"Development & Demonstration of Air Filtration Unit for Removing PM, VOC & NOx"

Mumbai Metropolitan Region – Environment Improvement Society (MMR-EIS)

Report Prepared By

Environment Policy and Research India

9B, 1st Floor, Ramanand Premises, Naupada, Gokhale Road,
Opp. Mango Showroom, Thane (W) – 400601, Maharashtra
Phone: 022 - 25450210
Email: manager@eprindia.com;
Website: www.eprindia.com

Compliance of 93rd Minutes of Meeting

With respect to the 93rd meeting held on 21st June 2019, the Sub-Committee of MMREIS has given us the following points for submission in detail reply. The points are depicted as under:

1) Proponent should measure ambient air quality at the inlet of the filtration unitat different locations.
2) The proponent should show how their prototype is different from Kent & Honeywell indoor filters.
3) Workout the capacity of the unit in terms of the area and the volume of air and cost versus effectiveness of the unit.

An executive point wise summary of the abovementioned points is summarised below:

1) Proponent should measure ambient air quality at the inlet of the filtration unit at different locations.

Reply: As per the recommendation of the Technical committee, the monitoring of pollutants was done at varied distances (viz. 3 mt, 10 mt and 15 mt) and the inlet and outlet concentration was measured accordingly. The results are given in the table below for Particulate Matter:

Table 1.1: Concentration of pollutants against distance with switching on and off the instrument (in ug/m3)

Pollutants	Inlet		Outlet		3 m		10 m		15 m	
	On	Off	On	Off	On	Off	On	Off	On	Off
PM1.0	175	182	10	176	19	157	20	152	19	162
PM2.5	236	239	12	224	24	201	35	187	42	211
PM10.0	252	249	15	255	30	216	41	209	48	247
Total VOC	362	362	60	362	52	320	31	241	20	180
NOx	73	73	14	73	13	68	11	57	7	51

From the above table, it can be seen that the prototype can combat about 96% of PM 10, 92% of PM 2.5 and about 88% of PM 1. The prototype is able to combat about 81% to 85% of Volatile Organic Compounds. The prototype is able to combat about 81% to 83% of NOx.

2) The proponent should show how their prototype is different from Kent & Honeywell indoor filters.

Reply: As suggested by the Technical Committee Members, a comparative table of the prototype with Kent & Honeywell Indoor filtration unit is shown below **Table 1.7**:

Table 1.7: Comparative statement of prototype with market available indoor units

Specifications	Kent Alps Air Purifier	Honeywell Lite Indoor Air Purifier	EPRI developed Air Filtration Unit
Model number	15004	HAC20M1000W	--
Price	21,990	19,990	2,00,000
Filter type	HEPA	Pre filter/HEPA/ Activated carbon	Primary Filter HEPA Filter
Specific Technology	Suction based with filtration	Suction based with filtration	TiO_2 coated Sheet UV lamp Technology is based on Photo-catalytic.
Pollutant coverage	Dust mites, mould spores, PM	Large dust particles, bacteria,PM	Dust, PM, NOx& VOC
Coverage area	Upto 42sqmt	Upto23sqmt	Up to 15 mt distance
Material	--	ABS Material	Stainless Steel
Noise level (db)	54 db	49.5db	55db
Usage	Indoor	Indoor	Indoor cum Outdoor

3) Workout the capacity of the unit in terms of the area and the volume of air and cost versus effectiveness of the unit.

Reply: The efficiency details of the prototype are classified into the following aspects. Detailed elucidation is given for each aspect.

a) Scope of filtration unit in terms of usage
b) Pollutants that the Unit can eliminate
c) Efficiency of filtration units
d) Area coverage
e) Cost of the Unit

a) Efficiencyof filtration units:

It can be seen from Chapter 4-Results & Interpretation that the efficiency rate using the prototype is highest for PM which is around 95%, for VOC it ranges from 80% to 85% and NOx elimination efficiency is around 82%. The other market available units, gives an efficiency rate only for dust/ particulate matter which is specifically an indoor pollutant.

b) Area coverage:

The Kent Alps Air Purifier is able to cover an area of 42 sqmt while the Honeywell Lite Indoor Air Purifier covers an area of 23 sqmt. EPRI developed prototype covers an area of about 500 to700 sqmt. with 90% efficiency for PM, 80-60% for VOC &NOx. In addition, the prototype can be installed at any place, no need to mount it at a specific place. Even if it is installed at the distance away from the source, the pollutants can be eliminated efficiently.

c) Cost of the Unit:

The unit comprises of axial fan, primary filter, HEPA filter, $TiO_2$and$CaCO_3$ coated aluminium sheetalongwith UV Lamps. The axial fan is used basically forair fed into the system through the inlet; both the filters would combat PM of different microns. The next stage helps to filter out the VOC and NOx from the polluted air. The unit fundamentally works on the Photo catalytic technology. All these features gears up the cost of the prototype. Whereas, the market available filtration units basically have filters and or activated Carbon; which helps to eradicate only dust and PM. Therefore, the cost of the prototype is bit higher, however, if compared to the other features which are not available in present units makes the prototype worth it in terms of efficiency rate, area coverage and usage patter.

Moreover, the O&M cost of the Unit is also much less, the pre filter only needs to be changed if chocked up. As the HEPA filter is placed after the pre filter, the load of the dust/PM is taken by the Pre filter and hence replacement of pre filter is must after a year or depending on the usage pattern of the prototype. The Operation & Maintenance cost is estimated for the Unit, which is given in **Table 1.8**.

Table 1.8: Estimated O&M Cost of the Prototype

Sr. No.	Particulars	Cost (INR)
1	Capital Cost of the Unit	2,00,000
	Estimated O&M Cost for the Unit	
2	Cleaning of Pre-filter	500
3	Replacement of Pre-filter	1,000
4	UV light replacement	2,500
5	**Total O&M Cost**	**4,000**

As explicated above, the cost verses effectiveness of the Unit is represented as under:

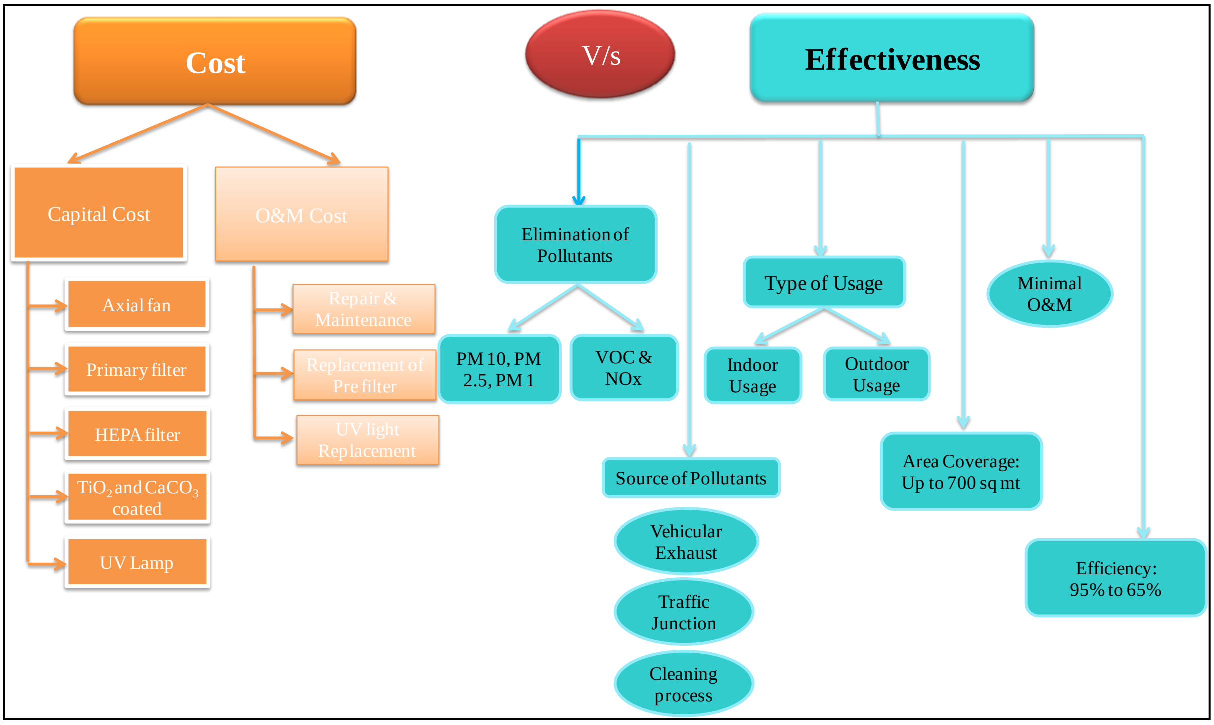


Figure 1.1: Cost versus Effectiveness of the Prototype

Compliance of Minutes of Meeting

With respect to the 92nd meeting held on 27th February 2019, the Sub-Committee of MMREIS has given us the following points for submission in detail reply. The points are depicted as under:

1) The outcome of the Unit
2) Proponent should compare the unit design with NEERI unit and do a comparative study
3) Practical utility should be shown for the design and clarify the efficiency
4) How the prototype is superior as compared to the other units in the market.

The Report states the details of all the points raised in the minutes. An executive point wise summary of the abovementioned points is summarised below:

1) The outcome of the Unit

The unit's outcome at different distance is calculated and the efficiency of the same is depicted as under:

Table 1: Efficiency of the Filtration unit for pollutant removal at varied distance of Petrol Pump (Unit in $\mu g/m^3$)

Average Concentration of Pollutants	Inlet Concentration	Outlet Concentration	Concentration at 3 mt	Concentration at 10 mt	Concentration at 15 mt
PM 10	229	15	25	60	64
PM2.5	130	12	17	39	50
PM 1	99	10	14	37	49
Methanol	83	10	13	24	29
Benzene	46	7	9	9	13
Toluene	69	11	15	16	23
Xylene mixed	43	8	10	10	14
Ethanol	75	13	17	22	28
TVOC	354	49	73	90	114
NOx (ppb)	73	14	19	23	28

Table 2: Efficiency of the Filtration unit for pollutant removal at varied distance in Basement (Unit in $\mu g/m^3$)

Pollutant	Inlet Concentration	Outlet Concentration	Concentration at 3 mt	Concentration at 10 mt	Concentration at 15 mt
PM 10	719	22	42	63	88
PM 2.5	294	46	53	66	85
PM 1	109	19	24	30	39
NOx (ppb)	71	6	11	14	22
Methanol	85	5	12	22	32
Benzene	39	5	8	13	15
Toluene	64	14	20	23	25
Xylene mixed	40	7	12	15	17
Ethanol	74	14	20	24	27
TVOC	325	59	74	86	105

From the above table no. 1 for petrol pump, the concentration of the particulate matter is 229 $\mu g/m^3$, 130 $\mu g/m^3$ and 99$\mu g/m^3$ For PM 10, PM 2.5 and PM 1 respectively. However it seen that the filtration unit filters the pollutants and the outlet concentration ranges from 15 $\mu g/m^3$, 12$\mu g/m^3$ and 10$\mu g/m^3$ respectively, where as the concentration taken at a distance of 3 mt again increases to 25$\mu g/m^3$, 17$\mu g/m^3$ and 14$\mu g/m^3$ and so on. However, the unit is successful to handle the pollutants up to 15 mt of distance. Similarly, the VOC concentration, for example, the inlet concentration for Methane is 83$\mu g/m^3$ whereas the filtration unit decreases the pollutant concentration to about 10$\mu g/m^3$, 13$\mu g/m^3$, 24$\mu g/m^3$, 29$\mu g/m^3$, at outlet concentration, 3 mt distance, 10 mt distance and 15 mt distances respectively.

Correspondingly, for Basement site, the concentration of particulate matter especially PM 10 is at higher level. The filtration unit is successful to decrease the concentration of PM 10 from 719$\mu g/m^3$ to 22$\mu g/m^3$, 42$\mu g/m^3$, 63$\mu g/m^3$ and 88$\mu g/m^3$. The results are monitored at the inlet of the filtration unit, outlet of the unit, at 3 mt distance, 10 mt distance and 15 mt distances respectively. It is observed that the unit is helpful to filter out the pollutants right at its outlet to up to 15mt of distance irrespective of the site.

2) Proponent should compare the unit design with NEERI unit and do a comparative study

WAAYU (Wind Augmentation PurifYing Unit):

NEERI and IIT (Bombay), has designed a filtration unit which helps to combat PM2.5 and PM10 particles, carbon monoxide and volatile organic compounds into carbon dioxide. Its prototype has capacity to purify air in area of 500 meter square. It consumes only half unit of electricity for 10 hours of running and has maintenance cost of Rs. 1500/-.

WAAYU technology is based on 'Thermal oxidation' technique. The device works on two principles mainly wind generation for dilution of air pollutants and active pollutants removal. It has filters for particulate matter (PM) removal and activated carbon (charcoal) and UV lamps for poisonous gases removal such as Volatile organic compounds (VOCs) and Carbon Monoxide.

EPRI developed Air Filtration Unit:

EPRI developed filtration unit which is able to combat Dust (PM), VOC, NOx removal. The unit is based on 'photo-catalytic' technology. The unit operates in 3 stages: The first stage, wherein air is fed into the system through the inlet with the help of an axial fan and is filtered from the pre filter and HEPA filter to remove the Particulate Matter. The second stage includes the Photo catalytic reaction in presence of TiO_2. The photo-catalysis is a process of acceleration of a photoreaction in the presence of a catalysed photolysis. Titanium dioxide is an excellent photo catalyst with high chemical stability when exposed to acidic and basic compounds. In the third stage the $CaCO_3$ coated aluminium sheet helps to neutralize the by-products of the preceding chemical reactions. The following are the oxidation reactions that take place:

i. Photo catalytic oxidation of hydrocarbons

$$HC + {}^{\cdot}OH^{-} \rightarrow CO_2 + H_2O$$

ii. Photo catalytic oxidation of NO_x: This involves a series of oxidation step

$$NO + {}^{\cdot}OH^{-} \rightarrow HNO_2 \xrightarrow{{}^{\cdot}OH^{-}} NO_2 \xrightarrow{{}^{\cdot}OH^{-}} HNO_3$$

iii. As a result NO_x gets ultimately converted to HNO_2 or HNO_3. To trap it within the filter unit, a $CaCO_3$ deposited pad will be kept beneath every cylindrical unit, such that the produced HNO_3/HNO_2 will react with $CaCO_3$ and form

$$HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$$

3) Practical utility should be shown for the design and clarify the efficiency

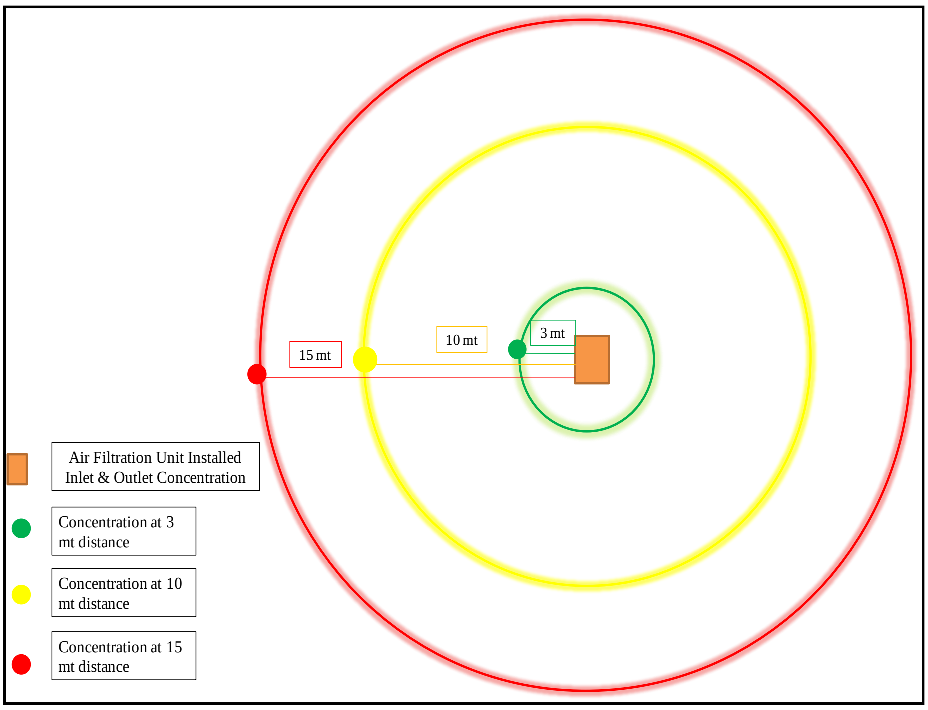
The filtration unit developed by EPRI is applied for ambient air filtration as well as for Basement air filtration. It is observed that the result ranges from 60% to 90%. The design and applied technology is already elucidated in the above point. Further, Chapter 3 and Chapter 5 deals with detailed design and technique used for the filtration Unit.

The unit's efficiency is calculated by taking the pollutant concentration from the Inlet of the Unit and outlet of the Unit. Further, reading is taken from a distance of 3 mt away from the Unit, similarly at a distance of 10 mt and 15 mt away from the unit.

Therefore we had four readings/concentration as under:

a) Inlet concentration of pollutants at the prototype
b) Outlet concentration of pollutants from the prototype
c) Concentration of pollutants at a distance of 3 mt from the prototype
d) Concentration of pollutants at a distance of 10 mt from the prototype
e) Concentration of pollutants at a distance of 15 mt from the prototype

The unit was installed at Petrol pump site and in Basement too with the above mentioned distances and concentration of the pollutants were monitored. Efficiency was calculated by subtracting the inlet concentration of the Unit and then the concentration of the pollutant taken at varied distances. It is seen that as the distance of checking the



concentration increases from the filtration unit, the pollutant concentration too increases. Table 3 and 4 above shows the concentration of the filtration Unit and the percentage efficiency of the same is given in table 3 and 4 with graphs in Figure 1 and 2.

Table 3: Efficiency of the Filtration unit for pollutant removal at varied distance of Petrol Pump

Distance		At Prototype	Distance		
			3 mt	**10 mt**	**15 mt**
Area covered (sq mt)		NA	28.3	314.0	706.5
Percentage Efficiency of the Air filtration unit (%)	**PM 10**	93	88	70	64
	PM 2.5	91	86	69	61
	PM 1	89	85	71	61
	Methanol	88	84	72	61
	Benzene	85	81	80	73
	Toluene	84	79	75	63
	Xylene	82	77	73	60
	Ethanol	82	78	70	59
	TVOC	86	80	73	63
	NOx	81	73	67	60

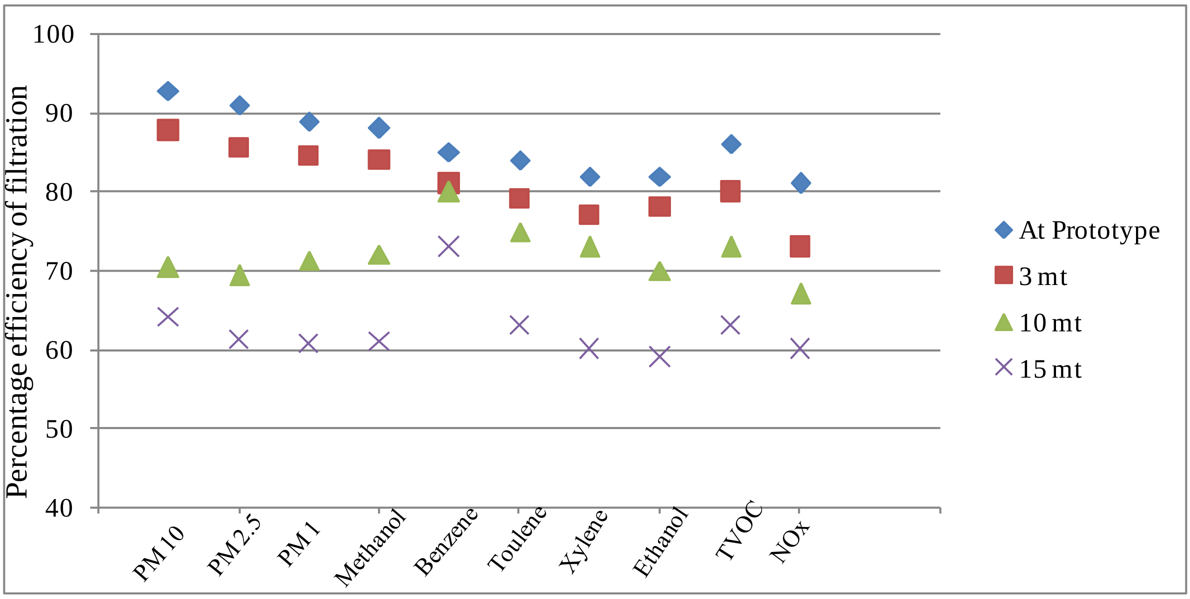


Figure 1: Comparative graph showing the percentage efficiency of the Filtration Unit at varied distance on Petrol Pump site

Table 4: Efficiency of the Filtration unit for pollutant removal at varied distance of Basement

Distance / Pollutants		At Prototype	Distance		
			3 mt	10 mt	15 mt
Area covered (sqmt)		NA	28.3	314.0	706.5
Percentage Efficiency of the Air filtration unit (%)	PM 10	97	94	91	87
	PM 2.5	85	82	77	71
	PM 1	82	77	72	63
	Methanol	94	85	74	62
	Benzene	86	81	67	59
	Toluene	79	69	64	61
	Xylene	82	70	61	58
	Ethanol	80	72	67	63
	TVOC	82	77	74	68
	NOx	91	84	80	68

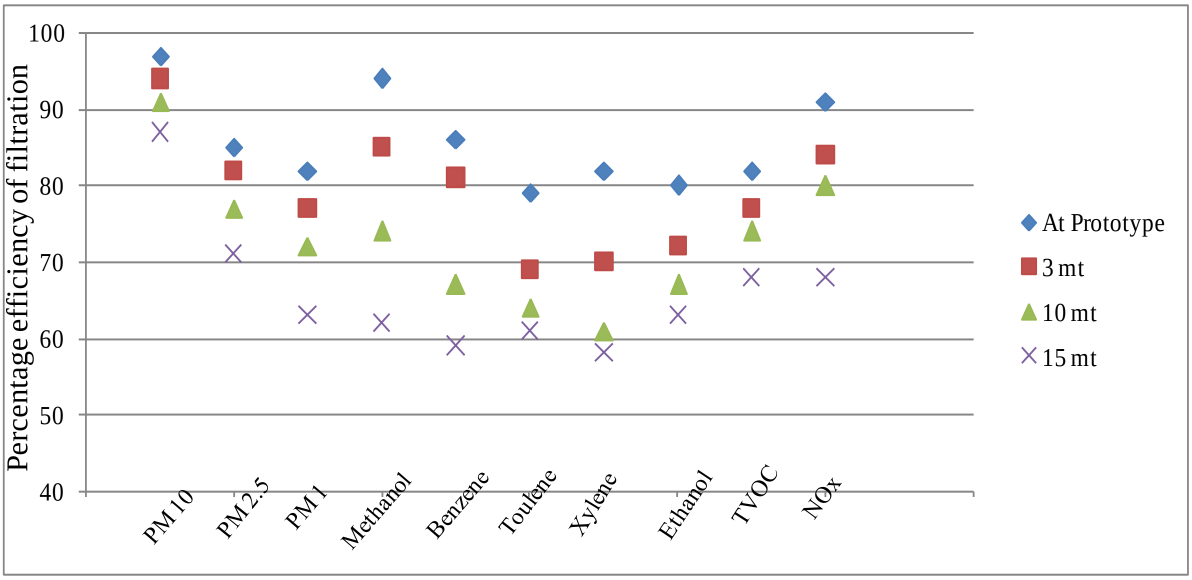


Figure 2: Comparative graph showing the percentage efficiency of the Filtration Unit from varied distance in Basement

Table 5: Percentage efficiency of filtration unit combating pollutants at both the sites

Pollutants	Basement (%)	Petrol Pump/ Outdoor (%)
PM 10	97	93
PM 2.5	85	91
PM 1	82	89
Methanol	94	88
Benzene	86	85
Toluene	79	84
Xylene mixed	82	82
Ethanol	80	82
TVOC	82	86
NOx	91	81

The above table no. 5 elucidates the percentage efficiency of the filtration unit at the outlet concentration for both the sites. It can be seen that the percentage efficiency for Particulate matter 10 is more in basement than at the outdoor site petrol pump. Similarly, the efficiency is more for Methanol, Benzene and NOx at Basement site.

