**Profiling of Nitrogen Dioxide ($NO_2$) and Ozone ($O_3$) in an Enclosed Car Park**

by

Nur Zawani binti Zahari

14337

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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(CIVIL)

Approved by,

_____

(Dr Nurul Izma binti Mohammed)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2014

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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NUR ZAWANI BINTI ZAHARI

# ABSTRACT

Air is one of an essential elements for human being to survive. Air pollution originated anthropogenic (man-made) and non-anthropogenic can give adverse effects to human health, environment and ecosystem. It is caused by high concentration of air pollutants present in the atmosphere that emitted directly from its sources or from the reaction between the pollutants itself. Emission and production of pollutants reduces the air quality of both indoor and outdoor environment. Air pollution has been mostly deteriorated by traffic emissions with increasing number of vehicles in the road or public highway and thus lead to high demand of parking area facilities in the city.

Nowadays, rapid industrial development in Malaysia cause shortage of land to sustain the facilities area and hence resulted in construction of high-rise commercial and industrial buildings with enclosed car park system beneath or above the buildings. The nature of air in enclosed car park is much differ from indoor, ambient environment or open-space area due to its confined space and poor ventilation flow system. This study is conducted mainly to determine the air quality in the enclosed car park area affected by reaction of pollutants and emission from vehicles that going in and out from the area.

Concerns of this study is the formation of ozone ($O_3$) due to the relationship between nitric oxide (NO), nitrogen dioxide ($NO_2$) and presence of ultraviolet energy. Since there is no direct sunlight in enclosed car park, ultraviolet energy may be emitted from other sources such as lights from the car. The objectives of this study is to identify the concentration level of $NO_2$ and possibility of $O_3$ formation in an enclosed car park with the absence of sunlight as the source of ultraviolet energy. Other than that, data is collected by using AQM 60 equipment and the relationship between $NO_2$ , $O_3$ and surrounding temperature in enclosed car park is analysed by using time series analysis.

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# CHAPTER 1 : INTRODUCTION

## 1.1 BACKGROUND OF STUDY

Air is one of the essential elements for human being to survive. Composition of air in our atmosphere are includes nitrogen (78 %), oxygen (about 21 %), argon (almost 1 %) and other molecules in very small quantities (NCAR & UCAR, 2014). Air pollution is a problem as old as history itself (Hutton, 2011). Air pollution can be defined as air in the environment contains gases, dusts, fumes and harmful substances which can give harmful effects to the earth, human beings, animals and plants (EPA Victoria, 2014).

Air pollution can be originated from anthropogenic (man-made) and non-anthropogenic (Hutton, 2011). Making fire, burning biomass and fossil fuel are examples of man-made pollution that lead to the increasing levels of air pollution (Hutton, 2011). Besides that, natural emissions caused by non-living world such as natural fires, volcanic emission and sea-salt emission could also give adverse effects on human and the ecosystem (Daly & Zannetti, 2007). It can affect our health and damages the environment in many ways such as irritation to the eyes, asthma, increase risk of heart problem, acid rain, haze, ozone depletion and global climate change (MassDEP, 2014).

As we breath every day, we come in contact with many kinds of air pollutants. Air pollutants is defined as any substance that emitted into the air whether it is not part of natural atmosphere or present in higher concentrations than the natural atmosphere (Daly & Zannetti, 2007). Pollutants can be classified into two category, which are primary and secondary pollutants (Daly & Zannetti, 2007). Primary pollutants are emitted directly from its sources such as carbon compound, nitrogen compounds and sulfur compounds (Daly & Zannetti, 2007). Secondary pollutants are not emitted directly as it formed as result of reaction or interaction of primary pollutants such as ozone, particulate matter and organic aerosol formed from volatile organic compounds reactions (Hutton, 2011).

Different types of pollutants may give different effects in different ways to the earth's climate and environment. Greenhouse gases are generated by human activities such as carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), ozone ($O_3$), and fluorinated gases hydrofluorocarbons (HFCs) give effects to the environment in such a way that they trap energy and heat in the atmosphere (US EPA, 2014). As the concentration of greenhouse gases continue to increase, temperature will also increase which lead to global warming and then climate change of the environment.

Particulate matter, nitrogen dioxide, sulphur dioxide, carbon monoxide are examples of harmful and toxic pollutants that are being released to the atmosphere that can affect the ecosystem (WHO, 2010). There are guidelines on concentration level of pollutants for ambient air quality and safe environment. Amount of pollutants that present above the concentration level are considered harmful to the environment and human beings. Table 1.1 shows the air quality guidelines provided by Malaysian government as compared to guidelines by World Health Organization (WHO).

TABLE 1.1 Air Quality Guidelines by Malaysian Government and WHO (DOE, 2013 & WHO, 2010)

| **Pollutant** | **Malaysian Government** | **World Health Organization (WHO)** |
|---|---|---|
| Particulate matter with a diameter of 10 μm or less ($PM_{10}$) | 50 μg/$m^3$ (annual mean) | 20 μg/$m^3$ (annual mean) |
| | 150 μg/$m^3$ (24 h mean) | 50 μg/$m^3$ (24 h mean) |
| Ozone | 120 μg/$m^3$ (8 h mean) | 100 μg/$m^3$ (8 h mean) |
| | 200 μg/$m^3$ (1 h mean) | - |
| Nitrogen dioxide | - | 40 μg/$m^3$ (annual mean) |
| | 320 μg/$m^3$ (1 h mean) | 200 μg/$m^3$ (1 h mean) |
| Sulphur dioxide | 105 μg/$m^3$ (24 h mean) | 20 μg/$m^3$ (24 h mean) |
| | 500 μg/$m^3$ (10 min mean) | 500 μg/$m^3$ (10 min mean) |
| Carbon monoxide | 10 mg/$m^3$ (8 h mean) | 10 mg/$m^3$ (8 h mean) |
| | 35 mg/$m^3$ (1 h mean) | 30 mg/$m^3$ (1 h mean) |

Air Pollutant Index (API) had been introduced by Department of Environment in Malaysia as a means to report the air quality (DOE, 1997). It acts as an indicator for the air quality status that may cause potential harm to human health when the concentration of air pollutants reach unsafe levels as shown in Table 1.2. Following the US EPA system, API is calculated by collecting data from automatic air quality stations within sufficient average time periods from five major air pollutants which are ozone ($O_3$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$) and suspended particulate matter of less than 10 microns in size ($PM_{10}$). The value is reported as the highest API value among all of the sub-APIs during that particular time and the specific air pollutant responsible for the value is stated (DOE, 1997).

TABLE 1.2 Air Pollutant Index used in Malaysia (DOE, 2014)

| **API** | **Air Pollution Level** |
|---|---|
| 0 - 50 | Good |
| 51 - 100 | Moderate |
| 101 - 200 | Unhealthy |
| 201 - 300 | Very unhealthy |
| 301 - 500 | Hazardous |
| 500+ | Emergency |

Emission of pollutants from its respective sources can affect the air quality around us. Contamination of air quality includes indoor (household) and outdoor (ambient) environment (WHO, 2014). Indoor air pollution could be in the building, house or office where the sources of pollution came from tobacco smoke, combustion of solid fuels, electronic equipments and household products where they can cause health risks until the source of pollution is removed or proper ventilation is installed (NIH, 2014). Sources that contributed to outdoor air pollution includes vehicles, forest fires, combustion of fossil fuel, power generating stations and industrial activities (WHO, 2010). Studies by Environmental Protection Agency on human exposure to air pollutants deduce that indoor level of pollutants is higher than outdoor pollutant levels.

Most people in our country have their own vehicles to go from one place to another. The usage of vehicles has been contributed to air pollution problem as the number of vehicles keep increasing from one year to another (Wargo et. al., 2006). Vehicles emits pollutants of volatile organic compounds (VOC), oxides of nitrogen ($NO_x$), particulate matter (PM) and carbon monoxide (CO) as the result of combustion process of burning fuel in the engine (US EPA, 2014).

In developed cities, lots of enclosed car parks has been built as a part of the building since there is shortage of land for open-space car parks. Pollutants emitted from vehicles in the enclosed car parks may differ from that in the open-space car parks in terms of concentration and sources of air pollution. Aware with the harmful effects of pollutants, this study will analyse the concentration $NO_x$ from the presence of nitric oxide (NO), nitrogen dioxide ($NO_2$) and possibility of ozone formation in an enclosed car park.

## 1.2 PROBLEM STATEMENT

Air pollution has been mostly deteriorated by traffic emissions as increasing number of vehicles in the road or public highway (Barnett & Knibbs, 2014). Increasing number of both public and private vehicles lead to a big demand of parking area facilities in the city (Burnett & Chan, 1997). Nowadays, industrial development has been expanding rapidly in Malaysia. Shortage of land had resulted in construction of high-rise commercial and industrial buildings with enclosed car park system beneath or above the buildings.

Enclosed car park is considered as outdoor environment but in worst state as there is no flow of air that make the air trapped inside the building system. However, there is very limited research done in Malaysia for air quality and pollutants level in an enclosed car park. As enclosed car park provide limited and confined space, proper ventilation need to be installed to channel out the hazardous pollutants from accumulating in the said area.

Ventilation of an enclosed car park should acts as functions of bringing in fresh air from the outside and removing the polluted air in order to limit the concentration of contaminants in the area (Lopez et. al., 2013). Ozone is a secondary pollutant formed from chemical reaction between oxygen ($O_2$) and nitrogen dioxide ($NO_2$) with the presence of ultraviolet energy from sunlight (Shakhashiri, 2007).

Since the concentration of $NO_2$ in air is usually very low, ozone can also formed by the reaction between oxygen atom (O) and molecular oxygen ($O_2$). This study will determine the possibility of ozone formation due to its precursor that may be present in an enclosed car park, which are $NO_2$ emitted from vehicles and presence of ultraviolet energy since there is no direct sunlight in the enclosed car park.

This research is mainly about the criteria of air quality in an enclosed car park. Therefore, it is crucial to conduct the research in order to know whether the quality of air at enclosed car park is the same with open space environment. The concern of this research are in terms of number of vehicles that are going in and out from the car park area. Burning fuel in vehicles' engine exhaust volatile organic compounds, oxides of nitrogen, particulate matter and carbon monoxide (US EPA, 2014).

Pollutants emitted from vehicles that circulate in the car park are likely will give adverse effects to two different groups which are car park users and car park employees or maintenance contractors (Burnett & Chan, 1997). These group of people has been exposed to the pollutants up to 8 hours per day as for their working period. Hence, it is crucial to identify the concentration level of harmful pollutants whether it will affect the safety of people in the enclosed car park.

## 1.3 OBJECTIVES

The objectives that need to be achieved at the end of this study are :

i. To determine the concentration level of nitrogen dioxide ($NO_2$) in an enclosed car park area. The pollutants that trapped and circulate in the area may give adverse effects on people within the area. Thus, it is important to get the concentration level of pollutants so that measures can be taken in order to maintain the pollutants concentration within the safe level.
ii. To identity the possibility of ozone ($O_3$) formation in the enclosed car park due to mixture of $O_2$ and O. Ozone is a secondary pollutant that produced from reaction of primary pollutants. Since there is no direct sunlight present in the enclosed car park, this study will identify whether ozone is possible to be form or not within the closed area.
iii. To analyse the relationship between $NO_2$ , $O_3$ and surrounding temperature in an enclosed car park by using time series analysis

## 1.4 SCOPE OF STUDY

The study area is at one of the famous car park located at Kuala Lumpur city centre. Kuala Lumpur is the capital of Malaysia and has been developed to act as the cultural, financial and economic centre for the country. The basement car park is located underground below the building, which satisfy the need of this study which is enclosed car park system. There are two (2) types of air pollutants that will be analysed, which are $NO_2$ and $O_3$. $NO_2$ are primary pollutant that produce from vehicles emission whereas $O_3$ is secondary pollutant formed from the reaction between $NO_2$ and $O_2$ in the atmosphere with the presence of ultraviolet energy. Sampling period for conducting this study is within 10 days. Results from this study will identify the concentration level of $NO_2$ and possibility of ozone formation in an enclosed car park with the absence of sunlight as the source of ultraviolet energy.

# CHAPTER 2 : LITERATURE REVIEW

## 2.1 AIR POLLUTANTS

Nowadays, air pollution has become a major problem to the environment. Gas and particles contaminants that present in the atmosphere are called as air pollutants (US EPA, 2014). Sources of air pollutants may come from natural emissions or human activities, which have been linked to give adverse effects to human health, environment and ecosystem (WHO, 2010). Table 2.1 shows pollutants that causes air pollution with respect to their sources and effects on our health or environment.

TABLE 2.1 Sources of Pollutants and Effects (DEFRA, 2014 & US EPA, 2014)

| **Pollutant** | **Sources and Description** | **Potential Effects on Health/Environment** |
|---|---|---|
| Ozone ($O_3$) | Not emitted directly from man-made source. Produced from chemical reactions between $NO_x$ and Volatile Organic Compounds (VOC) with the presence of strong sunlight. Ozone can be formed over several days or hours. Its emission may be arisen from many kilometres away. | Exposure to high concentrations may cause irritation to eyes and nose. Damage of airways that lead to inflammatory reactions could be due to very high level of ozone. Decrease function of lung and respiratory system. Ground level ozone give adverse impacts to vegetation and hence reduce the ability of plants or trees to uptake carbon dioxide ($CO_2$) in the atmosphere |
| Carbon Monoxide (CO) | Formed from incomplete combustion of carbon containing fuels. Mostly from vehicles or road transport. | Reduces capacity of the blood to transport oxygen to body's tissues and blocks crucial biochemical reactions in cell. Affect delivery of oxygen to the heart and brain. |

| | | |
|---|---|---|
| Particulate Matter (PM-$PM_{10}$ and $PM_{2.5}$) | Categorized based on particle size. Made up from wide range of materials where comes from both man-made and natural sources, which are chemical reactions, fuel combustion, industrial processes, agriculture, vehicles emission, quarrying and unpaved road. | Both short-term and long-term exposure effects. Short term exposure can aggravate lung or heart diseases. Long term exposure lead to development of lung or heart diseases and premature mortality. May also related to cardiovascular illness. |
| Oxides of Nitrogen ($NO_x$) | All combustion processes produce oxides of nitrogen. Main source is road transport, followed by electricity supply fuel combustion, wood burning, other industrial and commercial sectors | Contributes to eutrophication, acidification which leads to biodiversity loss damages vegetation. Affects human health (lung function, respiratory system and infection) and inflammation of airways at high level of $NO_2$. Promotes formation of secondary particles and ground level ozone, which associated with ill-health effects. |
| Sulphur dioxide ($SO_2$) | Emitted from combustion of fuels especially high-sulphur coal or heavy oils by power stations and refineries. Other sources are from electrical utilities, industrial processes and natural sources such as volcanoes. | Aggravate asthma, chest tightness, shortness of breath, constriction of lung airways and increased respiratory symptoms. At high level, give potential damage to ecosystem includes degradation of chlorophyll, reduce photosynthesis, change protein metabolism and increase respiration rates. Deposition contributes to acidification of soils and water. |

| | | |
|---|---|---|
| Ammonia ($NH_3$) | Mainly from agriculture, fertilizers, and livestock manure or slurry management. Limited source came from transport and waste disposal. | Damage terrestrial and aquatic ecosystem through deposition and acidifying of pollutants. Lead to eutrophication of surface water and nitrate contamination of ground water. Also acts as precursor to particulate matter as secondary pollutant. |
| Lead (Pb) | Emitted from combustion of coal, iron, steel, nonferrous metals and leaded gasoline in piston engine aircraft. Can also produce from metal refineries, waste incinerators and battery manufacturing. | High level of exposure give toxic biochemical effects to the kidney, gastrointestinal tract, joints, nervous system and reproductive system. Intellectual and behaviour development in young children also affected. As for adults, give cardiovascular and renal effects and early effects related to anaemia. Accumulates in soil which harms plants and wildlife |
| Benzene ($C_6H_6$) | Variety of sources, which primarily from road transport, domestic and industrial combustion. | Known as human carcinogen that attacks genetic materials where absolute safe level in ambient air has not been specified. Studies show that high level of exposure could lead to risk of leukaemia. |
| Volatile Organic Compounds (VOCs) | Deposition of fossil fuel and natural sources (e.g. volcanoes, vegetation and bacteria). Emission from transportation, industrial processes and gasoline evaporation that occur when transfer of gasoline is being made at service stations. | They are toxic air pollutants that cause cancer and serious health problems. Contributes to formation of ozone, carbon dioxide and greenhouse gases that associated with environmental and climate effects. |

## 2.2 OZONE

### 2.2.1 Definition

Ozone is a secondary pollutants that formed in the atmosphere through chemical reactions between primary pollutants (California EPA, 2008). Ozone present in the form of molecular oxygen that composed of three oxygen atoms, which acts as an important component for smog, very reactive and unstable gas (Nurwulan, 2007). Besides, ozone has been classified as a powerful oxidant that can oxidize many organic compounds as compared to bleach actions, which can kill living cells upon contact (Shakhashiri, 2007). Characteristics of ozone is that it has a sharp odour and can be detected after a thunderstorm or during electrical equipments discharges (California EPA, 2008).

There are two types of ozone, one type found in the stratosphere and the other one found in the troposphere (Nurwulan, 2007). Troposphere is the first layer of the earth's atmosphere where weather occur in this layer whereas stratosphere is atmospheric layer above the troposphere (Johnson, 2010). Formation of ozone in the stratosphere called as 'good ozone' since it absorbs harmful ultraviolet rays from the sun (Nurwulan, 2007). As for ozone that present in the troposphere known as 'bad ozone' where it create potential harm to human health, climate change, vegetation and natural materials (Ramli et. al., 2009).


FIGURE 2.1 Ozone in Layer of Troposphere and Stratosphere

### 2.2.2 Sources

Since stratosphere ozone protects life on earth from being exposed to ultraviolet rays emitted from sunlight, this study is focused on ozone that is formed in the troposphere. Presence of ozone in the troposphere has been a concern prior to its characteristics that promotes poor air quality, health risk, environmental problem and affects ecosystem productivity (Hess & Zbinden, 2013). Troposphere ozone is also known as ground-level ozone as it produced close to the ground level where living things live (California EPA, 2008). Moreover, it also plays an important role in the atmosphere since it oxidizes many chemical substances and it is a greenhouse gas that contributes to global warming (Nurwulan, 2007).

There are two major sources of troposphere ozone, which are transported from the stratosphere and photochemical production (Hess & Zbinden, 2013). Ozone is produced when nitrogen oxides, $NO_x$ that is NO and $NO_2$ reacts with volatile organic compounds (VOCs) in the presence of sunlight (Bailey, 2011). VOCs are organic compounds made up of carbon and hydrogen that can evaporate easily such as sugar, butane and octane (Nurwulan, 2007). Meanwhile, sources of $NO_x$ as primary pollutant mostly came from motor vehicles, fuel combustion, industrial facilities and electrical utilities (US EPA, 2003). In troposphere layer, net ozone production is very limited since reactions of turning NO into $NO_2$ will destroy the ozone at the same time (Ramli et. Al., 2009). The reaction cycles (1), (2) and (3) shows the process of generating and destroying ozone occur in the troposphere.

When $NO_2$ is exposed to ultraviolet energy with wavelength ($\lambda$) of less than 424 nm, it undergo photolysis reaction and will generated into oxygen atom and NO molecule.

$$NO_2 \xrightarrow{\text{uv light } (\lambda<424 \text{ nm})} NO + O\ (^3P) \qquad (1)$$

Oxygen atoms formed in this process is extremely reactive to oxygen molecules, $O_2$ hence producing ozone.

$$O\ (^3P) + O_2 \longrightarrow O_3 \qquad (2)$$

However, the ozone can quickly react with NO to convert back into $NO_2$ and $O_2$.

$$NO + O_3 \longrightarrow NO_2 + O_2 \quad (3)$$

Since production of ozone is limited, VOCs would play an important role in processes where they react and form 'free radicals' that convert NO into $NO_2$ without destroying $O_3$.

$$RO_2 + NO \longrightarrow RO + NO_2 \quad (4)$$

*R is hydrocarbons which are class of VOCs.

