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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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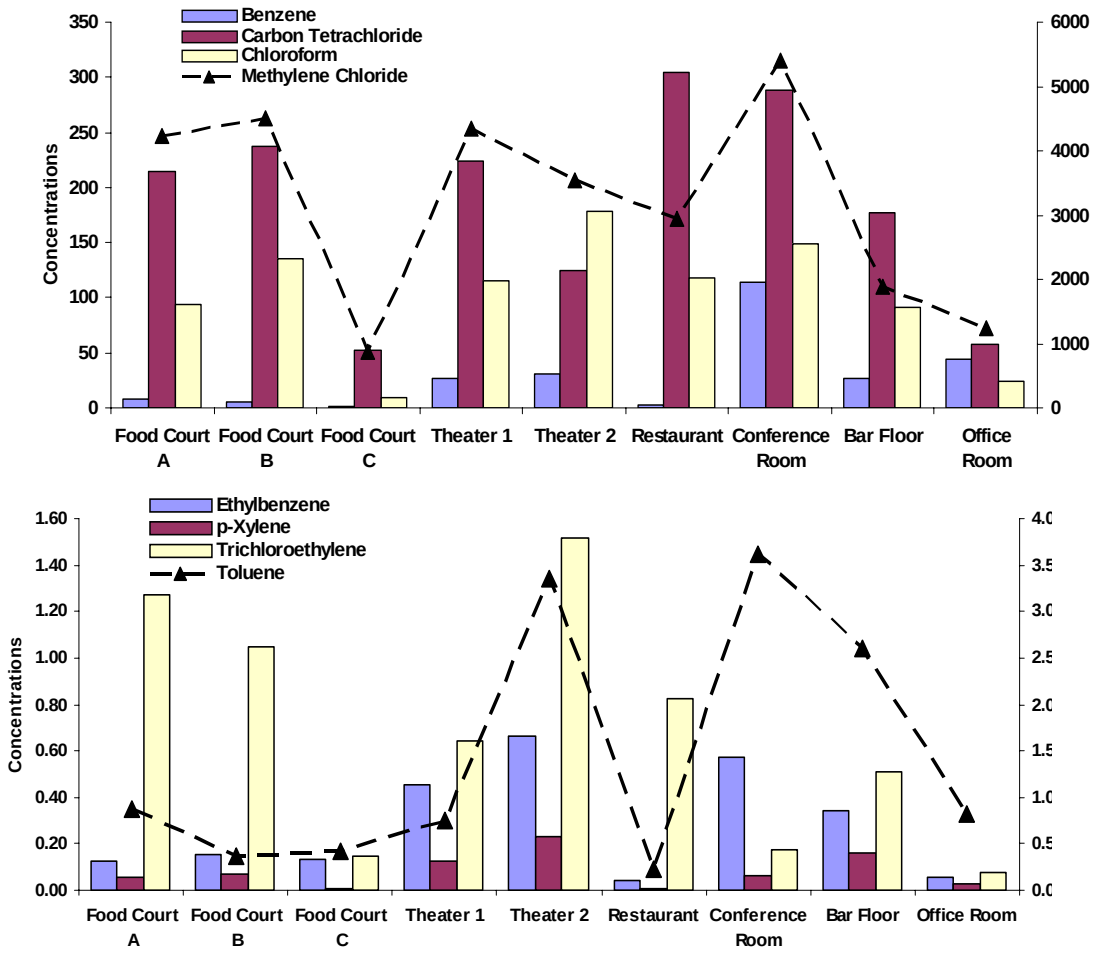
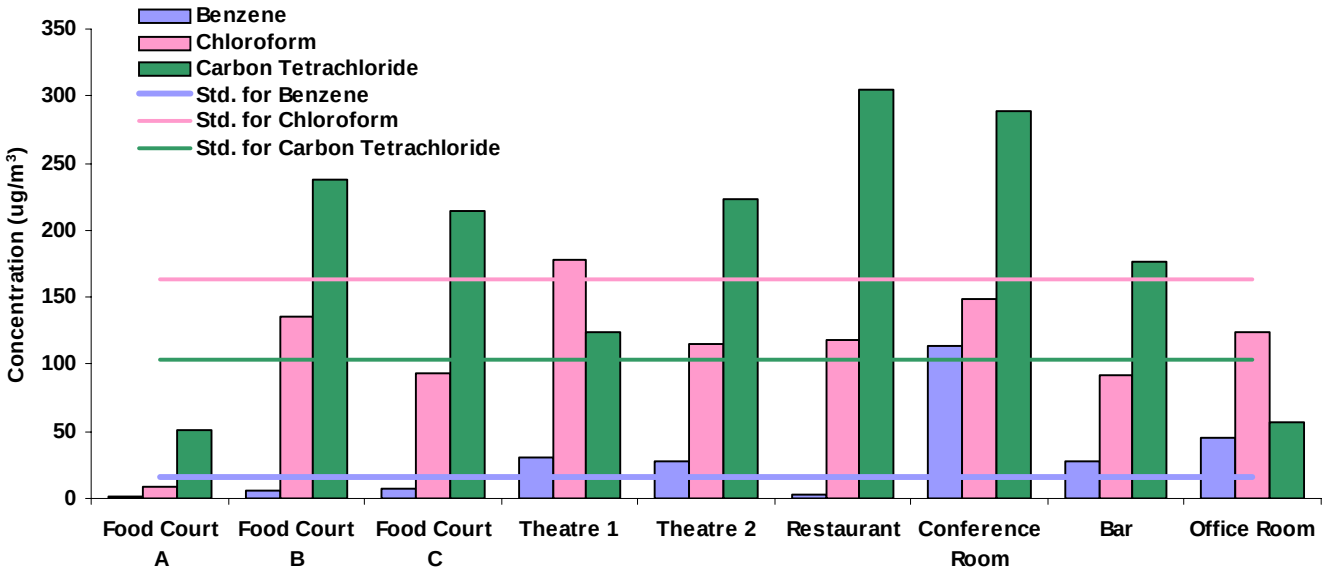



**Figure 1 : Concentrations of VOCs Identified at All Indoor Locations Monitored (Concentration are in µg/m$^3$)**




**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<br>RFC Not established | RFD Group B2 Carcinogen<br>0.0007 mg/kg/day based on tetrious in rats |
| Chloroform | 10.0 | 50.0 | Group B2 Carcinogen<br>REL – 35 µg/m3 | Group B2 Carcinogen<br>0.01 mg/kg/day |
| Methylene Chloride | | | | |
| Benzene | 0.5 | 1.0 | No safe level<br>Group A Carcinogenic | No safe level<br>Confirmed carcinogen effect on humans |
| Ethyl benzene | 100.0 | 100.0 | Group D Carcinogen<br>1 mg/m3 | Group D Carcinogen<br>1 E-1 mg/kg/day |
| p-Xylene | 100.0 | 100.0 | Group D Carcinogen<br>0.1 mg/m3 | Group D Carcinogen<br>0.2 mg/kg/day |
| Toluene | 50.0 | 200.0 | Group D Carcinogen<br>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 |