PROFILING OF INDOOR AIR POLLUTANTS AND POSSIBILITY OF OZONE FORMATION

NURFADHILAH BINTI OTHMAN

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by

Nurfadhilah Binti Othman

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Bandar Sri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Nurfadhilah Binti Othman

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Approved by,

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(Dr Nurul Izma Binti Mohammed)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NURFADHILAH BINTI OTHMAN

ABSTRACT

In the last 50 years, air pollution has undergone rapid changes and increased dramatically. Earlier in Malaysia, little attention was given to the environment concerns until there are a few series of high particulate event occurred. Among all environmental pollution problems, air pollution is stated to cause the greatest damage to health and loss of welfare from environmental causes especially in Asian countries including Malaysia and air pollution, whether it short- or long- term impacts can affect human health, well-being and environment. Researches indicated that indoor air pollutants exposure is greater than outdoor exposure for many people. Indoor air pollutants have the potential to cause transient morbidity, disability, disease, and even death in extreme cases. Thus, this study examined the concentration of several indoor air pollutants which are nitrogen oxides, sulphur dioxide and ozone in the enclosed KLCC car park area. Enclosed car park was chosen as the location of sampling because of the poor air quality in the car park. This issue has been raised up frequently by the community. These data were collected hourly by using GrayWolf Advanced Sense Direct Sense; Toxic Gas Test Meters for two weeks from 0800 to 1700 hour. Then the data was analyzed by using time series model to observe the trends of air pollutants in the sampling location which is at the determining the concentrations of the samples at the selected sampling location which is at the PETRONAS Twin Tower basement car park. From the analysis, the objectives of the study have been achieved. Firstly, the concentration of NO_x will be the highest among the three air pollutants. Secondly, there was formation of O_3 recorded at the sampling area. The O_3 might be infiltrated from the outside surrounding into the car park and there are also several other factors that can cause O_3 emissions. The concentration of NO_2 and SO_2 recorded in this study has exceeded the standard limit set by MAAQG thus action might have to be taken by the KLCC parking management to enhance the air quality in the enclosed car park.

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INTRODUCTION

1.1   Background of Study

In the last 50 years, air pollution has undergone rapid changes and increased dramatically. A lot of researches have been done on the causes and impacts of the air pollution to the environment. Air pollution is basically is the indoor and outdoor environment which is contaminated by any chemical, physical or biological agent that changes the natural characteristics of the atmosphere (WHO, 2013). Among all environmental pollution problems, air pollution is stated to cause the greatest damage to health and loss of welfare from environmental causes especially in Asian countries including Malaysia (Dominick, et al., 2012). Earlier in Malaysia, little attention was given to the environment concerns until there are a few series of haze episodes occurred. Since then, the awareness towards the environment has increases (Afroz, et al., 2003). There are two types of sources of air pollution which are natural and anthropogenic sources (Carvalho & Freitas, 2011). The natural sources of air pollution are from the vegetation, ground dust, salt spray from the oceans and cosmic dust, while the anthropogenic sources are resulted from the human activities. Some of them are from the industry, agriculture, transportation and household sources (Ionel & Popescu, 2010). A lot of studies had proven that most of the time, the air pollution is caused by combustion of fossil fuels especially from the emissions of mobile sources (Afroz, et al., 2003; Dominick, et al., 2012; Fenger, 2009). In Malaysia, according to Department of Environment (2011), the major sources of air pollution are from industries including power plants, motor vehicles and open burning activities with the major contributor of the pollution are motor vehicles. In 2010, there was an overall increment in the number of motor vehicles registered. The percentage of vehicles can be depicted in Figure 1. The number of registered passenger cars increased by 7.16 %, motorcycles by 5.61 %, buses by 3.86 %, goods vehicles by 3.20 % and taxis by 6.96 % in 2010 compared to 2009.
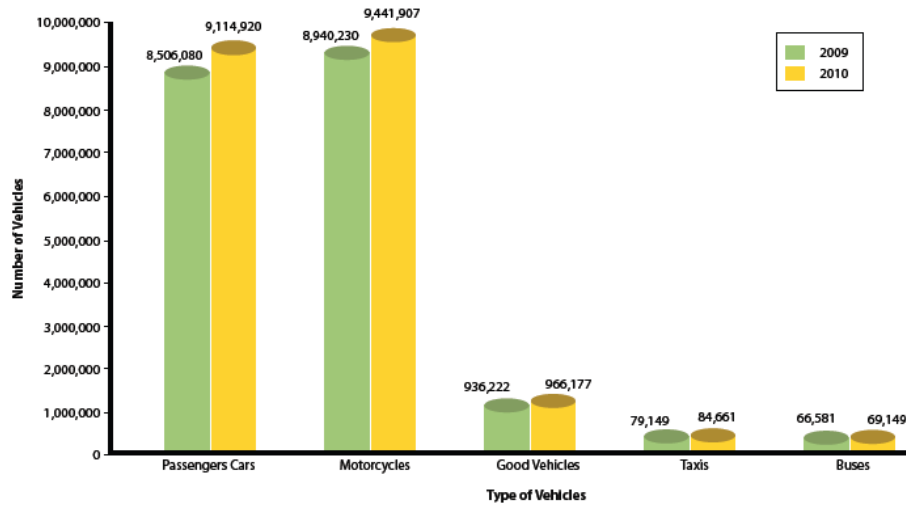
Figure 1: Malaysia: Number of Registered Vehicles in 2009 and 2010
(Source: Road Transport Department, 2010)

According to Department of Environment, 2010, total of 38,211 industrial sources were subjected to the Environmental Quality (Clean Air) Regulations, 1978. The total number of industrial sources is much higher in 2010 than in 2009 due to the increase in development of industrial and manufacturing sector. The breakdown of industrial sources by states is as shown in Figure 2. The highest number of stationary pollution sources was in Johor (9,276 : 24.3 %) followed by Selangor (5,431 : 14.2 %) and Sarawak (3,502 : 9.2 %).
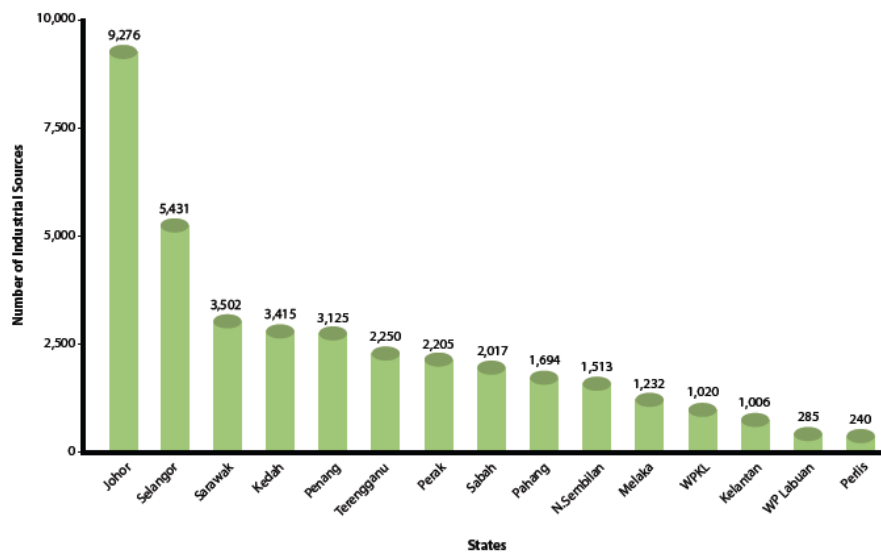
Figure 2: Malaysia: Industrial Air Pollution Sourcesby State, 2010
(Source: Road Transport Department, 2010)

Air pollution, whether it short- or long- term impacts can affect human health, well-being and environment (Azmi, et al., 2009; Gurjar, et al., 2008; Ozden, et al., 2008). In short term, high level of air pollution can lead to acute condition. Furthermore, the blockage of sunlight may promote the spread of harmful bacteria and viruses that originally can be killed by ultraviolet B (Beardsley, et al., 1997). In the long term, the effects are unknown and difficult to detect (Afroz, et al., 2003). Air pollution has both acute and chronic effects on human health and affecting numbers of different respiratory systems and organs (Castanas & Kampa, 2007). Apart from its effect on human health, it can also affect the ecosystems, materials, buildings, works of art, vegetation and visibility (Azmi, et al., 2009; Ilyas, et al., 2009; Riga-Karandinos & Saitanis, 2005) and the substances that can destruct humans, animals, vegetation or material are called air pollutants (Castanas & Kampa, 2007). There are two types of air pollutant which are the primary and secondary pollutant. Primary pollutant is the pollutant that emitted directly from the source such as carbon monoxide (CO), nitrogen oxides (NO_x), and sulphur dioxide (SO_2). On the other hand, secondary pollutant is formed when the primary pollutant reacted in the atmosphere such as ozone (O_3), formaldehyde and acidic mist (Bhatia, 2007).

A lot of people thought that the impact of outdoor air pollution is more severe than indoor air pollution. However, according to Fang, et al. (1999), indoor air pollution is reported to be responsible for 2.7 % of the global burden of disease. There are little concerns given to the indoor air pollution even though most of the people spend their time indoor. In United State, on average, individual spent 88 % of their day inside buildings, 7 % in a vehicle whilst only 5 % of their time was spent outside (Nelson and Robinson, 1995). This does not mean that indoor exposures will produce more harmful health effects but the point is that the indoor concentrations of many pollutants are higher than those usually encountered outside. Worldwide more than 1 million people die from chronic obstructive pulmonary disease (COPD) annually due to indoor exposure to smoke which generally contains a range of health-damaging pollutants (Hetland, et al., 2000). Today, concern over health effects of poor quality indoor air is increasing (Jones, 1999). Despite the fact that the vast majority of buildings exhibit no immediately apparent problems, a wide

spectrum of symptoms and illnesses are attributed to non-industrial air pollution (Redlich, et al., 1997). According to Maroni, et al., (1995) the concentrations of pollutants indoors depend on the relationship between the volume of air contained in the indoor space, the rate of production or release of the air pollutant, the rate of removal of the pollutant from the air via reaction or settling, the rate exchange with the outside atmosphere, and the outdoor pollutant concentration. Aware with the implication of the indoor air pollutant, this study will analyze the concentrations of the indoor air pollutants.

