FOOD REFINERY IN THE HOT-HUMID TROPICS

ABSTRACT

Poor indoor air quality will lead to health problems thus reducing the productivity of a company. The most common health problem reported in the food industry is respiratory diseases which can be caused by poor air quality. This study aims to ascertain the indoor air quality and elemental concentrations of particulate matter in a food refinery. Potential risks were evaluated to recommend appropriate risk minimisation strategies. An indoor air quality monitoring was carried out at eight sampling locations within the premises of a food refinery. Nine parameters including physical, chemical, biological parameters and the ventilation indicator were monitored using the methods of real time monitoring, gravimetric and plate count. The results were evaluated against standards. Particulate matter 10 micron (PM_{10}) was analysed for elemental concentrations using ICP-OES and health risks were determined. Air temperature, air velocity, carbon dioxide (CO_2) and PM_{10} at seven sampling locations exceeded the standards due to influence of outdoor air temperature, mechanical fan and natural wind, insufficient ventilation rate, air-conditioner settings, machinery emissions and food dust emissions. For elemental concentrations in particulate matter, Ca, Mg, Ni, Zn and Se were detected. The sources of detected elements could be from the food and human activities including traffic and industrial pollution. For the parameters that exceeded the standard, health impacts might stem from the exposure to high air temperature and high concentration of particulate matter. For potential health risk, Ni was found to pose both non-carcinogenic and carcinogenic health risk to the building occupants. Different

risk minimisation strategies were addressed which covered the responsibility of management of company and workers.

CHAPTER 1

INTRODUCTION

1.1 Background

Indoor air quality is the quality of air within and around buildings or structures. It relates to the health and comfort of the building occupants (USEPA, 2017a). Indoor air quality can be determined by measuring physical, chemical and biological parameters as well as ventilation indicators (DOSH Malaysia, 2010).

Different indoor air quality standards have been published and enforced around the world. Indoor air quality is dependent on the number of occupants, type of ventilation, interrelations between parameters and infiltration of outdoor pollutants. Poor indoor air quality can lead to detrimental health effects which might drive to low working efficiency and therefore, become a financial burden to the employer (Jones, 1999; Zhang & Smith, 2003; Franklin, 2007; Birnbaum et al., 2002; Horr et al., 2016). Potential health risks is the degree of likelihood that exposure to a hazardous substance may damage or will damage the health of the exposed person. When levels of the parameters are beyond the recommended range set in the standards, health impacts might emerge. The evaluation of health risks can be performed through risk assessments (Taner et al., 2013).

There has been a number of indoor air quality studies conducted in different types of buildings. Researchers studied the indoor air quality in offices, schools, restaurants, shopping malls, museums, residential buildings and hospitals (Lee et al., 2002; Saraga et al., 2011; El-Sharkawy & Noweir, 2014). Human activities affect the indoor air quality which is sometimes dependent on the category of the building. Most studies carried out were focused on particular building categories but not on a specific industrial activity which can consist of different building categories.

In this work, the indoor air quality of a food refinery was comprehensively studied. The food refinery is a food factory where raw food is refined. The complex processes during food refining might greatly affect the indoor air quality. High number of workers and long twenty-hour operational hours constantly expose the workers to poor indoor air quality. However, there is limited information on indoor air quality and potential health risks in the food refinery. In the food industry, the literature mainly focuses on microbe instead of indoor air quality (Salustiano et al., 2003; Tsai & Liu, 2009; Awad, 2007). Recently, most of the previous health risk evaluations focused on outdoor air and not on indoor air and not specific to the human activities within building categories in a food refinery (Hu et al., 2012; Kurt-Karakus, 2012; Wang et al., 2016). By monitoring and evaluating the indoor air quality and potential health risks available in different building categories of the food refinery, the quality of indoor air can be ascertained and the risks borne by the building occupants can be evaluated. Consequently, strategic steps can be taken to minimise the potential risks to the occupants.

1.2 Problem Statement

Indoor air quality is important because most people spend more time indoors as compared to outdoors. Their health might be affected due to pollutants present in the indoor air. The diseases caused by poor indoor air quality, like respiratory diseases and Sick Building Syndrome (SBS), can reduce working efficiency and cause financial burden to the employer. Different human activities and environmental conditions can affect the indoor air quality differently and the indoor air quality is even more polluted in industrial buildings.

Even though indoor air quality studies have been done in different countries in different building types and geographical areas, health impacts from indoor pollutants and health risks from particulate matter and its elemental contents, there is still limited information on the indoor air quality in the different building types of the food industry. Food industry is one of the industries characterized by high exposure to occupational allergens. Among different types of diseases, respiratory disease is the most commonly reported disease in the food industry which is caused by poor air quality. The unknown state of the indoor air quality of the food refinery industry, mainly due to management and confidentiality issues, could pose significant harm to the building occupants. It is crucial to determine the solutions and steps to be taken if health impacts and health risks are observed. This study aims to determine the indoor air quality of a food refinery and evaluate the potential health risks. This study also suggests strategies and practices to minimise the health risks associated with poor indoor air quality.

