INDIVIDUAL VOLATILE ORGANIC COMPOUND PREVALENCE AND CONCENTRATIONS IN 56 BUILDINGS OF THE BUILDING ASSESSMENT SURVEY AND EVALUATION (BASE) STUDY

J R Girman[1], G E Hadwen[2], L E Burton[1], S E Womble[1], and J F McCarthy[2]

[1]Indoor Environments Division, U.S. Environmental Protection Agency, USA
[2]Environmental Health & Engineering, Inc., USA

ABSTRACT

Volatile organic compounds (VOCs) were measured in indoor and outdoor air at 56 randomly selected public and private office buildings across the USA as part of the U.S. Environmental Protection Agency's Building Assessment Survey and Evaluation study (BASE). These VOC data and data on many other parameters associated with indoor air quality were collected to provide normative data on typical office buildings. Between the summer of 1995 and the winter of 1997-98, more than 200 VOC samples were collected on multisorbent samplers and analyzed by gas chromatography/mass spectrometry. These samples were collected at three indoor locations and at one outdoor location. Forty-eight VOCs were found indoors at quantifiable concentrations. Eight VOCs were found in all samples and an additional 26 VOCs were found in 81-99% of the samples. Concentration frequency distributions are presented for the twelve VOC with the highest median indoor concentrations: acetone; toluene; d-limonene; m- & p-xylenes; 2-butoxyethanol; n-undecane; benzene; 1,1,1-trichloroethane; n-dodecane; hexanal; nonanal; and n-hexane. Indoor VOC concentrations ranged from below the limit of detection to 450 $\mu g/m^3$. Indoor/outdoor concentration ratios for the same VOCs are also presented. The results from this study provide normative data on VOCs in U.S. office buildings that can be used to compare to data from complaint buildings, to examine the relationships of VOCs with other building factors collected in this study, to conduct risk assessments and to design more focused studies.

INTRODUCTION

Information on baseline indoor air quality in public and commercial office buildings in the USA has not been available. In 1994, the U.S. Environmental Protection Agency (U.S. EPA) initiated a major cross-sectional study, the Building Assessment Survey and Evaluation study (BASE), to characterize key characteristics of IAQ, occupant health symptoms and perceptions of IAQ in public and commercial office buildings. This paper presents a summary of the results from the measurement of volatile organic compounds (VOCs) in 56 randomly selected office buildings across the USA, including prevalence of selected VOCs, concentration frequency distributions and indoor/outdoor concentration ratios. VOCs were studied because many of them are potential irritants, carcinogens and systemic toxicants [1]. These data can be used to compare measurements made in complaint buildings; to examine relationships of VOCs with other building factors

collected in this study (e.g., ventilation rates or presence of sources) or occupant perceptions and symptoms; to develop hypotheses for more focused studies; and to use as data for risk assessments.

METHOD

Between summer 1995 and winter 1997-98, data and samples were collected in each of 56 office buildings using a standardized protocol over a one-week period during either the summer or winter season [2]. These buildings were randomly selected without regard to indoor air quality concerns, except that buildings with highly publicized indoor air quality problems were excluded. Additional information on building selection can be found in a previous paper [3]. Data and samples were collected on the following: VOCs including aldehydes; particulate matter; radon; microbiological contaminants; carbon monoxide; carbon dioxide; temperature and relative humidity; building characteristics; and occupant symptoms and perceptions of IAQ. Data were also collected regarding characteristics, operation and maintenance of the heating, ventilation and air-conditioning systems. Formaldehyde and acetaldehyde were sampled and analyzed by a separate method and results for these compounds are not presented in this paper. More than 200 samples were collected for VOCs on multisorbent media (Tenax-TA, Ambersorb XE-340, and activated charcoal). (Side-by-side VOC samples were also collected using another method, evacuated SUMMA® canisters, and some of these results have already been reported [4]. Some systematic differences observed between the two collection methods are currently being evaluated.) Samples were collected at three randomly selected indoor locations and at one outdoor location for each building on a Wednesday for 8-10 hours during normally occupied times. Indoor sample flow rates were nominally set at 5 ml/min. Outdoor flow rates were set at 6-8 ml/min because lower outdoor VOC concentrations were expected. The samples were analyzed for a target analyte list of 46 VOCs. In the summer of 1997, after reviewing VOC data collected, the list was changed to 51 analytes, by the addition of 12 VOCs and the deletion of 7 rarely detected VOCs. Samples were analyzed by thermal desorption and gas chromatography/mass spectroscopy using a modified version of EPA Method TO-1 (Berkeley Analytical Laboratories, Berkeley, CA). For quality control, two duplicates and one blank sample were also submitted for analysis for each building. Samples spiked with known concentrations of VOC were also submitted for analysis.