4) How the prototype is superior as compared to the other units in the market.

The EPRI developed Air filtration Unit is compared with the other filtration units available in the market. Most of the filtration unit available in the market are either used for indoor purpose or for specific industrial pollutant purpose. However, the prototype can be used for outdoor as well for indoor purpose too. For outdoor purpose, petrol pump was selected and indoor purpose, basement was selected. Other advantages of the Unit are given in the figure No. 3 below.

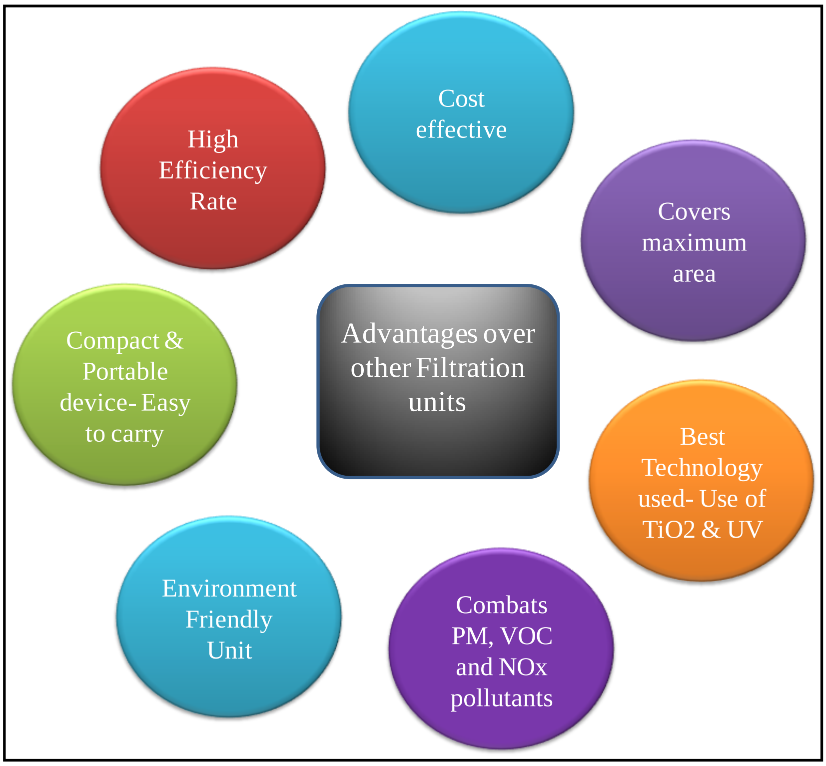


Figure 3: Advantages of EPRI developed Air filtration Unit

Also a comparative table is given under for details of the units available in the market.

Table 6: Comparative sheet of filtration units available in the market

Filtration Unit	NA	Span Filtermist India Pvt. Ltd.	Photon Cleantech Inc	Dust Pollution Control device installed at TMC	Camfil Industrial Air cleaner CC6000	WAAYU (Wind Augmentation PurifYing Unit)	EPRI Air Filtration Unit
Image of the Unit							
Type of filter used	Pre Filter Micro Vee Filter, HepaFilter Filter material: Stainless Steel	Filter material: Synthetic Fibre	HEPA filters	NA	HEPA Filter	Non-woven fabric filters	Primary Filter HEPA Filter
Other specific technology	NA	NA	NA	NA	NA	WAYU, designed by NEERI and IIT (Bombay),	TiO_2 coated Sheet UV lamp. Technology is

if any						works for removal of pollutants such as dangerous PM2.5 and PM10 particles, CO and VOC. Technology is based on Thermal Oxidation.	based on photo-catalytic.
Usage:	Industrial	Fume, smoke and Odor elimination Ideal for EDM and Laser marking machines	NA	Particles from the air like cement dust, soil, air pollen grains, etc., in the range of 25 to 50 microns.	Basically dust particles	Dust (PM), VOC	Dust (PM), VOC, NOx Removal Used for Outdoor as well as Basement air filtration
Cost (Rs.)	NA	60,000	1 Lakh	50,000	10 Lakh	2.5 Lakh	2 Lakh

Coverage area	NA	NA	NA	NA	NA	NA	10-15 m
Material	Stainless Steel	Aluminium	Stainless Steel	NA	NA	Stainless Steel	Stainless Steel
Noise level (db)	NA	NA	NA	NA	NA	NA	55 db
Remarks	--	--	--	Machine which has 0.5 HP (horse power) motor can suck 2000 CFM (cubic feet meter air) at a time and purify it.	Helps keep employees healthy, improve product quality and reduce dust.	Used for abating air pollution in ambient air	Used for abating air pollution in ambient air and basement where parking is provided.

There are units available in the market however; mostly the units are industrial pollutant specific or typical for one or the other pollutant. Basically there are several filtration units available but for the purpose of indoor air filtration. Therefore, such units cannot be used for pollutants which are of more intense in the ambient air like particulate matter and vehicular pollutants like VOC, NOx etc. To get rid of pollutants one need to design a filtration unit which will combat the particulate matter, VOC and NOx all in one and can also be used for outdoor as well for indoor purpose. EPRI developed filtration unit is a combination of both, it can be used for indoor as well as for outdoor purpose. Moreover, it is easy to use, operate and portable too. Other units are bulky, heavy and expensive too. EPRI developed filtration unit successfully decreases the pollutant concentration at an efficiency of 90% to 97%. Moreover it is also useful at varied distances and gives its efficiency at about 60% even at a distance of 15 mt away from the filtration unit.

Thus these features and results as illustrated above in comparison with other units make the filtration unit more superlative worth to utilise for combating pollution.

CONTENTS

No.	Topic	Page no.
1	Compliance of Minutes of Meeting	1

No.	Topic	Page no.
	Chapter 1: Introduction	1.1
1.0	Introduction	1.1
1.1	Problem Statement	1.2
1.2	Worldwide Litigations w.r.t. Air pollution	1.4
1.3	Major Air Pollutants & its health effects	1.7
1.4	Aims and Objectives	1.11
1.5	Air Quality and Standards in India	1.12
1.6	Case Studies	1.15
	Chapter 2: Methodology	2.1
2.0	Data Collection & Methodology	2.1
2.1	Monitoring Locations	2.1
2.2	Air Quality Monitoring Instruments	2.6
2.3	Data compilation& Interpretation	2.8
	Chapter 3: Design of Air Filtration Unit	3.1
3.0	Background & History of Air filtration Units	3.1
3.1	Principle and Model design of Air Cleaning Unit	3.2
	Chapter 4: Results & Interpretation	4.1
4.1	Rationale behind selecting different points for monitoring	4.9
4.2	Monitoring of results at Petrol Pump	4.12
4.3	Monitoring of results at Basement	4.22
	Chapter 5: Comparison & Superlative features of the Unit	
5.1	Air filter/ purifiers in Market	5.1
5.2	Technology behind the Unit	5.2
5.3	Merits over other filtration units	5.6

LIST OF TABLES

No.	Topic	Page no.
1.1	National Ambient Air Quality Standards lead by CPCB in 2009	1.13
1.2	International Standards for Pollutants	1.14

4.1	The pollutant concentration at Petrol Pump site location for Pre-Monsoon season	**4.1**
4.2	The pollutant concentration at Petrol Pump site location for Monsoon season	**4.4**
4.3	The pollutant concentration at Petrol Pump site location for Monsoon season	**4.6**
4.4	Concentration of Particulate Matter 10 at the petrol pump site	**4.12**
4.5	Concentration of Particulate Matter 2.5 at the petrol pump site	**4.13**
4.6	Concentration of Particulate Matter 1 at the petrol pump site	**4.14**
4.7	Concentration of Methanol at the petrol pump site	**4.15**
4.8	Concentration of Benzene at the petrol pump site	**4.16**
4.9	Concentration of Toulene at the petrol pump site	**4.17**
4.10	Concentration of Xylene at the petrol pump site	**4.18**
4.11	Concentration of TVOC at the petrol pump site	**4.19**
4.12	Concentration of NOx at the petrol pump site	**4.20**
4.13	Concentration of Particulate Matter 10 in Basement	**4.23**
4.14	Concentration of Particulate Matter 2.5 in Basement	**4.24**
4.15	Concentration of Particulate Matter 1 in Basement	**4.25**
4.16	Concentration of Particulate Matter 1 at the Basement	**4.26**
4.17	Concentration of Methanol at the Basement	**4.27**
4.18	Concentration of Benzene at the Basement	**4.28**
4.19	Concentration of Toulene at the Basement	**4.29**
4.20	Concentration of Xylene at the Basement	**4.30**
4.21	Concentration of TVOC at the Basement	**4.31**
4.22	Concentration of NOx at the Basement	**4.32**
4.23	Efficiency of the Filtration unit for pollutant removal at varied distance of Petrol Pump	**4.34**
4.24	Efficiency of the Filtration unit for pollutant removal at varied distance at Basement	**4.36**
5.1	Comparative sheet of filtration Units available in Market	**5.3**

LIST OF FIGURES

No.	***Topic***	**Page no.**
2.1	Petrol Pumps situated at different locations for carrying out	**2.3**

	monitoring	
2.2	Fuel loading points at Teen Petrol Pump	**2.4**
2.3	Location of Teen Petrol Pump in Thane	**2.4**
2.4	Methodology for the project	**2.9**
3.1	The Photo-catalysis Process	**3.2**
3.2	The schematic representation of the proposed unit	**3.3**
3.3	The outer body design of the proposed unit	**3.4**
3.4	The components and its positioning inside the proposed unit	**3.4**
3.5	Primary Filter and HEPA Filter	**3.5**
3.6	UV Lamp	**3.6**
3.7	$CaCO_3$ Filter	**3.6**
3.8	Axial fan	**3.7**
3.9	Air Filtration Unit by EPRI	**3.8**
4.1	Graph showing the Pre-monsoon readings of Pollutants	**4.3**
4.2	Graph showing the Monsoon readings of Pollutants	**4.6**
4.3	Comparative Graph of Monsoon & Pre Monsoon readings of Pollutants	**4.7**
4.4	Position of the Installed Filtration Unit and site of readings taken	**4.11**
4.4	Schematic pattern of installed Air filtration unit and monitoring locations	**4.11**
4.5	Comparative graph showing the percentage efficiency of the Filtration Unit at varied distance on Petrol Pump site	**4.35**
4.6	Comparative graph showing the percentage efficiency of the Filtration Unit from varied distance in Basement	**4.36**
5.1	Advantages of the Air filtration Unit	**5.6**

LIST OF ANNEXURES

No.	***Annexure***
1	Annexure for detailed Petrol pump- Particulate Matter
2	Annexure for detailed Petrol pump- VOC
3	Annexure for detailed Petrol pump- NOx
4	Annexure for detailed Basement- Particulate Matter
5	Annexure for detailed Basement- VOC
6	Annexure for detailed Basement- NOx

List of Abbreviations

AQI	Air Quality Index
B/T	Benzene to Toluene ratio
$CaCO_3$	Calcium carbonate
CFM	Cubic Feet per minute
CNG	Compressed natural gas
CO	Carbon Mono-oxide
CPCB	Central Pollution Control Board
DCR	Development Control Regulations
EPA	Environment Protection Agency
EPRI	Enviro Policy Research India
FPM	Feet Per Minute
GC-FID	Gas Chromatography- Flame Ionization Detector
HEPA	High Efficiency Particulate Arrestor
HPLC-PAD	High-performance Liquid Chromatography with Pulsed Amperometric Detector
IARC	International Agency for Research in Cancer
NCR	National Capital Region
PAH	Polycyclic Aromatic Hydrocarbons
PID	Photo-Ionization Detector
PM	Particulate Matter
PM 1.0	Particulate Matter with aerodynamic diameter Less than 1 µm
PM 2.5	Particulate Matter with aerodynamic diameter between 10 µm & 2.5 µm
PM 10	Particulate Matter with aerodynamic diameter $\geq$ 10 µm
NOx	Oxides of Nitrogen
TiO_2	Titanium dioxide
TVOC	Total Volatile Organic Matter
UK	United Kingdom
US	United States
UV	Ultra Violet
VOC	Volatile Organic Matter
WHO	World Health Organisation

Chapter 1 Introduction

1.0. Introduction

Air pollution in urban areas is one of the critical challenges, faced by India. Urbanization and extensive energy utilization has aggravated the air pollution problem. High concentration of pollutants such as NO_x, CO, VOC's, hydrocarbons, particulate matter and ozone are of major concern due to its carcinogenic and unhealthy conditions which are on peak. There are also several sources of contaminants that are present at work places which needs better environment quality to enable the daily life.

The rapid growing industrialization and urbanization is leading to lot of environmental issues by its uncontrolled polluted emissions, especially air pollution*(Hosamane and Desai, 2013)*. The studies around the world suggest that, high particulate matter concentration and various trace gases causes lung diseases and even premature mortality *(Tian et al., 2017; Ghude et al., 2016)*. Due to ambient air pollution, a high number of premature deaths were estimated in which around 91% is from developing countries *(WHO,2018)*. The Indian cities possess a crucial health risk due to poor ambient air quality causing severe respiratory health problems *(Kesavachandran et al., 2015)*.

> WHO's urban air quality database 2016 has sited Mumbai as the fifth most polluted megacity in the world in terms of PM10

Major reason of increase in air pollution is due to the industrial and vehicular emission which increases the percentage of trace gases such as Carbon monoxide, VOCs etc. Vehicles contribute up to 35 % of air pollution in the metropolitan cities of India like Delhi, Bengaluru, Mumbai, Kolkata, Chennai which tops in most polluted cities in the world *(WHO Report 2018)*.Recent study done by IIT-Bombay, has found that air pollution causes an excess death of 12000 Mumbaites than expected. As per the research 91% to 97% of excess death, is a result of inhaling harmful solid and liquid particles in the air. Similar report released by Central Pollution Control Board (CPCB) has noticed an increased level of benzene in air. They have also found increased levels of formaldehyde, methylene chloride and perchloroethylene and concluded that apart from being carcinogenic, they can also cause sudden death due to inhalation of these vapours.

Although we talk about air pollution in ambient air due to vehicles, industries etc still there are other areas where pollution is aggravated and suspension of dust is seen for longer period of time due to minimal ventilation. Such places are usually enclosed with poor ventilation especially indoors. Such indoor places are generally 'Basements' which are used for parking now a day in order to accommodate space in this emerging world of development. Therefore, whenever we talk about indoor air quality it's not only of houses or commercial tents etc.

Indoor air pollution is the degradation of indoor air quality by harmful chemicals and other materials; it can be up to 10 times worse than outdoor air pollution. This is because contained areas enable potential pollutants to build up more than open spaces. (25)

1.1 Problem Statement:

The issue with air pollution is not new, however; it has been aggravated these days with increase in population, industrial & other developmental activities. It has been observed and recorded in many reports and newspapers about the air pollution in India and worldwide.

Three main reasons for pollution issue in India:

1) Climate: India receives rain only in Monsoon season, which naturally helps to settle the dust. Being a tropical country, it has lot of dust.

2) Rapid urbanisation – Since India is a developing country, there is seen on-going construction of houses, commercial and roadways etc. Traffic congestion is already a issue however, due to above mentioned activities.

3) Poor Civic governance & planning: No laws for poor roads, digging of roads for repair purpose etc.

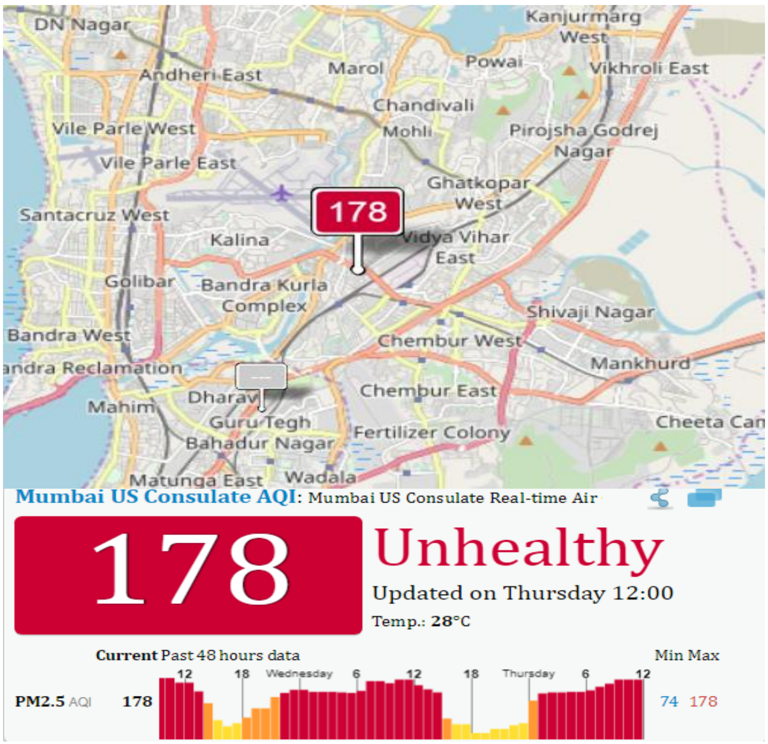
The Times of India in its May 2, 2018 edition stated as under:

"Among 10 global megacities (habitation of above 14 million). Mumbai, with an average PM10 level of 104ìg/m3 (microgram per cubic metre) came after Delhi (which topped the list), Cairo and Dhaka... More than 90% of air pollution-related deaths

occur in low- and middle-income countries, mainly in Asia and Africa, followed by Low middle income countries in eastern Mediterranean region, Europe and America.

WHO highlighted that air pollution is mainly responsible for non-communicable diseases (NCDs), causing an estimated one-quarter (24%) of all adult deaths from heart disease, 25% from stroke, 43% from chronic obstructive pulmonary disease and 29% from lung cancer."

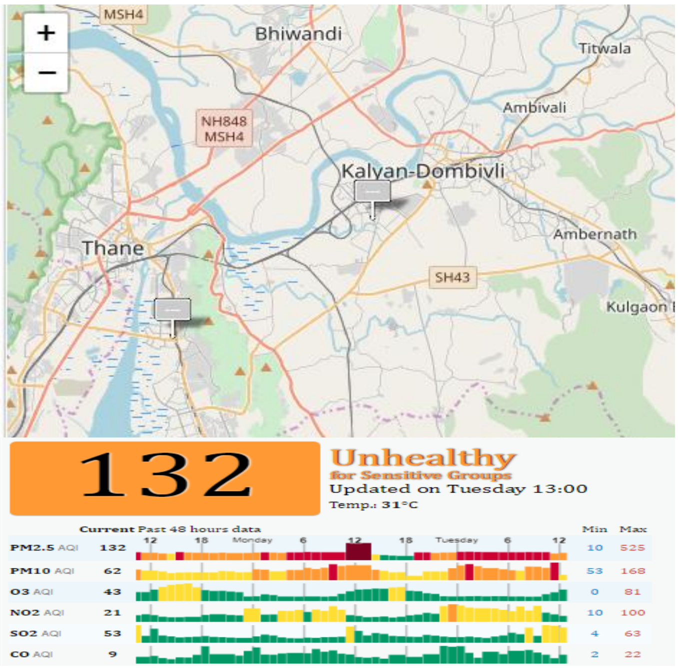
The Guardian in its UK legal claimsincrease over exposure at work to toxic diesel fumes states that *"Five years ago the International Agency for Research in Cancer (IARC) classified diesel engine exhaust emissions as carcinogenic to humans. That classification, combined with growing awareness over the damaging effects of diesel air pollution, the revelations in the VW emissions scandal, and research that shows some diesel cars have been emitting about six times more NOx on the road than is allowed in lab tests, has led to increasing numbers of employees considering action."*



Source: http://aqicn.org/city/india/mumbai/us-consulate/

The Times of India in its 7th December 2018 edition stated that the death rate in Maharashtra is more than Delhi w.r.t. air pollution. On the presence of harmful particulate matter in the air, the Global Burden of Disease Study 2017 says the population- weighted mean for PM 2.5 ug/m3—average exposure of less than 2.5 microns—was 209 in Delhi, the highest in the country. On the other hand the PM 2.5 mean for Maharashtra was 55.7 ug/m3.

The Two figures show actual data of two different locations from the Mumbai USConsulate Air Pollution: Real-time Air Quality Index (AQI). One of the locations is Bandra which shows 178 level of AQI whereas the other location is Thane which shows 132 AQI. Both the levels are mentioned as unhealthy for people.



Source: https://aqicn.org/city/india/thane/pimpleshwar-mandir--dombivali/

1.2 Worldwide Litigations w.r.t. Air pollution:

The New York Times in its Feb 27, 2018 pointed out thatGermany's highest administrative court ruled that vehicles can be banned from some city streets as part of efforts to improve air quality in urban areas. Other European countries have taken measures to reduce the number of diesel-powered cars, but the technology is almost synonymous with Germany, where there are 15 million diesel cars on the streets and where automakers bet their futures on technology they billed as environmentally friendly, even as they rigged software in their cars to pass stringent emissions tests.

In India, the Centre on 30thDecember, 2015 under Section 18 of Air (Prevention and control of Pollution) Act, 1981; issued directions to all agencies falling under Delhi area to control air pollution and improve the Ambient Air Quality in Delhi and National Capital Region (NCR). The directions were issued to State governments of Delhi, Rajasthan, Haryana and Uttar Pradesh. Orderswere given to control vehicular emissions include – immediate action against visibly polluting vehicles, carrying out checks of overloaded vehicles, ensuring No Parking in non-designated areas, decongestion of pathways, promoting battery-operated vehicles and considering introduction of flexi/staggered timings to minimize peak movement of vehicles.

