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VOLATILE ORGANIC COMPOUNDS IN INDOOR ENVIRONMENT OF PUBLIC PLACES IN MUMBAI – INDIA

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ABSTRACT

Indoor air quality in nine locations viz. food courts, restaurants, bar, conference rooms, office and theater which can be classified as public places have been monitored for VOC content. Forty VOCs have been identified and one forth of these are classified as Hazardous Air Pollutants. Most VOCs levels are observed to be below the guidelines values for public places and offices as adopted by Hong Kong. Consumer goods are found to be predominant source of indoor chlorinated VOCs. Benzene and carbon tetrachlorides levels were observed to be above the guideline values at all the locations.

Key Words: Indoor air pollution, VOC, benzene, Mumbai

INTRODUCTION

Indoor Air Quality (IAQ) in urban area of India is fast deteriorating. As more than eighty percent of our time is spent indoors IAQ is a major cause of concern in the modern concretized world. A rapid change in the urban lifestyle has given rise to a new genre of indoor air pollutants. A majority of these pollutants are linked to organic chemical contaminants termed as Volatile Organic Compounds (VOC's). VOC's are a wide range of hydrocarbons possessing a characteristic ability to vaporize at low temperatures also room temperature. In Indoor environment these originate from various sources including paints, adhesives, solvents, pressed wood, combustion of cooking fuel, use of household pesticides, deodorizers and also tobacco smoking. Certain VOC's, e.g. Benzene, Toluene, Ethylbenzene, have been classified in the USEPA Air Toxics Programme due to its toxic effects on humans and environment. Toxicity in humans range from acute symptoms to chronic conditions affects all vital systems of human body (Atkinson, 2000, Kuran and Sojak, 1994). Some VOC's are also known to have carcinogenic and teratogenic effects (USEPA, 1994, HSDB, 1993). Thus it is critical to manage the concentrations of VOC's in indoor air in order to regularize IAQ and test effectiveness of air cleaning devices. The present study attempts to identify VOC levels at indoor locations of the public places domains. Such a type of study is the first of its kind for indoor air quality assessment in the city of Mumbai.

STUDY AREA

Mumbai is located on the west coast of India on latitude 18.9^{o}N and longitude 72.8^{o}E. Mumbai is one of the largest metropolises of the world with a population of more than 12 million and which is expected to reach 14.4 million by 2011. Mumbai is the commercial capital of India housing many national and multinational companies. Over the last few years, Mumbai has seen an increase in the development of commercial estates in the form of Corporate Parks, Entertainment Malls etc. with high-end public service utilities, which include among others central air conditioning, water coolers and food courts. Keeping this trend in mind nine air-conditioned locations were selected which basically falls into public place category including offices, theatre hall, restaurant, bar rooms, food courts and conference rooms. Most of these were located in commercial zones across various parts of the city.

Mumbai has a tropical savanna climate with relative humidity ranging between 57%-87% and annual average temperature of 25.3^{o}C with a maximum of 34.5^{o}C in June and minimum of 14.3^{o}C in January. Average annual precipitation is 2,078 mm with 34% of total rainfall occurring in July. Prevailing wind directions are from west and northwest with west and southwest shifts during monsoon. Some easterly component is observed during winter.

METHOD OF ESTIMATION

At all of the above mentioned locations air was sampled for a period of four hours into cartridges containing absorbing media – Chromosorb ® 106, using a low volume sampler. VOC's were estimated using USEPA TO-17 method (USEPA, 1999). Analysis was carried out on Varian make GC-MS subsequent to thermal desorption at 180 ^{o}C. The column used was DB-624. The carrier gas used was Helium with flow rate of 1L/min and split ratio of 1:25. GC oven temperature was programmed for 35 oC and held for 2 mins. The ion trap temperature was maintained at 125 oC. The peaks obtained were identified using NIST Library. First three abundances were matched to identify the peaks. Quantification was done using calibration with liquid standards of VOC MIX-15 of Dr. Ehrenstorfer from Perkin Elmer.

RESULTS & DISCUSSIONS

As many as forty VOCs have been detected. One fourth of the total VOCs identified are classified as Hazardous Air Pollutants in USEPA Air toxic programme **(Table 1).** It is observed that carbon tetrachloride, methylene chloride, chloroform, trichloroethylene, benzene, toluene, ethyl benzene, xylenes and 135 trimethyl benzene have been identified in all the samples at all the locations. Table 2 gives the concentrations of the VOCs quantified using Ehrenstorfer standard VOC Mix 15. Time Weighted Average (TWA) Threshold limit values of these ubiquitous VOCs along with risk levels as given by World Health Organization (WHO) as given in Table 3. Table 4. presents indoor outdoor ratio (I/O) of these VOCs. Average concentrations of these VOCs in out door air are taken from Srivastava, et.al., 2004

and Srivastava, 2004. It is observed that I/O for chlorinated VOCs are greater than one while those for benzene, toluene, ethyl benzene, xylene and 135 trimethyl benzene are less than one. Presence of chlorinated VOCs in the indoor environment can be attributed mainly to the use of consumer products like paints, varnishes, aerosols, insecticides floor polishes etc. Some contribution may as well be from outdoor air with oceanic emissions and fuel burning emissions. However, high I/O ratio indicates predominant indoor sources of these VOCs. Trichloroethylene is found in paints, spot removers, carpet cleaning fluids, metal cleaners and varnishes (dhfs chemical fact sheet). Methylene chloride is also a constituent of paints and varnish thinners, cleaning solutions, degreasers, aerosols, pesticides fumigants, insecticides, refrigeration and air conditioning equipments (AFSME Health and Safety Fact Sheet) Carbon tetrachloride and chloroform are also contained as solvents in various consumer products like lacquers solvents, floor polishers, resins, gums, metal degreasers, dry cleaning fluid etc. (National Safety Council, Online Library, Chronic Toxicity Summary, Batch 2A December 2000).

I/O ratio for benzene, toluene, ethyl benzene, xylene and 135 trimethyl benzene are observed to be less than one at most location except conference room and bar floor. Benzene, toluene, ethyl benzene, xylene and 135 trimethyl benzene are constituents of vehicular exhaust. The source of these pollutants is thus mainly outdoor air which has vehicular emissions and to a some extent indoor tobacco smoke. (Conference room and bar floor)

Concentrations of VOCs identified at all indoor locations monitored are given in Figure 1. Comparison of observed indoor levels of VOCs with Indoor Air Quality objectives for office and public places as adopted by Hong Kong Government shows (Figure 2) that levels of most VOC are well within the limits. However, concentrations of chloroform were found to exceed at Theater 1 and benzene levels exceeded at almost all locations. Carbon tetrachloride levels were as well found to exceed at almost all the locations monitored.