1.3 Research Objectives

This aim of this research is to determine the indoor air quality of the food refinery and evaluate the potential health risks. Hence, the objectives of this research are:

1. To discern the indoor air quality of the food refinery.
2. To ascertain the elemental concentrations of particulate matter.
3. To evaluate the potential risks caused by the indoor air quality and recommend appropriate risk minimisation strategies.

1.4 Research Questions

The research questions of this study are:

1. What is the indoor air quality in the different types of buildings within the premises of the food refinery?
2. What are the elemental concentrations in the particulate matter?
3. Does the monitored indoor air parameters and elemental concentrations pose potential health risks to the building occupants and how can the health risks be minimised?

1.5 Research approach and methods

Research approach and methods used are divided into four stages which are data collection, laboratory analysis, data analysis and statistical analysis. Data collection includes walkthrough inspection and field sampling. Laboratory analysis includes analysis of multi elements concentration level using instrument. Data analysis includes comparisons with standards and calculation of hazard quotient and carcinogenic risk. Statistical analysis includes analysis using statistical graphics and correlations of measured parameters. Risk minimisation strategies were addressed to suggest ways to improve indoor air quality in the company.

1.6 Scope of Research

This research involved field data collection through monitoring campaigns, laboratory analyses and data analyses of a food refinery. For the field data collection, eight sampling locations, that are the administrative office, the engineer office, the screening station, the raw material house, the processing area, the warehouse, the packing department and the laboratory were chosen. Indoor air quality monitoring was carried in selected days between April 2016 and September 2016. The climate of the sampling locations was hot-humid tropics and maintained the same for whole year. The weather condition during sampling periods was hot weather condition and did not involve raining weather condition. Information including main materials of the buildings, the height and volume of the sampling locations is not covered in this research. Parameters like air temperature, relative humidity (RH), air velocity, carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOC), particulate matter 10 micron (PM_{10}), particulate matter 2.5 micron ($PM_{2.5}$) and total bacterial counts (TBC) were monitored.

For the laboratory analysis, PM_{10} were collected and analysed. The raw food sample and refined food sample were also collected and analysed for elemental concentrations. Twenty one elements including arsenic (As), beryllium (Be), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), strontium (Sr), titanium (Ti), thallium (Tl), vanadium (V) and zinc (Zn) were analysed using inductively-coupled plasma optical emission spectrometry (ICP-OES).

For the data analysis, correlations between the monitored parameters were determined. Comparisons of the monitored parameters to five different indoor air quality standards were carried out. The potential health effects from the monitored parameters and the potential health risks due to the elements in particulate matter were determined. Potential health risks were determined through the computation of hazard quotient (HQ) and carcinogenic risk (CR).

Due to the confidentiality agreement between the researcher and the management of the food refinery, several details of this research were not reported and displayed, such as the company name, its exact location, overall layout plan of the premises, sampling photos and the type of food refinery.

1.7 Importance of Research

This research helps to identify the indoor air quality in a food refinery. The associations between indoor air quality and food refining activity can be determined. The influence of food refining activity on various indoor air parameters in different building categories within the food refinery premises can be understood. All these findings will significantly contribute to the knowledge in the field of indoor air quality of the food industry. This information is important to understand the safety of building occupants and current risks that they might face and assist the management to initiate necessary action. Besides, this study can also help the company to participate in Green Building Index (GBI) accreditation since indoor air quality is one of the aspects in GBI.

1.8 Thesis Outline

For this thesis, there are a total of six chapters. These chapters will cover the introduction of this research, the literature review, the methods used, the data analysis methods, the discussions on the results, the conclusions and also future recommendations.

Chapter 1 gives an introduction of this research including the background, problem statement, research questions, research objectives, scope of research, importance of research and this thesis outline.

Chapter 2 highlights literature which covers the field of indoor air quality including significance of indoor air quality, parameters in indoor air quality and studies of indoor air quality in different building categories. Under parameters of indoor air quality, air temperature, RH, air velocity, CO_2, CO, TVOC, PM, TBC and studies of indoor air quality in different building categories (e.g., office, manufacturing area, laboratory and food industry) are covered. Local and international standards of indoor air quality, potential health risks are also discussed. Under potential health risks, steps in risk assessment (e.g., hazard identification, dose response assessment, exposure assessment and risk characterisation), studies on health risks of elements in particulate matter are covered.

Chapter 3 details the materials and methods including the flow chart of methodology, description of study area, field data collection, analysis of elements in particulate matter, statistical analysis and health risk evaluation. Field data collection comprises walkthrough inspection, real-time monitoring, gravimetric method, plate count method and validation of methods. Analysis of elements in particulate matter comprises of sample handling, reagents, apparatus and instrument and analytical procedures. Data analysis explains the calculation of the hazard quotient and carcinogenic risk.