According to National Institute of Safety & Health (NIOSH), (2012) there are five main causes of indoor air problems which are the building materials which are microbial, building materials, inside the buildings, outside the building, inadequate ventilation and the rest of the cause is unknown. Figure 3 illustrates the statistical data for each cause of indoor air problems.
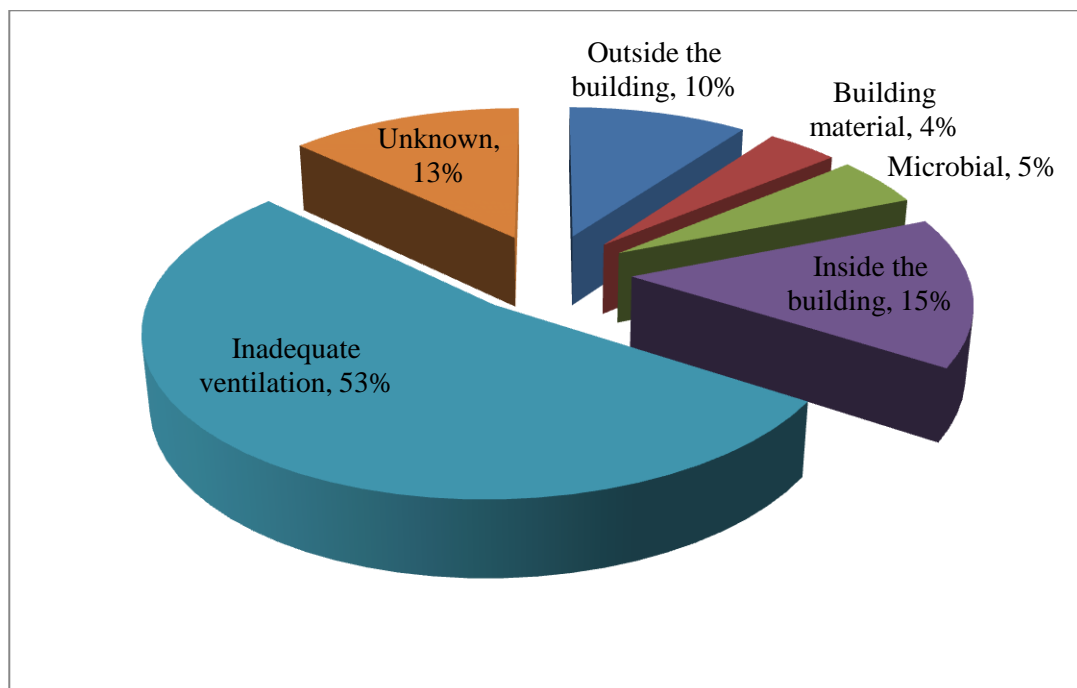

Figure 3: Main Causes of Indoor Air Pollutants (NIOSH, 2012)

The indoor air quality problems can be identified if there is;

1)   Unusual and noticeable odour
2)   Stale or stuffy nose

4

3)   Frequent headaches, nausea or fatigue experienced within the indoor environment

4)   Excessive humidity

5)   Presence of mold or mildew

6)   Noticing that one feels healthier when outside of the indoor environment

However, the indoor air quality can be improved by keeping the indoor environment well ventilated, installing air cleaners, preventing ones from smoking indoors, growing air cleaning plants indoors and choosing natural pest control (DOE, 2012). Kim, et al., (2008) also stated that ventilation is an effective way to control indoor air pollution especially the one caused by VOCs emissions. According to EPA (2013), indoor air quality can be improved from the source control, by improving ventilation and using air cleaners. Usually, the most effective way to improve indoor air quality is to eliminate individual sources of pollution or to reduce their emissions. In many cases, source control is also a more cost-efficient approach to protecting indoor air quality than increasing ventilation because increasing ventilation can increase energy costs. Another approach to lowering the concentrations of indoor air pollutants is to increase the amount of outdoor air coming indoors (EPA,2013). Lastly, EPA (2013) elaborated that the effectiveness of improving indoor air quality by air cleaners depends on how well it collects pollutants from indoor air and how much air it draws through the cleaning or filtering element. A very efficient collector with a low air-circulation rate will not be effective, nor will a cleaner with a high air-circulation rate but a less efficient collector. The long term performance of any air cleaner depends on maintaining it according to the manufacturer's directions.

1.2   Problem Statement

The emissions of gases from the exhaust of car engines due to the combustion will cause the air pollution. The burning of car fuel will produce a lot of smog and air pollutants. These gases, once emitted will circulate in the underground parking area. Insufficient or malfunctioning ventilation inside, allows the pollutants to accumulate, and the concentration to increase. The users and staffs that use the car park will be exposed to this polluted environment and a lot of negative effects if there is no action taken to control the concentration.

The concern is regarding the enclosed car park. Underground car park usually has problems with the air quality, thermal environment, and ventilation. The gases from the exhaust that are emitted will circulate longer and causing worse effects to the workers and the users of the car park if these problems are not resolved.

The presence of sunlight is essential in the formation of O_3. Although the underground car park is lack of sunlight, this study will determine the possibility of ozone formation in the enclosed car park as sunlight cannot penetrate entirely into the basement areas. However, the O_3 might also be presence from other sources such as air conditioning, building materials and infiltrated from the outside environment.

1.3   Objectives and Scope of Study

There are three objectives to be achieved during this study which are:

1)   To determine the concentrations of NO_x and SO_2, in the basement car park. As an enclosed car park always have problems with their ventilations, the air pollutants might circulate around the car park for a longer period. Thus it is very important to achieve this objective so that solution to the problems can be proposed.

2)   To study the possibility of O_3 formation without the presence of sunlight. This study will test the existance of ozone in the enclosed car park. Positive result will encourage other researchers to further the study on this subject.

3)   To analyze the concentrations of NO_x, SO_2, and O_3 using the time series model.

This study will take place at the PETRONAS Twin Tower basement car park. For this study, a period of 8 days is allocated for the sampling. The samples will be collected from 0800 hour until 1700 hour. Figure 3 and 4 illustrate the access to the basement car park and the condition inside the parking area.

Figure 3: Ramp to the basement car park

Figure 4: Conditions inside the basement car park

There are three air pollutants that will be analyzed in this study which are NO_x, SO_2 and O_3. NO_x and SO_2 are the primary pollutant from the emissions of motor vehicles. This is the opportunity to discover new things and come out with new findings. In the mean time, O_3 was also chosen in this study because nowadays, a lot of researchers have started to shift their attention from the primary pollutant to the secondary pollutant.

CHAPTER 2
LITERATURE REVIEW

2.1   Air Pollutants

The substances that can destruct humans, animals, vegetation or material are called air pollutants (Castanas & Kampa, 2007). It may cause or contribute to an increase in mortality or serious illness or may pose a present or potential hazard to human health. In Malaysia, the main pollutants recorded at the monitoring stations are particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3) (Awang, et al., 2000; Azmi, et al., 2009). Control of air pollutants is necessary to provide a better and safe environment for future generation. A lot of researches have been carried on this subject whether in Malaysia or abroad. Monitoring data and studies on ambient air quality show that some of the pollutants in several cities in Malaysia increasing with time and not are always acceptable according to the Malaysian Ambient Air Quality Guidelines (MAAQG) (see Table 1) (Afroz, et al., 2003).

Table 1: Malaysian Ambient Air Quality Guidelines (DOE, 2013)

Pollutant	Averaging Time	PPM	(μgm^{-3})
Ozone	1 Hour	0.1	200
	8 Hour	0.06	120
Carbon monoxide	1 Hour	30.0	**35
	8 Hour	9.0	10
Nitrogen dioxide	1 Hour	0.17	320
	24 Hour	0.04	
Sulphur dioxide	1 Hour	0.13	350
	24 Hour	0.04	105
Particulate matter (PM_{10})	24 Hour		150
	12 Month		50
Total suspended particulate (TSP)	24 Hour		260
	12 Month		90
Lead	3 Month		1.5

** measured in mg/m^3

In a study done by Department of Environment, 2001, after the economic recession in Malaysia in 1986-1988, the number of registered vehicles increased rapidly and this is parallel with the increased of pollutants especially in Kuala Lumpur and Selangor. The major contributors of atmospheric pollutants are from the private vehicles. They contribute about 75 % of total CO and particulate matters, as well as about 76 - 79 % of the sulphur oxides and nitrogen (DOE, 1991). The most common vehicles emissions to the atmosphere by mass are carbon dioxide (CO_2), and water vapor from the complete combustion of fuel. However, if the combustion is incomplete, some of the fuel will be oxidized into CO with some volatile organic compound (Colvile, et al., 2001). It is discharged by motor vehicles that have internal combustion. The type of fuel used, the age and working condition of the engine, the driving behaviour of the driver and the quantity of fresh air supplied affect the concentration of CO in an enclosed car park (Chow, 1995).

Besides that, fuels also contain impurities. Impurities like sulphur will mostly oxidised into the air pollutant SO_2 and sometimes to sulphate which can assist in the nucleaction of particles in the exhaust. The nucleation is the process where the mineral vapors in the exhaust diffuse into combustion chamber extrimities where oxygen content is higher. In this process, the fine particles will be formed and transported into the atmosphere by exhaust gases (Ionel & Popescu, 2010). Likewise, hydrocarbons (HC) are unburned or partially oxidised fuel is the source of HC emissions. HC with presence of sunlight and nitrogen oxides (NO) to form ground level ozone which can irritates the eyes, damages the lungs, and causing respiratory problems (Shuhaili, et al., 2013). Finally, at high combustion temperatures of most transport sources air pollution, nitrogen gas (N_2) will be oxised into NO_x (Colvile et al., 2001). Factors affecting the concentrations of pollutants from the vehicles emmisions are depend on the time activity patterns, meteorological conditions, vehicles volume and type, driving patterns, land-use patterns, the rate at which chemical transformations take place, and the degree to which temperal and spatial contribution reflects the traffic source (Shuhaili, et al., 2013).

2.2 Nitrogen Oxide (NO$_x$)

Two main principles of NO$_x$ are nitric oxide (NO) and nitrogen dioxide (NO$_2$). NO and NO$_2$ have their own physical properties, chemical affinities and environmental impacts. NO$_x$ in ambient air are formed by various combinations of oxygen and nitrogen at high temperatures during the combustion process. The higher the combustion temperature, the more nitric oxide is generated (WHO, 2012). Combustion always produces mixture of NO$_2$ and NO, even though more than 90% of combustion NO$_x$ production is in the form of NO (Bhatia, 2007). In motor vehicles emissions, NO is more dominant and established to be a high proportion of total NO$_x$ that leaves the vehicle's tailpipes (Shuhaili, et al., 2013). NO is formed in two different ways that can be illustrated by equation (1) and (2) while the production of NO$_2$ in equation (3):

$$N_2 + O \longrightarrow NO + N \tag{1}$$

$$N + O_2 \longrightarrow NO + O \tag{2}$$

$$NO + O_3 \longrightarrow NO_2 + O_2 \tag{3}$$

NO is a colorless, odorless and oxidized to NO$_2$ in a polluted atmosphere. Amazingly, NO can essentially induce vasodilation and hence improves the blood supply in the lung, reduces blood pressure, and improves the oxygen levels in the bloodstream at lower concentration. However, at high concentration, it can be lethal and its effects are different for different species (Hull, et al., 2008).The increase in the level of nitrogen oxides (NO$_x$) can cause human beings to suffer from odour, eye irritation, bronchitis to pulmonary congestion. In fact, prolonged exposure can cause fatality or accelerate the lung tumor growth (Bhatia, 2007). It is rapidly oxidized in air to form NO$_2$ by available oxidants such as oxygen, ozone and VOCs and this rapid oxidation velocity is such that it is NO$_2$ usually considered as primary pollutant. However, in indoor air, this oxidation process is generally much slower (Arashidani, et al., 1996). NO$_2$ is a brown pungent gas with irritating odor and emitted by fuel combustion and nitric acid plants. Road traffic is the main outdoor

source of NO_2 while for indoor environment; the main sources are tobacco smoke, gas-, wood-, oil-, kerosene-, and coal-burning appliances such as stoves, ovens space and water heaters and fireplaces. Occupational exposures can be elevated in indoor spaces, including accidents with silage and in ice arenas with diesel- or propane-suelled ice resurfacing machines and underground parking garages (Glorennec, et al., 2008). NO_2 is an oxidizing agent that can be very irritating to the mucous membranes of the lungs (Sprengler, 1993). While the boiling point of NO_2 is 21.15 °C, in normal ambient conditions its low partial pressure in the atmosphere prevents condensation so that it exists in the air in its gaseous form. It is highly soluble in water and most of the NO_2 will be removed in the respiratory tract (Lambert, 1997). It is thought to combine with water in the lung to form nitric acid (HNO_3) and may react with lipid and proteins to form nitric anions and hydrogen ions (Bidani & Postlethwait, 1990). According to WHO Guidelines for Indoor Air Quality (2012), one hour indoor guideline of 200 $\mu g/m^3$ is recommended. However, at twice this level, asthmatics exhibit small pulmonary function decrements. Those who are sensitized may have small changes in airway responsiveness to a variety of stimuli already at this level. Studies of the indoor environment provide no evidence for an indoor guideline different to the ambient guideline. Recent well conducted epidemiological studies that have used measured indoor nitrogen dioxide levels support the occurrence of respiratory health effects at the level of the guideline (WHO Guidelines for Indoor Air Quality).

