# MEASUREMENT AND ANALYSIS OF INDOOR AIR QUALITY CONDITIONS

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More than 80% of the people in urban regions and about 98% of cities in low and middle income countries have poor air quality according to the World Health Organization. People living in such environment suffer from many disorders like a headache, shortness of breath or even the worst diseases like lung cancer, asthma etc. The main objective of the thesis is to create awareness about the air quality and the factors that are causing air pollution to the people which is really important and provide tools at their convenience to measure and analyze the air quality. Taking real time air quality scenarios, various experiments were made using efficient sensors to study both the indoor and outdoor air quality. These experimental results will eventually help people to understand air quality better. An outdoor air quality data measurement system is developed in this research using Python programming to provide people an opportunity to retrieve and manage the air quality data and get the concentrations of the leading pollutants. The entire designing of the program is made to run with the help of a graphical user interface tool for the user, as user convenience is considered as one of the objectives of the thesis. A graphical user interface is made for the user convenience to visualize graphically the data from the database. The designed system is tested and used for the measurement and analysis of the outdoor air quality. This data will be available in the database so it can be used for analyzing the air quality data for several days or months or years. Using the GrayWolf system and the designed outdoor air quality data measurement system, both the indoor and outdoor air quality was measured to analyze and correlate.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Motivation

Air pollution these days is a serious threat to the human, animal and plant life. It is important to know the factors that cause air pollution and measures to be taken to protect our health. There are two kinds of air quality that we are concerned of, one is the Indoor Air Quality and the other is the Outdoor Air Quality. Indoor Air Quality is the air quality inside the buildings like home, office buildings, school buildings, etc. Whereas Outdoor Air Quality refers to the air quality that is present in the atmosphere or outside the buildings. There are a lot of studies done on the Indoor and Outdoor Air Quality by standard organizations like US Environmental Protection Agency, World Health Organization, ASHRAE, etc., all the studies state that indoor air is more polluted than outdoor [1] [2] [3]. But there are not so many sources which provide the local air quality levels in real time situations and the measurement evidences to the people to understand better. There are many factors which cause air pollution and they are the dangerous gasses that are released from the industries, harmful chemicals released from the chemical plants, pollutants released from the smoke of vehicles etc.

The indoor air pollution is caused mainly due to the poor ventilation, poor air conditioning system, sealants, humidifiers and several other home appliances. Most people often spend their time indoors by staying at home or working in an office, school and college buildings. Poor ventilation can cause an increase in the carbon dioxide levels which eventually cause a headache, breathing problems, but to the sensitive people suffering from asthma or lung diseases they experience shortness of breath which is a health risk. So home and buildings should have good indoor air quality. The major indoor as well as outdoor pollutants that are studied in this thesis are carbon monoxide (CO), carbon cioxide (CO2), ozone ($O_3$), TVOC, particulate matter, temperature and humidity. All the pollutants have certain concentration levels, based on their levels the extremities of their effects can be estimated to be good, bad, hazardous or even worse. There are not a lot of tools available where public can get the air quality data and tools to analyze it. So there is a need in knowing the air quality and the daily levels of major pollutants concentration and to understand their presence by analyzing their daily data levels.

## 1.2 Objectives

Since there are not many sources which can provide the data on local air quality levels in real time situations and also not many analysis results to show people how the air quality is affected. There is a need to know the air quality and the factors causing the air pollution. In order to know the air quality and to know the concentrations of the pollutants in the environment, there are many air quality sensing devices available in the market. The other way to know the air quality information is through the air quality services offered by the local air quality monitoring web services. There are several online applications and websites that are available in providing the air quality information. But the available websites are not designed to collect the air quality data from their website at user convenience in order to have a database of daily data or to see the air quality analysis graphically for the required period of time interval. So one of the objectives is developing software tools to the people at their convenience to measure and manage the air quality data and analyze them graphically. GrayWolf sensor is one of the efficient sensors available in the market. It is used to sense the pollutant gasses, temperature, humidity, etc. The significance of this device is explained in detail in Chapter 2. The GrayWolf sensor is extensively used in thesis to conduct many experiments to understand the conditions of air quality in real life. AirNow is one of standard web services which provide local air quality information and about AirNow, a detailed information is provided in Chapter 3. It provides the information of pollutant gasses like ozone, particulate matter, etc. Google Temperature provides local temperature, humidity, wind and precipitation.

This research has following objectives:

1. Conduct experiments to understand the air quality conditions in the real life scenarios.
2. Collect the measurement data for indoor and outdoor air quality.
3. Design of software tools to measure and manage the outdoor air quality data. As well as designing a tool to analyze the air quality data.
4. Correlate the indoor and outdoor air quality.

## 1.3 Contribution

Extensive experiments were conducted using GrayWolf sensor to understand air quality conditions at different cases in the real life. The experimental results were presented in this work to help people understand the air quality better. The work also involved designing a user interface tool to collect local air quality data using API of AirNow and a database to manage the data that have been collected. Designing an interface to analyze the data from the database graphically was challenging task during the thesis. Since the user convenience is one of the objectives, a Graphical User Interface has been designed for the plotting module so a user can easily analyze the data from their databases. GrayWolf sensor as well as the designed software system was used collectively to conduct few experiments to collect both the indoor and outdoor air quality data to correlate. These experiments helped to analyze the public air quality data that is provided by the air quality service websites. Since there is a database created, all the data collected for several months and years will be available, it can be used in the future to analyze the monthly or annual air quality of a region by using the plotting module that is designed in the thesis.

## 1.4 Organization of Thesis

The thesis initially involved a careful study of the air quality, air pollutants and their existence levels. In the first part of the thesis, different real time cases in the air quality were studied using GrayWolf sensor. About the GrayWolf sensor, a detailed description of its use is given in Chapter 2. Later the Outdoor air quality data is studied and for the outdoor air quality data API of AirNow is used. The importance of outdoor air quality and the way AirNow website and its API is used has been explained in detail in Chapter 3. The next major work is the design of the Graphical User Interface at user convenience to retrieve the data from AirNow using its API and the design of the database as well as the design of another Graphical User Interphase to design plotting module to the data collected in the database has been discussed in Chapter 4. All the experimental results and the data analysis have been discussed in Chapter 5. Chapter 6 involves the conclusion and future scope followed by the references and bibliography.

# CHAPTER 2

# AIR QUALITY MEASUREMENT SYSTEM

## 2.1 Introduction

The GRAYWOLF Sensing Solutions have different indoor air quality sensing devices such as Direct Sense IAQ- Indoor Air Quality Meters- IQ-410; IQ-604; IQ-610, Direct Sense TVOC-Multi-Gas PID Meters- TG-502; TG-503; VOC-103 VOC Probes, Direct Sense TOX- Toxic Gas Test Meters- TG-50; EC-202, etc. [4]. The device which is used in this study is the Advanced Sense-Direct Sense IAQ-Indoor Air IQ-610 Quality Probe as shown in the Fig 2.1. This device comes with WolfSense PC desktop software, which has features like data review, graph creation, cut and paste the generated report. It is easy to use and comes very handy to know the Indoor Air Quality with fast sensing capabilities.


Fig 2.1 GrayWolf System

The IQ-610 probe comes with VOCs, CO2, CO, Humidity (%RH), Temperature and one more toxic gas sensor which can be Ozone ($O_3$), Nitrogen Dioxide, Nitric Oxide, Ammonia, Chlorine, Hydrogen Sulfide, Sulfur Dioxide, Oxygen, HCN, HCl, H2, SiH4, AsH3, PH3, ClO2,

$COCl_2$, HF or $F_2$. So the parameters that are used for IQ-610 sensor in the thesis are Temperature, Humidity, Carbon Monoxide, Carbon Dioxide, VOCs and $O_3$ [5].

## 2.2 Sensor Specifications

The sensors that are used in IQ-610 Probe have the following operating range for each sensor according to the information that is provided by the manufacturer [6] [7].

Table 2.1 IQ-610 Indoor Air Quality Probe Specifications [6]

| Sensor | Operating Range |
|---|---|
| VOC (Volatile Organic Compounds) | 0.02 to 20.00 ppm<br>(10.6ev PID lamp, isobutylene calibration) |
| Carbon Dioxide | 0 to 10,000 ppm<br>Accuracy: ±3%rdg±50ppm |
| Carbon monoxide | 0 to 500 ppm<br>Accuracy: ±2ppm<50ppm, ±3%rdg>50ppm |
| Relative Humidity | 0 to 100%rh<br>Accuracy: ±2%rh<80%rh (±3rh>80%rh) |
| Temperature | 15º to 160 º (-10 º to +70 ºC)<br>Accuracy: ±0.3 ºC |
| Dew Point | -27 º to +158ºF (-33 º to +70 ºC)<br>Accuracy: ±2 ºC for %rh>10% |
| Response time | All sensors exhibit 90% response<1 minute |
| Probe Dimensions | 2in. (5cm) dia. X 12.5in. (30cm) length |
| Weight (probe) | w/batteries lb. 10oz. (0.7kg) |
| Power (probe) | 2 x D cells; typical battery life 120 hrs.<br>@ 15 ºC, or use 3VDC w/AC adapter |
| Ozone | 0.0 to 1.00ppm<br>Limit of Detection (0.02ppm) |

So with the VOC, Carbon Dioxide, Carbon Monoxide, Relative Humidity and Temperature sensors, there can be an additional socket available for an optional electrochemical gas sensor, whereas in here it is the ozone sensor. The IQ-610 probe can also measure Specific Humidity, Absolute Humidity, Wet bulb Temperature and Humidity Ratio [6].

Apart from the sensor specifications, GrayWolf sensor provides Factory Set Points for each sensor, these values come with the device. These Factory Set points are within the operating ranges of the sensors which can be seen from the Table 2.1 and they are set to ensure the safety of the sensors, so that they do not hit the peak values of their operating ranges. The Low Factory set point is the value that is set to the sensor which is slightly greater than the lowest possible value that can be detected by that particular sensor. The High Factory Set point is the value that is set to the sensor which is slightly less than the highest possible value that can be detected by that particular sensor. The sensors used in the thesis have the factory set point provided by the GrayWolf that can be seen from the Table 2.2.

Table 2.2 IQ-610 Sensor Factory Set Point

| Sensor | Factory Set Point |
|---|---|
| TVOC | Low- 50ppb, High- 7,500ppb |
| Ozone | Low- 0.00ppm, High -3.00ppm |
| Carbon Dioxide | Low- 375ppm, High- 1,250ppm |
| Carbon Monoxide | Low-0.5ppm, High- 100.0ppm |
| Relative Humidity | Low-1.5%RH, High-70.0%RH |
| Temperature | Low- 17.3°C, High- 33.7°C |

## 2.3 IQ-610 Operation

The WolfSense PC desktop software provides the sensor users with desktop display of the real time readings of all the parameters inside the sensor system as shown in the Fig 2.2.

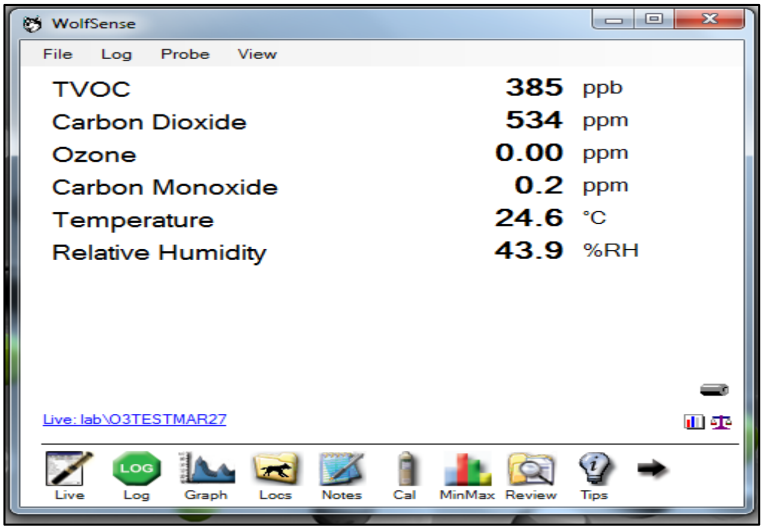



Fig 2.2 WolfSense Lap Display

It has several options like Live for display, Log to have the log of the readings into a file which will be explained later in this section, Graph to have the graphical display of the real time readings, Locs is the location files of the logs, Notes to note down the details, Cal is the Calibration which gives you the information of recent date of calibration, MinMax to have the current minimum reading of a parameter and the current maximum reading of the parameter, Review is to see the recent logs and the Tips will give you the basic information of the sensor like calibration, guidelines, specifications, etc. Since we have the option of storing the readings, storage can be done in the following way.

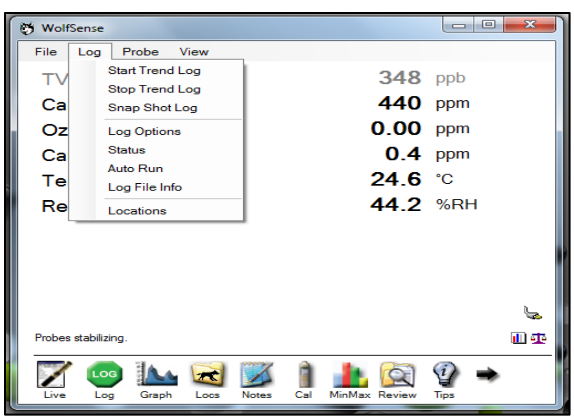



Fig 2.3 Log menu of WolfSense

From Fig 2.3, the Log menu has Start Trend Log option, which will provide the options to log the data. Once the name of the location file and the frequency at which the data is to be logged is given and then hit the start log button as shown in the Fig 2.4, then it automatically starts storing the data into that particular location.

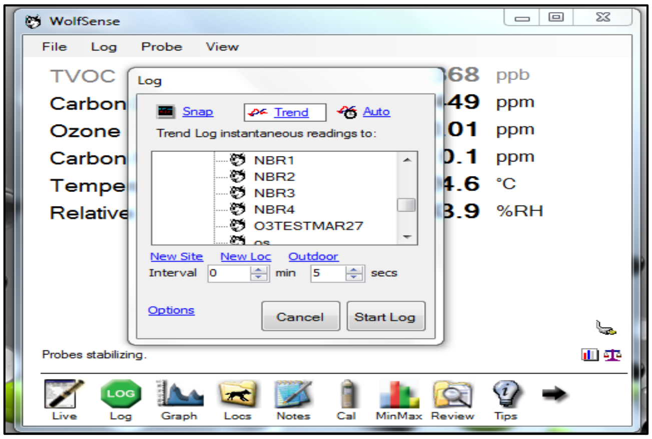
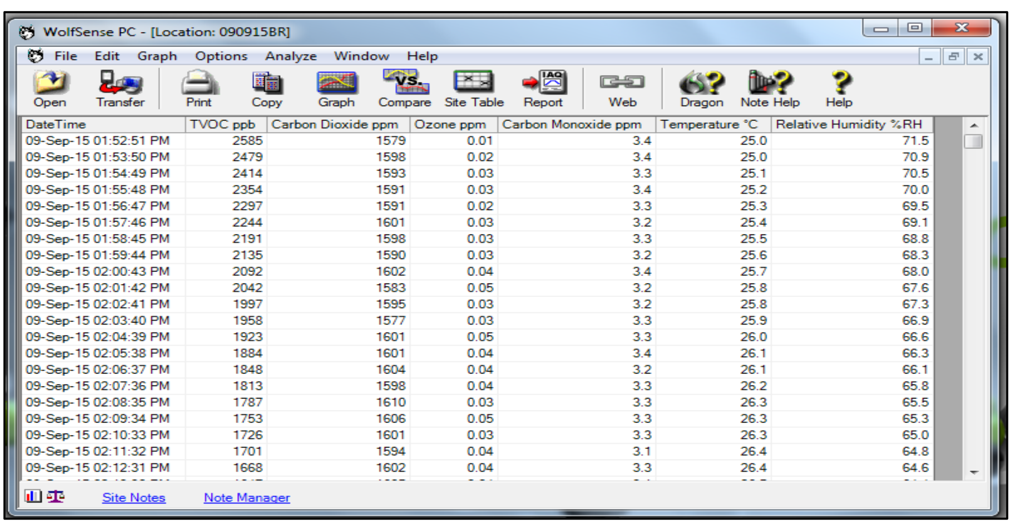



Fig 2.4 Log Options

The WolfSense PC+ARG which is the desktop software helps you to access the location files. The files are stored in filename.loc format, so the files can be opened only with help of WolfSense PC desktop software. In order to open these files, inside the window, choose file option, open the required file from the file browser as shown in the Fig 2.5.




| DateTime | TVOC ppb | Carbon Dioxide ppm | Ozone ppm | Carbon Monoxide ppm | Temperature °C | Relative Humidity %RH |
|---|---|---|---|---|---|---|
| 09-Sep-15 01:52:51 PM | 2585 | 1579 | 0.01 | 3.4 | 25.0 | 71.5 |
| 09-Sep-15 01:53:50 PM | 2479 | 1598 | 0.02 | 3.4 | 25.0 | 70.9 |
| 09-Sep-15 01:54:49 PM | 2414 | 1593 | 0.03 | 3.3 | 25.1 | 70.5 |
| 09-Sep-15 01:55:48 PM | 2354 | 1591 | 0.03 | 3.4 | 25.2 | 70.0 |
| 09-Sep-15 01:56:47 PM | 2297 | 1591 | 0.02 | 3.3 | 25.3 | 69.5 |
| 09-Sep-15 01:57:46 PM | 2244 | 1601 | 0.03 | 3.2 | 25.4 | 69.1 |
| 09-Sep-15 01:58:45 PM | 2191 | 1598 | 0.03 | 3.3 | 25.5 | 68.8 |
| 09-Sep-15 01:59:44 PM | 2135 | 1590 | 0.03 | 3.2 | 25.6 | 68.3 |
| 09-Sep-15 02:00:43 PM | 2092 | 1602 | 0.04 | 3.4 | 25.7 | 68.0 |
| 09-Sep-15 02:01:42 PM | 2042 | 1583 | 0.05 | 3.2 | 25.8 | 67.6 |
| 09-Sep-15 02:02:41 PM | 1997 | 1595 | 0.03 | 3.2 | 25.8 | 67.3 |
| 09-Sep-15 02:03:40 PM | 1958 | 1577 | 0.03 | 3.3 | 25.9 | 66.9 |
| 09-Sep-15 02:04:39 PM | 1923 | 1601 | 0.05 | 3.3 | 26.0 | 66.6 |
| 09-Sep-15 02:05:38 PM | 1884 | 1601 | 0.04 | 3.4 | 26.1 | 66.3 |
| 09-Sep-15 02:06:37 PM | 1848 | 1604 | 0.04 | 3.2 | 26.1 | 66.1 |
| 09-Sep-15 02:07:36 PM | 1813 | 1598 | 0.04 | 3.3 | 26.2 | 65.8 |
| 09-Sep-15 02:08:35 PM | 1787 | 1610 | 0.03 | 3.3 | 26.3 | 65.5 |
| 09-Sep-15 02:09:34 PM | 1753 | 1606 | 0.05 | 3.3 | 26.3 | 65.3 |
| 09-Sep-15 02:10:33 PM | 1726 | 1601 | 0.03 | 3.3 | 26.3 | 65.0 |
| 09-Sep-15 02:11:32 PM | 1701 | 1594 | 0.04 | 3.1 | 26.4 | 64.8 |
| 09-Sep-15 02:12:31 PM | 1668 | 1602 | 0.04 | 3.3 | 26.4 | 64.6 |

Fig 2.5 Location file browser

The file contains all the parameter readings at each interval specified. Tool bar provides several options like Transfer to have an active sync from the sensor probe to the device which can be a PC or a tablet, Print, Copy which enables us to copy the data and paste the data into a file which can be excel or any other file, we can even compare the data of a parameter from one file to data in the other file. The Graph is useful to plot the data from the file as shown in the Fig 2.6, Report is useful if a user like to report the data to GRAYWOLF Sensing Solutions provided a special serial number and key for access, Web button helps to directly connect the web service of wolfsense to have access to the useful information about the device and their software, Dragon menu is for Audio Note Transcription.

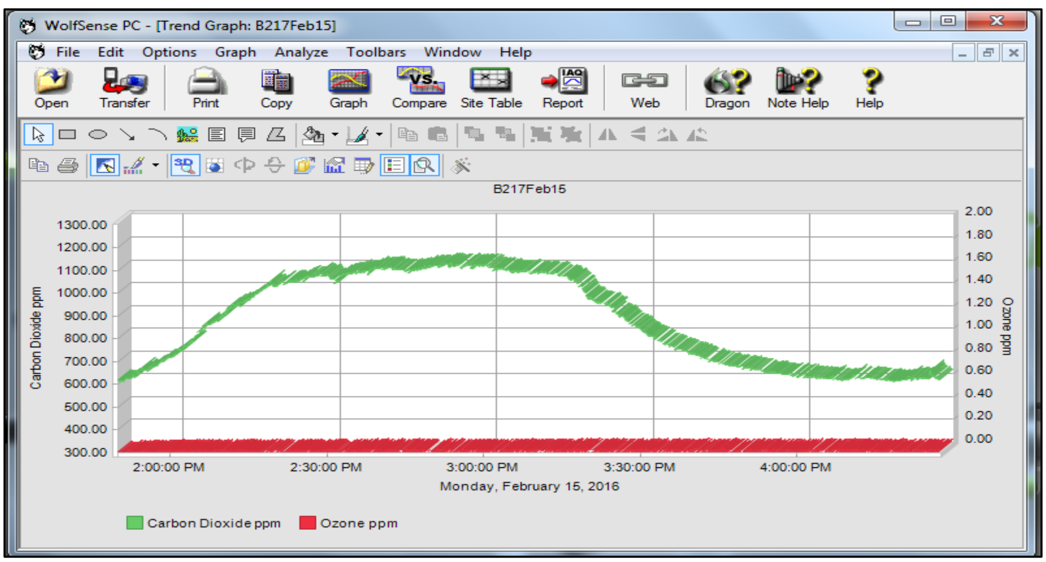



Fig 2.6 Graph showing the location file data

## 2.4 Sensor Calibration

Each sensor inside IQ-610 needs calibration as suggested by the GrayWolf device manufacturer and can be discussed in detail in this section. The calibration details of the device can be found through the GrayWolf Desktop software, as the device is connected to the PC.

### 2.4.1 Temperature Sensor

Temperature sensor needs a minimum calibration of once in 2 years. However, GrayWolf suggest once in a year calibration to have perfect functioning.

### 2.4.2 Relative Humidity

As suggested by GrayWolf the Relative Humidity sensor needs a minimum calibration of once in a year. It is also suggested that if the sensor is used in more unhygienic places like smoking areas or more polluted areas, then it would need more frequent calibration.

### 2.4.3 Carbon Monoxide

The recommended calibration of Carbon Monoxide sensor is a minimum of once in every year. Based on the requirement of IAQ applications, it can be even once in every 6 months. However, the lifetime of electrochemical Carbon Monoxide sensor is 24 to 36 months and if the response becomes improper then it needs a replacement. The WolfSense desktop PC software will provide a notification service showing CHECK CAL icon whenever there is a drift from zero value of any sensor reading, then it needs user re-zeroing.

### 2.4.4 Carbon Dioxide

Carbon Dioxide sensor needs a minimum of calibration once in every 12 months for best functioning as recommended by GrayWolf. Based on top priorities sometimes having it calibrated once in every 6 months is suggested for more accurate readings. It is stated that the typical outdoor reading for the carbon dioxide sensor is 399ppm. If it falls to 300ppm or below then it clearly needs calibration. It is also mentioned that the reading after the probe gets stabilized, shows a ‘-1’ value then the sensor is faulty.

### 2.4.5 Ozone

GrayWolf recommends calibration of once in every 2 months. Based on the applications of IAQ it may even need more frequent calibration. $O_3$ (ozone) is difficult to work with and its life expectancy is 18 months or more. If the sensor reading drifted from zero value, then it needs user re-zeroing. The CHECK CAL icon helps us to identify if $O_3$ sensor needs calibration.

### 2.4.6 TVOC

TVOC is considered as a very sensitive sensor and a daily calibration is recommended for it. However, if it is used in clean environments then the calibration requirement can come down to once in a week or month. Calibrating the TVOC sensor at the concentration of the target gas in an application range will improve the accuracy of its reading.

## 2.5 Data Export

GrayWolf Desktop PC software helps us to store the data in the form of location files. Since they are in the format of filename.loc, these location files cannot be useful in any other applications as they cannot be converted into any other files. But the best thing is the software has an option of Export in the file menu as shown in the Fig 2.7. This will help us to export the local file into an Excel File as shown in Fig 2.8.

