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Health Hazards in Indoor Air

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Abstract

Indentifying pollutants that pose a potential hazard indoors is an important first step to reducing risks. We reviewed key published studies reporting measurements of chemical pollutants in residences. Summary results were compiled and used to calculate representative mid-range and upper-bound concentrations relevant to chronic exposures for over 300 pollutants and peak concentrations relevant to acute exposures for a few episodic activity-associated pollutants. For the over 100 pollutants with available criterions, the measured concentrations are compared to available chronic and acute health-hazard standards and guidelines. Fifteen pollutants are identified as potential chronic or acute health hazards for many homes. A subset of pollutants are identified as priority chemical pollutants and suggestions are made for effectively reducing indoor concentrations.

Keywords: Indoor air quality; hazard analysis; residential; criteria pollutants; VOCs; air toxics

Citation

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Introduction

The importance of the residential environment to cumulative air pollutant exposures has been demonstrated in numerous studies [1-2]. As outdoor air pollutant concentrations decrease and residential air exchange rates are lowered with improved air tightness [3], the contribution of indoor pollutant sources to overall exposure is expected to become increasingly more significant. The first step to reducing indoor health risks is to identify the pollutants driving risks indoors and to understand their sources.

Ventilation standards aim to deliver acceptable indoor air quality through whole house and spot ventilation. Some of these hazards can be controlled through dilution ventilation, but for many that may not be an optimal strategy. Since the sources of many of the identified hazards are known, relevant control measures can be considered.

This paper presents the results of a hazard analysis designed to identify chronic and acute chemical contaminants of concern in U.S. residences. We undertook a literature review to identify and compile data on measured pollutant concentrations for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), metals, and criteria pollutants. From these data, we determined broadly representative mid-range and upper-bound concentrations relevant to assessing chronic pollutant exposures. We also compiled data on elevated short-term and peak concentrations resulting from episodic activities. These concentrations were compared to chronic and acute health guidelines or standards set by various agencies including the U.S. Environmental Protection Agency (USEPA), the World Health Organization (WHO), and the California Environmental Protection Agency (CalEPA). This analysis yielded a list of acute and chronic health hazards, from which priority pollutants were identified. For each priority pollutant, indoor sources are identified and suggestions are made for indoor pollutant mitigation.

Objectives

The objectives of this work were:

1) Determine representative and upper-bound indoor pollutant concentrations
2) Identify pollutants that pose a potential health hazard indoors
3) Ascertain likely sources of indoor pollutants; and
4) Suggest methods for the effective reduction of pollutant concentrations indoors

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Approach

Literature Review and Data Compilation

Our literature review identified 86 articles that were relevant to acute and chronic exposure in residences. Our review considered all chemical contaminants measured in residential air regardless of source. The contaminants considered thus include some emitted purely from indoor sources, some that enter predominantly from outdoors, and some having both indoor and outdoor sources.

Seventy-four studies had data relevant to chronic exposures indoors. The studies were of occupied homes and generally designed to avoid extreme emission sources. Sixty-seven studies used sampling durations on the order of one or more days. Eight studies used shorter sample durations but took steps to reduce the impact of any recent pollutant-generating occupant activities. Based on these 75 reports, we compiled a database of summary statistics for chronic-exposure relevant concentrations for SVOCs, VOCs, metals, and criteria pollutants. From this database, we calculated weighted (by sample size) summary statistics for each pollutant.

Eleven studies had data relevant to acute exposures in residences. These studies reported concentrations measured during scripted events or during occupant activities such as cooking or cleaning that happened to occur during sampling. The reported concentrations were either calculated from time-resolved measurement or from short duration integrated samples collected with the express intent of measuring air quality following specific events or activities. These sampling periods tended to be on the order of a few hours, however some studies reported peak concentrations from highly time resolved data.