In India, there are several cases on going in the Supreme Court and National Green Tribunal too w.r.t. to air pollution in specific. The Environment Protection Act, 1986 is enforced by the Central Pollution Control Board and the numerous State Pollution Control Boards. The National Green Tribunal was established under the National Green Tribunal Act 2010 for effective and expeditious disposal of cases relating to environmental protection and conservation on 18th October, 2010. The Central Pollution Control Board haspresent cases in its Law Division. The on-going cases are related to pollution from construction sites & vehicular emissions and Air Pollution in the City.

Order of the National Green Tribunal in the matter of VardhamanKaushikVs. Union of India & Others regarding air pollution in NCT Delhi.

The Court directed that the express highway project of Eastern Peripheral Expressway would continue subject to Senior most officer of the NHAI filing an undertaking that they shall fully ensure that there are no dust emission and no pollution is caused by their activity. NGT also directed the MoEF&CC, MoT, NCT Delhi, PCBs to fully coordinate and cooperate to control the pollutant in the ambient air quality of NCR Delhi and take all effective steps in accordance with the orders of the Tribunal.

Global Legal Framework

USA: In USA,The Clean Air Act is the key piece of legislation which requires EPA to set National Ambient Air Quality standards to protect public health. EPA has to demonstrate attainment of these standards with an adequate margin of safety. The states have to identify the major emission sources and then lay out a specific plan on how and when they will show attainment for a specific pollutant. The Act also requires the major sources of air pollution to meet stricter emissions control in non-attainment areas. Every 5 years EPA reviews all the health information for the criteria air pollutants and based on the review considers whether the existing air quality standard for that pollutant is adequate to protect public health with an adequate margin of safety.

Europe: The European Commission has set health-based target for air quality. The Thematic Strategy on AirPollution aims by 2020 to cut the annual number of premature deaths from air pollution related disease byalmost 40% from the 2000 level. While covering all major pollutants it pays special attention to fine particulates and ground level ozone. It would also set a cap on concentration on most polluted areas. Emissions ceiling will be brought into line with the objectives.

China: China has also drafted Clean Air Act that makes public health its stated objective. It states that itsobjective is “to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population”. It provides for environmental health effect research and preparation of environmental health assessments for each of the hazardous air pollutants.

1.3 Major Air Pollutants & its health effects:

This section discusses about the pollutants and its health effects. Considering the above elucidated literature review and necessity of the study, following pollutants were considered for analysis:

A. Volatile Organic Compounds (VOC):

Volatile Organic Compounds are important air pollutants in urban atmosphere. Some of the VOCs are toxic, potentially carcinogenic and mutagenic at concentrations levels found in urban environment. Exposure to VOC is of concern as it may result in significant risk to human health. Atmospheric reactions of VOCs lead to secondary pollutants, which is turn cause the deterioration of air quality and damage to crops and vegetation too. VOCs are emitted from number of sources, which include urban and industrial activities, and natural sources. Previous studies have reported vehicular emissions as the major source of VOCs in urban air.

> Pjeffer (1994) reported that 90% of benzene in ambient air is from traffic. Vega et al.(2000) estimated that motor vehicle exhaust contributes to 55% of non-methane hydrocarbons. Baldasano et al. (1998) have shown that 62% of VOC pollution in Martorell. Evaporative emissions of VOCs from gasoline distribution network are also one of the important sources of VOCs in ambient air.

The atmospheric behaviour of VOCs is governed to a large extent by their life time. In the process of long range transport, the primary pollutants such as VOCs and NOx will react with atmosphere to produce secondary pollutants such as ozone and PAH etc. with different reaction rates. Highly reactive species will react near the vicinity of the sources, while slow reacting species may be transported to large distances. Toluene has much shorter life time than benzene (Singh and Zimmer Mon, 1992). So higherBenzene to Toluene (B/T) ratio will be found in aged air via a long range transport. B/T ratio can be thus used as a tracer to predict long range transport. However, if sources of benzene or toluene other than vehicular exhaust are present B/T ratio cannot be considered as a tracer. High levels of VOCs have been observed in Asian Countries (Hussam et al., 2002; Iran et al., 1998). The present study focuses on estimating VOCs at urban petrol retail distribution centre in Thane.

Benzene which is an important component of crude oil and petrol is harmful to humans even at minimal levels. According to a report by the Delhi government's Centre for Occupational and Environmental Health, benzene levels are highest when the temperature is lower. This means the air is deadliest in the early hours of the day and the late hours of the evening, which unfortunately coincides with the times that residents of the hot& busy metro city like Mumbai, children and adults both, choose to get some fresh air by means of a walk or jog. The effect of this pollutant is lethal as it mixes with the blood as one inhale. Therefore, people with weak immune system are at the high risk.

B. Particulate Matter (PM):

In addition, Vehicles also release air pollutants like particulate matter, nitrogen oxides and hydrocarbons. Particles in air are either directly emitted, for instance when fuel is burnt and when dust is carried by wind, or indirectly formed, when gaseous pollutants previously emitted to air turn into particulate matter. The aerodynamic properties of particles determine how they are transported in air and how they can be removed from it. These properties also govern how far they get into the air passages of therespiratory system. Additionally, they provide information on the chemical composition and the sources of particles. Particulate matter are usually classified as Fine (<2.5 microns) and course (10 microns)particulates.Most of the total mass of airborne particulate matter is usually made up of fine particles ranging from 0.1 to 2.5 µm.Moreover, parking, to & fro of vehicles, in the basement or parking areas lead to

The report on Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide, 2003 has revealed that the Particulate matter like PM 2.5 and PM 10, have gone 75% above permissible levels in the last five years. Just between 2000 and 2011, the PM 10 level has increased by 47%, while nitrogen dioxide has gone up by 57%. The PM 2.5 data between November 2013 and January 2014 reveals that average levels have been 240 mg/cum (microgram per cubic metre). The winter of 2013 saw a drastic jump in the levels of PM 2.5, when they reached an astonishing 575 mg/cum.

Particulate matter pollution. Cleaning activities like dry brushing or sweeping of floors, cleaning of rooms etc also emphasis particulate levels.

C. Oxides of Nitrogen:

Nitrogen dioxide (NO2) is one of the nitrogen oxides (NOx), a group of air pollutants produced from combustion processes.In urban outdoor air, the presence of NO_2 is mainly due to traffic. Nitric oxide (NO), which is emitted by motor vehicles or other combustion processes, combines with oxygen in the atmosphere, producing NO_2. Indoor NO_2 is produced mainly by unvented heaters and gas stoves. NO_2 is the main source of nitrate aerosols, which form an important fraction of PM2.5 and, in the presence of ultraviolet light, of ozone. The major sources of anthropogenic emissions of NO_2 are combustion processes (heating, power generation, and engines in vehicles and ships).

Interpretation of evidence on NO_2 exposures outdoors is complicated by the fact that in most urban locations, the nitrogen oxides that yield $NO_2$are emitted primarily by motor vehicles, making it a strong indicator of vehicle emissions (including other unmeasured pollutants emitted by these sources). NO_2 (and other nitrogen oxides) is also a precursor for a number of harmful secondary air pollutants, including nitric acid, the nitrate part of secondary inorganic aerosols and photo oxidants (including ozone). The situation is also complicated by the fact that photochemical reactions take some time (depending on the composition of the atmosphere and meteorological parameters) and air can travel some distance before secondary pollutantsare generated.

The International Agency for Research on Cancer (IARC) has estimated the average contributions of transport to air pollution in developed countries. The increased contribution of air toxics in urban regions is due to so-called “urban canyoning” in crowded business districts. The below table shows the pollutant contribution level due to vehicle emission.

Carbon Monoxide (CO)	~ 90 %
$PM_{2.5}$	~25 – 30%
Nitrogen Oxides (NOx)	~40%
VOC	~35
Average Air toxics	~21
Urban Air Toxics	~42

Source: Environmental Analysis of Petrol, Diesel and Electric Passenger Cars in a Belgian Urban Setting Nils Hooftman, Luis Oliveira, Maarten Messagie, Thierry Coosemans and Joeri Van Mierlo

Health effects of VOC and their sources (Source: URL 6)

VOC	Source	Health effects
1,4-Dichlorobenzene	Used to control moths, molds, mildew and to deodorize restrooms and waste containers. Tobacco smoke	Dizziness, headaches and liver problems
1,1,1-Trichloroethane	Used as solvent to dissolve other chemicals	Dizzy, lightheaded, unconsciousness, low blood pressure and loss of heartbeat
Benzene	Crude oil, gasoline and cigarette smoke, volcanoes, forest fires and JP – 8 fuel (Jet Propellant 8)	Acute exposure: Eye and skin irritation, drowsiness, dizziness, rapid heartbeat, headaches, nausea, tremors, confusion, unconsciousness, vomiting, seizures, irregular heartbeats, coma & death Chronic / everyday exposure: anemia, low white blood cell count, low platelet count, affects immune system, acute myelocyticleukemia
Carbon Tetrachloride	Refrigeration fluid, propellants for aerosol cans	Liver, heart, kidney and central nervous system damage, headaches, dizziness, sleepiness, nausea and vomiting
Ethyl benzene	Coal tar, Petroleum products, Inks, Insecticides, Paints	Dizziness, throat and eye irritation, tightening of chest, burning feeling in eyes
Styrene	Cigarette smoke, automobile exhaust, rubber and plastic industry	Nausea, dizziness, headache, irritation of the eyes, nose and throat. Chronic exposure harms nervous system, concentration problems, leads to muscle weakness, depression and anxiety
Tetra chloro ethylene	Dry cleaning of fabrics, metal degreasing operations, water repellents.	Dizziness, headaches, sleepiness, confusion, nausea, unconsciousness, liver and kidney damage. Chronic exposure can cause skin irritation, nervous system problems, memory loss and concentration problems
Toluene	Crude oil, tolu tree, rubber, printing and leather industry, JP – 8 fuel	Light-headiness, dizziness, sleepiness, unconsciousness and death. High levels can affect kidney. Chronic exposure affects kidney, liver, nervous system, muscle weakness and memory loss
Trichloroethylene	Used as solvent to remove grease from metal parts, in typewriter correction fluid, paint removers, adhesives and spot removers	Dizzy, sleepy and even unconscious. Chronic exposure leads to liver and kidney damage and change in heartbeat.
Xylene	Petroleum products, coal tar, forest fires, as solvent in printing, rubber and leather industry, as thinner and cleaning agent for paint and varnishes	Headaches, lack of muscle coordination, dizziness, confusion change in balance, irritation to skin, eyes, nose and throat, stomach discomfort and changes in liver and kidney. It mainly affects the brain

Health effects of Particulate Matter and their sources (Source: WHO 2013)

Particulate Matter	Activities	Health effects
PM_{10}	Primary activities such as combustion, industrial activities (construction, mining), erosion of pavement, abrasion of brakes and tyres, Soil and dust resuspension contribute largely to PM_{10}.	PM_{10} less penetration occurs into the thoracic activity. Respiratory and cardiovascular morbidity, aggravation of asthma and respiratory systems
$PM_{2.5}$	Secondary activities of particulate matter emission as transformation of nitrogen oxide and sulphur dioxide into particulates, PAH condensation, elemental carbon and Biological components contribute largely to $PM_{2.5}$.	$PM_{2.5}$are the inhalable particles that can enter the thoracic cavity. Mortality from cardiovascular and respiratory diseases, lung cancer

Since, ambient air pollution has become a cause for alarm in India because recent data suggest that ambient pollution levels in Indian cities are some of the highest in the world. In light of the extremely high levels of air pollution encountered in Indian cities, Air purifiers are marketed as a tool that can be used to mitigate exposure to high levels of particulate pollution especially PM 2.5, NO_x and Volatile Organic Carbon compounds. Air filtration technique can remove air pollutants and effectively alleviate the deterioration of indoor air quality. As a result of these trends, the issue of sustainable and healthy environment has received increasing attention. Various air filtration techniques have been adopted to optimize indoor air quality.Air filtration technique can remove air pollutants and effectively alleviate the deterioration of indoor air quality. As a result of these trends, the issue of sustainable and healthy environment has received increasing attention.

Hence through this project, we would be designing an Air Filtration Unit which can treat Particulate Matter (PM), Oxides of Nitrogen (NOx) and Volatile Organic Carbon (VOC). The filtration unit is designed and field trials are taken at selected locations.

1.4 Aims and Objectives

There is a large percentage of human life which gets affected due to the non-regulatory sources of air pollutants (refilling of tanks, idling of vehicles, re-suspension of dust). As seen in the above sections, that the climate and rapid urbanisation is demanding a luxurious as well as a sci-fic lifestyle, hence there is a need to cope the pollution levels. Therefore, such type of atmosphere demandsthe need of a designed unit or operation that can reduce the concentration of harmful contaminants.

Hence, this project can be considered as a measure to mitigate the crisis by developing an Air cleaning/filtration unit and carry out various analysis to monitor the efficiency of the unit. The objectives of the project are depicted as under:

Objective and Scope
Study of the pollutants w.r.t. the sources and the sites where these pollutants are available.
To monitor the selected sites for determining the background concentration of pollutants.
To design/develop a unit which consist of a reusable filter that can capture particles of size less than 2.5µm and a Photo-catalytic unit that can absorb VOCs and NOx too
Demonstration of the proposed prototype at the chosen sites and determining its pollutant removal efficiency
Optimize the design of the unit with respect to the improved removal efficiency of pollutants and development of project sustainability and dissemination

1.5 Air Quality and Standards in India

With reference to the Air (Prevention and Control of Pollution) Act, 1981certain rules and regulations were binded on the Central Government with the objective of arresting the deterioration of air quality. The act describes the main functions of the CPCB wherein, CPCB has lead the standards values for Pollutants as given in the **Table1.1** below:

Table 1.1 National Ambient Air Quality Standards lead by CPCB in 2009

Sr. No.	Pollutant	Time	Industrial, Rural, Residential	Ecological, Sensitive area
1	SOx (ug/m^3)	Annual	50	20
		24 hours	80	80
2	NOx (ug/m^3)	Annual	40	30
		24 hours	80	80
3	PM 10(ug/m^3)	Annual	60	60
		24 hours	100	100
4	PM 2.5 (ug/m^3)	Annual	40	40
		24 hours	60	60
5	Carbon Monoxide(mg/m^3)	8 hours	2	2
		1 hour	4	4
6	Benzene(ug/m^3)	Annual	5	5

The standards are different for other countries, depending on the climate and the present condition of the air quality and standard of life style. The European standards and US standards are depicted in the **Table 1.2** below:

Table 1.2 International Standards for Pollutants

Sr. No.	Pollutants	EUROPEAN STANDARDS		US STANDARDS	
		Time	**Concentration**	**Time**	**Concentration**
1	SOx (ug/m^3)	1 hour	350 ug/m^3	24 hours	365 ug/m^3
2	NOx (ug/m^3)	1 hour	200 ug/m^3		100 ug/m^3
3	PM 10(ug/m^3)	24 hours	50 mg/m^3	24 hours	150 ug/m^3
4	PM 2.5 (ug/m^3)	Annual	25 u/mg^3	24 hours	35 ug/m^3
5	Carbon Monoxide(mg/m^3)	8 hours	10 mg/m^3	8 hours	10 ug/m^3

1.6 Case Studies

Emissions of VOCs at urban petrol retail distribution centres in India (Delhi and Mumbai)

Srivastava et al.,2005 had conducted a study on estimating the VOCs at urban petrol distribution centres in Mumbai and Delhi. Three petrol pumps each from Delhi (IIT Crossing, Cannaught Place and Race Course) and Mumbai (Worli, MaheshwariUdyan and Mahim) were chosen and monitored once in every month during peak hours (8am – 12pm, 5pm – 9pm). Sampling was conducted using adsorption cartridges of charcoal at a height of 5ft – 6ft in the middle of petrol pumps where vehicles halt for refilling.Total emissions were estimated as 3.685 gigagrams for Delhi in the year 2001 and 2.664 gigagrams for Mumbai in the year 2001. As per GCMS, out of the total VOCs identified, 14 VOCs at Mumbai petrol pumps were hazardous and 11 VOCs at Delhi petrol pumps were hazardous air pollutants.

Indoor Air Quality of everyday use spaces dedicated to specific purposes- A review

MariuszMarć , Monika Śmiełowska, JacekNamieśnik and BożenaZabiegała

The Authors in this paper has carried out literature and based on that found out that some of the main factors which significantly affect the quality of the indoor environment in residential apartments are human activities such as cooking, smoking, cleaning, and indoor exercising. It gives an overview related to air quality in daily used spaces dedicated for specific purposes which are integral parts of residential buildings, such as kitchens, basements, and individual garages. Some aspects of air quality in large-scale car parks, as a specific type of indoor environment is also discussed.

Development of a photo-reacting fabric filter for simultaneous removal of VOC vapors and fine particles

Park et al.,2006 had experimented with a photo-catalytic unit design. Non-woven polyester fabric was coated by TiO_2nano-particles of anatase structure. Photo-catalytic reaction was activated by using 4 blacklit blue lamps (350 nm – 390 nm) and one germicidal lamp (250 nm – 265 nm). The catalyst load used was 6.02 mg / cm^2. This unit served a dual purpose of dust separation and photo-catalytic oxidation.

It was observed that TiO_2particles less than 100 nm in diameter increase the rate of photo-catalytic reactions. Smaller the diameter increases the surface are to volume ratio. But increasing the load of the particles would decrease the permeability of the air thus inducing resistance to air flow.

Source apportionment of VOCs at the petrol pumps in Kolkata, India; exposure of workers and assessment of associated health risk.

Majumdar et al.,2008 had determined the workers exposure concentration of VOCs at petrol pump and assessed the associated health risks. The study was conducted at 5 busy petrol pumps with each representing north, south, central, east and west parts of Kolkata. Around 6-8 people at each station were selected, who were mainly employed with the refuelling work. Air was drawn at a flow rate of 6ml/min for the entire shift of 8 hours (6 am to 2 pm). Static monitoring of mono-aromatics and carbonyl compounds was done, within the distance of 5 – 10 meter radii from each fuel outlet at a height of 1.5 m. The charcoal adsorbed hydrocarbons were then analyzed using gas chromatography equipped with flame ionization detector (GC-FID) and high performance liquid chromatography equipped with photodiode array detector (HPLC-PAD). Results for static level measurement showed toluene (49.3 – 236.8μg/m^3) and benzene (17.4 – 81.6μg/m^3) to be the highest in mono-aromatics.

Personal exposure results of case study:

VOC	Concentration Measured
Benzene	137.5μg/m^3
Toluene	643.6 μg/m^3
Ethylbenzene	118 μg/m^3
m-p-xylene	209.7 μg/m^3
o-xylene	68.2 μg/m^3

Chapter 2 Methodology

2.0 Data Collection &Methodology

From the literature review based on many reports, latest news and condition of the air pollution in Mumbai especially due to vehicular and Indoor pollution, certain pollutant as are taken in to consideration. The pollutants Volatile Organic Compounds (VOC), Particulate Matter (PM) and Oxides of Nitrogen (NOx) were studied for the project purpose. The various case studies and monitoring of the sites suggest these three major pollutants. Moreover, the fabricated prototype can be installed on the selected locations and further analysis can be carried out. A background reading would be taken on the selected sites to get a raw data of pollution level at present.

2.1 Monitoring Locations

We have considered two different sites which are prone to have pollutants at high levels because of the vehicular emissions and combustion of fuels. One of thesite is where there is dampness and very low air movement so pollution levels are difficult to eliminate.Vehicle's exhaust is a complex mixture of compounds originated from unburned fuel, lubricant oil and combustible products. Its main components are Carbon Monoxide (CO), Carbon dioxide (CO2), Oxides of Nitrogen (NOx), Sulphur Oxides (SOx), Volatile Organic Carbon (VOC) and Particulate matter. These emissions are directly released from the vehicles in to the air. Transportation would be a line source of pollutant and therefore, the pollutant travels along with the wind and depends on the intensity of atmospheric conditions. However, 'fuel pumping stations' would be a major hub of these emissions. Therefore, it is necessary to collect a basic data of pollution level on petrol pump sites.

Source apportionment of VOCs at the petrol pumps in Kolkata by C. Duttaa, A.K. Mukherjee, B.S.Sen

The Research paper states that the monitoring of the service station revealed that the average exposure level for benzene and toluene were 3.9 and 5.5 fold higher than the ambient air.

The integrated lifetime cancer risks due to benzene, ethyl benzene, formaldehyde and acetaldehyde and the overall hazard index due to chronic exposure to some hazardous volatile organic compounds.

The monitoring locations were identified viz- petrol pumps and basement parking areas where there is vehicular congestion at peak hours and ventilation issue respectively.

A. Petrol Pump

During peak hours, the vehicles are queued in the area which may create an adverse condition. Therefore, as discussed above, petrol pump is an important source of VOC, NOx and PM too.

Selection criteria for Petrol Pump site:

The detailed selection criteria on the basis of which petrol pump was decided for analysis are elucidated as under:

The parameters considered for Petrol pumps are as under:

a) Location: The Teen Petrol Pump was selected as it had three pumping stations on the either side of the petrol pump. There are petrol, diesel, and CNG filling stations available and is situated in the major hub of the road. Therefore, there is crowd of vehicles for fuel loading.

b) Pollutant levels: As the petrol pump is located in the middle of the road and road connected on the three sides, there is always traffic near the petrol pump. Hence, there are mere chances of VOC, PM and NOx pollutants to emerge in the ambient air.

c) Traffic: Since, the site is in the mid of the road and also construction work is in progression. Therefore, there is congestion of vehicles near the site which leads to increase in pollution level.

Considering the above mentioned facts, four petrol pumps were visited in Thane city in order to select the probable petrol pump in terms of pollution level. More the frequency of vehicle fuel loading more will be the emission levels. The visited petrol pumps before selection for taking background air pollution concentration are Kapurbavdi, Majiwada, Teen hath naka and Teen Petrol pump. Some of the petrol pumps were seen crowded with vehicles but only for specific time interval, while other petrol pump had average no. of vehicles for loading fuel tanks. **Figure 2.1**shows the photographs of the visited petrol pumps.

Figure 2.1: Petrol Pumps situated at different locations for carrying out monitoring

Among the four visited petrol pumps, Teen petrol Pump was observed with high frequency of vehicles for fuel loading all over the day period. Some of the significant observations are depicted under:

i. The Teen Petrol pump is situated in the centre part where there are three roads accessible. The petrol pump is near to Thane Station and is a hustle bustle area.

ii. There are three pumping stations available for fuel loading viz. CNG for Autos, two wheelers and for four wheelers.

iii. It is observed that there is queue for fuel loading and also congestion of vehicles on the residing roads. With these facts, there is congestion observed all over the day.

iv. Moreover, since the petrol pump is situated in the vicinity of Thane station, maximum numbers of vehicles prefer fuel loading over here.

Considering all the above stated facts, this petrol pump proves to be a good source of pollutants compared to other ones. Based on this, Teen petrol pump was selected for taking the background concentration of the pollutants.