Reaction (5) shows $NO_2$ combines with radical to produce product that is not a radical which is nitric acid, $HNO_3$

$$NO_2 + OH \longrightarrow HNO_3 \quad (5)$$

Ozone formation continues until $NO_x$ is removed in the atmosphere, where it is removed more rapidly than VOCs (Carter, 2014). The reaction thought to be permanent sink for $NO_x$ (Carter, 2014). Hence, availability of $NO_x$ would ultimately limits the formation of ozone in the troposphere. As this study conducted in an enclosed car park, source of $NO_x$ depends on vehicles exhaust that affects the amount of ozone that will be formed in the area.

### 2.2.3 Effects

Anthropogenic activities by human that continues to happen will increase the emission of air pollutants and hence increase the formation of troposphere ozone (Bornman et. al., 2010). At ground level, ozone is a harmful pollutants especially during hot weather since concentration of ozone may reach dangerous level for human health and the environment (US EPA, 2003). Breathing of ozone can cause various health problems includes coughing, throat irritation, chest pain and may become worsen to asthma, bronchitis and emphysema (US EPA, 2014).

Exposure to ground-level ozone can affects lung tissue and its function in such a way that reducing the volume of air for the lung to breathe and cause shortness of breath (California EPA, 2008). Adults and children who spend more time outdoor are at greatest risk from exposure to ozone. Children that active outdoor are more likely to suffer the harmful effects than adults because their lungs are still developing that make them breathe and inhale more pollution as compared to adults (California EPA, 2008).

While stratosphere ozone protects us from ultraviolet radiation, troposphere ozone damages forest and crops, destroy leaf tissues, reduce productivity of plants and overall ecosystem (Bailey, 2011). With that, plants' ability to carry out photosynthesis and produce their own food are affected. Ozone can also cause damage on materials such as rubber, plastics, fibres, paint and metals (UCAR, 2014). Both functional and aesthetic qualities of the materials are damaged hence shortens their life span due to ozone exposure (California EPA, 2008). State of California and US EPA had established ambient air quality standards for ozone as for human health protection.

TABLE 2.2 Ambient Air Quality Standard for Ozone (California EPA, 2008)

| Averaging Time | National EPA Standard | California Standard |
|---|---|---|
| 1-Hour | 0.09 ppm | - |
| 8-Hour | 0.07 ppm | 0.075 ppm |

## 2.3 OXIDES OF NITROGEN

### 2.3.1 Definition

Oxides of nitrogen ($NO_x$) is the sum of mainly nitric oxide ( > 95 %) and lesser amount of nitrogen dioxide ( < 5%).

$$NO_x = NO + NO_2 \quad (6)$$

Nitric oxide (NO) is a gas composed of one atom of nitrogen and one atom of oxygen (Butler & Nicholson, 2003). Naturally, NO is being released to the atmosphere and reacts with oxygen to form a brown gas known as nitrogen dioxide, $NO_2$ (Butler & Nicholson, 2003). $NO_2$ is a reddish-brown coloured gas that is highly reactive and visible although present in small concentration (Thompson, 2011). Characteristics of $NO_2$ are corrosive, non-combustible, highly oxidizing and has a pungent odour (Kindzierski et. al., 2007). $NO_2$ is soluble in concentrated sulphuric acid, nitric acid, carbon disulphide and chloroform (Kindzierski et. al., 2007). Table 2.3 provides list of identification and common properties for nitrogen dioxide.

TABLE 2.3 Identification and Properties of Nitrogen Dioxide
(Kindzierski et. al., 2007)

| Property | Value |
|---|---|
| Formula | $NO_2$ |
| Structure | O = N = O |
| Molecular Weight | 46.01 $g.mol^{-1}$ |
| Physical State | Clear colourless volatile liquid |
| Melting Point | -9.3 $^oC$ |
| Boiling Point | 21.12 $^oC$ |
| Density (liquid) | 1.448 (at 20 $^oC$) |
| Density (gas) | 1.58 |
| Common Synonyms / Trade Names | azote, azoto, dinitrogen tetroxide, nitrite, nitro, nitrogen dioxide (liquid), nitrogen oxide, nitrogen peroxide, nitrogen peroxide liquid, nitrogen tetroxide |

### 2.3.2 Sources

Naturally, source of $NO_2$ in the environment could come from forest fires, atmospheric lightning charges (Kindzierski et. al., 2007), biological processes in the soil and oxidation of ammonia in the atmosphere (Thompson, 2011). If $NO_2$ is released to water, it will decompose into nitric acid that contributes to acid rain phenomena (Kindzierski et. al., 2007). However, man-made sources such as vehicles exhaust, fuel combustion and appliances such as gas stoves, dryers, portable heaters and fireplaces are more crucial to the production of $NO_2$ (DHFS, 2011). Figure 2.2 shows emission of $NO_x$ from various sources with their respective percentages.

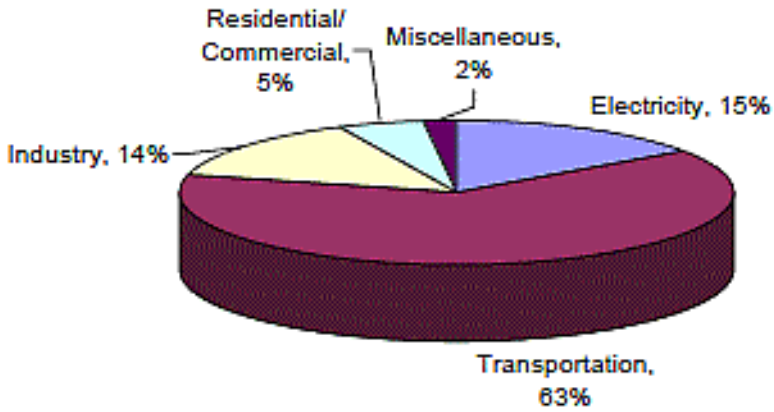


FIGURE 2.2 $NO_x$ emissions from various sources

$NO_2$ is released directly into the air from the reaction between NO and hydroperoxy radicals ($HO_2$), alkylperoxy radicals ($RO_2$) or ozone radicals (Kindzierski et. al., 2007).

$$HO_2 + NO \longrightarrow NO_2 + HO \quad (7)$$

$$RO_2 + NO \longrightarrow NO_2 + RO \quad (8)$$

$$O_3 + NO \longrightarrow NO_2 + O_2 \quad (9)$$

NO and $NO_2$ are often grouped together as $NO_x$ because of their relationship and rapid reaction between these two compounds itself (Kindzierski et. al., 2007). For instance, $NO_2$ can rapidly dissociates when exposed to bright light to produce NO.

$$NO_2 \xrightarrow{\text{light}} NO + O \qquad (10)$$

Besides, $NO_2$ is the main cause of smog (DHFS, 2011) and also a major component in the chemical reactions to produce ground-level ozone (Thompson, 2011). In a high populated area, emission of nitrogen oxides to the atmosphere from fuel combustion is mainly in the form of NO (Ramli et. al., 2009). Generally, complete combustion of fuel combines with sufficient oxygen produced carbon dioxide and water (BBC, 2014). Alternately, insufficient oxygen lead to incomplete combustion with by-products of many types of pollutants including oxides of nitrogen ($NO_x$), carbon monoxide (CO) and VOCs (DHFS, 2011).

During fuel combustion in automobile engines, nitrogen combine with oxygen to form nitric oxide (Brown, 2014).

$$N_2 + O_2 \xrightarrow{\text{heat}} 2\,NO \qquad (11)$$

The NO that formed inside vehicles' engine reacts spontaneously with $O_2$ to produce nitrogen dioxide, $NO_2$

$$2NO + O_2 \longrightarrow 2\,NO_2 \qquad (12)$$

From reaction (11) and (12), it can be concluded that increasing number of traffic in the cities tend to promotes higher concentration level of $NO_2$ due to incomplete combustion that occur in the vehicles powered engine. Production of $NO_2$ from vehicles exhaust will lead to formation of ozone in the troposphere. As in an enclosed car park, formation of ozone promotes by presence of $NO_2$ emitted from vehicles and possible sources of ultraviolet energy that will be proven in this study.

### 2.3.3 Effects

Exposure to $NO_2$ have been linked to adverse effects on human respiratory system since the particles are small, which can penetrate easily into sensitive part of the lung (US EPA, 2011). Short term exposure to $NO_2$ ranging from 30 minutes to 24 hours (US EPA, 2011) can cause health symptoms of slight cough, mild fatigue, nausea, eye and throat irritation (DHFS, 2011). At higher concentrations, it can irritate the lungs, cause bronchitis, severe coughing, headache, choking and lower the resistance to respiratory infections (Thompson, 2011). Otherwise, the symptoms may continue as the result of frequent or long term exposure that cause pulmonary edema (Thompson, 2011) and difficulty to breath for weeks (DHFS, 2011). People who spend more time on or near the road have high potential to $NO_2$ exposures. It happens that $NO_2$ concentration level in the road especially heavy traffic can be twice than the levels in residential areas and less congested roads (US EPA, 2011).

Presence of $NO_2$ in the air contributes to several effects to the environment such as acid rain, degradation of vegetation and eutrophication (Thompson, 2011). Eutrophication is the phenomena where nutrients in a body of water increase and reduce amount of oxygen in the water, resulting in destruction of plant and animal life (Thompson, 2011). Since $NO_2$ is the precursor for nitric acid as a large contributor of acid deposition, it gives effects on materials such as metals, leather, fabrics, paints and coatings (Kindzierski et. al., 2007). In addition, corrosion and structural damages of underground pipes, cables, bridges, buildings and foundation can occur if they are exposed the acidic elements (Kindzierski et. al., 2007). Visibility of the eyes becomes limited when $NO_2$ and NO react with water vapor to form aerosol droplets in the air (Thompson, 2011).

As this study conducted in an enclosed car park, possible source of $NO_2$ production that are being taken into consideration are from vehicles exhaust. Thus, it becomes the precursor to formation of ozone in the study area.

## 2.4 ULTRAVIOLET RAY

### 2.4.1 Definition

Ultraviolet (UV) ray can be defined as the small portion of the electromagnetic spectrum with wavelength between 10 nm to 400 nm (Li & Nathan, 2005). The electromagnetic spectrum is the range of all types of electromagnetic radiation, which the energy that travels and transport energy from any source such as gamma rays, X-rays, infrared light, and microwaves (Mattson, 2014).

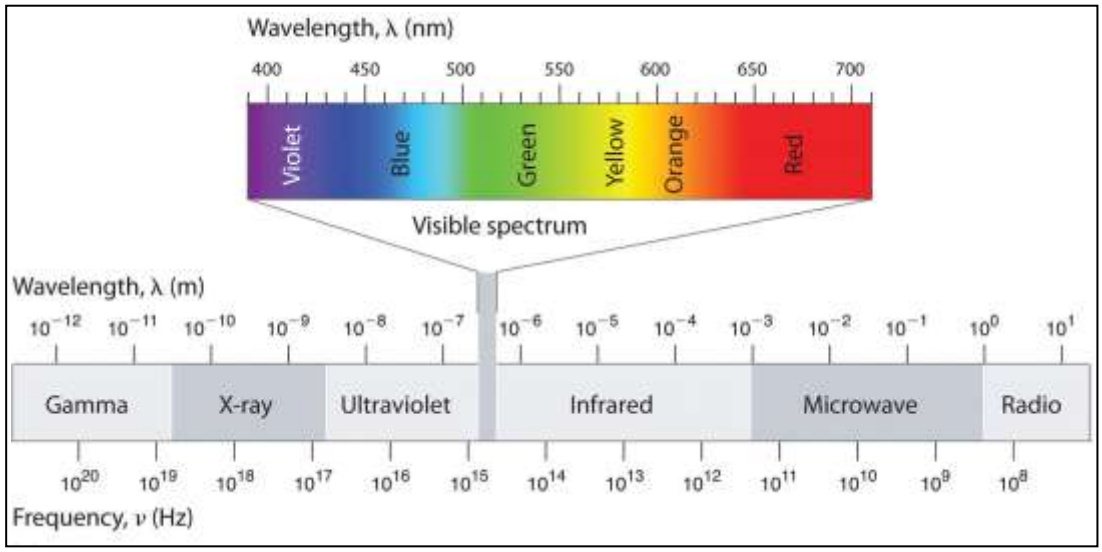


FIGURE 2.3 Electromagnetic Spectrum (Mattson, 2014)

Ultraviolet light is in between the longer wavelength visible light and the shorter wavelength X-ray energy. The term ‘ultra’ means beyond in Latin word whereas violet is the colour with the shortest wavelength of visible light (Li & Nathan, 2005). Besides, ultraviolet radiation can be expressed in terms of energy, wavelength and frequency where units measured are electron volts, meters and hertz respectively (Mattson, 2014).

Apart from that, ultraviolet radiation has been divided into three (3) wavelength ranges with distinctive properties, potential damage and effects when exposed to such radiation.

**i) UVA**

UVA ray are the weakest among the UV rays with wavelength of 315 - 400 nm (Akram & Rubock, 2005). It is not absorbed by the ozone layer and thought to play role in causing skin cancer where it can penetrate to the deeper layers of the skin (US FDA, 2010). Adverse health effects that may occur due to exposure are indirect damage to DNA cells, skin cancer, wrinkles and skin allergic reactions such as rash (American Cancer Society, 2014).

**ii) UVB**

UVB ray are slightly stronger than UVA ray with wavelength of 280 - 315 nm (Akram & Rubock, 2005). Mostly of the rays absorbed by the ozone layer but some does reach the earth's surface (US EPA, 2010). UVB rays can penetrate into the top layers of skin and they are mainly responsible for sunburns (US FDA, 2010), direct damage to the DNA, skin cancer (American Cancer Society, 2014) and erythema (Akram & Rubock, 2005).

**iii) UVC**

UVC ray are the strongest of UV rays with wavelength of 100 - 280 nm (Akram & Rubock, 2005). It is completely absorbed by the ozone layer and atmosphere (US EPA, 2010). Fortunately, they react with ozone at the upper layer of the atmosphere and do not reach the ground level (American Cancer Society, 2014). Thus, UVC rays are not present in sunlight and are normally not a risk factor for skin cancer.

### 2.4.2 Sources

Main source of ultraviolet ray is emitted from the sun (American Cancer Society, 2014). However, they may be found in man-made sources such as phototherapy, back-light lamps, mercury-vapour lamps, welding torches and tanning beds (American Cancer Society, 2014). As sunlight passes through the atmosphere, all UVC and approximately 90 % of UVB radiation are absorbed by ozone, water vapour, and carbon dioxide since UVA radiation is less affected by the atmosphere (WHO, 2002).

Therefore, UV radiation that reached the earth's surface is largely composed of UVA with a small amount of UVB component. The level of ultraviolet radiation reaching the earth varies depending on several factors, which are stratospheric ozone layer, time of day, time of year, latitude, altitude, weather condition and surfaces reflections (US EPA, 2010).

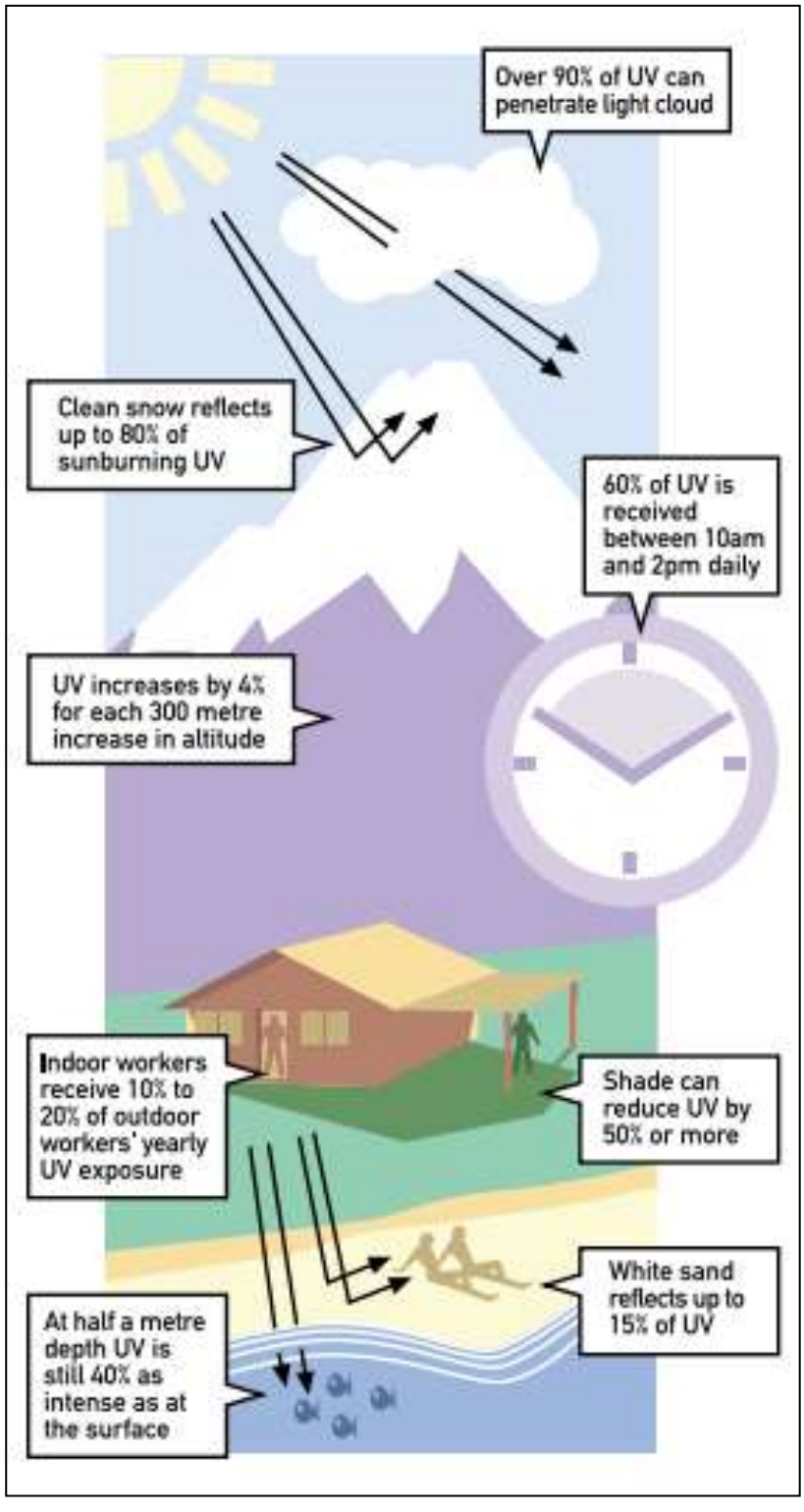


FIGURE 2.4 Factors Influenced UV Radiation (WHO, 2002)

### 2.4.3 Effects

Presence of ultraviolet radiation at the earth's surface has important implications for human health, biogeochemical cycles, air quality, damage to materials, terrestrial and aquatic ecosystems (Bornman et. al., 2010). Human exposure to solar radiation may result in acute and chronic health effects on the skin, eye and immune system (WHO, 2002). Acute effects appear within a few hours of exposure to radiation while chronic effects are long lasting, cumulative and may not appear for years (Akram & Rubock, 2005). Sunburn and redness of skin called erythema are the acute effects of excessive exposure to the UV radiation (Akram & Rubock, 2005). Chronic effects include accelerates skin ageing, skin cancer and gradual loss of skin's elasticity that results in wrinkles, dry and coarse skin (WHO, 2002).

Risk of skin exposure to radiation is independent to skin type, whether fair-skinned or dark-skinned people (WHO, 2002). People need to be concerned about overexposure to the sun regardless of skin colour. Darker skin has more protective melanin pigment that make them to have lower risk of skin cancer (WHO, 2002). In addition to serious risk of skin cancer, tanning can lead to premature aging, immune suppression, eye damage and allergic reaction (US FDA, 2010).

Eye problems that can impair vision caused by radiation are inflammation of cornea, cataracts formation, affects retina that senses light and pterygium where tissue growth on the surface of the eye (American Cancer Society, 2014). Other than that, sensitivity of the eyes to the exposure of UVB and UVC rays will give effects of conjunctivitis and photokeratitis (Akram & Rubock, 2005).