Hazard Assessment

We conducted the hazard assessment by comparing the compiled summary statistics for representative mid-range and upper-bound chronic-relevant concentrations to available chronic and the activity-associated short-term concentrations to acute health standards. Various governmental organizations publish standards or guidelines that specify either safe or hazardous pollutant concentrations for chronic and acute exposures. Such standards or guidelines are available for diverse sets of chemicals including criteria pollutants, hazardous air pollutants, and toxic air contaminants.

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The U.S. Environmental Protection Agency (USEPA) sets National Ambient Air Quality Standards (NAAQS) for six criteria pollutants specified in the 1970 Clean Air Act: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone, particulate matter (PM), lead, and sulfur dioxide. Title III of the 1990 Clean Air Act Amendments established a new regulatory category for chemical air contaminants that are known or suspected to cause serious health effects; 189 chemicals were named to the initial list of hazardous air pollutants (HAPs, also called "air toxics"), of which 187 are still on the list. The USEPA is charged to maintain and update this list, which includes VOCs, SVOCs, metals, and polycyclic organic matter (POM). The CalEPA maintains a separate list of toxic air pollutants referred to as Toxic Air Contaminants (TACs). There is considerable overlap between the CalEPA TAC and the USEPA HAP lists, but there are some key differences. For a subset of these pollutants the USEPA has listed chronic non-cancer reference concentrations (*RfCs*) and cancer unit risk estimates (*UREs*) through its Integrated Risk Information System (IRIS) and Health Effects Assessment Summary Tables (HEAST). Non-cancer *RfCs* report the exposure concentrations that are assumed to represent a safe level in that they are unlikely to cause health effects even for sensitive subgroups of the population. *URE*s estimate the incremental increase in cancer risk that accrues for each 1 μg m^{-3} increase in chronic exposure. The California Office of Environmental Health Hazard Assessment (OEHHA) publishes non-cancer Reference Exposure Levels (*REL*s) and its own cancer *URE*s. In addition to the California and USEPA values, the U.S. Occupational Safety and Health Administration (OSHA) sets reference concentrations for workplace exposures, and the Agency for Toxic Substances and Disease Registry (ATSDR) publishes *RfCs* for chronic exposure. Since OSHA regulations are intended to protect generally healthy adult workers, their allowable concentrations tend to be higher than those set for HAPs/TACs by the USEPA and CalEPA.

Whereas exposure concentration limits are specified for acute effects and for chronic non-cancer endpoints, concentration-based standards are not uniformly available for cancer. The European Union and the CalEPA have estimated no-effect concentration levels based on an acceptable level of risk. The USEPA has not defined a generally acceptable cancer risk level for HAPs. However, a case-specific determination was made in the 1989 Benzene National Emission Standard for Hazardous Air Pollutants (NESHAP). This rule set an upper limit of acceptability of 1 in 10^4 lifetime cancer risk for highly exposed individuals and the goal of reducing lifetime risk to 1 in 10^6 for the general public. In consideration of this range, we used available cancer UREs to calculate acceptable exposure concentration for cancer risk that correspond to a lifetime incremental risk of 1 in 10^5 assuming 70 years of continuous exposure. The resulting cancer-based exposure concentration values are health protective and comparable to but not necessarily equivalent to the *RfC*s.

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As a final point, although the our analysis focuses on the method of comparing measured concentrations to health-based standards to establish hazard, we note that there are three indoor air hazards that are already well established—radon, second-hand tobacco smoke, and carbon monoxide (CO).

Potential Health Hazards from Chronic Exposures

In Figure 1 we compare our representative indoor air concentrations to the relevant standards for chronic health hazards. The bars indicate the representative mid-range concentration with a line that extends to the representative upper bound concentration. The graph is arranged, in decreasing order, by the ratio of the mid-range concentration to the lowest available health standard.

The figure identifies 2 criteria pollutants and 20 HAPs/TACs that have mid-range or upper bound concentrations higher than at least one health standard. The majority of the 20 pollutants have indoor concentrations that exceed cancer standards only; only four of the pollutants have indoor concentrations that exceed a non-cancer standard.