CONCLUSION

Forty VOC's were identified and more than one - fourth of the total VOC's identified are classified in the USEPA Air Toxic Programme as Hazardous Air Pollutants (HAP's). Some compounds including HAP's like benzene, toluene, ethyl benzene, chloroform and carbon tetrachloride have been observed in appreciably high concentrations even in the absence of a predominant source. When compared with standard limiting values as stated in the Hong Kong Indoor Air Quality Guidelines (Hong Kong Government, 2003), concentrations of most VOC's were found to be within the limits. Outdoor air concentrations of benzene which exceeded indoor air quality objectives limits is observed to be high and much above the guideline value of 5 $\mu g/m^3$ in outdoor ambient air. Also excessive use of consumer products has led to higher indoor concentrations of chlorinated VOCs viz chloroform and carbon tetrachloride. In order to achieve healthy indoor environment it is thus necessary to have clean outdoor air and restricted use of consumer products containing VOCs. In long run it is advisable to look for alternative safe solvents in consumer products.

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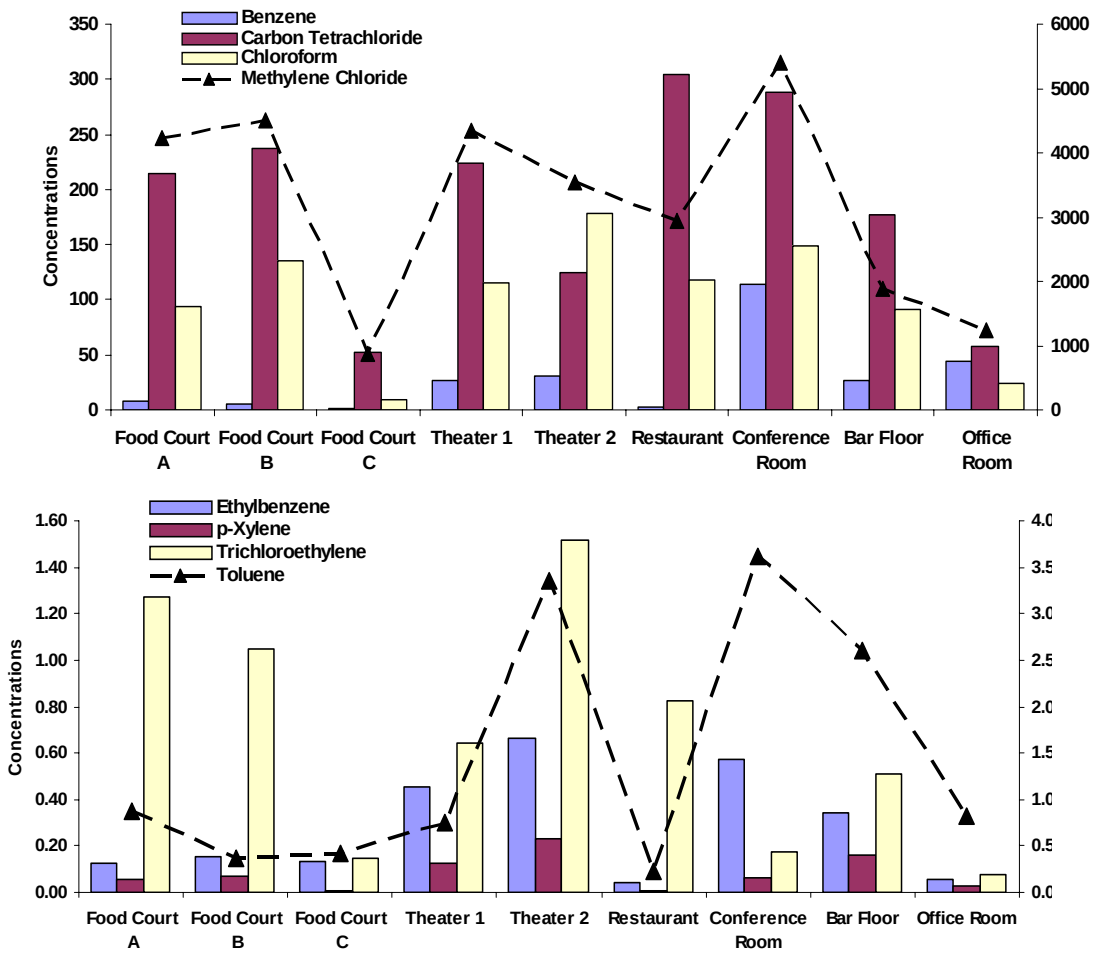
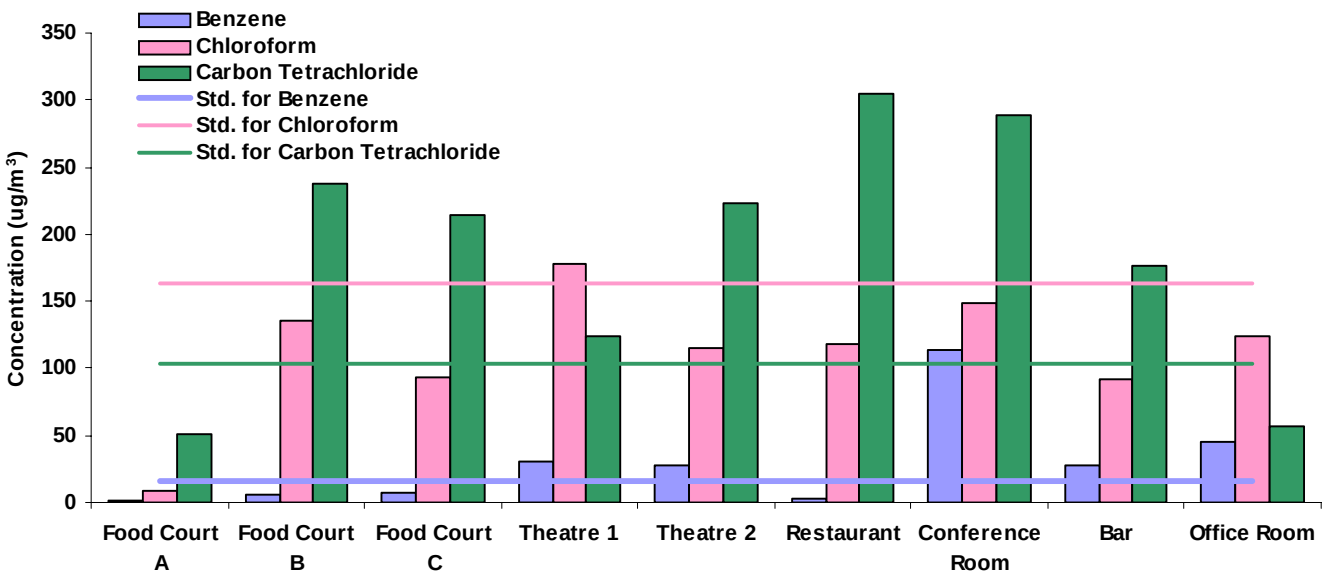


Figure 1 : Concentrations of VOCs Identified at All Indoor Locations Monitored

(Concentration are in µg/m^3)