For computation, compounds reported as below the limit of quantitation (LOQ) were assigned a concentration of half their respective LOQ. At sites with duplicate samples, the mean concentration of the duplicates was used for calculations. Concentration frequency distributions are represented by reporting the 5th, 25th, 50th, 75th, and 95th percentiles as well as the minimum and maximum values. Concentration frequency distributions were calculated across all buildings and all sample locations, including those, if any, where analytes were not detected. For a given VOC, the prevalence (or frequency of appearance) was calculated by dividing the number of indoor samples with quantifiable concentrations by the total number of indoor samples. Ratios of indoor to outdoor concentrations were calculated by dividing the indoor concentration at each location by the mean outdoor concentration at the same building. Ratios were calculated

for VOCs at all locations that had at least one quantifiable concentration indoors and an outdoor concentration. As with the frequency distribution calculations, for the purpose of averaging and computing ratios, VOCs reported below the LOQ were assigned values of half the LOQ.

RESULTS

In the 56 U.S. buildings studied, 48 VOCs were measured indoors at quantifiable concentrations. Table 1 presents the frequency with which VOCs were detected in the indoor air of office buildings and the range of concentrations quantified.

Table 1
Frequency* of VOCs at Quantifiable Concentrations in Indoor Air

VOCs	Range of Quantifiable Concentrations ($\mu g/m^3$)	VOCs	Range of Quantifiable Concentrations ($\mu g/m^3$)
81-100 % Frequency		Continued 81-100%	
Acetone	7.1 – 220	Naphthalene	0.3 - 9.7
Toluene	1.6 – 360	1-Butanol	0.8 - 15
m- & p-Xylenes	0.8 – 96	61-80%	
n-Undecane	0.6 – 58	1,4-Dichlorobenzene	0.3 - 85
n-Dodecane	0.5 – 72	41-60%	
Nonanal	1.2 - 7.9	3-Methyl pentane	1.0 - 16
n-Decane	0.3 – 50	Trichloroethene	0.2 - 18
o-Xylene	0.3 - 38	21-40%	
d-Limonene	0.3 – 140	Methylene chloride	0.5 - 360
Benzene	0.6 – 17	Trichlorofluoromethane	2.2 - 160
1,1,1-Trichloroethane	0.6 – 450	t-Butyl methyl ether	2.0 - 30
Hexanal	0.8 – 12	1-20%	
Ethylbenzene	0.3 – 30	Trichloro-trifluoroethane	1.4 - 23
1,2,4-Trimethylbenzene	0.3 – 25	Chloroform	0.3 - 9.6
Tetrachloroethene	0.3 – 50	Carbon tetrachloride	1.2 - 3.9
Phenol	0.3 - 9.5	4-Phenylcyclohexene	0.3 - 0.6
Ethyl acetate	0.22 – 65	Carbon disulfide	1.0 - 18
2-Butanone	0.7 – 18	Chlorobenzene	0.3 - 0.7
Styrene	0.2 - 6.7	1,2,4-Trichlorobenzene	0.9 - 1.2
TXIB	0.2 - 2.8	1,2-Dichlorobenzene	1.1 - 13
4-Ethyltoluene	0.3 – 11	Not Detected	
2-Butoxyethanol	0.7 – 78	1,2 – Dichloropropane	--
2-Ethyl-1-hexanol	0.3 – 48	Hexachlorobutadiene	--
Nonane	0.3 – 46	cis-1,2-Dichloroethene	--
Octane	0.2 – 280	1,1,2-Trichloroethane	--
Butyl acetate	0.3 – 51	1,2-Dichloroethane	--
n-Hexane	0.6 – 21	Benzyl chloride	--
Pentanal	0.5 - 3.3	1,3- Dichlorobenzene	--
1,3,5- Trimethylbenzene	0.3 - 8.6	Dimethyl disulfide	--
a-Pinene	0.3 - 8.4	1,2- Dibromoethane	--
Texanol 1&3	0.5 – 28	Butylated hydroxytoluene	--
4-Methyl-2-pentanone	0.2 – 28		

* Frequency is the ratio of indoor samples with quantifiable concentrations to total number of indoor samples for the given analyte. VOCs are listed in descending order of frequency within each group.