Table 1 summarizes the results of the hazards analysis. The table subdivides the chronic hazards into three groups: hazards in most homes, hazards in some homes (on the order of 5-50%) and hazards in very few homes (on the order of a few percent or less) based on what percentage of the available data has concentrations greater than available standards. These groupings are based on our representative mid-range and upper-bound concentrations that generally derive from weighted median and 95th percentile values of reported concentrations in homes. The table also indicates the type of hazard (cancer or non-cancer), the number of available studies, and the level of certainty. The level of certainty reflects whether we believe that the available data is representative of the current state of US homes and was based on the number of available studies, whether reported concentrations were above a standard in U.S. homes or only in homes outside of the U.S, and, in a few cases, information about concentrations outdoors.

Of the 15 compounds identified in most homes, nine were identified as priority chronic hazards in U.S. residences: acetaldehyde, acrolein, benzene, 1,3-butadiene, 1,4-dichlorobenzene, formaldehyde, naphthalene, NO_2, and $PM_{2.5.}$ These are nine of the ten pollutants identified as hazards with a high level of certainty in most homes. The tenth pollutant, carbon tetrachloride, was used extensively as a refrigerant in the past, but was

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banned as part of the Montreal Protocol and has been largely phased out. Due to a long atmospheric lifetime, carbon tetrachloride is still present in the atmosphere at hazardous concentrations.

Several studies have looked at specific events or activities in the home that give rise to high transient pollutant concentrations. The highest concentration for each pollutant was compared to acute standards from WHO, USEPA, and CalEPA. The results are summarized in table 1. The pollutants identified as acute hazards are, for the most part, a subset of the pollutants identified as chronic pollutants. Chloroform was additionally identified as posing a potential acute hazard.

Our results are similar to those identified by the reviews done by Dawson et al.[4], Koistinen et al.[5], and Loh et al.[6] with some distinct differences. Loh et al. [6] identified a similar subset of high priority VOC and SVOC chemical air pollutants using a combination of measurements and modeling. Our review identified a similar set of VOC and SVOC priority pollutants with the addition of acrolein, which was not included in their study. Dawson et al. [4] identified benzene as a having an elevated cancer risks in most homes by comparing concentrations of 10 VOCs to available standards. Koistinen et al. [5] identified 5 priority pollutants in European homes, formaldehyde, CO, NO_2, benzene, and naphthalene. With the exception of CO, these pollutants were identified as priority pollutants in this study as well. The difference appears to be due to higher long term concentrations in European homes.

Identifying Pollutant Sources and Mitigation Strategies

In the residential environment there are 3 main options for reducing indoor concentrations: 1) spot ventilation, 2) removal through whole house ventilation, and 3) reducing or eliminating the use of pollutant containing materials. The most effective method varies from pollutant to pollutant based on the major indoor sources. Table 2 lists the known sources of the nine priority pollutants indoors as well as the strategies that would most effectively reduce indoor pollutants.

The main indoor source of naphthalene, 1,4-dichlorobenzene, benzene, and 1,3-butadiene are specific products. Naphthalene and 1,4-dichlorobenzene are used in mothballs and deodorizers. Solvents, paints, stored fuel and other household products can emit benzene into the indoor environment. Removing these products from the living space would be the most effective method of reduction indoor concentrations.

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Cooking and combustion appliances are large contributors to acrolein and NO_2 respectively indoors indicating that spot ventilation is the most effective risk reduction scheme. Outdoor infiltration is a dominate contributor to $PM_{2.5}$ mass indoors although cooking and cleaning are large indoor contributors to the number of particles comprising $PM_{2.5}$ and has been shown to cause short-term concentrations above acute standards. Spot ventilation can effectively reduce the $PM_{2.5}$ risk due to cooking. Reducing outdoor concentration or turning off whole house ventilation during high $PM_{2.5}$ time period will also reduce risks.

The main source of formaldehyde indoors is home furnishings and manufactured wood products, however cooking can also be a source of short term elevated concentrations. Therefore, a combination of spot and whole house ventilation should be used to reduce formaldehyde concentrations in the short term. In the long term, steps should be taken to reduce concentrations in products and materials in homes.