IAQ Guideline Values Adopted by Hong Kong

Benzene	**– 16.1 µg/m^3**
Carbon Tetrachloride	**– 103 µg/m^3**
Chloroform	**–163 µg/m^3**
Ethyl benzene	**– 1447 µg/m^3**
Toluene	**– 1092 µg/m^3**
Trichloroethylene	**– 770 µg/m^3**
Xylene (o,m,p-isomer)	**– 1447µg/m^3**

Figure 2 : Comparison of Concentrations of Some VOCs with IAQ Guideline of Hong Kong

Table 1 : List of VOC's Identified Quantified at the Monitoring Sites

			Office Room	Food Court A	Food Court B	Food Court C	Theater 1	Theater 2	Restaurant	Conference Room	Bar Floor
1	1-Propene, 3-chloro	107 - 05 - 1				✓#					
2	Benzene	71 - 43 - 2	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
3	Benzene,1,2-dimethoxy	91 - 16 - 7						✓#			
4	Cumene	98 - 82 - 8					✓# ∗	✓# ∗			✓# ∗
5	Benzene, (1-methylpropyl)	135 - 98 – 8	✓#				✓#	✓#		✓#	
6	Benzene, 1,2,3-trichloro-	87 - 61 – 6					✓#				
7	Benzene, 1,2,4-trimethyl-	95 - 63 – 6	✓#	✓#	✓#		✓#	✓#			✓#
8	Benzene, 1,2-dichloro-	95 - 50 – 1		✓#	✓#		✓#	✓#			✓#
9	Benzene, 1,3,5-trimethyl-	108 - 67 – 8	✓#	✓#	✓#	✓#	✓#	✓#	✓#	✓#	✓#
10	Benzene, 1,3-dichloro	541 - 73 – 1					✓#	✓#			
11	m-Xylene	108- 38 -3	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
12	para-Chlorotoluene	106 - 43 – 4									✓#
13	n-Butylbenzene	104 - 51 – 8		✓#		✓#	✓#	✓#			
14	Benzene, tert-butyl	98 - 06 – 6					✓#		✓#	✓#	
15	Chloroform	67 - 66 - 3	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
16	Ethane-trichloride	79 - 00 - 5						✓#		✓#	
17	Ethane, 1,2-dibromo-	106 - 93 - 4				✓# ∗		✓# ∗			✓ ∗
18	Ethyl benzene	100 - 41 - 4	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
19	Dichlorobromomethane	75 - 27 - 4			✓#						
20	Methylene Chloride	75 - 09 - 2	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
21	Naphthalene	91 - 20 -3	✓# ∗	✓# ∗	✓# ∗		✓# ∗	✓# ∗	✓# ∗		✓# ∗
22	p-Xylene	106 - 42 - 3	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗

(✓= VOC Identified; # = VOC Quantified; ∗ = VOC Listed in USEPA Hazardous Air Pollutants List)

Table 1 (Contd..) : List of VOC's Identified Quantified at the Monitoring Sites

			Office Room	Food Court A	Food Court B	Food Court C	Theater 1	Theater 2	Restaurant	Conference Room	Bar Floor
23	Toluene	108 - 88 - 3	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
24	Trichloroethylene	79 – 01 - 6	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
25	2-Methyl-1-Pentene	763-29-1		✓	✓	✓	✓	✓	✓	✓	✓
26	3-Methylpentane	96-14-0	✓	✓	✓	✓	✓	✓	✓	✓	✓
27	Carbon Disulfide	75-15-0	✓ ∗			✓ ∗		✓ ∗	✓ ∗	✓ ∗	✓ ∗
28	Carbon Tetrachloride	56-23-5	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗	✓# ∗
29	Cyclohexane	110-82-7	✓	✓	✓	✓	✓	✓	✓	✓	✓
30	Cyclohexane, methyl-	108-87-2							✓		✓
31	Dodecane	112-40-3						✓			
32	Ethyl Acetate	141-78-6	✓		✓	✓	✓	✓	✓	✓	✓
33	Hexane, 3-methyl-	589-34-4	✓	✓	✓	✓	✓		✓		✓
34	n-Butyl Alcohol	71-36-3	✓	✓	✓	✓	✓	✓		✓	✓
35	n-Butyl ether	142-96-1	✓				✓			✓	✓
36	n-Pentane	109-66-0						✓			
37	Pentane, 2,4-dimethyl-	108-08-7									
38	Propane	74-98-6	✓	✓			✓	✓		✓	✓
39	Tetradecane	629-59-4					✓				
40	Undecane	1120-21-4					✓				

(✓= VOC Identified; # = VOC Quantified; ∗ = VOC Listed in USEPA Hazardous Air Pollutants List)

Table 2 : Concentrations of VOCs at Different Indoor Locations

	Food Court A	Food Court B	Food Court C	Theater 1	Theater 2	Restaurant	Conference Room	Bar Floor	Office Room
Benzene	**7.44**	**5.43**	**1.65**	**27.44**	**30.95**	**2.58**	**113.89**	**27.18**	**44.92**
Carbon Tetrachloride	**215.00**	**237.50**	**51.67**	**223.33**	**124.17**	**304.44**	**288.33**	**176.67**	**57.50**
Chloroform	**94.03**	**135.28**	**8.86**	**115.92**	**178.64**	**118.25**	**148.33**	**91.77**	**24.17**
Methylene Chloride	**4219.17**	**4498.33**	**884.17**	**4341.67**	**3530.00**	**2941.11**	**5406.67**	**1895.98**	**1251.67**
Benzene, (1-methylethyl)				**0.01**	**0.01**			**0.01**	
Benzene, (1-methylpropyl)				**0.01**	**0.01**		**0.02**		**0.01**
Benzene, 1,2,4-trimethyl	**0.24**	**0.02**		**0.04**	**0.06**			**0.01**	**0.01**
Benzene, 1,2-dichloro	**0.24**	**0.13**		**0.24**	**0.10**			**0.06**	
Benzene, 1,3,5-trimethyl	**0.06**	**0.16**	**0.08**	**0.30**	**0.30**	**0.04**	**0.06**	**0.09**	**0.10**
Benzene, 1,3-dichloro				**0.01**	**0.01**				
Benzene, 1,3-dimethyl	**0.06**	**0.08**	**0.03**	**0.17**	**0.29**	**0.03**	**0.14**	**0.16**	**0.04**
Benzene, butyl	**0.01**		**0.01**	**0.01**	**0.17**				
Benzene, tert-butyl					**0.02**	**0.00**	**0.00**		
Ethane, 1,1,2-trichloro				**0.05**			**0.03**		
Ethane, 1,2-dibromo			**0.02**	**0.02**				**0.01**	
Ethyl benzene	**0.12**	**0.16**	**0.13**	**0.45**	**0.67**	**0.04**	**0.57**	**0.34**	**0.06**
Naphthalene	**0.01**	**0.07**		**0.05**	**0.04**	**0.07**		**0.02**	**0.02**
p-Xylene	**0.05**	**0.07**	**0.01**	**0.13**	**0.23**	**0.01**	**0.06**	**0.16**	**0.03**
Toluene	**0.88**	**0.37**	**0.42**	**0.76**	**3.35**	**0.22**	**3.61**	**2.60**	**0.82**
Trichloroethylene	**1.28**	**1.05**	**0.15**	**0.64**	**1.52**	**0.82**	**0.17**	**0.51**	**0.08**
1-Propene, 3-chloro			**0.02**						
Benzene, (1,2-dimethoxyet)				**0.25**					
Benzene, 1,2,3-trichloro					**0.02**				
Benzene, 1-chloro-4-methy								**0.02**	
Methane, bromodichloro		**0.03**							