These facts justify the selection of Teen Petrol pump for the project analysis. A preview of the Teen Petrol Pump is shown in the **Figure 2.2** below:

Figure 2.2 Fuel loading points at Teen Petrol Pump

Teen Petrol pump of Thane was selected for assessment of air quality, the detail location is given in **Figure 2.3.**The site is situated in the North side of Thane and is about 1.4 km away from the railwaystation.

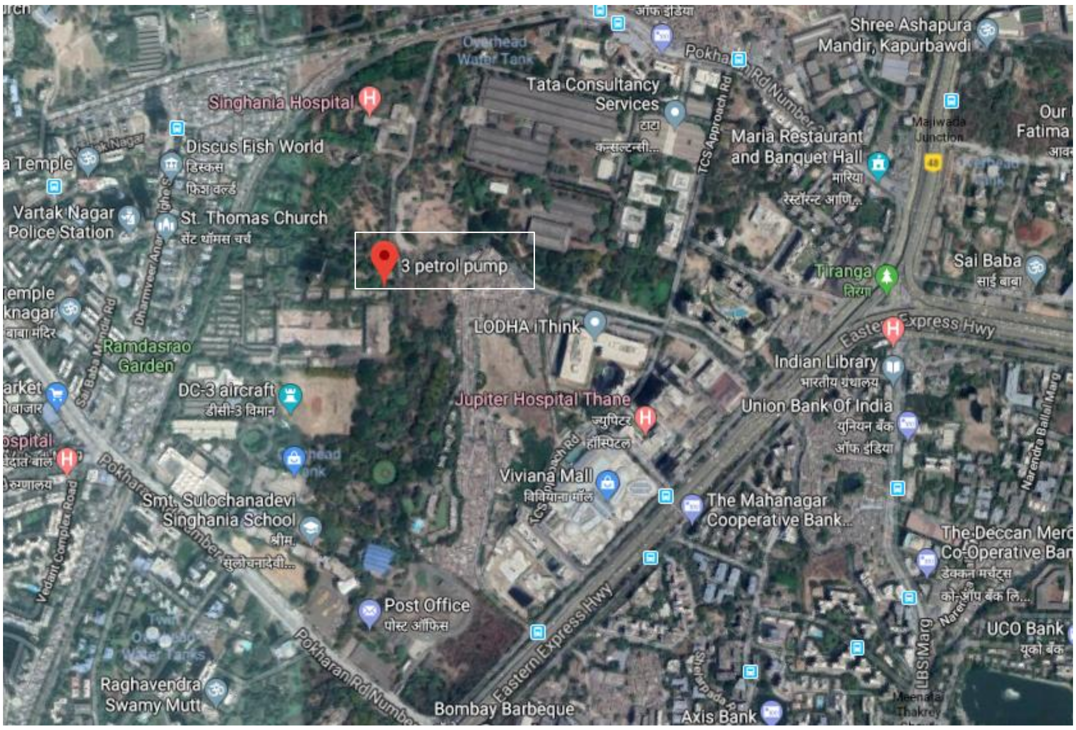


Figure 2.3: Location of Teen Petrol Pump in Thane

B. Basements

Generally Indoors of homes are considered whenever, air quality and human health is thought of. However, other important site other than the home indoors, which is rarely taken in to deliberation is the 'Basement' area. In previous times, basements were 'Cellers' and these were dank, dark places wherecoal use to be stored. People never intended to live or use these cellers to carry out daily activities. Now, we call them as Basement where multiple activities are taken place.

The basement parking area of a private building was monitored for quantifying the pollutants in the site. The basement also has high congestion of vehicles during peak hours.

Selection criteria for Basement:

Certain parameters were taken into consideration with respect to the research assignment for selection of the above mentioned sites.

Basement was the other location selected for demonstration of research prototype. The following parameters were considered for selecting the basement location.

a) Source of pollutants: Since, Basements are used for parking purpose, services and storage section.
b) The parking of vehicles is a source of pollutants viz- Particulate matter and NOx basically.
c) While others like services include cleaning which creates suspension of dust (particulate matter)
d) VOC are present in paints which are usually stored in basements. Therefore, basements are a source of VOC, PM and NOx.
e) Enclosed area: Since Basements are closed therefore, there is minimal natural ventilation. The area of basement is closed and hence, the indoor pollutants remain in the premises as there is no escape to free air.

In today's urbanisation, there are parking spaces provided as per the mandatory conditions of Municipalities, CFO, DCR Regulations and other Government authorities. Due to area constrains, developers are providing parking spaces in the Basement area too. Therefore, the Basement area is of hassle bustle as parking of vehicles, and to and fro activity of the house-keeping workers, drivers and other service maintenance personnels are moving in and out continuously.

Location	Parameters	Characteristics
Petrol Pump	a) Location	Three pumping stations available for petrol, diesel, and CNG filling and is situated in the major hub of the road. Therefore, there is queue of vehicles for fuel loading.
	b) Traffic	Construction work is in progression. Therefore, there is traffic congestion.
	c) Pollution level	The petrol pump is connected on three road sides; therefore there is always traffic near the petrol pump. Hence, there are sheer chances of pollutants to emerge in the ambient air.
Basement	a) Source of Pollution	
	- Parking	Parking of vehicles is a source of pollutants viz- Particulate matter and NOx basically
	- Cleaning	Services include cleaning which creates suspension of dust (especially Particulate Matter)
	- Storage	VOC are present in paints which are usually stored in basements. Therefore, basements are a source of VOC, PM and NOx.
	b) Enclosed Area	Enclosed structure reveals minimal ventilation. Therefore, pollutants remain in the premises for longer time period.

2.2 Air Quality Monitoring Instruments

The study was carried out in the monitoring locations during Pre-monsoon and monsoon season. The monitoring of the air was carried out using air quality monitoring instruments. The different air quality monitoring instruments are discussed below:

a. Dust Trak II

"Dust Trak"- TSI DustTrak™ II and DRX monitors are light years ahead of any other. The DustTrak DRX monitor, for instance, simultaneously measures both mass and size fraction – something no other dust monitor can do. It measures PM1, PM2.5, Respirable, PM10 and TPM.

Principle: The DustTrak DRX desktop monitor is a battery operated, data-logging, light-scattering laser photometers that provides real-time aerosol mass readings. It uses a sheath air system that isolates the aerosol in the optics chamber to keep the optics clean for improved reliability and low maintenance. It measures aerosol contaminants such as dust, smoke, fumes and mists.

b. Tigerlt VOC Analyzer

TIGERLT is a portable gas detector that uses Photo-ionization technology to detect a large range of Volatile Organic Compounds (VOC's) which can be dangerous from both a poisoning and explosive perspective.

The TIGERLT uses a Photo-Ionization Detector (PID) to measure gas concentrations. The patented fence electrode technology minimizes the effects of moisture and contamination, avoiding the need for compensation.

Principle:

Photons also strike cathode and electrons are emitted (Photoelectron Effect). These photoelectrons produce background current. This current is by the fence electrode, resulting in a low background. Contamination cannot be prevented, and even in a fence electrode cell, contamination builds up on the cell wall. The lamp still produces molecular fragments (and low volatility gases), some of which may condense on the walls. The presence of humidity on this ionic contamination still results in a path for current to leak from cathode to anode along the cell wall. However, because the fence electrode is embedded in the cell wall, it wall current and virtually eliminates the background current that causes drift. The result is a humidity-resistant cell with no wall effect and a more stable detector.

c. ATS-206A gas analyser

The **ATS-206 gas analyser** offers a portable and continuous analysis of gases such as NOx, O_2, CO_2,SO_2etc. It is a microcontroller based embedded intelligent instrument with single graphic LCD display with self-calibration and self-diagnostic options.

2.3 Data compilation& Interpretation:

The monitoring of the above mentioned pollutants would be carried out at Petrol pumps and Basements as discussed in the Introduction chapter. The detailed pollutant data recording of the project is given in Table 2.1.

Table 2.1 Detailed Pollutant Data recording Sheet

Site	Background readings	After application of Air Filtration Unit	Efficiency w.r.t. pollutant removal	Efficiency w.r.t. Vol of Air filtered
Petrol Pump	VOC			
	PM			
	NOx			
Basement	VOC			
	PM			
	NOx			

The methodology elucidated in **Figure 2.4** in schematic form is as under:

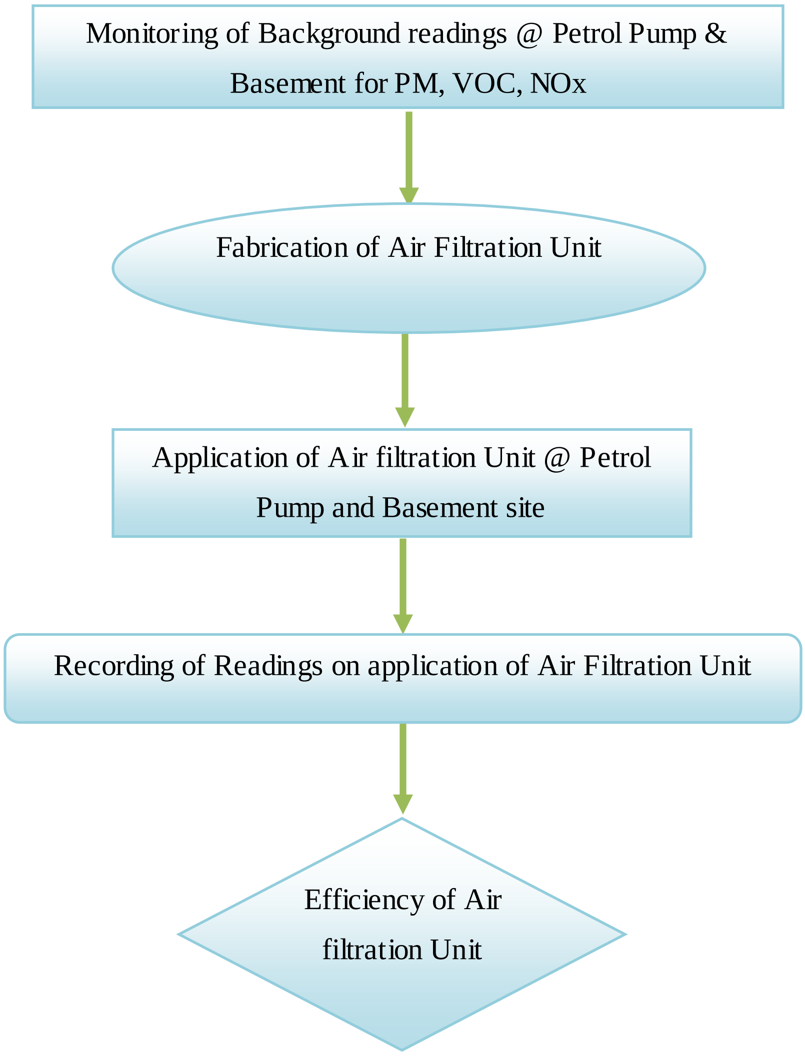


Figure 2.4 Methodology for the project

Chapter 3 Design of Air Filtration Unit

3.0 Background & History of Air filtration Units

In 2014, the World Health Organization (WHO) announced that air pollution exposure represents the single largest environmental health risk, causing one-eighth of total deaths in 2012. In light of extremely high levels of air pollution encountered in Indian cities, air purifiers are marketed as a tool that can be used to mitigate exposure to high levels of particulate pollution especially PM 2.5, NO_x and Volatile Organic Carbon compounds. Air filtration technique can remove air pollutants and effectively alleviate the deterioration of indoor air quality. As a result of these trends, the issue of sustainable and healthy environment has received increasing attention. Various air filtration techniques have been adopted to optimize indoor air quality.

During the era of World War II, in order to combat pollution; HEPA filters came to existence; however, the technology was not rationalized and costly to incorporate. Now-a-days, there are ample of air filtration units available in the market. Commonly the devices use HEPA (High Efficiency Particulate Arrestor) filters. These filters help to remove pet dander and other common forms of allergens.Though, HEPA filters are designed to arrest very fine particles effectively, but they do not filter out gasses and odour molecules. Circumstances requiring filtration of volatile organic compounds, chemical vapours, cigarette, pet, and/or flatulence odours call for the use of an activated carbon (charcoal) or other type of filter instead of or in addition to a HEPA filter.

In all HEPA filters can trap Particulate matter but not efficient enough to trap other pollutants like VOC, NO_x, SO_x and odour spreading microbes. Therefore, there is a need to look out of the box and have prototypes which can take care of both the particulates and gaseous pollutants too.

3.1 Principle and Model design of Air Cleaning Unit

From the above section, it is clear that there are filtration units which are suitable to get rid of the indoor pollution and Particulate Matter to some extent. However, other gaseous pollutants (as discussed in Chapter 2 of the report) cannot be trapped and therefore, there is a need to design and develop a filtration unit which will help to combat the PM, VOC and NOx too.

Air Cleaning Unit can be defined as a device that improves the air quality by removing various toxic pollutants. Thus, it can help in improving the health of the consumers.

3.1.1 Principle

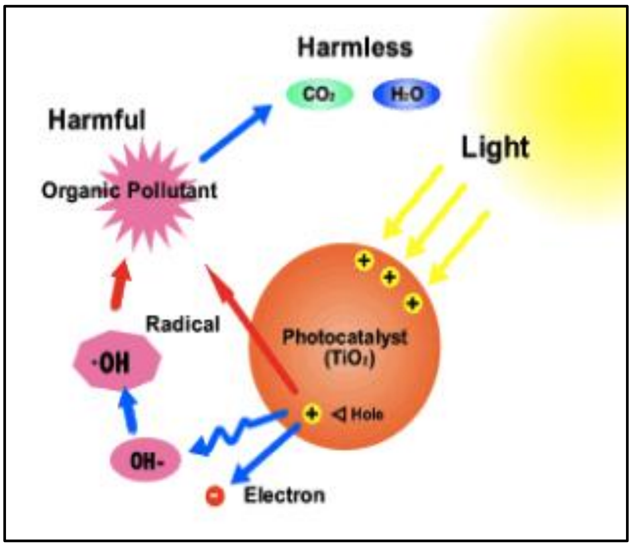


Figure 3.1: The Photo-catalysis Process

The photo-catalysis is a process of acceleration of a photoreaction in the presence of a catalysed photolysis. The **Figure 3.1** explains photo-catalytic process of TiO_2. The Titanium dioxide is an excellent photo catalyst with high chemical stability when exposed to acidic and basic compounds. Other advantages of TiO_2 are:

- Non-toxicity
- Cheaply available
- High oxidizing power

TiO_2as a photo catalyst is not as effective in the removal of VOCs and NOx and thus need to be doped with substrates to improve its activity. This improves the surface area of TiO_2 thus providing greater number of active sites for the removal of toxic pollutants.

3.1.2. Design of the Air cleaning unit

The design of the air cleaning unit has been made considering various factors such as compact, economical, durability and efficiency without compensating on efficiency and effectiveness.

The **Figure 3.2** shows the schematic representation of the proposed unit. The air is fed into the system through the inlet with the help of an axial fan. The air is passed through Pre-filter and HEPA filter where the particulate matter is minimized and the other toxic pollutants are removed when the air gets passed through the components such as UV Lamps, TiO_2 Layers and $CaCO_3$ filter. The clean air fed out through the outlet into the atmosphere.

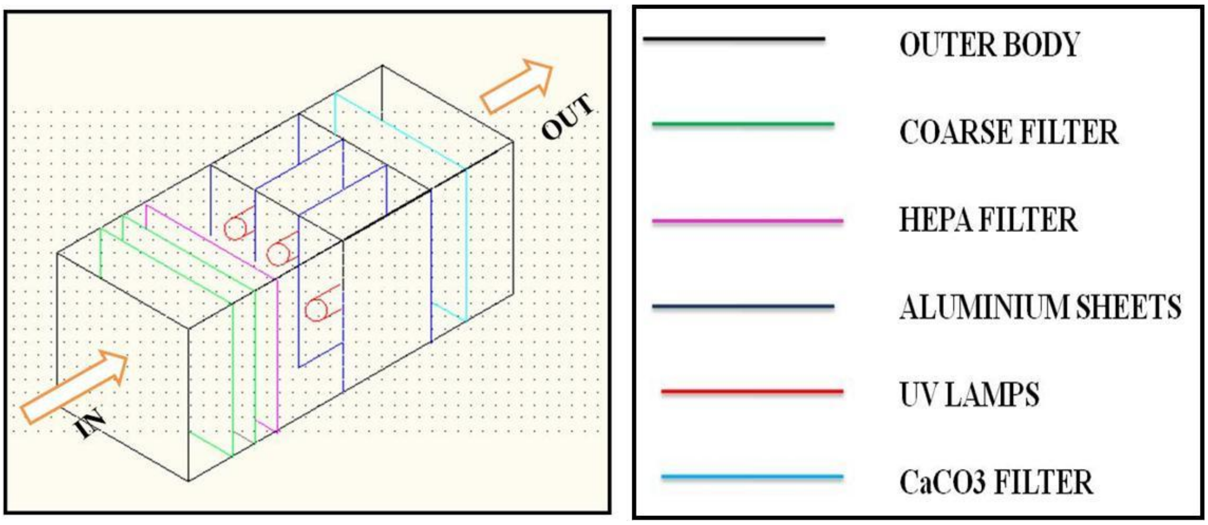


Figure 3.2:The schematic representation of the proposed unit

3.1.3 Outer Body

The **Figure 3.3** shows the outer body design of the proposed unit. The outer body is designed in such a way that it is compact, aesthetic, economical and durable. The outer body is made up of metal preferably stainless steel which protects the inner components from mechanical shocks and maintain high life cycle. The body part is also designed considering the fact to make it easier while operation and maintenance.

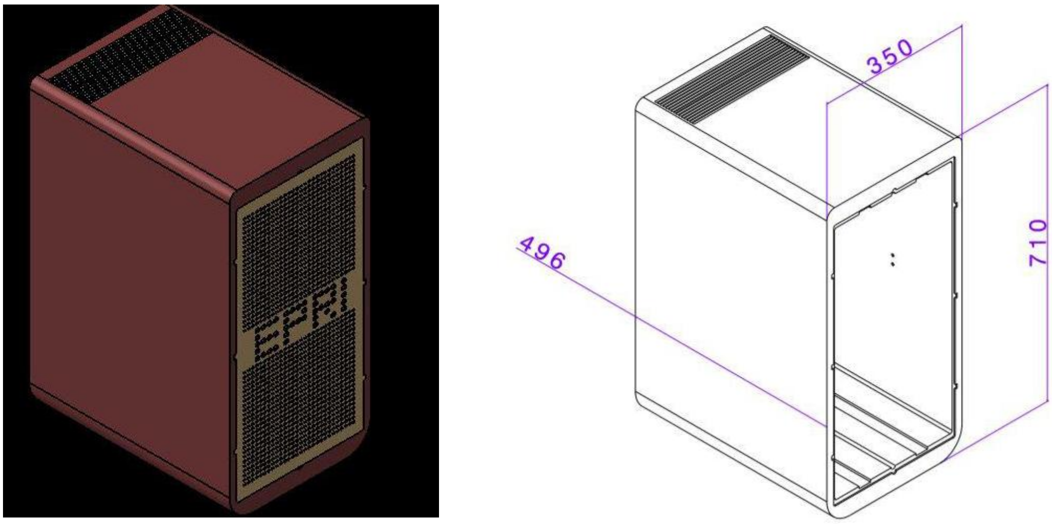


Figure 3.3: The outer body design of the proposed unit

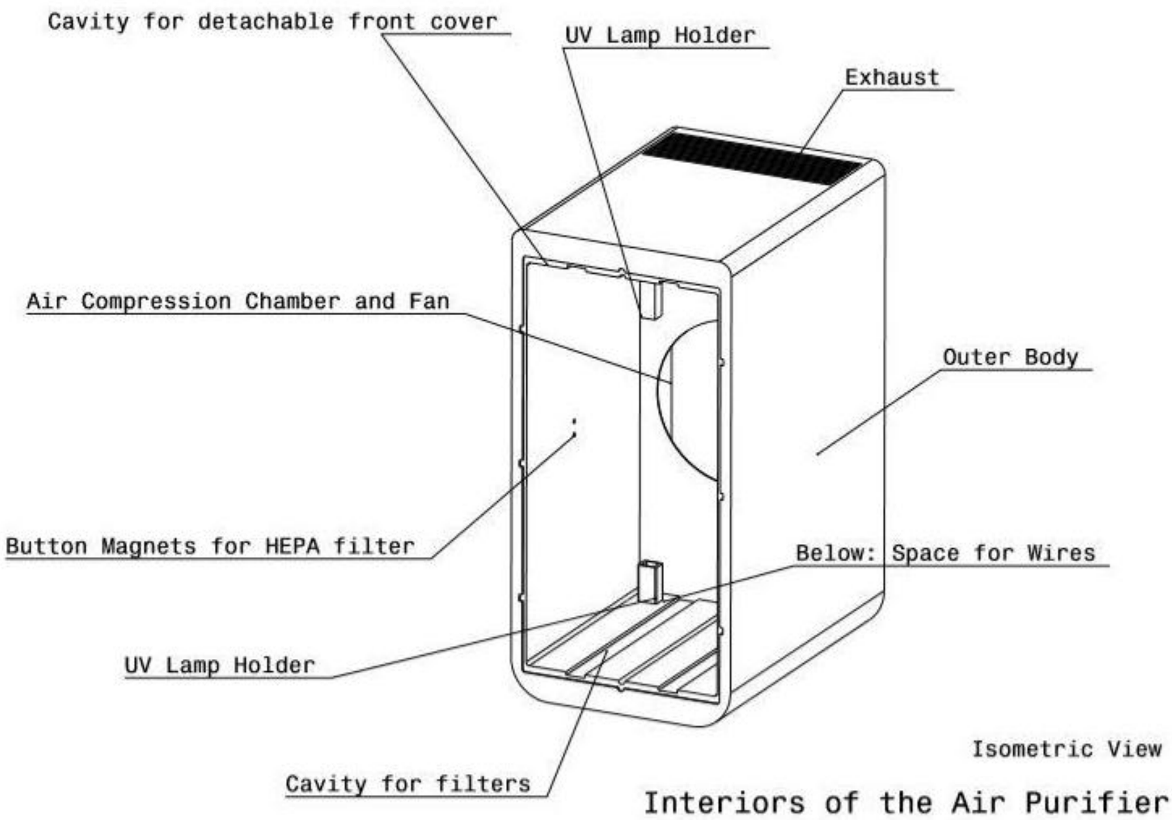


Figure3.4: The components and its positioning inside the proposed unit

The **Figure 3.4** shows the positioning of the components inside the proposed unit. The each componenthas been positioned in such a way that it gives good efficiency and performance.