Eight VOCs (acetone, toluene, m- & p-xylenes, o-xylene, n-decane, n-undecane, n-dodecane and nonanal) were detected in all indoor samples. Twenty-six VOCs were detected in 81 to 99% of the samples of indoor air in these office buildings, one VOC was found in 61 to 80% of the indoor air samples, two VOCs were found in 41 to 60% of the indoor air samples, three VOCs were found in 21 to 40% of the indoor air samples and eight VOC were found in 1 to 20 % of the indoor air samples. Ten VOCs were not detected in any of the samples of these 56 office buildings: 1,2–dichloropropane; hexachlorobutadiene, cis 1,2-dichloroethene; 1,1,2-trochloroethane; 1,2-dichloroethane; benzyl chloride; 1,3-dichlorobenzene; dimethyl disulfide; 1,2-dibromoethane; and butylated hydroxytoluene.

The distributions of the indoor concentrations of the twelve VOCs with the highest indoor median concentrations are shown in Figure 1. Acetone, toluene, d-limonene, m- & p-xylenes, 2-butoxyethanol and n-undecane had the largest median indoor concentrations at 29, 9.0, 7.1, 5.2, 4.5 and 3.7 $\mu g/m^3$ respectively. The maximum indoor concentrations for these VOCs were 220, 370, 140, 96, 78, and 58 $\mu g/m^3$, respectively. The six VOCs with the next largest median indoor concentrations are benzene, 1,1,1-trichloroethane, n-dodecane, hexanal, nonanal and n-hexane with median concentrations of 3.7, 3.6, 3.5, 3.2, 3.1 and 2.9 $\mu g/m^3$ respectively; the maximum concentrations measured indoors for these VOCs were 17, 450, 72, 12, 7.9 and 21 $\mu g/m^3$ respectively. 1,1,1-Trichloroethane had the highest concentration measured.

Figure 2 presents the distribution of indoor to outdoor concentration ratios for the twelve VOCs with the highest median indoor concentrations. All VOCs detected had median concentration ratios greater than one. Twenty-seven VOCs had a median indoor/outdoor concentration ratio greater than two. Five of the VOCs (d-limonene, 2-butoxyethanol, n-undecane, n-dodecane, and hexanal) had median indoor/outdoor concentration ratios near or greater than 10.

DISCUSSION

The results of the BASE study show a broad range of VOCs present in the air inside office buildings. In this study of 56 randomly selected office buildings, 48 VOCs were measured indoors at quantifiable concentrations. Many VOCs were commonly found in these office buildings: 34 VOCs were detected in 81% or more of the samples. However, ten VOCs were not detected in any of the more than 200 indoor samples from the 56 office buildings. Thus, if these VOCs were detected in the indoor air of an office building, it would be unusual and may warrant further investigation. Alternatively, it may not be necessary to analyze for these VOCs when sampling in office buildings. All detectable VOCs had median indoor/outdoor concentration ratios greater than one, suggesting that all detectable VOCs had indoor sources. Twenty-seven VOCs had a median indoor/outdoor concentration ratio greater than two.