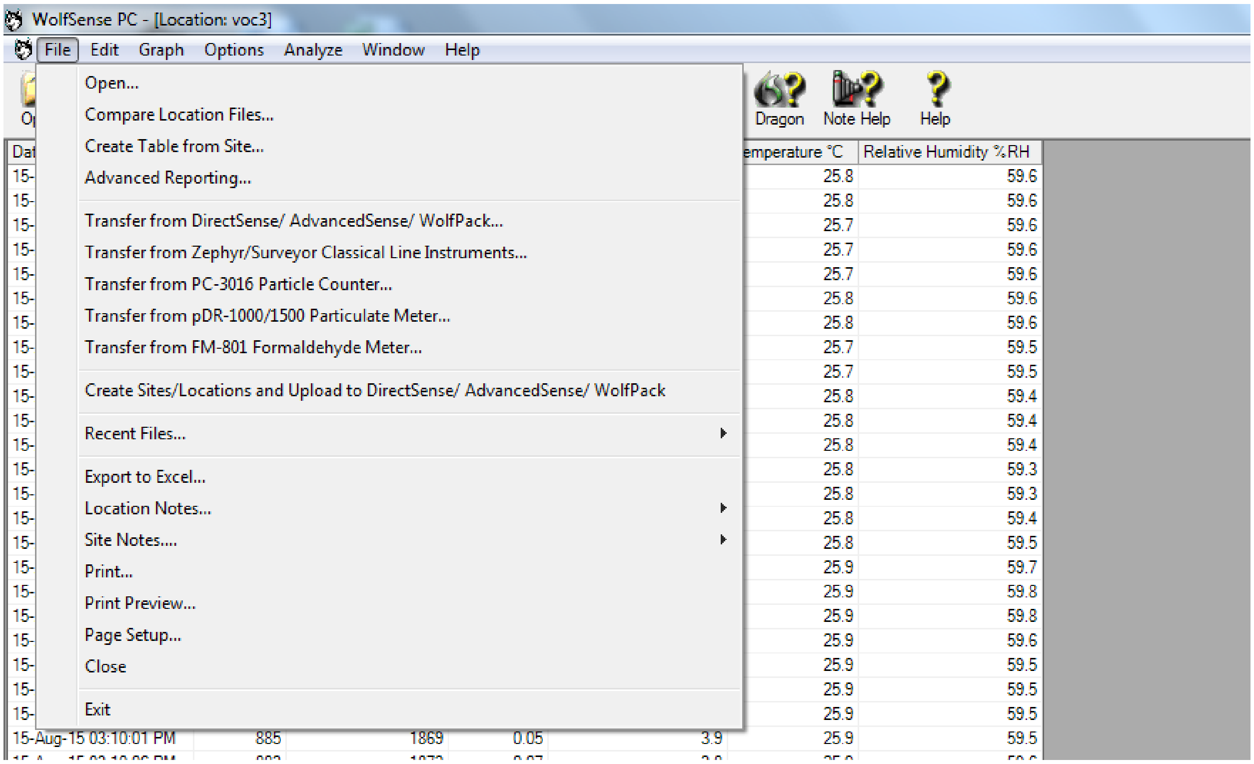



Fig 2.7 GrayWolf PC software showing File Menu which contains Export option in it

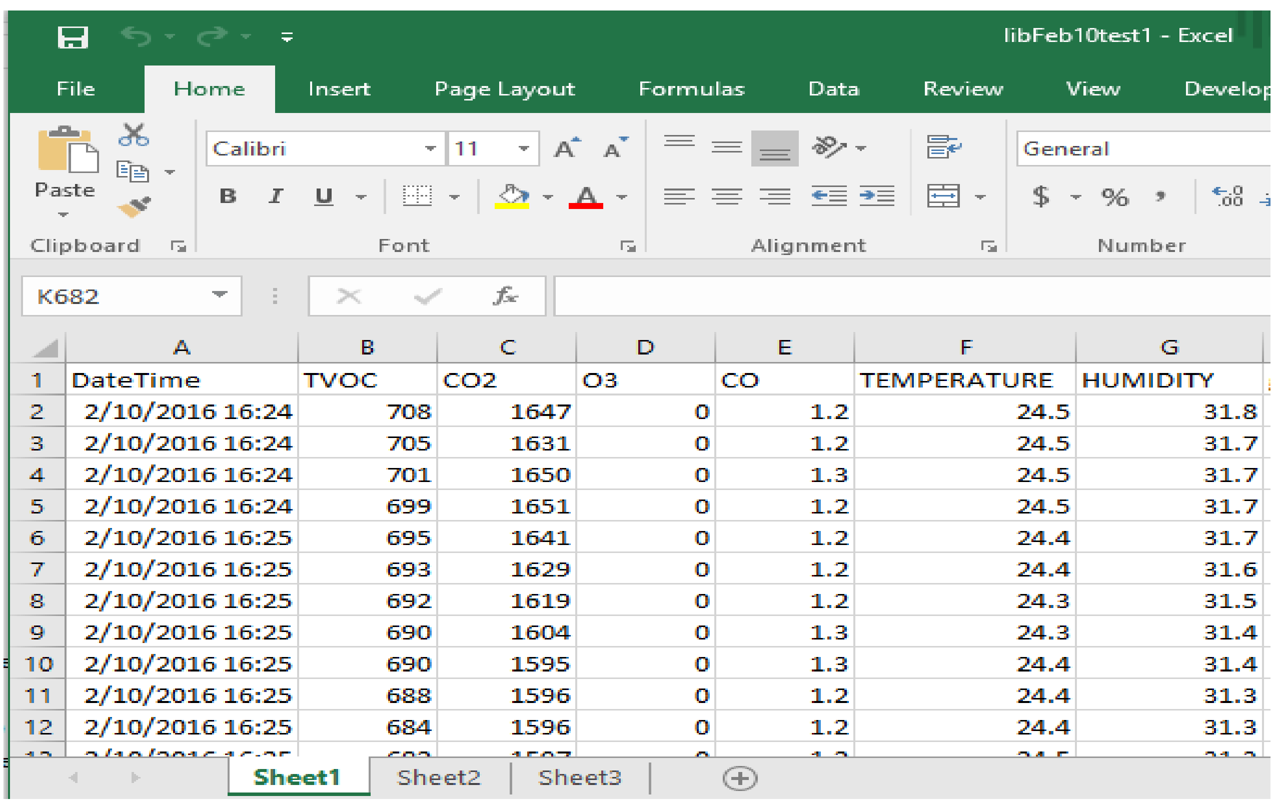



Fig 2.8 Excel Sheet converted from location file

The Excel files help us to analyze the data with help of plotting option. Since we have already seen the graphs that are obtained with the help of GrayWolf Desktop PC software in the Section 2.3, it can be observed that they are not good enough to see the large data. So I have used Matlab to plot the data using the excel sheets which will be explained in detail in Chapter 4.

# CHAPTER 3

# OUTDOOR AIR QUALITY DATA

## 3.1 Introduction

It is important to know the outdoor air quality these days because of the increasing pollution day by day, with the increase in usage of number of vehicles, increasing number of industries and with decreasing forest areas due to the modern civilization. Indoor air is more polluted than outdoor air these days because of closed buildings with less ventilation. Most people prefer to exercise outdoors. To understand the effects of outdoor air quality let us have an example, it is good to exercise outdoors when the outdoor air quality is good, but exercising outdoors when the air quality is bad would rather deteriorate your health by breathing the polluted air. So there is a need to know the outdoor air quality to maintain the health. Knowing the temperature and humidity is also very important. Too high or too low temperature and humidity are also not good for human health. There are many pollutants that are present in our surroundings, but the pollutants of interest that are considered for study in the thesis are $CO_2$, $O_3$, PM, CO, Temperature and Humidity. $CO_2$ gas is present in large amounts around us and the sources of it are all the transportations systems and industries etc. Having high $CO_2$ levels in the atmosphere or our surroundings may cause breathing problems, so it is dangerous to the sensitive people. Sensitive people refers to the people who are suffering from asthma, any kind of heart or lung diseases, cough etc. But in outdoor the $CO_2$ levels are not so bad according to the study that is made during the thesis, most of the $CO_2$ is found in the closed areas like inside the buildings which are less ventilated. When $O_3$ is considered, having high concentrations of $O_3$ in the atmosphere or in our surroundings also causes shortness in breath, coughing symptoms. So sensitive people with lung diseases, asthma, older people, children and teenagers should know the daily $O_3$ levels. Spending most of the time in an atmosphere of high $O_3$

levels will result in serious problems. Asthma people are recommended to have their quick relief medicine handy. $O_3$ is not directly released into the atmosphere, it is formed due to the chemical reactions of volatile organic compounds (VOC) and nitrogen oxides in the presence of sunlight and heat. The sources of VOCs are vehicles, factories, chemical plants, refineries etc. [11].

Particulate Matter is nothing but the particle pollution, which is caused due to small dust, dirt, smoke in the surroundings. They are usually present in the sizes larger than 2.5 micrometers or less than 10 micrometers. The sources of particle pollution can be construction areas, unpaved roads, fields, extremely smoked areas, fireplaces, power plants, industries and automobiles. The particle pollution comprises of small dust particles and water droplets which can go deep into the person's lungs when they breath and some even enter the blood streams and cause serious health problems. So people should be aware of the daily particle pollution levels. It is not good for the sensitive people like people suffering from asthma or any lung problems, older people and small children. There are many websites which provides the daily pollution levels of particulate matter. Taking measures during the days of high particle pollutions like staying inside the home is advisable. In many ways knowing outdoor air quality before you step out of your home is considered to be safe which eventually helps you in maintaining good health [11].

There are lots of websites like Bedford Texas weather, NCTCOG (North Central Texas Council of Governments), AirNow, Texas Commission on Environmental Quality, MESQUITE Weather, Air Quality Index China (aqicn) which report the daily air quality outside. Most of these sites report on the basis of AirNow which is considered to be the most significant site to report current and forecast outside air quality, whereas 'aqicn' has current data. These sites report the air quality in numbers called the Air Quality Index. This index helps us to understand how the air quality is, based on the quantity of pollutant gases around us. The Air quality index will be explained in more detail in the following section. The daily temperature and humidity are also reported by many websites like Weather Underground, Intellect the authority in expert weather, Google, Open Weather Map etc. In the thesis, Google local temperature service is used to collect data for local temperature and humidity which can be seen in Fig 3.1.

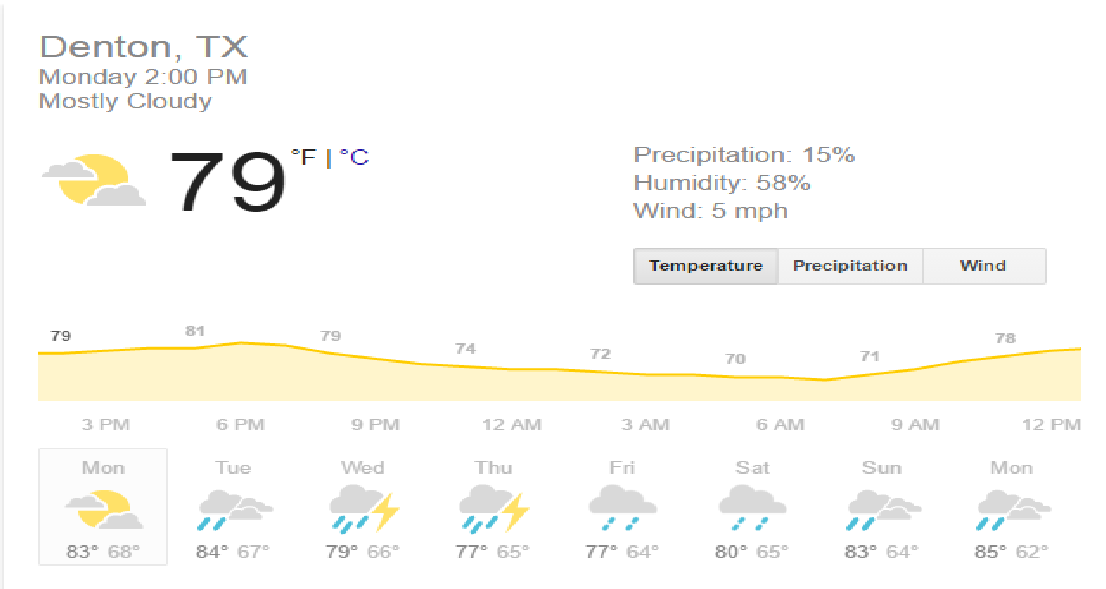



Fig 3.1 Google showing local temperature and humidity

3.2 Understanding AQI

The AQI (Air Quality Index) is an index which helps in reporting the daily air quality data. It will help people to understand how clean the air is and if the air is bad, then what kind of precautions are to be taken in order to protect their health. The main focus of the AQI is on the health effects which are caused when we breathe polluted air within a time period of a few hours or a few days. There are 5 major pollutants which are regulated by the Clean Air Act and they are ground- level ozone, particle pollution (particulate matter), carbon monoxide, sulfur dioxide and carbon dioxide. EPA has national air quality standards for the listed pollutants to protect people's health. The ground-level ozone and airborne particles are considered to be the two major pollutants which cause a significant threat to human health [9].

AQI has yardstick which runs from 0 to 500. The larger the AQI the more is the air pollution. Since it is mentioned before that AQI helps people to understand the air quality, EPA has divided AQI yardstick into six categories which can be shown in the following Table 3.1.

Table 3.1 AQI Ranges showing corresponding health conditions [9]

| AQI Range | Air quality conditions | Color code |
|---|---|---|
| 0 to 50 | Good | Green |
| 51 to 100 | Moderate | Yellow |
| 10 to 150 | Unhealthy for sensitive groups | Orange |
| 151 to 200 | Unhealthy | Red |
| 201 to 300 | Very unhealthy | Purple |
| 301 to 500 | Hazardous | Maroon |

EPA has made it easier to people to understand the air-quality index by color code. Each color code has a meaning which can be seen in the following Table 3.2.

Table 3.2 AQI ranges showing meaning to each color code [9]

| Color code | AQI Range | Meaning |
|---|---|---|
| Green | 0 to 50 | Air quality is considered satisfactory, and air pollution poses little or no risk. |
| Yellow | 51 to 100 | Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution. |
| Orange | 101 to 150 | Members of sensitive groups may experience health effects. The general public is not likely to be affected. |
| Red | 151 to 200 | Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects. |
| Purple | 201 to 300 | Health warnings of emergency conditions. The entire population is more likely to be affected. |
| Maroon | 301 to 500 | Health alert: everyone may experience more serious health effects. |

The AirNow website reports the air quality data to the people throughout US, as well as in some parts of Canada and Mexico [12]. The AirNow system is developed by the US Environmental

Protection Agency, National Oceanic and Atmospheric Administration, National Park Service, tribal, state and local agencies to provide the public with easy access to national air quality information. This website gives you the everyday air quality in the numbers called AQI (Air Quality Index) and also the color representation to the people for easy interpretation and it helps them react to maintain their health [8].

The information from their website can be accessed by visiting their website and by choosing the required area by entering zip code and selecting a state to know the air quality of that particular region. It provides today's and tomorrow's Air Quality Index and AQI- Pollutant Details which includes Particles (PM 10), Particles (PM 2.5), Ozone as shown in the Fig 3.2

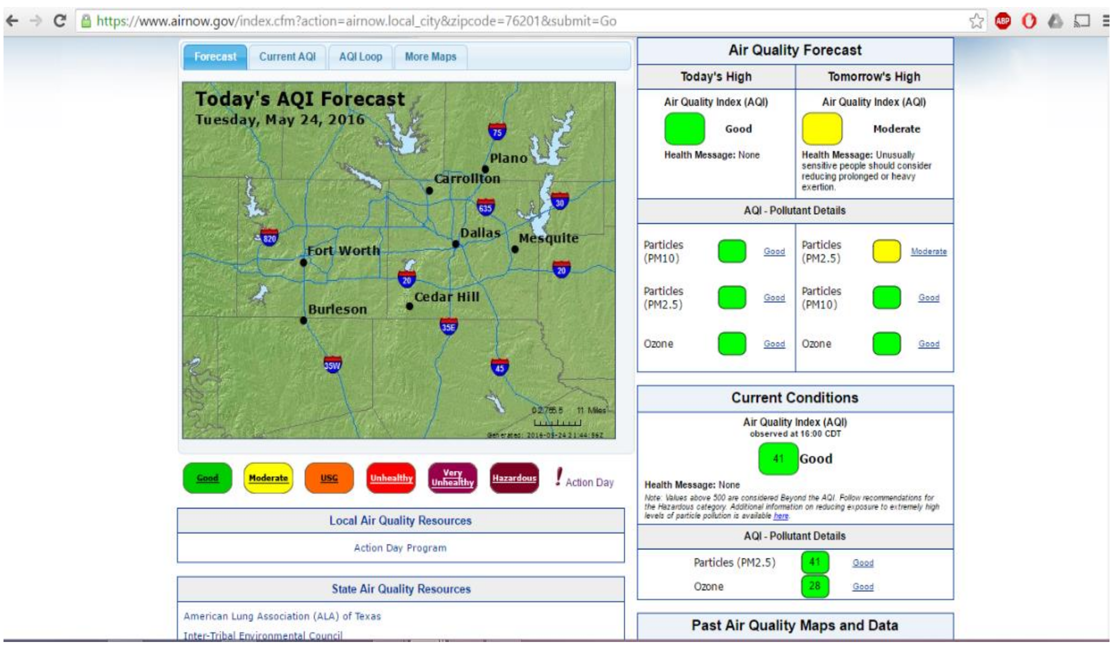



Fig 3.2 AirNow Website [12]

## 3.3 Calculation of AQI

Each pollutant has an AQI for itself. But the AQI of air will be the AQI of dominant pollutant. EPA has a formula specified to calculate the AQI for each pollutant. Calculation of AQI is done using the pollutant concentration and it can be done in 4 steps. Identify the highest concentration pollutant gas and truncate to the decimal as suggested by EPA. The truncation for each pollutant has can be specified in the following Table 3.3.

Table 3.3 Pollutants concentration truncation rules [9]

| Pollutant gas | Truncation |
|---|---|
| Ozone | Truncate to 3 decimals |
| PM 2.5 | Truncate to 1 decimal |
| PM 10 | Truncate to integer |
| CO | Truncate to 1 decimal place |
| $SO_2$ | Truncate to integer |
| $NO_2$ | Truncate to integer |

In this thesis, I have used just the ozone and Particulate Matter (PM2.5, PM10). The formula to calculate the concentration of pollutants is:

Equation 1:

$$Ip = \frac{Ihi - Ilo}{BPhi - BPlo}(Cp - BPlo) + Ilo$$

Where,

*Ip* = the index for pollutant *p*

*Cp* = the rounded concentration of pollutant *p*

*BPhi* = the breakpoint that is greater than or equal to *Cp*

*BPlo* = the breakpoint that is less than or equal to *Cp*

*BPhi* = the breakpoint that is greater than or equal to *Cp*

*Ihi* = the AQI value corresponding to *BPhi*

*Ilo* = the AQI value corresponding to *BPlo*

In order to calculate the index, we need the highest and lowest breakpoints for each pollutant which can be found in the following Table 3.4.

Table 3.4 Breakpoints for the AQI [9]

| $O_3$ (ppm) 8-hour | $O_3$ (ppm) 1-hour[1] | $PM_{10}$ (µg/m$^3$) 24-hour | $PM_{2.5}$ (µg/m$^3$) 24-hour | CO (ppm) 8-hour | $SO_2$ (ppb) 1-hour | $NO_2$ (ppb) 1-hour | AQI | |
|---|---|---|---|---|---|---|---|---|
| 0.000 - 0.059 | - | 0 – 54 | 0.0 - 12.0 | 0.0-4.4 | 0-35 | 0-53 | 0-50 | Good |
| 0.060 - 0.075 | - | 55 – 154 | 12.2 - 35.4 | 4.5-9.4 | 36-75 | 54-100 | 51-100 | Moderate |
| 0.076 - 0.095 | 0.125 - 0.164 | 155 - 254 | 35.5 - 55.4 | 9.5-12.4 | 76-185 | 101-360 | 101-150 | Unhealthy for Sensitive Groups |
| 0.096 - 0.115 | 0.165 - 0.204 | 255 - 354 | (55.5 - 150.4)[3] | 12.5-15.4 | (186-304)[4] | 361-649 | 151-200 | Unhealthy |
| 0.116 - 0.374 | 0.205 - 0.404 | 355 - 424 | (150.5-250.4)[3] | 15.5-30.4 | (305-604)[4] | 650-1249 | 201-300 | Very unhealthy |
| ([2]) | 0.405 - 0.504 | 425 - 504 | (250.5-350.4)[3] | 30.5-40.4 | (605-804)[4] | 1250-1649 | 301-400 | Hazardous |
| ([2]) | 0.505 - 0.604 | 505 - 604 | (350.5-500.4)[3] | 40.5-50.4 | (805-1004)[4] | 1650-2049 | 401-500 | Hazardous |

With the help of the Table 3.4 and using the Equation 1, with a known concentration of the pollutants the AQI is calculated. If there is more than one pollutant, then the AQI will be calculated for each pollutant and the dominant pollutant's AQI will be considered as the AQI to determinate the air quality [9]. An example to understand AQI calculation is discussed below.

Suppose you have an 8-hour ozone value of 0.078 ppm, a PM2.5 value of 35.9 µg/m3, and a CO value of 8.4 ppm. You apply the equation three times.

$$O3\colon\ \frac{(150-101)}{(0.095-0.076)}(0.078-0.076)+101\quad =106.157$$

$$PM\colon\ \frac{(150-101)}{(55.4-35.5)}(36-35.5)+101\quad =102.2$$

$$CO\colon\ \frac{(100-51)}{(9.4-4.5)}(9-4.5)+51\quad =96$$

The AQI is 104, with ozone as the responsible pollutant. I have used the Equation 1 and the Table 3.4 for the calculation of concentration of the pollutants in my thesis which will be explained in Chapter 4.

## 3.4 Application Peripheral Interface

The Application Peripheral Interface(API) is provided by only few websites. A user can access the information from a website through its API. It provides users with login credentials to their website and also provides secure access to the website's useful data. A user can get data from website in two ways, either by scraping the data directly from a website or by using the website API to request for their data. It is always good to use data from a website by their acknowledgment. The data in the thesis is collected using the AirNow API [10].

All the AirNow Gateway web services have now been replaced by the AirNow API. The access to its file outputs and data feeds can be obtained using the user login information.

The US EPA AirNow program is mainly focused on protecting public health by constantly tracking and providing forecasts and real-time air quality information across Canada, Mexico and the United States. The AirNow at present receives observations of real-time air quality from more than 2000 monitoring stations, collecting forecast from more than 300 cities. Providing such huge data has been made possible with the help of 120 local, tribal, state, provincial and government agencies. This data reported is mainly for the express purpose of forecasting and reporting the AQI and are not fully verified or validated. Hence, they should not be used to formulate or support any public or government decision making [8].

The AirNow API is called AirNow Developer Tools, it has option of Web Services using which a user can get information and data related to their Forecasts using zip code, by latitude/longitude, geographic bounding box etc. based on the requirement which can be seen in Fig 3.3 [10].

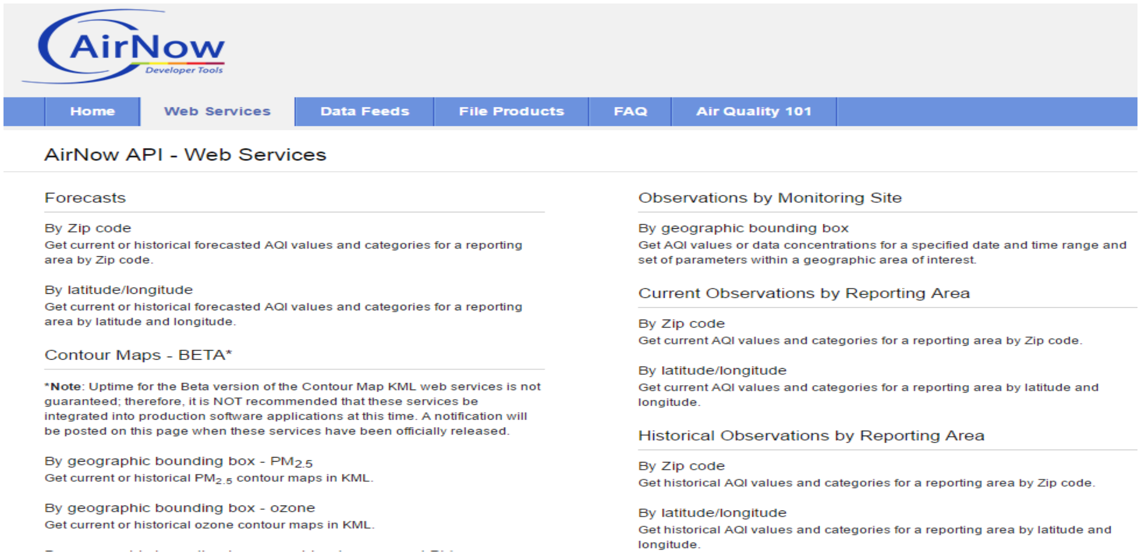



Fig 3.3 AirNow API showing Web Services

It even provides Data Feeds of AirNow for all the cities that are Forecast RSS, Action Day RSS and Current Conditions RSS which can be seen in Fig 3.4. It has File Products which provides the fact sheet of the AirNow reporting and more [10].