Table 3 : Threshold Limit Values and Risk Levels of Some VOCs

VOCs	AICGH TWA (ppm)	OSHA TWA (ppm)	RFC	RFD
Trichloroethylene	50.0	10.0	Not Established	Not Established
Carbon Tetrachloride	5.0	50.0	Group B2 carcinogen RFC Not established	RFD Group B2 Carcinogen 0.0007 mg/kg/day based on tetrious in rats
Chloroform	10.0	50.0	Group B2 Carcinogen REL – 35 µg/m3	Group B2 Carcinogen 0.01 mg/kg/day
Methylene Chloride				
Benzene	0.5	1.0	No safe level Group A Carcinogenic	No safe level Confirmed carcinogen effect on humans
Ethyl benzene	100.0	100.0	Group D Carcinogen 1 mg/m3	Group D Carcinogen 1 E-1 mg/kg/day
p-Xylene	100.0	100.0	Group D Carcinogen 0.1 mg/m3	Group D Carcinogen 0.2 mg/kg/day
Toluene	50.0	200.0	Group D Carcinogen 0.4 mg/m3	0.2 mg/kg /day
Benzene, 1,3,5-trimethyl	25.0	25.0	--	--

RFC – Provisional Reference concentration that is likely to be without appreciable risk of deleterious non cancer effects during a life time

RFD – Provisional Reference close

Group A – Confirmed carcinogenic effect on humans by all routes of exposure

Group B2 – Probable human carcinogenic

Group D- Not classified as to human carcinogenicity

Source :

- USEPA 1994 Integrated Risk Information System (IRIS) online Office of Health and Environment Assessment, USEPA, Cincinnati, OH
- American Conference of Governmental Industrial Hygienists - www.acgih.org
- Occupational Safety and Health Administration - www.osha.gov

Table 4 : Indoor Outdoor Ratio of Observed VOCs

VOCs	Food Court A	Food Court B	Food Court C	Theater 1	Theater 2	Restaurant	Conference Room	Bar Floor	Office Room
Trichloroethylene	63.8	52.5	7.5	32.0	75.8	41.1	8.6	25.5	3.8
Carbon Tetrachloride	81.1	89.6	19.5	413.6	229.9	114.9	108.8	66.7	21.7
Chloroform	34.4	49.6	3.2	60.4	93.0	43.3	54.3	33.6	8.9
Methylene Chloride	838.8	894.3	175.8	727.2	591.3	584.7	1074.9	376.9	248.8
Benzene	0.2	0.1	0.0	0.2	0.2	0.1	2.5	2.8	0.9
Ethyl benzene	0.6	0.8	0.7	1.6	2.3	0.2	2.8	1.7	0.3
p-Xylene	0.1	0.1	0.0	0.8	1.4	0.0	0.1	0.2	0.0
Toluene	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
Benzene, 1,3,5-trimethyl	0.1	0.2	0.1	0.5	0.5	0.1	0.1	0.1	0.1

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CHARACTERISTICS OF PM_{10} and $PM_{2.5}$ AS MONITORED IN INTERIORS AND PLATFORMS OF SUBWAY TRAIN IN KOREA

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ABSTRACT

This study was performed to investigate the concentration of PM_{10} and $PM_{2.5}$ in inside trains and platforms on subway lines 1, 2, 4 and 5 in Seoul, KOREA. PM_{10}, $PM_{2.5}$, and carbon dioxide were monitored using a Portable Aerosol Spectrometer in the afternoon (between 13:00 and 16:00). The concentrations of PM_{10} and $PM_{2.5}$ inside trains was significantly higher than those measured on platform sand in ambient air reported by the Korea Environmental Protection Agency (EPA). This study found that PM_{10} levels inside subway lines 1, 2 and 4 exceeded 150 / of the Korea indoor air quality standard (IAQ). The average percentage that exceeded the PM_{10} standard was 83.3 % on line 1, 37.9 % on line 2 and 63.1 % on line 4, respectively. $PM_{2.5}$ concentration ranged from 77.7 / to 158.2 / , which were found to be much higher than the ambient air $PM_{2.5}$ standard promulgated by United States Environmental Protection Agency (US-EPA) (24 hours arithmetic mean: 65 /). The reason for interior PM_{10} and $PM_{2.5}$ being higher than those on platforms is due to subway trains in Korea not having mechanical ventilation system to supply fresh air inside the train. The percentage of $PM_{2.5}$ in PM_{10} was 86.2 % on platforms, 81.7 % inside trains, 80.2 % underground and 90.2 % at ground track. These results indicated that fine particles ($PM_{2.5}$) accounted for most of PM_{10} and polluted subway air. Further study is required to examine whether differences of the ratio in $PM_{2.5}$ to PM_{10} among several subway characteristics is significant.

Key Words: PM_{10}, $PM_{2.5}$, Fine Particulate, Subway, Inside Train, Platform

1. INTRODUCTION

In Korea, the subway is considered as the most convenient commuter transport mode. About ten million take it everyday in Seoul. Seven subway lines run in Seoul, Korea. Subway line 1 opened in 1974.

Several studies have reported the PM_{10} concentrations on subway platforms in Korea (Kim et al, 2004). However, concentrations of $PM_{2.5}$ in the subway system and interior particulate matter have not been reported.

The objectives of this study are to compare PM_{10} and $PM_{2.5}$ concentrations between the monitoring locations (inside the trains, subway platforms subway, ground and underground) and to probe the ratio of $PM2_{2.5}$ to PM_{10} concentration.

2. METHOD

2.1 Subject

The experiment on platform and inside subway 1, 2, 4 and 5 lines was performed in the afternoon (13:00-16:00) during 4 days of January.

28 stations on line 1(underground track: 12, ground track: 16), 36 stations on line 2(underground track: 29, ground track: 7), 20 stations on line 4(underground track: 19, ground track: 1), and 5 underground stations on line 5 were studied.

