A REVIEW:
Residential Indoor Air Concentrations of Common Volatile Organic Compounds

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ABSTRACT

Residential indoor air concentrations of volatile organics compounds (VOCs) can be contributed to, or stem from, vapor intrusion from underlying VOC-contaminated subsurface soil or groundwater. However, indoor air sources represent confounding influences. A database providing the environmental manager with a general understanding of background conditions could significantly assist pragmatic risk management decisions where site-specific data are limited or not available. This paper presents a cursory summarization of mean and upper-bound background levels of common residential indoor air contaminants and presents an assessment of the associated incremental lifetime cancer risk or hazard.

INTRODUCTION

Residential indoor air concentrations of volatile organics compounds (VOCs) can be contributed to, or stem from, vapor intrusion from underlying VOC-contaminated subsurface soil or groundwater. However, household breathing zones are at risk from VOCs even if they are not underlain by contaminated environmental media. Household products including paints, paint strippers and other solvents, wood preservatives, aerosol sprays, cleansers and disinfectants, moth repellents, air fresheners, stored fuels and automotive products, hobby supplies, and dry-cleaned clothing all commonly contribute to VOC loading of residential indoor air. Studies have found that levels of several organics average two to five times higher indoors than outdoors.

Numerous studies have been conducted to quantify background concentrations of volatile organic compounds (VOCs) in residential indoor air; however, a searchable database of these concentrations on a regional or national level is not currently available. This poster focuses on the most commonly encountered volatile organic contamination in residential indoor air and presents an initial compilation of data from 25 publicly available background studies and investigation reports. Due to the limited number of sources, the available data were compiled into a database for assessment without prioritization.

MATERIALS AND METHODS

Median and upper confidence limit (UCL) values were compiled from 25 sources and compared to the 2008 US Environmental Protection Agency (EPA) residential ambient air Regional Screening Levels (RSLs). Minimum and maximum median vales and upper confidence limits were summarized for each study. For the purposes of this assessment, the maximum reported median value across all the reporting studies was selected as the appropriate metric for use in comparison to health-based standards. In a true health assessment, uncertainty underpinning the actual exposure point concentration could lead to the selection of an upper-bound estimate on the mean, such as the 90-95th UCL. Following selection of the maximum reported median value as the *de facto* exposure point concentration for each contaminant, we divided this value by the RSL. For contaminants administered on the basis of their noncarcinogenic potential, this simple ratio equates to a hazard quotient. For carcinogens, this ratio was multiplied by 1E-06 to develop an age-adjusted incremental lifetime cancer risk (ILCR) estimate under residential land use. Table 1 presents data available from the subject sources for the most common residential indoor air contaminants.