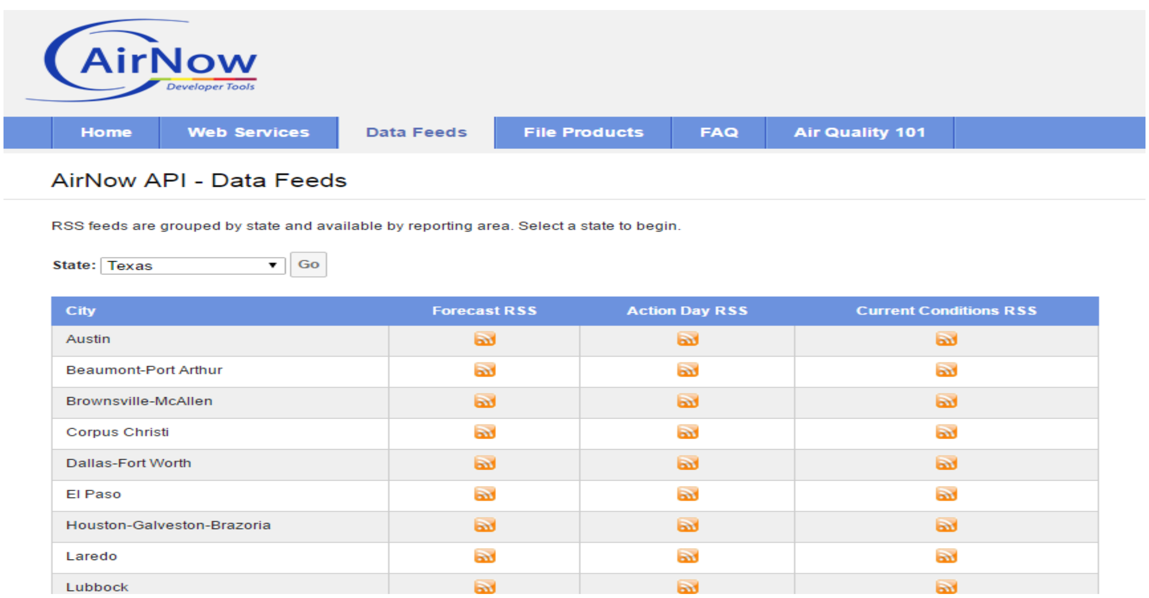



Fig 3.4 AirNow API showing Data Feeds

In order to use the AirNow API web services, as a user, an account has been created to get the login details to access. Once the account is created, then the user will be provided with a unique API key. In the thesis python programming has been used, so to retrieve the data an API request is done using the API key. Whenever the program is made to run, it requests AirNow API services to retrieve the requested data. Obtaining valuable data directly from a website without the website's permission is not legal. So in the thesis the data collected from the AirNow website has been requested during the programming.

# CHAPTER 4

# DATA MANAGEMENT AND VISUALIZATION

## 4.1 Introduction

Data management has played a significant role in this work. Large amount of data from the sensors has been stored and later used for analysis. There are two systems whose data have been used and managed. One of them is a GrayWolf sensor which has been discussed in Chapter 2 has its own GrayWolf Desktop PC software which can store the readings of the sensor into files. The other one is a graphical user interface module which is designed in this work to receive the outdoor air quality data from the AirNow and Google local temperature services websites and get stored in the designed database. The visualization tool to graphically analyze the data from the database has also been designed in this work. The following sections will give a detailed explanation of the GrayWolf system data management and the thesis work.

## 4.2 GrayWolf Sensor

### 4.2.1 Design

The GrayWolf sensor IQ-610 is used to observe the air quality at different locations like home, college, classroom, park, bus, library etc. At every experiment station the sensor readings were logged for a specific period of time. The data is collected at very close intervals for long periods of time to obtain better results in observation and drawing conclusions.

### 4.2.2 Implementation

The GrayWolf sensor is easy to carry and it is taken to the experiment station, which can be any one of the places listed in the above section. The probe has to be setup and every time it needs to be tested. So once the probe is on it has to wait for 2-5 minutes till it gets stabilized. Since it has an option to log the readings from the sensor. The sensor once it gets stabilized it needs a setup to start a log. A specific filename and frequency of intervals is given to the sensor using the GrayWolf desktop PC software and then it is set to ‘Trend Log’ which can be seen from the Fig 2.4. Once the log is done, ‘Snap Shot Log’ which is an option in the software tools which can be seen in Fig 2.3, helps us to log all the readings into the given filename. After the Snap Shot Log, you can finish the readings to log using the ‘Stop Trend Log’ which can be seen in Fig 2.3. All the readings at different places were taken in the same way. Since there are few readings which needed longer duration to log, the number of readings went up to 8000 -10,000. Observing this large data on the GrayWolf desktop software is hard. Matlab is very good at plotting graphs of large data. The way Matlab is used to plot the data is explained in detail within this section.

Since the GrayWolf Desktop PC software has an option to export its files into an excel file. The excel files are very handy to use in Matlab plots. Matlab provides an import tool which can be seen in the Fig 4.1.

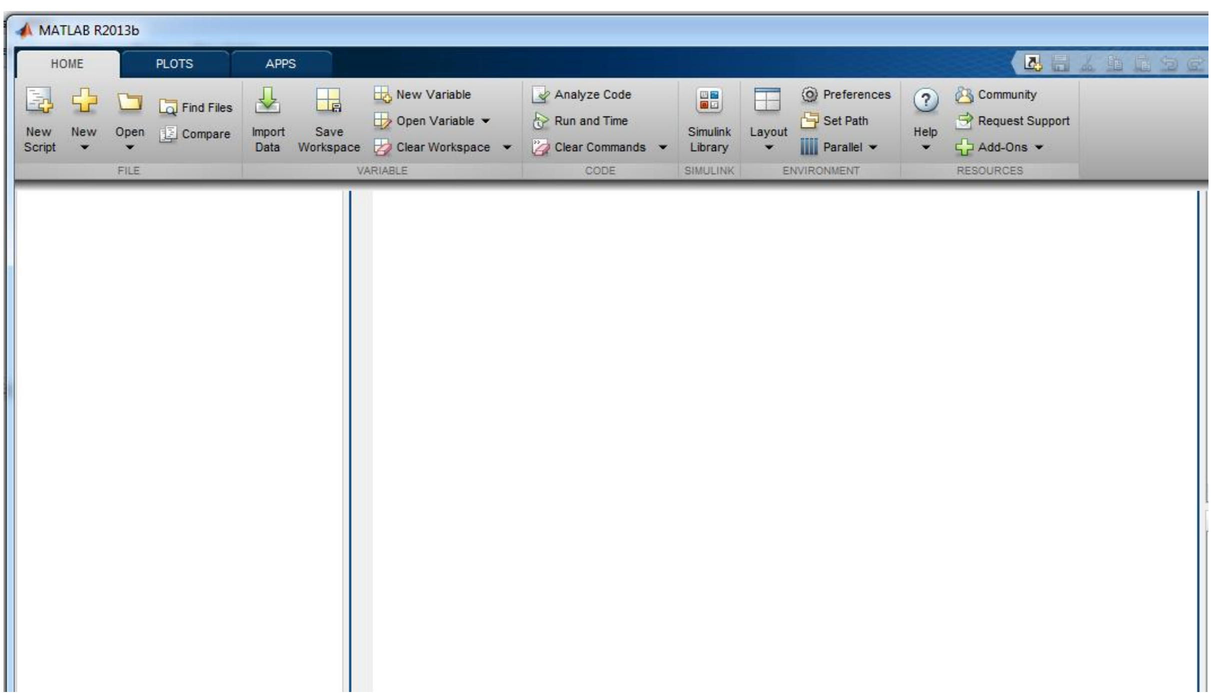



Fig 4.1 Matlab Home page showing Import tool

Once you select the import tool you can browse and upload the required excel file into the Matlab. You can view the uploaded file in the import window which just pops up once the file gets imported which you can see in the Fig 4.2.

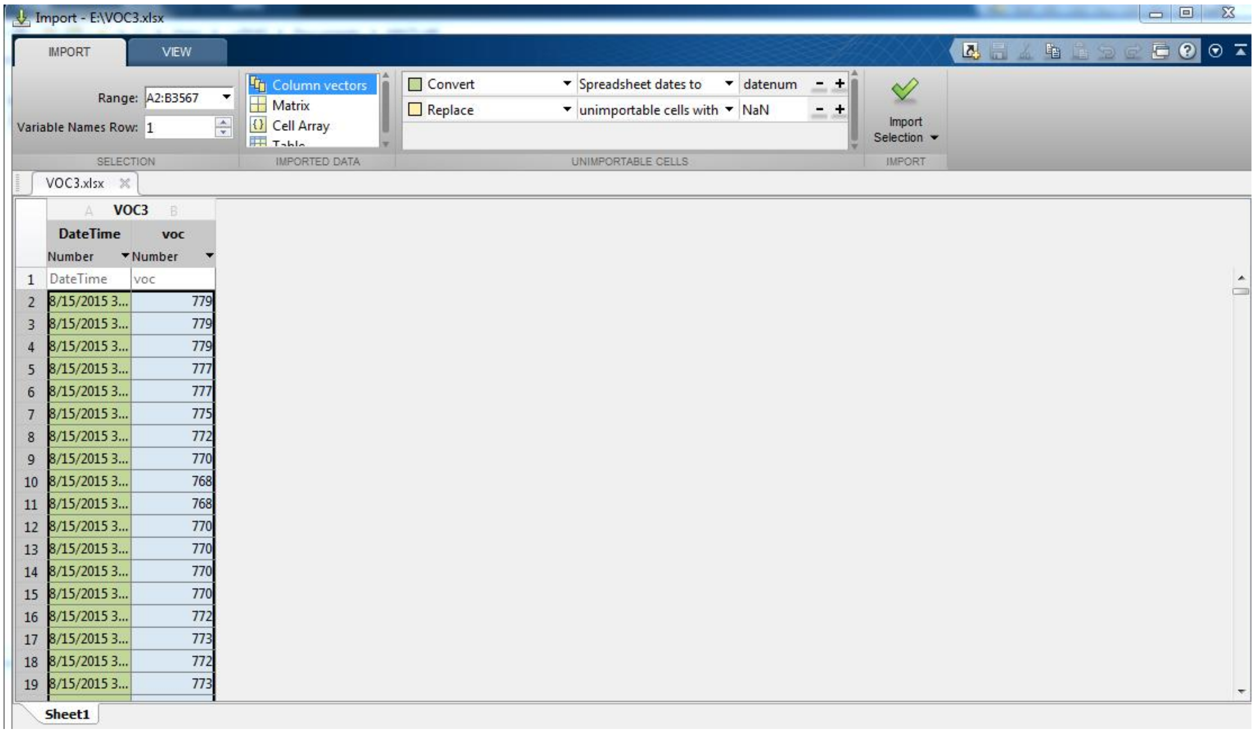


Fig 4.2 Matlab import tool

From the import window you can select the columns required or even the entire data can also be selected and then select the 'Import selection' button. Now you will be directed to the Matlab Workspace where the columns of each variable and gets the values stored into the workspace as seen in Fig 4.3. These variables can be used to plot a graph individually or against any other variables with their variable names in Matlab. In the command window the plot command to the variables can be seen in Fig 4.3 and the corresponding plot can be seen in Fig 4.4.

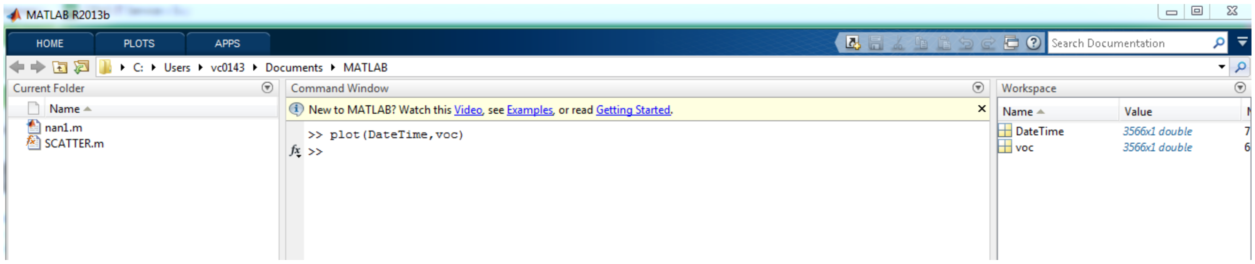



Fig 4.3 Matlab Workspace showing the imported variables

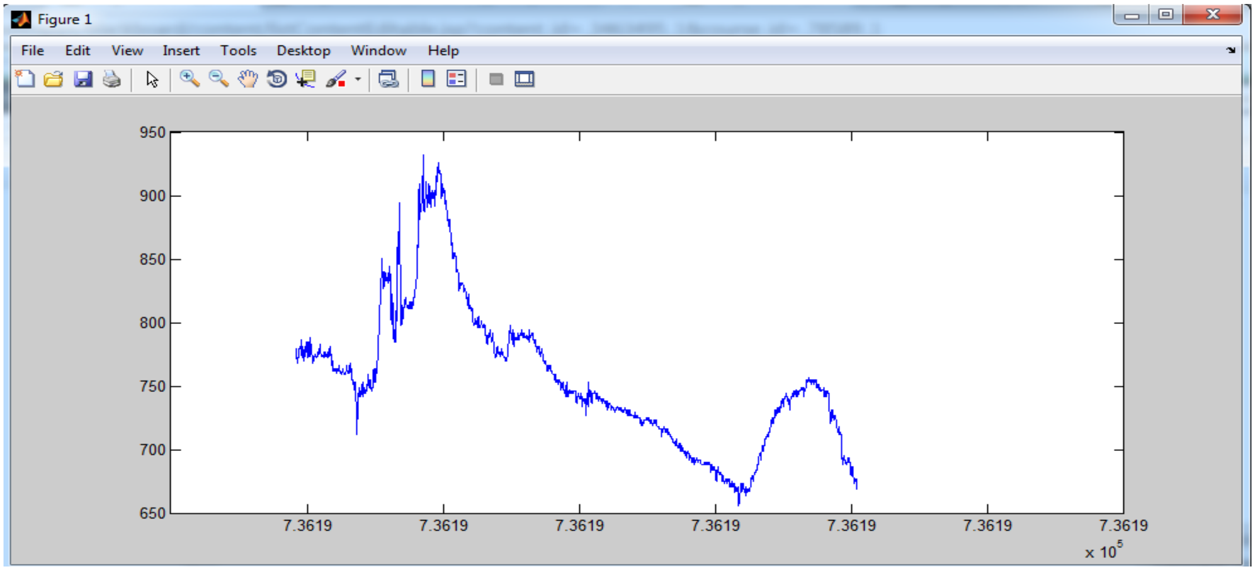



Fig 4.4 Plot of the imported variables

The different variables that are of best interest in the thesis has already been discussed in the earlier sections. Based on several public air quality reporting sites data and the information provided by them, the air quality standards that are used in the thesis are shown in the Table 4.5.

Table 4.1 Air Quality Standards [13] [14] [15]

| Parameter | Good | Limit acceptable | Unhealthy / Uncomfortable |
|---|---|---|---|
| Co | 0.0-4.4 ppm | 4.4-9.4 ppm | > 9.4 ppm |
| Co2 | 350-600 ppm | 600-1000 ppm | > 1000 ppm |
| O3 | 0.000-0.084 ppm | 0.065-0.084 ppm | > 0.084 ppm |
| VOC | 0-300 ppb | 300-750 ppb | > 750 ppb |
| Relative Humidity | 20-60% | <=70% | > 70% |
| Temperature | 22.5-25.5℃ | 25.5-30℃ | < 22.5 ℃ or > 30 ℃ |

All the data that are collected at all the different places are stored in the Excel files. This data is plotted to observe the air quality behavior. This helps to understand the environment we are living in and helps us to plan to make our surroundings a better place to live. Eventually we can make our world a better place to live. The data that is stored is later on used to compare with the outdoor air quality. Living indoors for long hours may not be a healthy habit, since it is proven that indoor air quality is more polluted than outdoor air quality. So even if it is a quick walk or just an exercise, it is good to get some fresh outdoor air. In order to help you understand more about indoor and outdoor air quality, there are several experiments performed during the thesis which will be discussed in the next chapter. Since the outdoor air quality is not so simple to predict with the help of a device which is limited to certain area. There are many websites which provide us the information about current air quality over an area with the help of the area zip code. Few of them provide the current day air quality as well as forecast tomorrow's air quality. Since we already discussed about the websites briefly in the Chapter 3, the programming that is done in thesis will be discussed in the following section. All the observational graphs and results will be discussed in the next chapter briefly.

### 4.3 Outdoor Air Quality Data Monitoring System

#### 4.3.1 Introduction

The entire programming in thesis is done using Python. Since we already have GrayWolf sensor to sense indoor air quality, there is a need to know the outdoor air quality in order to correlate the indoor and outdoor air quality. The websites AirNow and google local temperature service is used in the programming in order to get the daily outdoor air quality data like overall air quality index of the day, ozone, particulate matter, temperature and humidity. As part of the thesis a Graphical user interface (GUI) is designed to get the outdoor air quality which has a similar functioning of GrayWolf sensor. The programming included a GUI design to provide an easy access to the user to use it. In order to store the data files of the daily readings a database is created. There is an another GUI designed to analyze the data from the database by plotting. The design of the complete outdoor air quality sensing along with the database and plotting modules has been done in several stages. Each stage will be described in detail in the following section.

### 4.3.2 Design

The initial programming was to get the air quality data from the AirNow. So the web scraping technique was used in the python programming to acquire the Air Quality Index (AQI) which tells the overall air quality of an area. AQI tells you whether the outdoor air quality is good or bad. So after scraping the AQI from the website, it is programmed to store the data into a text file. So whenever the GrayWolf sensor is used, at the same time the python program is also made to run. Hence, by the end of the readings both the GrayWolf sensor readings and the outdoor air quality index are available. So now both data can be compared and correlated and can draw the conclusions based on the observations. At first the programming is not made flexible to get the data for different areas. Using the URL of AirNow the initial programming was to get the outdoor air quality data which is done just for one area and it is Denton. The data is acquired for every time period that is set for, so the initial default frequency is set for every 5 seconds. It is as shown in the Fig 4.5.

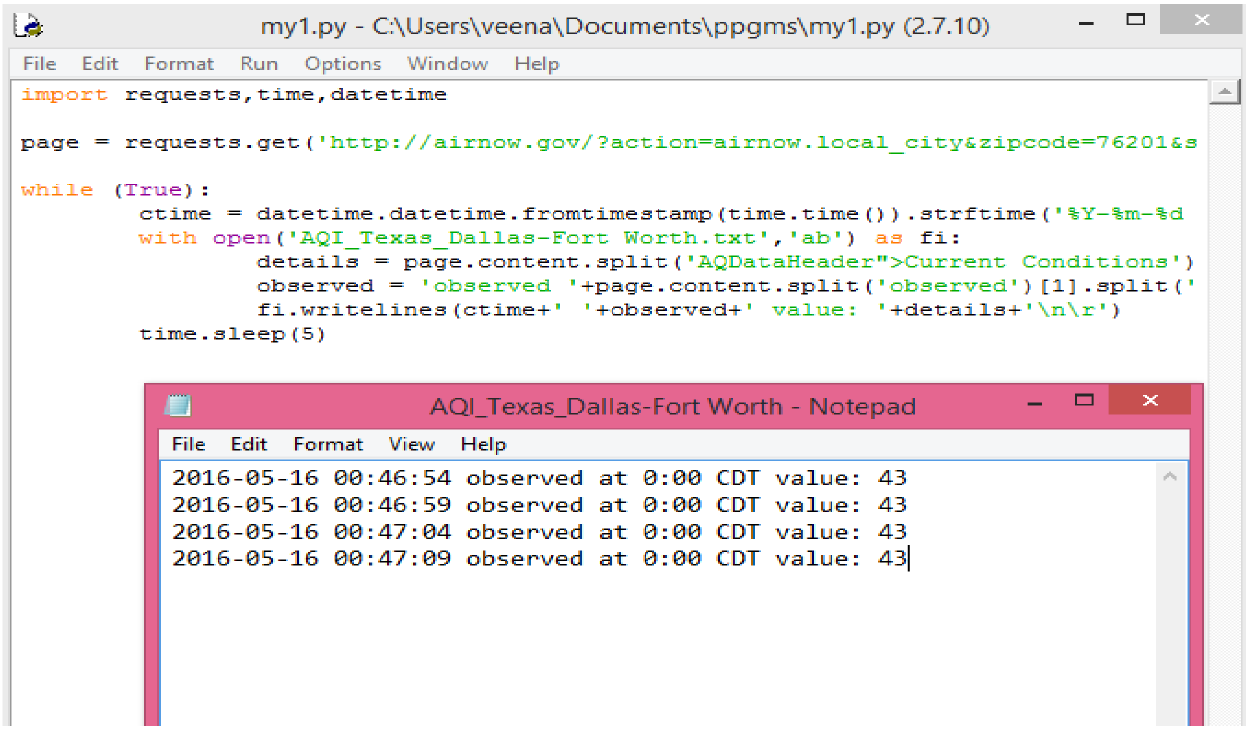



Fig 4.5 Python module receiving AQI into the text file

The next level of programming is to get the Local AQI of outdoor along with local AQIs of Particulate Matter(PM), Ozone ($O_3$) and also the Local Temperature and Humidity. The humidity and temperature values are web scraped from the google local temperature page. So this level of programming has 5 parameters that are Local AQI, AQI of PM, AQI of $O_3$, Temperature and Humidity. When the program is made to run, it automatically gets all those parameter values for a fixed frequency which can be seen in Fig 4.6. Since the data collected will be used in future to plot the comparison graphs, the readings are made to store automatically into text file when the program is running. Keeping the user convenience in mind, a graphical user interface is created which pops right away when the program is made to run which can be seen in Fig 4.7. It will ask the user to enter the desired text file name and as well as the frequency at which the readings are to be noted. Previously in the initial programming the frequency is fixed within the program. But the frequency feature is made flexible to the user at this level. So the user can get the readings at any frequency like for every 2 seconds or 5 seconds or other than that depending the user requirements.

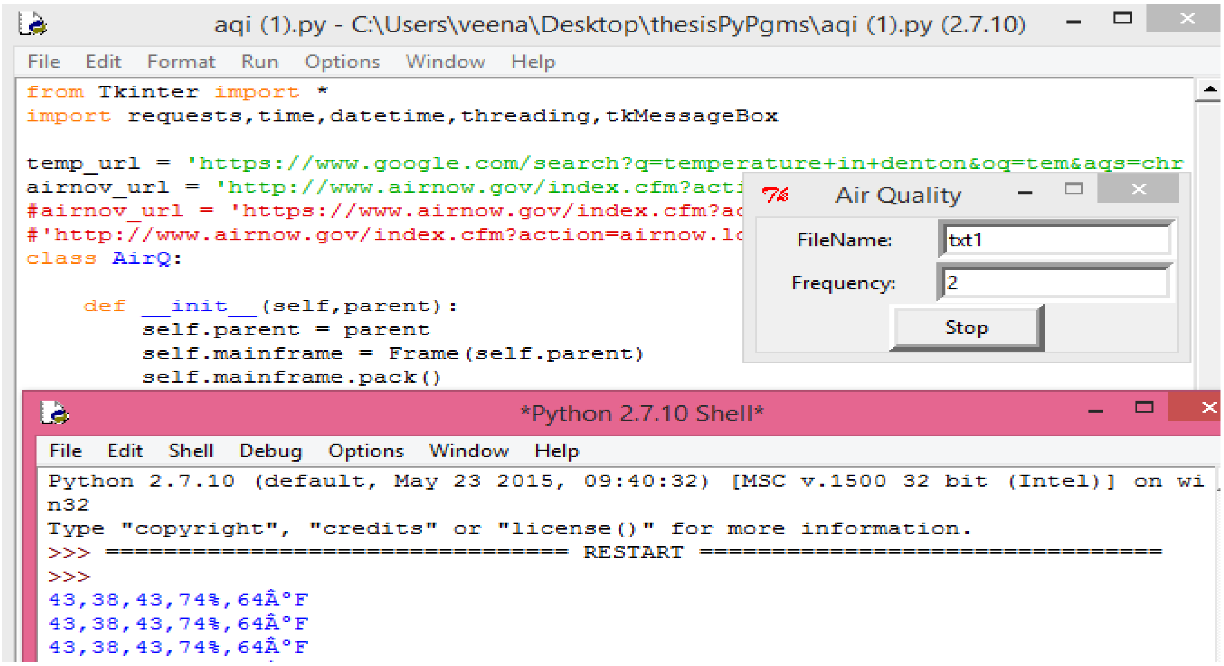



Fig 4.6 Python module with GUI, Shell display and Text file storage

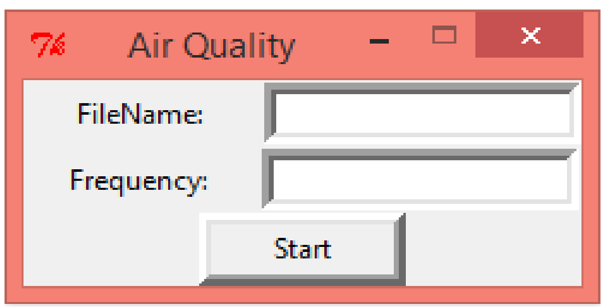



Fig 4.7 GUI of Outdoor Air Quality Receiver

At this stage since data that is collected from AirNow is web scraped from the website, it is difficult as the webpage source is modified frequently. So to collect the data more securely and improve the programming standard, the API of AirNow is used. Where the data is provided to the AirNow API users. All the information about the API is discussed in the Chapter 3 in detail. So now the data collected is not from the AirNow webpage source. The AirNow API is made as the source to collect their data. The API key is used in the program to request the air quality data from AirNow API, the URL along with API key is used.