Chapter 4 discusses the analyses of the indoor air quality of the food refinery including concentrations of monitored parameters, comparisons with existing standards and analysis of potential health risks from monitored parameters, associations of monitored parameters including correlational analysis of monitored concentrations, elemental analysis of particulate matter and food samples including analysis of potential health risks from elements in particulate matter.

Chapter 5 discusses the risk minimisation strategies which cover the strategies to comply with the Industry Code of Practice on Indoor Air Quality 2010 and good practices in controlling indoor air quality.

Chapter 6 discusses the conclusions drawn from this study. In addition, future recommendations are also included in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor Air Quality

Indoor air is defined as the air inside a building, including air which is within a room and air which is removed from a room by mechanical means (DOSH Malaysia, 2010). Indoor air quality refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants (USEPA, 2017a). An average adult breathing rate is from 10 to 60 L min^{-1} depending on the activities carried on (Holmes, 1994) and thus, indoor air is a critical aspect of the well-being of the occupants.

2.1.1 Significance of Indoor Air Quality

Indoor air quality is important because most people tend to spend more time indoors as compared to outdoors. A study suggests that the average person spends more than 80% of the day in an indoor environment (Robinson & Nelson, 1995). Other studies suggest that people can even spend more than 90% of their time indoors (Lee & Chang, 2000; USEPA & USCPSC, 1995). Recently, increasing attention has been given to the indoor air quality, due to the health problems resulting from poor indoor air quality. Studies found that different health impacts might occur due to the different pollutants present in the indoor air (Jones, 1999; Zhang & Smith., 2003; Franklin, 2007). The health impacts are mostly related to the Sick Building Syndrome (SBS), respiratory diseases and cardiovascular diseases. Meanwhile, studies also suggest that indoor pollutant levels might be greater than outdoor pollutant levels (Chao & Wong, 2002; Montgomery & Kalman, 1989; USEPA & USCPSC, 1995). This is due to outdoor air pollutant sources can degrade indoor air quality, in addition to indoor sources, thus making indoor air even more polluted. The diseases caused by poor indoor air quality like respiratory diseases can cause financial burden to the employer (Birnbaum et al., 2002). Working efficiency will drop due to the time lost from work. A review study shows that productivity loss due to poor air quality was well documented in a number of studies (Horr et al., 2016). On average, performance losses due to poor indoor air quality were estimated at 2 to 4% (USEPA, 2017b).

2.1.2 Indoor Air Quality Parameters

Parameters involved when measuring indoor air quality can be divided into physical parameters, chemical parameters, and biological parameters as well as ventilation indicator (DOSH Malaysia, 2010). Physical parameters include air temperature, RH and air velocity; chemical parameters include CO, TVOC and particulate matter (PM); biological parameter such as TBC; ventilation indicator is represented by CO_2.

Physical Parameter: ***Air Temperature***

Temperature means the measured amount of heat in a place or a body (Cambridge Dictionary, 2017a). In indoor air quality, the air temperature monitored is referring to the air temperature of the air surrounding the occupant. The air temperature here also refers to dry bulb temperature which is determined by ordinary thermometer without taking moisture and radiation into account and is always reported in weather reports (Shelton & Bodman, 1997). The recommended temperature range in Malaysia is 23°C to 26°C (DOSH Malaysia, 2010). The unit of air temperature is usually expressed in °C or °F. Air temperature is one of the microclimate parameters. Microclimate means a local atmospheric region where the climate differs from surrounding area (Ragheb et al., 2016). A research done by Jamaludin et al. (2014) demonstrated that variation in indoor thermal environment was affected by temperature, relative humidity (RH) and air velocity in a tropical climate. Besides, air temperature is one of the parameters in determining thermal comfort (ASHRAE, 2004). Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 2004). When the occupants complained of feeling too cold or too hot, there is thermal discomfort. Several studies have identified the relationship between thermal comfort and working performance. A study by Cui et al. (2013) found that the optimum air temperature range for best performance is between 22°C and 26°C and that hot environments have a negative effect on the latter (Lan et al., 2011a). Another study done by Tanabe et al. (2015) shows that individual thermal satisfaction was positively correlated to worker performance. SBS was found to be associated with air temperature (Lan et al., 2011b; Seppanen & Fisk, 2011). Significant health effects will only occur when the air temperature is too high and the human body can no longer cope with the additional heat. Significant health effects that are heat-related are heat edema, heat rashes, heat cramps, heat exhaustion, heat syncope and heat stroke (CCOHS, 2017).