The immune system is the body's defence mechanism against infections and cancers (WHO, 2002). Exposure to UV rays weaken the immune system and alter activity of cells responsible for triggering immune responses in human (American Cancer Society, 2014). As the result, body has a harder time fending off infections and reduce the effectiveness of vaccines (American Cancer Society, 2014).

## 2.5 CRITICAL ANALYSIS

There are several researches done about formation of ozone and other pollutants such as sulphur dioxide ($SO_2$), carbon monoxide (CO) and oxides of nitrogen ($NO_x$) at indoor environment or enclosed area. Study done by Nzotungicimpaye et. al. (2014) on sources of air pollution in Cape Town, South Africa proves that ozone levels in the site area mainly due to the presence of $NO_x$. During daytime, production of ozone is mainly driven by traffic emissions while sunlight acts as main contributor to the formation process.

Apart from that, Lopez et. al. (2013) proves that ventilation flow of an enclosed parking garage need to be improved since polluted substances emitted by vehicles are harmful to people's health. Pollutants present in the parking area influenced by the number of vehicles and duration of vehicles movement. In this research, Lopez et. al. (2013) has proposed method to calculate the ventilation flow and solution to achieve greater efficiency in the ventilation system of enclosed parking garage. It is crucial to have an efficient ventilating system for an enclosed car park to ensure the safety of people and workers from dangerous exposure to pollutants.

Contribution of vehicles exhaust to ozone formation was studied by Dong et. al. (2014) in China where emission from heavy-duty diesel vehicles were tested. The main factors for carbonyl emissions are vehicle types, average speed and emission standard. Carbonyl compounds are species of VOCs that highly reactive and serve as one of the major sources of free radicals. They are important precursors leading to the formation of ozone, hence vehicle exhaust should be considered as a stringent issue in controlling level of ozone in the environment.

In Japan, study by Hasunuma et. al. (2014) shows that increasing automobile traffic caused increasing level of air pollutants includes $NO_x$ and particulate matter (PM). As mention before, presence of $NO_x$ contributes to the formation of ozone through chemical reaction in the atmosphere. The study also proved that the enforcement of measures to control automobile emissions had reduced the pollutants levels and thus improve the quality of air.

Chaloulakou et. al. (2002) conducted a research of air monitoring for pollutant levels at enclosed parking garages in Athens urban area. They concluded in their study that workers in enclosed car park were exposed to long-term stay inside the location where pollutants concentrations gave adverse effects on their health. Generally, pollutant levels were found to depend on vehicles entering and exiting the enclosed car park. Besides, the levels are expected to reach the highest value on weekdays during afternoon period of time.

As in Malaysia, a research on modelling of ozone in urban environment in Malaysia done by Ramli et. al. (2009) which focuses on ozone characteristics and management to its precursor in the atmosphere. There are very limited studies done about on ozone formation and its effects in an enclosed car park. Most of the researches particularly done in other countries such as South Africa, China, Japan and Athens. Therefore, it is crucial to conduct this study so that the precursors and effects of ozone formation in enclosed area can be identified. Production of ozone can be controlled and take into consideration if it gave adverse effects to human health or environment. Other than that, ventilation flow system need to be improved to channel out hazardous pollutants from the enclosed area provided clean environment to the car park users and workers. Since the guidelines for indoor environment has not been established in Malaysia, this study is relevant and could contribute to continuation of further researches in this particular field.

# CHAPTER 3 : METHODOLOGY

## 3.1 INTRODUCTION

This chapter elaborates the research methodology conducted to obtain concentration levels of air pollutants in the study area of an enclosed car park located at one of the famous building in Kuala Lumpur city centre. The sampling of air pollutants was carried out from 6$^{th}$ November 2014 until 16$^{th}$ November 2014. Data were collected for every two (2) minutes interval from 12:00 am to 11:00 pm and tabulated for hourly average of pollutants concentration by using Microsoft Office Excel. Trends of each pollutants will also be analysed, which provides information on high or low concentration level of pollutants at certain period of time. At the end of this chapter, a Gantt chart with project activities and milestones will summarize the whole of the research process.

## 3.2 STUDY AREA

Kuala Lumpur is a developed and most populous city as the federal capital in Malaysia. The city covers an area of 243 km$^2$ with estimated population of 1.6 million where it is among the fastest growing city in the country in terms of urban development, population and economy. This study will be conducted at one of the famous building located in Kuala Lumpur city centre.


FIGURE 3.1 Map of Study Area Location

Designed for commercial places and tourist attractions, the building consists of offices, shopping malls and basement parking area. There are 5 levels of basement parking and occupied with 5400 parking bays. Study area where sampling procedures takes place was at level 2 (P2) of the building's basement parking. The location of sampling contains 1363 parking bays and the spot chosen is near to the office of the building. The equipment for data recording is placed at the path that the car park users commonly used to access the main road, coming in and going out from the building.

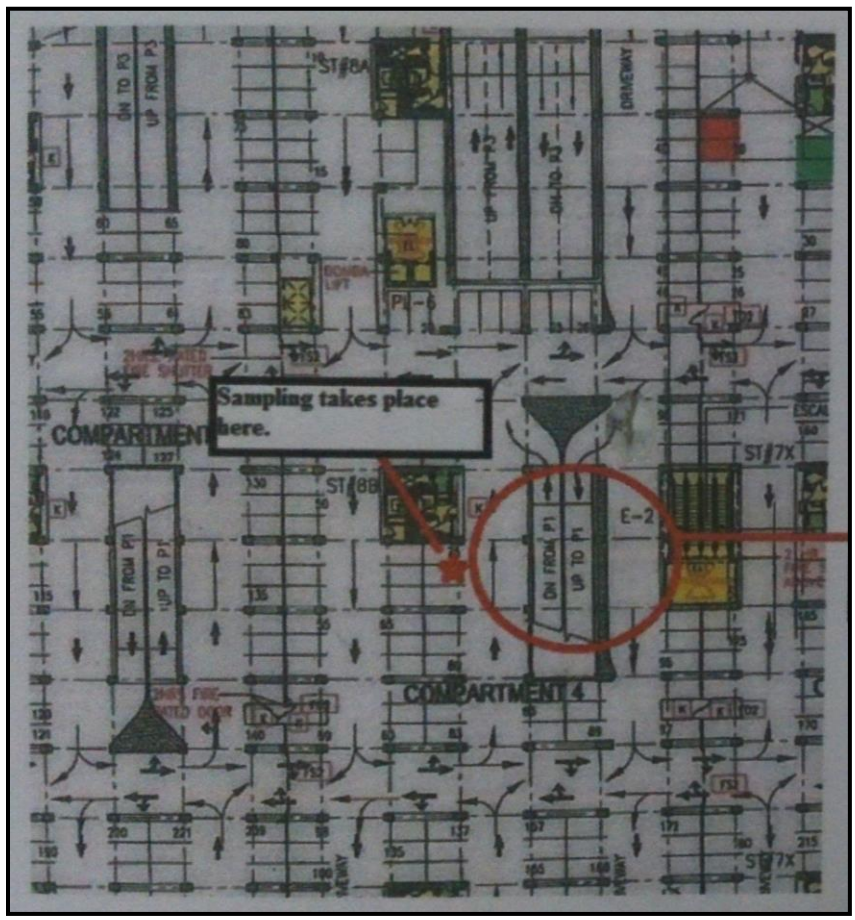


FIGURE 3.2 Sampling Location at Level P2

## 3.3 DATA COLLECTION

### 3.3.1 Pollutants Concentration

This study involves data collection by using Aeroqual's AQM 60 Air Quality Station. In this particular study, concentration level of two (2) air pollutants will be collected from the recorded data that are nitrogen dioxide ($NO_2$) and ozone ($O_3$). These pollutants were chosen because $NO_2$ is precursor to the formation of $O_3$, which involves chemical reactions and contributors to the production process. For the sampling, AQM 60 Station will be installed and set up in the study area before the data collection started.

Pollutants level will be recorded throughout the sampling period of 10 days and readings were taken by the equipment at 2 minutes interval for 24 hours per day. It is significant to determine the changes of concentration level of pollutants for 24 hours period of time so that the validity of the field's measurement data can be obtained. However, data will be taken and analysed from average reading for every hour where trends of pollutants level can be clearly seen. Moreover, $NO_2$ are the nitrogen oxides that produced from vehicles emissions.

Vehicles acts as the main contributor to the presence of $NO_2$ and $O_3$ in the enclosed car park. Therefore, this study depends on the number of vehicles that entering and leaving the study area. All the information can be used to analyse the concentration level of respective pollutants and its trends throughout the day. Specific time that the level of pollutants are the highest and lowest can be obtained from the analysis done.

### 3.3.2 Equipment (AQM 60)

The Aeroqual AQM 60 Station is a custom-built ambient air quality instrument for maintaining our safe environment. The station is designed for low-cost and easy monitoring of air quality, which concerns about adverse impacts that may occur to our environment and human well-being. It is a highly flexible instrument that it's platform is configurable to measure common air pollutants including ozone ($O_3$), nitrogen dioxide ($NO_2$), nitrogen oxides ($NO_x$), carbon monoxide (CO), sulphur dioxide ($SO_2$), volatile organic compounds (VOC), hydrogen sulphide ($H_2S$), non-methane hydrocarbons (NMHC), carbon dioxide ($CO_2$), particulate matter ($PM_{10}$, $PM_{2.5}$, $PM_1$), noise and meteorological parameters such as temperature, humidity, wind speed and direction.

Key features of AQM 60 includes :

i. Continuous high quality measurement of gases and particles
ii. Compact instrument and small footprint for network deployment
iii. Lower capital cost for affordable profiling and assessments
iv. Calibrated against EPA and EU Reference Methods (2008/50/EC)
v. Built-in zero air scrubber and optional automatic calibration system
vi. User calibration to available and traceable primary standards
vii. Climate-controlled compact enclosure for pole or wall installation
viii. Active sampling via brushless pumps and PTFE filter
ix. Single-board computer and Secure Digital card data storage
x. PC configuration and data logging software in units ppm or $mg/m^3$
xi. Remote communication and diagnostics solutions
xii. Flexible instrument platform for meteorological and noise sensors

The components of AQM 60 consists of an enclosure typically containing control module, power module, thermal management system, gas treatment module, a number of gas sensor modules, a RH/T sensor and associated cabling and plumbing.

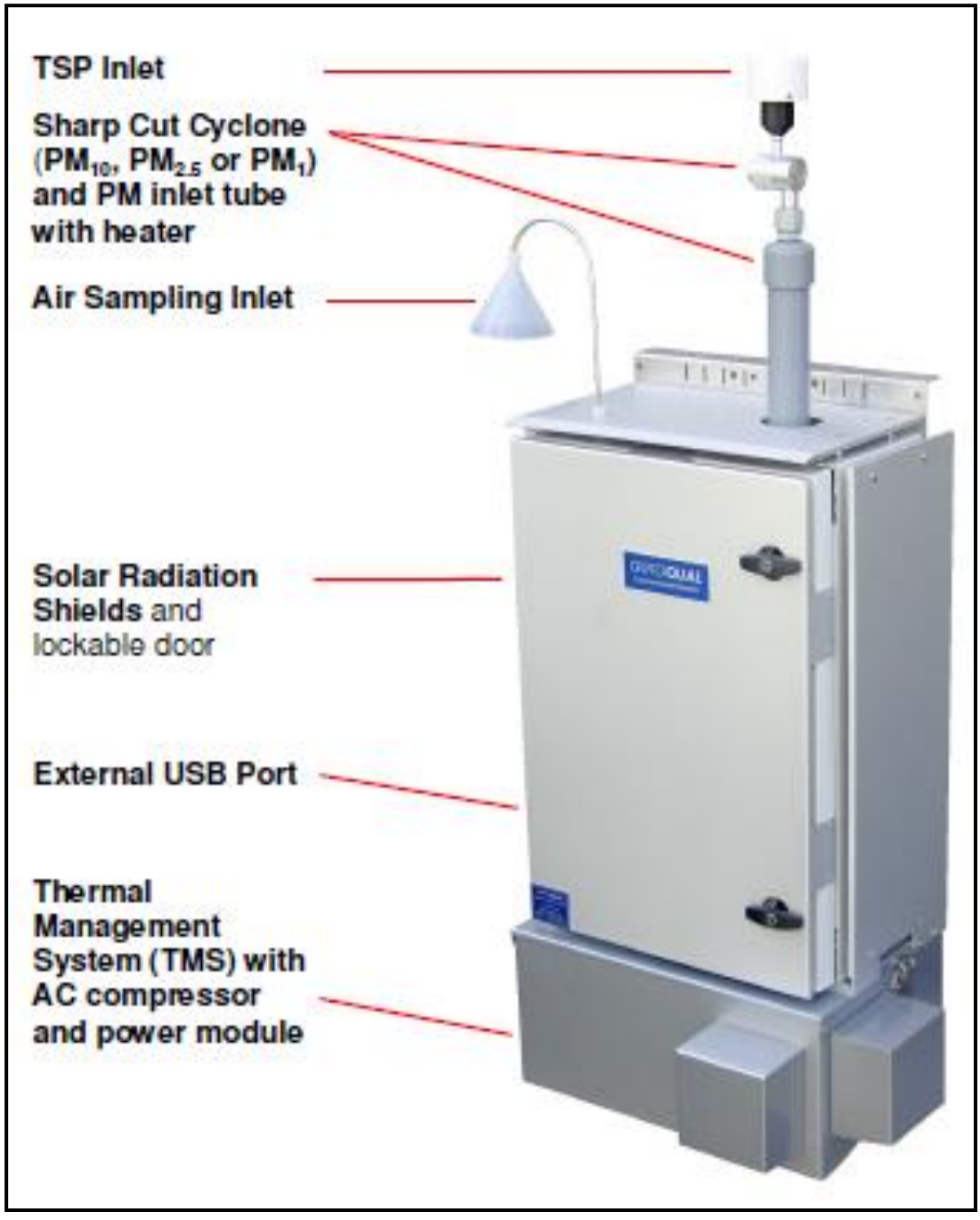


FIGURE 3.3 Aeroqual AQM 60 Station

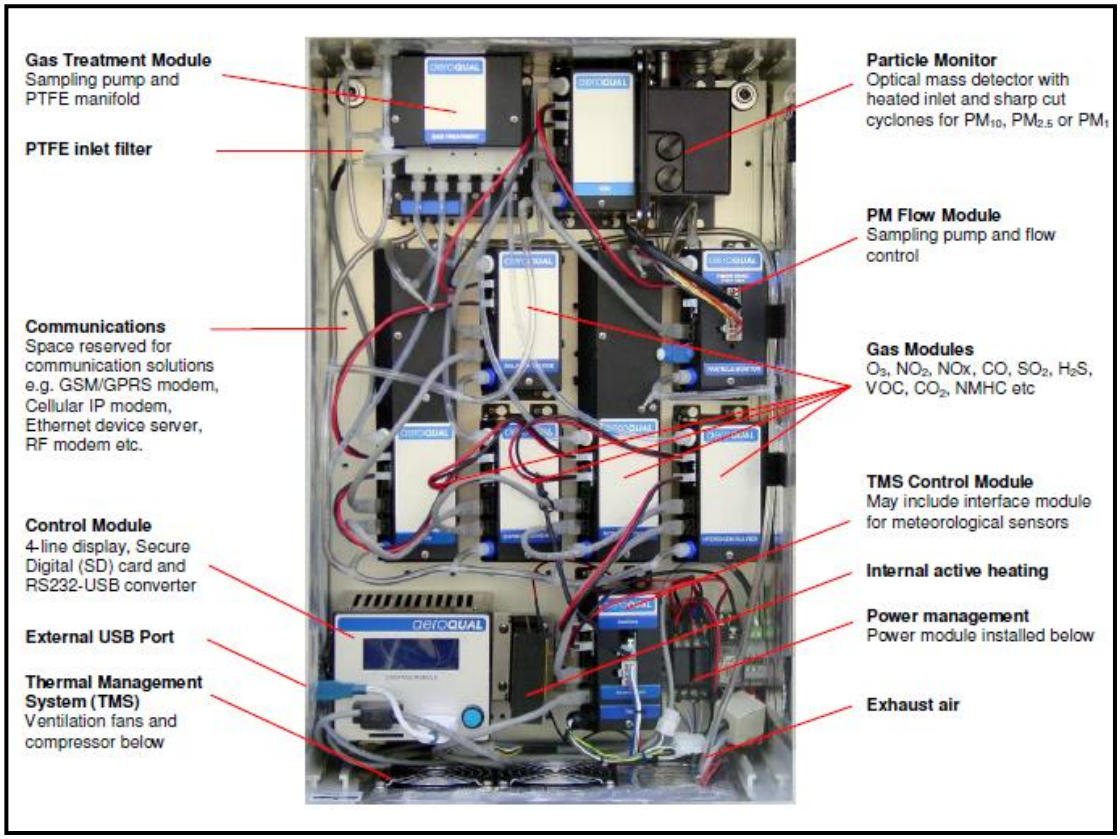


FIGURE 3.4 Individual Modules in AQM 60

There are various applications for the usage of AQM 60 instrument :

i. Urban air quality monitoring
ii. Local area air quality networks
iii. Community exposure : epidemiological studies, microenvironment, residential, schools and hospital
iv. Near road : motorways, street canyons, traffic information systems
v. Perimeter : petrochemical, power plants, waste sites, industrial point sources
vi. Airport, ports, railways, construction sites
vii. Open space : parks, forests, crop research
viii. Environmental impact assessment

## 3.4 DATA ANALYSIS

### 3.4.1 Microsoft Office Excel

Data collected by the equipment AQM 60 are tabulated in table forms using Microsoft Office Excel software. The software can be used to arrange the results properly according to the pollutants concentration with respect to time of the data sampling period. This study emphasis on concentration level of pollutants in an enclosed car park which are nitrogen dioxide and ozone.

### 3.4.2 Time Series Model

Analysis of the results are done by using time series model analysis. Time series is a sequence of data points measured typically at successive points in time spaced of uniform time intervals. The analysis will be shown graphically with the relationship between two or more variables in so that it can be related to one another. From data sampling and analysis of time series model, the trends of $NO_2$ and $O_3$ formation at the site in variation of time can be observed. Other than that, results will be analysed to produce reliable statistics of $NO_2$ levels and possibility of $O_3$ formation in an enclosed car park.

## 3.5 KEY MILESTONE

The key milestone for this study tabulated in Table 3.1 and Table 3.2, which listed out the project activities, targeted weeks to complete works and the research process.

TABLE 3.1 Key Project Milestone (FYP I)

| Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project Title Selection | | | | | | | | | | | | | | |
| Preliminary Research Work | | | | | | | | | | | | | | |
| Literature Review | | | | | | | | | | | | | | |
| Submission of Extended Proposal | | | | | | ● | | | | | | | | |
| Revised on Literature Review | | | | | | | | | | | | | | |
| Research Work Continues | | | | | | | | | | | | | | |
| Proposal Defense | | | | | | | | | | ● | | | | |
| Project Work Continues | | | | | | | | | | | | | | |
| Field Measurement & Data Sampling | | | | | | | | | | | | | | |
| Draft Report | | | | | | | | | | | | | | |
| Submission of Interim Report | | | | | | | | | | | | | | ● |

● Milestone

TABLE 3.2 Key Project Milestone (FYP II)

| Detail/Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project Work Continues | | | | | | | | | | | | | | |
| Submission of Progress Report | | | | | | | ● | | | | | | | |
| Collection of Data | | | | | | | | | | | | | | |
| Data Analysis | | | | | | | | | | | | | | |
| i) Concentration Level of Pollutants | | | | | | | | | | | | | | |
| ii) Trends of Pollutants over Time | | | | | | | | | | | | | | |
| iii) Relationship between pollutants formation and vehicles | | | | | | | | | | | | | | |
| Draft Final Report | | | | | | | | | | | | | | |
| Submission of Dissertation (soft bound) | | | | | | | | | | | | ● | | |
| Submission of Technical Paper | | | | | | | | | | | | ● | | |
| Viva Presentation | | | | | | | | | | | | | ● | |
| Submission of Project Dissertation (hard bound) | | | | | | | | | | | | | | ● |

● Milestone

# CHAPTER 4 : RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

This chapter evaluates the results obtained from the data sampling done for this study. Data sampling of air pollutants was carried out from 6th November 2014 until 16th November 2014. The ten (10) days data collection was done at the study area of an enclosed car park located in one of the building in Kuala Lumpur city centre. Equipment used in this study is Aeroqual's AQM 60 that can record data for 24 hours in every two (2) minutes interval.