2.2 Monitoring method

A Portable Aerosol Spectrometer (Model 1108, Grimm, Germany) calibrated to 1.2 L/min was used to monitor total suspended particles (TSP), PM_{10} and $PM_{2.5}$. The data logging interval was set at 30s. The concentration inside the trains was monitored from the middle of the center car of the subway when it was running. Monitoring on platform was conducted at the center of the platform. The total number of monitoring was 2,709 (1,820 on underground, 899 on platform). In addition, carbon dioxide was measured using Indoor Air Quality Meters (Model 8760, TSI) to assess the efficiency of ventilation.

2.3 Data analysis

SPSS Version 12.0 was used to analyze data monitored. T-test was employed to compare TSP, PM_{10} and $PM_{2.5}$ concentrations between underground and ground as well as platform and inside train.

General linear model (GLM) was used to examine the effect of location (ground and underground, and platform and inside train) on TSP, PM_{10} and $PM_{2.5}$ concentrations.

3. RESULTS

3.1 PM_{10} and $PM_{2.5}$ concentration

Average PM_{10} concentration inside train was 144.0 / , which was far higher than 125.8 / monitored on platform ($p=0.026$) and the concentration range (35 - 81 /) measured in outdoor air in Seoul from January to November, 2004 (Seoul city, 2004). There are many stations that exceeded indoor air quality standard for PM_{10}. Subway line 1 constructed in 1974, the oldest line, showed that 10 of 12 investigated stations exceeded for PM_{10}. The highest concentration was 207.5 / , which was monitored inside the underground track on subway line 1. Average PM_{10} concentrations in line 2 and 4 were 144.3 / and 143.8 / , respectively. The percentages that exceeded Korea IAQ standard inside the train was 37.9 % in line 2 and 63.2 % in line 4. PM_{10} concentration in line 5, which is the most recently operated line, was below standard. Only one station on line 5 was over the IAQ on platform. PM_{10} concentration for Korea's indoor air quality (150 /) was established to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly (Koran EPA, 2004)

$PM_{2.5}$ concentration inside trains was significantly higher than those on platforms regardless of the location of monitoring ($p<0.001$). These results were the same as those found in PM10 concentration. $PM_{2.5}$ concentration inside train ranged from 84.1 / to 158.2 / . These concentrations greatly exceeded the airborne 24 hours arithmetic mean standard (65 /) promulgated by U.S environmental protection agency (US EPA) as shown in Figure 1.

PM_{10} and $PM_{2.5}$ concentrations monitored on underground track were significantly higher than those on ground tracks regardless of line and location (Table 1 and Figure 1). GLM statistical analysis indicated that two factors such as monitoring

locations (underground and ground or inside and platform) significantly influence PM_{10} and $PM_{2.5}$ concentrations ($p<0.001$).

3.2 The ratio of $PM_{2.5}$ to PM_{10}

The percentage of $PM_{2.5}$ that accounted for PM_{10} is shown in Table 2. It was slightly higher on platform and ground track than inside train and underground track. The percentages of $PM_{2.5}$ in PM_{10} on line 1 and 4 were a little higher than those on line 2 and 5 (Figure 2). A similar pattern was found in the percentage of PM_{10} that accounted for TSP. However, the percentage of $PM_{2.5}$ in PM_{10} was far higher than that of PM_{10} in TSP. This result indicated that the subway environment was contaminated with fine particulates.

Table 1. The average concentration(/) and standard deviation of PM_{10} and $PM_{2.5}$ by the location of sampling

	Ground track	**Underground track**	**Total**
PM_{10}, /			
Platform	123.0±6.6	129.3±20.9	125.8±15.0
Inside train	141.5±13.4	145.3±12.8	144.0±13.1
Total	132.2±13.0	140.6±17.2	137.0±16.4
$PM_{2.5}$, /			
Platform	115.6±8.6	105.4±14.4	111.1±12.6
Inside train	121.7±16.1	116.6±14.2	118.4±15.1
Total	118.6±13.2	113.3±15.2	115.6±14.6

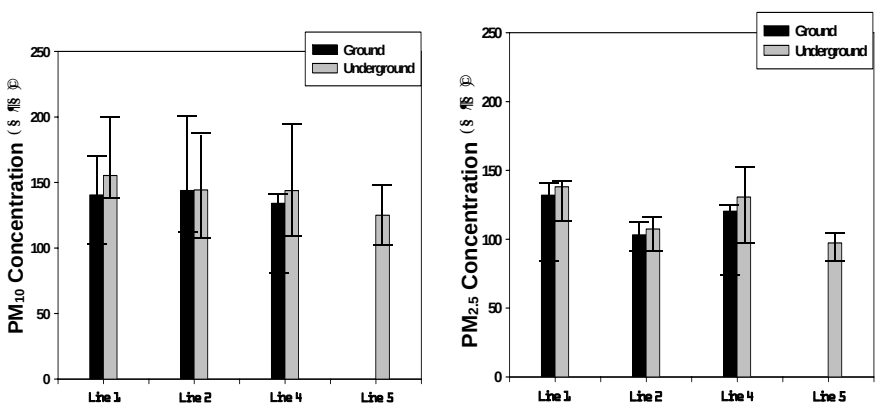
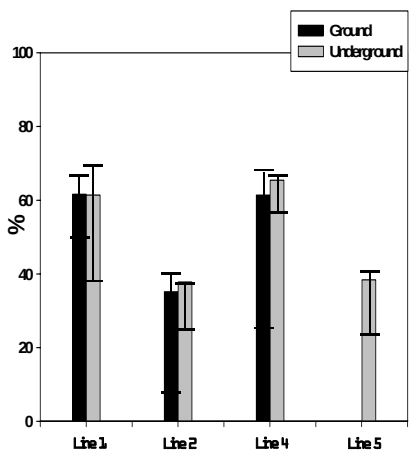


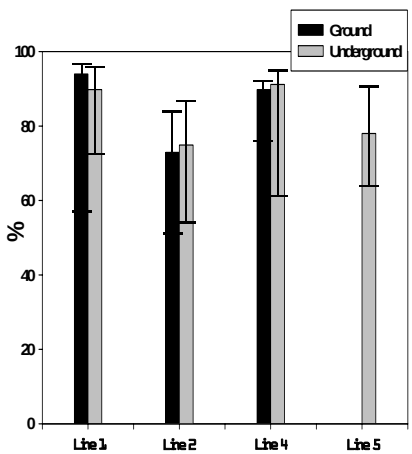
Figure 1. PM_{10} and $PM_{2.5}$ concentration by subway line.