Physical Parameter: ***Relative Humidity (RH)***

The RH of the air is the amount of water that is present in the air compared to the greatest amount it would be possible for the air to hold at that temperature (Cambridge Dictionary, 2017b). The recommended RH range in Malaysia is 40% to 70% (DOSH Malaysia, 2010). RH is one of the microclimatic parameters together with air temperature (Ragheb et al., 2016). Besides, RH is one of the parameters in determining thermal comfort (ASHRAE, 2004). Two studies suggested that building occupants were thermally comfortable at wide RH range and the optimum RH was at 73% and 78% respectively corresponding to the optimum comfort temperature in the hot humid tropics (Djamila et al., 2014; Chinedu et al., 2016). It reacts with other parameters, like air temperature and air velocity in a complex way when determining thermal comfort (Davis et al., 2016). In term of health impacts, a study shows that low RH can cause the increase of eye irritation symptoms and dry eyes (Wolkoff & Kjaergaard, 2007). The same study also shows that low RH might cause elder people to be susceptible to respiratory diseases. In addition, high RH promotes the growth of fungi and bacteria (Dannemiller et al., 2016) while low RH (between 40% to 60%) inhibits the latter (Alsmo & Alsmo, 2014) (**Figure 2.1**). Sources of RH are human activities, leaking water, standing water and malfunctioning dehumidifier.

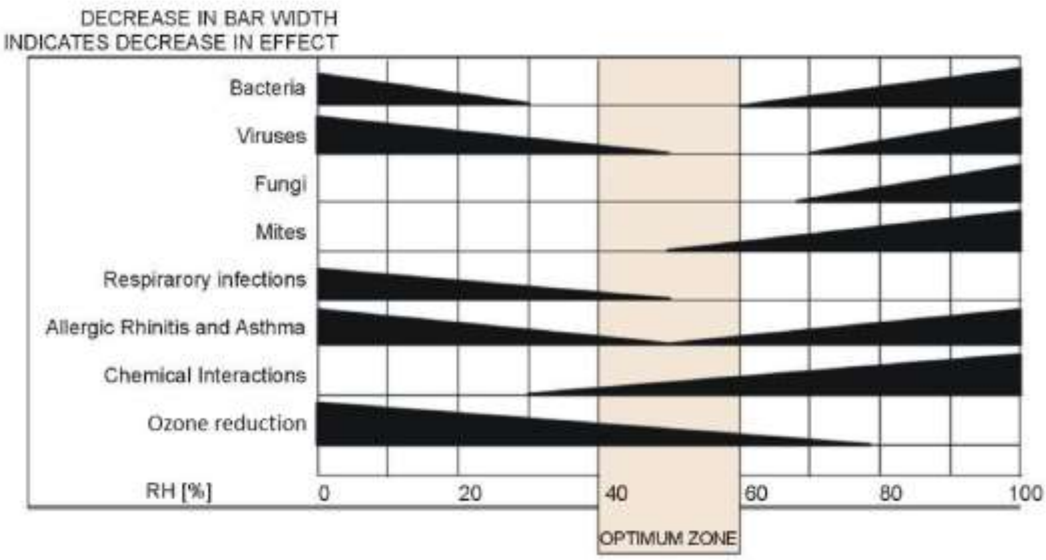

Figure 2.1: The optimal relative humidity (RH) zone: 40-60% to inhibit the growth rate of microorganisms and minimise health risk; figure taken from Alsmo & Alsmo (2014).

Physical Parameter: ***Air Velocity***

Air velocity is the rate of air movement at a point without regards to the direction. The unit of air velocity is usually expressed in m s^{-1}. The recommended air velocity range in Malaysia is 0.15 m s^{-1} to 0.50 m s^{-1} (DOSH Malaysia, 2010). Air velocity is one of the parameters in determining thermal comfort (ASHRAE, 2004). It is dependent on ventilation and the number of opened windows. Air velocity was found to be related to heat loss, skin temperature and skin wettedness (Fountain et al., 1993) which will affect thermal comfort. The air velocity are perceived by the occupants as freshness, yet at times can also be annoying. Air velocity was also found to be positively correlated to the number of bacteria and fungi in a study (Matkovic et al., 2013).

Chemical Parameter: ***Carbon Monoxide (CO)***

CO is a colourless, non-irritant, odourless and tasteless toxic gas. The unit of CO in air is usually expressed in ppm or mg m^{-3}. The source of CO is from the incomplete combustion of carbonaceous fuels (WHO, 2010). CO displaces oxygen in the blood and deprives the heart, brain and other vital organs of oxygen (OSHA, 2002). The exposure to CO at different concentrations and different duration will cause varying health effects. Occupational Safety and Health Administration suggests an exposure limit of 50 ppm (OSHA, 2017); National Institute for Occupational Safety and Health (NIOSH) suggests an exposure limit of 35 ppm (NIOSH, 2017b) and the American Conference of Governmental Industrial Hygienists (ACGIH) suggests an exposure limit of 25 ppm (ACGIH, 2016) in order to avoid significant health effect. At low concentrations, symptoms like headache, nausea, dizziness and some neurobehavioral effects might occur. At high concentrations, asphyxiation might occur which can lead to coma and death (Blumenthal, 2001; Department of Labor, 2017b).