Data collected is tabulated by using Microsoft Office Excel for hourly average of concentration level of air pollutants. Trends of the air pollutants can be analysed by time series model plotted. In addition, evaluation of the results are in terms of pollutants concentration level, their relationship and the surrounding temperature. Analysis of the results is done according to three (3) categories which are weekdays, friday and weekends. Friday is chosen along with weekdays and weekend because it has slight difference in working hour period as compare to weekdays. Raw data received from the equipment during sampling and remaining results is attached in Appendix A.

## 4.2 ANALYSIS OF AIR POLLUTANTS

Results from data sampling is taken from 12:00 am to 11:00 am for one day analysis. Concentration levels of nitrogen dioxide ($NO_2$), ozone ($O_3$) and surrounding temperature at the study area are tabulated with respect to time. From the table, it shows that concentration of $NO_2$ has higher level than $O_3$. Main source of $NO_2$ in the enclosed car park area emitted from incomplete combustion of vehicles' exhaust. Fluctuations of $NO_2$ concentration level happens since amount vehicles that coming in and out from the area changes at different period of time. Formation of $O_3$ occur in the enclosed car park due to $NO_2$ as its precursor. Malaysia standard limit for $NO_2$ is 0.17 ppm and 0.10 ppm for ozone in one (1) hour mean time.

### 4.2.1 Concentration of Air Pollutants on Weekdays

TABLE 4.1 Pollutants Concentration on Weekday

| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0297 | 0.0057 | 31.91 |
| 1:00 AM | 0.0284 | 0.0076 | 31.88 |
| 2:00 AM | 0.0202 | 0.0208 | 31.82 |
| 3:00 AM | 0.0161 | 0.0209 | 31.66 |
| 4:00 AM | 0.0157 | 0.0176 | 31.80 |
| 5:00 AM | 0.0182 | 0.0151 | 31.86 |
| 6:00 AM | 0.0191 | 0.0121 | 31.92 |
| 7:00 AM | 0.0179 | 0.0163 | 31.94 |
| 8:00 AM | 0.0125 | 0.0200 | 31.71 |
| 9:00 AM | 0.0094 | 0.0154 | 31.36 |
| 10:00 AM | 0.0110 | 0.0276 | 31.52 |
| 11:00 AM | 0.0097 | 0.0607 | 32.01 |
| 12:00 PM | 0.0095 | 0.0678 | 32.58 |
| 1:00 PM | 0.0096 | 0.0787 | 32.85 |
| 2:00 PM | 0.0050 | 0.0704 | 32.98 |
| 3:00 PM | 0.0084 | 0.0762 | 33.30 |
| 4:00 PM | 0.0076 | 0.0733 | 33.14 |
| 5:00 PM | 0.0073 | 0.0580 | 32.78 |
| 6:00 PM | 0.0073 | 0.0640 | 32.40 |
| 7:00 PM | 0.0041 | 0.0536 | 32.33 |
| 8:00 PM | 0.0102 | 0.0436 | 32.13 |
| 9:00 PM | 0.0146 | 0.0327 | 32.12 |
| 10:00 PM | 0.0164 | 0.0210 | 32.20 |
| 11:00 PM | 0.0176 | 0.0470 | 32.18 |

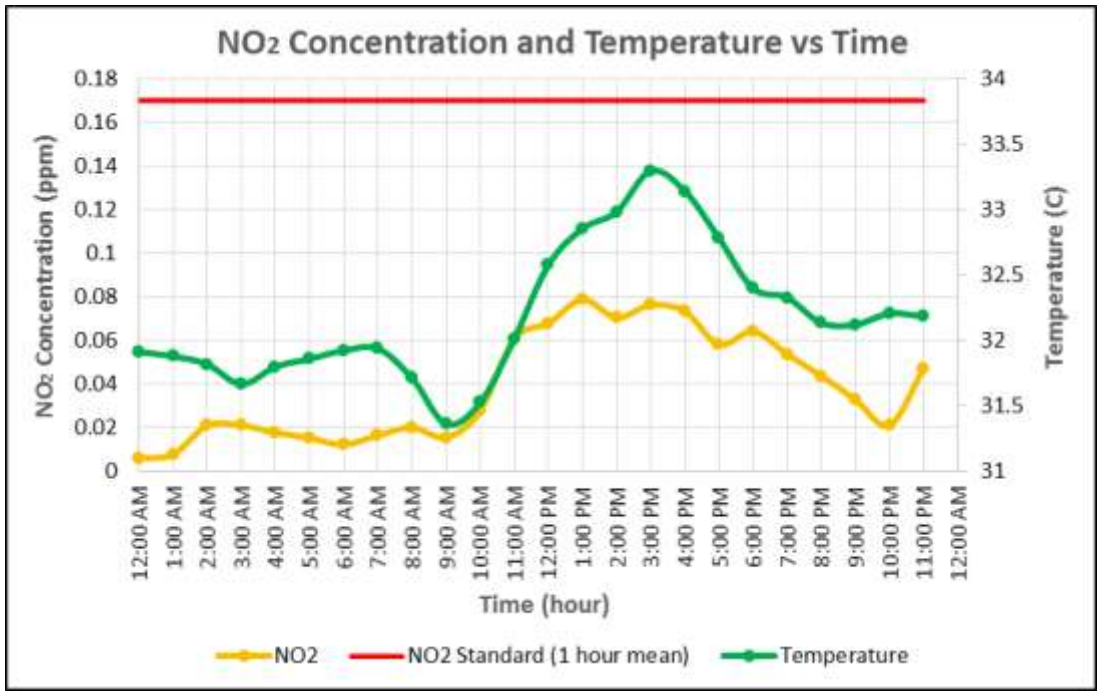


FIGURE 4.1 Concentration of $NO_2$ against Time on Weekday

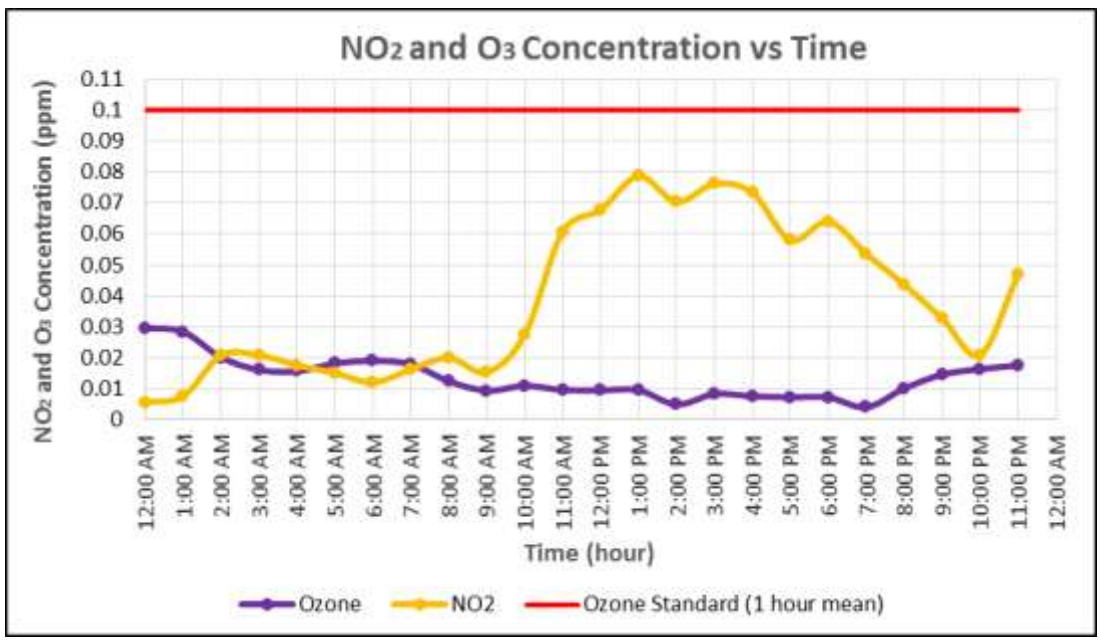


FIGURE 4.2 Concentration of $NO_2$ and $O_3$ against Time on Weekday

Figure 4.1 shows the concentration of $NO_2$ (ppm) and temperature (°C) against time (hour) on weekday. It can be said that the trends of $NO_2$ is much related to the temperature in the enclosed car park. The concentration level for $NO_2$ started to increase from 9:00 am and reached the highest value at 1:00 pm with the concentration of 0.079 ppm. After that, concentration of $NO_2$ decreased starting from 3.00 pm until 10:00 pm where it started to increase back at this particular hour. The lowest value of $NO_2$ is observed at 12:00 am with concentration of 0.006 ppm.

The concentration of $NO_2$ increase from 9:00 am because number of vehicles that emits $NO_2$ increases when people comes to work at the building. Highest concentration value at 1:00 pm since it is the time for people going out for lunch. However, it starts to decrease back at 3:00 pm because it is the time for people to get back to work after lunch period. Increasing of $NO_2$ concentration shows that most of the working people going back from work at 10:00 pm on weekday. This is because they might have stayed back at the office to finish their work or attended meetings for urgent project works.

From Figure 4.2, it can be seen the trends of $NO_2$ and $O_3$ with respect to time. Concentration level of $O_3$ increase and decrease inversely with the concentration of $NO_2$ in the area. In this case, it happened because $NO_2$ has become the precursor to the occurrence of $O_3$ formation. Although there is no presence of direct sunlight in enclosed car park area, the source of UV to form ozone may come from the lights in the car park area or lights from vehicles present inside the area.

Therefore, the results for weekday shows concentration level of $NO_2$ depends on number of vehicles as well as effect of temperature and existence of $O_3$ in the study area. Both pollutants indicated that the concentration level do not exceed the Malaysian Standards limit for $NO_2$ and $O_3$ which is given by 0.17 ppm and 0.10 ppm respectively. This means that the pollutants in the study area are considered safe to people for 1 hour mean time of exposure.

### 4.2.2 Concentration of Air Pollutants on Friday

TABLE 4.2 Pollutants Concentration on Friday

| **Time** | | | **Temperature (°C)** |
|---|---|---|---|
| 12:00 AM | 0.0167 | 0.0073 | 32.79 |
| 1:00 AM | 0.0138 | 0.0069 | 32.63 |
| 2:00 AM | 0.0083 | 0.0150 | 32.69 |
| 3:00 AM | 0.0078 | 0.0105 | 32.65 |
| 4:00 AM | 0.0063 | 0.0091 | 32.64 |
| 5:00 AM | 0.0078 | 0.0066 | 32.57 |
| 6:00 AM | 0.0054 | 0.0055 | 32.53 |
| 7:00 AM | 0.0061 | 0.0168 | 32.75 |
| 8:00 AM | 0.0049 | 0.0079 | 32.34 |
| 9:00 AM | 0.0026 | 0.0084 | 31.88 |
| 10:00 AM | 0.0003 | 0.0210 | 31.99 |
| 11:00 AM | 0.0036 | 0.0334 | 32.62 |
| 12:00 PM | 0.0051 | 0.0421 | 33.10 |
| 1:00 PM | 0.0064 | 0.0421 | 33.32 |
| 2:00 PM | 0.0013 | 0.0390 | 33.41 |
| 3:00 PM | 0.0024 | 0.0370 | 32.71 |
| 4:00 PM | 0.0033 | 0.0366 | 32.12 |
| 5:00 PM | 0.0018 | 0.0326 | 31.57 |
| 6:00 PM | 0.0048 | 0.0188 | 31.31 |
| 7:00 PM | 0.0009 | 0.0250 | 31.23 |
| 8:00 PM | 0.0059 | 0.0269 | 31.61 |
| 9:00 PM | 0.0123 | 0.0404 | 32.06 |
| 10:00 PM | 0.0161 | 0.0233 | 32.42 |
| 11:00 PM | 0.0272 | 0.0369 | 32.65 |

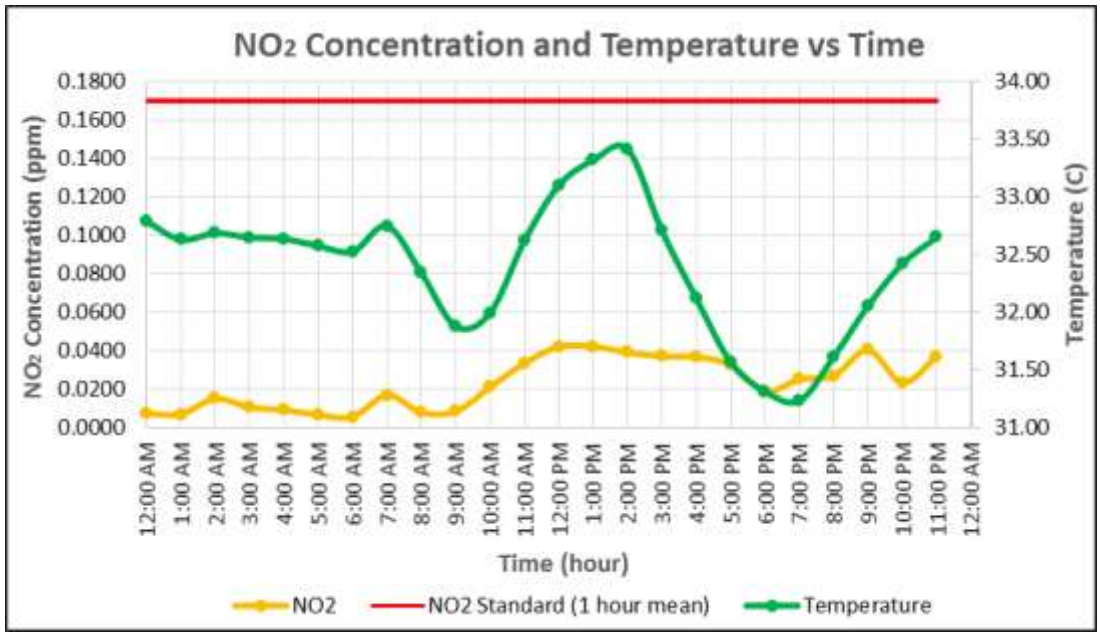


FIGURE 4.3 Concentration of $NO_2$ against Time on Friday

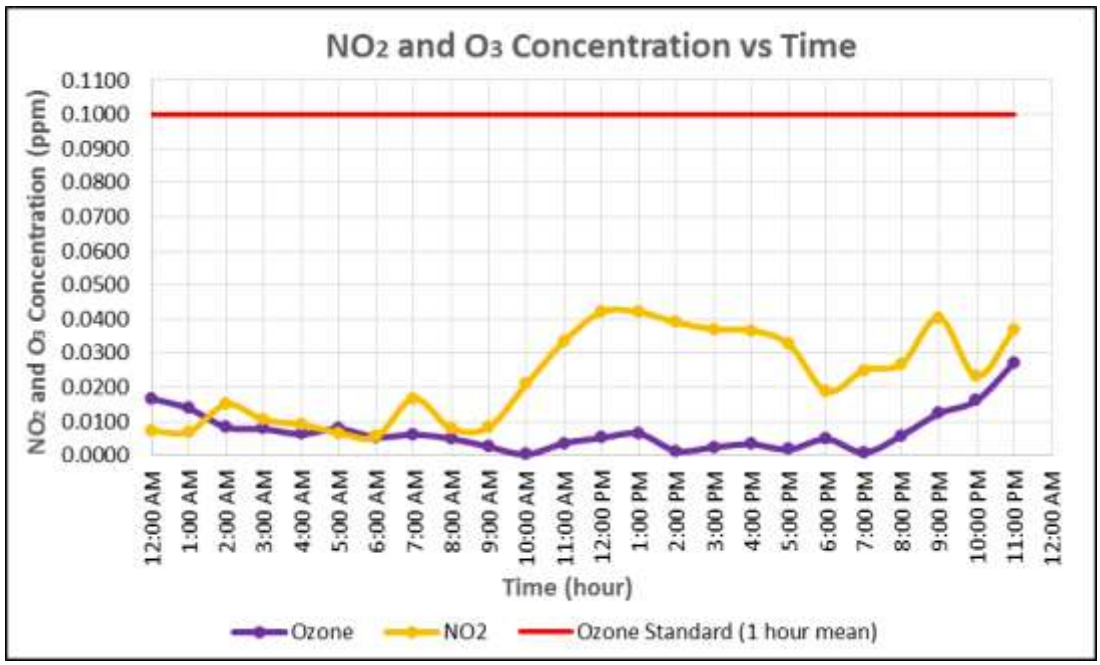


FIGURE 4.4 Concentration of $NO_2$ and $O_3$ against Time on Friday

On Friday, the results from Figure 4.3 shows the concentration of $NO_2$ (ppm) and temperature (°C) against time (hour). It can be said that the trends of $NO_2$ is similar with the results obtained from weekday. The concentration level for $NO_2$ started to increase consistently from 9:00 am to the highest concentration value of 0.042 ppm at 12:00 pm. After that, the concentration of $NO_2$ is having fluctuations and increase back starting from 6:00 pm. Lowest value recorded during 6:00 am with concentration of 0.006 ppm.

The concentration of $NO_2$ increase from 9:00 am during starting of working period and have the highest concentration at 12:00 on friday instead of 1:00 pm on weekday. This is due to difference in lunch hour period between Friday and weekday. In Malaysia, the lunch period allocated for workers is longer on Friday than that on weekday. However, it starts to decrease at the same time of 3.00 pm because after lunch period is over. $NO_2$ concentration increased back at 6:00 am which early than on weekday due to people coming back home more early than usual. They might be celebrating that weekends is coming or going out with their family and friends.

As from Figure 4.4, it is observed that concentration of $NO_2$ and $O_3$ have lower value as compared to weekday. This happen as concentration of $NO_2$ depends on number of vehicles going in and out from the area. Nevertheless, $O_3$ fluctuations occur due to presence of its precursor which is $NO_2$ that reacts with UV lights in the enclosed car park.

The analysed results for Friday can be considered same with weekday in terms of the relationship between concentration level of $NO_2$ and surrounding temperature which is the precursor to formation of ozone in an the enclosed car park. On top of that, the pollutants concentration are within the Malaysian Standards limit for 1 hour mean time of exposure.