2.3   Sulphur Dioxide (SO_2)

SO_2 is a colorless gas with a pungent smell detected at about 0.5 ppm. It is a primary pollutant which means that it emitted directly from the sources Popescu & Ionel, 2010). It is the largest source of sulphur emissions and usually emitted from the industrial activities (Pereira, et al., 2007), combustion of coal and petroleum products, oil refining and metallurgical operations. The combustion of fossil fuels that contain relevant sulphur content can produce SO_2 through this reaction:

$$CH_3 + SH + 3O_2 \longrightarrow SO_2 + CO_2 + 2H_2O \qquad (4)$$
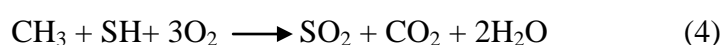
According to Colls (2002), different fuels offer a wide range of sulphur contents. Oil and its by-products contain between 0.1 % sulphur (paraffin) and 3 % (heavy fuel oil) in the form of sulphides and thiols. Petrol contains negligible sulphur in the context of overall mass emissions, although there can be an odor problem from conversion to hydrogen sulphide (H_2S) on catalytic converters. However, coal contains 0.1 – 4 % sulphur, mainly as flakes of iron pyrites (FeS_2). The average sulphur content of European coal reservoirs is 1.7 %. Lastly, Natural gas (mainly methane, CH_4) can be up to 40 % H_2S when it is extracted from the well. The sulphur is taken out very efficiently at a chemical processing plant before distribution, so natural gas is effectively sulphur free.

The major natural sulphur emissions are in the reduced forms such as hydrogen sulphide (H_2S) and carbon disulphide (CS_2) and consequently will be oxidized to become SO_2 (Colls, 2002). It can be found at high levels during the high particulate events due to the composition of the sulphur compound, mostly from biomass burning (Azmi, et al., 2009). SO_2 can cause irritation to the upper respiratory mucus membrane when it reacts with moisture in the upper respiratory tract. This is because it is relatively soluble in water (Gujhar, et al., 2010). Based on the MAAQG (Table 1), the allowable concentration of SO_2 at the average of one hour and 24 hours are 0.13 ppm and 0.04 ppm respectively. Higher concentration

levels of SO_2 will cause a lot of negative effects. SO_2 affects human health when it is breathed in. It irritates the nose, throat, and airways to cause coughing, wheezing, shortness of breath, or a tight feeling around the chest. Absorption of SO_2 in the mucous membranes of the nose and upper respiratory tract will be dependent upon the size distribution of the droplets and the level of humidity indoors (Jones, 1999). The effects of SO_2 are felt very quickly and most people would feel the worst symptoms in 10 to 15 minutes after breathing it (Department of Environment and Heritage Australia, 2005). According to Who Health Organization (2005), individual will experience changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2 as short as 10 minutes. Based on this evidence, it is recommended that a SO_2 concentration of 500 µg/m^3 should not be exceeded over averaging periods of 10 minutes duration.

2.4   Ozone (O₃)

O_3 is a gas of three atoms of oxygen and exists both in the stratosphere which is the earth's upper atmosphere and at troposphere which is at the ground level of the earth (Ramli, et al., 2010). O_3 is bluish in color and is 1.6 times heavier than the air and very reactive oxidant (Ghazali, et al., 2009). It is a secondary pollutant that is produced in the presence of sunlight through a series of photochemical reactions with the primary pollutants and VOCs (Ramli, et al., 2010; USEPA, 2007). The earth atmosphere consists of five layers which are troposphere, stratosphere, mesosphere, thermosphere and exosphere (Figure 5).


Figure 5: The earth atmosphere layers

The troposphere is the first layer above the surface and extends up to six to 20 km high. The stratosphere is the second major layer of the atmosphere which is situated between 10 to 13 km and 50 km above the surface. O_3 in the stratosphere should not be labeled as photochemical air pollutant (Ghazali, et al., 2009) as it is naturally present in comparatively bulk concentrations there (Ramli, et al., 2010). In the stratosphere, the atomic oxygen is produced by the photo-dissociation of molecular oxygen and the process does not involve any precursors as in the troposphere layer (Ismail, et al., 2011). The formation of O_3 at the stratosphere involves the radiant energy (hυ) from the sun. A wavelength of 430 nm in the ultraviolet range can break the oxygen (O_2) into two low-energy oxygen atom,

$O(^3P)$. Each atom can further combine with an oxygen molecule to form ozone (Ghazali, et al., 2009). This formation can be illustrated in the equation (5) and (6):

$$O_2 \longrightarrow O(^3P) + O(^3P) \tag{5}$$

$$O(^3P) + O^2 \longrightarrow O^3 \tag{6}$$

In the troposphere layer, the O_3 is also known as ground level O_3 and forms from the photochemical reactions mostly between VOCs and NO_x (Ismail, et al., 2011). The sources of nitrogen oxides (NO_x) are usually from both anthropogenic such as industry and vehicle emissions and from biogenic sources such as forest and soil (Ramli, et al., 2010; USEPA, 2007) whilst the VOCs are emitted by the automobiles and various commercial and industrial sources. These two components are referred to as O_3 precursors. Radiant energy with a wavelength of 430 nm was shown to break NO_2 into NO and $O(^3P)$. Then, free oxygen atom will combine with oxygen molecule to form O_3. However, the O_3 formed can quickly react with NO to produce NO_2 and O_2. These reactions are a cycle which first generates the O_3 but then destructs them. At the troposphere, the O_3 production net is very limited unless there is a process for turning the NO to NO_2 without destructing the O_3 at the same time. This cycle can be illustrated as in equation (7), (8), and (9):

$$NO_2 \longrightarrow NO + O(^3P) \tag{7}$$

$$O(^3P) + O_2 \longrightarrow O_3 \tag{8}$$

$$NO + O_3 \longrightarrow NO_2 + O_2 \tag{9}$$
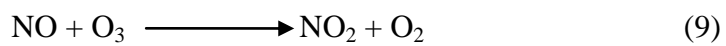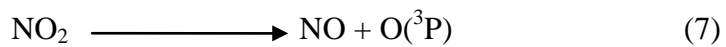
This is when the VOCs involved in the O_3 formation. The VOCs or the free radicals convert NO to NO_2 without destructing the O_3. The next reaction [equation (10) and (11)] will illustrate the process of NO converted to NO_2 without losing O_3 in the process.

$$RO_2 + NO \longrightarrow RO + NO_2 \tag{10}$$
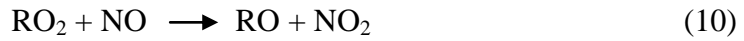
*R is hydrocarbons (a class of VOCs)

$$NO_2 + OH \longrightarrow HO_3 \tag{11}$$

The NO_2 combines with the radicals to form a non-radical product (Ghazali, et al., 2009) and thus preventing the cycle to repeat.

O_3 is one of the major air pollutants and can cause negative impacts not only to the human health but also to the plant species, natural materials and manufactured goods. Thus, most of the country in the world including Malaysia has creating a guideline on the limit of O_3 concentration that is permissible at the averaging time. Based on the Malaysian Ambient Air Quality Guidelines (MAAQG) (Table 1), the allowable concentration of O_3 are 0.1 ppm average of one hour and 0.06 ppm for average of eight hours. An area is facing O_3 pollution if the concentration of O_3 exceeds the allowable limit. Obnoxious human health effects related to O_3 concentration has been studied and the short term exposure can cause irritation to nose, throat and if one is expose to much higher concentration, it can cause asthma and bronchitis (Helaleh, et al., 2002). Besides that, lot of studies shown that O_3 exposure can affect the respiratory tract where it can decrease the pulmonary function, increase the air way responsiveness, and induce air way inflammation in human and experimental animals (Lee, et al., 2013). In one of their study also shown that the exposure of O_3 to the cornea of the eyes can induce the erosions of the cornea and cause staining to the eyes.

According to Mc.Kee (1994), O_3 exposure can lead to subjective symtoms and physiological impairment and can be worsen by environmental stresses such as heat and high relative humidity (RH). Higher ventilation will be caused if there is high tempetature and humidity. This will lead one to inhale higher volume of O_3 and caused higher penetration in the lung.

According to Felzer, et al. (2007), O_3 also affected the trees and crops based on the laboratory and field experiments held by researchers. The plants that is exposed to O_3 will encounter a visible injury as well as affecting its growth responses, reduces the growth, affecting the amount of carbon in vegetation and soils, and the harvastable portions of the crops. The major air pollutants such as SO_2 and NO_2 and O_3 are significant threat to the plants. The effects include many physiological and biochemical changes in plants, which can cause growth reduction and yield loss even at low levels of exposure (Felzer, et al., 2007).

Furthermore, O_3 also is one of the cause of global warming. Heat will be trapped in the lower atmosphere if the O_3 concentration is high. The O_3 molecules absorb heat from the incoming sunlight and pushed back the heat toward's the earth's surface, causing heat to build up in the lower atmosphere (Nardo, 1991). Thus, this study is very important determine the O_3 trend at the site and consequently can propose for any solutions if the result is beyond the limit of safety.

2.5 Underground Car Park: One of the Indoor Air Pollution Origin

In order to cater the limitation of the land usage especially in urban area, a lot of car parks have been constructed underground. The definition of underground car park is any car park which has a significant part of its floor more than 1.2 m below the level of surrounding ground (Chan, et al., 1997). Away from the entrance openings, the ventilation systems were set up to supply the fresh air. It is also provided to remove the air contaminants including the air pollutants (Chow, 1995). However, improper design of mechanical ventilation systems in car parks would give poor indoor environment.

Since 1993, complaints about the poor air quality in the enclosed car park have been raised up among the community and might bring serious health effects to the drivers, passengers and labors working in these premises (Chan & Chow, 2003). Thus, this study will be focusing on the NO_x, SO_2 and O_3 formation at the enclosed car park. This is due to the lack of study on this subject while at the same time there are many studies for buildings, with different human activity and outdoor pollution conditions (Drakou, et al., 2000; Levy, et al., 1998; Loupa, et al., 2006; Weschler, et al., 1994). According to Ismail, et al., (2010) the effect of indoor air quality to children and elderly are severe than the ambient atmospheric air. The study also indicated that indoor air pollutants exposure is greater than outdoor exposure for many people (Weschler, et al., 1989). Indoor air pollutants have the potential to cause transient morbidity, disability, disease, and even death in extreme cases (Jones, 1999). Table 2 shows the range of sources of indoor air pollutants. They are emitted by fabric of buildings, and may also be a by product of the activities that are undertaken within them. Sources can be from the biological sources, combustion of substances, and infiltration from outside.