Lastly, acetaldehyde has numerous sources indoors including cooking, indoor combustion, emissions from materials and products. It is unclear which of these pathways is dominant. Whole house ventilation, spot ventilation in kitchens, and reducing the use of products that emit acetaldehyde will all reduce concentrations, but it is unclear which method would be most effective.

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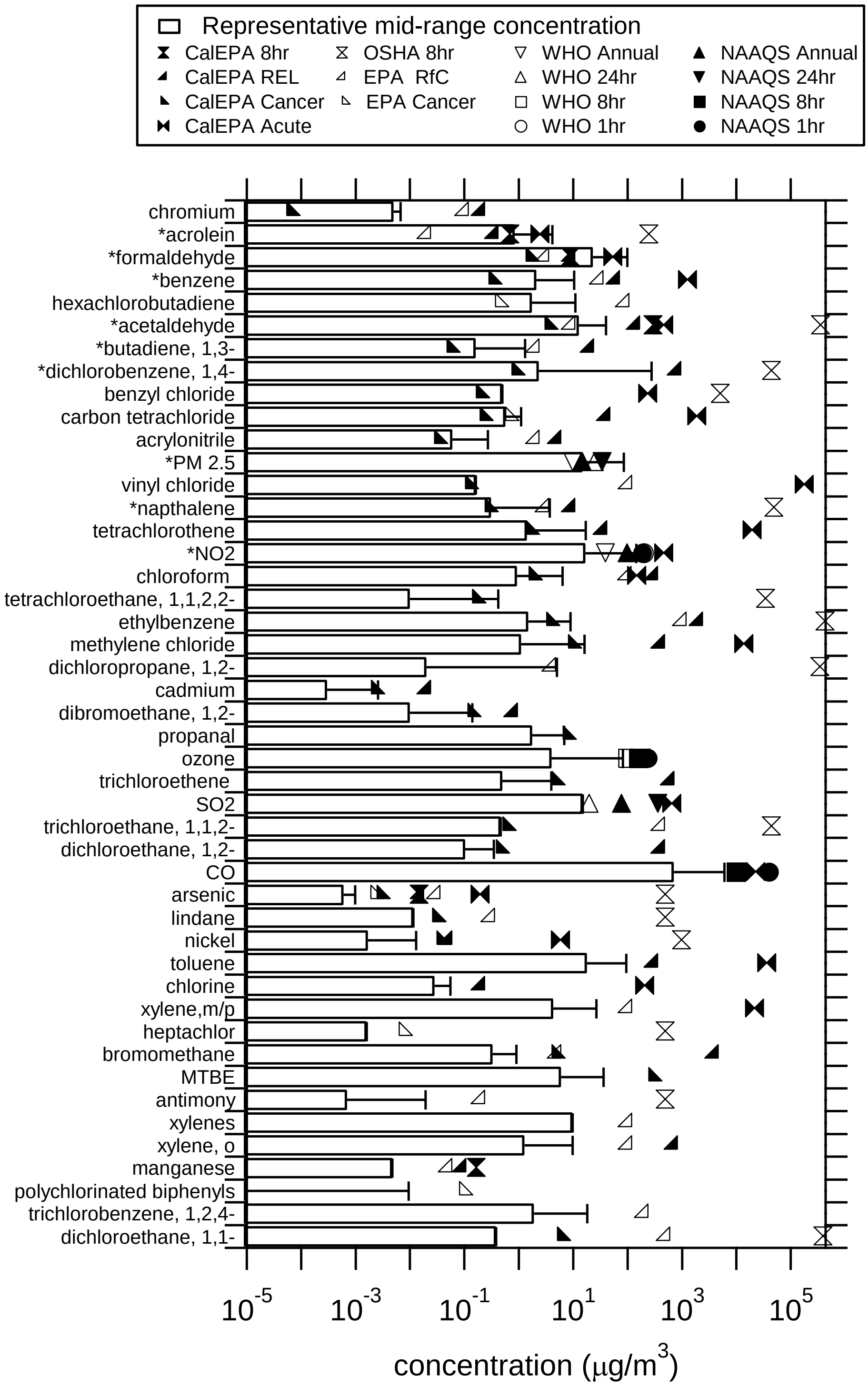