Table 2. The ratios (%) of $PM_{2.5}$ to PM_{10} and PM_{10} to total suspended particulate (TSP)

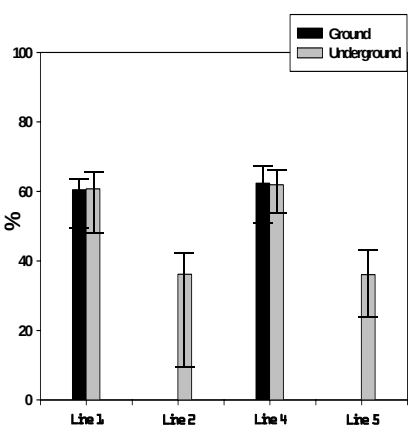
	Ground track	**Underground track**	**Total**
PM_{10} to TSP, %			
Platform	61.4±2.8	40.3±10.6	49.1±13.3
Inside train	53.1±53.1	42.9±12.2	45.7±12.9
Total	57.3±9.4	42.0±11.7	47.1±13.2
$PM_{2.5}$ to PM_{10}, %			
Platform	93.9±2.8	80.7±8.1	86.2±9.1
Inside train	86.5±12.1	79.9±9.1	81.7±10.4
Total	90.2±9.5	80.2±8.8	83.5±10.2

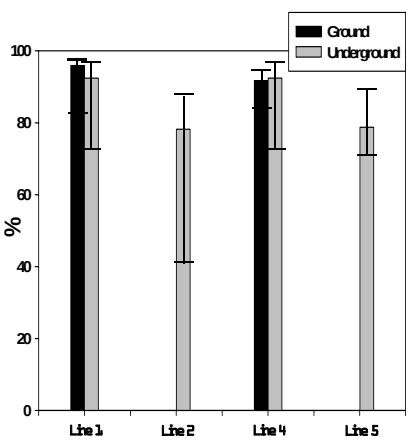


PM_{10} to TSP inside train



$PM_{2.5}$ to PM_{10} inside train





PM_{10} to TSP on platform **$PM_{2.5}$ to PM_{10} on platform**

Figure 2. The ratio (%) of PM_{10} to TSP and $PM_{2.5}$ to PM_{10} by subway.

4. DISCUSSION

4.1 PM_{10} and $PM_{2.5}$ concentration

In Korea, no study on particulate matter including fine particle inside trains has been reported, although a few studies reported PM_{10} concentration on platforms (Kim et al, 2004; Park et al., 2004). Our study was the first to report PM_{10} and $PM_{2.5}$ concentration inside train and $PM_{2.5}$ on platform.

Our study was conducted during the afternoon (between 15:00 and 18:00), a period of time when passenger and traffic density could be low. PM_{10} and $PM_{2.5}$ concentrations inside train were significantly higher than those on platform (Table 1). PM_{10} and $PM_{2.5}$ concentration could rise during rush hours, in view of the increased passengers and traffic density outside the subway. Even though traffic gives rise to high level of particulate in the urban air, people are exposed to even higher levels in the subway. However, there is a lack of knowledge about this.[14)] There are many factors that could influence PM_{10} and $PM_{2.5}$ concentration in the subway system, e.g. weather, season, estimation of traffic and passenger density.

The main reason for interior PM_{10} and $PM_{2.5}$ concentrations being higher is that subway trains don't have mechanical ventilation systems to supply fresh air to inside the train. CO_2 concentration monitored on line 2 and line 5 ranged from 1,153 ppm to 3,377 ppm (Average: 1,775 ppm), which greatly exceeded 1,000 ppm, limit for efficient ventilation (Figure3). This result indicated a lack of fresh air inside train. Passengers generally could not recognize that fresh air was sufficiently supplied to interior, and just concerned more about heating and cooling. The Seoul Metropolitan Rapid Transit Corporation has been in charge of the safe management of the subway, but has not paid attention to the measures needed to supply fresh air to the interior train or subway stations.

PM_{10} and $PM_{2.5}$ concentrations monitored inside train on underground tracks when train doors were open showed temporary increases. After the doors were closed, they

showed again constant pattern before doors of next station were opened (Figure4 right). On the ground track, opposite tendency was found. PM_{10} concentration became lower when train was open because less contaminated air than inside was naturally coming in (Figure4 left). The re-suspension of particulates from the trains floor and entry of particulate from outside the train due to passengers moving around or taking a seat whenever train is open could result in the rise of particulate contamination inside the train.

Interior particulate contaminated by several factors could not be lowered if dilution air from outside train was not supplied. Our study results were similar to those reported by several studies, in that PM concentration inside public transportations was higher than that of outside air.

Praml et al (2000) reported in a comprehensive 4-year survey that interior PM_{10} concentration exposure on Munich's public buses and trams was 244 / and 279 / , respectively. These concentrations were 1.7 to 4 times above those collected at the static stations.

Chan et al.(2002a) reported that in four kinds of transport modes, particulate level in non-air-conditioned roadway transport was highest recorded level (175 ug/m^3). This concentration was about 3-4 times higher than the value in trains with air-conditioned facilities. The particulate level is greatly affected by transportation mode as well as the ventilation system of the transport.

$PM_{2.5}$ concentrations we monitored ranged from 77.7 / to 158.2 / , which showed that the subway in Korea was terribly contaminated with fine particle not only inside train, but also on platform.

The average PM_{10} or $PM_{2.5}$ concentration from our study were far higher than those monitored from rush hours on subways in Hong Kong (Chan et al, 2002b), Mexico (Chow et al, 1997) and China (Chan et al, 2002b). Chan et al (2002b) reported that PM_{10} and $PM_{2.5}$ concentration monitored during rush hour on Mass Transit Railway, mostly running on the underground in Hong Kong were 44 / and 33 / [10]. Chan et al (2002b) reported similar PM10 (55 /) and $PM_{2.5}$ concentration (44 /) in subway with air-conditioned ventilation in Guangzhou, China. These concentrations were monitored on a subway running mostly on its own underground

track during both non-peak hours (14:00-16:30) and evening peak hours (17:00-19:30). The average of $PM_{2.5}$ measured on the Mexico Metro with underground (or subway system) was 61 / (Chow et al, 1997).

PM_{10} and $PM_{2.5}$ concentration measured from underground tracks in China, Hong Kong and Mexico were far lower than those by our results and reported by Adams et al (2001) even though they were measured from the time including rush hours, where there is high traffic density and a greater number of passengers. Adams et al (2001) reported $PM_{2.5}$ concentration higher than those from our study results. $PM_{2.5}$ concentration measured during winter in the underground track (tube) ranged from 12.2 to 263.5 / (average 157.3 ug/m^3). $PM_{2.5}$ concentration measured during the summer was far higher (range: 105.3 ug/m^3 – 371.2 / , average: 247.2 /). High concentrations of particles have been reported in the underground previously, e.g. London Transport (1982), and more recently Priest et al.(1999) and Pfeifer et al.(1999).

The difference in monitoring results for PM_{10} and $PM_{2.5}$ in subways among cities might be due to time and season, the type of brake system, the ventilation system and depth of tunnel. The PM_{10} and $PM_{2.5}$ concentrations inside and outside subway is greatly influenced by the ventilation condition of the transport. Most of particulate found in subway had penetrated ventilation grids installed at street level. Most ventilation grids type in Seoul may allow fine particles released from motor vehicle exhausts on the streets, to easily penetrate into the subway.