Table 2 : Major indoor pollutants and emission sources
(Spengler and Sexton, 1983)

Pollutant	Major emission sources
Allergens	House dust, domestic animals, insects
Asbestos	Fire retardant materials, insulation
Carbon dioxide	Metabolic activity, combustion activities, motor vehicles in garages
Carbon monoxide	Fuel burning, boilers, stove, gas or kerosene heaters
Formaldehyde	Particleboard, insulation, furnishings
Micro-organisms	People, animals, plants, air conditioning systems
Nitrogen dioxide	Outdoor air, fuel burning, motor vehicles in garages
Organic substances	Adhesive, solvents, building materials, volatilization, combustion, paints, tobacco smoke
Ozone	Photochemical reactions
Particles	Re-suspension, tobacco smoke, combustion products
Polycyclic aromatic hydrocarbons	Fuel combustion, tobacco smoke
Pollens	Outdoor air, trees, grass, weeds, plants
Radon	Soil, building construction material (concrete, stone)
Fungal spores	Soil, plants, foodstuffs, internal surfaces
Sulphur dioxide	Outdoor air, fuel combustion

Those who are exposed to the indoor air pollutant may face symptoms or a subjective consciousness of a disturbance in bodily function – somatisation (Wolkoff, 2013). Wolkoff (2013) reported that during the exposure of air pollutant, the symptoms may be persistent or transient. Some might be delayed and some will have immediate impact for example the odors perception. The example of the delayed symptoms is the sensory irritation in eyes and respiratory tract. However,

Wolkoff (2013) was only focusing on the office indoor air quality (IAQ) and VOCs, which are differ from the parameters of this study. Another term that is usually associated with the indoor air pollution is Sick Building Syndrome (SBS). Sick building is a term used to describe the workplace with poor ventilation where the excess above the expected numbers of occupants report the symptoms of fatigue, headache, nasal, eye or skin irritation, sore throat and cough (Bernstein, et al., 2008). Air quality factors that might be related to this symptoms are inadequate ventilation, poor building maintanence, increased dust, VOCs, and fungal contamination.

As for the underground car park, the concerns are more towards air quality and thermal environment which can give the direct impacts on the users (Ho, et al., 2004). Because of the enclosed nature, underground car parks usually have the limited interaction with the ambient. Thus, many design guides on mechanical ventilation are written by American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to fulfil the air quality and thermal comfort requirement for users in underground car park (Ho, et al., 2004). However, it is definitely difficult to estimate precisely the pollutant emissions and heat generation from moving vehicle in a car park. Ho, et al.(2004) reported that, the pollutants emissions are correlated with engines operating time. In a car park, engine operating time varies randomly and closely related to the numbers of cars entering/leaving the car park, degree of congestion and level of occupancy of the parking lots.

CHAPTER 3
METHODOLOGY

3.1 Location of Sampling Station

This study was conducted at the enclosed car park of PETRONAS Twin Tower. It is located in Kuala Lumpur which is a federal capital and most populous city in Malaysia. Designed for commercial offices and tourist attraction, this skyscraper had been established as the tallest building in the world from year 1998 until 2004. In this building, there are offices, shopping malls and also some tourist attractions such as the sky bridge and observation deck. PETRONAS Twin Tower is an 88 storey twin skyscraper with the height of 451.9 m. It was designed with 5400 parking bays on five levels of basement parking. Figure 6 shows the map to the sampling location.

Figure 6: Map of sampling location

The location of the sampling was at level 2 (P2) KLCC basement car park. Figure 1 and Figure 2 show the plan view of the P2 parking areas where the sampling was carried out and this area contains 1363 bays of car park. The spot that

is chosen is near to the path that is used by the users to go to the main road which is to Jalan Ramlee.

Figure 7: KLCC P2 Basement Car Park Plan View

3.2 Measurement Methods of Air Pollutants

The equipment used in this study was GrayWolf Advanced Sense Direct Sense; Toxic Gas Test Meters (Figure 8). It provides a descriptive name for files using the virtual keyboard. The data of the sampling can be recorded as a snap-shot data captures, or as trend logs over time. There are several sensors available for this equipment which are auto zeroing differential pressure, VOCs, CO_2, % RH, C/F, CO, O_3, NH_3, H_2S, NO, NO_2, SO_2, Cl_2, EtO, HCN, HF and HCL. The unit can be calibrated according to the requirement needed. The data collected can also be documented by using the Data Analysis and Generation software provided by GrayWolf. Besides that, the data also can be documented on laptops, notebooks, tablets or desktop PCs.

Figure 8: GrayWolf Advanced Sense Direct Sense; Toxic Gas Test Meters

The sampling of the air pollutants was carried out from 1st November 2013 to 5th November 2013 and 15th November to 17th November 2013. The data were collected for every one (1) minute interval from 0800 hour to 1700 hour. The data collected was tabulated for an hourly average by using Microsoft Excel. The sampling took place in the same location everyday so that the pattern of air pollutants concentration can be analyzed. The result for eight (8) days of sampling is categorized into weekday, weekend and public holiday.

3.3 Analysis of Data

3.3.1 Time series model

A time series is a sequence of data points, measured typically at successive points in time spaced at uniform time intervals. The data from the sampling were analyzed by using time series model, so that we can observe the trend of the NO_x, SO_2 and O_3 formation at the site in the variation of time. By using time series model, the data will be analyzed to produce a reliable statistics and characteristics.

3.4 Project Gantt Chart and Key Milestone

The project Gantt chart and key milestone for both final year project (FYP) 1 and FYP 2 is as in Table 3 and Table 4:

Table 3**:** The project Gantt chart and key milestone for FYP 1

NO	PROGRESS	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of project topic	■	■													
2	Preliminary research work		■	■	■	■										
3	Submission of extended proposal						●		MID SEMESTER BREAK							
4	Proposal defense									■	●					
5	Project work continues											■	■	■		
6	Submission of Interim Draft Report														●	
7	Submission of Interim Report															●

● Key milestone   ■ Process

Table 4: The project Gantt chart and key milestone for FYP 2

NO	PROGRESS	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continues	■	■	■	■	■	■	■								
2	Submission of Progress Report									●						
3	Project Work Continues															
4	Pre-SEDEX									■	■	■	■	■		
5	Submission of Draft Report												●			
6	Submission of Dissertation (soft bound)													●		
7	Submission of Technical Paper													●		
8	Oral Presentation															●
9	Submission of Project Dissertation (Hard Bound)															●

(MID SEMESTER BREAK — between columns 7 and 8)

● Key milestone   ■ Process

CHAPTER 4

RESULTS AND DISCUSSION

4.1   Introduction

The sampling of the air pollutants was carried out from 1st November 2013 to 5th November 2013 and 15th November to 17th November 2013. The data were collected for every one (1) minute interval from 0800 hour to 1700 hour. The data collected was tabulated for an hourly average by using Microsoft Excel. The sampling took place in the same location everyday so that the pattern of air pollutants concentration can be analyzed.
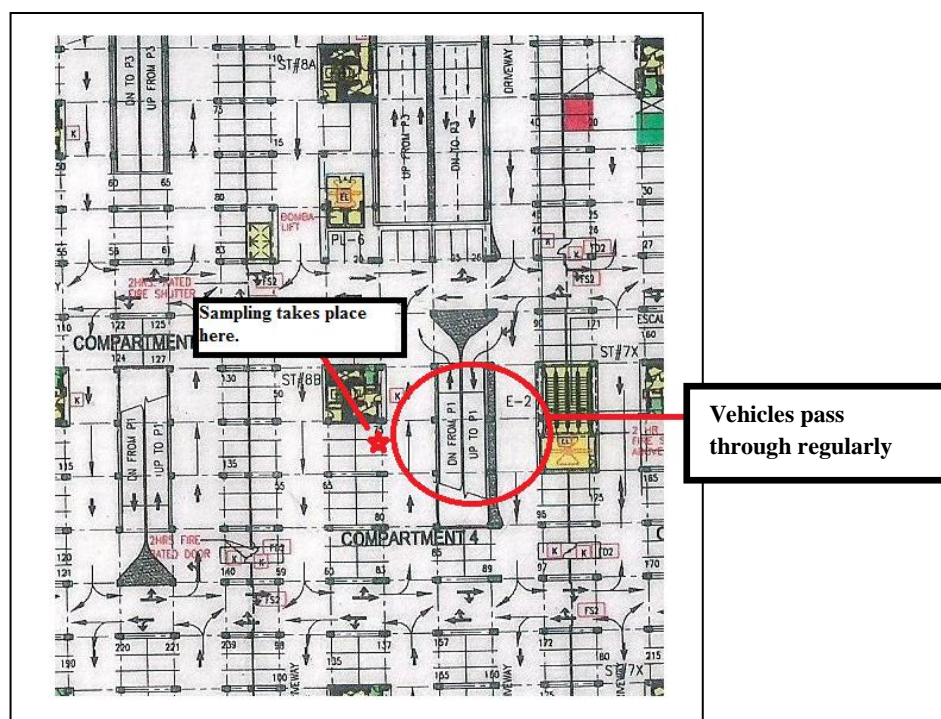

Figure 9: Location of Sampling

The result for eight (8) days of sampling is categorized into weekday, weekend and public holiday and tabulated in Table 5. The rest of the result is attached in Appendix A. The raw data received during the sampling was first being processed into data of average for every one hour. From the table, it was analyzed that the highest diurnal air pollutant concentration inside the basement car park is sulphur dioxide (SO_2). SO_2 is emitted directly by the vehicles that are passed through the car park. Besides SO_2, nitrogen oxides (NO_x) also released by the

exhaust vehicles. The result signifies that concentration of NO2 is much higher than NO even though NO is more dominant to be released by tailpipes.

Table 5: The Result of the Data Collection a) weekday b) weekend c) public holiday

a) weekday

Time	Sulphur Dioxide	Nitric Oxide	Ozone	Nitrogen Dioxide	Temperature
hour	ppm	ppm	ppm	ppm	°C
0800	0.00	0.00	0.00	0.00	0.00
0900	0.00	0.00	0.01	0.38	30.20
1000	0.00	0.00	0.00	0.23	31.60
1100	0.00	0.00	0.01	0.03	31.80
1200	0.00	0.00	0.01	0.08	32.90
1300	0.00	0.10	0.01	0.07	33.60
1400	0.00	0.30	0.02	0.14	34.60
1500	0.00	0.40	0.04	0.11	34.70
1600	0.00	0.40	0.03	0.00	34.60
1700	0.00	0.30	0.02	0.00	34.40

b) weekend

Time	Sulphur Dioxide	Nitric Oxide	Ozone	Nitrogen Dioxide	Temperature
hour	ppm	ppm	ppm	ppm	°C
0800	0.00	0.00	0.00	0.00	0.00
0900	0.20	0.00	0.01	0.50	30.79
1000	0.10	0.00	0.00	0.30	31.63
1100	0.10	0.00	0.00	0.14	32.46
1200	0.20	0.00	0.00	0.18	33.67
1300	0.20	0.10	0.01	0.16	34.35
1400	0.20	0.10	0.03	0.14	34.78
1500	0.20	0.20	0.03	0.03	34.79
1600	0.40	0.30	0.02	0.00	34.70
1700	0.30	0.30	0.01	0.00	34.60

c) public holiday

Time	Sulphur Dioxide	Nitric Oxide	Ozone	Nitrogen Dioxide	Temperature
hour	ppm	ppm	ppm	ppm	°C
0800	0.00	0.00	0.00	0.00	0.00
0900	0.30	0.01	0.01	0.10	29.00
1000	0.20	0.00	0.00	0.14	32.00
1100	0.30	0.00	0.00	0.06	32.90
1200	0.20	0.00	0.00	0.20	33.60
1300	0.30	0.10	0.01	0.01	34.00
1400	0.30	0.30	0.01	0.00	34.10
1500	0.40	0.40	0.01	0.00	34.50
1600	0.40	0.30	0.01	0.00	34.10
1700	0.30	0.30	0.01	0.00	34.50