.................................................................. Python Code for API Request ..................................................................

```
from Tkinter import *
import requests,time,datetime,threading,tkMessageBox,json
import sqlite3
connection = sqlite3.connect('AQI4.db',check_same_thread=False)
cursor = connection.cursor()
temp_url='https://www.google.com/search?q=temperature+in+denton&oq=t
em&aqs=chr
ome.0.69i59l2j69i57j69i59j0l2.3320j0j7&sourceid=chrome&es_sm=93&ie=U
TF-8'#
airnov_url='http://www.airnowapi.org/aq/observation/zipCode/current/
?format=application/json&zipCode=####&distance=00&API_KEY=A3495774-
701B-4584-8805-744095298675 '
```

..........................................................................................................................................................................................

Initially the values that are collected for the Particulate matter and the Ozone were the Air Quality Index, which basically tells whether the concentration levels of them in the air are good or bad. They eventually influence the overall outdoor air quality as we discussed earlier in Chapter 3, where dominant pollutant influences the overall outdoor air quality. But in order to get the direct concentrations of PM and $O_3$, a conversion formula is being used to convert the AQIs of PM and $O_3$ into their concentrations. So the formula which has been discussed in the Chapter 3 is used in the programming. It needed a stepwise procedure to get the things done, which can be explained with the help of the following flow chart shown in the Fig 4.8. In the existing program since we have already gotten the AQI values of PM and $O_3$ directly from the AirNow. The conversion formula is added to the program. PM and O3 have different air quality limits which can be seen in Table 3.4 from Chapter 3. So once the AQI values are received, each parameter checks for its AQI limits and then checks for its corresponding concentrations limits. Once the AQI range and concentration ranges are known then concentrations are calculated and processed as the output. The overall outdoor AQI can be determined either by the AQIs of PM and $O_3$ or with concentrations of PM and O3. The coding blocks of the concentration calculation logic is followed after the flow diagram.

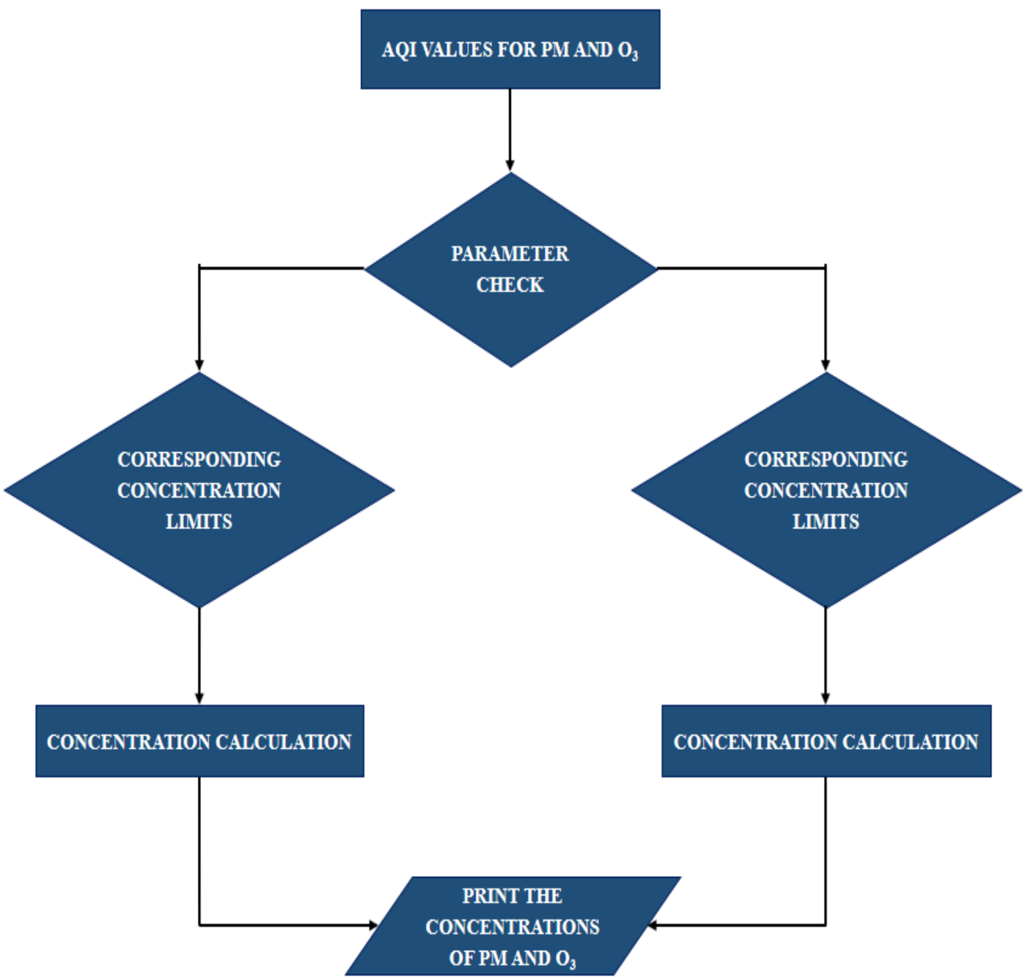



Fig 4.8 Concentration calculation module

…………………………… Python Code for PM Concentration calculation ……………………………

```
def PMcal(self,PM):

    CpPM = None

    if PM in range(0,51):

        CpPM=(((PM-0)*(15.5-0.0))/(50-0))+0.0

    elif PM in range(51,101):

        CpPM=(((PM-51)*(40.4-15.5))/(100-51))+15.5

    elif PM in range(101,151):

        CpPM=(((PM-101)*(65.4-40.5))/(150-101))+40.5

    elif PM in range(151,201):

        CpPM=(((PM-151)*(150.4-65.5))/(200-151))+65.5

    elif PM in range(201,301):

        CpPM=(((PM-201)*(250.4-150.5))/(300-201))+150.5

    elif PM in range(301,401):

        CpPM=(((PM-301)*(350.4-250.5))/(400-301))+250.5

    elif PM in range(401,501):

        CpPM=(((PM-401)*(500.4-350.5))/(500-401))+350.5

    else:

        print("CpPM out of range")

        CpPM = "CpPM out of range"

    return CpPM
```

……………………………………………………………………………………………………

……………………………… Python Code for $O_3$ Concentration calculation ………………………………

```
def o3cal(self,O3):

       Cpo3 = None

       if O3 in range(0,51):#(0-50)

           Cpo3=(((O3-0)*(0.064-0.000))/(50-0))+0.000

       elif O3 in range(51,101):  #(51-100)

           Cpo3=(((O3-51)*(0.084-0.065))/(100-51))+0.065

       elif O3 in range(101,151):

           Cpo3=(((O3-101)*(0.164-0.125))/(150-101))+0.125

       elif O3 in range(151,201):

           Cpo3=(((O3-151)*(0.204-0.165))/(200-151))+0.165

       elif O3 in range(201,301) :

           Cpo3=(((O3-200)*(0.404-0.205))/(300-201))+0.205

       elif O3 in range(301,401) :

           Cpo3=(((O3-200)*(0.504-0.405))/(400-301))+0.405

       elif O3 in range(401,501) :

           Cpo3=(((O3-200)*(0.604-0.505))/(500-401))+0.505

       else:

           print("Cpo3 out of range")

           Cpo3 = "Cpo3 out of range"

       return Cpo3
```

…………………………………………………………………………………………………………………………

Along with concentration calculation new feature of zip code is added to the existing program, where a user can know the air quality of a particular area by entering the zip code of that place. It can be done by changing the zip code in the URL used in the program. But for the user convenience it is an option included in the GUI, so the existing GUI is modified using this new feature. The modified GUI can be seen in the Fig 4.9.

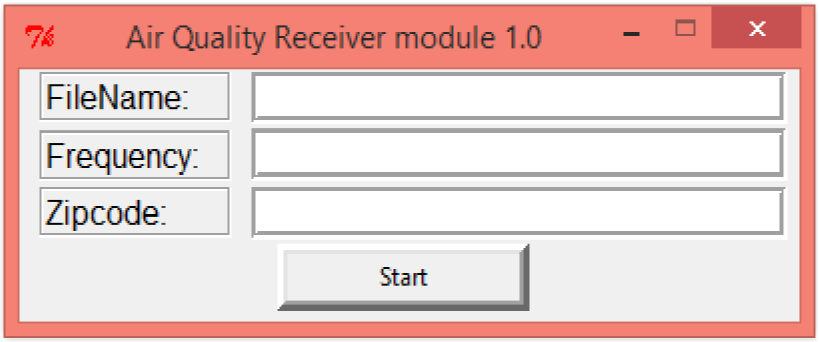



Fig 4.9 Modified GUI of the Outdoor Air Quality Receiving module

All the readings are still stored in the text file whenever the program is made to run. So to have all the data collected daily to get stored in a database, a new module is introduced in the program. A database is created so that the data gets stored into the database whenever the program is made to run. There is still a filename option, so that user can still give a file name. Now the data gets stored in the text file with given filename as well as in the database. Hence, users can look for the data of one day with a particular filename along with all the data on a daily basis stored in the database. The database that is used in the thesis is sqlite3 which is a module provided in the python. So using this module a database can be created to the required variables to get stored in it. In order to browse the data in the database user should have SQLite browser installed in the system. The browser can be viewed in the Fig 4.10.

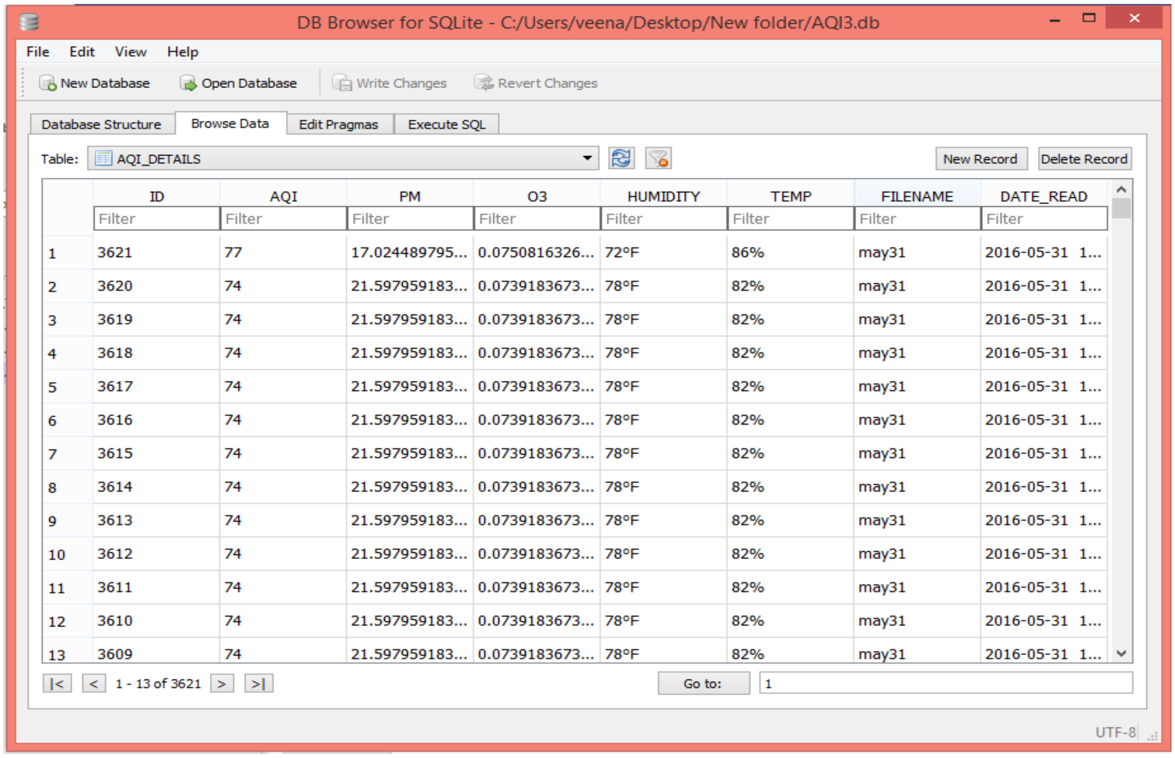



Fig 4.10 Database Browser for SQLite showing the data collected

Whenever the outdoor air quality monitoring program is made to run, now it provides user with filename, frequency and the zip code option. So while the program is running the data get stored in a text file with the given filename as well as in the database.

In order to analyze the data contained in the database the next feature that is added to the system is the plotting module. So the user can actually plot the data of the required variables from the database. For the user convenience a GUI is created, so when the program is made to run the GUI will ask the user to choose the variable to be plotted as well as the start date and end date of the data. So the user can see the air quality varying day to day. If it is done for a month, then we can have the outdoor air quality graph which varies day by day in a month and if it is a data of a year, then an annual outdoor air quality can be analyzed. This kind of data will be very helpful to analyze how the air quality varies every day or every month. On a long run with the help of this programming, we can compare data for 2 years. This will really help to know how outdoor air quality is in different areas and the measures to be taken to build a healthy environment around us. The GUI of the plotting module can be seen in Fig 4.11.

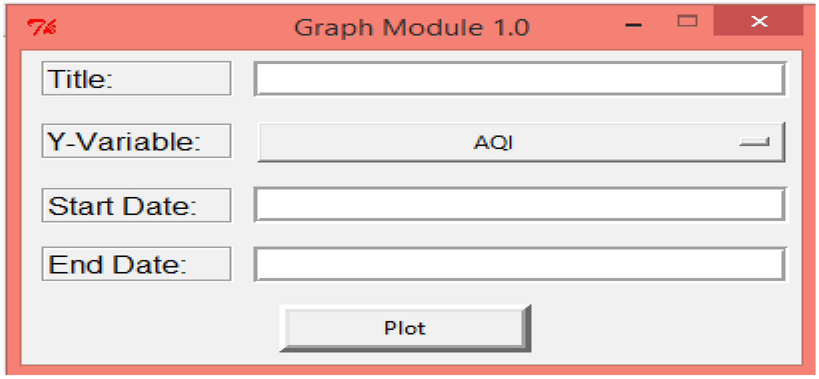



Fig 4.11 GUI of the Plotting module

Using this GUI user can enter a graph title choose a Y-variable which has drop down list as seen in Fig 4.12 and the start date and end date of the data in the database. So once the users hit the plot button, then the graph is plotted. In order to plot the graph matplot.lib module is used in the python program.

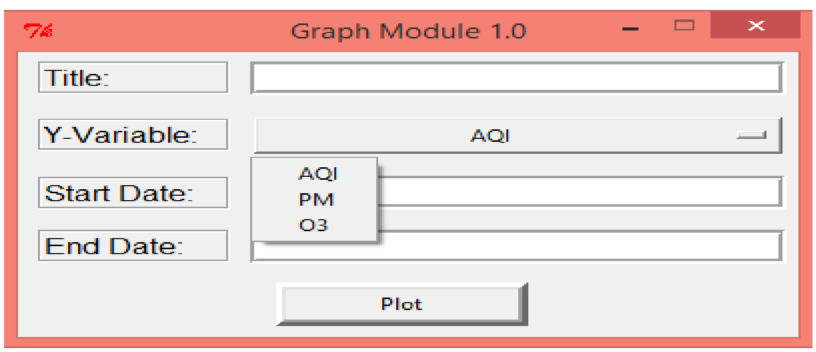



Fig 4.12 Graph module showing the plotting options

The main schematic diagram of Data management and Visualization system that involved thesis can be seen in the Fig 4.13.

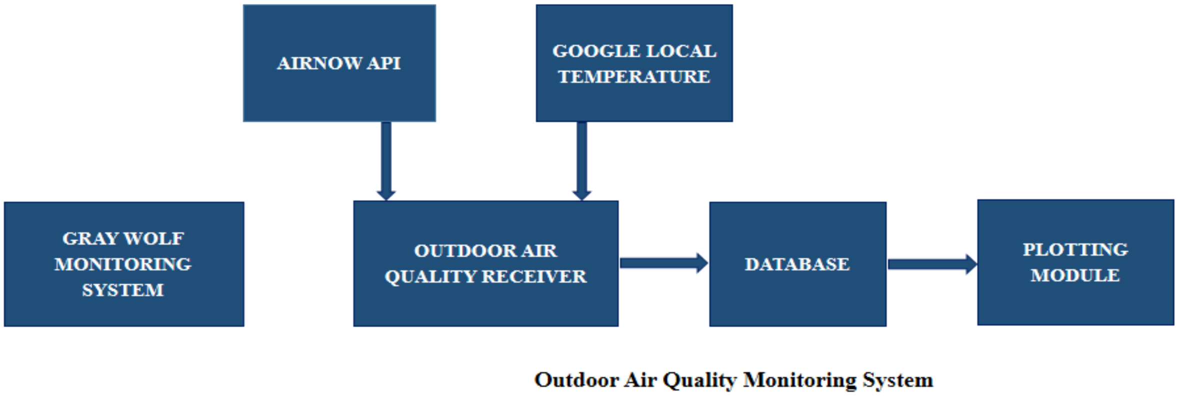



Fig 4.13 Basic Block Diagram of Data Management and Visualization

The Gray Wolf Monitoring System, which consists of the GrayWolf sensor that is IQ-610 probe and desktop to visualize the sensor readings using GrayWolf desktop software. The Outdoor Air Quality monitoring system consists of the data sources that are AirNow API and Google Local Temperature, GUI of Outdoor Air Quality Receiver module, Database of the data collected from the Outdoor Air Quality Receiver module and the GUI of the Graph plotting module to the data collected in the database.

# CHAPTER 5

# MEASUREMENT RESULTS AND ANALYSIS

## 5.1 Introduction

The GrayWolf sensor system is used to test different parameters like $CO_2$, $O_3$, CO, TVOC, Temperature and Humidity. The device has been taken to different places to test the surrounding air quality indoor and outdoor. Since $CO_2$ is an active pollutant which is present in large amounts and dominates the air quality, most of the observations are made on it. The next parameter is $O_3$ which has been tested since the $O_3$ layer is really important to be maintained in the environment. Having right concentrations of ozone in our surroundings is important. The other parameter which is also tested is TVOC which is also a common pollutant found around us. The detailed explanations about each pollutant can be found in Chapter 3 and the observations made during the testing will be provided in the following section.

The Outdoor Air Quality monitoring system which has been designed for the thesis is used along with the GrayWolf sensor system to know how the outdoor air quality is during the indoor air quality readings taken using GrayWolf sensor system. Since the functionality of both systems is similar, they are made to run at the same time and with the same frequency. Once the readings are taken both systems are made to stop. Once we have the data from both the systems, a comparison graph can be plotted between indoor and outdoor air quality. This helps in understanding how the indoor air quality varies with outdoor air quality. Simple remedies to maintain good air quality will also be discussed in the following section.

### 5.1.1 Test 1

The test is taken in the bedroom with two people sleeping. The bedroom door is closed during the time of taking readings and the red color graph represents the readings when the door is closed. The other day the bedroom is left open, there were no fixed conditions during both the times that is, when the door is either closed or open. The blue color graph represents the readings when door is left open.

It is a test to see how the CO2 levels are in the bedroom when the bedroom door is closed and when it is left open. The resulting graph can be seen in Fig 5.1. The readings are taken at both the times using GrayWolf Sensor. The equipment was placed in the room and made to run around for 6 hours and the data is logged into the GrayWolf PC. During the test observation notes has been taken to note the changes in the room conditions.

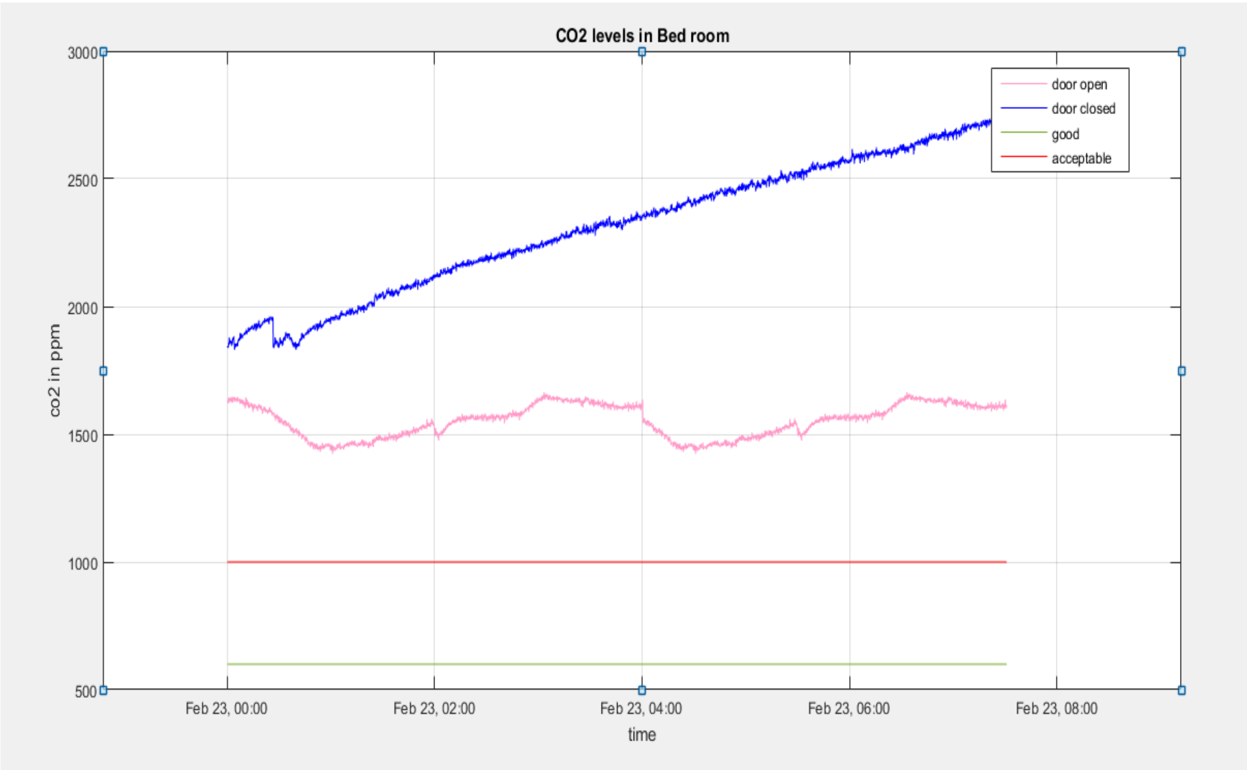



Fig 5.1 CO2 levels in a Bedroom under normal conditions of daily routine

5.1.2 Test 2

It is the test taken in a bedroom with two people inside. The door is locked and the readings are taken for short hours during the sleep time. The black graph shows the readings when there is no plant inside the bedroom. The blue graph represents the readings that are taken when there is a plant inside. No change in the conditions of the room. The AC is ON both the times. The GrayWolf sensing system is used to measure the air quality readings inside the bedroom. So the equipment is placed in the room and made to run, the readings are logged all the night. The measurement is stopped in the morning as you can see from the Fig 5.2, that is at 7:30 AM. During the reading, a small plant is placed in one of the corners of the room. During the test an observation notes is taken whenever there are changes in the room conditions.