### 4.2.3 Concentration of Air Pollutants on Weekend

TABLE 4.3 Pollutants Concentration on Weekend

| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0105 | 0.0246 | 31.90 |
| 1:00 AM | 0.0194 | 0.0061 | 31.91 |
| 2:00 AM | 0.0145 | 0.0124 | 31.94 |
| 3:00 AM | 0.0116 | 0.0099 | 31.89 |
| 4:00 AM | 0.0098 | 0.0124 | 31.90 |
| 5:00 AM | 0.0090 | 0.0133 | 32.01 |
| 6:00 AM | 0.0093 | 0.0084 | 31.99 |
| 7:00 AM | 0.0127 | 0.0071 | 32.04 |
| 8:00 AM | 0.0138 | 0.0120 | 32.08 |
| 9:00 AM | 0.0185 | 0.0165 | 31.94 |
| 10:00 AM | 0.0197 | 0.0164 | 32.13 |
| 11:00 AM | 0.0234 | 0.0407 | 31.99 |
| 12:00 PM | 0.0215 | 0.0313 | 31.57 |
| 1:00 PM | 0.0197 | 0.0306 | 31.66 |
| 2:00 PM | 0.0237 | 0.0318 | 31.87 |
| 3:00 PM | 0.0259 | 0.0341 | 31.79 |
| 4:00 PM | 0.0251 | 0.0293 | 31.77 |
| 5:00 PM | 0.0239 | 0.0203 | 31.77 |
| 6:00 PM | 0.0183 | 0.0148 | 31.52 |
| 7:00 PM | 0.0167 | 0.0301 | 31.88 |
| 8:00 PM | 0.0178 | 0.0296 | 31.78 |
| 9:00 PM | 0.0169 | 0.0186 | 31.66 |
| 10:00 PM | 0.0154 | 0.0196 | 31.76 |
| 11:00 PM | 0.0229 | 0.0174 | 31.93 |

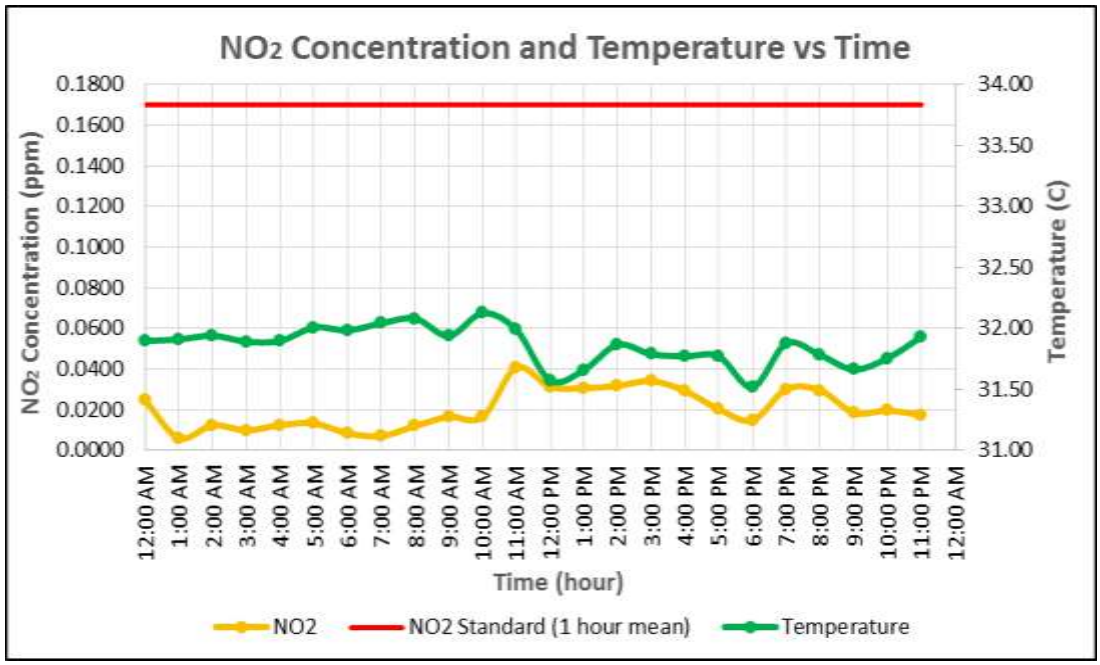


FIGURE 4.5 Concentration of $NO_2$ against Time on Weekend

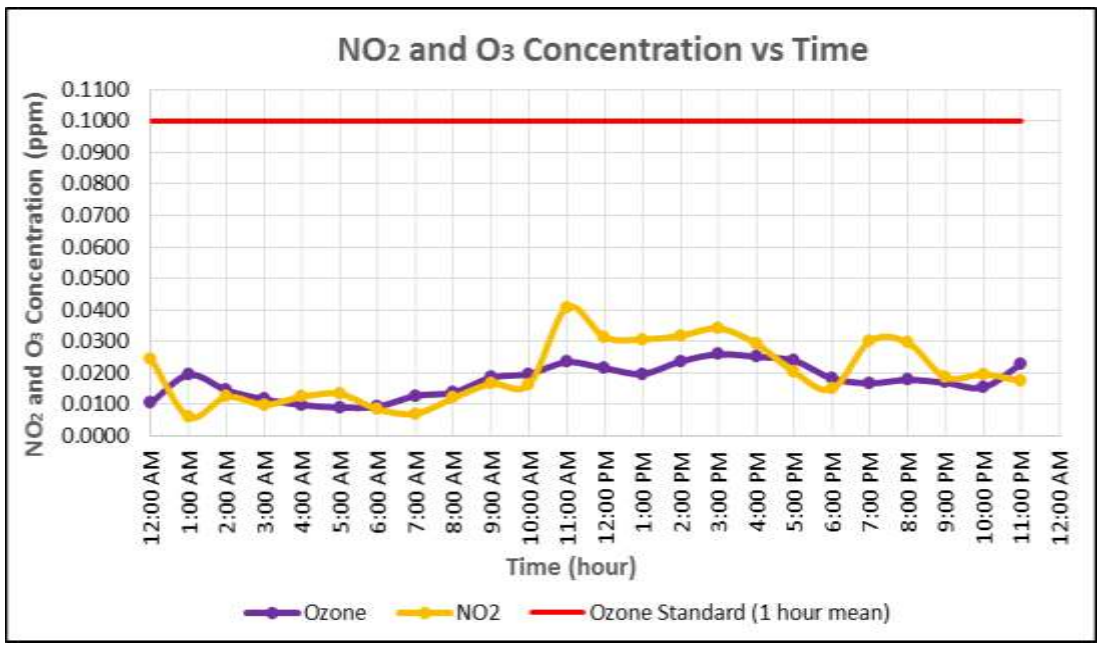


FIGURE 4.6 Concentration of $NO_2$ and $O_3$ against Time on Weekend

Figure 4.5 and Figure 4.6 indicates the correlation between concentration level of $NO_2$ and $O_3$ in enclosed car park with respect to its surrounding temperature and time on weekend. The concentration levels of $NO_2$ and $O_3$ showed lower values than during weekday and Friday. $NO_2$ concentration started to increase from 7:00 am to its highest value recorded at 11:00 pm with the reading of 0.041 ppm. Then, the concentration of $NO_2$ started to decrease inconsistently until 6:00 pm. After 6:00 pm, it started to increase back as according to the surrounding temperature of the study area. The lowest value of $NO_2$ is observed at 1:00 am with concentration of 0.006 ppm.

Concentration level of $NO_2$ is lower on weekend as compare to weekday and Friday because only few people came to the building during holiday. Hence, reduced number of vehicles in the study area leads to the decreasing level of $NO_2$ emission. $NO_2$ increase at certain period of time that might be the time for people coming in and leaving the building. Other than that, the maintenance workers probably came and do their works on weekend to avoid crowded area during weekdays.

As for concentration level of $O_3$ , the fluctuation patterns is inversely with the concentration of $NO_2$ in the area where it is converted to $O_3$. Consequencely, possibility of $O_3$ formation in an enclosed car park is practical as according to the analysis done. From figure 4.6, it signifies that the decreasing of $NO_2$ leads to increasing of $O_3$ and vice versa. It can be explained by $NO_2$ that is the precursor of $O_3$ has been used up in the reaction process of producing $O_3$ with reliable source of UV light in the enclosed car park.

Results of concentration level of $NO_2$ and $O_3$ on weekends satisfied with the standards limit given by Malaysian government and classified as below hazardous level of pollutants in 1 hour mean time of exposure.

# CHAPTER 5 : CONCLUSION AND RECOMMENDATIONS

Quality of air in an enclosed car park must not be taken for granted as the area is differ from ambient or open-space area. The confined space and high concentration level of pollutants could give adverse effects especially to human health. This study examines the concentrations of air pollutants in an enclosed car park area to comply with hazardous levels given by the Malaysian Standards limit. Analysis of the results was done to evaluate the trends of air pollutants during weekdays, Friday and weekends.

Objectives of this study have been achieved. Firstly, the concentration level of $NO_2$ in an enclosed car park can be determined. Secondly, there is formation of $O_3$ occurring in enclosed car park even with absence of direct sunlight. Lastly, the relationship between $NO_2$ , $O_3$ and surrounding temperature of the study area is analysed by using time series analysis. By using time series model, trends of selected air pollutants against time can be clearly seen.

From the analysis, $NO_2$ concentration in an enclosed car park is corresponding with the working trends in Malaysia. The $NO_2$ emission depends on incomplete combustion of vehicles' exhaust and much related to the surrounding temperature of the study area. Possibility of $O_3$ formation aligned to its precursor which is $NO_2$ and reliable source of UV light inside the enclosed car park area. The concentration for both $NO_2$ and $O_3$ recorded in this study do not exceed the Malaysian Standard limit.

In Malaysia, there is no regulation and guideline on indoor ambient air quality and thus this study can be used as continuation for further research in the future. Indoor air quality guideline is crucial to ensure people who working with indoor environment are safe from being exposed to dangerous level of air pollutants. On top of that, intense study regarding ozone need to continue in such a way in future the value may increase because NO2 is the precursor to the formation of ozone.

The study can be improved by some modifications as follows :

1) Installation of equipment in the study area that able to measure UV radiation level

2) Data sampling is done for a longer period of time to get more reliable results

3) Air sample is taken from several points in the enclosed car park area to increase accuracy

4) Number and types of vehicles in the enclosed car park area can be measured to relate with the rate of pollutants emission from vehicles' exhaust

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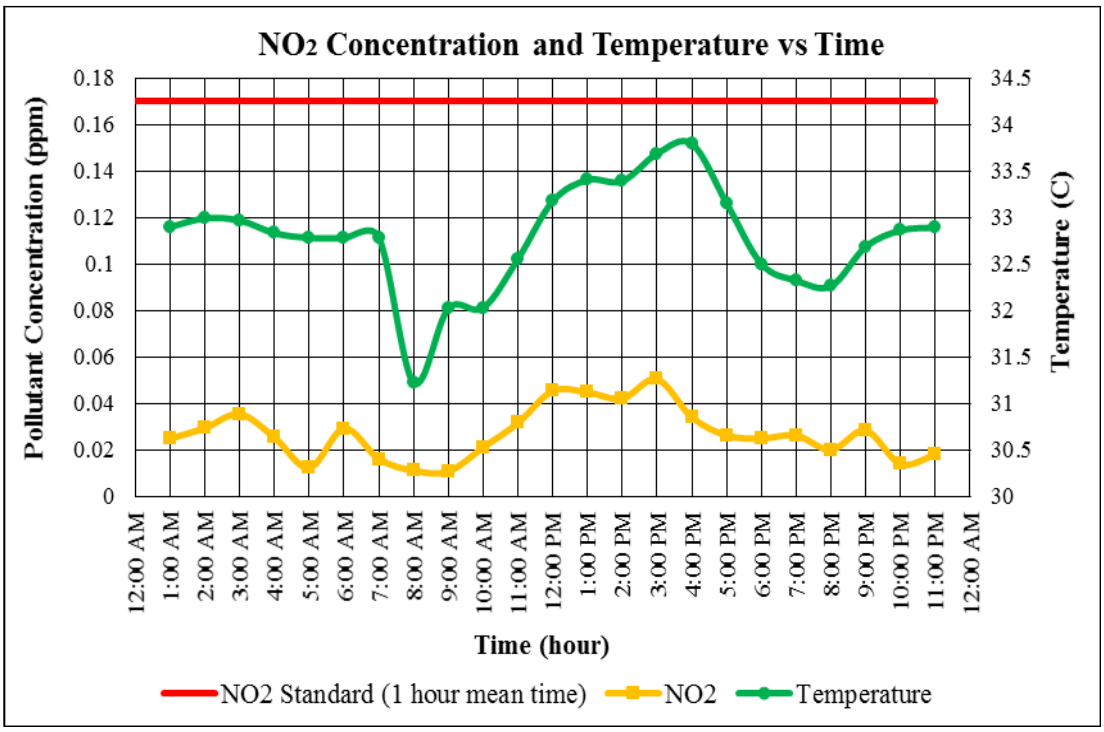
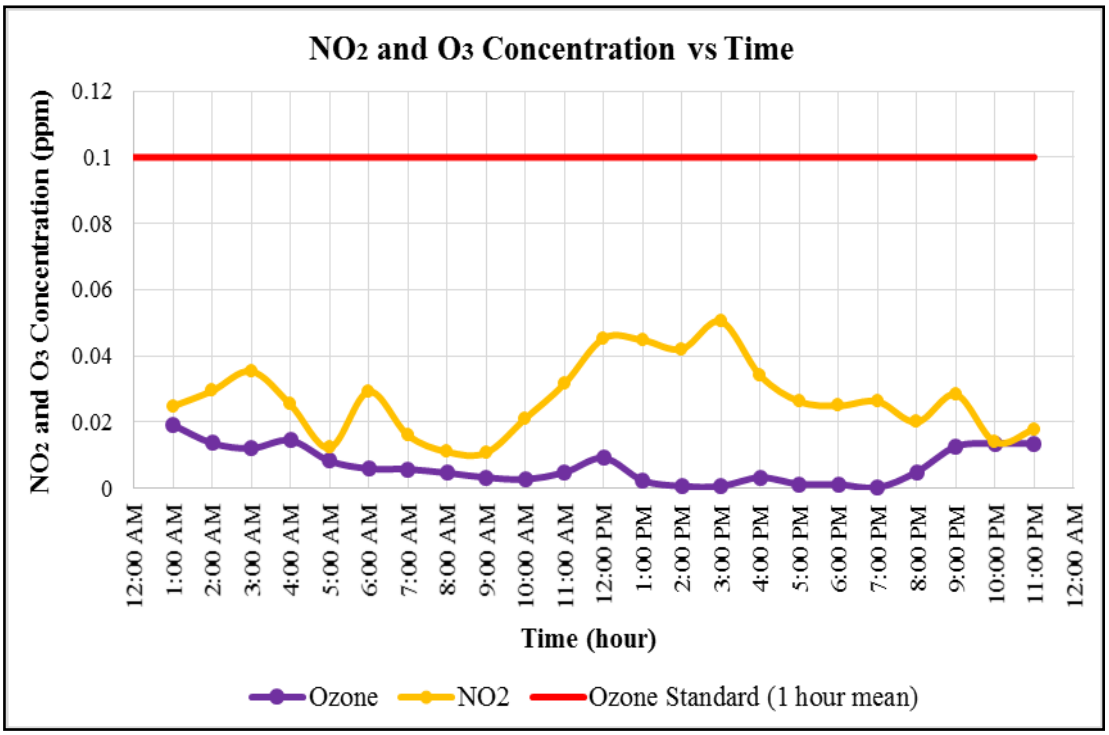
# APPENDICES

6th November 2014 – DAY 1

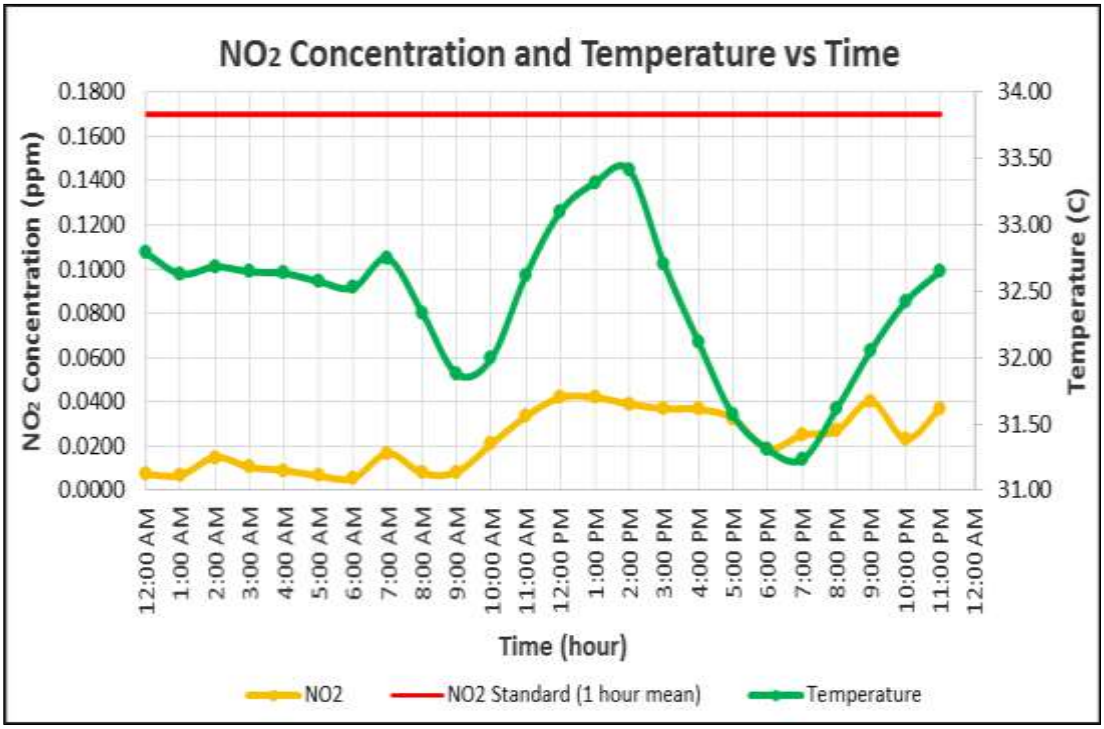
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | - | - | - |
| 1:00 AM | 0.0191 | 0.0247 | 32.90 |
| 2:00 AM | 0.0136 | 0.0294 | 32.99 |
| 3:00 AM | 0.0120 | 0.0353 | 32.97 |
| 4:00 AM | 0.0144 | 0.0252 | 32.83 |
| 5:00 AM | 0.0082 | 0.0122 | 32.78 |
| 6:00 AM | 0.0059 | 0.0292 | 32.78 |
| 7:00 AM | 0.0057 | 0.0160 | 32.79 |
| 8:00 AM | 0.0046 | 0.0110 | 31.22 |
| 9:00 AM | 0.0032 | 0.0107 | 32.02 |
| 10:00 AM | 0.0027 | 0.0210 | 32.03 |
| 11:00 AM | 0.0047 | 0.0315 | 32.55 |
| 12:00 PM | 0.0091 | 0.0453 | 33.18 |
| 1:00 PM | 0.0023 | 0.0447 | 33.40 |
| 2:00 PM | 0.0006 | 0.0420 | 33.39 |
| 3:00 PM | 0.0006 | 0.0504 | 33.69 |
| 4:00 PM | 0.0032 | 0.0340 | 33.79 |
| 5:00 PM | 0.0012 | 0.0262 | 33.15 |
| 6:00 PM | 0.0011 | 0.0248 | 32.50 |
| 7:00 PM | 0.0002 | 0.0262 | 32.32 |
| 8:00 PM | 0.0049 | 0.0199 | 32.26 |
| 9:00 PM | 0.0126 | 0.0283 | 32.68 |
| 10:00 PM | 0.0135 | 0.0139 | 32.86 |
| 11:00 PM | 0.0134 | 0.0178 | 32.89 |

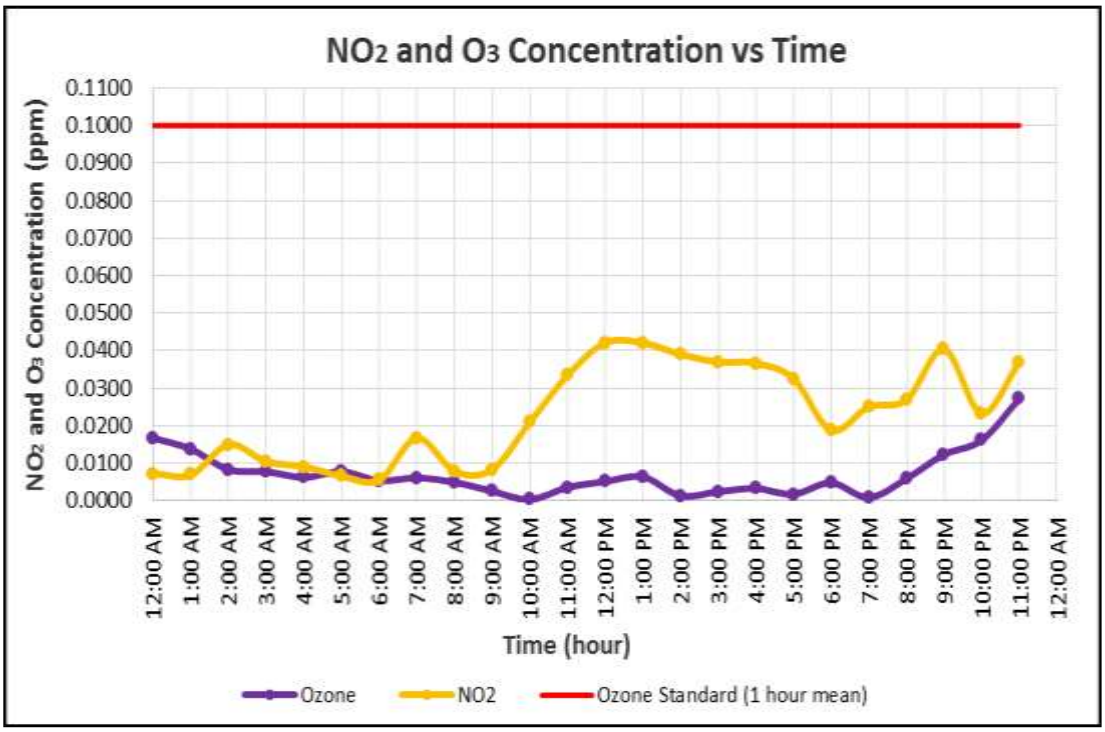

NO2 Concentration and Temperature vs Time
Pollutant Concentration (ppm)
Temperature (C)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
34.5
34
33.5
33
32.5
32
31.5
31
30.5
30
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
NO2 Standard (1 hour mean time)
NO2
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