4.2 Comparisons of Air Pollutants Concentration on Weekday, Weekend and Public Holiday.

4.2.1 Concentration of Air Pollutants on Weekday.

Figure 10 represents the concentration of air pollutants on weekday. The result for SO_2 on weekdays might encounter some technical error as the concentration was 0.00 ppm for the whole sampling duration from 0800 hour to 1700 hour. SO_2 is one of the primary pollutants of motor vehicles thus there should be existence of SO_2 in the enclosed car park. It can be observed that the emission of NO in the morning was 0 ppm and started to increase at 1200 hour until it reached the highest concentration at 1400 hour to 1500 hour with the concentration of 0.40 ppm.
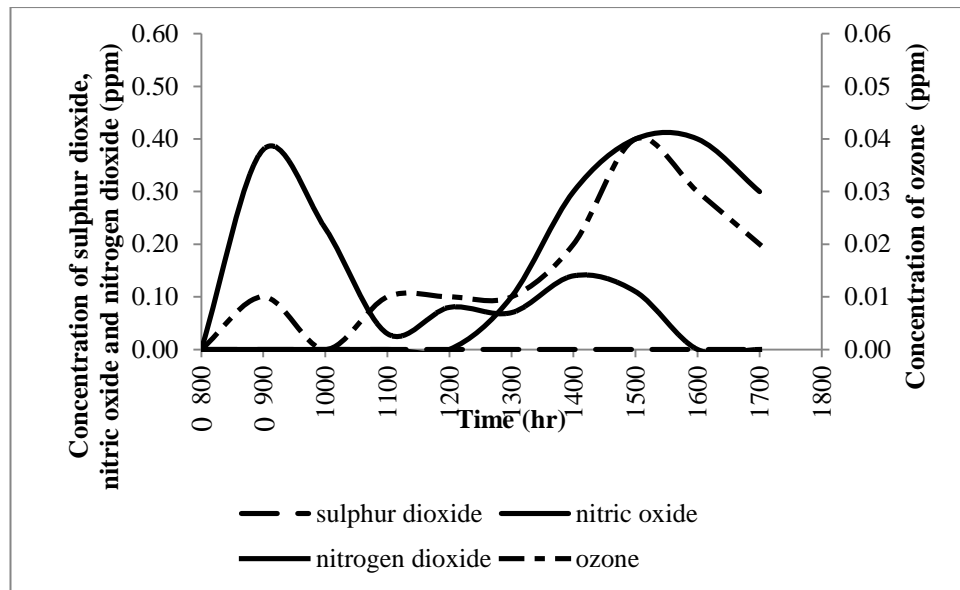
Figure 10: Concentration of Air Pollutants on Weekday

The concentration of NO_2 was at the highest during the morning and started to decrease until it reached 0 ppm at 1600 hour. The highest reading of NO_2 recorded during the study was 0.38 ppm. This value has exceeded the standard limit of Malaysian Ambient Air Quality Guideline (MAAQG) which is 0.17 ppm (average time of 1 hour) and 0.04 ppm (average time of 8 hour). Result for O_3 indicated that the air pollutant concentration during the morning was lesser to be compared with the evening. The concentration increased inconsistently until 1500 hour and started to decrease until 1700 hour. The concentration of O_3 for weekday is within the standard limit of MAAQG which is 0.10 ppm (average time 1 hour) and 0.06 ppm (average time 8 hour). The result of the study for weekday shows that only NO_2 has exceeded the limit of MAAQG. Figure 11 also indicated that the relationship between NO_2 and O_3 was inversely proportional. When the concentration of NO_2 decreased, the concentration of O_3 started to increase. The result for weekday shows the existence of O_3 in the sampling area.

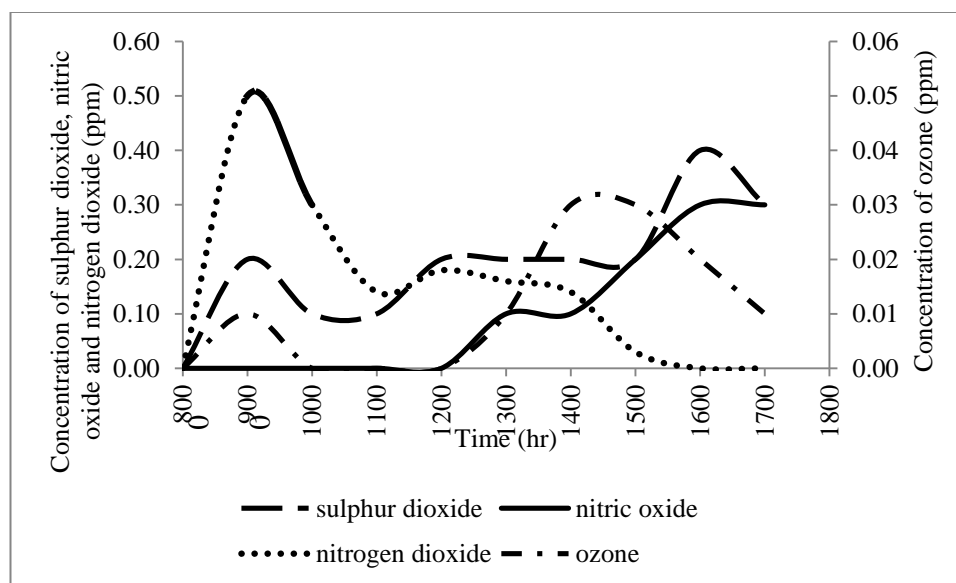### 4.2.2 Concentration of Air Pollutants on Weekend.

Figure 11: Concentration of Air Pollutants on Weekend

Similar with the result from the weekday, NO_2 shows the highest reading among all the pollutants examined in this study. The highest concentration is recorded during the morning which is at 0800 hour. It was then decreased gradually until 1100 hour. The concentration of NO_2 was then decreased until it reached zero at 1500 hour. Figure 11 also indicated that the reading of NO_2 has exceeded the standard limit of MAAQG. The reading of SO_2 concentration shows a reasonable reading for the weekend. The concentration of SO_2 decreased and increased gradually until 1700 hour. Based on the observation during the study, huge amount of vehicles were passing through the road that connected to the highway during the weekend. This might be a factor for the concentration of SO_2 to be high and the highest concentration of SO_2 was at 1600 hour with the reading of 0.4 ppm. This reading was totally exceeded the standard limit of MAAQG (0.13 ppm for average of 1 hour and 0.04 ppm for average time of 24 hour) and can harm the safety of the users and workers of the basement car park. In the morning, there was no trace of NO in the basement. However, starting from 1200 hour, the concentration started to increase and reach the peak at 1600 hour with the reading of 0.3 ppm. The concentration of NO was starting to increase when the concentration NO_2 decreases. During the morning, there was no reading of NO recorded in the study area. After

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being analyzed, the pattern was as such because in the morning, the NO released was immediately oxidized into NO_2. However, the reading was increasing with time as NO was not oxidized into NO_2. O_3 concentration during the weekend shows the highest reading at 1400 hour with the concentration of 0.03 ppm. The recorded concentration of O_3 for the whole sampling day is still under the standard limit of MAAQG which 0.1 ppm for average time of 8 hour and 0.06 ppm for average time of 1 hour.

4.2.3   The Concentration of Air Pollutants on Public Holiday

The trend of SO_2 concentration during public holiday is practical, similar with the result during the weekend. For weekend and public holiday, the trend of the concentration shows that the concentration of SO_2 was increasing inconsistently. The result can be considered valid because the result during the weekend and public holiday showed similar pattern of data.
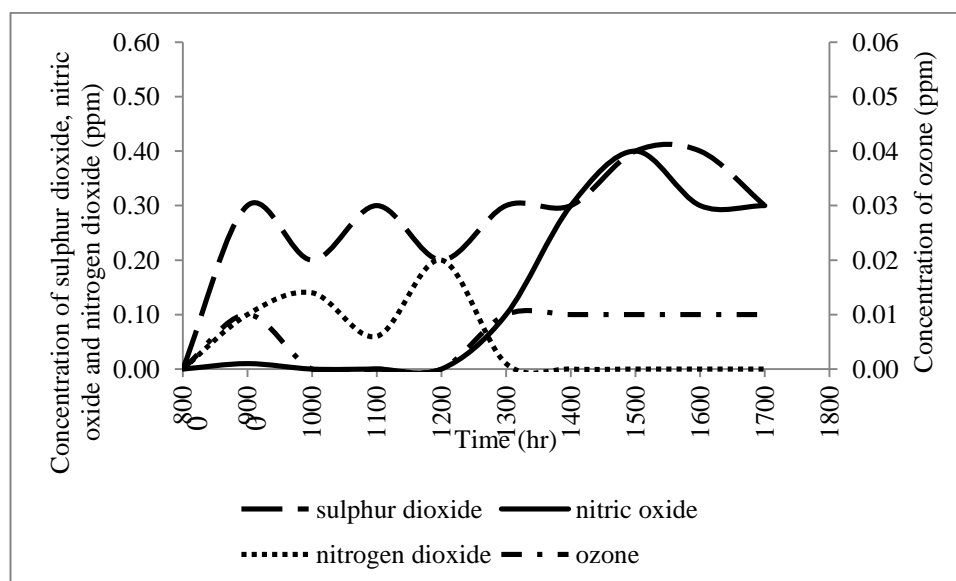

Figure 12: Concentration of Air Pollutants on Public Holiday

However, the concentration for NO_2 was differs with the previous sampling day. The concentration was lower than during weekday and weekend. The highest concentration was recorded at 1200 hour with the reading of 0.2 ppm which was also lower than the highest reading from the previous days. Conversely, the reading of NO was higher to be compared with the reading from weekday and weekend. The concentration of NO also shows the highest reading among the four pollutants. On

the other hand, the result for O_3 was lower than the weekday and weekend. It shows that for day 5, only some of the NO was converted to NO_2 which is the precursor for O_3 formation. Consequently, there is lower concentration of O_3 during public holiday.

4.2.4 Discussion

The result for SO_2 denoted an irregularity during the study. There was no SO_2 detected by the GrayWolf Advanced Sense Direct Sense; Toxic Gas Test Meters for the weekday. Instead, the results only appeared for weekend and public holiday. The result for the weekend illustrates that the concentration of SO_2 was increasing inconsistently. The result during weekday might encounter some error because it is not possible for the result to be zero throughout the diurnal sampling because SO_2 is one of the primary pollutants emitted by motor vehicles. However, for the rest of the day, the result can be considered valid because both days show similar pattern of data.

Figure 10, 11 and 12 illustrated that the concentrations of NO_2 were the highest during the morning. This is due to the amount of the vehicles passing through the basement car to the highway. However, as time passed by, the concentration of NO_2 become lessen. The similar morning peaks of NO_2 corresponded fairly well with the morning traffic rush hours were observed by Ghazali, et al., (2009) and Beig, et al., (2013).

The result also showed that the concentration of NO_2 was inversely proportional with the concentration of NO. During the morning, the concentration of NO_2 was higher than NO. The concentration of NO_2 was gradually decreasing by time. On the contrary, the concentration of NO is the lowest during the morning and kept increasing by time. Thus, from the graph, it signifies that the NO is oxidized into NO_2.