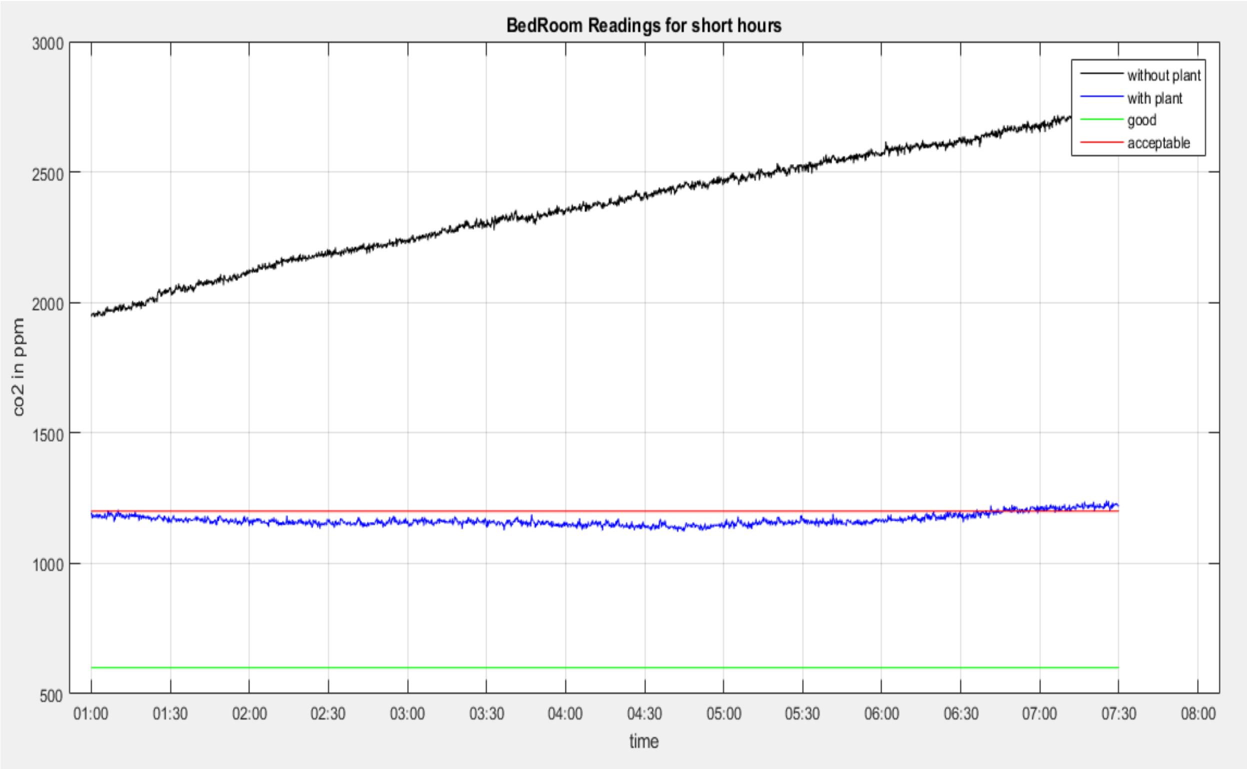



Fig 5.2 Bedroom $CO_2$ level test with a plant for short hours

5.1.3 Test 3

This is the test taken in the bedroom with two people sleeping inside. First, the readings were taken in the bedroom without placing a plant inside and there are no fixed conditions like the door closed or left open. But most of the time door is closed after 10:00PM when the people inside the room are about to sleep. The readings are taken from 5:00PM to 12:00AM next day. The black graph in the Fig 5.3 represents the readings without a plant and the blue graph represents the readings with a small plant inside. Compared to test 2 the readings are for test 3 are taken for a longer duration so we can see the variations in the $CO_2$ levels at different instances during the day and night. These readings are taken using the GrayWolf sensor. Notes are taken during the test to note the changes like a door is opened or closed and when the people are moving around. The resulting graph of the test 3 can be seen in the Fig 5.3.

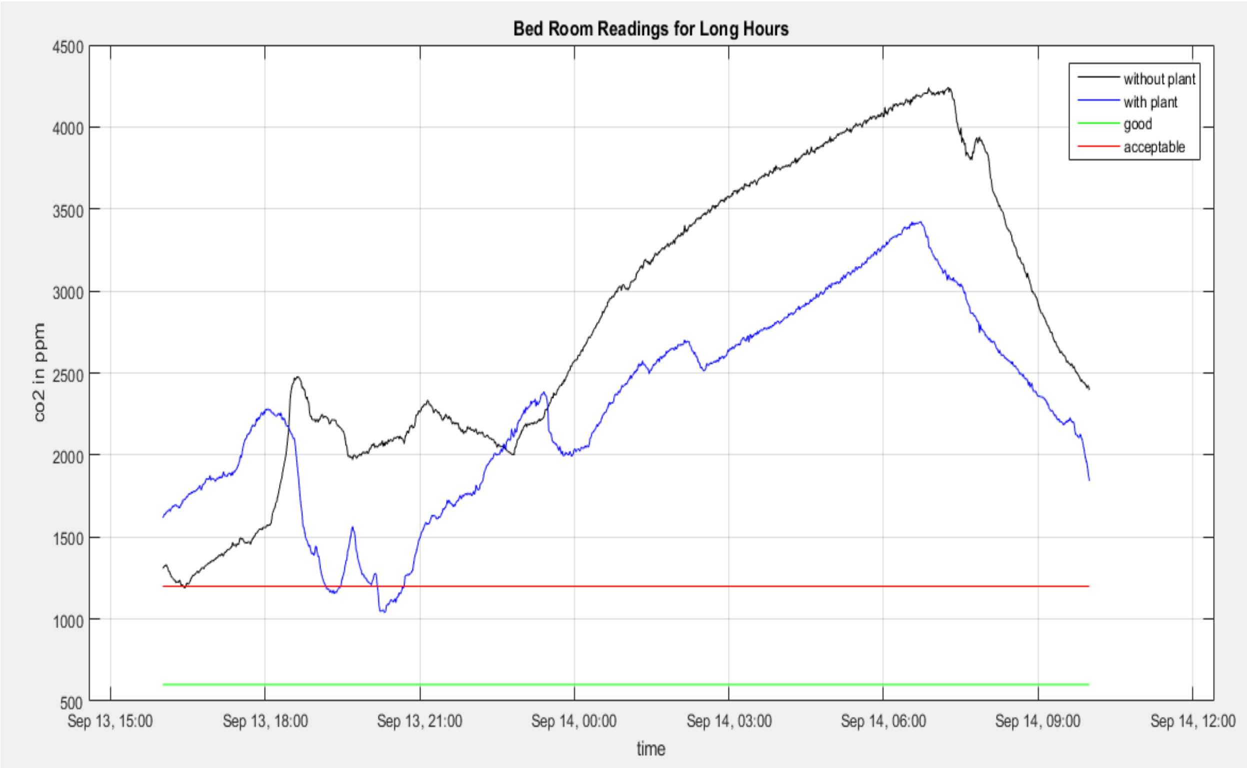



Fig 5.3 $CO_2$ levels in the bedroom taken for longer duration

5.1.4 Test 4

It is the test taken in the hall of the apartment. Where all the doors and windows are closed and the room is air conditioned. The readings were taken for 1 and half hour after the probe is stabilized and later the door is opened for around 10 minutes and again closed to see how the $CO_2$ levels changed when there is ventilation. The readings are taken using GrayWolf sensor. During the test an observation notes are taken whenever there is a change in the room conditions. The equipment is placed in the hall and is made to run during the test time and the data is logged into the GrayWolf desktop PC software. This test is taken to observe the $CO_2$ levels in the hall and how the ventilation helps to maintain room air quality. The resulting graph of the test can be seen in the Fig 5.4.

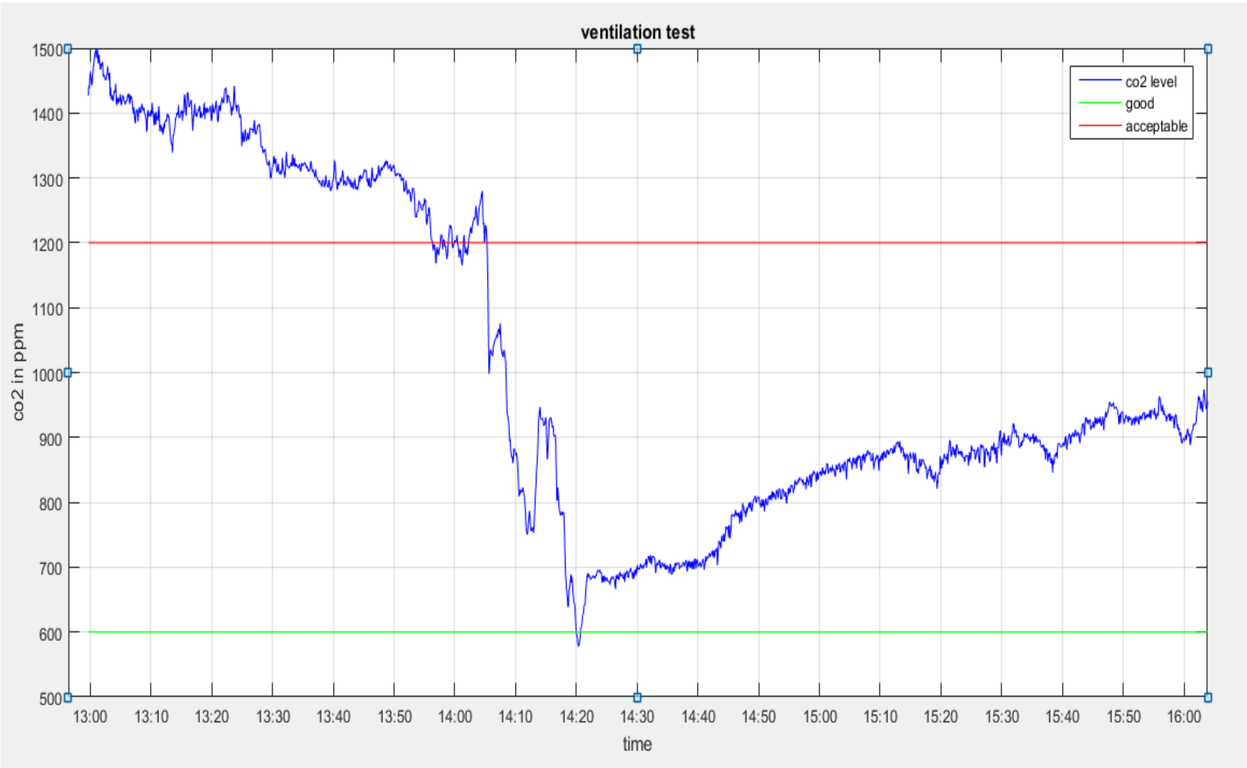



Fig 5.4 Ventilation test

5.1.5 Test 5

This test is conducted in the hall of an apartment, where there is 1 person in the hall. The GrayWolf sensor is used to take the readings. The equipment is placed in the hall. During the test all the windows and door are closed and the room is air conditioned. The readings were logged into the GrayWolf desktop PC. During the test an observation notes are taken to note any changes in the room conditions. This test is done to observe the air quality in the hall and to see the levels of $CO_2$ on a regular day. The resulting graph can be observed from the Fig 5.5.

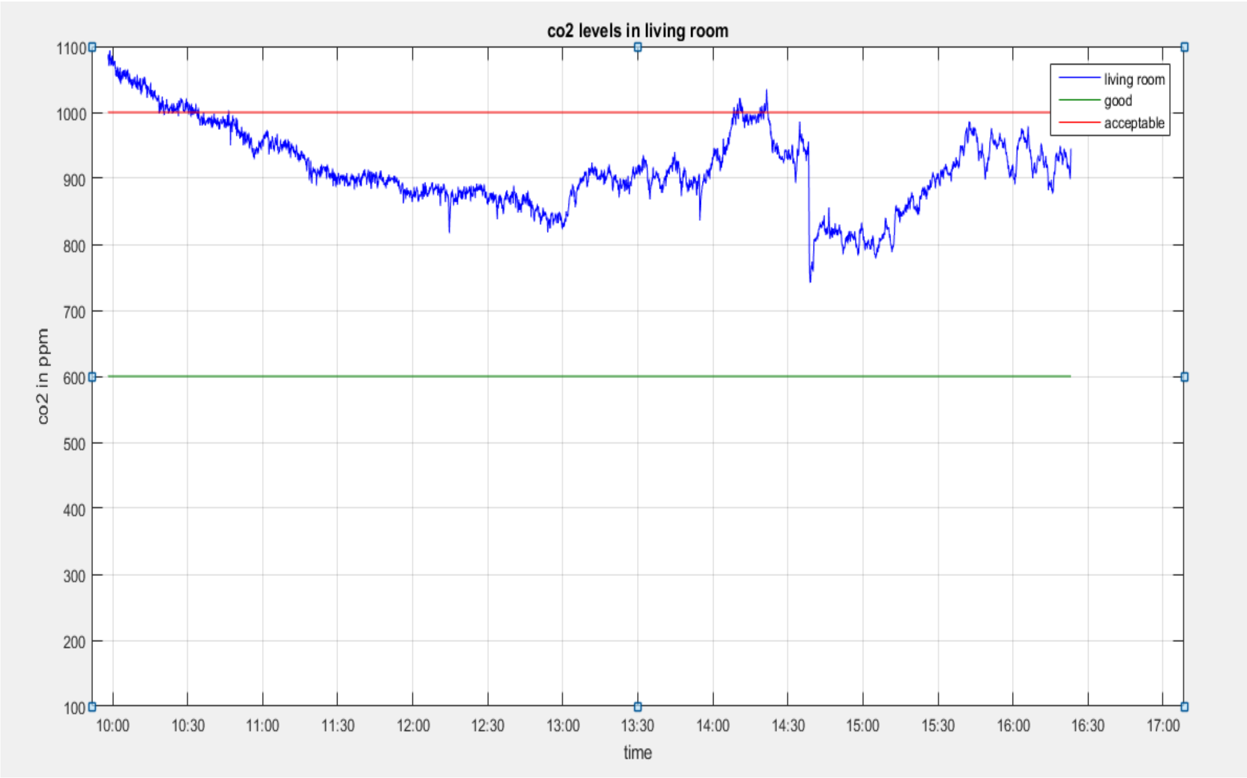



Fig 5.5 $CO_2$ levels in the living room

5.1.6 Test 6

This test is done outside the apartment within the open area of the apartment which is located in Denton. The test is done during the same time of test 5 to compare the indoor air quality to the outdoor air quality. The readings are taken using the outdoor air quality measurement system that is designed for the thesis. The readings were received from the AirNow website. The system is made to run on the PC during the test. Since it is a web based application there is no need to have the measuring system at the test location. By the pin code of the area the data can be collected into the database of the measuring system and then can be used for plotting. The resulting graph can be seen in the Fig 5.6. The blue dotted line represents the AQI. During the test an observation notes of the surroundings are taken.

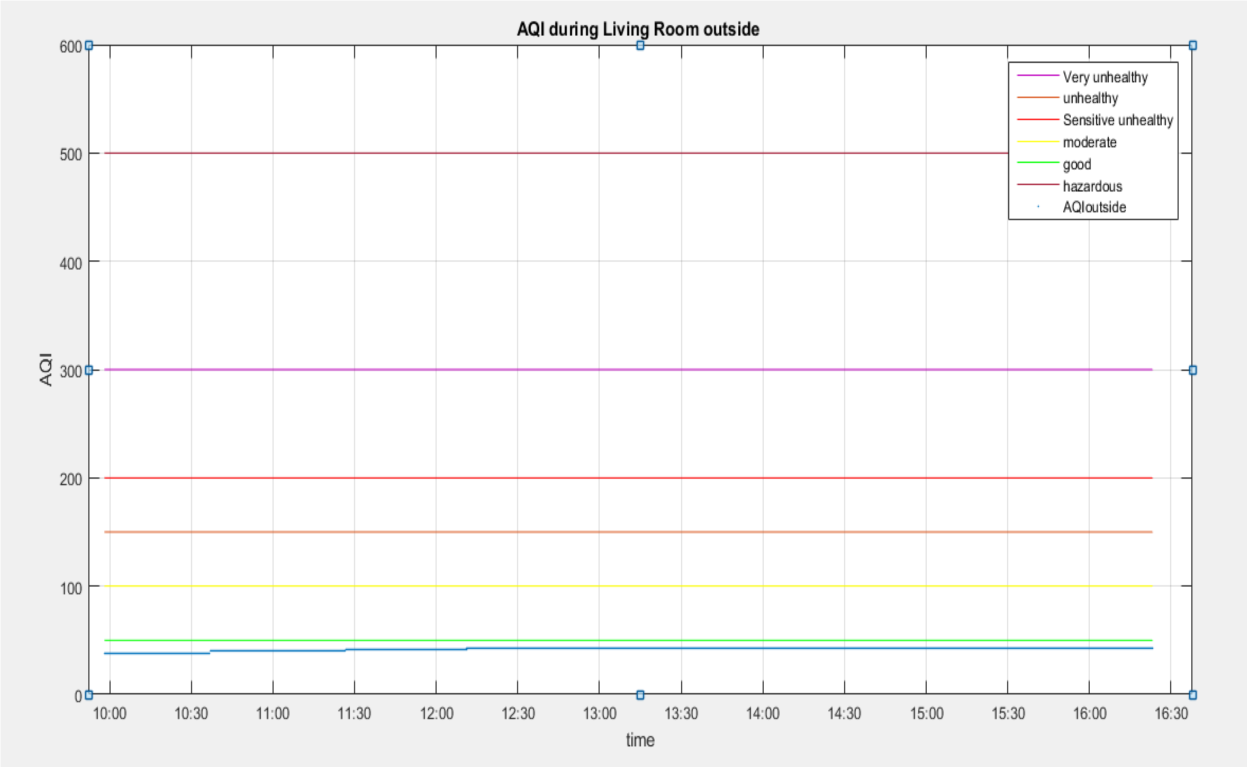



Fig 5.6 AQI readings taken outside during the test 5

5.1.7 Test 7

This test is done in the living room of the apartment and the outdoor of the apartment. The readings are taken using the GrayWolf system. The equipment is placed in the living room with one person inside. During the test in the living room all the doors and windows are closed the whole time. The blue color graph represents the readings taken in the living room. The test is continued on the next day during the same hours of test done in the living room, the equipment is taken outside into an open area close to the apartment. During the test an observation notes are made of the changes in the surroundings. The pink color graph represents the readings taken outdoor. During the test in the living room and outdoor the data is stored in the GrayWolf PC. The resulting graph of the test 7 can be seen in the Fig 5.7.


Fig 5.7 $CO_2$ levels in the living room and the outdoor

5.1.8 Test 8

This is the test taken in the lab B251 of Electrical Engineering Department, UNT. The readings were taken using the GrayWolf System. The equipment was placed inside the lab and the door is closed for most of the time. An observation notes are taken during the time of test to note down any changes to the test environment conditions. There are 4 AC vents inside the lab. During the lab readings there are 2 persons inside the lab. Along with the GrayWolf PC there are 2 desktops functioning in the lab. The lab has all the lab equipment, but there were no experiments or soldering done during the time of the readings. The readings were taken from 12:45PM to 6:00PM. All the data is logged into the GrayWolf PC. The resulting graph shows the $CO_2$ levels in the lab at different time intervals which can be seen from the Fig 5.8.

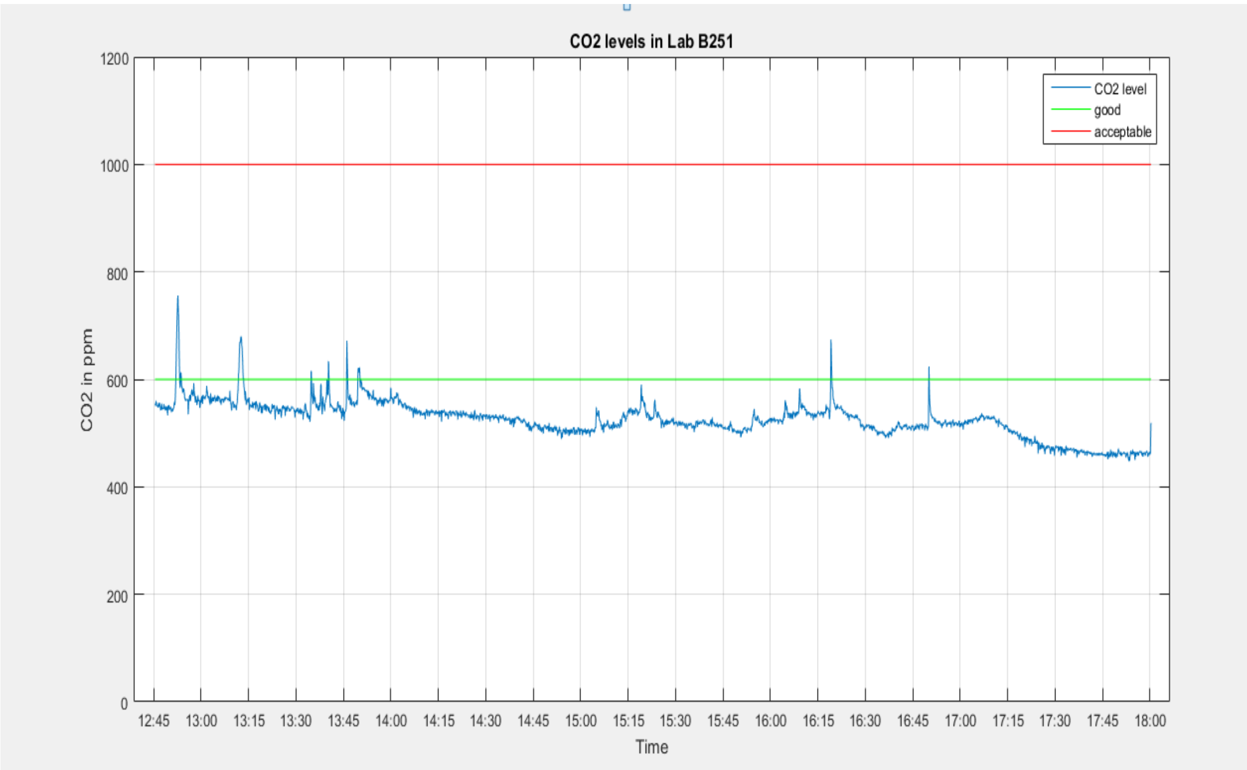



Fig 5.8 $CO_2$ levels in lab

5.1.9 Test 9

This is the test done in the classroom B217, Electrical Engineering Department, UNT. The readings are taken using GrayWolf System. The equipment was placed in the classroom before the class has begun. The initial $CO_2$ levels in the class are about 600ppm. The lecture was taken in the class from 2:00 PM to 3:20 PM. During the test an observation notes has been taken on every event. Students began to come to the class at 1:52PM gradually. The number of students in the class are 30. After the class the readings are taken to observe the settling time of the $CO_2$ level. The variations in the $CO_2$ levels at each interval during the test, before and after the class were plotted in the Fig 5.9. The readings from the test are logged into the GrayWolf PC.

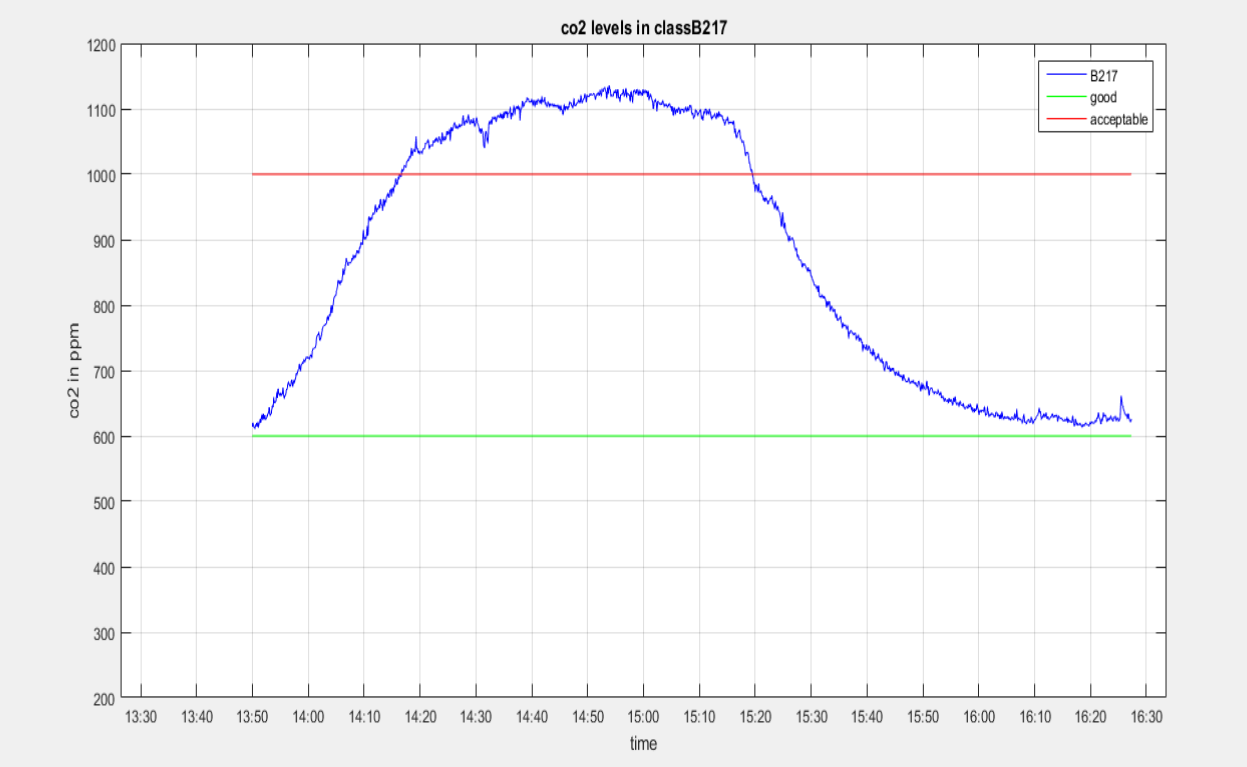



Fig 5.9 $CO_2$ Levels in the class room

5.1.10 Test 10

This test is done in Willis Library Floor 2, UNT. GrayWolf Sensor is used in taking readings in the library. The equipment was placed inside the library and the library is very spacious and is of large area which can facilitate students around 400. During the test there is a regular number of students in the Floor 2 of the library which is around 100. When the test began the count of the students is 150. Even though few are leaving and entering the library the count maintained to be around 150-160. More than half of the students were using the personal computers. Observation notes were taken during the time of the test. The levels of $CO_2$ in the library during the test can be seen in the Fig 5.10. There were no special measures taken during the test.