Chemical Parameter: ***Total Volatile Organic Compounds (TVOC)***

TVOC is the total amount of volatile organic compounds (VOCs) in the indoor air. VOCs are organic chemicals that can easily vaporise at room temperature. The sources of VOCs are usually from paints, solvents, cleaning chemicals, printers and furniture (Bernstein et al., 2008; Franklin, 2007). The unit of TVOC is usually expressed in ppm or $\mu g\ m^{-3}$. Monitoring of TVOC is different from the monitoring of certain VOCs whereas the latter monitors only a specific VOC, like benzene, formaldehyde and toluene (Wolkoff & Nielsen, 2001). The monitored TVOC can be used as an indicator of insufficient or poorly designed ventilation in a building and the identification of high polluting activities. High TVOC can cause sensory irritation, dryness, weak inflammatory irritation in eyes, nose, air ways and skin (ECA, 1997). Both Department of Occupational Safety and Health Malaysia and National Environment Agency Singapore suggest to keep the indoor TVOC below 3 ppm for eight hours exposure time (DOSH Malaysia, 2010; NEA Singapore, 1996).

Chemical Parameters: ***Particulate Matter (PM)***

PM is a complex mixture of extremely small particles and liquid droplets that get into the air. PM can be classified based on its aero-dynamic diameter. PM_{10}, also known as coarse particulate matter, has an aero-dynamic diameter of 10 micrometre and below whereas $PM_{2.5}$, also known as fine particulate matter, has an aero-dynamic diameter of 2.5 micrometre and below (Esworthy, 2015). Both sizes of particulate matter are usually expressed in unit of $\mu g\ m^{-3}$. The sources of particulate matter in indoor air are from environmental tobacco smoke, cooking, house dust, the use of products containing aerosols and outdoor infiltration, like from traffic, industrial activity and open burning (Bernstein et al., 2008; Kim et al., 2015). The chemical components inside PM are complex and can be made up of nitrates, sulphates, carbon, organic compounds, biological compounds and elements like iron, copper and nickel (WHO, 2013). The health effects resulted from both sizes of particulate matter are well documented in many studies. $PM_{2.5}$ is more harmful than PM_{10} due to its smaller diameter enabling it to travel from the respiratory tract to the alveoli. On the other hand, PM_{10} will deposit in the tracheobronchial tree (Londahl et al., 2006). Some studies found out that PM was a risk factor for stroke and hospital admissions for heart and lung diseases (Scheers et al., 2015; Zanobetti et al., 2000). Other studies determined that PM can cause respiratory, cardiovascular and cerebrovascular diseases as well as decreased lung function (Du et al., 2016; G et al., 2013; Wu et al., 2014; Xing et al; 2016). Other findings show that increased in particulate matter would increase mortality rate (Lu et al., 2015a; Janssen et al., 2013; Pascal et al., 2014). World Health Organisation suggests to keep PM_{10} below 50 µg m^{-3} and $PM_{2.5}$ below 25 µg m^{-3} for twenty four hours exposure time (WHO, 2010). Both Department of Occupational Safety and Health Malaysia and National Environment Agency Singapore suggest to keep the indoor PM_{10} below 150 µg m^{-3} for eight hours exposure time (DOSH Malaysia,2010; NEA Singapore,1996) but they do not suggest exposure limit for $PM_{2.5}$.

Biological Parameters: ***Total Bacterial Counts (TBC)***

TBC can be defined as the quantity or concentration of bacteria present in a sample. The unit TBC in air is usually expressed in cfu m^{-3}; cfu stands for colony forming unit. There are two methods to monitor TBC, which are the active method and the passive method. Both methods are acceptable but the active method has the advantage when measuring low microbial concentration (Swenson, 2013). Several factors that can affect the TBC are the type of ventilation, human activities, climate, air temperature, humidity and air movement (Kim & Kim, 2007; Kim et al., 2009; Tsai & Macher, 2005; Tsai & Liu, 2009). High TBC does not necessarily imply health risk but serve as an indicator for further investigation (DOSH Malaysia, 2010). In this case, information on the bacteria, like species, gram and shape, can be further investigated (Hayleeyesus & Manaye, 2014, Verde et al., 2015). Both Department of Occupational Safety and Health Malaysia and National Environment Agency Singapore suggest to keep the indoor TBC below 500 cfu m^{-3} for eight hours exposure time (DOSH Malaysia, 2010; NEA Singapore, 1996).

Ventilation Indicator: ***Carbon Dioxide (CO_2)***

The unit of the carbon dioxide (CO_2) is usually expressed in ppm (parts per million) or % (by mol). It can be found naturally in the ambient air at the concentration of about 390 ppm (Kumar et al., 2017) or 0.04% in the ambient air. The sources of CO_2 in indoor are from the exhalation of occupants and fuel combustion (Zhang & Smith, 2003). CO_2 present in indoor can always act as an indicator of adequate ventilation (Gladyszewska-Fiedoruk, 2013). A study done by Satish et al. (2012) shows that CO_2 can affect decision-making of the building occupants where at lower concentration of CO_2, the building occupants performed better. Another study shows that carbon dioxide (CO_2) was positively correlated to one or more SBS (Apte et al., 2000). The exposure to high CO_2 (5000 ppm time-weighted average or 30000 ppm short term exposure limit) significantly affects human health by inducing headache, dizziness, sweating, restlessness, asphyxiation, increased pulmonary respiration rate, metabolic stress, respiratory stimulation or loss of consciousness (United States Department of Labor, 2017a) (ACGIH, 2010; NIOSH, 2017a).