In Korea, outdoor air from the ventilation grid on street is supplied to the platform subway. We couldn't study if contaminated outdoor air was appropriately filtered and supplied into subway environment by the ventilation system. It is obvious that subway trains in Korea doesn't have a mechanical ventilation system to supply fresh air to inside train, resulting in the increase in interior particulate matter.

4.2 The $PM_{2.5}$ and PM_{10} relationship

The $PM_{2.5}$ and PM_{10} ratio was high, ranging from 41.3 % to 97.8 % (Table 2). The highest ratio was 93.9 % on platforms of ground track mode. The average ratio (83.5%) from this study was slightly higher than 73.8 % for the Hong Kong (Chan et al., 200a) and 79 % underground track subway of Guangzhou, China (Chan et al., 2002b).

The $PM_{2.5}$ to PM_{10} ratios on platform of ground track mode were significantly higher than those for underground track. The reason that $PM_{2.5}$ concentrations and $PM_{2.5}$ to PM_{10} ratios on ground track were higher than those in underground tracks was that ground track stations were close to traffic exhaust on street-level, the main source of fine particulate (Table 1). This result may indicate that the air outside, as well as inside the subway, is greatly deteriorated by vehicle exhaust, especially diesel vehicles which may be the main source of fine particulate matter on subway. The average ratio of $PM_{2.5}$ to PM_{10} outside subway were slightly higher than those in interior train both underground and ground track although these ratio differences were not quite obvious.

The ratio of $PM_{2.5}$ to PM_{10} in all transportation modes including subway was found to be relatively high on the interior of an air-conditioned vehicle. Chan et al (2002) assumed that the air-conditioning system filter part of the larger portion (2.5-10 um), resulting in lowering the portion of PM_{10}. These patterns can't be examined in our study because the subway we investigated does not have an air-conditioned ventilation system.

Further study is required to examine the differences of the ratio of $PM_{2.5}$ to PM_{10} among several subway characteristics and to quantify the diesel exhaust concentration on subway air.

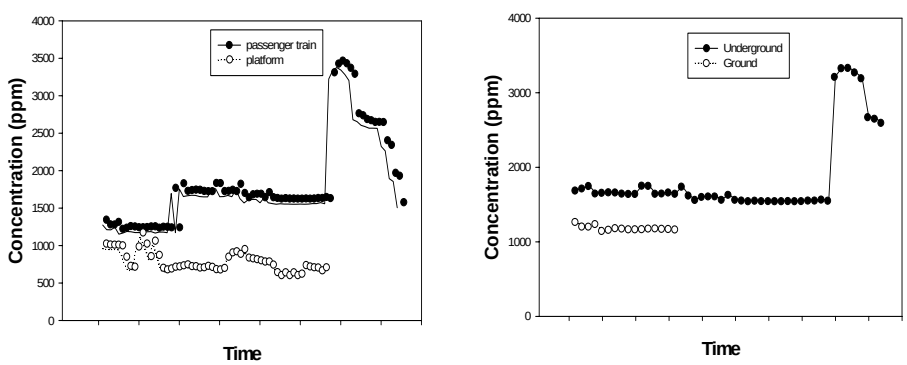


Figure 3. The typical concentration profile of CO_2 on platform and inside train (left: between platform and inside, right: between ground and underground track in inside train).

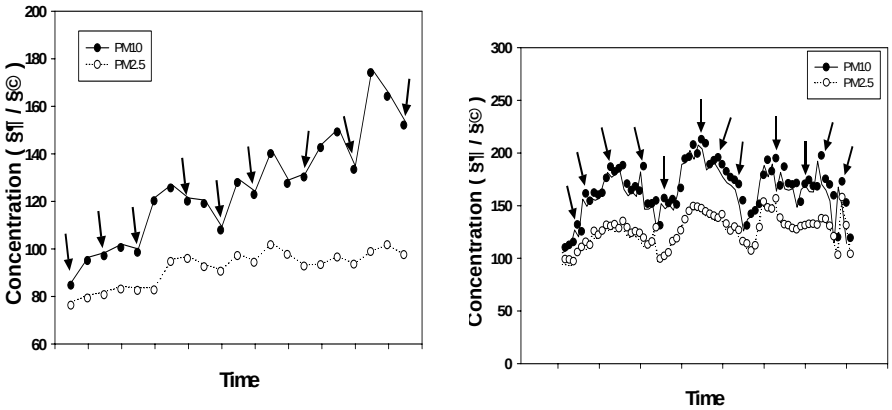


Figure 4. The typical concentration profile of PM_{10} and $PM_{2.5}$ while subway train is running. Arrows show the concentration monitored when door of train is open (left: ground, right: underground).

5. CONCLUSION

The concentrations of PM_{10} and $PM_{2.5}$ inside train were found to be higher than those measured on platform. The percentage of $PM_{2.5}$ that accounted for PM_{10} was slightly higher on platform and ground track than inside train and underground tract. PM_{10} and $PM_{2.5}$ concentrations monitored from underground tracks were significantly higher than those on ground track regardless of line and location. GLM statistical analysis indicated that monitoring locations (underground and ground or inside and platform) significantly influence PM_{10} and $PM_{2.5}$ concentration ($p<0.001$). The average of PM_{10} ratio was 83.5 %. $PM_{2.5}$ to PM_{10} ratios on platform during ground track mode were significantly higher than those in underground track. The highest ratio was 93.9 % on a platform on ground track mode. The percentage of $PM_{2.5}$ in PM_{10} was far higher than that of PM_{10} in TSP. This result indicates that the subway environment was contaminated with fine particulates.

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INDOOR AIR QUALITY AND INDOOR/OUTDOOR RELATIONSHIP IN DOMESTIC HOMES OF CENTRAL PART OF INDIA

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ABSTRACT

Indoor Air Quality (IAQ) has gained great attention in recent years, chiefly due to the large amount of time we spend indoors. People spend on average 87% indoors and only a mere 6% outdoors. We also tend to believe that the indoor environment is better and more livable than the outdoor environment, being cleaner, more comfortable and healthier on the obvious ground that the building will shelter us from harmful substances in the ambient environment. For this reason a number of air quality indication system in the world, which are designed for outdoor use also, gives warnings or advice during episodes of poor air quality, to stay indoors. However, the fundamental question is: Is indoor air really cleaner? Is it cleared of outdoor pollutants? Number of studies on the relationship between indoor and outdoor pollutants has been conducted and the results of these studies confirmed the importance of ambient air in determining the quality of air indoors (Lawrence et al, 2005 a, b). The largest exposure to health damaging indoor pollution probably occur in the developing world, not in households, schools and offices of developed countries where most research and controls efforts have focused to date. As a result, much of the health impacts from air pollution worldwide seem to occur among the poorest and most vulnerable populations (Smith, 2002). As India is developing country and as no such relevant studies have been done in this central part of country, this study was carried out at 12 houses in three different microenvironment i.e. urban, rural and roadside in Agra.