Table 1: Reported Concentrations of Common Residential Indoor Air Contaminants

Source/Reference	Units	Percentile	Benzene		Toluene		Ethylbenzene		m,p-Xylene		o-Xylene		1,2,4-Trimethylbenzene	
			Median	Percentile	Median	Percentile	Median	Percentile	Median	Percentile	Median	Percentile	Median	Percentile
EPA (1998) - Shah and Singh (1988)	ug/m^3	NE	**10**	NE	6.3	NE	**4.9**	NE	NE	NE	NE	NE	NE	NE
EPA (1988)	ug/m^3	75	NE	21	NE	0	NE	9.6	NE	18	NE	9.3	NE	4
MDH (2006) - Stolwijk (1990)	ug/m^3	90	**10**	20	65	150	**10**	20	20	40	5	10	5	20
Wallace (1991)	ug/m^3	NE	**15**	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Sheldon, et al (1992)	ug/m^3	90	**2.2**	8.3	NE	NE	NE	NE	3.8	13	1.9	6.5	NE	NE
NYSDOH (1997)	ug/m^3	95	**2.5**	14	13	46	<4.4	6.5	5	21	<5.2	7.9	5	20
MDH (2006) - ATSDR (1997a)	ug/m^3	90	**7-10.5**	NE	NE	NE	NE	NE	14	NE	4.9	NE	NE	NE
Morandi and Stock (1998) - Pasadena	ug/m^3	NE	**2.17**	NE	8.27	NE	NE	NE	NE	NE	NE	NE	NE	NE
Morandi and Stock (1998) - Southwest	ug/m^3	NE	**1.33**	NE	19.25	NE	NE	NE	NE	NE	NE	NE	NE	NE
MDH (2006) - Clayton et al (1999)	ug/m^3	90	**4.35**	12.95	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
MDH (2006) - Gordon et al (1999)	ug/m^3	90	**1.3**	9.5	10	49	NE	NE	NE	NE	NE	NE	NE	NE
EPA (2001)	ug/m^3	95	**3.4**	12.5	15.7	70.8	**1.4**	7.6	6.9	28.5	2.4	11.2	2.8	13.7
Kurtz and Folkes (2002)	ug/m^3	95	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Zhang, et al (2003)	ug/m^3	95	**2.06**	11.62	2.65	20.70	0.6	5.05	1.48	16.67	0.86	8.24	1.46	6.42
Hodgson and Levin (2003)	ug/m^3	95	**0.87**	4.0	3.3	NE	0.53	NE	1.4	5	0.53	1.6	0.79	NE
Adgate, et al (2004)	ug/m^3	95	NE	7.5	NE	66.5	NE	NE	NE	10.7	NE	3.7	NE	NE
Hippelein (2004)	ug/m^3	90	**2.4**	5.4	12	46	**1.4**	2.7	NE	NE	1.4	2.4	1.3	3.5
Health Effects Institute (2005)	ug/m^3	95	**2.19**	10	10.1	39.8	**1.46**	7.62	4.07	22.2	1.46	7.24	NE	NE
Ayoko, et al (2005)	ug/m^3	95	**14.64**	4.83	37.27	15.6	**7.17**	0	27.65	11.6	11.33	2.81	NE	NE
Kinney (2005) - Summer	ug/m^3	75	**3.62**	5.51	11.9	15.8	**1.6**	2.02	5.14	6.81	1.69	2.22	NE	NE
Kinney (2005) - Winter	ug/m^3	75	**1.46**	2.43	10.1	14	**1.63**	2.27	4.91	6.46	1.73	2.37	NE	NE
NYSDOH (2005), Fuel Oil Heated Homes	ug/m^3	90	NE	15	NE	58	NE	7.4	NE	12	NE	7.6	NE	9.5
Weisel (2006)	ug/m^3	95	NE	13.1	NE	90.2	NE	12	NE	41.1	NE	13.1	NE	13.1
MA DEP (2008)	ug/m^3	90	NE	11.475	NE	53.8	NE	7.4	NE	NE	NE	NE	NE	NE
MA DEP (2008b)	ug/m^3	90	NE	11	NE	54	NE	7.4	NE	NE	NE	NE	NE	NE

Bold - Indicates exceedance of the corresponding USEPA residential ambient air Regional Screening Level, predicated on: TR = 1E-06 / THQ = 1.0

Notes:

1. Source/Reference information provided in separate document

Acronyms:

NE	Not Evaluated
ND	Not Detected
ug/m^3	microgram per cubic meter

Table 1: Reported Concentrations of Common Residential Indoor Air Contaminants

Source/Reference	Units	Percentile	MTBE		n-Hexane		Naphthalene		PCE		TCE		Chloroform	
			Median	Percentile	Median	Percentile	Median	Percentile	Median	Percentile	Median	Percentile	Median	Percentile
EPA (1998) - Shah and Singh (1988)	ug/m^3	NE	NE	NE	NE	NE	NE	NE	**5.1**	NE	0.7	NE	**0.5**	NE
EPA (1988)	ug/m^3	75	NE	NE	NE	4	NE	NE	NE	11	NE	4.5	NE	3.4
MDH (2006) - Stolwijk (1990)	ug/m^3	90	NE	NE	NE	NE	**2**	5	**5**	20	**5**	20	NE	NE
Wallace (1991)	ug/m^3	NE	NE	NE	NE	NE	NE	NE	**15**	NE	**7**	NE	**3**	NE
Sheldon, et al (1992)	ug/m^3	90	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
NYSDOH (1997)	ug/m^3	95	NE	NE	<3.6	15	<10	12	<3.8	9.7	<2.8	5	<4.8	5
MDH (2006) - ATSDR (1997a)	ug/m^3	90	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Morandi and Stock (1998) - Pasadena	ug/m^3	NE	NE	NE	NE	NE	NE	NE	**0.48**	NE	NE	NE	**0.67**	NE
Morandi and Stock (1998) - Southwest	ug/m^3	NE	NE	NE	NE	NE	NE	NE	**1.52**	NE	NE	NE	**1.94**	NE
MDH (2006) - Clayton et al (1999)	ug/m^3	90	NE	NE	NE	NE	NE	NE	**1.89**	6.83	0.56	2.28	NE	NE
MDH (2006) - Gordon et al (1999)	ug/m^3	90	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
EPA (2001)	ug/m^3	95	<1.7	16.1	3.1	15.2	<2.5	20.9	**3**	25.4	<1.4	6.5	<0.05	1.4
Kurtz and Folkes (2002)	ug/m^3	95	NE	NE	NE	NE	NE	NE	**1**	6.5	0.13	0.7	NE	NE
Zhang, et al (2003)	ug/m^3	95	NE	NE	2.12	19.19	**2.84**	32.28	**1.34**	1.34	**1.31**	2.05	**3.37**	3.37
Hodgson and Levin (2003)	ug/m^3	95	NE	NE	0.51	NE	**0.09**	NE	0.15	0.72, 1.0	0.08	0.13, 0.26	**0.19**	1.2
Adgate, et al (2004)	ug/m^3	95	NE	NE	NE	NE	NE	NE	NE	5.2	NE	1.1	NE	3.7
Hippelein (2004)	ug/m^3	90	NE	NE	0.37	3.6	**0.46**	1.6	NE	NE	<0.60	<0.60	NE	NE
Health Effects Institute (2005)	ug/m^3	95	5.98	36	NE	NE	NE	NE	**0.56**	6.01	0.12	1.36	**92**[2]	6.34
Ayoko, et al (2005)	ug/m^3	95	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Kinney (2005) - Summer	ug/m^3	75	**10.6**	17.1	NE	NE	NE	NE	**3.53**	6.13	0.44	0.74	**2.57**	4.15
Kinney (2005) - Winter	ug/m^3	75	**13.49**	16.2	NE	NE	NE	NE	**2.01**	4.48	0.14	0.36	**1.73**	2.92
NYSDOH (2005), Fuel Oil Heated Homes	ug/m^3	90	NE	27	NE	18	NE	NE	NE	2.9	NE	0.48	NE	1.4
Weisel (2006)	ug/m^3	95	NE	72	NE	20.2	NE	NE	NE	9.53	NE	2.74	NE	4.05
MA DEP (2008)	ug/m^3	90	NE	39.02	NE	NE	NE	2.66	NE	4.095	NE	0.8	NE	3.01
MA DEP (2008b)	ug/m^3	90	NE	39	NE	NE	NE	2.7	NE	4.1	NE	0.8	NE	3

Bold - Indicates exceedance of the corresponding USEPA residential ambient air Regional Screening Level, predicated on: TR = 1E-06 / THQ = 1.0

Notes:

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Acronyms:

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ND	Not Detected
ug/m^3	microgram per cubic meter

RESULTS

Of the 22 VOCs evaluated, eight VOCs were detected in background studies and investigation reports with median concentrations that exceeded the applicable RSL.

All 18 median concentrations of benzene available in background studies and investigation reports exceeded the applicable RSL of 0.31 micrograms per cubic meter (ug/m^3). Similarly, all five median concentrations of formaldehyde available in the studies and reports exceeded the applicable RSL of 0.19 ug/m^3. PCE and chloroform were detected in over 80% of the studies and/or reports with median concentrations that exceeded the applicable RSLs of 0.41 ug/m^3 and 0.11 ug/m^3, respectively. Ethyl benzene, naphthalene, and methyl tert butyl ether (MTBE) were detected in over 50% of the studies and/or reports with median concentrations that exceeded the applicable RSLs of 0.97 ug/m^3, 0.072 ug/m^3, and 9.4 ug/m^3, respectively.