3.2.4 Inner Components

The air cleaning unit consists of various components namely,

- Primary Filter
- HEPA Filter
- Photo catalytic Filter
- UV Lamps
- $CaCO_3$ coated Filter
- Axial Fan

A. Primary and HEPA Filter

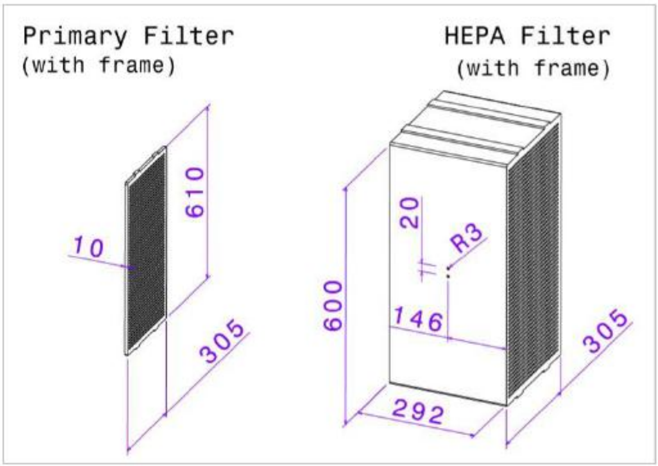


Figure 3.5: Primary Filter and HEPA Filter

Figure 3.5 shows the pre-filter and HEPA filter for the air cleaning unit. The pre-filter will separate the large portions of dust up to 10 µm. The air from the pre filter will be filtered out again through HEPA filter with an MERV rating of 9-12, which can remove about 99.99% of particles of very minute particle size.

B. Photo catalytic Filter

The photo catalytic filter is installed in between the HEPA Filter and $CaCO_3$ Filter where the pollutants are allowed to react with the TiO_2 coating. The aluminium sheets are coated with TiO_2-SiO_2 mixture and placed.

C. UVLamps

Figure 3.6: UV Lamp

The UV Lamp acts as a source of UV rays (Figure 3.6) which induces the photo catalytic reactions. Illumination of the TiO_2 surfaces induces the separation of two carriers, an electron and a hole, as shown in the equation 1.

$$TiO_2 + hv \rightarrow h^+ + e^- \quad \text{...equation1}$$

D. $CaCO_3$ Filter

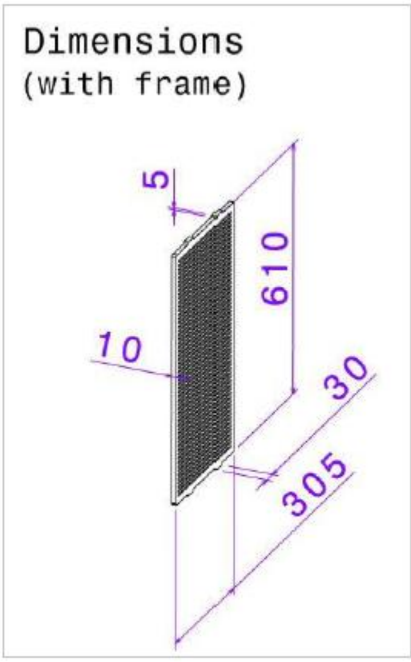


Figure 3.7: $CaCO_3$ Filter

The $CaCO_3$ coated aluminium sheet (**Figure 3.7**) helps to neutralize the by-products of the preceding chemical reactions. The following are the oxidation reaction takes place.

i. Photo catalytic oxidation of hydrocarbons

$$HC + {}^{\cdot}OH^{-} \rightarrow CO_2 + H_2O............(equation 2)$$

ii. Photo catalytic oxidation of NO_x: This involves a series of oxidation step

$$NO + {}^{\cdot}OH^{-} \rightarrow HNO_2 \xrightarrow{{}^{\cdot}OH^{-}} NO_2 \xrightarrow{{}^{\cdot}OH^{-}} HNO_3...........(equation 3)$$

iii. As a result NO_x gets ultimately converted to HNO_2 or HNO_3. To trap it within the filter unit, a $CaCO_3$ deposited pad will be kept beneath every cylindrical unit, such that the produced HNO_3/HNO_2 will react with $CaCO_3$ and form

$$HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O...............(equation 4)$$

E. Axial Fan

Figure 3.8:Axial fan

An axial fan(**Figure 3.8**) would be mounted in the unitto draw the air into the system and to throw back the clean air into the atmosphere. The axial fan is positioned at the exhaust part of the proposed unit. The average air flow rate of the axial fan is estimated to 1900-2000 m^3/hr. for an optimum performance of the proposed unit.

Based on the filtration unit design and the above elucidated components, the unit was fabricated. The test results revealed that the filtration unit is capable to filter air in an average area of 510 sqmt.The flow rate is about 1145 m^3/hour. The pictorial image of the filtration unit is given in the **Figure 3.9**

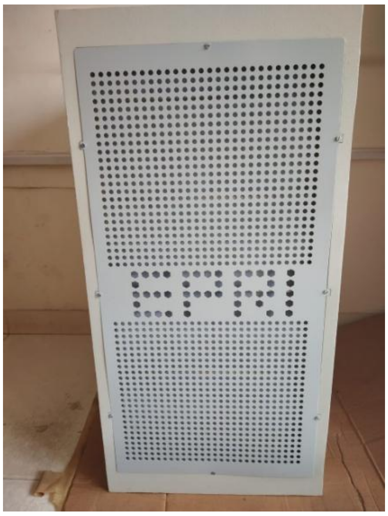


Figure 3.9: Air Filtration Unit by EPRI

Chapter 4 Results & Interpretation

As discussed in **Figure 2.4** Methodology for the project which is detailed in Chapter 2; initially the background readings of the pollutants were taken for getting an overview of the quantum of pollutants present in the selected site. Therefore, monitoring was carried out for the said site and readings were taken. Seasonal readings were taken for more accurateness viz- pre monsoon and monsoon season readings. These background readings are depicted in **Table 4.1** for Pre monsoon season and **Table 4.2** for Monsoon readings.

Table 4.1: Pollutant concentration at Petrol Pump site location for Pre-Monsoon season

Date	Methanol	Benzene	Toluene	Xylene mixed	TVOC	NOx	PM1	PM 2.5	PM 10
29-May	0.64	0.38	0.1	0.3	13.4	56	66	53	83
30-May	0.8	1.6	0.1	1.8	16.4	61	55	59	64
31-May	0.6	0.1	0.2	0.6	36	52	46	49	93
01-Jun	1.2	0	0.3	0	13	40	45	42	77
02-Jun	0.5	0.5	0.2	0.3	21.2	57	52	53	67
04-Jun	0.5	0	0.2	0	5.9	35	45	38	66
05-Jun	0.2	0.2	0.1	0.1	12.6	23	45	53	70
06-Jun	1.1	0.1	0	0.9	4.8	56	52	43	61
07-Jun	0.4	0.3	0	0	35.5	32	56	58	94
08-Jun	0.5	0.6	0.1	0	6.5	56	53	49	96
09-Jun	0.7	0.7	0	1.2	7.2	44	59	55	74
11-Jun	0.1	0.1	0.2	0.5	40.2	42	42	45	96
12-Jun	0.4	0.3	0.1	0.1	3	35	53	52	66
13-Jun	1.1	0.5	0	0.2	6.7	53	36	53	78
14-Jun	1.1	0.6	0.2	0	5.2	56	38	45	46
15-Jun	1.6	0.8	0.3	1.1	15.5	32	49	46	80
16-Jun	0.6	0.2	0.4	1.2	12.6	38	51	45	78
18-Jun	0.4	0.3	0	0	25.5	68	45	46	66
19-Jun	1.1	0.5	0	0.5	3.7	49	56	61	72
20-Jun	0.5	0.4	0.1	0	7.2	57	52	41	63
21-Jun	0.3	0.2	0	0	5.5	43	29	39	94
22-Jun	0.5	0.8	2	0.5	12.6	46	36	52	87
23-Jun	0.5	0.7	0	0.2	10.2	55	33	59	88

25-Jun	1.3	0.8	0.3	0.1	0.5	41	58	39	90
26-Jun	0.4	0.2	0	0.7	7.2	43	49	67	76
27-Jun	0.1	0.1	0	0	20.1	52	55	44	69
28-Jun	0.2	0.5	0.6	0	9.5	46	39	66	93
Mean	**0.6**	**0.4**	**0.2**	**0.3**	**13.4**	**47**	**47.3**	**49.9**	**77.5**
Mode	0.5	0.2	0.0	0.0	12.6	56	45	53	66
95% Percentile	1.25	0.85	0.5	1.2	35.75	60.5	58.5	63.5	95

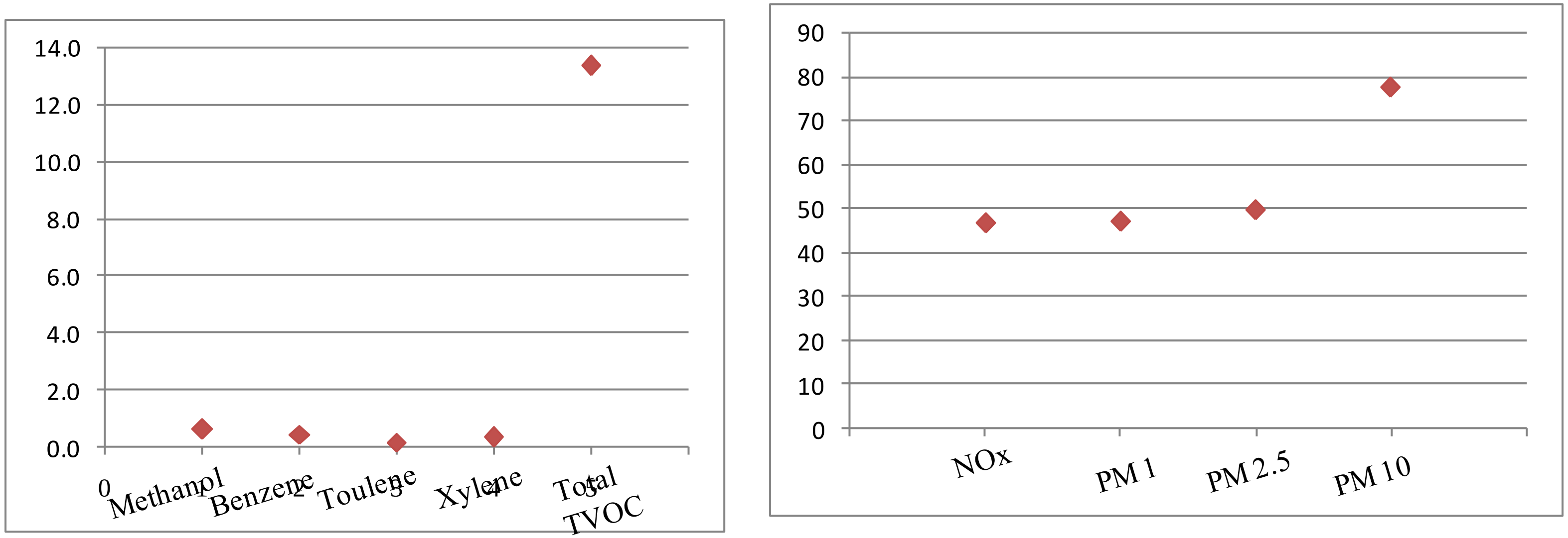


Figure 4.1: Graph showing the Pre-monsoon readings of Pollutants

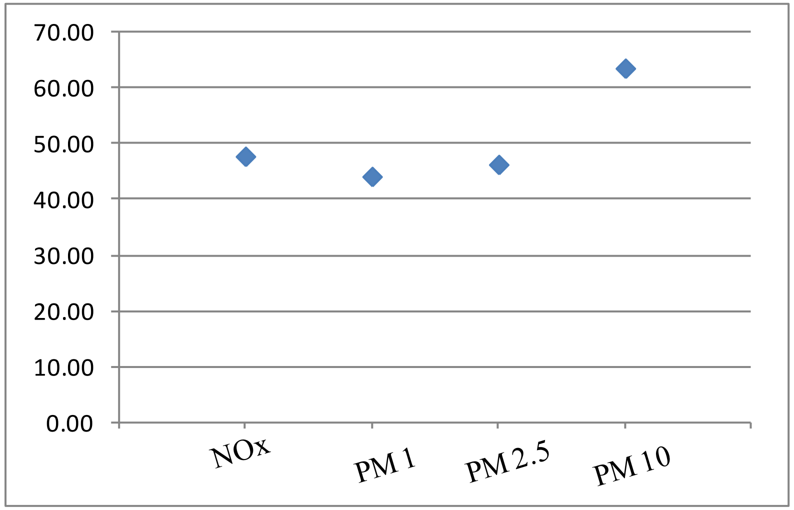
It can be seen that the total Volatile Organic Carbon, NOx and Particulate matter especially the PM 10 is at the highest. There is also Methane and Benzene presence observed, whereas low levels of Toulene and Xylene is seen.

Pollutant concentration in the month of Monsoon was also monitored in order to get an idea of the pollutant level at the site for w.r.t. seasonal variation, if any.

Table 4.2: The pollutant concentration at Petrol Pump site location for Monsoon season

Date	Methanol	Benzene	Toluene	Xylene mixed	TVOC	NOx	PM1	PM 2.5	PM 10
07-Jul	0.10	0.3	0.2	0.2	10.1	55	37	53	74
09-Jul	0.3	0.1	0.1	0.5	27	49	46	36	68
10-Jul	0.1	1.1	0.2	0.1	13	57	45	52	79
11-Jul	0.4	0.9	0.3	0.4	21.2	33	52	29	60
12-Jul	0.2	0.6	0.4	0	5.2	46	46	36	47
13-Jul	0.5	0	0.2	0	19	55	45	43	69
14-Jul	0.1	0.2	0.1	0.2	9	50	48	43	73
16-Jul	0.4	0.2	0	0	9.2	49	46	58	57
17-Jul	0.5	0.6	0.5	0.1	10.2	36	41	49	66
18-Jul	0.4	0.8	0	0.7	5.5	44	39	55	54
19-Jul	0.5	0.3	0.2	0.2	11.6	49	51	39	65
20-Jul	0.3	0.7	0.1	0	6.3	36	42	37	68
21-Jul	0.4	0.4	0	0.1	6	45	37	44	45
23-Jul	1.2	0.2	0.1	0	15	56	38	45	46
24-Jul	0.7	0.2	0	1.2	8.8	47	49	52	50
25-Jul	0.6	0.5	0.2	0.6	9.6	52	51	47	78
26-Jul	0.5	0.6	0	0	15	55	33	39	62

27-Jul	0.2	0.5	0.2	0.6	11.9	48	45	67	66
28-Jul	0.1	0.3	0.4	0.3	9	59	36	44	69
30-Jul	0.3	0.1	0.1	0.1	9.2	46	29	41	65
31-Jul	0.4	1.1	1.2	0.1	10.2	55	36	39	49
01-Aug	0.2	0.1	1.1	0.2	22	50	43	59	66
02-Aug	0.4	0.2	0.4	0.1	11.6	43	43	49	78
03-Aug	0.6	0.6	1.1	0.2	19	31	52	55	46
04-Aug	0.3	0.3	0	0.4	13.2	42	49	39	69
06-Aug	0.4	0.2	0.6	0.2	10.1	39	49	46	61
Mean	**0.42**	**0.40**	**0.2**	**0.2**	**12.7**	**47.6**	**44.1**	**46.2**	**63.3**
Mode	0.4	0.2	0	0	10.1	55	52	39	69
95% Percentile	0.9	1	1.1	0.8	21.6	58	52	62.5	78



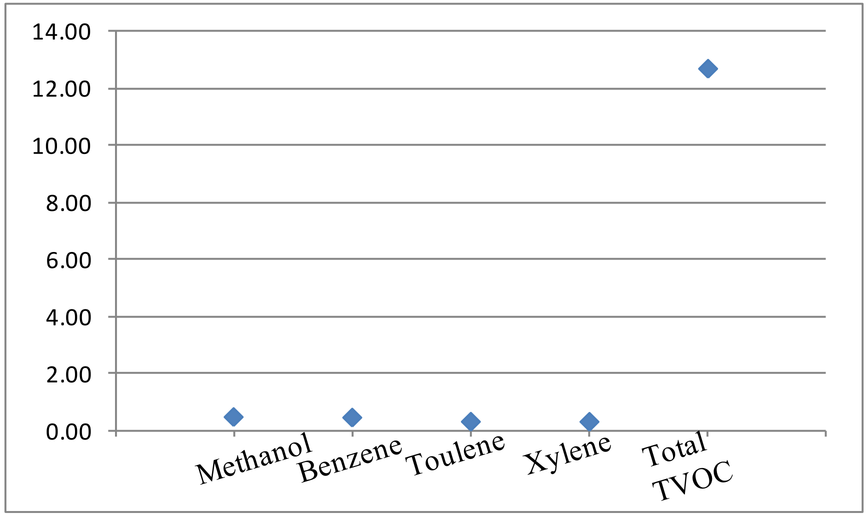


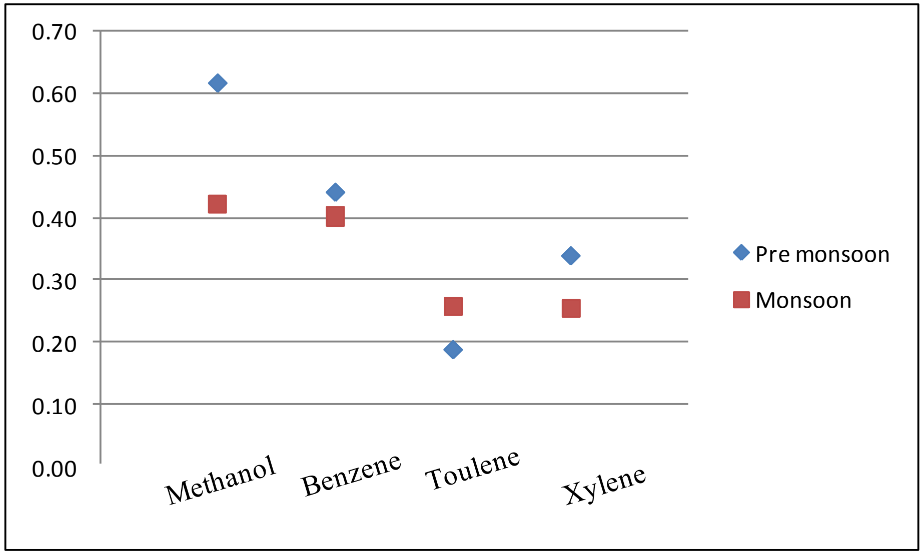
Figure 4.2: Graph showing the Monsoon readings of Pollutants

The concentration of pollutants such as PM, NOx, VOCs has been monitored for both pre-monsoon and monsoon seasons from the Petrol Pump site. The mean value of the total VOC during pre-monsoon season is 13.4 ppm whereas during monsoon it comes down to the value of 12.7 ppm. Similarly, PM_{10} with a value of 77.5µg/m^3 in pre-monsoon season comes down to 63.9µg/m^3 during monsoon season. It is understood from the **Table 7.1 and Table 7.2** that there is a gradual decrease in monsoon when comparing it with the pre-monsoon which indicates the impact of rain subsided down the pollutant level.

A comparative statement of Pre-monsoon and Monsoon season is done as an additional study and shown in **Table 4.3 and a graph is shown for the same in Figure 4.3**

Table 4.3: The pollutant concentration at Petrol Pump site location for Monsoon season

Particulars	Methanol	Benzene	Toluene	Xylene mixed	TVOC	NOx	PM1	PM 2.5	PM 10
Pre - monsoon	0.62	0.44	0.19	0.34	13.38	46.94	47.29	49.87	77.48
Monsoon	0.42	0.40	0.26	0.25	12.70	47.68	44.10	46.23	63.32



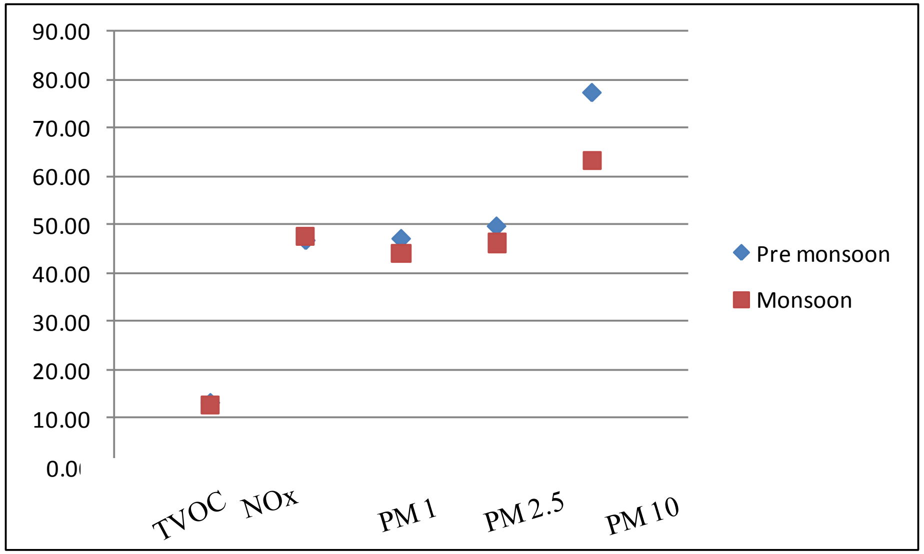


Figure 4.3: Comparative Graph of Monsoon & Pre Monsoon readings of Pollutants

Further, analysis was also carried out for winter season. The pollutant levels were monitored using the instruments with and without installation of the Air filtration Unit at the selected site. The Air filtration Unit was mounted @ the Teen Petrol Pump and readings were taken @ a distance of 3 meters, 10 meters and 15 metres away from the filtration Unit. **Figure 4.4** shows the image and position of the installed filtration Unit and spots were readings were taken to know the ideal efficiency of the filtration unit w.r.t. the distance.

4.1 Rationale behind selecting different points for monitoring:

The Air filtration unit was installed at the point of source near the petrol pump. Readings are taken from the inlet and out let of the prototype. Further, in order to check the efficiency of the prototype, readings were taken at varied distance viz.3 mt, 10 mt and 15 mt of distance from the prototype. The intension behind keeping varied distance is to check the concentration of the pollutants that the filtration unit can combat.