2.1.3 Studies of Indoor Air Quality in Different Building Categories

Numerous studies on indoor air quality have been carried out around the world because of the importance of good indoor air quality in maintaining the health of building occupants. Different environmental settings and parameters were covered and assessed in those studies. Literatures of food industry and three building categories related to this study including office, manufacturing area and laboratory are covered below. The sampling locations in this study fall under these three building categories. These literatures highlight the findings of related studies to convey the knowledge and ideas that have been established in order to further compare and discuss with the findings of this study.

Food Industry

In the food industry category, several indoor air quality studies were conducted and are mostly studies on bioaerosols or airborne bacteria. A study by Salustiano et al. (2003) investigated the microbiological air quality of the processing area in a dairy plant. Two methods were used to evaluate the TBC which were the impaction and the culture settling plate techniques. The TBC was assessed in several sampling locations, the milk reception, packaging, and pasteurization rooms. The range TBC was from 10 cfu m^{-3} to 920 cfu m^{-3}. Increased RH was found to be positively correlated with TBC. The impaction technique was recommended due to its advantage of recovering airborne microorganisms. Tsai & Liu (2009) investigated the exposure of humans to culturable airborne bioaerosols during noodle manufacturing. Air samples were collected using the impaction technique from several sampling sites, the stirring site, the sheeting and compounding site, the packaging site, the warehouse site and the staff offices. The TBC at the warehouse, crushing site and stirring site exceeded 500 cfu m^{-3}. The authors recommended the workers at these sites to wear breathing protection. Awad (2007) investigated the airborne dust and bacteria at a flour mill. The concentration of the suspended dust varied from 1.96 mg m^{-3} to 16.3 mg m^{-3} indoors while outdoors, 0.69 mg m^{-3} to 1.8 mg m^{-3}. The indoor locations (the packaging site, roller site and storage site) were dustier than the outdoor locations. TBC was significantly higher at the purifying site and the roller site compared to the outdoor reference site.

Building Category: ***Office***

In the office category, indoor air quality studies were carried out together with the determining of associations of occupant outcomes like SBS. A study by Aizat et al (2009) was investigating on the indoor air quality and sick building syndrome in Malaysian buildings. The results show that increases in ventilation rates could reduce prevalence of SBS. Several parameters including air temperature, RH, CO_2 and CO were monitored. CO_2 was approximately correlated with other indoor parameters like air temperature and humidity that might cause symptoms.

Another study by Zamani et al. (2013) was also looking at the indoor air quality and prevalence of sick building syndrome in two different offices which one was old and one was new. Levels of indoor air pollutants in old building were significantly higher compared to new building. CO_2, CO, TVOC, PM_{10} and $PM_{2.5}$ in old building recorded 704 ppm, 1.7 ppm, 0.1 ppm, 57 µg m^{-3} and 57 µg m^{-3} respectively.

Another study by Mendell et al (2015) was studying on how ventilation rates were related to respiratory illness. Several parameters including CO_2, air temperature and RH and ventilation rates were monitored. The CO_2 recorded in sixteen sampling locations ranged from 441 ppm to 660 ppm. No significant relationship was found between CO_2 or ventilation rates with occupant outcomes.

Building Category: ***Manufacturing area***

In manufacturing area, indoor air quality studies were conducted in different industries. A study by Sarage at al. (2011) was investigating indoor air quality in a printing industry, a museum and an office. Total suspended particles (TSP), PM_{10}, $PM_{2.5}$, inorganic pollutants and organic pollutants were monitored. Different activities were found to affect the levels of pollutants. TSP, PM_{10} and $PM_{2.5}$ were the highest in the bookbindery section of the printing industry which recorded 218 μg m^{-3}, 205 μg m^{-3} and 151 μg m^{-3} respectively. The reasons contributed to this were number of occupants, emissions from the equipment and the outdoor environment.

Another study by Arunkumar et al (2014) was investigating on the indoor air quality in an automobile industry. Suspended particulate matter, respirable particulate matter and CO were monitored in different sampling locations in the industry including painting area, shot blasting area, dynamometer testing area and fuel tank cell area. Suspended particulate matter recorded ranged from 15.7 mg m^{-3} to 17.3 mg m^{-3} and respirable particulate matter recorded ranged from 6.1 mg m^{-3} to 6.7 mg m^{-3}. Low CO was recorded in all sampling locations.

The other study by Reinhold et al. (2009) was investigating on the indoor air quality in industrial premises. Indoor air quality in different industries was assessed including clothing, printing, wood, mechanical, plastic and offices. Parameters including air temperature, RH, air velocity, CO and CO_2 were assessed. The levels of pollutants varied in different industries and mainly depended on the industrial activities. Wood industry was found to be most polluted.