Based on comparison to median indoor air levels, none of the common contaminants was associated with excess noncarcinogenic hazard (not superseded by risk, where both endpoints were pertinent). The primary driver contributing to carcinogenic risk is formaldehyde which had a calculated ILCRs in excess of 1E-04 of 2.74E-04. Benzene, naphthalene (using an inhalation Unit Risk value from the RSLs), ethyl benzene, chloroform and tetrachloroethene (PCE) are all associated with ILCRs in excess of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) relative risk range (RRR) midpoint of 1E-05. Two additional compounds, MTBE and trichloroethene, are associated with ILCRs above the NCP *de minimis* level of 1E-06.

Please note that the median concentration value of 92 ug/m^3 for chloroform from the Health Effects Institute (2005) was not utilized. This concentration translates to a health risk in excess of 1E-04; however, TechLaw believes this concentration is a transcription error due to the upper-bound indoor air concentration from the same report being listed at 6.34 ug/m^3. As such, the next highest median concentration value identified – a value of of 3.37 ug/m^3 (Zhang, 2003) - was utilized for ILCR calculations.

Table 2 presents a summary of the available data, including median and upper-bound indoor air concentrations of the common contaminants list in comparison to health-based levels and the associated carcinogenic risk or noncarcinogenic hazard. The final column presents the common sources of these VOCs.

Table 2: Summary of Database Median and Upper-bound Values in Comparison to Health-based Criteria

Contaminant	Median (ug/m^3)		UCL				Regional Screening Level Residential Ambient Air (ug/m^3)	Basis	Number of Studies	Number of Values that Exceeded Regional Screening Level	Ratio of Maximum Reported Median Value to the Ambient Air RSL	**Extrapolated Risk or Hazard - Based on Median Values**	**Common Sources**
	Minimum	Maximum	Minimum	Percentile	Maximum	Percentile							
Benzene	0.87	15	2.43	75	21	75	0.31	ca	18	18	48.39	**4.84E-05**	Gasoline, paint, degreasers, adhesives, adhesive removers.
Toluene	2.65	65	0	75	150	90	5200	nc	14	0	0.01	**0.01**	Gasoline, fuel oil, paint, paint thinner, adhesives, nail polish, furniture polish, shoe polish.
Ethylbenzene	0.53	10	0	95	20	90	0.97	ca	11	8	10.31	**1.03E-05**	Gasoline, fuel oil,paint, paint thinner, floor polish, insecticides, tub and tile cleaner.
m,p-Xylene	1.4	27.65	5	95	41.1	95	100	nc	11	0	0.28	**0.28**	Gasoline, fuel oil, paint, paint thinner, degreasers, lubricating oils, water proofing, pesticides, pruning paint, flea medicine.
o-Xylene	0.53	11.33	1.6	95	13.1	95	73	nc	12	0	0.16	**0.16**	Gasoline, fuel oil, paint, paint thinner, degreasers, lubricating oils, water proofing, pesticides, pruning paint, flea medicine.
1,3,5-Trimethylbenzene	0.25	2	1.2	90	6.43	95	-	-	6	0	*na*	*na*	Gasoline, paint, varnish, auto products, wood floor wax, insecticides.
1,2,4-Trimethylbenzene	0.79	5	3.5	90	20	90/95	7.3	nc	6	0	0.68	**0.68**	Gasoline, paint, varnish, auto products, wood floor wax, insecticides.
1,2,3-Trimethylbenzene	0.2	1.63	2.7	90	2.9	95	-	-	2	0	*na*	*na*	Gasoline, paint, varnish, auto products, wood floor wax, insecticides.
MTBE	5.98	13.49	16.1	95	72	95	9.4	ca	4	2	1.44	**1.44E-06**	Gasoline
n_hexane	0.37	3.1	3.6	90	20.2	95	730	nc	5	0	0.00	**0.00**	Gasoline
n-Heptane	0.26	1	4.8	90	19	90	-	-	2	0	*na*	*na*	Gasoline
n-Octane	0.24	0.64	1.03	95	8.6	95	-	-	4	0	*na*	*na*	Gasoline
n-Nonane	0.25	1.7	3.1	90	12.4	95	-	-	3	0	*na*	*na*	Gasoline, fuel oil
n-Decane	0.44	4.6	6.7	90	22.4	95	-	-	3	0	*na*	*na*	Gasoline, fuel oil
n-Undecane	0.28	8.9	8.3	90	27.4	95	-	-	4	0	*na*	*na*	Gasoline, fuel oil
Naphthalene	0.09	2.84	1.6	90	32.28	95	0.072	ca	6	3	39.44	**3.94E-05**	Gasoline, fuel oil, insectcides, moth balls, herbicides, automotive products
PCE	0.15	15	1.34	95	25.4	95	0.41	ca	14	12	36.59	**3.66E-05**	Dry cleaned clothes, rug & upholstery cleaners, auto products, paint and varnish removers, adhesives.
TCE	0.08	7	0.36	75	20	90	1.2	ca	13	1	5.83	**5.83E-06**	Paint and varnish removers, brake cleaner, adhesive cleaner.
Chloroform	0.19	3.37	1.2	95	6.34	95	0.11	ca	11	9	30.64	**3.06E-05**	Chlorinated water, adhesive remover
1,1,1-Trichloroethane	0.36	30	0.4	90	33	95	5200	nc	9	0	0.01	**0.01**	Furniture cleaner, adhesive, lubricant, insecticides, paint and varnish remover.
Vinyl chloride	0.01	0.01	0.04	95	0.09	95	0.16	ca	3	0	0.06	**6.25E-08**	Pipe sealant, breakdown product of TCE, PCE, etc.
Formaldehyde (HCHO)	12.2	52	4.48	95	88	75	0.19	ca	5	5	273.68	**2.74E-04**	Pressed wood products (hardwood plywood wall paneling, particleboard, fiberboard) and furniture made with these pressed wood products. Urea-formaldehyde foam insulation (UFFI). Combustion sources and environmental tobacco smoke. Durable press drapes, other textiles, and glues.
											Cumulative Excess Cancer Risk:	**4.46E-04**	