Fig. 1 Representative indoor air concentrations compared to relevant national and international standards. Line extends to the upper bound indoor concentration. Cal AREL is the CalEPA acute reference exposure level (1hr). Cancer, RfC, and REL standards are for chronic long term exposure (70 years). OSHA standards are for workday exposure for a significant portion of a lifetime. (CAL=CalEPA, EPA=USEPA) . (CAL=CalEPA, EPA=USEPA). Priority pollutants are identified with an asterisk.

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Table 1 Pollutants that potentially pose an adverse indoor health risks.

Chronic Health Hazard

Hazards in most homes	*# of studies (# of data points, midpoint, upper bound)*		*Hazard**	*Level of certainty*
acetaldehyde**	**12**	**(1578, 965)**	**C/NC**	**high**
acrolein**	**5**	**(1241,965)**	**NC**	**high**
benzene**	**21**	**(6897, 3240)**	**C**	**high**
butadiene, 1,3-**	**8**	**(328, 7)**	**C**	**high**
dichlorobenzene, 1,4-**	**12**	**(1691, 1626)**	**C**	**high**
formaldehyde**	**18**	**(1916, 965)**	**C/NC**	**high**
naphthalene**	**9**	**(2043, 1544)**	**C/NC**	**high**
NO2**	**19**	**(7797, 1642)**	**NC**	**high**
PM2.5**	**18**	**(2822, 1141)**	**NC**	**high**
carbon tetrachloride	5	(861, 554)	C	high
acrylonitrile	1	(75, 75)	C	medium
chromium	4	(284, 334)	C	medium
hexachlorobutadiene	1	(443,400)	C	low
benzyl chloride	1	(39, --)	C	low
vinyl chloride	1	(447, 447)	C	low
Hazards in most homes	*# of studies (# of data points, midpoint, upper bound)*		*Hazard**	*Level of certainty*
chloroform	12	(1217, 1107)	C	high
ETS	not applicable		C/NC	high
ethylbenzene	18	(5689, 2640)	C	high
methylene chloride	8	(1538, 1130)	C	high
radon	not applicable		C	high
tetrachlorothene	13	(3648, 3158)	C	high
cadmium	3	(275, 372)	C	medium
dichloropropane,1,2-	2	(75, 538)	NC	medium
ethanol	2	(444, 227)	C	medium

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Table 1(Cont.) Pollutants that potentially pose an adverse indoor health risks.

Acute Health Hazards

Hazards in most homes	*# of studies (# of data points, midpoint, upper bound)*	*Hazard**	*Level of certainty*
acrolein	3	SI	high
formaldehyde	7	SI	high
CO	2	H	high
PM2.5	15	R/H	high
NO2	6	R	high
chloroform	1	RD	low

Table 2 Priority pollutant sources and effective mitigation methods indoors

Priority Pollutants	**Indoor Sources**	**Mitigation Methods** PU	SV	WHV
acetaldehyde	combustion, products, materials, infiltration	X	X	X
acrolein	combustion, materials		<u>**X**</u>	X
benzene	combustion, infiltration, products	<u>**X**</u>	X	
butadiene, 1,3	products (ETS)	<u>**X**</u>		
dichlorobenzene, 1,4-	products	<u>**X**</u>		
formaldehyde	combustion, materials		<u>**X**</u>	<u>**X**</u>
naphthalene	products	<u>**X**</u>		
NO2	combustions, products		<u>**X**</u>	X
PM2.5	combustion, secondary reactions, infiltration	X	<u>**X**</u>	

PU=reducing product use, SV=spot ventilation, WHV=whole house ventilation

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