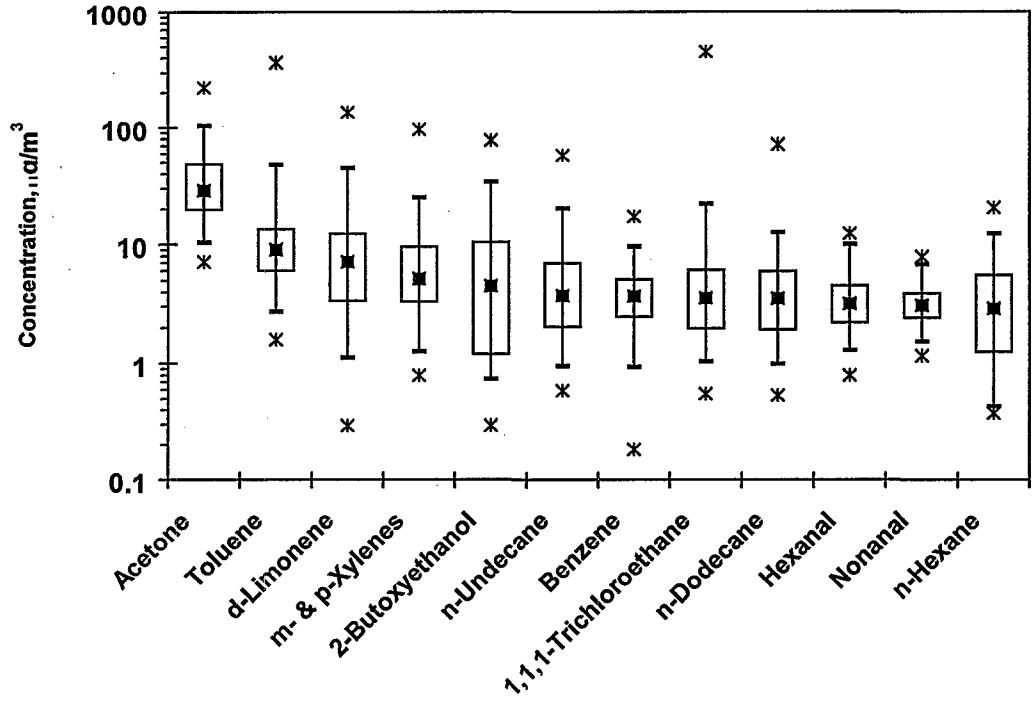

Figure 1: Minimum, 5th, 25th, 50th, 75th, 95th Percentile, and Maximum Concentrations for BASE VOCs Measured Indoors by Multisorbent Methods for 12 VOCs

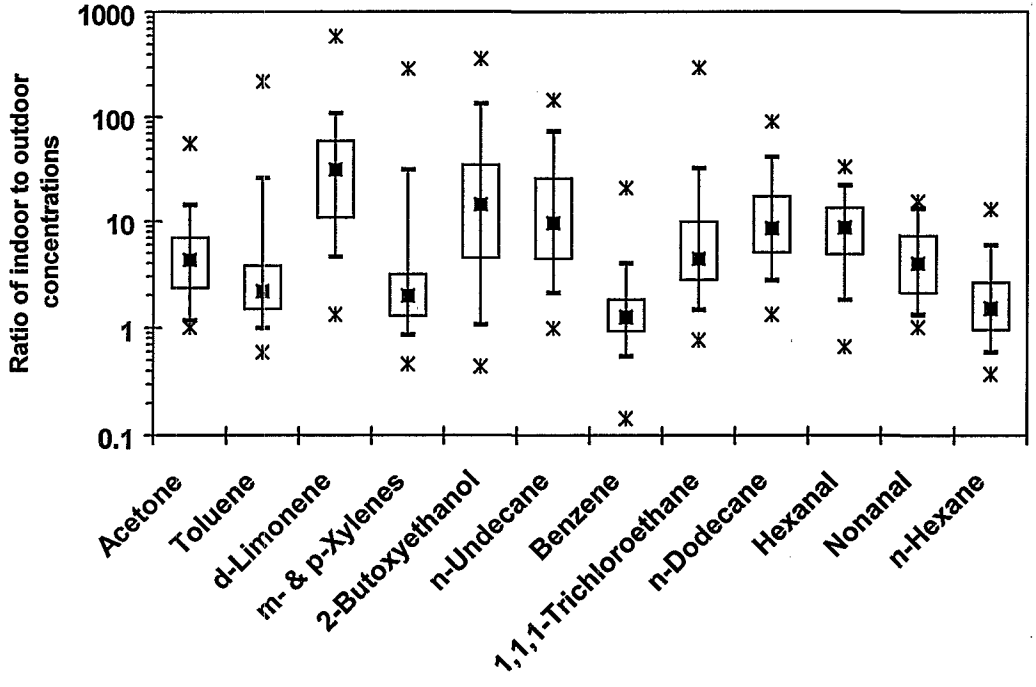

Figure 2: Minimum, 5th, 25th, 50th, 75th, 95th Percentile, and Maximum for Indoor to Outdoor Concentration Ratios of BASE VOCs Measured by Multisorbent Methods for 12 VOCs

Acetone, toluene, d-limonene, m- & p-xylenes, 2-butoxyethanol, n-undecane, benzene, 1,1,1-trichloroethane, n-dodecane, hexanal, nonanal and n-hexane had the largest median indoor concentrations. It is interesting to note that four of these twelve VOCs are oxygenated VOCs, because of many oxygenated VOCs have the potential to cause irritancy.

The range of concentrations observed for many individual VOCs is large and there is often a large increase in concentrations from the 95th percentile to the maximum concentration observed for a particular VOC. For seven VOCs, the concentration from the 95th percentile to the maximum concentration observed increases by an order of magnitude or more, suggesting that some buildings have very strong sources of VOCs.

The results from this study provide normative or baseline data on VOCs in U.S. office buildings that can be used in building diagnostics for comparisons to data from complaint buildings, for examining the relationships of VOCs with other building factors collected in this study, for conducting risk assessments and for designing more focused studies.

ACKNOWLEDGMENTS

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