The following schematic diagram in **Figure 4.4** and **Figure 4.5** shows the position of the Air filtration installed and the locations as said above selected for monitoring the pollutant levels. There are four readings taken at different locations. They are elucidated as under:

a) Inlet concentration of pollutants at the prototype
b) Outlet concentration of pollutants from the prototype
c) Concentration of pollutants at a distance of 3 mt from the prototype
d) Concentration of pollutants at a distance of 10 mt from the prototype
e) Concentration of pollutants at a distance of 15 mt from the prototype

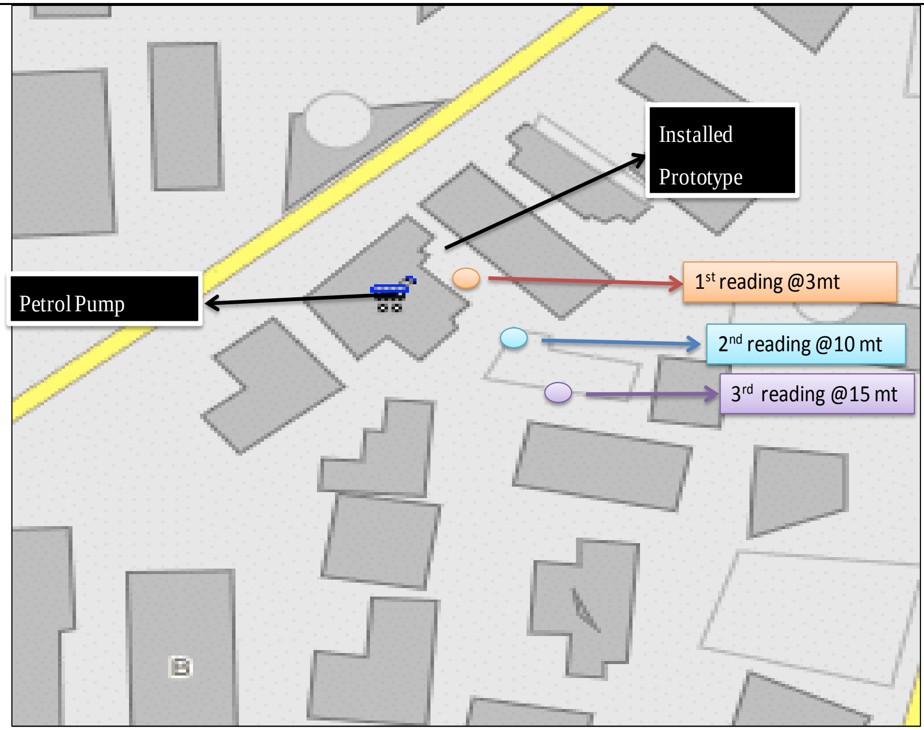


Figure 4.4: Position of the Installed Filtration Unit and site of readings taken

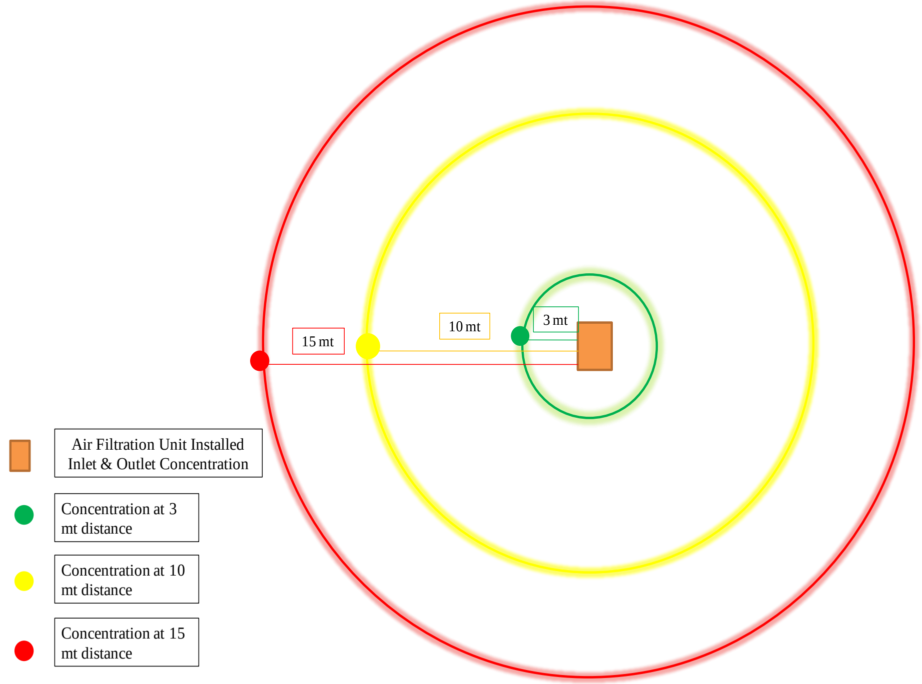


Figure 4.5: Schematic pattern of installed Air filtration unit and monitoring locations

4.2 Monitoring of results at Petrol Pump:

Following are tables with concentration of pollutants monitored at different locations along with its efficiency calculated as per change in the distance. **Table 4.4, Table 4.5 and Table 4.6**shows the concentration of Particulate matter 10, PM 2.5 and PM 1 respectively taken at the inlet & outlet of the prototype which was installed at the petrol pump. Further, concentration of pollutants at a distance of 3 mt, 10 mt and 15 mt from the prototype is also shown in the same.

Table 4.4: Concentration of Particulate Matter 10 at the petrol pump site

Particulate Matter-10									
Sr. No.	**PM 10 Inlet concentration**	**Outlet concentration**	**PM 10 -% Efficiency**	**At 3 mt distance**	**PM 10 - % Efficiency**	**At 10 mt distance**	**PM 10 -% Efficiency**	**At 15 mt distance**	**PM 10 -% Efficiency**
1	268	14	95	39	85.4	62	77	83	69
2	393	36	91	42	89.3	74	81	62	84
3	125	20	84	23	81.6	61	51	77	38
4	166	16	90	21	87.3	33	80	56	66
5	150	11	93	22	85.3	39	74	91	39
6	124	6	95	19	84.7	49	60	58	53
7	385	5	99	13	96.6	77	80	50	87
8	127	9	93	14	89.0	62	51	71	44
9	268	11	96	25	90.7	75	72	64	76
10	286	21	93	35	87.8	65	77	46	84
Average	**229**	**15**	**93**	**25**	**88**	**60**	**70**	**64**	**64**
Mode	268	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	389	29	97	41	94	71	81	87	86

Table 4.5: Concentration of Particulate Matter 2.5 at the petrol pump site

Particulate Matter-2.5									
Sr. No.	**PM 10 Inlet concentration**	**Outlet concentration**	**PM 2.5 -% Efficiency**	**At 3 mt distance**	**PM 2.5 -% Efficiency**	**At 10 mt distance**	**PM 2.5 - % Efficiency**	**At 15 mt distance**	**PM 2.5 -% Efficiency**
1	101	10	90	12	88.1	31	69	40	60
2	163	16	90	21	87.1	29.00	82	59	64
3	95	11	88	16	83.6	43.00	55	45	53
4	126	11	91	23	81.7	34.00	73	41	67
5	157	12	92	18	88.7	41.00	74	66	58
6	99	9	91	14	85.7	33.00	67	41	59
7	134	6	96	12	91.0	60.00	55	44	67
8	169	11	93	16	90.2	45.00	73	66	61
9	111	10	91	21	81.1	39.00	65	34	69
10	143	19	87	30	79.0	28.00	80	66	54
Average	**130**	**12**	**91**	**17**	**86**	**39**	**69**	**50**	**61**
Mode	#N/A	11	#N/A	12	#N/A	#N/A	#N/A	66	#N/A
95% Percentile	166	18	95	27	91	53	81	66	69

Table 4.6: Concentration of Particulate Matter 1 at the petrol pump site

Particulate Matter-1									
Sr. No.	**PM 1 Inlet concentration**	**Outlet concentration**	**PM 1 -% Efficiency**	**At 3 mt distance**	**PM 1 -% Efficiency**	**At 10 mt distance**	**PM 1 -% Efficiency**	**At 15 mt distance**	**PM 1 -% Efficiency**
1	77	9	88	11	85.7	66.00	35	31	69
2	94	10	89	10	89.4	35.00	79	55	66
3	106	7	93	11	89.7	41.00	57	79	17
4	93	6	94	17	81.9	46.00	63	44	65
5	87	5	94	18	79.7	24.00	85	38	76
6	46	11	76	10	78.4	19.00	81	33	67
7	101	16	84	21	79.2	33.00	75	41	69
8	98	10	90	12	87.8	62.00	63	52	69
9	196	12	94	19	90.1	41.00	63	65	41
10	94	13	86	15	84.0	34.00	76	47	67
Average	**99**	**10**	**89**	**14**	**85**	**37**	**71**	**49**	**61**
Mode	94	10	#N/A	#N/A	#N/A	41	#N/A	#N/A	#N/A
95% Percentile	156	15	94	20	90	64	83	73	73

Detailed graphs of PM levels and efficiency of the Air filtration Unit estimated at varied distances is given in Annexure I of the report.

Table 4.7, Table 4.8, Table 4.9, Table 4.10, Table 4.11 and 4.12 shows concentration of Volatile Organic compounds

Table 4.7: Concentration of Methanol at the petrol pump site

Methanol									
Sr. No.	**Methanol Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt Distance**	**% Efficiency**	**At 10 mt distance**	**% Efficiency**	**At 15 mt distance**	**% Efficiency**
1	85	4	95	9	89	24	72	30	61
2	81	10	88	16	80	19	76	24	68
3	93	11	88	13	86	32	66	39	55
4	70	7	90	11	84	23	67	29	55
5	69	9	87	9	87	19	73	23	64
6	95	12	87	18	81	30	68	37	56
7	79	15	81	12	85	17	79	21	71
8	87	14	84	19	78	27	69	33	58
9	92	15	84	17	81	31	67	38	55
10	79	4	95	8	90	16	80	19	72
Average	**83**	**10**	**88**	**13**	**84**	**24**	**72**	**29**	**61**
Mode	#N/A	4	#N/A	9	#N/A	#N/A	#N/A	#N/A	55
95% Percentile	94	15	95	19	90	31	79	38	72

Table 4.8: Concentration of Benzene at the petrol pump site

Benzene									
Sr. No.	**Benzene Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt Distance**	**% Efficiency**	**At 10 mt Distance**	**% Efficiency**	**At 15 mt Distance**	**% Efficiency**
1	26	3	89	3	89	7	72	6	77
2	46	6	87	8	83	9	81	12	75
3	38	9	76	11	72	10	74	6	84
4	28	3	89	3	91	8	72	8	71
5	53	7	87	10	81	11	79	19	63
6	44	4	91	5	89	4	90	15	67
7	57	6	89	9	84	13	77	14	75
8	49	9	82	11	78	10	80	12	77
9	59	12	80	18	69	9	85	21	64
10	56	10	82	12	79	8	86	16	72
Average	**46**	**7**	**85**	**9**	**81**	**9**	**80**	**13**	**73**
Mode	#N/A	3	#N/A	#N/A	#N/A	8	#N/A	#N/A	#N/A
95% Percentile	58	11	90	15	90	12	88	20	81

Table 4.9: Concentration of Toluene at the petrol pump site

Toluene									
Sr. No.	**Toluene Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt Distance**	**% Efficiency**	**At 10 mt distance**	**% Efficiency**	**At 15 mt distance**	**% Efficiency**
1	80	20	75	26	67	12	84	14	82
2	57	11	81	14	76	14	76	15	71
3	70	12	83	15	78	15	77	19	70
4	65	9	86	11	83	21	66	23	61
5	77	8	90	9	88	26	63	29	57
6	73	13	82	17	77	20	72	27	58
7	69	14	80	19	72	20	70	39	38
8	69	10	86	16	76	14	80	15	77
9	75	6	92	8	90	12	83	35	47
10	55	10	82	13	77	10	81	13	74
Average	**69**	**11**	**84**	**15**	**79**	**16**	**75**	**23**	**63**
Mode	#N/A	10	#N/A	#N/A	#N/A	14	#N/A	#N/A	#N/A
95% Percentile	79	17	91	23	89	24	84	37	79

Table 4.10: Concentration of Xylene at the petrol pump site

Xylene mixed									
Sr. No.	**Xylene Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt Distance**	**% Efficiency**	**At 10 mt Distance**	**% Efficiency**	**At 15 mt Distance**	**% Efficiency**
1	35	8	77	12	66	12	59	16	40
2	38	5	87	11	70	12	67	15	51
3	40	6	85	8	81	8	81	10	72
4	35	6	83	7	80	7	82	9	74
5	46	10	78	13	72	13	70	18	55
6	42	4	90	5	89	5	88	7	82
7	36	5	86	4	89	4	87	6	81
8	56	10	82	15	73	16	52	21	30
9	45	13	71	16	66	16	61	21	43
10	53	9	83	10	81	10	79	14	69
Average	**43**	**8**	**82**	**10**	**77**	**10**	**73**	**14**	**60**
Mode	#N/A	5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	55	12	89	15	89	16	87	21	82

Table 4.11: Concentration of Ethanol at the petrol pump site

Ethanol										
Sr. No.	**Ethanol Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt Distance**	**% Efficiency**	**At 10 mt Distance**	**% Efficiency**	**At 15 mt Distance**	**% Efficiency**
1	75	13	83	16	79	17	77	22	68
2	67	9	86	11	83	12	82	15	75
3	84	17	80	22	75	22	72	29	62
4	65	15	77	18	72	19	69	24	59
5	74	13	83	16	79	26	63	35	48
6	86	20	77	22	75	23	71	31	60
7	64	11	83	14	78	15	76	20	66
8	82	12	85	14	84	24	69	32	57
9	82	14	83	22	73	24	69	32	56
10	71	9	87	13	82	33	51	42	35
Average	**75**	**13**	**82**	**17**	**78**	**22**	**70**	**28**	**59**
Mode	#N/A	13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	85	19	87	22	84	30	80	38	72

Table 4.12: Concentration of Total VOC at the petrol pump site

TVOC										
Sr. No.	**TVOC Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt Distance**	**% Efficiency**	**At 10 mt distance**	**% Efficiency**	**At 15 mt distance**	**% Efficiency**
1	350	36	90	74	79	80	76	101	66
2	398	78	80	111	72	120	68	151	55
3	356	55	85	71	80	77	77	97	68
4	342	78	77	93	73	109	66	138	55
5	317	53	83	66	79	71	77	92	69
6	354	42	88	51	86	66	80	83	73
7	370	39	89	69	81	100	71	126	61
8	359	33	91	71	80	86	73	109	64
9	335	41	88	62	81	121	62	152	50
10	359	37	90	60	83	66	79	87	70
Average	**354**	**49**	**86**	**73**	**80**	**90**	**73**	**114**	**63**
Mode	#N/A	78	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	385	78	90	102	84	120	80	151	71

Detailed graphs of VOC levels and the efficiency of the Air filtration Unit estimated at varied distances are given in Annexure II of the report.

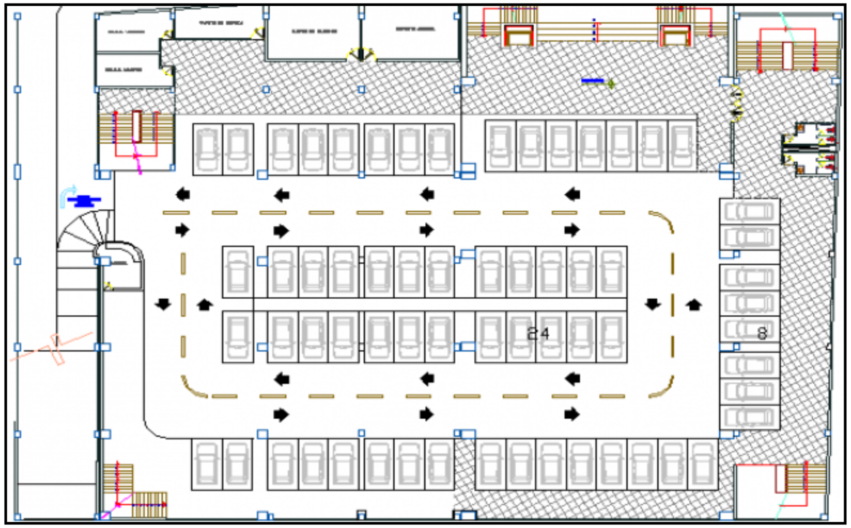
Table 4.13 shows concentration of Oxides of Nitrogen at petrol pump sites.

Table 4.12: Concentration of NOx at the petrol pump site

Nox									
Sr. No.	**NOx Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt distance**	**% Efficiency**	**At 10 mt distance**	**% Efficiency**	**At 15 mt distance**	**% Efficiency**
1	99	16	84	24	76	31	69	39	61
2	84	15	82	22	74	26	69	23	73
3	64	10	85	19	70	33	48	35	45
4	105	18	83	15	86	21	80	29	72
5	48	10	80	22	54	20	58	26	46
6	96	15	85	27	72	21	78	34	65
7	74	21	71	20	73	16	78	25	66
8	54	13	76	16	70	26	52	23	57
9	63	16	74	16	74	23	63	22	65
10	47	23	85	11	77	14	70	21	55
Average	**73**	**14**	**81**	**19**	**73**	**23.1**	**67**	**28**	**60**
Mode	#N/A	#N/A	#N/A	22	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	102	19	85	26	82	24	83	40	75

Detailed graphs of NOx levels and the efficiency of the Air filtration Unit estimated at varied distances are given in Annexure III of the report.

4.3 Monitoring of results at Basement:



Further, analysis was also carried out in Basement, which is enclosed. The selected basement is used for parking and storage purpose. In addition routine activities like sweeping of the basements, cleaning in short are carried out. The pollutant levels were monitored using the monitoring instruments same way as for Petrol pump site. The Air filtration Unit was mounted at the entrance of the parking next to the ramp. Some of the highlights of the observation are that there are frequent in and out movement of the vehicles, simultaneously there is sweeping and cleaning of the floors taken place at frequent intervals. Therefore, pollutants were monitored at the inlet, outlet of the prototype and also from a distance of 3 mt, 10 mt and 15 mt from the installed filtration unit.

Detailed concentration of pollutants are depicted in **Table 4.13** to **Table 4.15** for Particulate matter , **Table 4.16** to **Table 4.21** for VOC and for NOx in **Table 4.22.**

Table 4.13: Concentration of Particulate Matter 10 in Basement

Particulate Matter-10										
Sr. No.	**PM 10 Inlet Concentration**	**Outlet Concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	627	22	96	29	95	50	92	76	88
2	691	33	95	48	93	69	90	95	86
3	675	13	98	35	95	56	92	82	88
4	447	11	98	27	94	48	89	74	83
5	585	22	96	52	91	73	88	99	83
6	1292	42	97	49	96	70	95	96	93
7	1030	34	97	41	96	62	94	88	91
8	723	21	97	56	92	77	89	91	87
9	549	14	97	45	92	66	88	92	83
10	571	26	95	39	93	60	89	86	85
Avg	**719**	**22**	**97**	**42**	**94**	**63**	**91**	**88**	**87**
Mode	#N/A	22	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	1174	38	98	54	96	75	94	98	92

Table 4.14: Concentration of Particulate Matter 2.5 in Basement

Particulate Matter 2.5									
Sr. No.	**PM 2.5 Inlet Concentration**	**Outlet Concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	385	80	79	87	77	92	76	108	72
2	352	74	79	81	77	90	74	106	69
3	393	65	83	72	82	77	80	93	76
4	296	56	81	63	79	68	77	84	71
5	315	49	84	56	82	71	77	87	72
6	325	36	89	43	87	48	85	64	80
7	285	46	84	53	81	58	80	74	74
8	253	33	87	40	84	55	78	71	71
9	211	31	85	38	82	69	67	85	59
10	216	27	88	34	84	62	71	78	63
Average	**294**	**46**	**85**	**53**	**82**	**66**	**77**	**85**	**71**
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	390	77	88	84	86	91	83	107	79

Table 4.15: Concentration of Particulate Matter 1 in Basement

Particulate Matter-1									
Sr. No.	**PM 1-Inlet Concentration**	**Outlet Concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	109	12	89	16	85	26	76	33	70
2	88	26	71	31	65	35	60	42	52
3	91	19	79	22	76	29	68	37	59
4	86	12	86	19	78	21	76	32	63
5	135	17	87	23	83	28	79	35	74
6	89	19	79	21	76	23	74	37	58
7	127	22	83	29	77	32	75	44	65
8	103	20	80	21	80	29	72	35	66
9	123	27	78	30	76	41	67	50	59
10	135	22	84	28	79	36	73	46	66
Average	**109**	**19.6**	**82**	**24**	**77**	**30**	**72**	**39**	**63**
Mode	#N/A	12	#N/A	29	#N/A	29	#N/A	37	#N/A
95% Percentile	135	27	88	39	78	39	78	48	72

Detailed graphs of Particulate levels and the efficiency of the Air filtration Unit estimated at varied distances are given in Annexure IV of the report.

Table 4.16: Concentration of Methanol in Basement

Methanol									
Sr. No.	**Methanol Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	93	9	90	16	83	25	70	36	61
2	89	2	98	9	90	32	64	43	52
3	95	4	96	11	88	23	74	24	75
4	77	6	92	13	83	21	75	32	58
5	65	7	89	14	78	22	72	33	49
6	93	4	96	11	88	22	75	36	61
7	79	1	99	8	90	17	81	21	73
8	87	5	94	12	86	25	71	36	59
9	91	8	91	15	84	20	76	31	66
10	78	7	91	14	82	16	81	27	66
Average	**85**	**5**	**94**	**12**	**85**	**22**	**74**	**32**	**62**
Mode	93	4	#N/A	11	#N/A	#N/A	#N/A	36	#N/A
95% Percentile	94	9	98	16	90	29	81	40	74

Table 4.17: Concentration of Benzene in Basement

Benzene									
Sr. No.	**Benzene Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	31	6	81	7	77	12	61	15	52
2	33	3	91	8	76	11	67	12	64
3	45	6	87	11	76	16	64	19	58
4	22	5	77	3	88	10	55	14	36
5	43	4	91	9	79	15	65	18	58
6	36	11	69	5	86	11	69	14	61
7	42	4	90	9	78	17	60	18	57
8	39	2	95	6	85	9	77	12	69
9	47	3	94	8	83	12	74	15	68
10	56	7	88	12	79	15	73	16	72
Average	**39**	**5**	**86**	**8**	**81**	**13**	**67**	**15**	**59**
Mode	#N/A	3	#N/A	8	#N/A	12	#N/A	15	#N/A
95% Percentile	52	9	94	11	87	17	76	19	70

Table 4.18: Concentration of Toluene in Basement

Toluene									
Sr. No.	**Toluene Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	77	23	70	24	69	28	64	30	61
2	62	12	81	15	76	18	71	21	66
3	53	11	79	19	64	24	55	26	51
4	61	18	70	25	59	28	54	28	54
5	69	10	86	16	77	19	72	21	70
6	69	15	78	21	70	26	62	27	61
7	77	14	82	18	77	21	73	23	70
8	63	12	81	15	76	17	73	18	71
9	55	13	76	24	56	27	51	29	47
10	54	8	85	19	65	21	61	23	57
Average	**64**	**14**	**79**	**20**	**69**	**23**	**64**	**25**	**61**
Mode	77	12	#N/A	24	#N/A	28	#N/A	21	#N/A
95% Percentile	77	21	85	25	77	28	73	30	71

Table 4.19: Concentration of Xylene in Basement

Xylene mixed									
Sr. No.	**Xylene Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	39	9	77	14	64	17	56	19	51
2	33	6	82	11	67	15	55	16	52
3	35	8	78	13	64	17	53	19	47
4	42	7	84	12	72	13	69	15	64
5	39	9	77	10	74	14	64	14	64
6	32	5	85	9	72	11	66	13	59
7	48	4	91	9	81	13	73	14	71
8	39	7	82	15	62	19	51	21	46
9	43	9	79	16	63	20	53	21	51
10	46	5	89	9	80	12	74	14	70
Average	**40**	**7**	**82**	**12**	**70**	**15**	**61**	**17**	**58**
Mode	39	9	77	9	#N/A	#N/A	#N/A	14	#N/A
95% Percentile	47	9	90	16	81	20	73	21	70

Table 4.20: Concentration of Ethanol in Basement

Ethanol									
Sr. No.	**Ethanol Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	84	11	87	17	80	22	74	25	70
2	67	12	82	15	77	19	71	20	70
3	77	12	84	18	77	23	70	26	66
4	69	13	81	20	71	22	68	23	67
5	72	12	83	18	75	23	68	26	64
6	82	19	77	25	70	30	63	33	60
7	66	9	86	16	76	19	71	23	65
8	79	12	85	19	76	24	70	27	66
9	77	21	73	27	65	30	61	36	53
10	65	23	65	27	58	32	51	33	49
Average	**74**	**14**	**80**	**20**	**72**	**24**	**67**	**27**	**63**
Mode	77	12	#N/A	18	#N/A	22	#N/A	26	#N/A
95% Percentile	83	22	87	27	79	31	73	35	70

Table 4.21: Concentration of TVOC in Basement

TVOC									
Sr. No.	**TVOC Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	269	54	80	69	74	81	70	100	63
2	362	86	76	101	72	113	69	132	64
3	356	71	80	86	76	98	72	117	67
4	349	63	82	78	78	90	74	109	69
5	283	42	85	57	80	69	76	88	69
6	363	50	86	65	82	77	79	96	74
7	340	59	83	74	78	86	75	105	69
8	321	63	80	78	76	90	72	109	66
9	313	58	81	73	77	85	73	104	67
10	296	43	85	58	80	70	76	89	70
Average	**325**	**59**	**82**	**74**	**77**	**86**	**74**	**105**	**68**
Mode	#N/A	63	#N/A	78	#N/A	90	#N/A	109	#N/A
95% Percentile	363	79	86	94	81	106	78	125	72

Detailed graphs of VOC and the efficiency of the Air filtration Unit estimated at varied distances are given in Annexure V of the report.