7th November 2014 – DAY 2

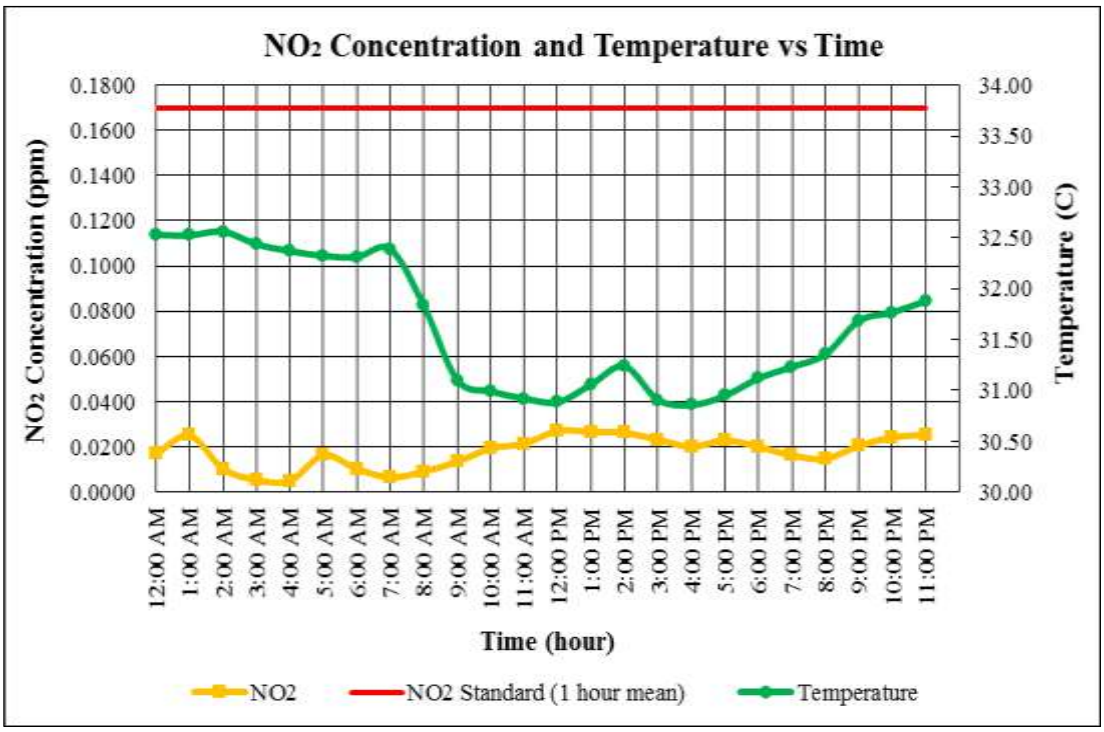
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0167 | 0.0073 | 32.79 |
| 1:00 AM | 0.0138 | 0.0069 | 32.63 |
| 2:00 AM | 0.0083 | 0.0150 | 32.69 |
| 3:00 AM | 0.0078 | 0.0105 | 32.65 |
| 4:00 AM | 0.0063 | 0.0091 | 32.64 |
| 5:00 AM | 0.0078 | 0.0066 | 32.57 |
| 6:00 AM | 0.0054 | 0.0055 | 32.53 |
| 7:00 AM | 0.0061 | 0.0168 | 32.75 |
| 8:00 AM | 0.0049 | 0.0079 | 32.34 |
| 9:00 AM | 0.0026 | 0.0084 | 31.88 |
| 10:00 AM | 0.0003 | 0.0210 | 31.99 |
| 11:00 AM | 0.0036 | 0.0334 | 32.62 |
| 12:00 PM | 0.0051 | 0.0421 | 33.10 |
| 1:00 PM | 0.0064 | 0.0421 | 33.32 |
| 2:00 PM | 0.0013 | 0.0390 | 33.41 |
| 3:00 PM | 0.0024 | 0.0370 | 32.71 |
| 4:00 PM | 0.0033 | 0.0366 | 32.12 |
| 5:00 PM | 0.0018 | 0.0326 | 31.57 |
| 6:00 PM | 0.0048 | 0.0188 | 31.31 |
| 7:00 PM | 0.0009 | 0.0250 | 31.23 |
| 8:00 PM | 0.0059 | 0.0269 | 31.61 |
| 9:00 PM | 0.0123 | 0.0404 | 32.06 |
| 10:00 PM | 0.0161 | 0.0233 | 32.42 |
| 11:00 PM | 0.0272 | 0.0369 | 32.65 |

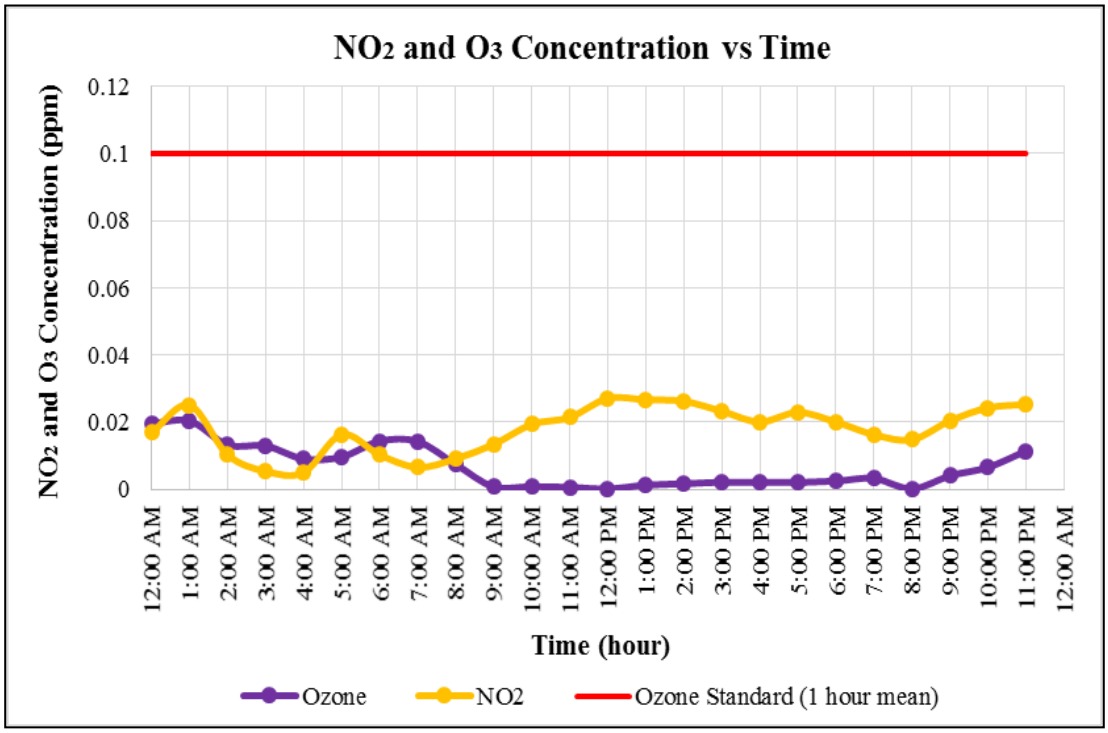

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
34.00
33.50
33.00
32.50
32.00
31.50
31.00
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

8th November 2014 – DAY 3

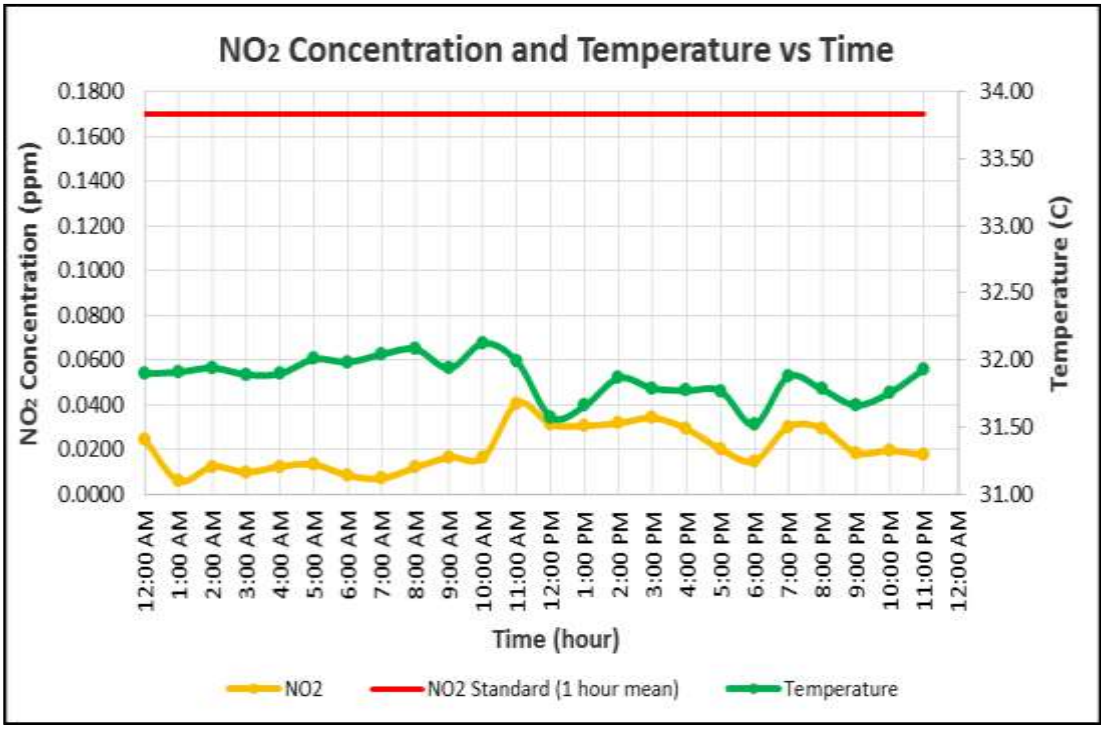
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0196 | 0.0170 | 32.53 |
| 1:00 AM | 0.0204 | 0.0251 | 32.52 |
| 2:00 AM | 0.0133 | 0.0104 | 32.56 |
| 3:00 AM | 0.0130 | 0.0054 | 32.44 |
| 4:00 AM | 0.0091 | 0.0051 | 32.37 |
| 5:00 AM | 0.0097 | 0.0164 | 32.32 |
| 6:00 AM | 0.0144 | 0.0103 | 32.31 |
| 7:00 AM | 0.0143 | 0.0066 | 32.39 |
| 8:00 AM | 0.0075 | 0.0092 | 31.83 |
| 9:00 AM | 0.0008 | 0.0135 | 31.10 |
| 10:00 AM | 0.0009 | 0.0194 | 30.99 |
| 11:00 AM | 0.0007 | 0.0215 | 30.92 |
| 12:00 PM | 0.0002 | 0.0271 | 30.88 |
| 1:00 PM | 0.0013 | 0.0267 | 31.06 |
| 2:00 PM | 0.0017 | 0.0263 | 31.24 |
| 3:00 PM | 0.0022 | 0.0233 | 30.91 |
| 4:00 PM | 0.0021 | 0.0201 | 30.86 |
| 5:00 PM | 0.0021 | 0.0230 | 30.95 |
| 6:00 PM | 0.0025 | 0.0201 | 31.12 |
| 7:00 PM | 0.0033 | 0.0163 | 31.23 |
| 8:00 PM | 0.0002 | 0.0148 | 31.35 |
| 9:00 PM | 0.0041 | 0.0205 | 31.68 |
| 10:00 PM | 0.0066 | 0.0243 | 31.77 |
| 11:00 PM | 0.0115 | 0.0254 | 31.88 |

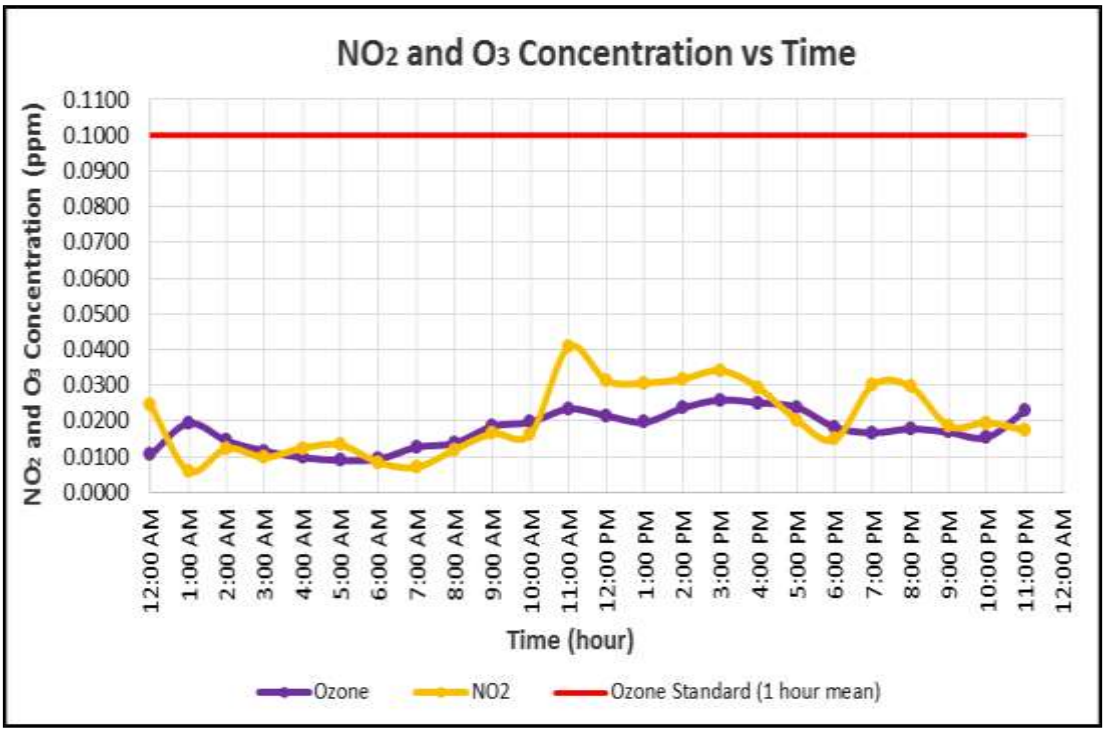

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
34.00
33.50
33.00
32.50
32.00
31.50
31.00
30.50
30.00
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

9th November 2014 – DAY 4

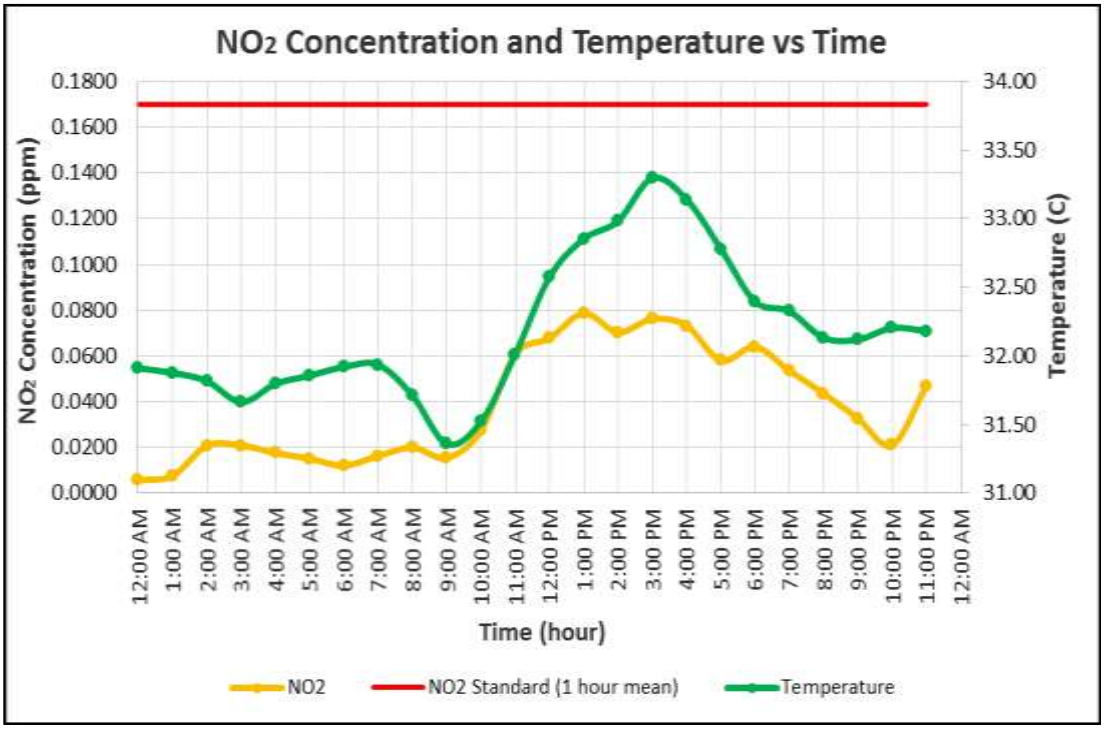
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0105 | 0.0246 | 31.90 |
| 1:00 AM | 0.0194 | 0.0061 | 31.91 |
| 2:00 AM | 0.0145 | 0.0124 | 31.94 |
| 3:00 AM | 0.0116 | 0.0099 | 31.89 |
| 4:00 AM | 0.0098 | 0.0124 | 31.90 |
| 5:00 AM | 0.0090 | 0.0133 | 32.01 |
| 6:00 AM | 0.0093 | 0.0084 | 31.99 |
| 7:00 AM | 0.0127 | 0.0071 | 32.04 |
| 8:00 AM | 0.0138 | 0.0120 | 32.08 |
| 9:00 AM | 0.0185 | 0.0165 | 31.94 |
| 10:00 AM | 0.0197 | 0.0164 | 32.13 |
| 11:00 AM | 0.0234 | 0.0407 | 31.99 |
| 12:00 PM | 0.0215 | 0.0313 | 31.57 |
| 1:00 PM | 0.0197 | 0.0306 | 31.66 |
| 2:00 PM | 0.0237 | 0.0318 | 31.87 |
| 3:00 PM | 0.0259 | 0.0341 | 31.79 |
| 4:00 PM | 0.0251 | 0.0293 | 31.77 |
| 5:00 PM | 0.0239 | 0.0203 | 31.77 |
| 6:00 PM | 0.0183 | 0.0148 | 31.52 |
| 7:00 PM | 0.0167 | 0.0301 | 31.88 |
| 8:00 PM | 0.0178 | 0.0296 | 31.78 |
| 9:00 PM | 0.0169 | 0.0186 | 31.66 |
| 10:00 PM | 0.0154 | 0.0196 | 31.76 |
| 11:00 PM | 0.0229 | 0.0174 | 31.93 |