Building Category: ***Laboratory***

In laboratory category, indoor air quality studies were carried out by measuring various parameters and focusing on TVOC. A study conducted by Valavanidis &Vatista (2006) was investigating on undergraduate and postgraduate laboratories of a university's chemistry department. CO, CO_2, TVOC, TSP, air temperature and RH were monitored. Results show that levels of most pollutant were below the guidelines for upper limits. However, TVOC ranged from 4 ppm to 8 ppm while concentrations of TSP in few laboratories ranged from 100 μg m^{-3} to 700 μg m^{-3}. Sources of pollutants were mainly contributed by human activities including smoking.

Yau et al. (2012) conducted a study on indoor air quality of four pharmaceutical laboratories in Malaysia. Several parameters were assessed including air temperature, RH, air velocity, CO, CO_2, TVOC and PM_{10}. The air temperature in three laboratories were relatively low if compared to standards which recorded at 22.38°C, 20.53°C and 19.50°C respectively. TVOC at two laboratories recorded 22.8 ppm and 6.5 ppm. The authors concluded that an average performance existed in the pharmaceutical laboratories.

Another study by Ugranli et al. (2015) was investigating on indoor air quality of two research laboratories. Parameters including PM_{10}, $PM_{2.5}$, TVOC, CO, CO_2, air temperature and RH were monitored. All monitored concentrations were similar and under the limits in both laboratories except for TVOC which recorded a mean of 182 ppb. Higher concentrations of both sizes of PM were observed in the more intensively used laboratory.

2.2 Local and International Standards of Indoor Air Quality

Different standards of indoor air quality have been established in different countries all over the world. The purpose of all these standards is to ensure the occupants are protected from poor indoor air quality that could adversely affect their health and well-being. The only local standard of indoor air quality in Malaysia is the Industry Code of Practice on Indoor Air Quality 2010 (DOSH Malaysia, 2010). The other standards of indoor air quality in other countries are the National Environment Agency-Office Indoor Air Quality Guidelines (NEA Singapore, 1996), the Hong Kong Indoor Air Quality Objectives (HKEPD, 2003) and the American Society of Heating, Refrigerating and Air-conditioning Engineers Standard 55 (ASHRAE, 2004). Another related standard in Malaysia is Malaysian Standard MS 1525:2014 which is energy efficiency and use of renewable energy for non-residential buildings. These standards cover the importance of good indoor air quality, steps or methods on investigating indoor air quality problem, practices to control indoor air quality and most importantly is the limit of exposure of indoor air quality parameters. The recommended range of parameters from the five different standards is shown in **Table 2.1**. Most of the parameters covered by the five standards propose similar ranges but with some exceptions. It has to be noted that $PM_{2.5}$ was not covered in any of the standards. However, $PM_{2.5}$ was still monitored in this study because previous studies showed that $PM_{2.5}$ is more hazardous than PM_{10} (Xing et al., 2016; Yang et al., 2018). Therefore, the acceptable limit of $PM_{2.5}$ should be lower than PM_{10}.

Table 2.1: The recommended range of indoor air quality parameters of five different standards.

Parameters (unit)	ICOPIAQ 2010[a]	NEA Office IAQ Guidelines[b]	HKIAQO[c]	ASHRAE Standard 55[d]	MS 1525: 2014[e]
Air temperature (°C)	23-26	22.5-25.5	< 25.5	22.5-26.0	24-26
Relative humidity, RH (%)	40-70	≦ 70	< 70	< 60	50-70
Air velocity (m s^{-1})	0.15-0.50	≦ 0.25	< 0.3	< 0.25	0.15-0.50
Carbon dioxide, CO_2 (ppm)	< 1000	< 1000	< 1000	< 1000	-
Carbon monoxide, CO (ppm)	< 10	< 9	< 8.7	< 10	-
Total volatile organic compounds, TVOC (ppm)	< 3	< 3	< 0.26	< 3	-
Particulate matter 10 micron, PM_{10} (µg m^{-3})	< 150	< 150	< 180	-	-
Particulate matter 2.5 micron, $PM_{2.5}$ (µg m^{-3})	-	-	-	-	-
Total bacterial counts, TBC (cfu m^{-3})	< 500	< 500	< 1000	-	-

[a] Industry Code of Practice on Indoor Air Quality 2010 (DOSH, 2010)
[b] National Environment Agency-Office Indoor Air Quality Guidelines (NEA Singapore, 1996)
[c] Hong Kong Indoor Air Quality Objectives (HKEPD, 2003)
[d] American Society of Heating, Refrigerating and Air-conditioning Engineers Standard 55 (ASHRAE, 2004)
[e] Malaysian Standard MS 1525:2014 (Standards Malaysia, 2014)

2.3 Potential Health Risks

Potential health risks is defined as the degree of likelihood that exposures to a hazardous substance may damage or will damage the health of the exposed person. Robson & Toscano (2007) defined risk as a function of hazard and exposure. The risk will diminish by eliminating or decreasing either one of these components. A ‘source-pathway-receptor’ framework can be utilised in determining health risks (Lu et al., 2015b). Source is the contaminants; pathway is potential or existing physical links between sources and receptors; receptor is the organisms that is exposed to the contamination (WHO, 2000).