Table 4.22: Concentration of Oxides of Nitrogen in Basement

NOx										
Sr. No.	**Inlet concentration**	**Outlet concentration**	**% Efficiency**	**At 3 mt**	**% Efficiency**	**At 10 mt**	**% Efficiency**	**At 15 mt**	**% Efficiency**
1	79	8	90	13	84	15	81	19	76
2	81	9	89	14	83	13	84	29	64
3	66	6	91	11	83	11	83	19	71
4	58	12	79	17	71	22	61	17	71
5	101	4	96	9	91	14	86	21	79
6	82	10	88	15	82	26	69	26	68
7	54	3	94	8	85	6	89	21	61
8	77	8	90	13	83	11	86	24	69
9	60	2	97	7	88	9	85	18	70
10	51	2	96	7	86	10	80	26	49
Avg	**71**	**6**	**91**	**11**	**84**	**14**	**80**	**22**	**68**
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
95% Percentile	92	11	96	16	90	24	83	40	75

Detailed graphs of NOx and the efficiency of the Air filtration Unit estimated at varied distances are given in Annexure IV of the report.

4.4 Interpretation:

Petrol Pump: In addition to the installation of the fabricated Air filtration Unit, efficiency of the Unit was estimated using the above mentioned monitoring results and graphs (refer Annexure I, II and III). The below table shows the efficiency of the instrument with respect to the distance covered. The Average percentage efficiency of the filtration unit is depicted in the comparative **Table 4.23** for all the pollutants monitored and a graph depicting the percentage efficiency in **Figure 4.5.**

Table 4.23: Efficiency of the Filtration unit for pollutant removal at varied distance of Petrol Pump

Distance		At Prototype	Distance		
			3 mt	10 mt	15 mt
Area covered (sqmt)		NA	28.3	314.0	706.5
Percentage Efficiency of the Air filtration unit	PM 10	93	88	70	64
	PM 2.5	91	86	69	61
	PM 1	89	85	71	61
	Methanol	88	84	72	61
	Benzene	85	81	80	73
	Toluene	84	79	75	63
	Xylene	82	77	73	60
	Ethanol	82	78	70	59
	TVOC	86	80	73	63
	NOx	81	73	67	60

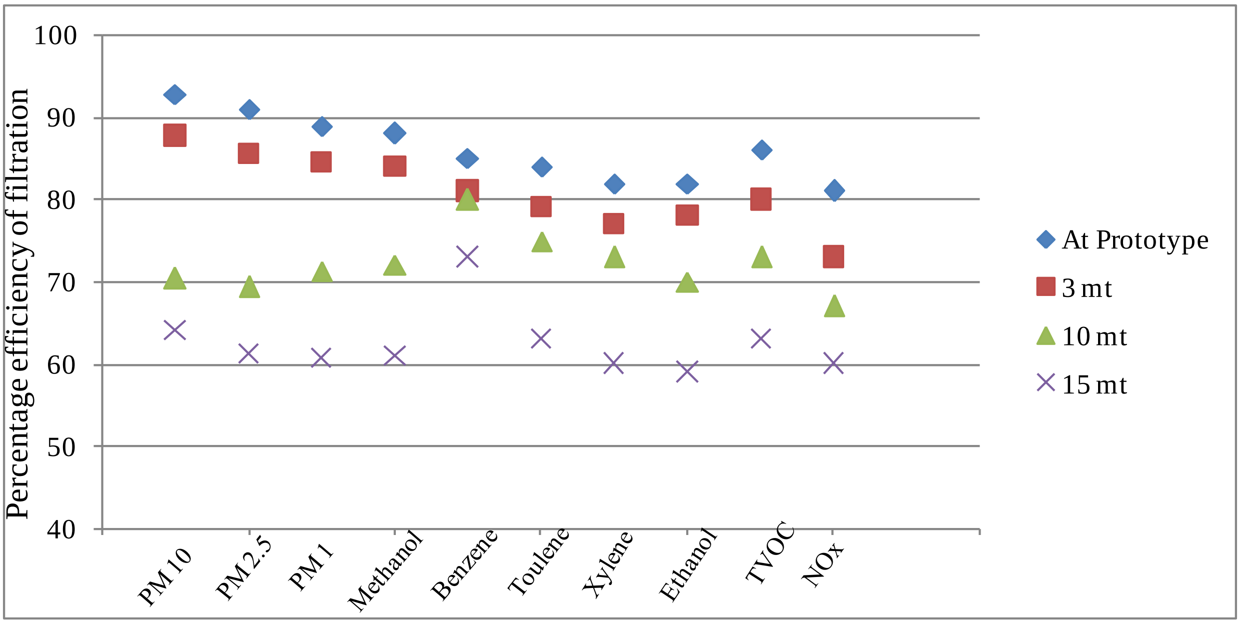


Figure 4.5: Comparative graph showing the percentage efficiency of the Filtration Unit at varied distance on Petrol Pump site

It is clear from the above graph and table that the Air filtration unit filters about more than 90% of the pollutants when monitored its outlet air. Whereas, at 3 mt too it filters around90-80% and rest it ranges from more than 70% to 60% for 10mt and 15 mt respectively.

Basement: As discussed above, the Unit was installed at a point where there was in as well as outward continuous movement of vehicles. This allows the unit to filter out maximum pollutants as it is near the source. Therefore, initially the results were monitored at the outlet of the unit and then at 3 mt, 10 mt and 15 mt distance away from the unit were selected for monitoring the results. The efficiency of the Unit was determined based on the results observed and comparison **Table 4.24** as below:

Table 4.24: Efficiency of the Filtration unit for pollutant removal at varied distance in Basement

Distance / Pollutants		At Prototype	Distance		
			3 mt	10 mt	15 mt
Area covered (sqmt)		NA	28.3	314.0	706.5
Percentage Efficiency of the Air filtration unit	PM 10	97	94	91	87
	PM 2.5	85	82	77	71
	PM 1	82	77	72	63
	Methanol	94	85	74	62
	Benzene	86	81	67	59
	Toluene	79	69	64	61
	Xylene	82	70	61	58
	Ethanol	80	72	67	63
	TVOC	82	77	74	68
	NOx	91	84	80	68

A graphical representation of the same is given in **Figure 4.6.**

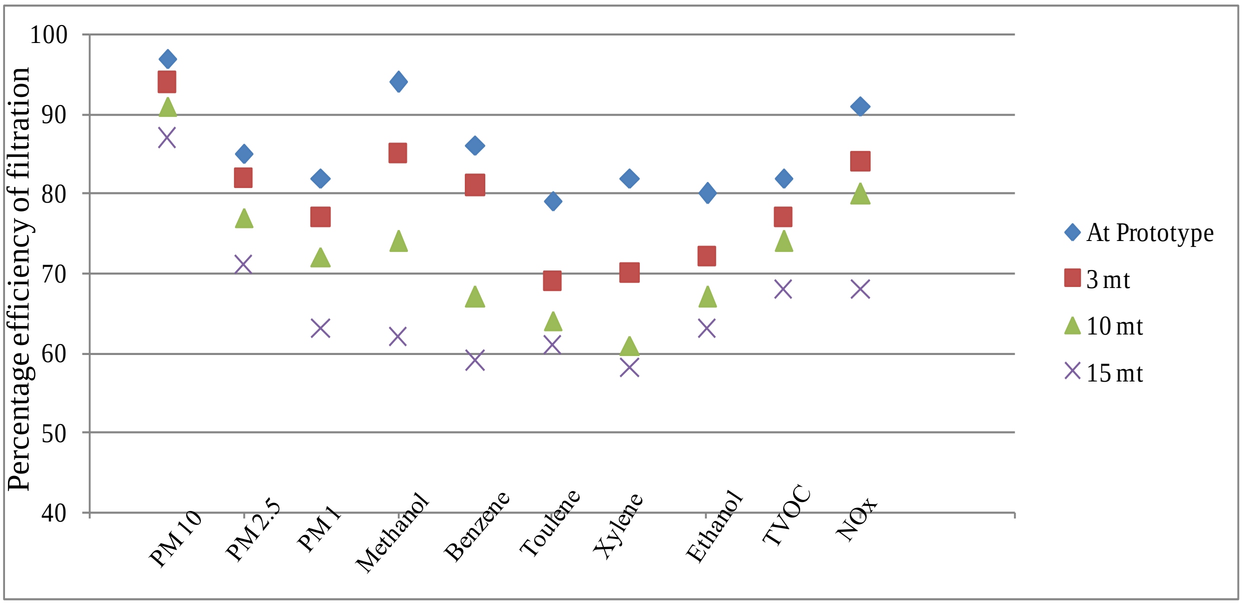


Figure 4.6: Comparative graph showing the percentage efficiency of the Filtration Unit from varied distance in Basement

It can be observed that the Air filtration system has successfully filtered out the pollutants especially at the outlet level the efficiency comes to about 90% for particulate matter. Whereas for the 3 mt , 5 mt and 10 mt distance it ranges between 90% to 80%, 80% to 70 % and 70% to 60%.

Overall the Unit successfully removes the Particulate matter to greater extent along with VOC and NOx too.

Chapter 5 Comparison & Superlative features of the Unit

5.1 Air filter/ purifiers in Market

An air purifier system is a device that aids to remove the pollutants or contaminants present in the air of a room. There are many filtration units in the market for abating pollution. However, most of the units are designed especially for Indoor units which are useful for removal of odour, molds, second hand smoke etc. these devices are beneficial to allergy sufferers and asthmatics etc. The commercially graded air purifiers are manufactured as either small stand-alone units or larger units that can be affixed to an air handler unit (AHU) or to an HVAC unit found in the medical, industrial, and commercial industries. Such units are useful only for indoor purpose as other pollutants like particulate matter, Volatile Organic compounds, NOx, SOxetc cannot be combated. Such pollutants are present in ambient air, vehicular pollution, on traffic congested places, petrol pumping stations, parking places etc. Therefore, for such pollutants a different kind of filtration unit is required other than the indoor filtration unit.

There are industrial specific or product specific filtration units available in the market. For example the Span Filtermist Ltd has a filtration unit which is used specifically for fume, smoke and odour elimination, etc. This filtration unit is made up of Aluminium and ideal for EDM and Laser marking machines. Another unit is used for industrial purpose and it consists of Pre-filter, Micro Vee Filter, Hepa Filter. The material is made up of Stainless Steel. These units are not capable of filtering ambient pollutants like Particulate Matter, VOC, NOx etc.

Recently, National Environmental Engineering Research Institute (NEERI) has developed an air filtration unit named WAYU. 'WAYU' stands for Wind Augmentation PurifYing Unit; this unit is made up of Stainless Steel and based on Thermal oxidation technology. The filter is made up of non-woven fabric and is capable of removing PM2.5 and PM10 particles, carbon monoxide and volatile organic compounds. The WAYU device works in two stages. In the first stage a fan is used to suck in air, which contains all kinds of pollutants like dust and particulate matter. These are separated using three blades of different dimensions. The air enters into a specially designed chamber where oxidation takes place using activated carbon coated with Titanium oxide. The oxidation is supported by two ultraviolet lights. The purified air is then pumped out into the atmosphere.

5.2 Technology behind the Unit

EPRI has developed an Air Filtration Unit which is able to combat Dust (PM), VOC, NOx removal. The unit is based on photo catalytic technology and the unit works in three stages: The first stage, wherein air is fed into the system through the inlet with the help of an axial fan and is filtered from the pre filter and HEPA filter to remove the Particulate Matter. The second stage includes the Photo catalytic reaction in presence of TiO_2. The photo-catalysis is a process of acceleration of a photoreaction in the presence of a catalysed photolysis. Titanium dioxide is an excellent photo catalyst with high chemical stability when exposed to acidic and basic compounds. In the third stage the $CaCO_3$ coated aluminium sheet helps to neutralize the by-products of the preceding chemical reactions. The following are the oxidation reactions that take place:

i. Photo catalytic oxidation of hydrocarbons

$$HC + {}^{\cdot}OH^{-} \rightarrow CO_2 + H_2O$$

ii. Photo catalytic oxidation of NO_x: This involves a series of oxidation step

$$NO + {}^{\cdot}OH^{-} \rightarrow HNO_2 \xrightarrow{{}^{\cdot}OH^{-}} NO_2 \xrightarrow{{}^{\cdot}OH^{-}} HNO_3$$

iii. As a result NO_x gets ultimately converted to HNO_2 or HNO_3. To trap it within the filter unit, a $CaCO_3$ deposited pad will be kept beneath every cylindrical unit, such that the produced HNO_3/HNO_2 will react with $CaCO_3$ and form

$$HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$$

A comparative sheet is given in the Table 5.1 below for the filtration units available in market.

Table 5.1: Comparative sheet of filtration Units available in Market

Filtration Unit	NA	Span Filtermist India Pvt. Ltd.	Photon Cleantech Inc	Dust Pollution Control device installed at TMC	Camfil Industrial Air cleaner CC6000	WAAYU (Wind Augmentation PurifYing Unit)	EPRI Air Filtration Unit
Image of the Unit							
Type of filter used	Pre Filter Micro Vee Filter, Hepa Filter Filter material: Stainless Steel	Filter material: Synthetic Fibre	HEPA filters	NA	HEPA Filter	Non-woven fabric filters	Primary Filter HEPA Filter
Other specific technology if	NA	NA	NA	NA	NA	WAYU, designed by NEERI and IIT (Bombay), works	TiO_2 coated Sheet UV lamp

any						for removal of pollutants such as dangerous PM2.5 and PM10 particles, CO and VOC	
Usage:	Industrial	Fume, smoke and Odor elimination Ideal for EDM and Laser marking machines	NA	Particles from the air like cement dust, soil, air pollen grains, etc., in the range of 25 to 50 microns.	Basically dust particles	Dust (PM), VOC. Thermal Oxidation based technology.	Dust (PM), VOC, NOx Removal Used for Outdoor as well as Basement air filtration. Photo-catalytic based technology
Cost (Rs.)	NA	60,000	1 Lakh	50,000	10 Lakh	2.5 Lakh	2 Lakh
Coverage area	NA	NA	NA	NA	NA	NA	10-15 m
Material	Stainless Steel	Aluminium	Stainless Steel	NA	NA	Stainless Steel	Stainless Steel

Noise level (db)	NA	NA	NA	NA	NA	NA	55 db
Remarks	--	--	--	Machine which has 0.5 HP (horse power) motor can suck 2000 CFM (cubic feet meter air) at a time and purify it.	Helps keep employees healthy, improve product quality and reduce dust.	Used for abating air pollution in ambient air	Used for abating air pollution in ambient air and basement where parking is provided.

NA: Not Available

5.3 Merits over other filtration units

The EPRI Air filtration unit thus successfully combats Particulate Matter, VOC and then NOx in its three stage model. A schematic figure is illustrated in **Figure 5.1** below. The advantages of the unit are as under:

a) Combats PM, VOC and NOx pollutants
b) TiO_2 is cheaply available and has high oxidizing power
c) No noise pollution
d) Useful for both indoor as well as for combating ambient air pollution
e) The presence of VOC which are detected at petrol pumps and traffic congested roads can be handled appropriately
f) Generates no noise pollution
g) Compact and easily portable from one place to another.
h) Efficiency of combating the pollutants ranges from 95% to 60% by installing only one air filtration unit.
i) Efficacy of the Unit can be increased by further research.

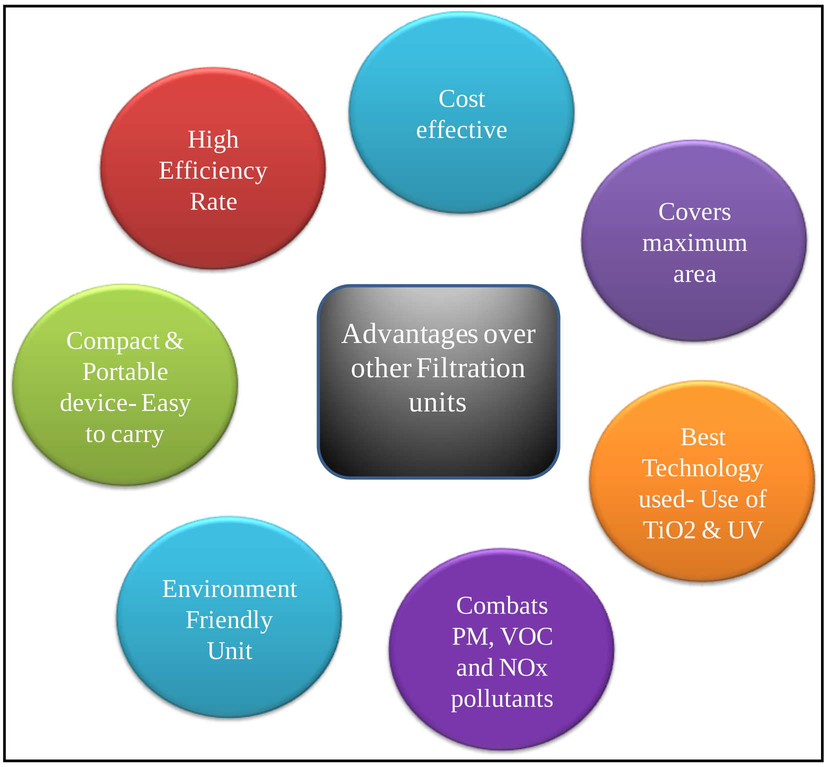
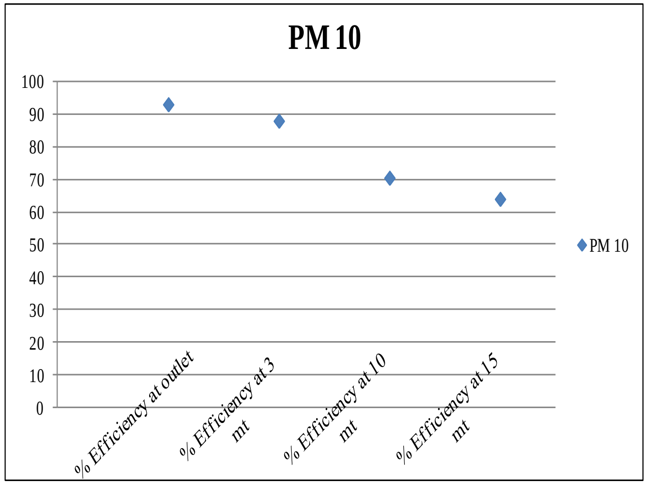
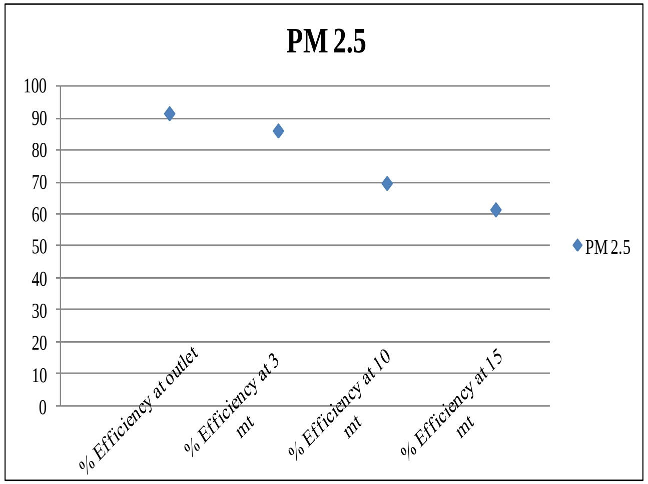


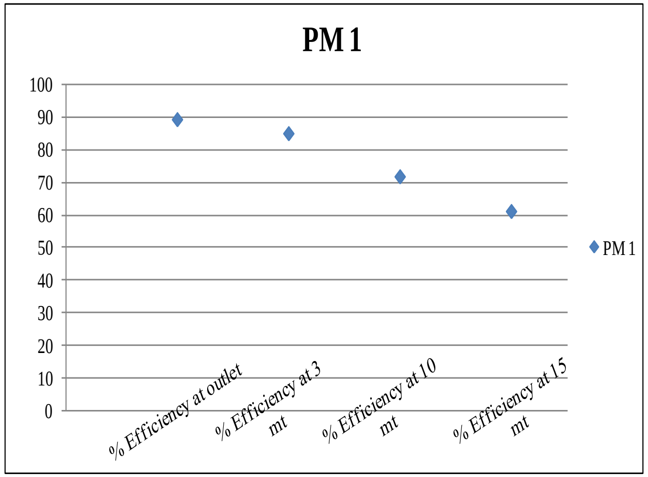
Figure 5.1: Advantages of the Air filtration Unit

Annexure I (Petrol pump- Particulate Matter)

Efficiency of the Air filtration Unit estimated at varied distances for Particulate matter