Simultaneously measurements of indoor and outdoor CO, CO_2, NO, NO_2 and SO_2 were done during winter season (Oct.2003-Feb.2004) using YES-205 and YES-206 monitors. Results (Table-1) revealed that during winter season CO and CO_2 was maximum at roadside, NO and NO_2 was maximum at urban areas and SO_2 was found maximum in rural locations. A statically correlation analysis (except for SO_2 due to lack of outdoor reading) of indoor concentration with outdoor concentration was carried out which revealed that indoor environment is positively influenced by outdoor sources. An activated scheduled of inside and outside these houses were also prepared and was seen that activities like wood and coal by the residence increases the indoor level concentration of all the pollutant.

This study was done in order to provide useful information to help to understand the microenvironments of different types of residences of which huge population is residing in developing countries like India and thereby contribute towards the improvement of indoor atmosphere in residential homes of Asian countries.

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Table 1.

Micro-Environment	CO_2		CO		NO_x ($NO+NO_2$)		SO_2	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Rural	392±19	361±09	1.0±0.3	0.4±0.2	---	---	**0.02±.02**	**0.03±.03**
Urban	387±10	378±14	1.3±0.4	0.7±0.2	**0.6±0.3**	**0.9±0.5**	0.01±0.06	----
Roadside	**480±63**	**390±25**	**2.3±1.0**	**1.3±0.2**	0.5±0.2	0.6±0.2	---	---

Key Words: Indoor Air Quality, Indoor/Outdoor Relationship, Microenvironments, Statically Correlation.

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THE BUILDING AS AN EFFECTIVE FACTOR TO INDOOR AIR QUALITY DEFINING THE BUILDING AS A SOURCE OF INDOOR AIR POLLUTION

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ABSTRACT

Energy-efficiency improvements became one of the main design and use objectives within the building due to the 'energy crisis'. This lead, even sometimes forced, people to design, construct and use air tight buildings to reduce energy cost of heating and cooling their buildings. Also, invention of new building materials and products encouraged this movement.

Stopping draughts by sealing buildings with new insulation materials, using devices for mechanical ventilation, reducing ventilation rate in spaces, using reciculated air were some of the preventive solutions for energy conservation. However, serious health incidents on occupants of these types of buildings were recognised. Those of incidents vary from complaints of headaches, lethargy, dizziness, eye and respiratory irritation, loss of concentration to fatal diseases such as legionnaire's disease.

Number of factors which may cause health problems have been identified within the building. Poor organisation within the building, and poor hardware and environmental design of the building are main headings of those of factors which affect the indoor environmental features and their qualities. Lack of privacy, lack of control over environment, repetitive work, poor maintanence and cleaning are some examples for poor organisation. Low standards in construction and services, inappropriate building material and product selection, poor detailing are some results of poor hardware design; and inefficient lighting, noise, fluctuations of air temperature, low air quality and inadequate space planning are some examples of poor environmental design.

Indoor air quality (IAQ) is one of the major environmental features which contributes those of health complaints and may have other severe health effects such as long term suffering from lung cancer and death. And the building itself is an important factor which affects IAQ by its design, construction and organisation. Most of the indoor air pollutants are released from building materials, services, furnishings and fittings, office machines and supplies. Besides, layout of the spaces and constructional details help indoor air pollution to enter, settle and flow from one space to another space within the building.

In this paper, the building is defined as one of the major indoor air pollution sources by a systematic approach. In this systematic examination, first hardware and environments of the building are classified, and users' activities are determined. Then those of features of the building and its users' activities are correlated with the occurence of indoor air pollution. This, examination model of the building as an effective factor of IAQ enables people who are involved in the life of the building to take preventive actions and to control air pollution at source.

Keywords: IAQ, indoor air pollutants, building design, construction, user, user activities

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CONSIDERATION OF THREE PROCESSES INDOOR AIR QUALITY - RISK ASSESSMENT / RISK MANAGEMENT – THE ARCHITECTURAL DESIGN PROCESSES

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ABSTRACT

The building is one of the major factors which affects indoor air quality (IAQ) and contributes serious health problems. Architects' resposibility for people's health is determine the triangular relationship between IAQ, the building itself and its users, and to produce alternative design solutions in terms of IAQ.

Indoor air pollutants and their concentration levels affect IAQ. The pollution of indoor air is one of the situation. The other situation is improving this worse condition to a better level. The improvement of indoor air covers both reducing indoor air pollutants emissions, and controlling their concentration levels. Indoor air pollution and indoor air improvement actions are compilations of a series of actions and have interrelationships. Thus, they become two main parts of IAQ; and combining a series of indoor air related actions make indoor air quality a process (IAQP).

During the whole life of a building, evaluations are necessary to make judgements on whether it meets people's needs or there is a failure of its quality. From this, requirements within the building evaluation help to set the performance and economic values of the building. But, still there are the possibilities that unpleasant or undesirable things might happen and causes danger within the building. Therefore, those uncertainties should be considered to complete the total qualitative evaluation of the building. This is the risk evaluation of the building.

Building design is the creative process in which a building is produced theoretically. The Architectural Design Process (ADP) is the core of the whole building design. The decisions for the physical appearance of the building and the living conditions within the building are actively taken during ADP. Besides demonstrating their creativity, the designers aim to reach functional suitability and the utility of the building, flexibility in the design for possible changes, and structural and environmental performance of the whole building.

IAQ affects directly people's health, and should be considered as a risky factor. Missing its importance can cause hazardous effects from headache to death of a person. Therefore, IAQ should be covered by Risk Assessment / Risk Management

Work. Beside this, IAQ is part of the indoor physical environment and affects the environmental performance of the building. One of the remedial actions to control indoor air pollution is the control of building design. Therefore IAQ should be taken into account during the ADP.

Because IAQ related studies are mostly done either in science or in engineering, the results are either in the form of mathematical models or in the form of technical devices. Sometimes it is difficult to interpret these results into architectural design. Therefore they are required to be in a form that architects can relate above three interrelated factors. The most accepted way is systematic thinking.

In this paper a systematic approach is presented to consider IAQ, Risk Assessment / Risk Management and ADP. The outcomes of the propesed condideration model are,

- Considering IAQP and Risk Assessment / Risk Management process will help people who are involved in the existence of the building and affected by IAQ to understand the occurence of health risk chain related to IAQ.
- Considering IAQP - Risk Assessment / Risk Management and ADP will help architects to make design decisions related to the improvement of IAQ.
- Consideration model of IAQP - Risk Assessment / Risk Management also allows other professions to place their decision-making activities instead of ADP to produce IAQ related solutions.

The life of IAQP is determined by the life of the building. The conceptual existence of the building leads the conceprual existence of IAQP. If IAQ is taken into account during the architectural design stage of the building preventive design solutions can be produced to reduce the effects of an indoor air pollution event before it occurs.

Keywords: IAQ, IAQ process, risk assessment, risk management, architectural design process.