The concentration of O_3 shows regularity for each day of the sampling. The data recorded shows that for every sampling day, O_3 concentration is increasing and its concentration is at the highest during the afternoon and then drop steadily to a low in the evening except for public holiday. According to Sadanaga et al. (2008), the O_3 concentration have a maximum value between 1300 hour to 1600 hour and a minimum value in early morning (Beig, et al., 2013) which is similar with the result of this study. However, during public holiday, the diurnal reading signifies that at 1200 hour, the O_3 concentration started to remain constant and slightly decreasing until the end of sampling hour. Nevertheless, the highest concentration recorded during the sampling which is 0.04 ppm is still within the safe range of MAAQG limit for O_3 which is 0.06 ppm for an average of 8 hour exposing time.

The result from the sampling shows that O_3 can exist in an enclosed environment. However, there are a few possibilities that can cause this to happen. The first possibility is that the outdoor ozone diffused into the basement car park through the entrance and stays in the indoor environment. Second possibility is the car park itself and the furnishings emit the hazardous chemicals. The last possibility is the ozone is produced inside the basement car park with the absence of sunlight but with the presence of UV rays from the lighting.

Since O_3 concentrations depend on NO/NO_2 ratio, decreasing of NO_2 leads to increasing in O_3 concentration and vice versa (Bronniman and Neu, 1996). Based on Figure 10, 11 and 12, the concentration of NO_2 is decreasing when the O_3 reading started to rise with time. NO_2, which is the precursor of O_3 has been used up in the process of reaction of producing O_3. It is also possible that during the morning, the O_3 produced was immediately reacted with NO to produce NO_2 and oxygen (O_2). During the morning, the concentration of NO_2 was the highest while for NO and O_3, their concentration in the morning was to be compared with other pollutants. As the time passed, the concentrations of NO_2 decreased while the concentration of NO and O_3 kept increasing. O_3 was produced directly by photolysis as illustrated in equation (7). The oxygen atom, O rapidly recombined with molecular oxygen, O_2 to produce

O_3. This reaction was compensated by the equation of NO with O_3 via equation (9) (Pudasainee, et al., 2010).

The use of weekend-weekday emission rate has been suggested as alternative to display the modelling of changes of emissions (National Research Council, 1991). The lower NO concentrations on weekends are considered to be the effect of ozone destruction as stated by Bronniman and Neu (1996) in their study. The concentration of O_3 tends to be higher in weekend compared to weekday and is called the ozone "weekend effect" (Qin et al., 2004; Sadanaga et al., 2008). In this study, the concentration of O_3 is higher during weekday to be compared to weekend. Only the concentration of NO_2 reached the maximum in weekend.

From Figure 10, it can be observed that the concentrations of air pollutants are higher during the morning as a lot of vehicles used the car park and passed through the road. The concentrations started to decrease and increased again in the afternoon starting from 1300 which was during lunch hour until 1700 where the workers started to go back from their work place. However, in Figure 11 and Figure 12, the distributions of concentrations of air pollutants are very much constant and concentrated throughout the day. This showed that on weekend and public holiday, there were a lot of vehicles used and passed through the car park for the whole days.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The effect of indoor air pollution cannot be taken by granted. The effects are dangerous especially to human health. This study examined the concentrations of air pollutants in an enclosed car park area and the data was analyzed to find out whether the concentrations of the pollutants are at the dangerous level. The concentration of air pollutants during the weekend showed a consistent distribution of air pollutant throughout the day. From this study, the objectives of the study have been achieved. Firstly, the concentration of NO_x will be the highest among the three air pollutants. Secondly, there was formation of O_3 recorded at the sampling area. The O_3 might be infiltrated from the outside surrounding into the car park and there are also several other factors that can cause O_3 emissions. Lastly, the result achieved from the sampling had been tabulated and analyzed in time series model. By using this model, we can see clearly the selected air pollutants' trend over time. The concentration of NO_2 and SO_2 recorded in this study has exceeded the standard limit set by MAAQG thus action might have to be taken by the KLCC parking management to enhance the air quality in the enclosed car park.

There is no regulation and guideline given for indoor ambient air quality thus the data from this study can be used by other researchers to continue doing researches on indoor air quality. Later, a guideline can be proposed so that any party concern can make sure that their indoor building environment is safe for the users. This study can be more accurate if some modifications and addition done to the sampling such as:-

1)   use equipment that can measure the UV radiation
2)   take the air sample from different areas of the enclosed car park
3)   increase the duration of the sampling
4)   measure the volume of vehicles in the car park

REFERENCES

Abdul-Wahab, S. A., Bakheit, C. S., & Al-Alawia, S. M. (2005). Principal component and multiple regression analysis in modelling of ground-level ozone and factors affecting its concentrations. *Environmental Modelling & Software 20 (2005) 1263–1271* .

Afroz, R., Hassan, M. N., & Ibrahim, N. A. (2003). Review of air pollution and health impacts in Malaysia. *Environmental Research 92* , 1-7.

Awang, M. B., Jaafar, A. B., Abdullah, A. M., Ismail, M. B., Hassan, M. N., Abdullah, R., et al. (2000). Air quality in Malaysia: Impacts, management issues and future challenges. *Respirol 5:183–196. doi:10.1046/j.1440-1843.2000.00248.x* .

Azmi, S. Z., Latif, M. T., Ismail, A. S., Juneng, L., & Jemain, A. A. (2009). Trend and status of air quality at three different monitoring stations in Klang Valley, Malaysia. *Air Qual Atmos Health (2010)* , 1-12.

Banan, N., & Latif, M. T. (2011). An Investigation into Ozone Concentration at Urban and Rural Monitoring Stations in Malaysia. *World Academy of Science, Engineering and Technology 53 2011* .

Bernstein, J. A., Alexis, N., Bacchus, H., Bernstein, I. L., Fritz, P., Horner, E., et al. (2008). The health effects of nonindustrial indoor air pollution. *American Academy of Allergy, Asthma & Immunology* , 4.

Bhatia, S. (2007). *Textbook of Air Pollution and Its Control.* New Delhi : Atlantic Publishers & Distributors (P) LTD.

Bidani, & Postlethwait. (1990). Reactive uptake governs the pulmonary air space removal of inhales nitrogen dioxide. *Journal of Applied Physiology 68* , 594-603.

Carvalho, A. O., & Freitas, M. d. (2011). Sources of Trace Elements in Fine and Coarse Particulate Matter in a Sub-urban and Industrial Area of the Western European Coast. *Urban Environmental Pollution 2010* , 1.

Chan, M., & Chow, W. (2003). Car park ventilation system: performance evaluation. *Building and Environment* .

Chan, M., Burnett, J., & Chow, W. (1997). Energy Use for Ventilation Systems in Underground Car Park. *Building and Environment* .

Chow, W. K. (1995). On Ventilation Design for Car Parks. *Tunnelling and Underground Space Technology* , 1-21.

Colls, J. (2002). *Air Pollution.* London: Spon Press.

Colvile, R., Hutchinson, E., Mindell, J., & Warren, R. (2001). The transport sector as a source of air pollution. *Atmospheric Environment 35* , 3.

Danielsen, E. F. (1968). Stratospheric-Tropospheric Exchange Based on Radioactivity, Ozone and Potential Vorticity. *J. Atmos. Sci. 25, 502-518.*

Dominick, D., Juahir, H., Latif, M. T., Zain, S. M., & Aris, A. Z. (2012). Spatial assessment of air quality patterns in Malaysia using multivariate analysis. *Atmospheric Environment 60* , 5.

Drakou, G., Zerefos, C., Ziomas, I., & Ganitis, V. (n.d.). Numerical Simulation of Indoor Air Pollution Levels in a Church and in a Museum in Greece. *Studies in Conservation, 45 (2). pp. 85-94. ISSN 00393630* .

Environmental Protection Agency (EPA). (2007). Retrieved March 2013, from http://www.epa.gov

Felzer, B. S., Cronin, T., Reilly, J. M., Melillo, J. M., & Wang, X. (2007). Impacts of ozone on trees and crops. *C. R. Geoscience 339, 784–798* .

Fenger, J. (2009). Air pollution in the last 50 years – From local to global. *Atmospheric Environment 43* , 1-10.

Flachsbart, P. (1999). Human exposure to carbon monoxide from mobile sources. *Chemosphere: Global Change Science 1* , 1.

Ghazali, N. A., Ramli, N. A., Yahaya, A. S., Yusof, N. F., Sansuddin, N., & Madhoun, W. A. (2009). Transformation of nitrogen dioxide into ozone and prediction of ozone concentrations using multiple linear regression techniques.

Guicherit, R., & Roemer, M. (2000). Tropospheric ozone trends. *Chemosphere - Global Change Science 2, 167-183* .

Gurjar, B. R., Molina, L. T., & Ojha, C. S. (2010). *Air Pollution.* New York: CRC Press.

Gurjar, B., Butler, T., Lawrence, M., & Lelieveld, J. (2008). Evaluation of emissions and air quality in megacities. *Atmos Environ 42:1593–1606. doi:10.1016/j.atmosenv.2007.10.048* .

Helaleh, M. I., Ngudiwaluyo, S., Korenaga, b., & Tanaka, K. (2002). Development of passive sampler technique for ozone monitoring. Estimation of indoor and outdoor ozone concentration. *Talanta 58 (2002) 649-/659* .

Heritage, D. O. (2005). Air Quality Fact Sheet. 1.

Ho, J., Xue, H., & Tay, K. (2004). A field study on determination of carbon monoxide level and thermal environment in an underground car park. *Building and Environment 39* , 1.

Ilyas, S. Z., Khattak, A. I., Nasir, S. M., Qurashi, T., & Durrani, R. (2009). Air pollution assessment in urban areas and its impact on human health in the city of Quetta, Pakistan. *Clean Technol Environ Policy* , 1-9.

Ismail, M., Sofian, N. Z., & Abdullah, A. M. (2010). Indoor Air Quality in Selected Samples of Primary Schools in Kuala Terengganu, Malaysia. *EnvironmentAsia 3(special issue) (2010) 103-108* .

Ismail, M., Suroto, A., Ibrahim, T. A., & Abdullah, A. M. (2011). Tropospheric Ozone Trend in the Muda Irrigation Area, Kedah. *Journal of Physical Science, Vol. 22(2), 87–99* .

J.Weschler, C., V.Naik, D., & C.Shields, H. (1989). Indoor Ozone Exposures Resultiong from the Infiltration of Outdoor Ozone.

James, A., & Martin, A. (1952). Gas-Liquid Partition Chromatography: The Separation and Micro-Estimation of Volatile Fatty Acids from Formic Acid to Dodecanoic Acid . *Biochem. J. 50* , 679-680.

Jones, A. P. (1999). Indoor air quality and health. *Atmospheric Environment 33* , 1-30.

Kampa, M., & Castanas, E. (2007). Human Health Effects of Air Pollution. *Environmental Pollution* , 1.

Lee, H., Kim, E. K., Kang, S. W., Kim, J. H., Hwang, H. J., & Kim, T.-i. (2013). Effects of ozone exposure on the ocular surface. *Free Radical Biology and Medicine 63, 78 – 89* .

Levy, J., Lee, K., Spengler, J., & Yanagisawa, Y. (1998). Impact of residential nitrogen dioxide exposure on personal exposure: an international study. *J Air Waste Manag Assoc.;48(6):553-60* .

Loupa, G., Charpantidou, E., Kioutsioukis, I., & Rapsomanikis, S. (2006). Indoor microclimate, ozone and nitrogen oxides in two medieval churches in Cyprus. *Atmospheric Environment 40 , 7457–7466* .

Mage, D., Ozolins, G., Peterson, P., Webster, A., Orthofer, R., Vandeweerd, V., et al. (1996). Urban air pollution in megacities of the world. *Atmos Environ 30:681–686. doi:10.1016/1352-2310(95)00219-7* .