na - Not available/applicable

RED - Indicates exceedance of the NCP's upper-bound of one-in-ten thousand excess lifetime cancer cases

ORANGE - Indicates exceedance of the NCP's mid-range of one-in-one hundred thousand excess lifetime cancer cases

BLUE - Indicates exceedance of the NCP's lower-bound of one-in-one million excess lifetime cancer cases

GREEN - Indicates no associated excess risk or hazard

* - The maximum identified median value for chloroform of 92 ug/m^3 (Health Effects Institute, RIOPA Data, 2005) was eliminated and the second highest value (3.37 ug/m^3) was selected from Zhang, 2003. The RIOPA-based value is associated with an ILCR in excess of 1E-04 under residential land use. The RIOPA datum was eliminated as an apparent typographical or transcription error, since this number represnts the 50th percentile, while a value of 6.34 ug/m^3 was reported as the 95th percentile. Based on this, and further comparison of other reported values within the reported study, the 50th percentile value for chloroform from the RIOPA database was eliminated from further consideration.

DISCUSSION

Pragmatic risk management decisions regarding the vapor intrusion pathway need to account for anthropogenic background and confounding sources. The optimal sampling approach for the typical RCRA or CERCLA corrective action site targeting multiple lines of evidence (i.e., groundwater, subslab soil gas, and indoor and ambient air data) is not routinely encountered by TechLaw in its oversight role on behalf of USEPA. A database, organized to reflect building characteristics (e.g., construction materials, structural design, or age of structure), subsurface conditions (e.g., soil type), and regional phenomena (e.g., seasonality influences) could be used to improve the overall assessment process, but would not obviate the need for indoor air testing. This cursory review underscores the pervasive and ubiquitous nature of volatile constituents in residential indoor air and the need to consider, holistically, adult and child baseline exposures as well as vapor intrusion potential/influence. For example, remediation of a vapor intrusion source may be contraindicated if the same contaminant arises from an indoor air source. In such a situation, active remediation of the subsurface vapor intrusion source may not have a substantive impact on overall indoor air quality.

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