2.3.1 Steps in Risk Assessment

Risk assessment involves four steps which are hazard identification, dose-response assessment, exposure assessment and risk characterisation (Taner et al., 2013). This four-step risk assessment is well accepted and has been utilised in many studies (Shi et al., 2011; Taner et al., 2013; Wang et al., 2016). Before that, a planning of the risk assessment about the purpose, scope and technical approaches to be used has to be conducted (USEPA, 2017c).

Hazard Identification

The first step in risk assessment is hazard identification. Hazard identification is the process of determining whether exposure to a stressor can cause an increase in the incidence of specific adverse health effects (USEPA, 2017c). A stressor can be a chemical or non-chemical agent, environmental condition or external stimulus that causes stress to organisms. The sources of data can be obtained from statistically controlled clinical studies, epidemiological studies or even animal studies if human studies are unavailable. An important component in hazard identification is the weight of evidence regarding a chemical's potential to cause human health effects (USEPA, 2017c). An example of data with good weight of evidence is IARC monographs by International Agency for Research on Cancer under World Health Organization. Under these monographs, the agents are classified based on carcinogenicity and cancer sites. Under classification group of carcinogenicity, the agents are classified into five group which are group 1 (carcinogenic to humans), group 2A (probably carcinogenic to humans), group 2B (possibly carcinogenic to humans), group 3 (not classifiable as to its carcinogenicity to humans) and group 4 (probably not carcinogenic to humans) (IARC, 2017). From this data, the agents are known of their hazards. Carcinogenicity, target organ with sufficient evidence and limited evidence of twenty one elements are shown in **Table 2.2**.

Table 2.2: Carcinogenicity, target organ with sufficient evidence and limited evidence of twenty one elements.

Elements	Carcinogen class[a]	Target organ with sufficient evidence[b]	Target organ with limited evidence[b]
As	1	Lung, skin, urinary bladder	Liver, bile duct, prostate, kidney
Be	1	Lung	-
Ca	-	-	-
Cd	1	Lung	
Co	2B	-	Lung
Cr	1 for Cr (IV) 3 for Cr (III), Cr (Metallic)	Lung	Nasal cavity, paranasal sinus,
Cu	-	-	-
Fe	-	-	-
Li	-	-	-
Mg	-	-	-
Mn	-	-	-
Mo	-	-	-
Ni	2B for Ni (metallic) 1 for Ni (Compounds)	Nasal cavity, paranasal sinus, lung	-
Pb	2B for Pb, 2A for Pb (Inorganic) 3 for Pb (Organic)	-	Stomach
Sb	-	-	-
Se	3	-	-
Sr	-	-	-
Ti	-	-	-
Tl	-	-	-
V	-	-	-
Zn	-	-	-

[a] IARC (2017). Class 1- Carcinogenic to humans, class 2A- Probably carcinogenic to humans, class 2B- Possibly carcinogenic to humans, class 3- not classifiable as to its carcinogenicity to humans, Group 4- Probably not carcinogenic to humans, Group not stated- not yet classified by IARC.
[b] IARC (2016).

Dose-response Assessment

The second step in risk assessment is dose-response assessment. Dose-response assessment is the process of determining the likelihood and severity of adverse health effects (the responses) are related to the amount and condition of exposure to an agent (the dose provided) (USEPA, 2017c). Dose-response relationship will be established in order to identify the amount or concentration of an agent to cause health effects on organisms. There are two types of dose-response assessments which are non-linear dose-response assessment and linear dose-response assessment. Non-linear dose-response assessment applies the threshold hypothesis. It means that a range of exposures from zero to some finite value will not cause health effects. However, once the range of exposures passes the threshold, the health effects occur. On the other hand, linear dose-response assessment suggests that toxicity does not have a threshold. No observed adverse health effects level (NOAEL), lowest observed adverse health effects level (LOAEL) and benchmark dose lower-confidence limit are further incorporated with uncertainty factors (UFs) to generate the reference concentration (RfC) in non-linear dose assessment and inhalable unit risk (IUR) in linear dose assessment (USEPA, 2017c). In health risk assessment related to air quality, reference concentration (RfC) and inhalable unit risk (IUR) are preferred because the main exposure pathway is through inhalation (Taner et al., 2013; Wang et al., 2016). Reference concentration (RfC) is generally expressed in mg m^{-3} and inhalable unit risk (IUR) is generally expressed in $(\mu g\ m^{-3})^{-1}$. Inhalable unit risk (IUR) and reference concentration (RfC) of twenty one elements are shown in **Table 2.3**.