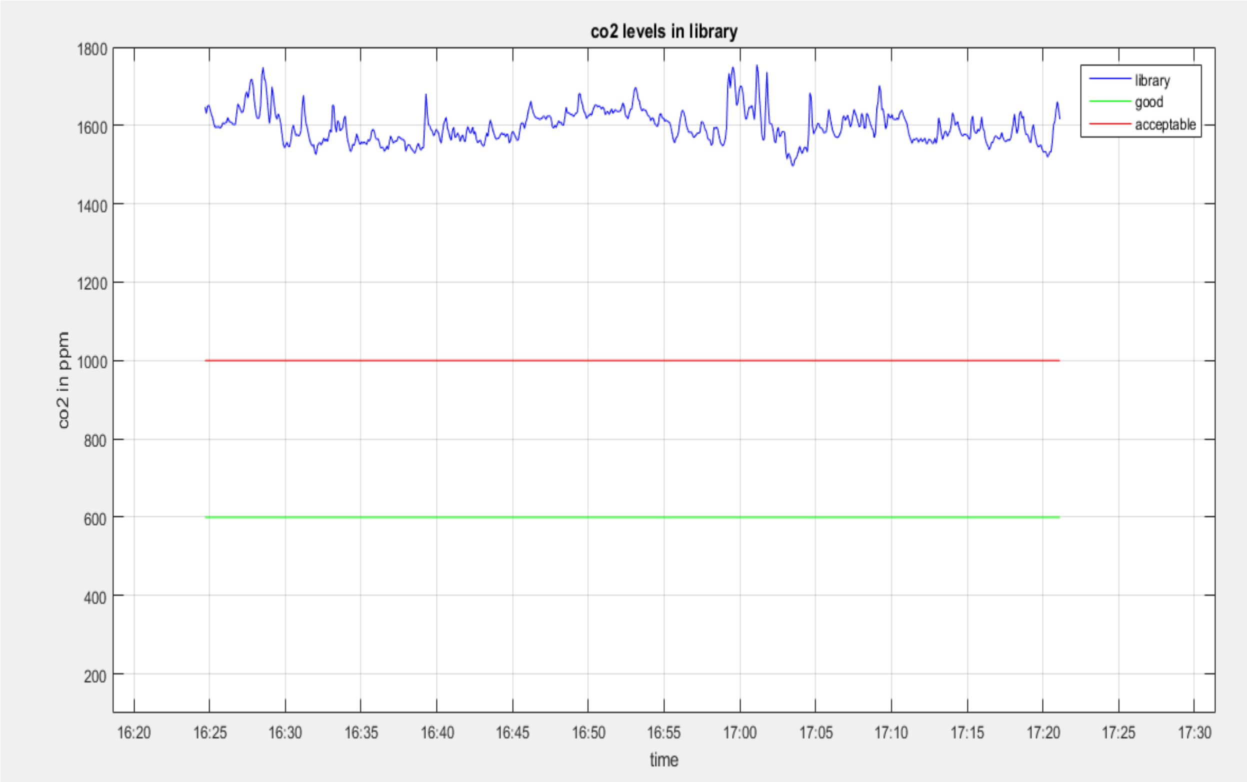



Fig 5.10 $CO_2$ levels in the library

5.1.11 Test 11

This test is done in the Recreational Center (REC), UNT to observe the air quality inside. Lot of students and other people go to REC to workout. It is important to know the air quality of the surroundings where we workout. The readings are taken using the GrayWolf sensor. The equipment was placed in the workout station and the readings were taken. During the readings, observation notes were also taken to understand the air quality better. No special conditions were considered during the test. Once the readings are taken all the data is logged into GrayWolf PC. The $CO_2$ levels in the recreational center can be seen in the Fig 5.11.

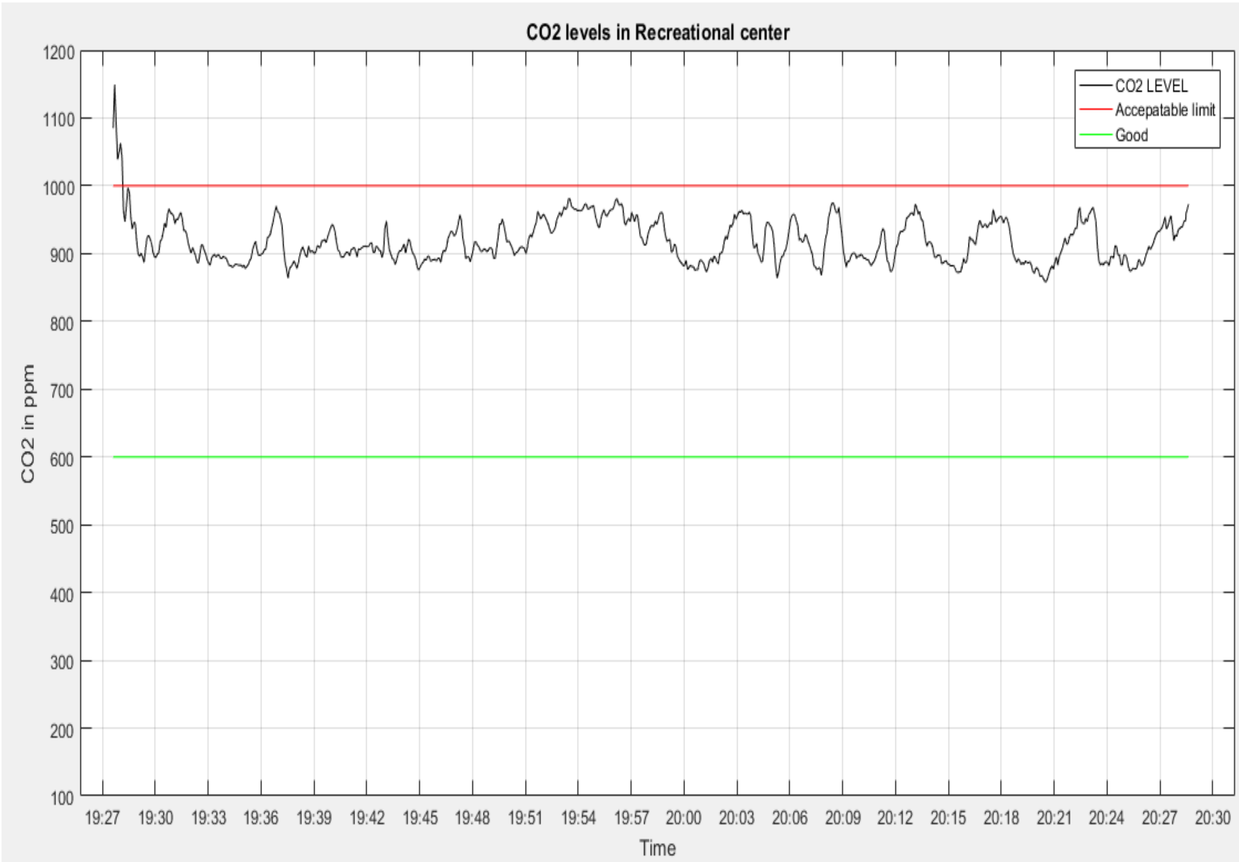



Fig 5.11 $CO_2$ level in the Recreational center

5.1.12 Test 12

This test is done on the bus, UNT Shuttle with 12 people in it during the test and the bus is air conditioned. The air quality readings inside the bus were taken using the GrayWolf sensor. The equipment was placed inside the bus and is made to run and the readings were logged into the GrayWolf PC. This test is done to observe the air quality inside the bus. During the test an observation notes are taken to note down the changes to the test conditions, which eventually helps in understanding the deviations in the data plotted. The number people inside the bus were kept changing and even the bus doors were opened and closed all the time. But however the readings were taken in the bus with its regular routine, no special measures were taken. The resulting graphs of the test can be seen in the Fig 5.12.

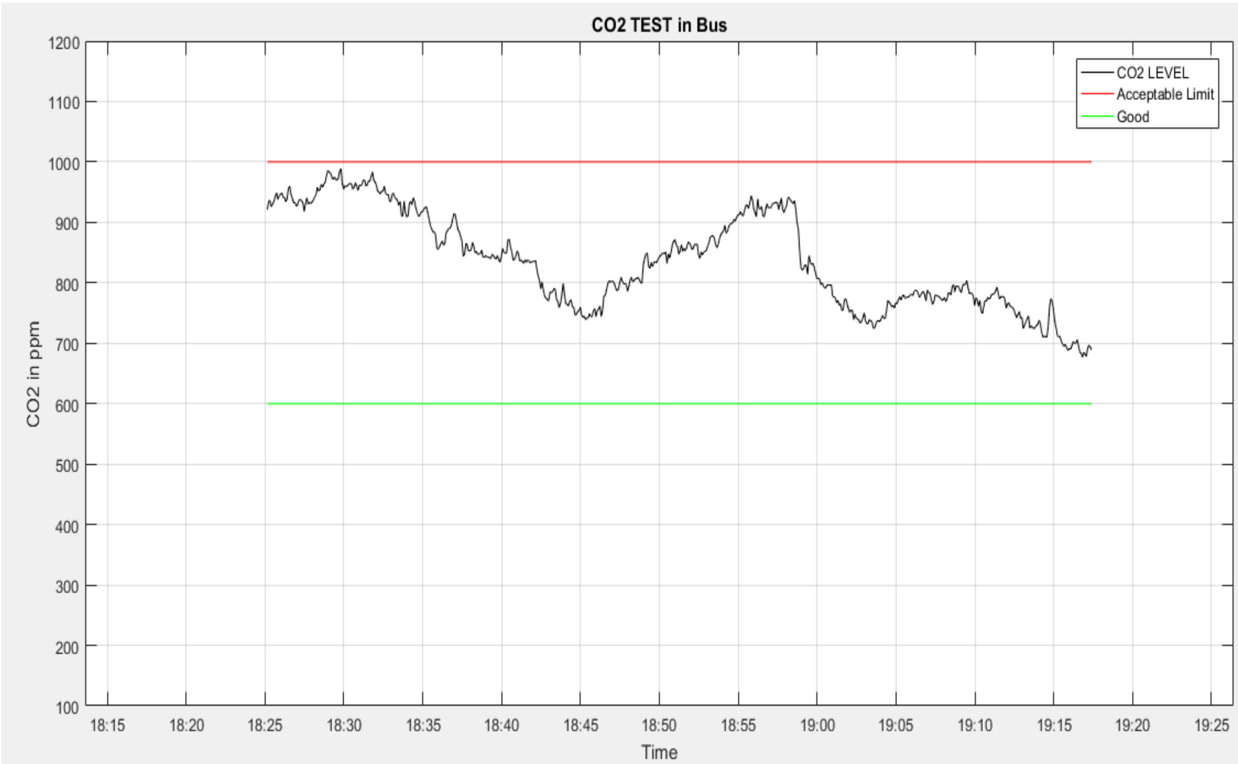



Fig 5.12 $CO_2$ Levels in the Bus

5.1.13 Test 13

This test is done in the park to measure the ozone levels in the atmosphere using GrayWolf PC. The equipment was placed in the park and there were few children playing around. The GrayWolf sensor is made to run and all the readings were logged into the GrayWolf Desktop. Park is a pleasant place for the children to play and for adults to workout. Having good levels of ozone is very important in places like parks. Since there were lots of trees in the surroundings, the air quality is maintained. During the test observation notes was taken to note down the environment conditions in the surroundings which eventually helps in understanding the readings in the plot. The resulting graph of the test can be seen in the Fig 5.13.

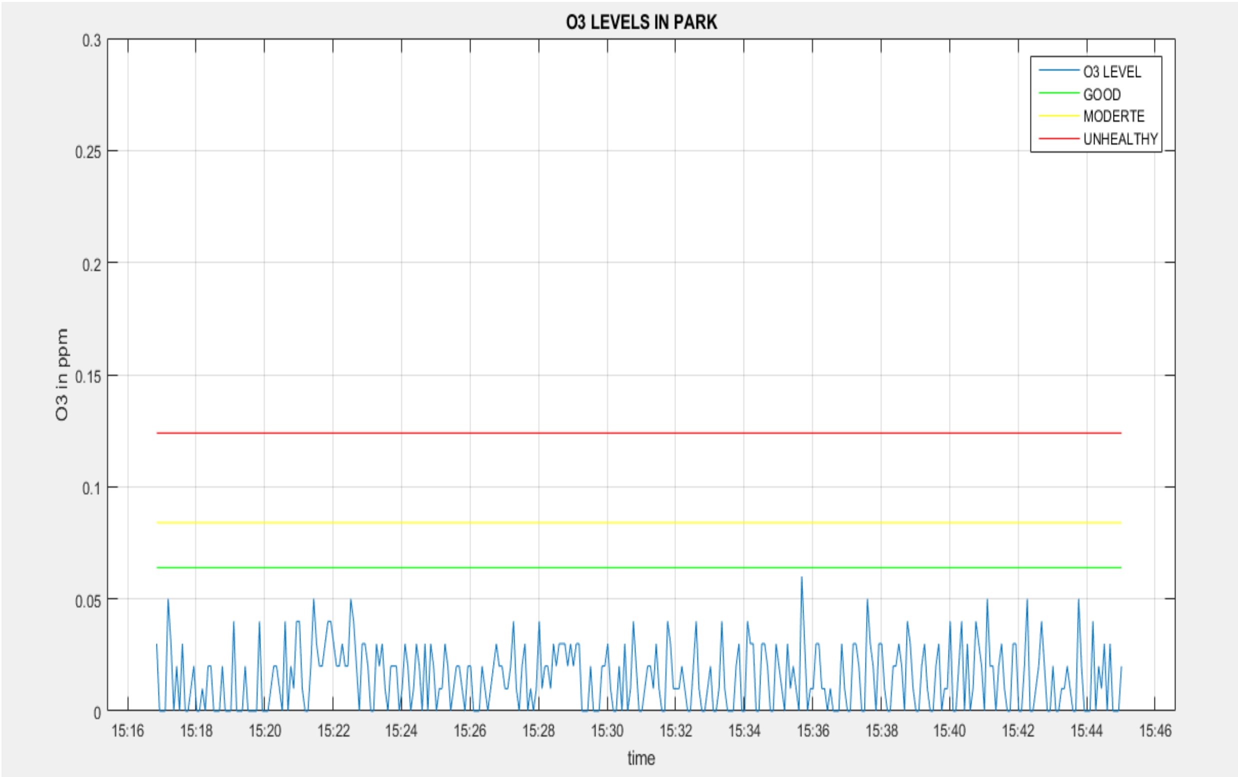



Fig 5.13 $O_3$ levels in the park

5.1.14 Test 14

This test was taken in a garden at Discovery park with lot trees in the surroundings. This test is done to observe the ozone levels. The black graph is plotted using the readings taken from the GrayWolf sensor. The equipment was placed on one of the tables in the garden and the device is made. All the data collected from the GrayWolf sensor is logged into the GrayWolf PC. The blue graph is plotted using the readings taken from the outdoor air quality measurement system where the readings are taken from the AirNow local website. In order to compare the results both readings were plotted together in the Fig 5.14. During the test observation notes is taken to note down the surroundings condition.

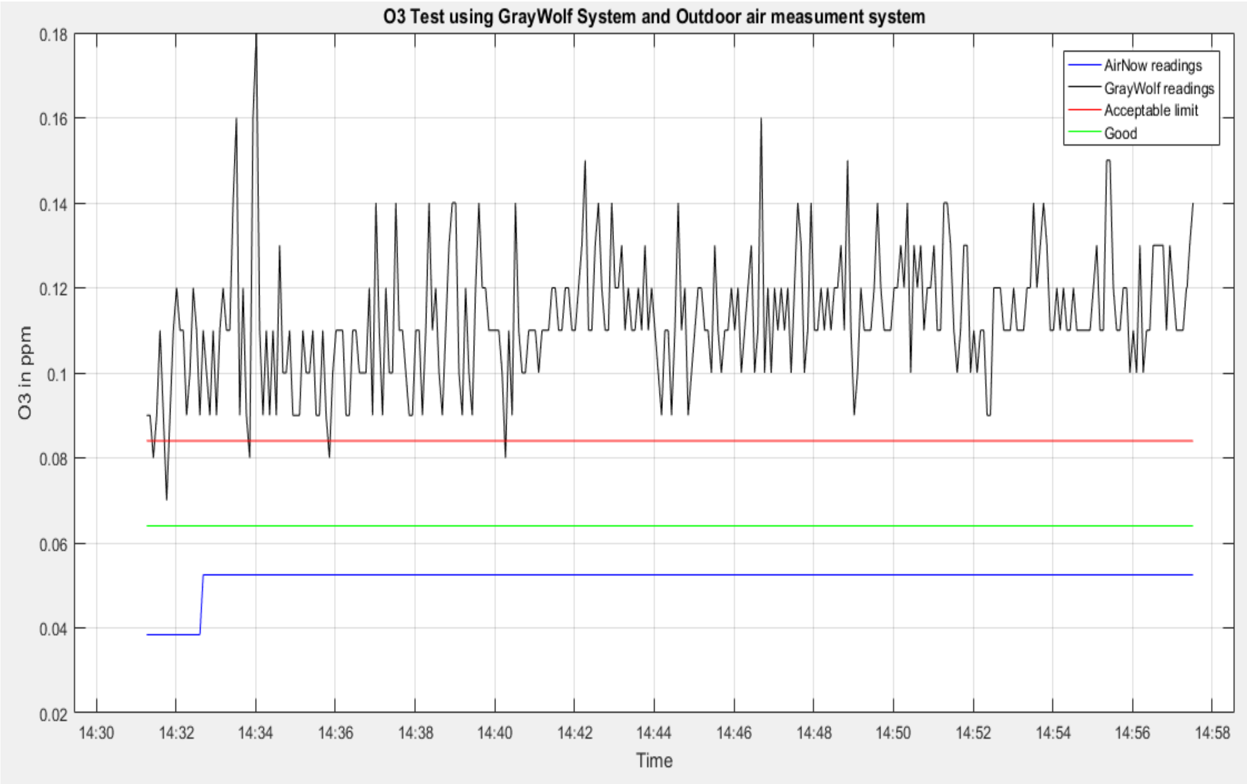



Fig 5.14 $O_3$ test using GrayWolf and Outdoor air quality measurement systems

5.1.15 Test 15

This is the test done in the living room of the apartment to observe the TVOC levels when the floor is clean and to observe the settling time. The readings were taken using GrayWolf sensor. The GrayWolf sensor is placed in the living room and it is made to run, at 4:00PM the cleaning mop is placed to clean the floor. The cleaning time is about 5 minutes, later it is set to dry. The readings are taken till the levels got settled down. During the test observation notes was taken at each point of the task. All the readings are logged into the GrayWolf PC. Doors and windows are closed during the whole time of the test. The resulting graph of the test showing VOC levels can be seen in the Fig 5.15.

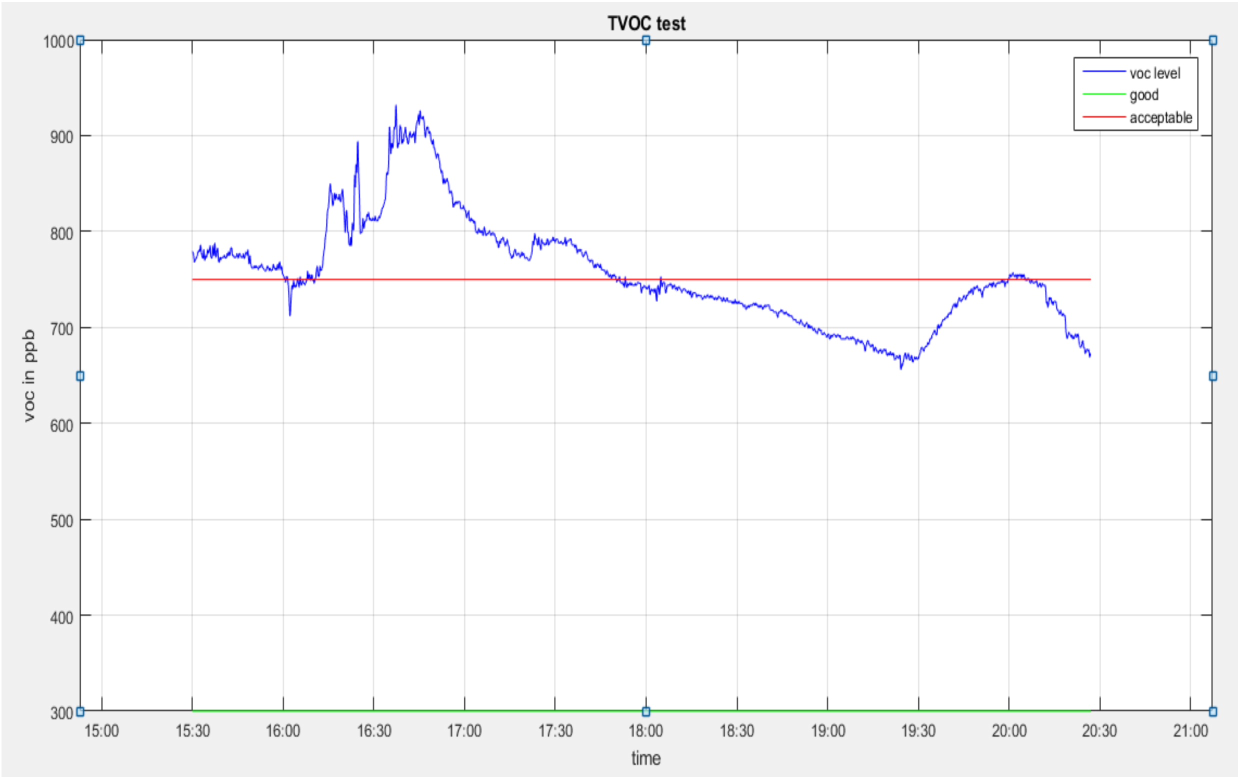



Fig 5.15 TVOC test

5.1.16 Test 16

This test is done to test the TVOC concentration inside the bus, UNT Shuttle with 12 people in it during the test and the bus is air conditioned. The air quality readings inside the bus were taken using the GrayWolf sensor. The equipment was placed inside the bus and is made to run and the readings were logged into the GrayWolf PC. During the test an observation notes are taken to note down the changes to the test conditions, which eventually helps in understanding the deviations in the data plotted. The number people inside the bus were kept changing and even the bus doors were opened and closed all the time. But however the readings were taken in the bus with its regular routine, no special measures were taken. The resulting graphs of the test can be seen in the Fig 5.16.