Mckee, D. J. (1994). *Tropospheric Ozone.* Florida: CRC Press, Inc.

Nardo, D. (1991). Ozone. In *What is Ozone* (pp. 16-17). San Diego: Lucent Books, Inc.

Organization, W. H. (2005). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. 22.

Ozden, O., Dogeroglu, T., & Kara, S. (2008). Assessment of ambient air quality in Eskişehir, Turkey. *Environ Intern 34:678–687.doi:10.1016/j.envint.2007.12.016* .

Paul, K., Hull, T., Lebek, K., & Stec, A. (2008). Fire smoke toxicity: The effect of nitrogen oxides. *Fire Safety Journal 43* , 4-5.

Percy, K., & Feretti, M. (2003). Air Pollution and Forest Health: Toward New Monitoring Concepts . *Environmental Pollution130(2004) 113-126* , 1.

Popescu, F., & Ionel, I. (2010). *Anthropogenic Air Pollution Sources.* University "Politehnica" from Timisoara Romania.

Poschl. (2005). Atmospheric Aerosols: Composition, Transformation, Climate and Health Effects .

Pudasainee, D., Sapkota, B., Bhatnagar, A., Kim, S.-H., & Seo, Y.-C. (2010). Influence of weekdays, weekends and bandhas on surface ozone in Kathmandu valley. *Atmospheric Research* , 153.

Qin, Y., Tonnesen, G., & Wang, Z. (2004). Weekend/weekdaydifferences of ozone, NO_x, Co, VOCs, PM_{10} and the light scatter during ozone season in southern California. *Atmospheric Environment* , 1.

Ramli, N. A., Ghazali, N. A., & Yahya, A. S. (2010). Diurnal Fluctuations of Ozone Concentrations and its Precursors and Prediction of Ozone Using Multiple Linear Regressions. *Malaysian Journal of Environmental Management 11(2) (2010): 57-69* .

Raub, J. (1999). Health effects of exposure to ambient carbon monoxide. *Chemosphere: Global Change Science 1* , 1.

Riga-Karandinos, A.-N., & Saitanis, C. (2005). Comparative assessment of ambient air quality in two typical Mediterranean coastal cities in Greece. *Chemosphere: 1125–1136. doi:10.1016/j.chemosphere.2004.11.059* .

Sadanaga, Y., Shibata, S., Hamana, M., Takenaka, N., & Bandow, H. (2008). Weekday/weekend difference of ozone and its precursors in urban areas of Japan, focusing on nitrogen oxides and hydrocarbons. *Atmospheric Environment* , 1.

Shuhaili, A. F., Ihsan, S. I., & Faris, W. F. (2013). Air Pollution Study of Vehicles Emission In High Volume Traffic: Selangor, Malaysia as Case Study. *WSEAS TRANSACTIONS on SYSTEMS* , 1-18.

U.S. Environmental Protection Agency. (2012, October). Retrieved June Friday, 2013, from http://www.epa.gov/airquality/carbonmonoxide/

U.S. Environmental Protection Agency. (2012, November). Retrieved June Friday, 2013, from http://www.epa.gov/airquality/ozonepollution/basic.html

U.S. Environmental Protection Agency. (2013). Retrieved June Friday, 2013, from http://www.epa.gov/airquality/urbanair/

Weschler, C. J., Shields, H. C., & Naik, D. V. (1994). Indoor Chemistry Involving O_3, NO, and NO_2 as Evidenced by 14 Months of Measurements at a Site in Southern California. *Environmental Science and Technology (impact factor: 5.23). 11/1994; 28(12):2120-32. DOI:10.1021/es00061a021* .

WHO Regional Office for Europe . (2000). Particulate Matter. In *Air Quality Guidelines - Second Edition* (pp. 1-40). Copenhagen .

Wolkoff, P. (2013). Indoor air pollutants in office environments: Assessment of comfort, health, and performance. *International Journal of Hygiene and Environmental Health 216* , 2.

World Health Organization. (2013). Retrieved June Monday, 2013, from http://www.who.int/topics/air_pollution/en/index.html
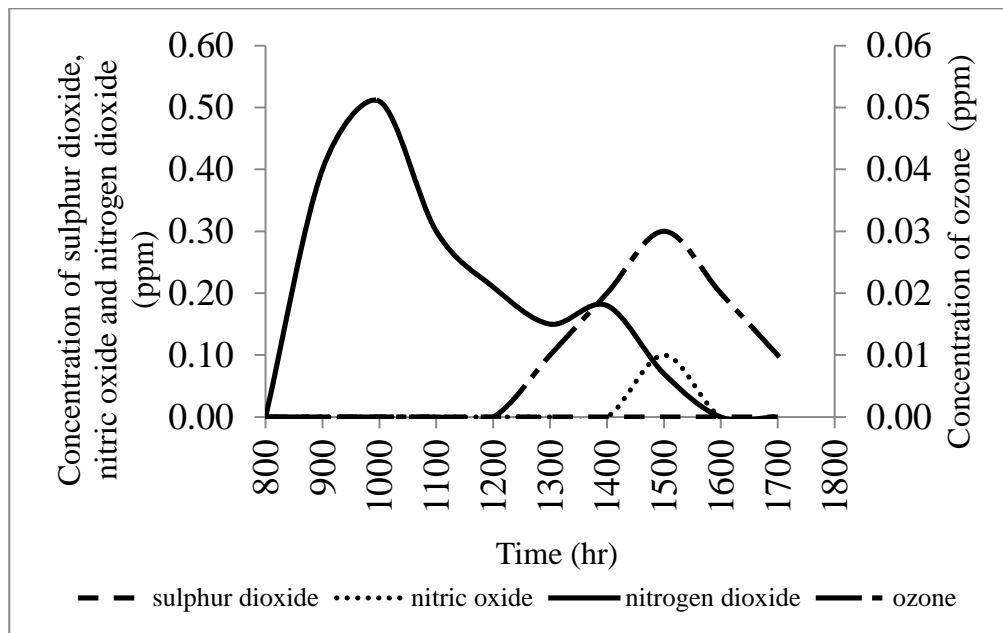
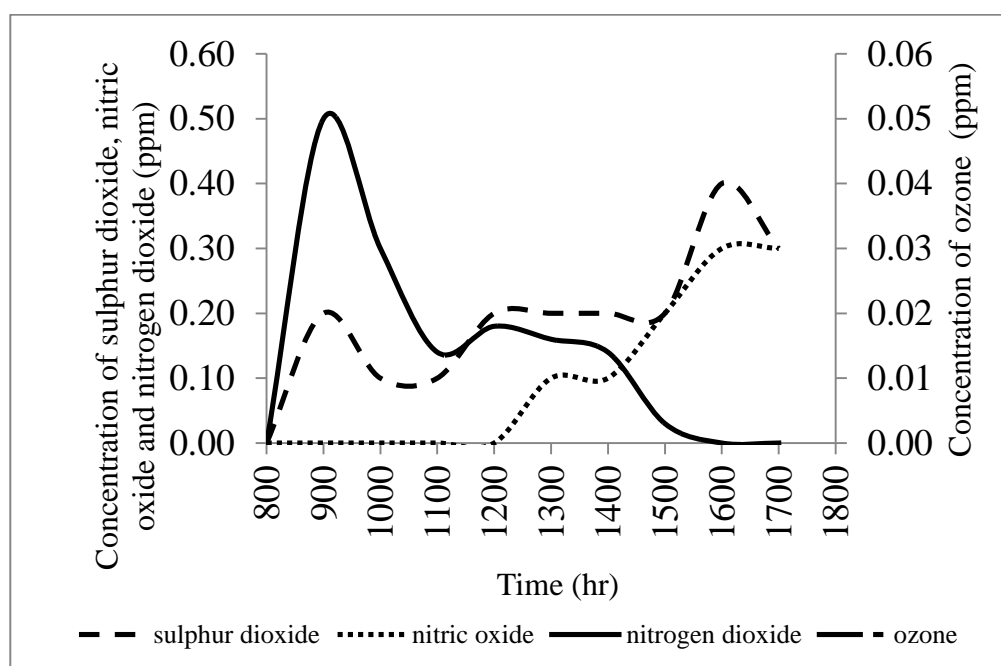# APPENDICES

APPENDIX A

Result for 8 days of sampling

DAY 1

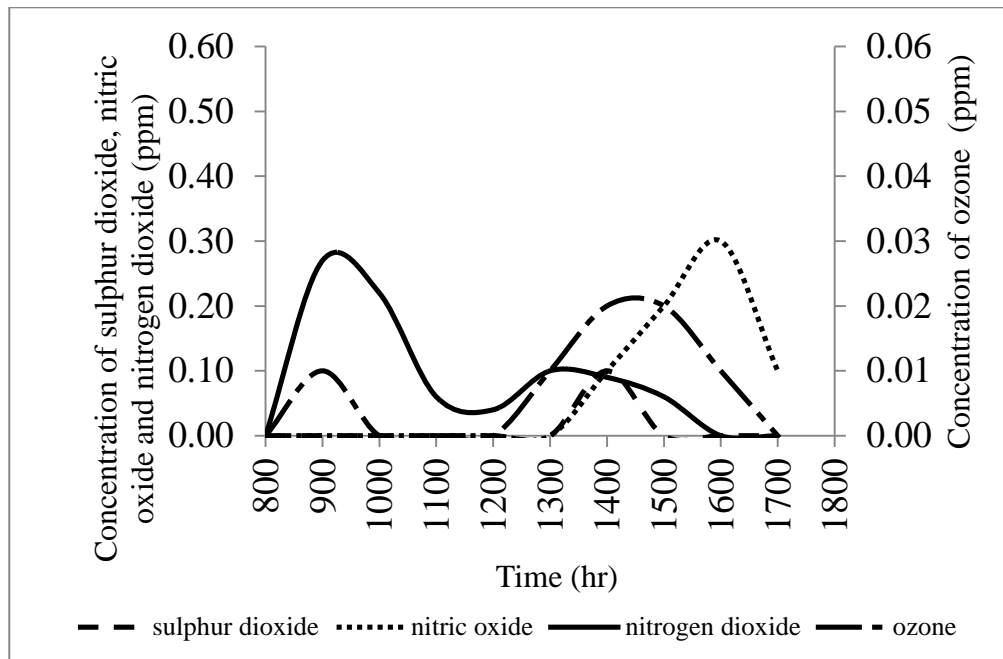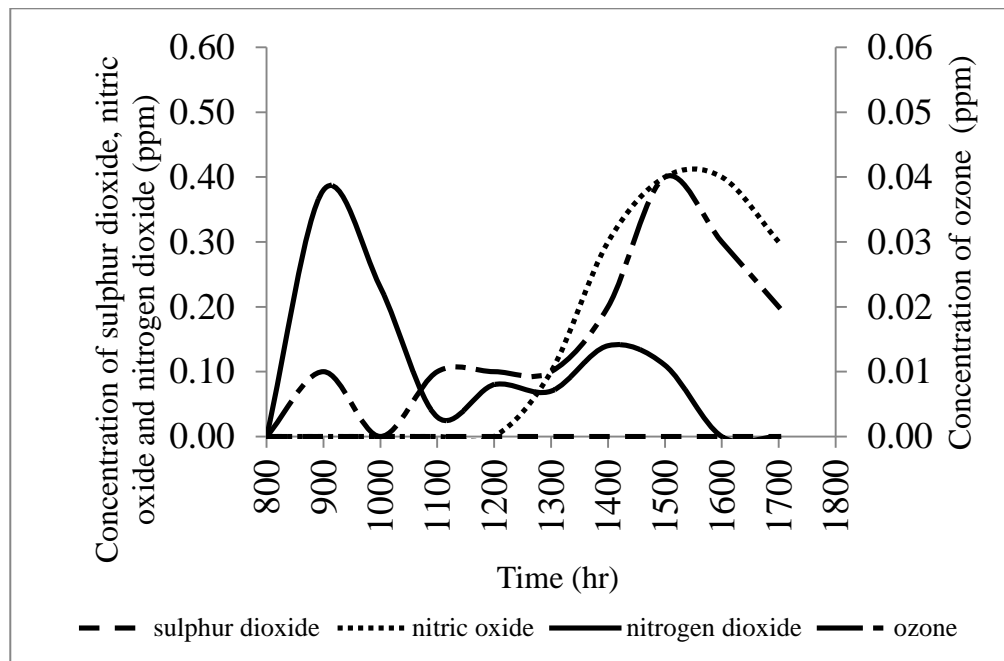| Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.00	0.40	31.00
1000	0.00	0.00	0.00	0.51	32.40
1100	0.00	0.00	0.00	0.30	33.30
1200	0.00	0.00	0.00	0.21	33.20
1300	0.00	0.00	0.01	0.15	34.10
1400	0.00	0.00	0.02	0.18	34.40
1500	0.00	0.10	0.03	0.07	34.20
1600	0.00	0.00	0.02	0.00	32.30
1700	0.00	0.00	0.01	0.00	33.70