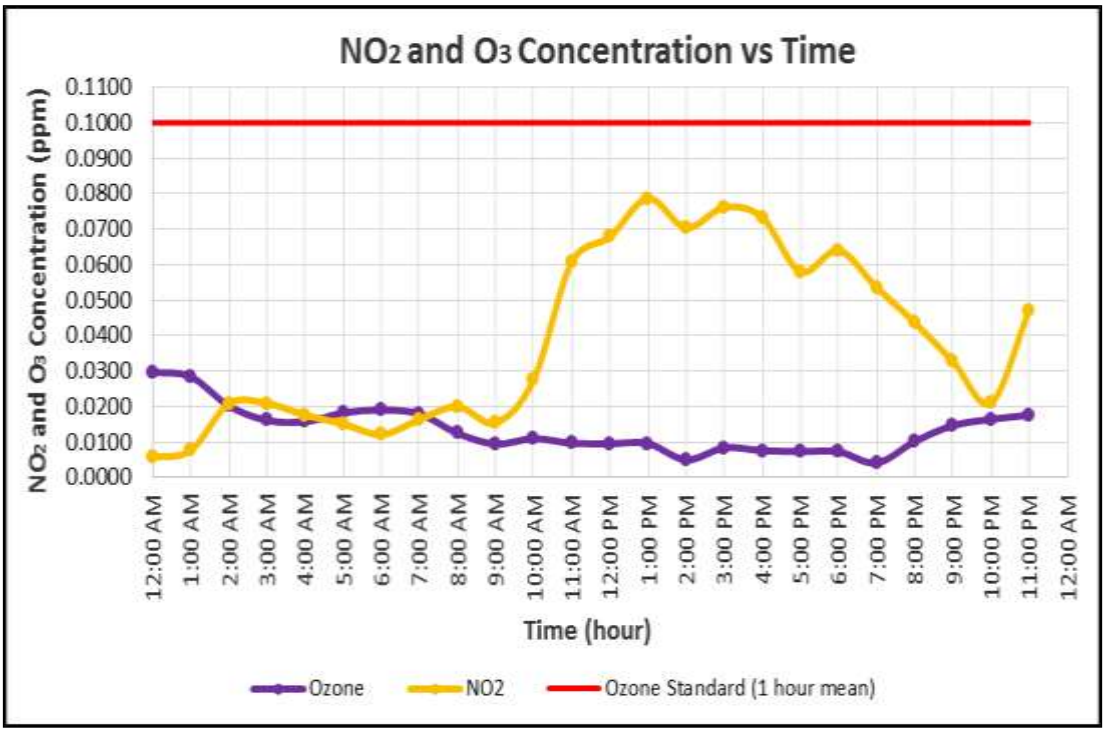

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
34.00
33.50
33.00
32.50
32.00
31.50
31.00
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

10th November 2014 – DAY 5

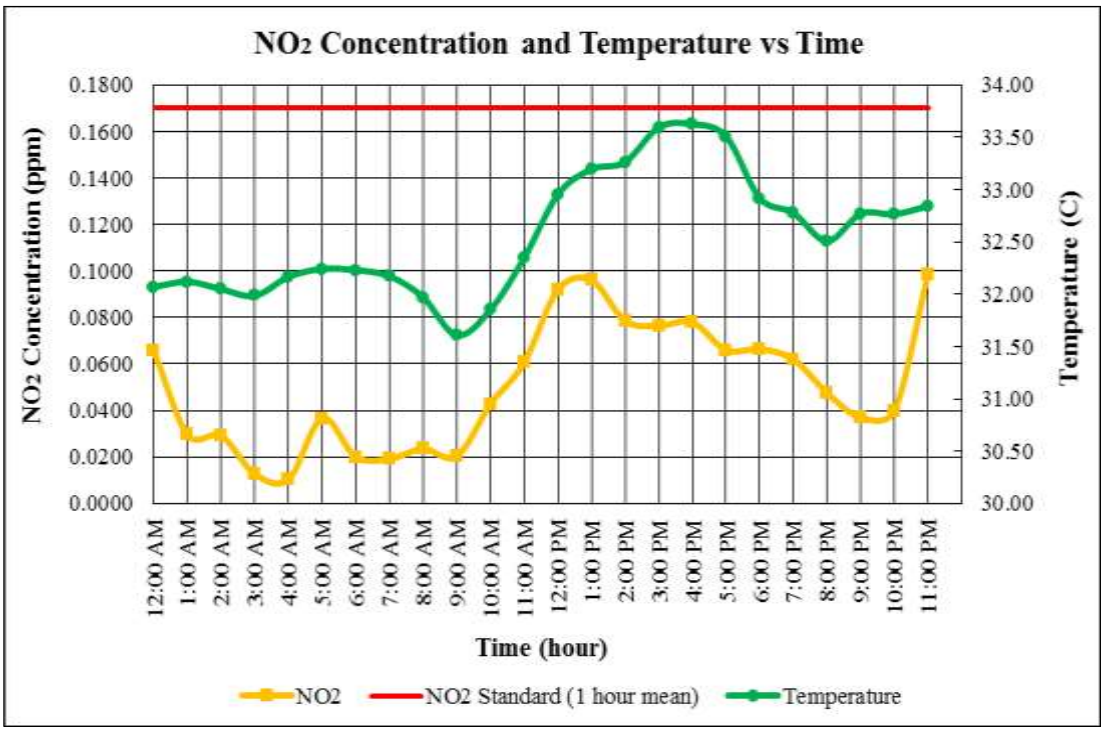
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0297 | 0.0057 | 31.91 |
| 1:00 AM | 0.0284 | 0.0076 | 31.88 |
| 2:00 AM | 0.0202 | 0.0208 | 31.82 |
| 3:00 AM | 0.0161 | 0.0209 | 31.66 |
| 4:00 AM | 0.0157 | 0.0176 | 31.80 |
| 5:00 AM | 0.0182 | 0.0151 | 31.86 |
| 6:00 AM | 0.0191 | 0.0121 | 31.92 |
| 7:00 AM | 0.0179 | 0.0163 | 31.94 |
| 8:00 AM | 0.0125 | 0.0200 | 31.71 |
| 9:00 AM | 0.0094 | 0.0154 | 31.36 |
| 10:00 AM | 0.0110 | 0.0276 | 31.52 |
| 11:00 AM | 0.0097 | 0.0607 | 32.01 |
| 12:00 PM | 0.0095 | 0.0678 | 32.58 |
| 1:00 PM | 0.0096 | 0.0787 | 32.85 |
| 2:00 PM | 0.0050 | 0.0704 | 32.98 |
| 3:00 PM | 0.0084 | 0.0762 | 33.30 |
| 4:00 PM | 0.0076 | 0.0733 | 33.14 |
| 5:00 PM | 0.0073 | 0.0580 | 32.78 |
| 6:00 PM | 0.0073 | 0.0640 | 32.40 |
| 7:00 PM | 0.0041 | 0.0536 | 32.33 |
| 8:00 PM | 0.0102 | 0.0436 | 32.13 |
| 9:00 PM | 0.0146 | 0.0327 | 32.12 |
| 10:00 PM | 0.0164 | 0.0210 | 32.20 |
| 11:00 PM | 0.0176 | 0.0470 | 32.18 |

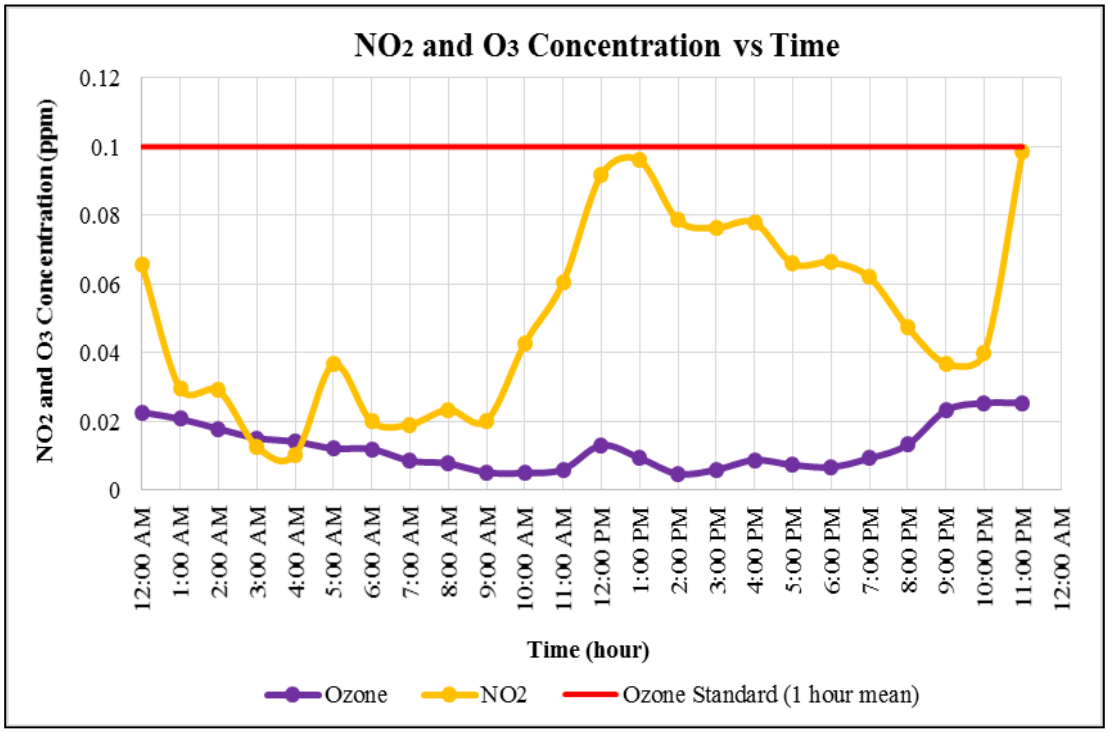

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

11th November 2014 – DAY 6

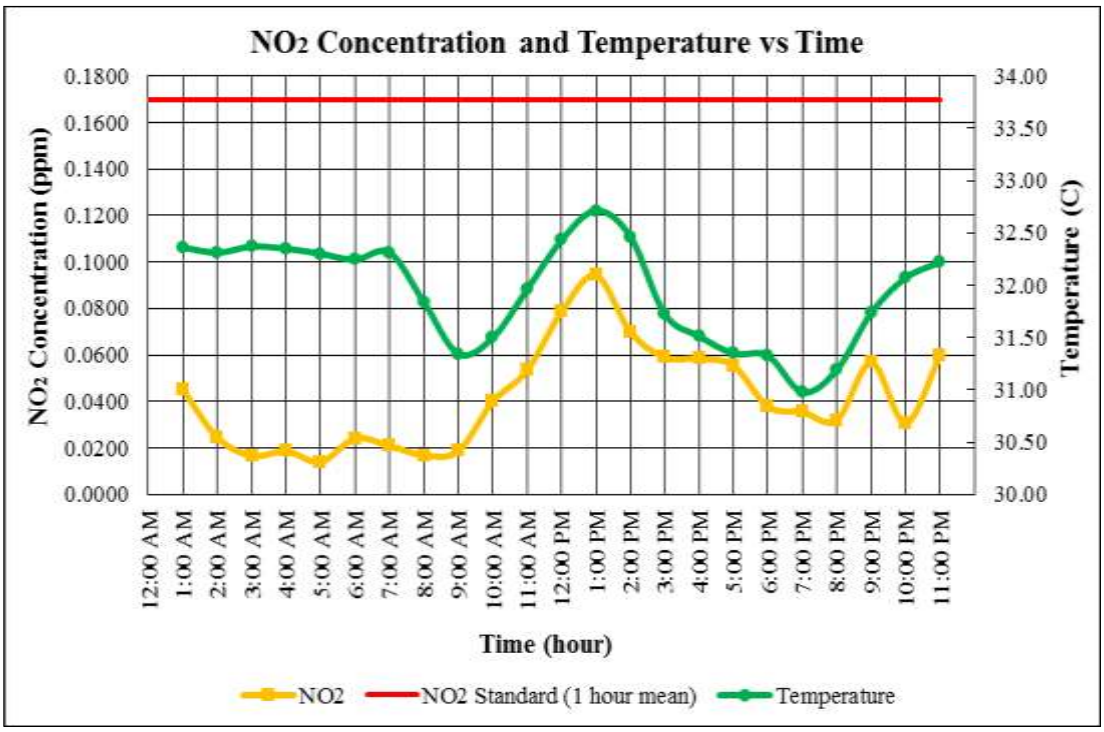
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0227 | 0.0657 | 32.07 |
| 1:00 AM | 0.0208 | 0.0296 | 32.12 |
| 2:00 AM | 0.0179 | 0.0291 | 32.05 |
| 3:00 AM | 0.0152 | 0.0127 | 31.99 |
| 4:00 AM | 0.0142 | 0.0104 | 32.17 |
| 5:00 AM | 0.0122 | 0.0366 | 32.24 |
| 6:00 AM | 0.0120 | 0.0200 | 32.23 |
| 7:00 AM | 0.0086 | 0.0192 | 32.17 |
| 8:00 AM | 0.0078 | 0.0235 | 31.97 |
| 9:00 AM | 0.0052 | 0.0203 | 31.61 |
| 10:00 AM | 0.0050 | 0.0428 | 31.85 |
| 11:00 AM | 0.0061 | 0.0606 | 32.35 |
| 12:00 PM | 0.0131 | 0.0919 | 32.95 |
| 1:00 PM | 0.0094 | 0.0960 | 33.20 |
| 2:00 PM | 0.0048 | 0.0786 | 33.26 |
| 3:00 PM | 0.0060 | 0.0765 | 33.60 |
| 4:00 PM | 0.0088 | 0.0779 | 33.63 |
| 5:00 PM | 0.0074 | 0.0660 | 33.51 |
| 6:00 PM | 0.0068 | 0.0664 | 32.92 |
| 7:00 PM | 0.0093 | 0.0620 | 32.78 |
| 8:00 PM | 0.0133 | 0.0475 | 32.51 |
| 9:00 PM | 0.0233 | 0.0369 | 32.77 |
| 10:00 PM | 0.0254 | 0.0400 | 32.77 |
| 11:00 PM | 0.0254 | 0.0987 | 32.84 |

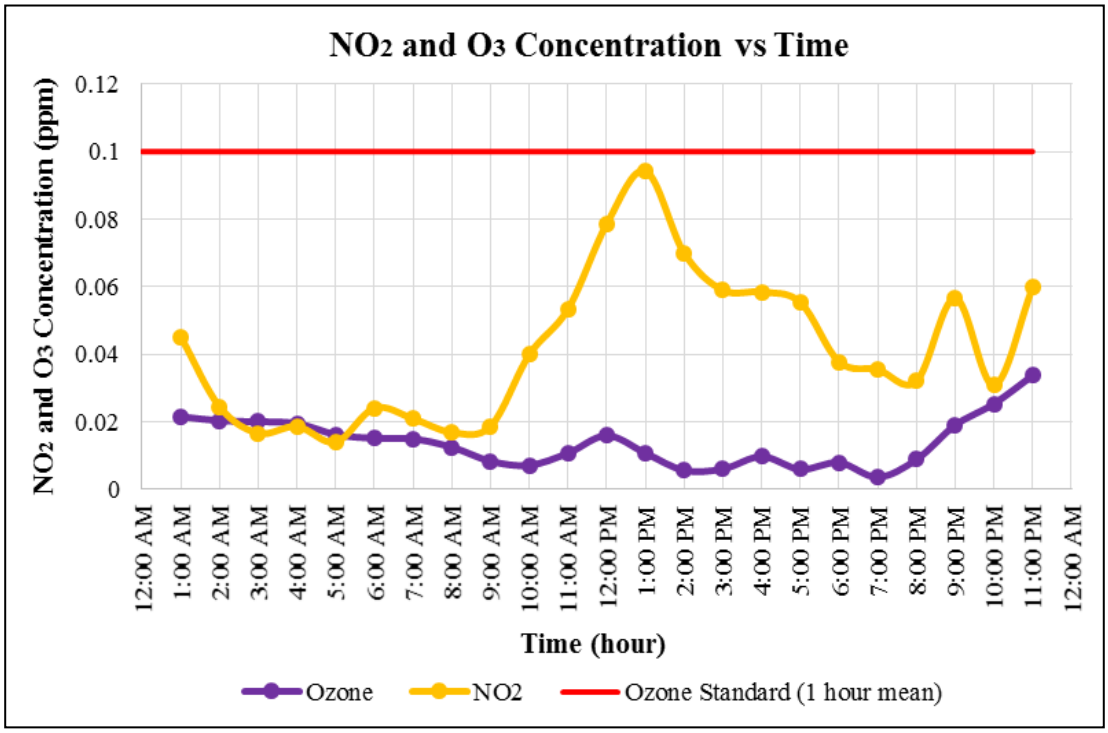

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
34.00
33.50
33.00
32.50
32.00
31.50
31.00
30.50
30.00
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

13th November 2014 – DAY 7

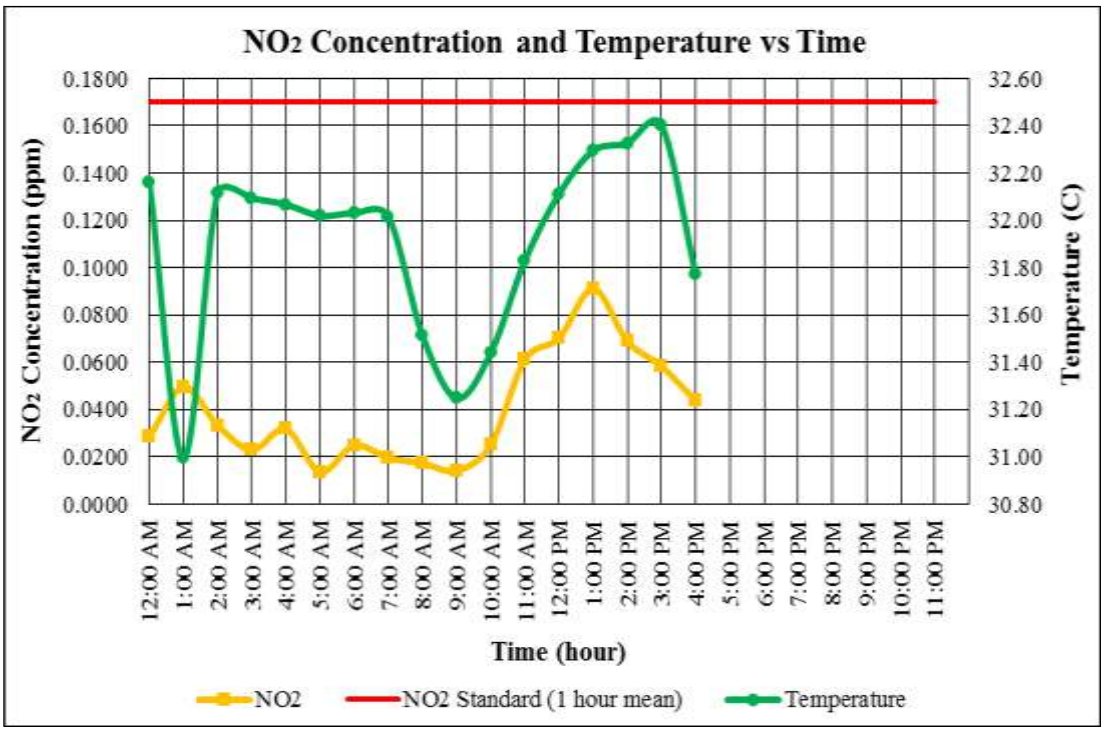
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | - | - | - |
| 1:00 AM | 0.0215 | 0.0451 | 32.36 |
| 2:00 AM | 0.0203 | 0.0244 | 32.31 |
| 3:00 AM | 0.0200 | 0.0166 | 32.37 |
| 4:00 AM | 0.0195 | 0.0186 | 32.35 |
| 5:00 AM | 0.0162 | 0.0140 | 32.30 |
| 6:00 AM | 0.0151 | 0.0241 | 32.24 |
| 7:00 AM | 0.0149 | 0.0209 | 32.31 |
| 8:00 AM | 0.0125 | 0.0168 | 31.84 |
| 9:00 AM | 0.0083 | 0.0187 | 31.34 |
| 10:00 AM | 0.0071 | 0.0399 | 31.50 |
| 11:00 AM | 0.0107 | 0.0534 | 31.96 |
| 12:00 PM | 0.0159 | 0.0786 | 32.43 |
| 1:00 PM | 0.0107 | 0.0942 | 32.71 |
| 2:00 PM | 0.0056 | 0.0699 | 32.47 |
| 3:00 PM | 0.0060 | 0.0589 | 31.72 |
| 4:00 PM | 0.0097 | 0.0584 | 31.51 |
| 5:00 PM | 0.0059 | 0.0554 | 31.35 |
| 6:00 PM | 0.0079 | 0.0377 | 31.33 |
| 7:00 PM | 0.0036 | 0.0354 | 30.98 |
| 8:00 PM | 0.0088 | 0.0320 | 31.19 |
| 9:00 PM | 0.0190 | 0.0567 | 31.74 |
| 10:00 PM | 0.0253 | 0.0308 | 32.07 |
| 11:00 PM | 0.0337 | 0.0598 | 32.22 |