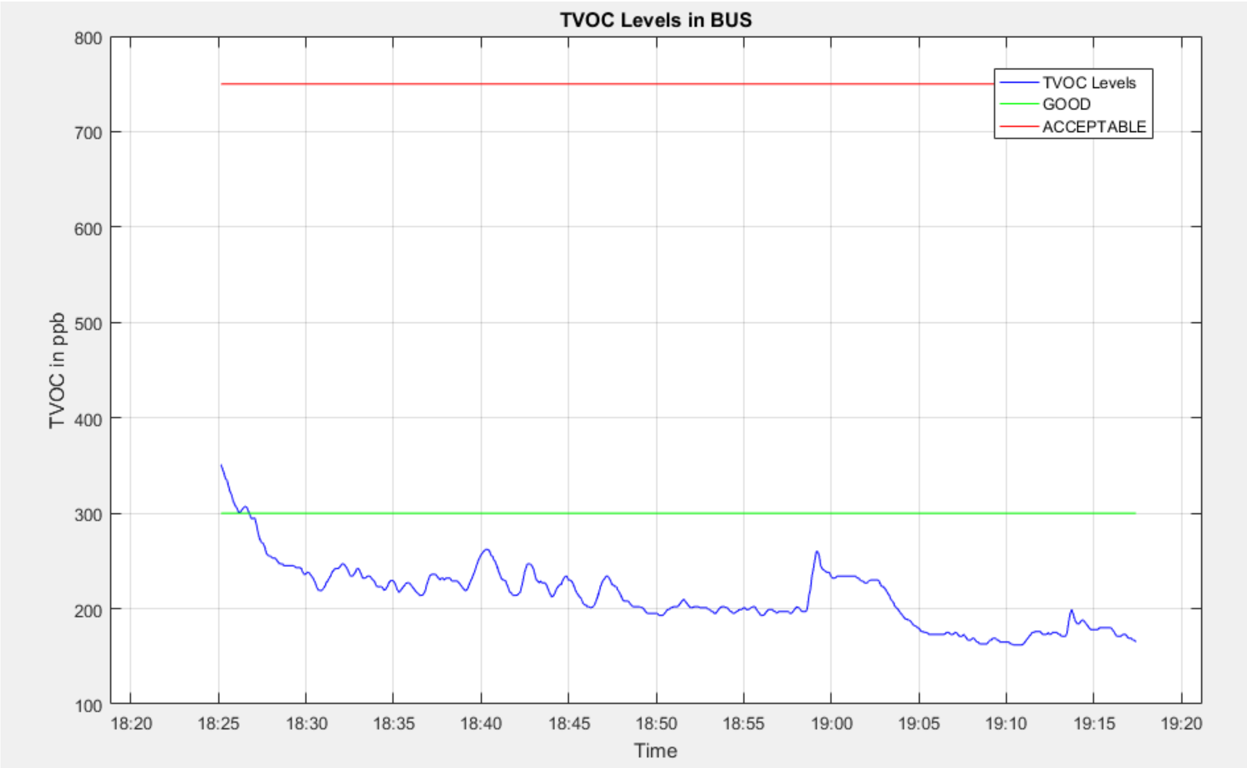



Fig 5.16 TVOC test in UNT Shuttle

5.1.17 Test 17

This is the test done to test the levels of TVOC in the Lab B251. The GrayWolf sensor was used for taking the air quality measurement readings. During the test the equipment was placed inside the lab and the lab is tested without considering any special conditions. Most of the time door is closed. During the experiment, observational notes were taken to note down the surrounding conditions of the test. The experimental results can be seen from the Fig 5.17

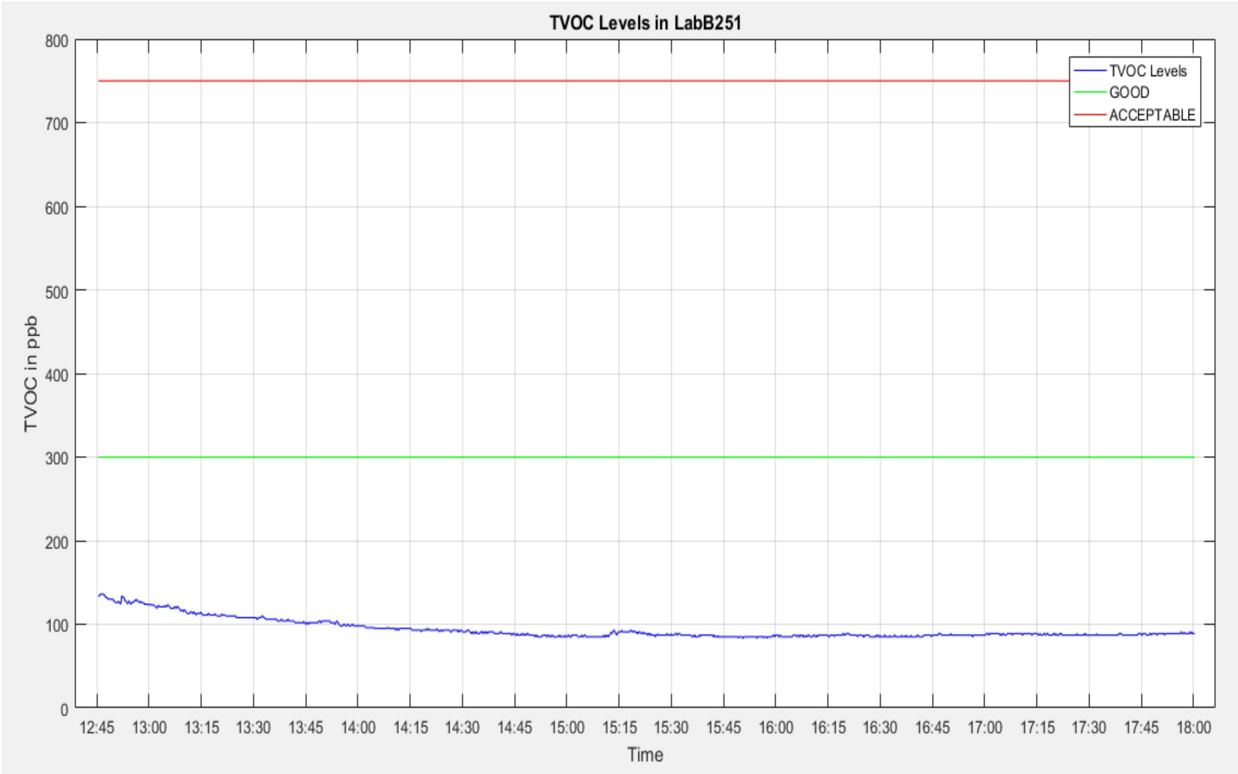



Fig 5.17 TVOC test in Lab B251

5.1.18 Test 18

This is a test performed at the Recreational Center (REC) to see the concentration levels of TVOC inside the REC. Since this is a place where people come to work out, having good air quality is very important in such places. During the test the equipment is placed inside the building. No special conditions were considered during the measurement. GrayWolf sensor is used for the measurement. Observation notes were taken to note the test surroundings. The experimental results can be seen in the Fig 5.18.

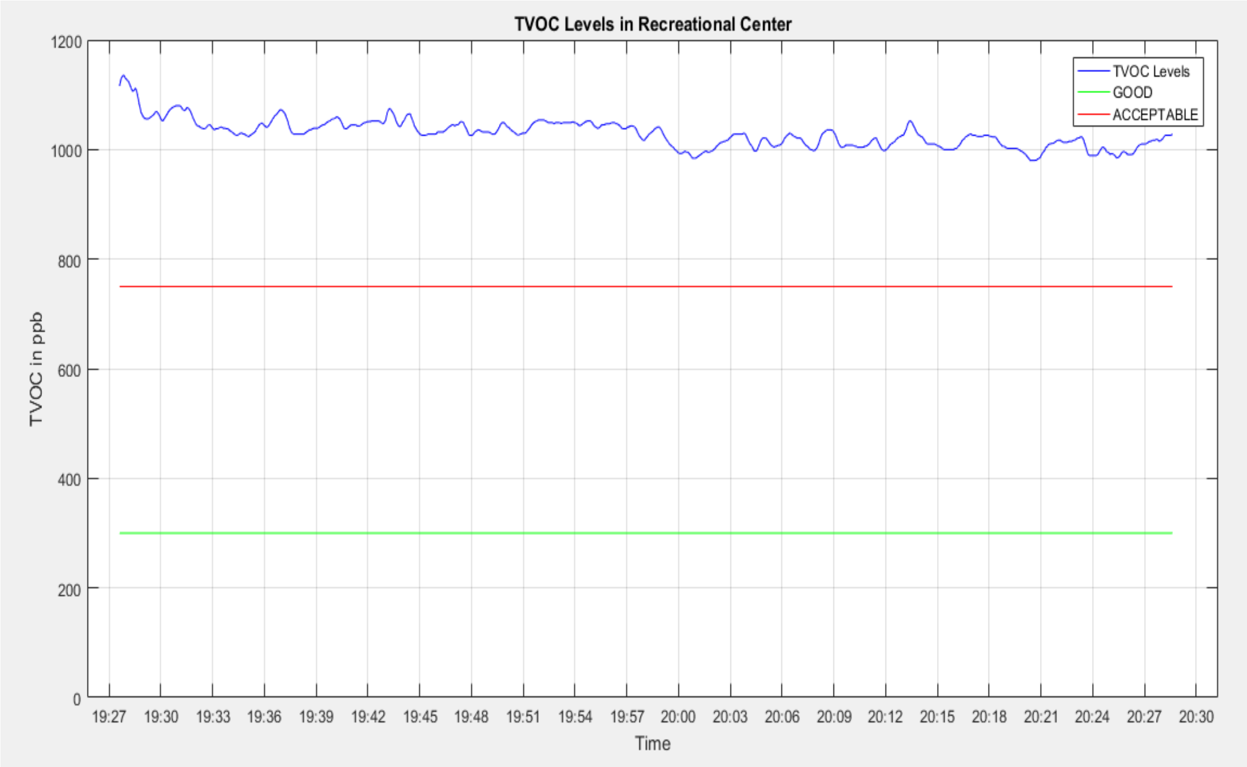



Fig 5.18 TVOC test in REC

5.1.19 Test 19

This is the test done at home in the living room to test the TVOC levels inside. The GrayWolf sensor is used to find the measurements during the test. The equipment is placed inside and no special conditions were considered during the test. Most of the time windows and doors were closed and the room is air conditioned. Observation notes were taken during the test. The experimental results can be seen from the Fig 5.19.

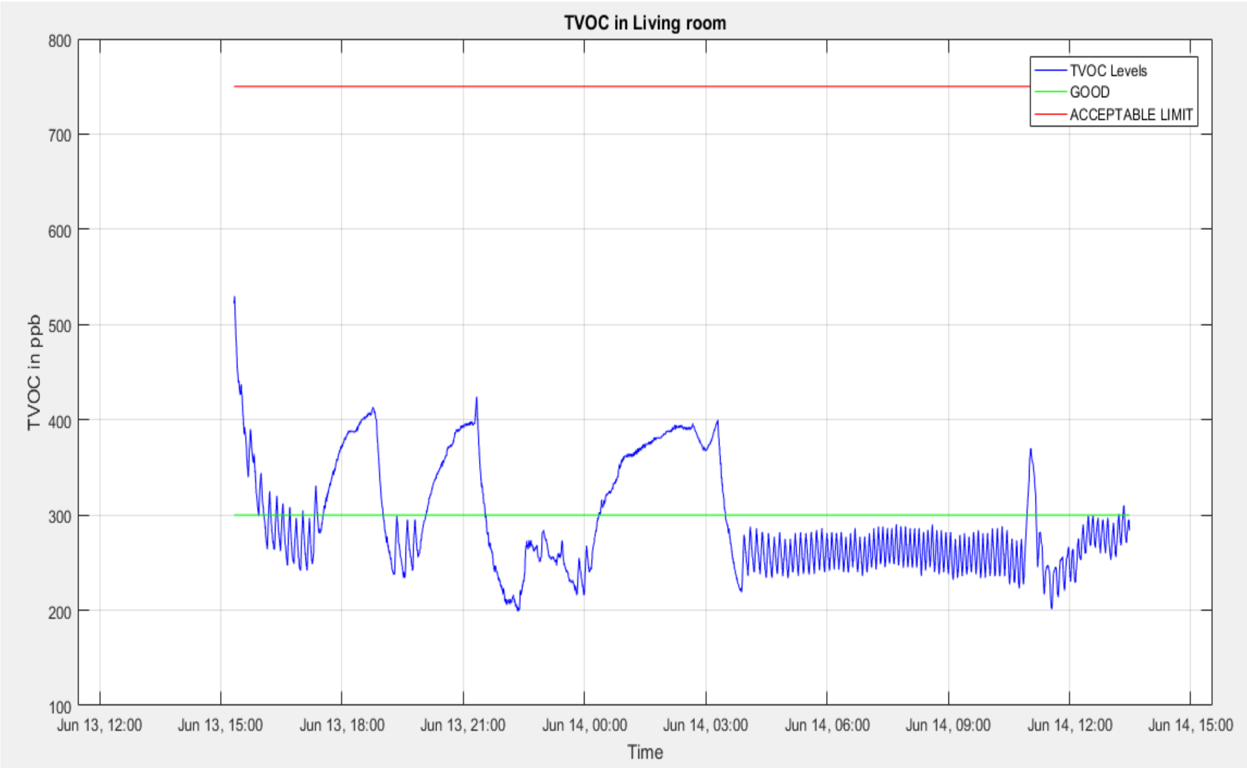



Fig 5.19 TVOC test in Living room

5.1.20 Test 20

This is the test to measure the temperature levels inside the REC. The GrayWolf sensor was used to take the measurements. During the test the equipment is placed inside the building and there were no special conditions considered during the test. Observational notes were taken during the test. The experimental results can be seen from the Fig 5.20.

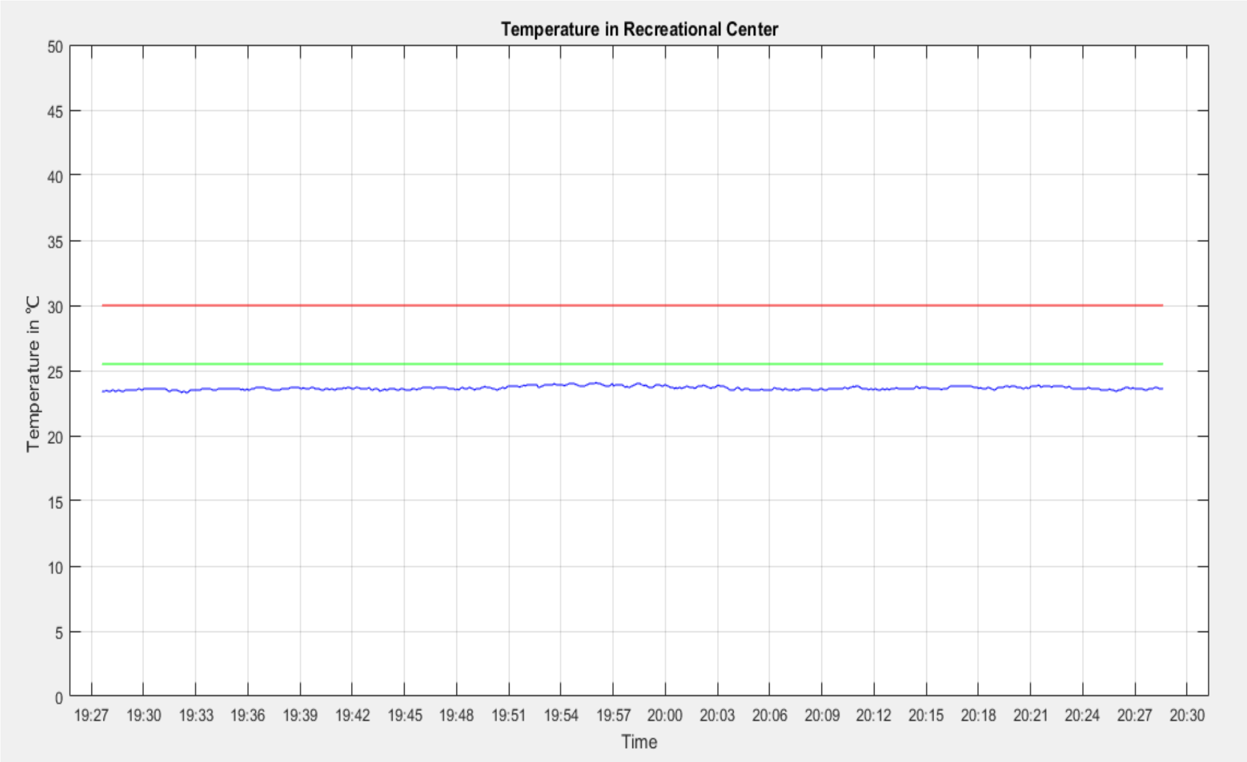



Fig 5.20 Temperature test in REC

5.1.21 Test 21

Temperature test was conducted inside the UNT shuttle using the GrayWolf sensor. During the test equipment was placed inside the bus. There were around 12 people inside the bus during the test and the bus is air conditioned. During the test no special conditions were considered, the bus is functioning on its regular routine so the people kept changing from time to time. Observation notes were taken during the time of the test. The experimental results can be seen in the Fig 5.21.

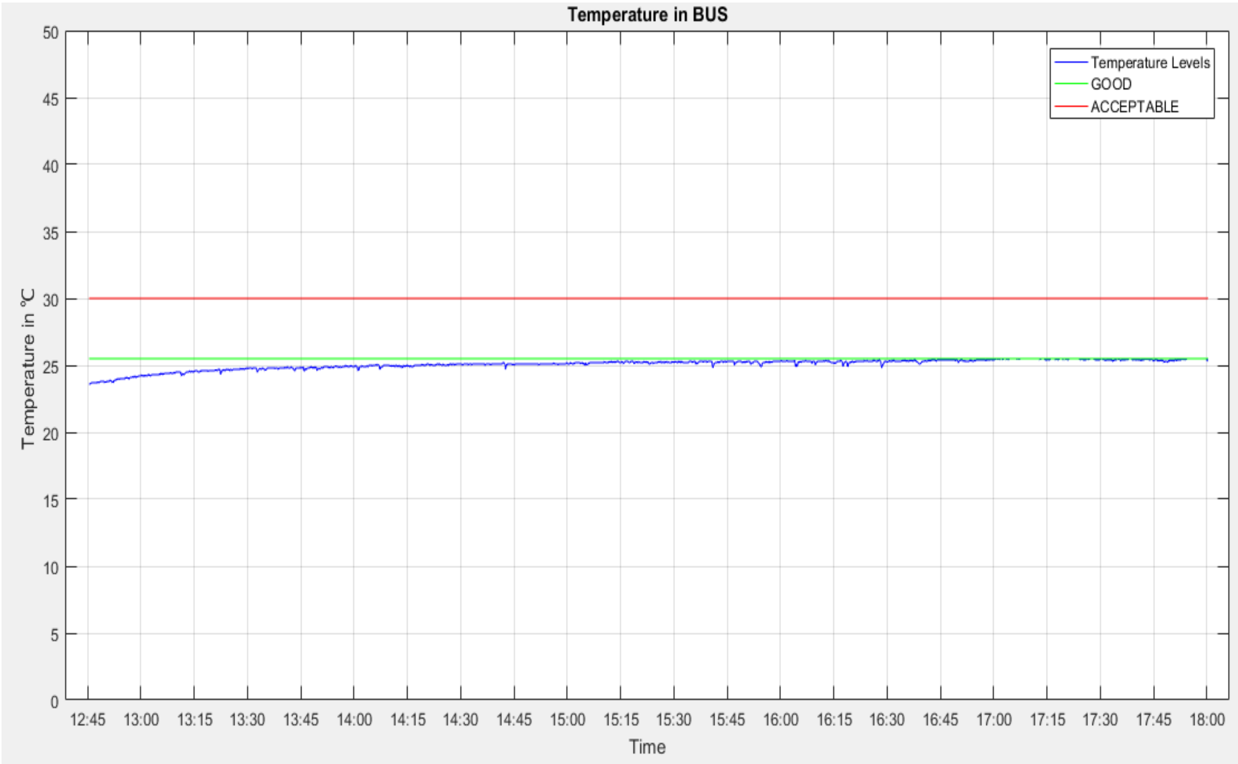



Fig 5.21 Temperature test in UNT shuttle

5.1.22 Test 22

This test is to observe the temperature levels at home. The GrayWolf sensor is used for measurement, During the test the equipment was placed inside the living room and the readings were taken. During the test most of the time doors and windows are closed and no special conditions were considered. Observation notes were taken during the test. The experimental results were shown in the Fig 5.22.

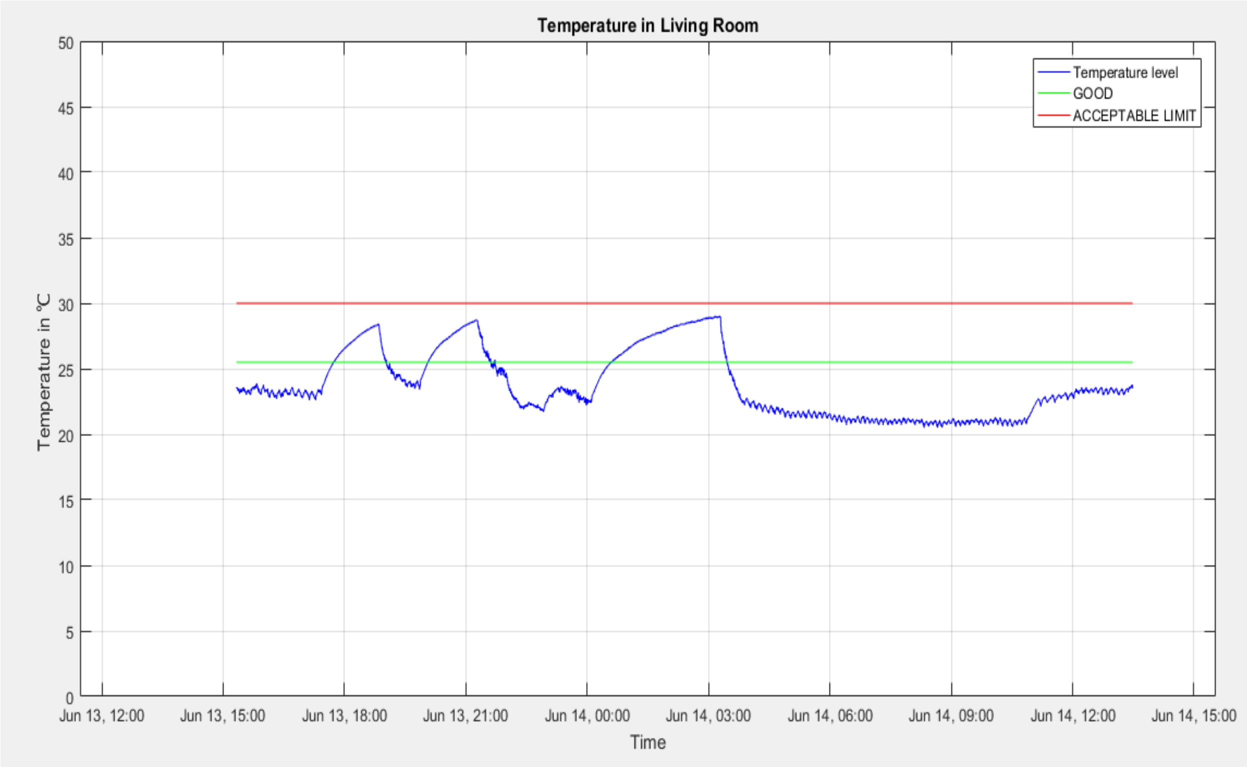



Fig 5.22 Temperature test in Living room

5.1.23 Test 23

This test was done to measure the temperature levels in the lab B251. GrayWolf sensor is used for the readings. During the test the equipment was placed inside the lab and the door was closed most of the time. No special conditions were considered during the test. Observation notes were taken during the test. The experimental results can be seen from the following Fig 5.23.

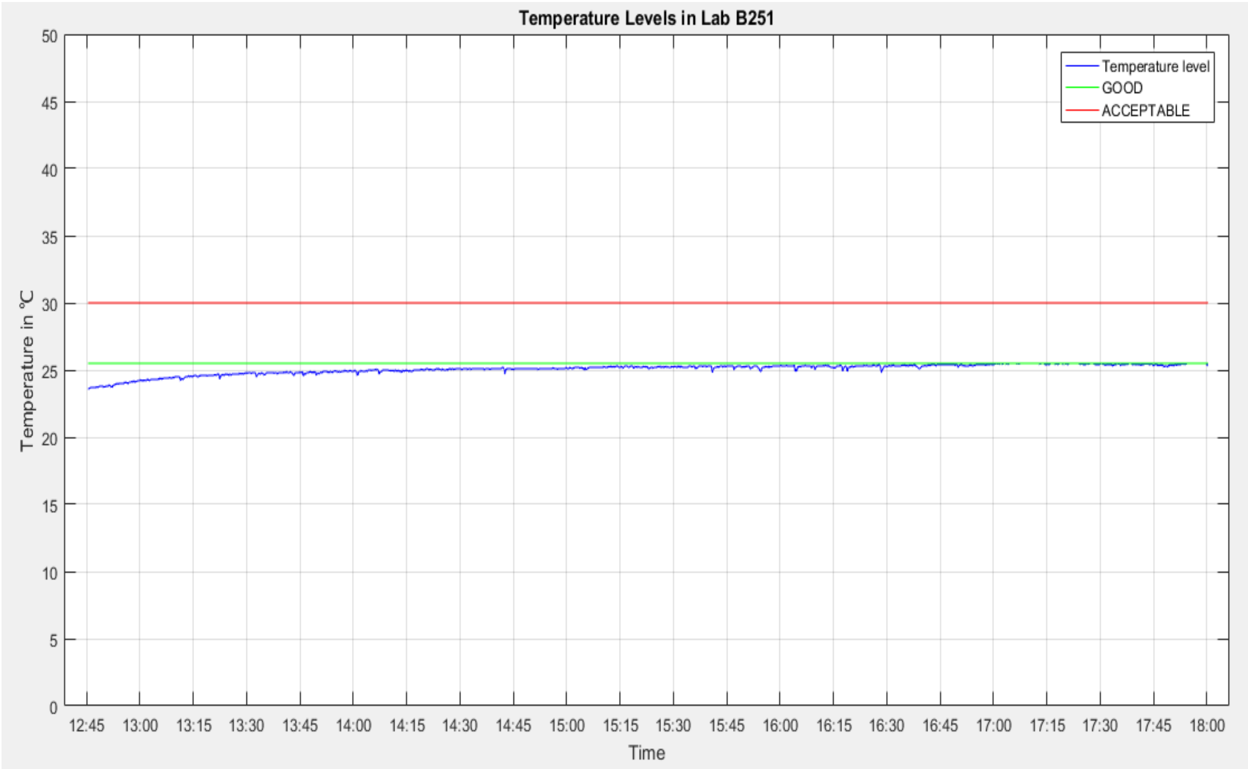



Fig 5.23 Temperature test in Lab B251

5.1.24 Test 24

This test to test the Carbon Monoxide (CO) levels inside the UNT shuttle. GrayWolf sensor is used for taking the measurements. During the test the equipment is placed inside the bus and no special conditions were considered during the time of the test, the bus was on its regular daily routine. No passengers inside the bus were kept changing. Observation notes were taken during the time of the test. The experimental results can be seen from the following Fig 5.24.