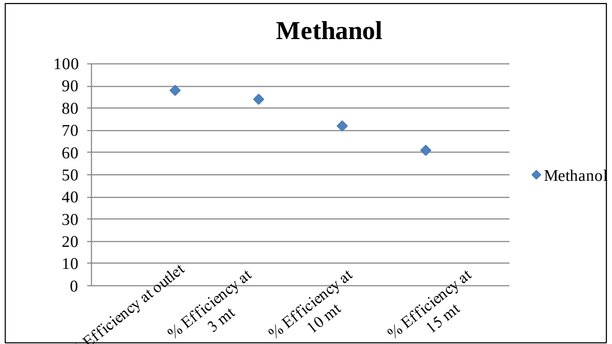


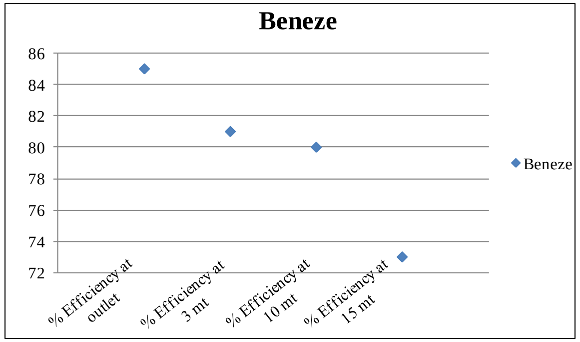


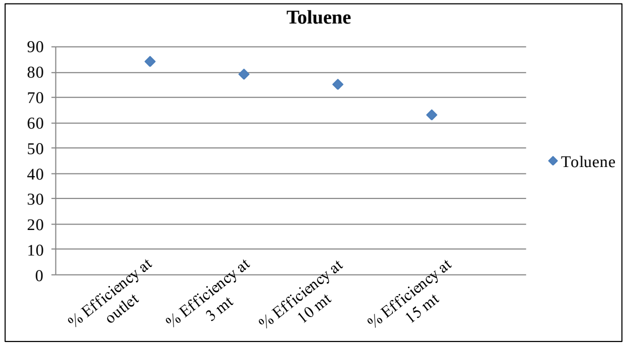


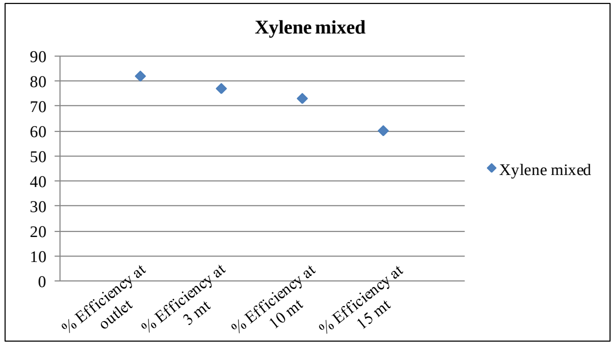
Annexure II (Petrol pump- VOC)

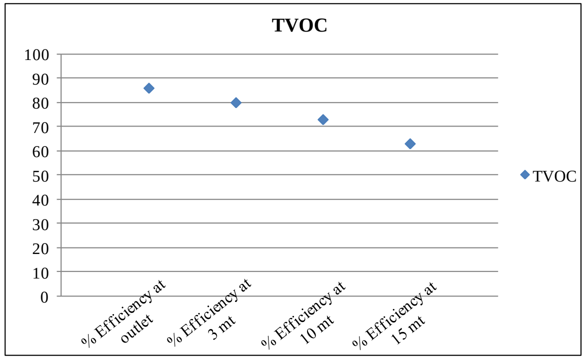
Efficiency of the Air filtration Unit estimated at varied distances for VOC

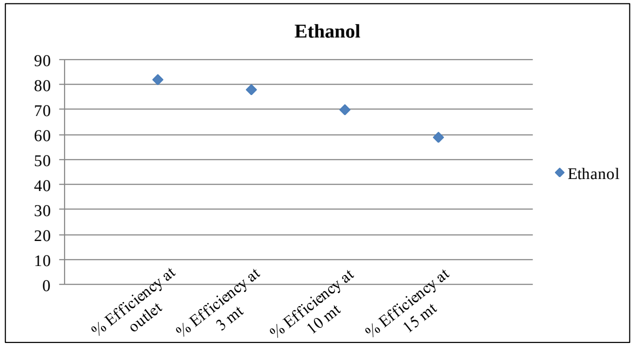






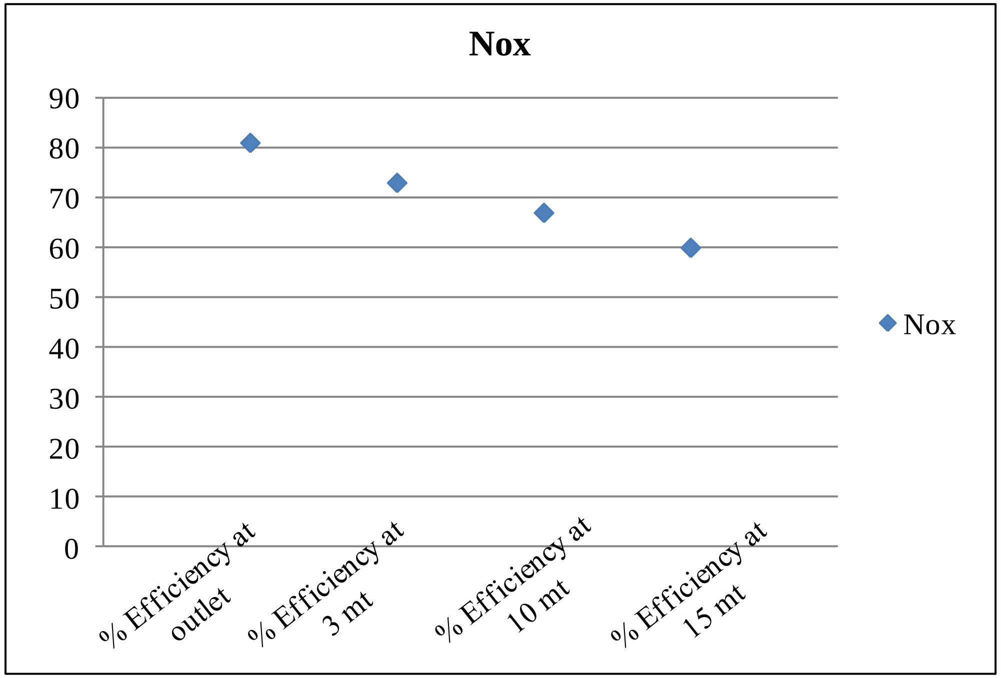






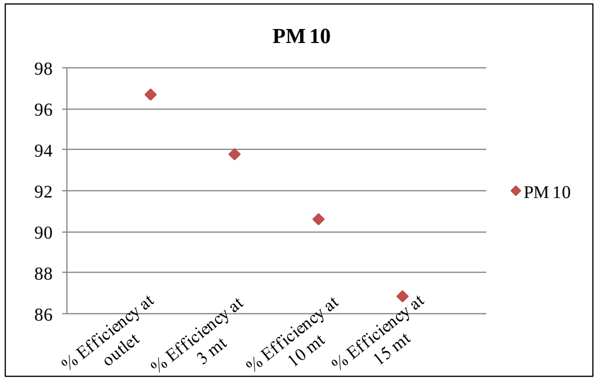
Annexure IV (Petrol Pump- NOx)

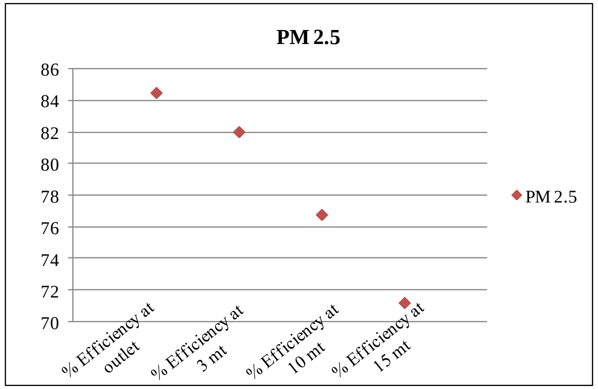
Efficiency of the Air filtration Unit estimated at varied distances for NOx

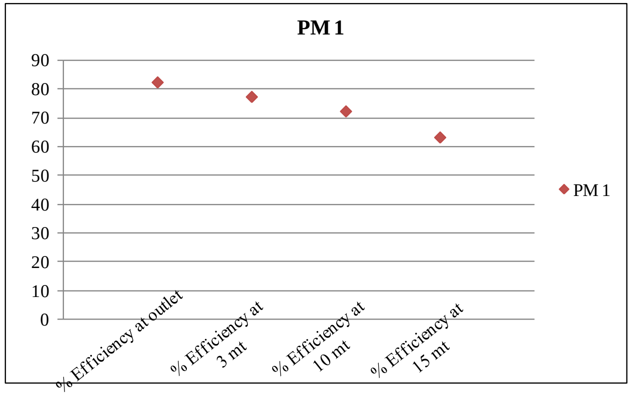


Annexure IV (Basement- Particulate Matter)

Efficiency of the Air filtration Unit estimated at varied distances for Particulate matter

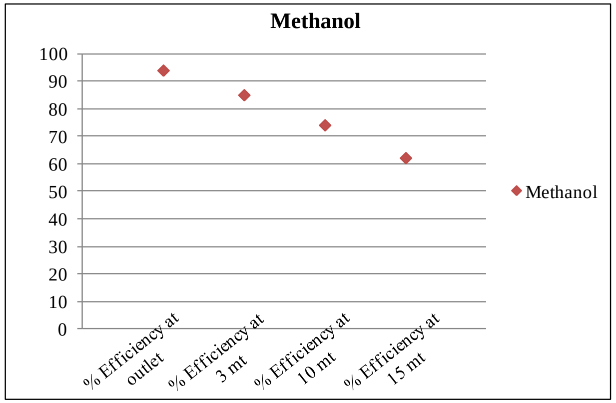


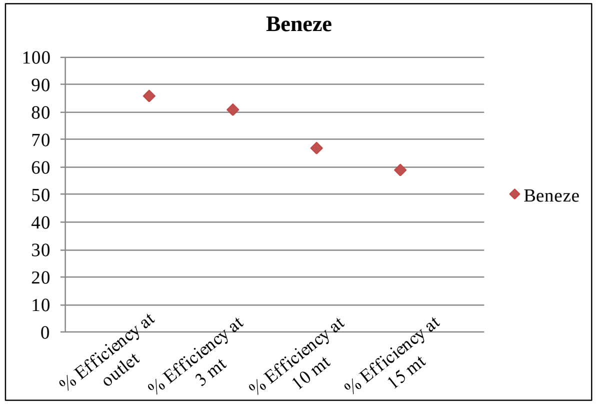


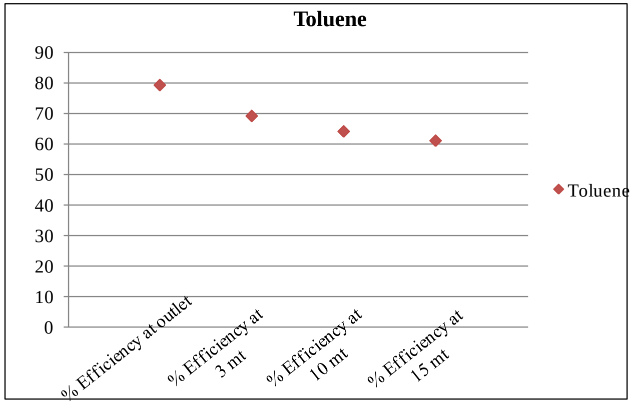


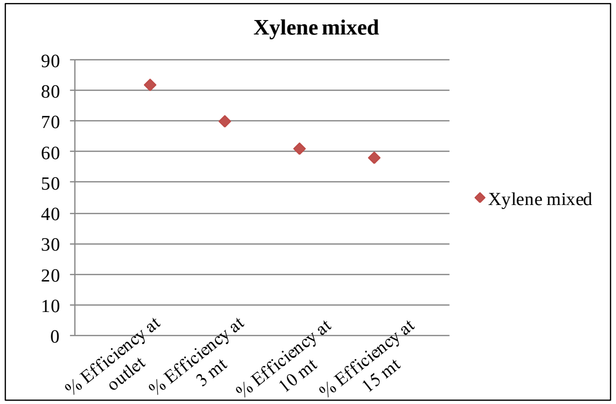
Annexure V (Basement- VOC)

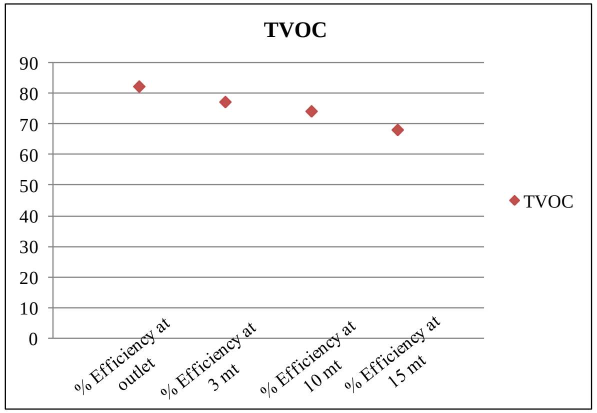
Efficiency of the Air filtration Unit estimated at varied distances for VOC

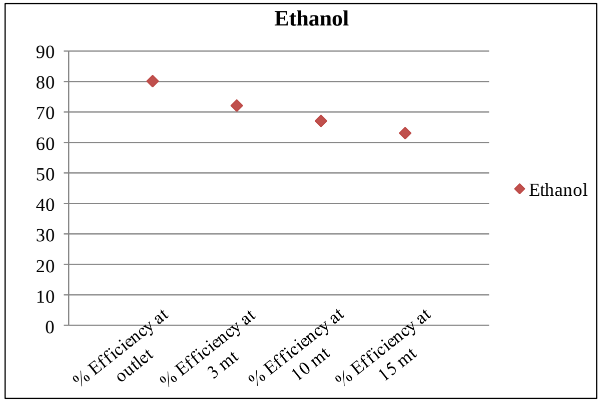






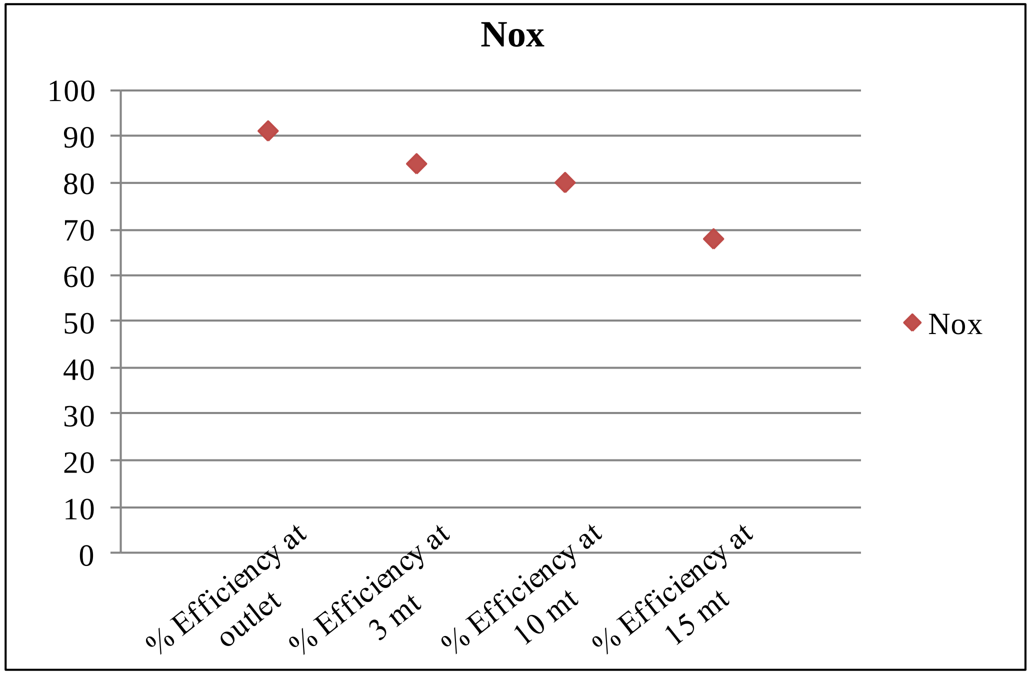






Annexure VI (Basement- NOx)

Efficiency of the Air filtration Unit estimated at varied distances for NOx



References

1. Emissions of VOCs at Urban Petrol retail distribution centres in India (Delhi and Mumbai) by Anjali Srivastava, A.E. Joseph, Ajit More and Sunil Patil (2004)
2. Environmental Analysis of Petrol, Diesel and Electric Passenger Cars in a Belgian Urban Setting by Nils Hooftman, Luis Oliveira, Maarten Messagie, Thierry Coosemans and Joeri Van Mierlo (2016)
3. Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide-Report on a WHO Working Group by Bonn, Germany (2003)
4. Evolution of on-road vehicle exhaust emissions in Delhi by Rahul Goel, Sarath K. Guttikunda (2015)
5. Your neighbourhood petrol pump is the source of India's deadliest pollution, by ShibaniRoychoudhary (2014)
6. Source apportionment of VOCs at the petrol pumps in Kolkata, India; exposure of workers and assessment of associated health risk by D.MajumdarC.Duttaa, ,S.Sen (2008)
7. Air exchange rates and migration of VOCs in basements and residences by Liuliu Du, Stuart Batterman, Christopher Godwin, Zachary Rowe, and Jo-Yu Chin
8. An Experiment with Air Purifiers in Delhi during Winter 2015-2016 by Sangita Vyas, Dean Spears (2016)
9. Sampling and composition of airborne particulate matter (PM10) from two locations of Mexico City, by Yolanda I. Chirinoa, Yesennia Sánchez-Pérezb, Irma Rosasd Claudia María García-Cuellar, 2016
10. Gupta, S. M., & Tripathi, M. (2011). A review of TiO2 nanoparticles. *Chinese Science Bulletin*, *56*(16), 1639-1657.
11. Han, Z., Chang, V. W., Zhang, L., Tse, M. S., Tan, O. K., & Hildemann, L. M. (2012). Preparation of TiO2-coated polyester fiber filters by spray-coating and its photocatalytic degradation of gaseous formaldehyde. *Aerosol Air Qual. Res*, *12*, 1327-1335.
12. Krarti, M., &Ayari, A. (2001). Ventilation for enclosed parking garages.*ASHRAE journal*, *43*(2), 52.

13. Majumdar, D., Dutta, C., Mukherjee, A. K., &Sen, S. (2008). Source apportionment of VOCs at the petrol pumps in Kolkata, India; exposure of workers and assessment of associated health risk. *Transportation Research Part D: Transport and Environment*, *13*(8), 524-530.
14. Park, O. H., & Kim, C. S. Development of a photoreacting fabric filter for simultaneous removal of vocvapors and fine particles.
15. Patankar, A. M., &Trivedi, P. L. (2011). Monetary burden of health impacts of air pollution in Mumbai, India: implications for public health policy. *Public Health*, *125*(3), 157-164.
16. Schwarzenegger, A. (2008). Evaluation of titanium dioxide as a photocatalyst for removing air pollutants.
17. Srivastava, A., Joseph, A. E., More, A., &Patil, S. (2005). Emissions of VOCs at urban petrol retail distribution centres in India (Delhi and Mumbai).*Environmental Monitoring and Assessment*, *109*(1-3), 227-242.
18. Šuligoj, A., Štangar, U., &Tušar, N. (2014). Photocatalytic air-cleaning using TiO2 nanoparticles in porous silica substrate. *Chemical Papers*, *68*(9), 1265-1272.
19. Tasbihi, M., Kete, M., Raichur, A. M., Tušar, N. N., &Štangar, U. L. (2012). Photocatalytic degradation of gaseous toluene by using immobilized titania/silica on aluminum sheets. *Environmental Science and Pollution Research*, *19*(9), 3735-3742.
20. World Health Organization. (2013). Health effects of particulate matter. Policy implications for countries in eastern Europe, Caucasus and central Asia. *World Health Organization Regional Office for Europe, Copenhagen*.
21. Chandrasekharan Nair Kesavachandran, Ritul Kamal, VipinBihari, Manoj Kumar Pathak, Amarnath Singh, *"Particulate Matter in ambient air and its association with alterationsin lung functions and respiratory health problems among outdoor exercisers in National Capital Region, India"*, Atmospheric Pollution Research 6, 2015, 618-625.
22. Ghude, S. D., D. M. Chate, C. Jena, G. Beig, R. Kumar, M. C. Barth, G. G. Pfister, S. Fadnavis, and P. Pithani (2016), Premature mortality in India due to PM2.5 and ozone exposure, Geophys. Res. Lett., 43, 4650–4658.

23. Sateesh. N.Hosamane, Dr. G. P. Desai, *"Urban Air Pollution Trend in India- Present Scenario"*, IJRSET, Vol.2, Aug 2013, 3738-3747.
24. YaohuaTian, Xiao Xiang, Yiqun Wu, Yaying Cao, Jing Song, Kexin Sun, Hui Liu & Yong Hu, *"Fine Particulate Air Pollution and First Hospital Admissions for Ischemic Stroke in Beijing, China"*, Scientific Reports, June 2017, 1-8.
25. Ankita Kankaria, Baridalyne Nongkynrih, and Sanjeev Kumar Gupta, "Indoor Air Pollution in India: Implications on Health and its Control
26. CPCB's Parivesh- A newsletter from ENVIS Centre
27. Report of the Steering Committee on Air Pollution and Health Related Issues, August 2015
28. Air pollution: from sources of emissions to health effects, C. Pénard-Morand I. Annesi-Maesano, INSERM U472, Epidemiology of Allergic and Respiratory Diseases (EPAR), Villejuif, France

Websites Referred

1. Mumbai is the fifth most polluted megacity in the world, says WHO (site visited on 29th August 2016) http://timesofindia.indiatimes.com/city/mumbai/Mumbai-is-the-fifth-most-polluted-egacity-in-the-world-says-WHO/articleshow/52248695.cms
2. Poor air kills 'extra' 12,000 a year in Mumbai (site visited on 9th September 2016) http://www.hindustantimes.com/mumbai-newspaper/poor-air-kills-extra-12-000-a-year/story-0OVv8jKkYrmbwANUqiEfrN.html
3. Cancer-causing pollutants released at fuel filling stations alarm government (site visited on 9th September 2016) http://indiatoday.intoday.in/story/air-pollution-cancer-petrol-pumps-emission/1/429704.html
4. What is a photocatalyst (site visited on 9th September 2016) http://www.greenearthnanoscience.com/what-is-photocatalyst.php
5. Titanium dioxide nanoparticles as a highly active photocatalytic material (site visited on 17th September 2016)

http://www.cinkarna.si/en/files/default/izdelki/tio2/uf_tio_as_highly_active_photocatalytic_material.pdf

6. Glossary of volatile organic compounds (VOC) (site visited on 16th September 2016) http://www.cdc.gov/nceh/clusters/fallon/glossary-voc.pdf
7. The geography of transport systems (site visited on 16th September 2016) https://people.hofstra.edu/geotrans/eng/ch8en/conc8en/table_airpollutionexternalities.html
8. http://www.indiaenvironmentportal.org.in/content/449149/order-of-the-national-green-tribunal-regarding-air-pollution-in-nct-delhi-14112017/
9. https://timesofindia.indiatimes.com/city/mumbai/pollution-related-death-rate-in-2017-higher-in-maha-than-delhi/articleshow/66978603.cms