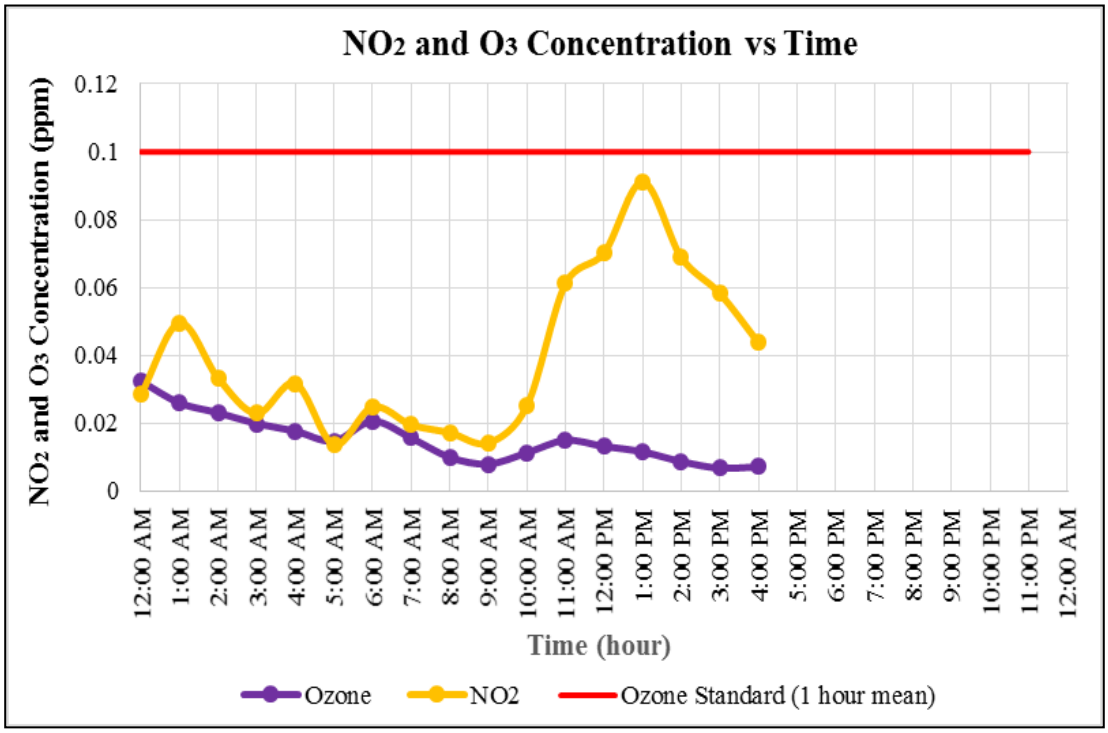

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
34.00
33.50
33.00
32.50
32.00
31.50
31.00
30.50
30.00
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

14th November 2014 – DAY 8

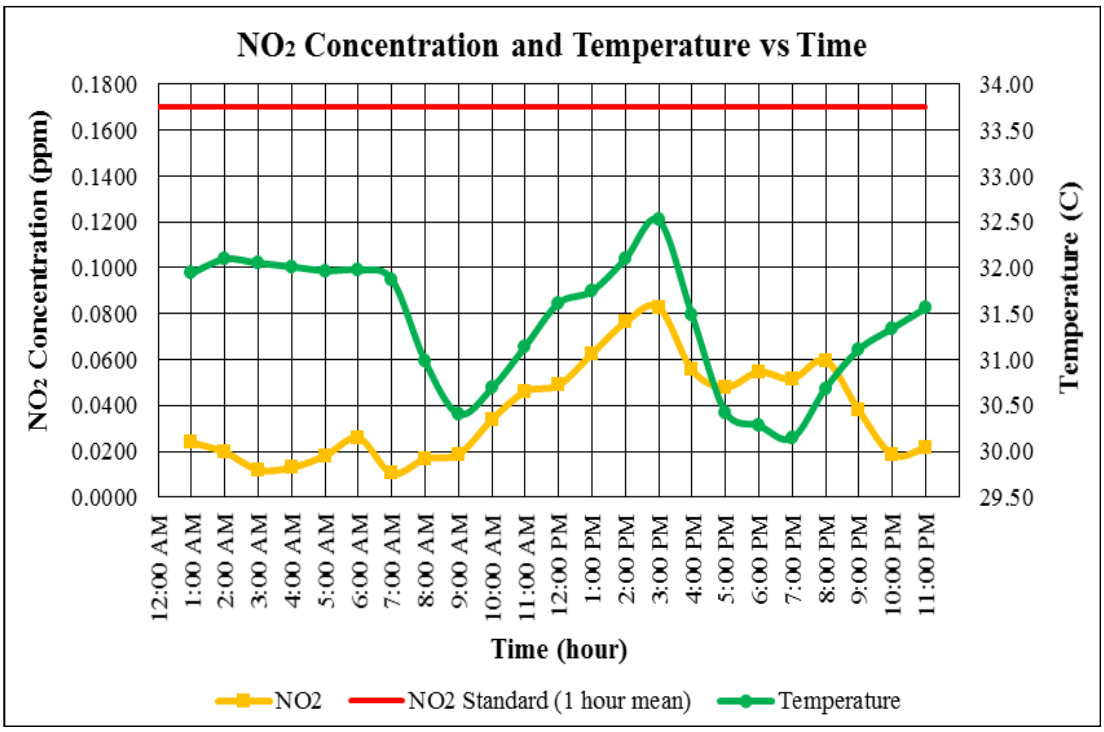
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0324 | 0.0284 | 32.16 |
| 1:00 AM | 0.0260 | 0.0495 | 30.99 |
| 2:00 AM | 0.0231 | 0.0333 | 32.11 |
| 3:00 AM | 0.0199 | 0.0229 | 32.09 |
| 4:00 AM | 0.0177 | 0.0318 | 32.07 |
| 5:00 AM | 0.0148 | 0.0137 | 32.02 |
| 6:00 AM | 0.0206 | 0.0248 | 32.03 |
| 7:00 AM | 0.0157 | 0.0196 | 32.02 |
| 8:00 AM | 0.0100 | 0.0172 | 31.51 |
| 9:00 AM | 0.0080 | 0.0142 | 31.25 |
| 10:00 AM | 0.0113 | 0.0251 | 31.44 |
| 11:00 AM | 0.0150 | 0.0611 | 31.83 |
| 12:00 PM | 0.0132 | 0.0702 | 32.11 |
| 1:00 PM | 0.0116 | 0.0911 | 32.29 |
| 2:00 PM | 0.0087 | 0.0689 | 32.33 |
| 3:00 PM | 0.0068 | 0.0583 | 32.40 |
| 4:00 PM | 0.0072 | 0.0437 | 31.77 |
| 5:00 PM | - | - | - |
| 6:00 PM | - | - | - |
| 7:00 PM | - | - | - |
| 8:00 PM | - | - | - |
| 9:00 PM | - | - | - |
| 10:00 PM | - | - | - |
| 11:00 PM | - | - | - |

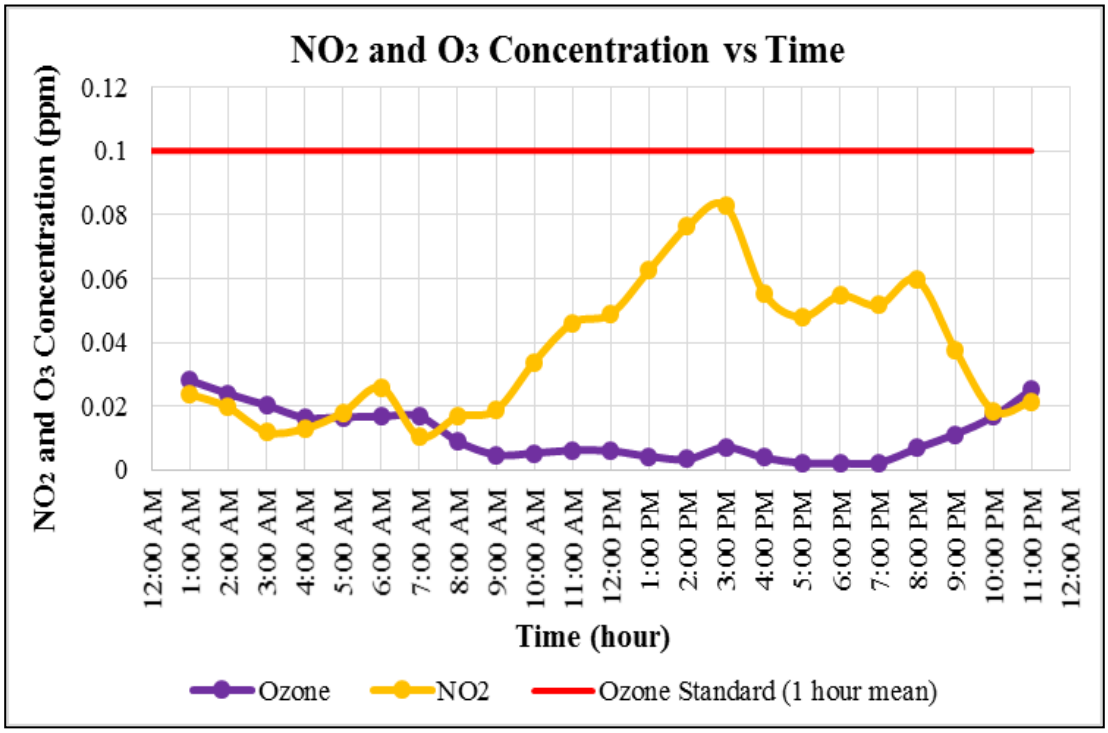

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
32.60
32.40
32.20
32.00
31.80
31.60
31.40
31.20
31.00
30.80
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

15th November 2014 – DAY 9

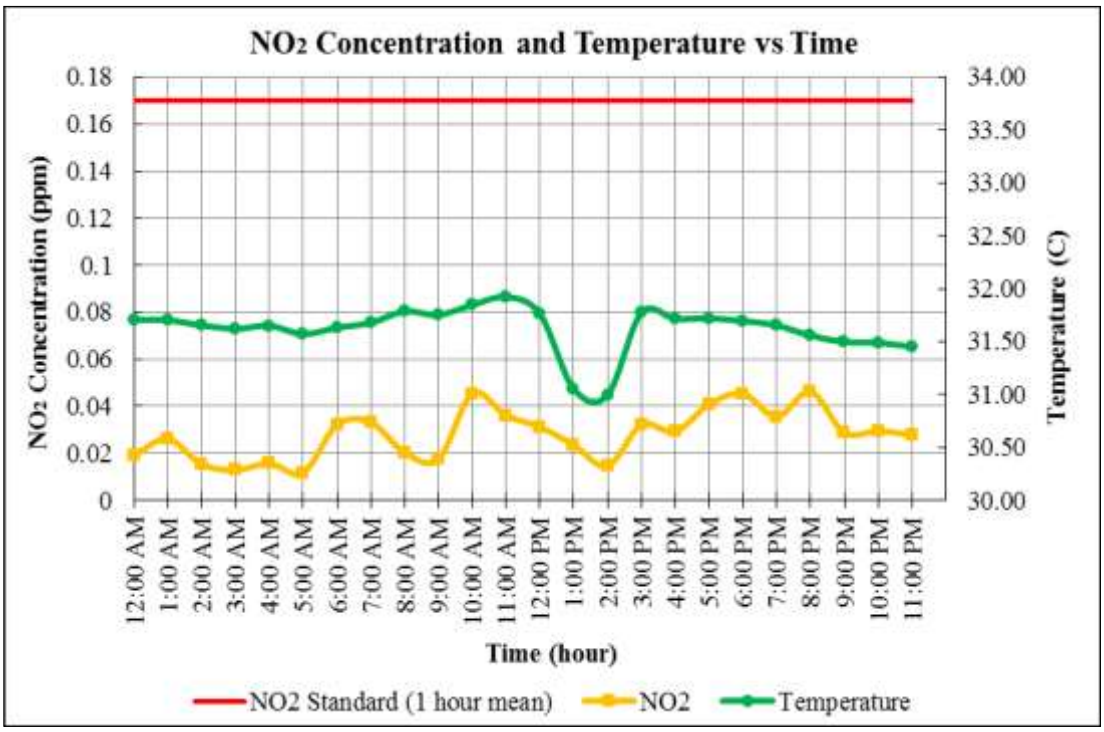
| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | - | - | - |
| 1:00 AM | 0.0281 | 0.0238 | 31.94 |
| 2:00 AM | 0.0239 | 0.0196 | 32.10 |
| 3:00 AM | 0.0203 | 0.0119 | 32.05 |
| 4:00 AM | 0.0164 | 0.0130 | 32.01 |
| 5:00 AM | 0.0166 | 0.0180 | 31.97 |
| 6:00 AM | 0.0168 | 0.0258 | 31.98 |
| 7:00 AM | 0.0168 | 0.0104 | 31.87 |
| 8:00 AM | 0.0090 | 0.0167 | 30.98 |
| 9:00 AM | 0.0048 | 0.0188 | 30.41 |
| 10:00 AM | 0.0053 | 0.0338 | 30.69 |
| 11:00 AM | 0.0062 | 0.0461 | 31.14 |
| 12:00 PM | 0.0060 | 0.0489 | 31.62 |
| 1:00 PM | 0.0043 | 0.0626 | 31.75 |
| 2:00 PM | 0.0034 | 0.0763 | 32.10 |
| 3:00 PM | 0.0071 | 0.0827 | 32.52 |
| 4:00 PM | 0.0039 | 0.0555 | 31.48 |
| 5:00 PM | 0.0022 | 0.0480 | 30.43 |
| 6:00 PM | 0.0021 | 0.0546 | 30.28 |
| 7:00 PM | 0.0023 | 0.0516 | 30.14 |
| 8:00 PM | 0.0068 | 0.0596 | 30.69 |
| 9:00 PM | 0.0112 | 0.0378 | 31.11 |
| 10:00 PM | 0.0168 | 0.0186 | 31.34 |
| 11:00 PM | 0.0253 | 0.0214 | 31.56 |

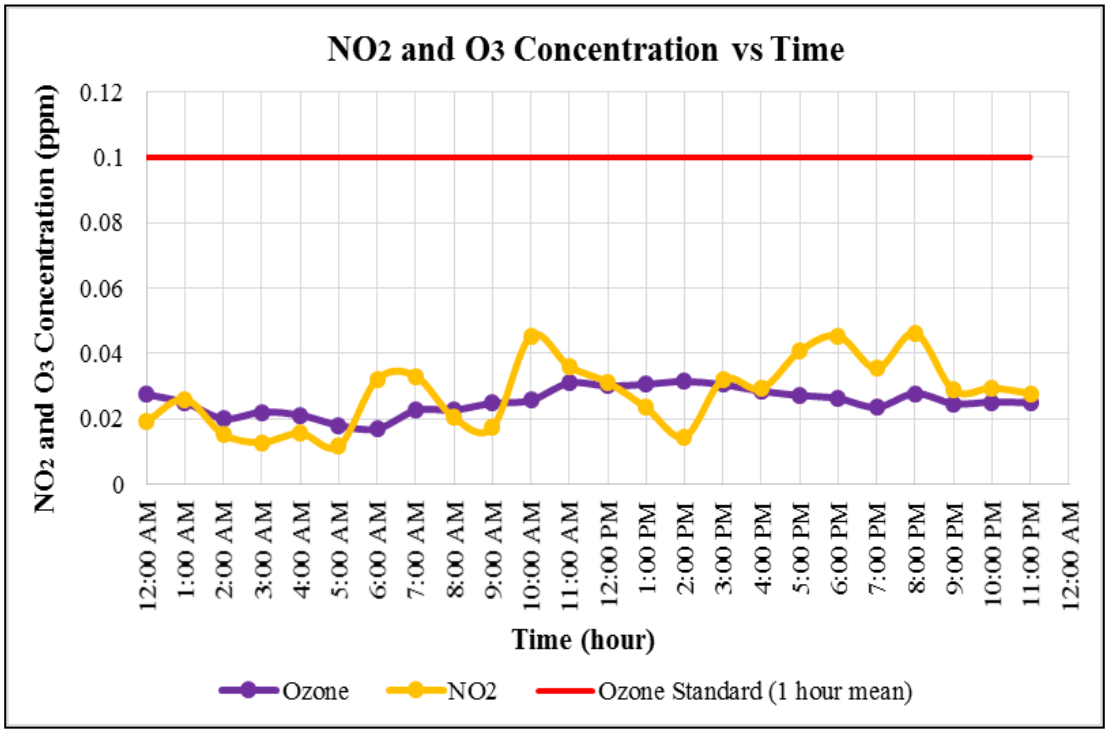

NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
34.00
33.50
33.00
32.50
32.00
31.50
31.00
30.50
30.00
29.50
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
Time (hour)
NO2
NO2 Standard (1 hour mean)
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
0.12
0.1
0.08
0.06
0.04
0.02
0
12:00 AM
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)

16th November 2014 – DAY 10

| Time | Ozone (ppm) | Nitrogen Dioxide (ppm) | Temperature (°C) |
|---|---|---|---|
| 12:00 AM | 0.0275 | 0.0192 | 31.71 |
| 1:00 AM | 0.0250 | 0.0261 | 31.70 |
| 2:00 AM | 0.0201 | 0.0153 | 31.65 |
| 3:00 AM | 0.0221 | 0.0129 | 31.62 |
| 4:00 AM | 0.0212 | 0.0156 | 31.65 |
| 5:00 AM | 0.0181 | 0.0117 | 31.57 |
| 6:00 AM | 0.0170 | 0.0321 | 31.63 |
| 7:00 AM | 0.0226 | 0.0331 | 31.68 |
| 8:00 AM | 0.0228 | 0.0204 | 31.79 |
| 9:00 AM | 0.0248 | 0.0175 | 31.75 |
| 10:00 AM | 0.0257 | 0.0453 | 31.85 |
| 11:00 AM | 0.0310 | 0.0361 | 31.92 |
| 12:00 PM | 0.0301 | 0.0312 | 31.76 |
| 1:00 PM | 0.0306 | 0.0235 | 31.05 |
| 2:00 PM | 0.0315 | 0.0146 | 31.00 |
| 3:00 PM | 0.0305 | 0.0321 | 31.77 |
| 4:00 PM | 0.0285 | 0.0292 | 31.72 |
| 5:00 PM | 0.0272 | 0.0408 | 31.72 |
| 6:00 PM | 0.0263 | 0.0454 | 31.69 |
| 7:00 PM | 0.0236 | 0.0355 | 31.65 |
| 8:00 PM | 0.0278 | 0.0463 | 31.56 |
| 9:00 PM | 0.0247 | 0.0287 | 31.50 |
| 10:00 PM | 0.0252 | 0.0295 | 31.49 |
| 11:00 PM | 0.0250 | 0.0278 | 31.45 |


NO2 Concentration and Temperature vs Time
NO2 Concentration (ppm)
Temperature (C)
Time (hour)
NO2 Standard (1 hour mean)
NO2
Temperature


NO2 and O3 Concentration vs Time
NO2 and O3 Concentration (ppm)
Time (hour)
Ozone
NO2
Ozone Standard (1 hour mean)