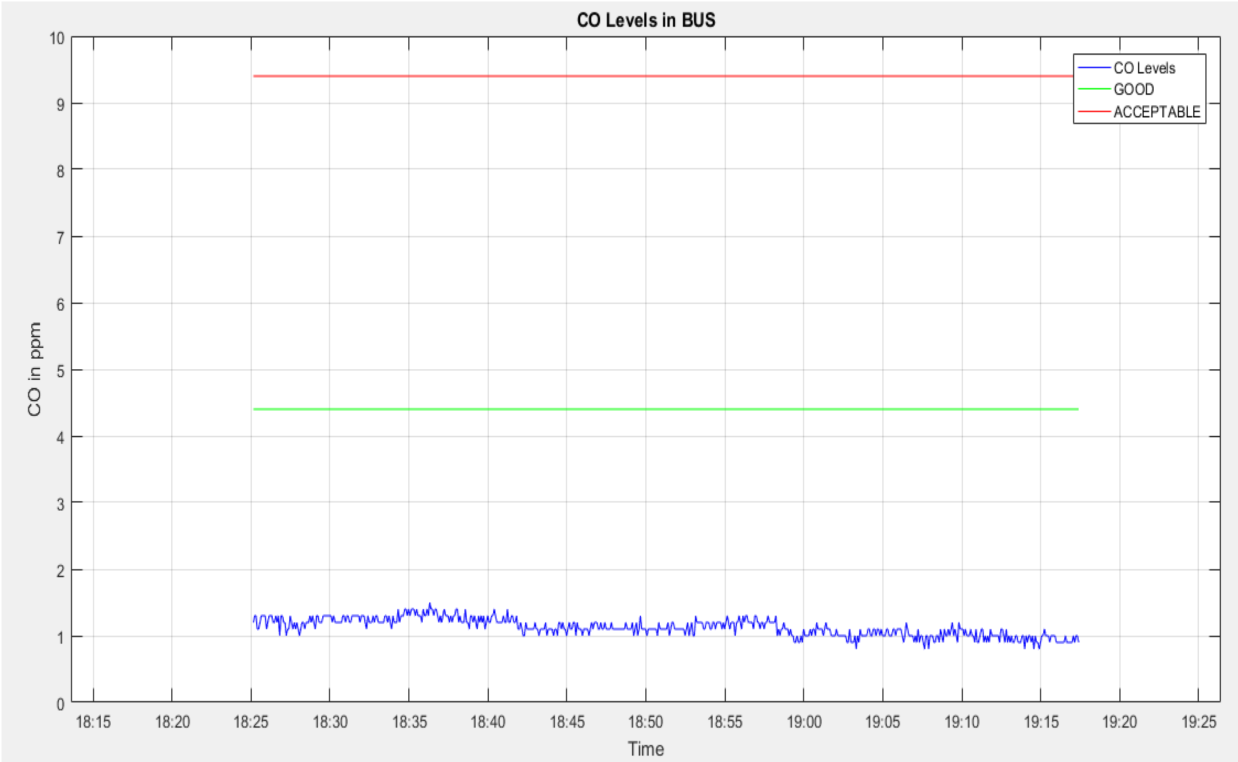



Fig 5.24 CO test in UNT Shuttle

5.1.25 Test 25

This is the test to measure the CO levels in the living room of an apartment. The GrayWolf sensor was used to take the measurements. During the test the equipment was placed inside the living room. There were no special conditions considered during the test. Although an observational note has been taken to note the surroundings during the test. The test result can be seen in Fig 5.25.

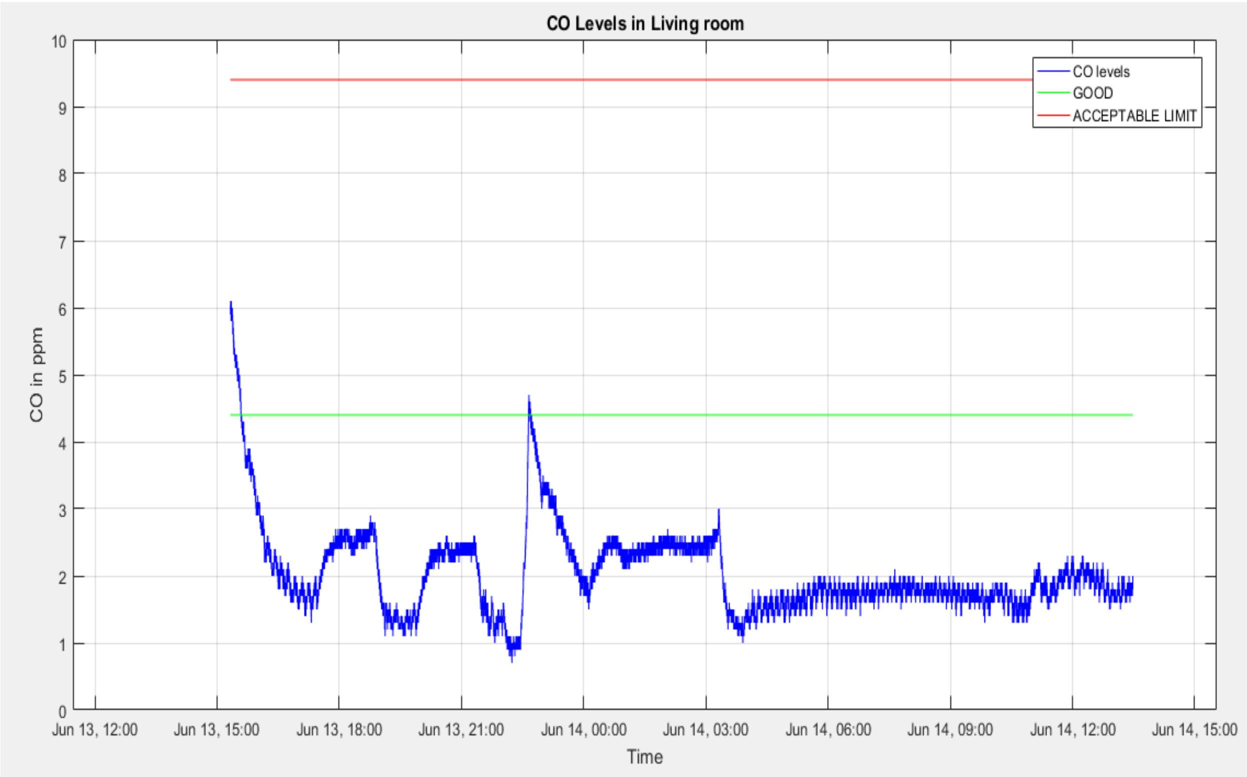



Fig 5.25 CO test in the Living Room

5.1.26 Test 26

This test was taken to measure the CO levels in the Lab B251, Electrical Engineering Department, UNT. The GrayWolf sensor was used to measure the readings. During the test the equipment was placed inside the lab. No special conditions were considered during the time of teat. However, observational notes were taken during the time of test to note down the surrounding conditions. The experimental results can be seen from the Fig 5.26.

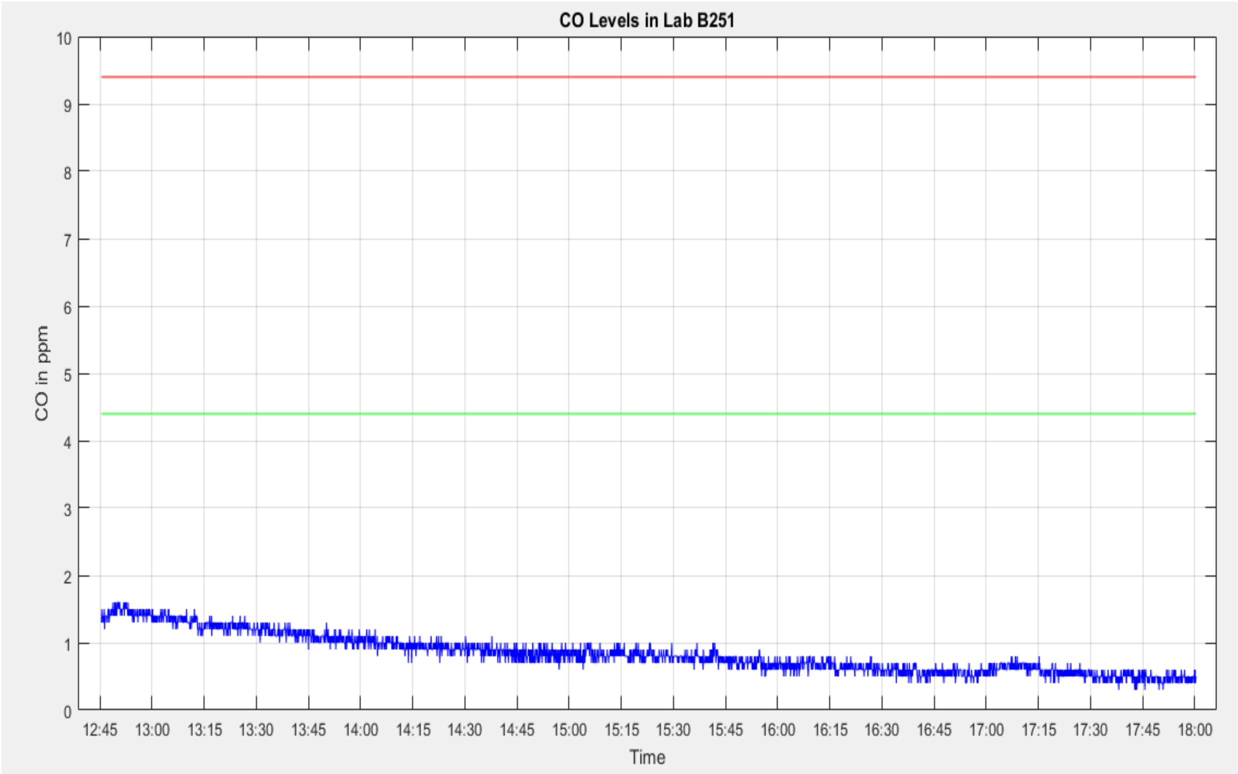



Fig 5.26 CO levels in Lab B251

5.1.27 Test 27

This is the test performance in the REC to measure the levels of CO inside its building. The GrayWolf sensor was used to measure the air quality. Equipment was placed inside the building and there were no special measures or conditions considered during the time of the test. Observation notes were taken during the test. The experimental results from the test performed can be seen from the following Fig 5.27.

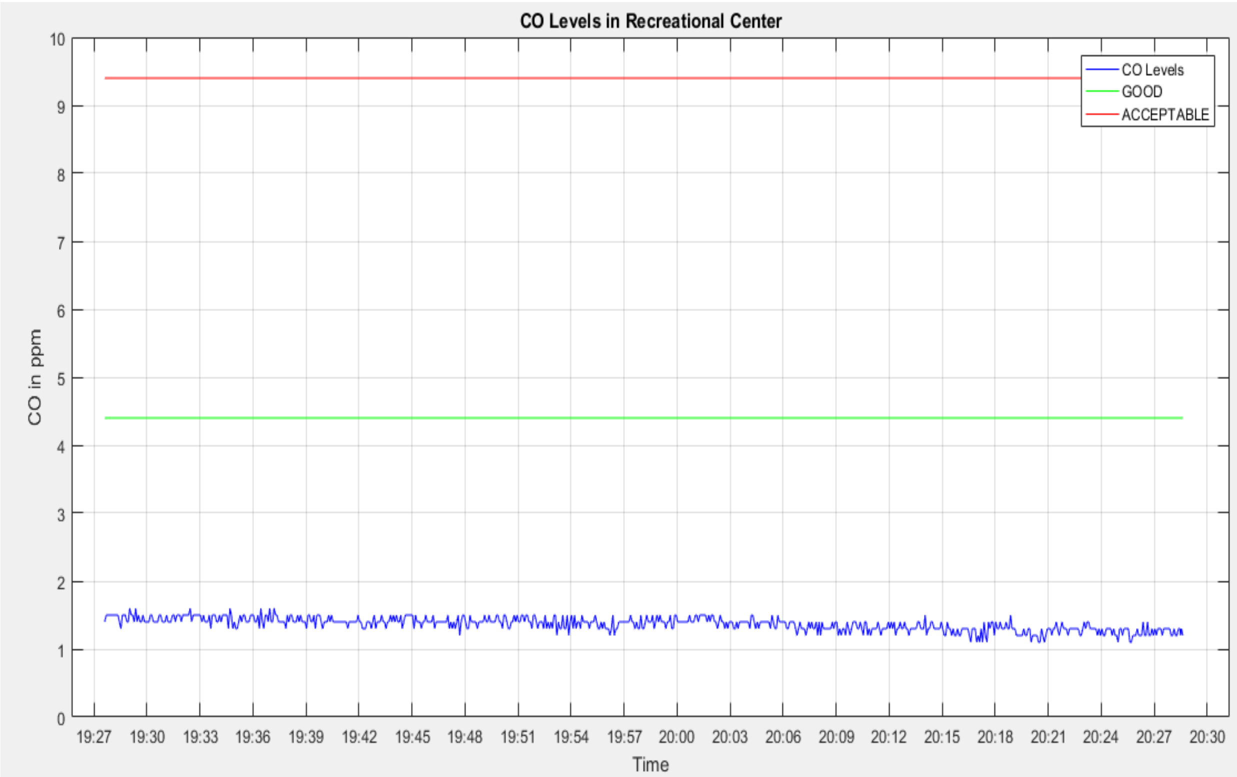



Fig 5.27 CO test in REC

5.1.28 Test 28

This test is done in the lab B251 with 1 person inside and the door is closed all the time. This test is done to observe how a plant would affect the air quality inside the lab. Initially the GrayWolf sensor is placed in the lab and the readings were taken without a plant placed inside. Once the readings got stabilized later a plant is placed inside the lab and the door is still closed and the readings are taken till the readings are again stabilized. Next another plant is placed along with an existing plant, so the readings are taken again with two plants inside. The readings were continued till the readings got stabilized. The values are noted at each stage of the test. From the observations analyzed from the readings the resulting changes were explained in the following Table 5.1. The two plants used are of same kind and in order to have an idea of the plant size one of the plant can be seen in the Fig 5.28.

Table 5.1 Plant test in the lab

| Parameter | Originally | 1 plant inside | 2 plants inside |
|---|---|---|---|
| TVOC | 455ppb | 468ppb | 463ppb |
| CO2 | 578ppm | 548ppm | 524ppm |
| O3 | 0.03ppm | 0.03ppm | 0.04ppm |
| C0 | 1.2ppm | 1.0ppm | 0.8ppm |
| TEMPERATURE | 25.3c | 25.4c | 25.4c |
| REL HUMIDITY | 57.9% | 57.4% | 57.4% |


Fig 5.28 Plant used for the Test 28

As you can see from the Table 5.1, the $CO_2$ level dropped from 578 ppm to 548 ppm, which is a 5.1% decrease in the carbon dioxide level when a plant is placed inside. When two plants were placed inside the lab the $CO_2$ levels dropped from 578 ppm to 524 ppm, which shows a 9.3% decrease in the $CO_2$ level.

5.2 Analysis

All the tests were analyzed by plotting the graphs using Matlab. The detailed explanation how the Matlab is used in the thesis is discussed in Chapter 4. The comparison of indoor and outdoor air quality is done in several tests. The results prove that indoor air is more polluted than outdoor air. From Test 1, the bedroom air quality is tested for short as well as long hours. When the $CO_2$ levels are too high it means that the room is poorly ventilated. The readings taken in the bedroom when the door is opened indicated that as it ventilated compared to a closed room the $CO_2$ levels are decreased. Having high $CO_2$ levels causes breathing difficulties as well as cough and headache. The next test 2, test 3 is done with the bedroom door closed but having a plant inside and compared it with the bedroom with no plant. The results show the levels of $CO_2$ is decreased in the presence of plants. Having good ventilation is must to maintain good air quality. The next measure to maintain air quality can be having plants inside a room.

The test 4 is a ventilation test, since the $CO_2$ levels are high during the time of test the door is opened and for a while and then closed. From the test results we can see the $CO_2$ levels dropped due to the ventilation or the exchange of air flow between indoor and outdoor. So it can be advised to open the doors or windows once in a while at home to maintain good air quality at home.

The test 5, test 6 and test 7 are to observe the air quality in the living room of the apartment and at the same time observe the outdoor air quality during the time spent in the living room. Finally, compare the indoor and outdoor air quality. From the test results shown in the test 7, outside air quality is good compared to indoor air quality. This tells us spending more time indoors is not considered as a good habit. Coming out once in a while to get fresh air is suggested.

The test 8 is to observe the air quality in Lab B251, From the test results the air quality is good in the lab and it is efficiently ventilated. Test 9 is done to observe the $CO_2$ levels in the classroom. Initially the $CO_2$ levels were good but as the students gathered the classroom is packed and the ventilation is decreased, so the $CO_2$ levels were increased. Once the class gets over, the students left the classroom and gradually the $CO_2$ levels decreased. There is a need of a ventilation system which automatically maintain the air quality, so the students do not feel drowsy with high $CO_2$ levels and can maintain good health.

The test 10 is to observe the $CO_2$ levels in the library, from the results it can be observed that the library has poor ventilation. Test 11 is to observe the air quality in recreational center, where most of the people come to work out. From the test results, though the $CO_2$ levels are within the limits of indoor air quality but compared to outdoor the indoor work out is not preferable, since the outdoor air quality is more good when compared to indoor. Test 12 is to test the air quality inside the bus, from the results the air quality is considered to be within the acceptable limits. So UNT shuttle does maintain good ventilation system.

Test 13 is to test ozone levels in the atmosphere using the outdoor air quality measurement system designed using AirNow. From the test results it can be said that the ozone levels are good. Test 14 is also to test the ozone levels but in a different location that is in the park at Discovery Park. The readings are taken outside so both the GrayWolf and outdoor air quality measurement system are used to measure the ozone levels. The test result shows the comparison graph of both the measurements. The ozone levels varied a lot in the park when measured by GrayWolf but the local ozone levels data which were received from the AirNow has not changed, the overall ozone level remained good. This shows that the local air quality web services in this case were not good enough to provide the air quality information to the public in the areas experiencing a bad air quality compared to the other areas in that region.

Test 15 is a TVOC test done in the living room. It is to test the effect of cleaning detergents when used. This can be harmful to the infants at home. The results from this test does show a significant increase in the TVOC levels when a cleaning detergent is used for cleaning. It takes a minimum of half an hour to settle down its levels. Test 16,17,18,19 were also TVOC test done without considering any special conditions to study the TVOC levels in different places that we encounter daily like on UNT shuttle, Lab B251, REC, Living room at home. From these tests we can observe that TVOC levels at all the places are in acceptable limits but the TVOC levels at REC are not in acceptable limit which is an important thing to notice. Since having high levels of TVOC is not good for health. People go REC to work out and improve their health.

Test 20, 21, 22, 23 were done to observe the temperature levels in the real time places that we encounter daily. From these experimental results obtained it can be said that the temperature levels at all the places are maintained and are within the acceptable limits.

Test 24 ,25 ,26 ,27were performed to observe the CO levels in real time situations. Generally, CO levels are effected when there is minor or major gas leakage or during any fire accidents etc. At normal circumstances it can be observed from the experimental results that the CO levels are within the acceptable limits and are maintained.

Final test 28 is to observe how the plants can help in maintaining the air quality. From the test results it can be seen that having plants indoor will certainly improve the air quality.

With the help of the Outdoor air quality measurement system that is designed for the thesis. All the data that is collected was able to be stored in the database and the graph module is useful to analyze the data from the database. The daily changes in the AQI levels for a few days was being analyzed using the Graph module of the outdoor air quality measurement system which can be seen in the Fig 5.29. But using this we can actually analyze the air quality data for different areas for longer periods of time.

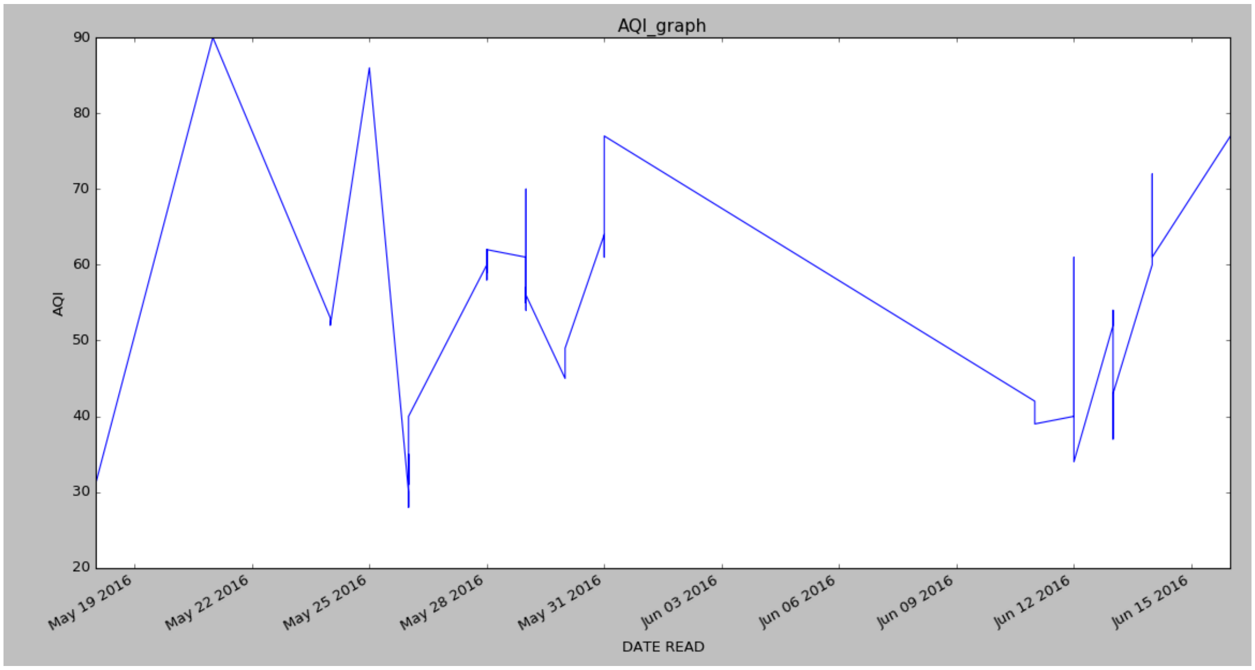



Fig 5.29 AQI graph

# CHAPTER 6

# CONCLUSION AND FUTURE WORK

An outdoor air quality measurement system which can retrieve and manage the data of overall air quality index of outdoor, ozone, particulate matter, temperature and humidity has been designed by creating a graphical user interface. A database is created in the system to store all the retrieved data as well as a graphical user interface of plotting module is created in the system where users can graphically analyze the data from database easily. Subsequently the data collected in the database will be available and used for future analysis. Several comparison graphs are made and the data analysis is done to study the air quality in real time cases. This study will help to interpret the importance of air quality better.

Since the developed system has the flexibility to measure the air quality data from any location in US as well as in some parts of Mexico and Canada, an app can be developed so user can have the air quality information. Moreover, the designed system has an ability to store all the data collected in the database on the daily basis, this data will be useful in the future to analyze. So all the features like display of air quality information and databases as well as a real time graphical display of the air quality data can be the app features.

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