DAY 2

Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.20	0.00	0.01	0.50	30.79
1000	0.10	0.00	0.00	0.30	31.63
1100	0.10	0.00	0.00	0.14	32.46
1200	0.20	0.00	0.00	0.18	33.67
1300	0.20	0.10	0.01	0.16	34.35
1400	0.20	0.10	0.03	0.14	34.78
1500	0.20	0.20	0.03	0.03	34.79
1600	0.40	0.30	0.02	0.00	34.70
1700	0.30	0.30	0.01	0.00	34.60

DAY 3

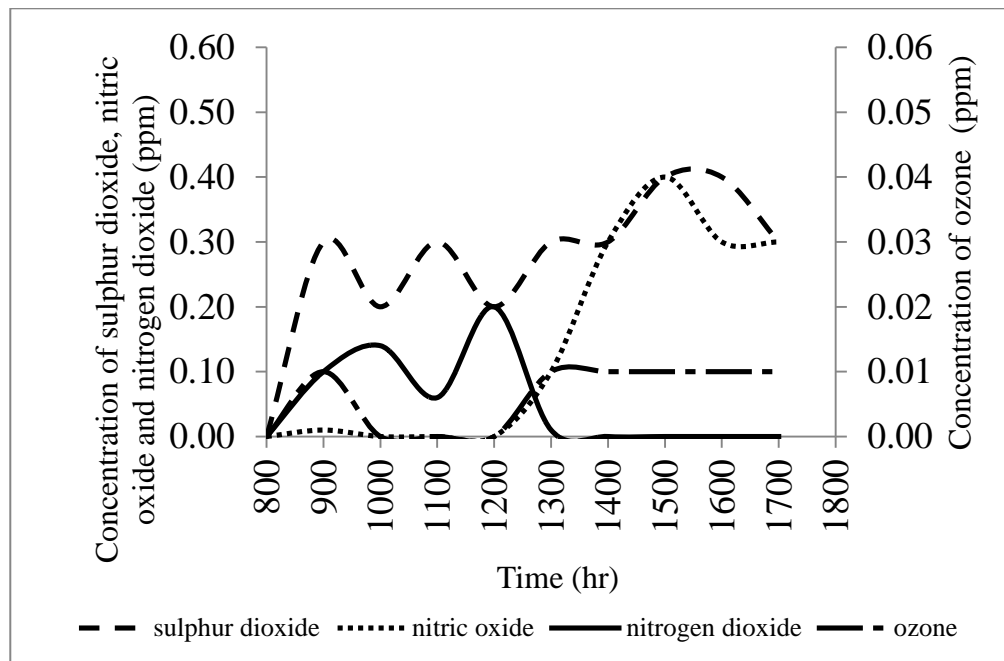| Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.01	0.27	30.20
1000	0.00	0.00	0.00	0.22	31.20
1100	0.00	0.00	0.00	0.06	31.30
1200	0.00	0.00	0.00	0.04	32.80
1300	0.00	0.00	0.01	0.10	33.60
1400	0.10	0.10	0.02	0.09	34.20
1500	0.00	0.20	0.02	0.06	34.20
1600	0.00	0.30	0.01	0.00	34.20
1700	0.00	0.10	0.00	0.00	34.40

DAY 4

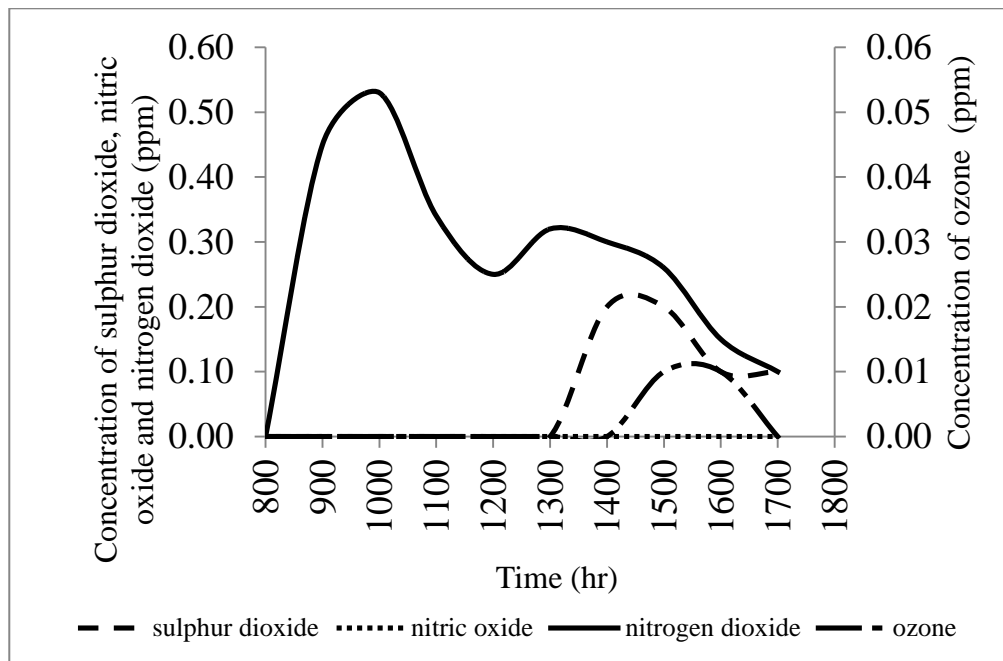| Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.01	0.38	30.20
1000	0.00	0.00	0.00	0.23	31.60
1100	0.00	0.00	0.01	0.03	31.80
1200	0.00	0.00	0.01	0.08	32.90
1300	0.00	0.10	0.01	0.07	33.60
1400	0.00	0.30	0.02	0.14	34.60
1500	0.00	0.40	0.04	0.11	34.70
1600	0.00	0.40	0.03	0.00	34.60
1700	0.00	0.30	0.02	0.00	34.40

DAY 5

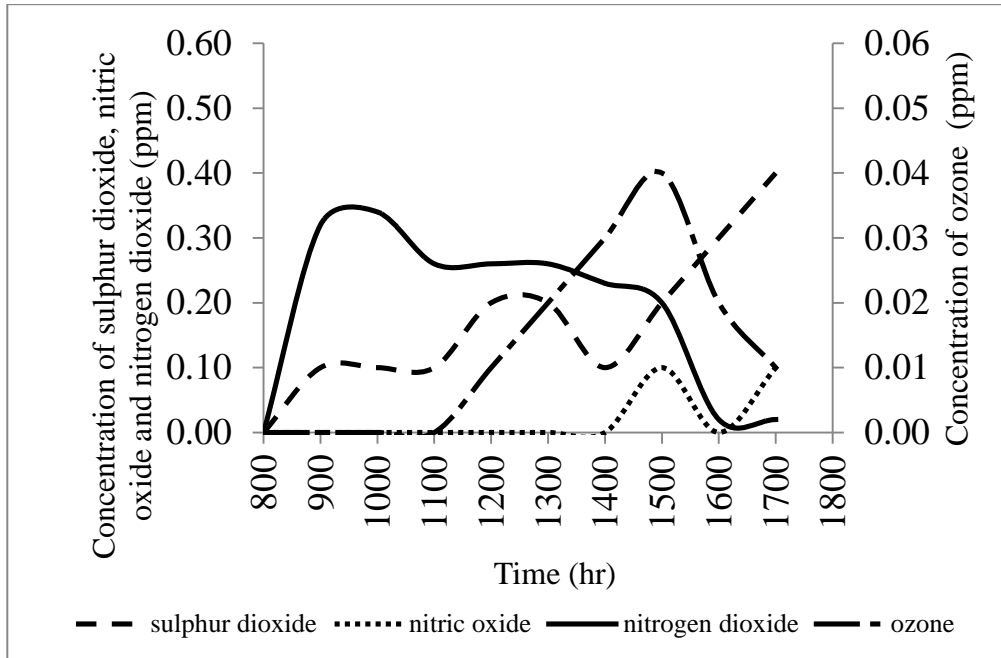| Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.30	0.01	0.01	0.10	29.00
1000	0.20	0.00	0.00	0.14	32.00
1100	0.30	0.00	0.00	0.06	32.90
1200	0.20	0.00	0.00	0.20	33.60
1300	0.30	0.10	0.01	0.01	34.00
1400	0.30	0.30	0.01	0.00	34.10
1500	0.40	0.40	0.01	0.00	34.50
1600	0.40	0.30	0.01	0.00	34.10
1700	0.30	0.30	0.01	0.00	34.50

DAY 6

Time	SO₂	NO	O₃	NO₂	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.00	0.45	32.10
1000	0.00	0.00	0.00	0.53	33.60
1100	0.00	0.00	0.00	0.34	33.90
1200	0.00	0.00	0.00	0.25	34.10
1300	0.00	0.00	0.00	0.32	34.30
1400	0.20	0.00	0.00	0.30	34.80
1500	0.20	0.00	0.01	0.26	35.00
1600	0.10	0.00	0.01	0.15	35.00
1700	0.10	0.00	0.00	0.10	35.00

DAY 7

Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.10	0.00	0.00	0.32	31.60
1000	0.10	0.00	0.00	0.34	33.20
1100	0.10	0.00	0.00	0.26	33.90
1200	0.20	0.00	0.01	0.26	34.50
1300	0.20	0.00	0.02	0.26	35.00
1400	0.10	0.00	0.03	0.23	35.20
1500	0.20	0.10	0.04	0.20	35.30
1600	0.30	0.00	0.02	0.02	34.60
1700	0.40	0.10	0.01	0.02	34.70

DAY 8

Time	SO$_2$	NO	O$_3$	NO$_2$	Temp
800	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.00	0.15	29.80
1000	0.00	0.00	0.00	0.22	32.50
1100	0.00	0.00	0.00	0.20	33.20
1200	0.00	0.00	0.00	0.20	33.70
1300	0.00	0.00	0.00	0.21	34.30
1400	0.00	0.10	0.00	0.18	34.50
1500	0.00	0.10	0.01	0.09	34.80
1600	0.00	0.10	0.01	0.06	34.90
1700	0.00	0.30	0.01	0.05	35.00