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Hazard Assessment of Chemical Air Contaminants Measured in Residences

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Abstract

Identifying air pollutants that pose a potential hazard indoors can facilitate exposure mitigation. In this study, we compiled summary results from 77 published studies reporting measurements of chemical pollutants were representative of concentrations in residences in the United States. These data were used to calculate representative mid-range and upper bound concentrations relevant to chronic exposures for 267 pollutants and representative peak concentrations relevant to acute exposures for 5 activity-associated pollutants. Representative concentrations are compared to available chronic and acute health standards for 97 pollutants. Fifteen pollutants are identified as contaminants of concern for chronic health effects in a large fraction of homes. Nine pollutants are identified as potential chronic health hazards in a substantial minority of homes and an additional nine are identified as potential hazards in a very small percentage of homes. Nine pollutants are identified as priority hazards based on robustness of reported concentration data and fraction of residences that appear to be impacted: acetaldehyde; acrolein; benzene; 1,3-butadiene; 1,4-dichlorobenzene; formaldehyde; naphthalene; nitrogen dioxide; and $PM_{2.5}$. Activity-based emissions are shown to pose potential acute health hazards for $PM_{2.5}$, formaldehyde, CO, chloroform, and NO_2.

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Introduction

The importance of the residential environment to cumulative air pollutant exposures has been demonstrated in numerous studies (Edwards et al. 2001; Weisel et al. 2005). As outdoor air pollutant concentrations decrease and residential air exchange rates are lowered with improved air tightness (Sherman and Matson 2002), the contribution of indoor pollutant sources to overall exposure is expected to become increasingly more significant.

The management and mitigation of health risks and disease burden associated with indoor air pollutant exposures can be advanced using the environmental health approaches of hazard analysis and risk assessment. Hazard analysis is a binary identification of pollutants that may cause harm under some prevailing conditions. Risk assessment attempts to quantify the probability and/or extent of harm that would be caused under a given set of conditions. Identified contaminants of concern can be managed in many ways including reducing emission sources and designing ventilation systems to achieve dilution and removal so as to maintain concentrations below harmful levels. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1 allows this latter approach as an alternative to prescriptive ventilation rates designed to achieve acceptable indoor air quality in many buildings (ASHRAE 2007). Sherman and Hodgson (2004) suggested that residential ventilation rates should be set to reduce formaldehyde concentrations below hazardous levels. Two recent studies examined pollutants posing chronic health hazards in residences. Hodgson and Levin (2003) and Dawson and McAlary (2009) identified volatile organic compounds (VOCs) that potentially pose an elevated cancer and non-cancer risk respectively by comparing concentrations to published health standards. As part of a broad examination of semi-volatile organic compounds (SVOCs) in indoor environments, Weschler and Nazaroff (2008) reviewed available data on residential concentrations (air and surface) of these chemicals. Mendell (2007) reviewed 21 epidemiological studies to identify pollutants and common household items that are potential indoor-risk drivers.

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 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 that may be used as a foundation for ongoing residential indoor air quality management efforts.

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Approach

Literature Review to Identify Residential Measurements

The initial step of this work was a review of recent studies reporting measurements of pollutant concentrations in residences. The review was focused on the U.S. but also covered data from other industrialized countries. The review focused first on studies that measured pollutant concentrations relevant to chronic exposures. Many studies reported results from integrated samples collected over periods of 24 hours or more in occupied homes. Some reported concentrations measured over shorter periods in homes that were unoccupied or measured during periods when no substantial pollutant-generating activities were occurring. A second set of studies was identified to obtain data on elevated short-term and peak concentrations resulting from pollutant generating activities. These data included time-resolved or short-term sampling at times and/or for rooms in which pollutant generating activities were occurring. The activities were in some cases scripted and in some cases occupant initiated.

We used the ISI web of knowledge database as our main search engine. We also reviewed proceedings from the 2009 Healthy Building Conference held in Syracuse, NY and the 2008 Indoor Air conference held in Lyngby, Denmark; we scanned titles and abstracts from the conferences for relevance. We conducted the search based on pollutant search terms, ignoring data from developing countries. For the Web of Knowledge database key words and combinations of key works were used. Search terms included combinations of "VOC" "SVOC" "indoor" "measurements" "residential" "metals" "indoor air quality" "indoor air pollution" "CO" "PM" "NO2" "activity" "emissions" "emission rate" "organic compound". This search yielded over 150 articles. The articles were manually reviewed to determine which had useful data for determining reprehensive chronic and acute exposure relevant concentrations in the indoor environment. Articles were chosen that had measurements taken in the last 15 years (1995-2010) from industrialized nations that were thought to be comparable to the United States. This search yielded 77 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. Table 1 lists the reference, study location, pollutant measurements, sample period, and pollutant classes measured in each of the studies with chronic-exposure relevant concentration data. Much of the data applicable to chronic hazard assessment were collected during large exposure studies. 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. As an example, in a study comparing VOCs in homes using fuel oil versus control homes, the New York State Department of Health (2006) measured concentrations over a two-hour period. To compensate for the short measurement time, the study was limited to homes that did not regularly use and had not recently used VOC containing products.

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Studies with data relevant to assessing short-term peak concentrations and acute exposures are listed in Table 2. 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.

Data Compilation

Of the articles collected in the initial screening, 67 reported data relevant to chronic exposure. Based on these 67 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 summary statistics for each pollutant. When calculating summary statistics, we weighted statistics from individual studies by the number of unique measurements in each study. Typically this was the number of homes in which measurements were made, though some studies included repeat measurements for some homes. This approach was used in a previous compilation effort (Dawson and McAlary 2009). Results include the total number of studies measuring the pollutant; the total number of unique measurements of a pollutant across all studies and weighted arithmetic mean, 25th, 50th, 75th, and 95th percentile values. A complete set of summary statistics is available for each of the criteria pollutants. Available data for VOCs varied from compound to compound. Each VOC listed has at least one study with mean or median values reported. Benzene was measured in more studies (15) than any other VOC. Fewer data were found for SVOCs. Naphthalene was reported in nine studies, but for some of the SVOCs only a Top of Range, TOR, value was reported. Since SVOC data are so limited, TOR values are included in the data summary.

We used the database and summary statistics to determine representative mid-range and upper-bound concentrations relevant to chronic exposures. When sufficient data were available to calculate a weighted median concentration, we used that value as the representative mid-range concentration. If not, we used the weighted mean value. The upper bound representative concentration for each pollutant is based on the highest concentration for which a summary statistic was available. For most compounds, this was the 95th percentile concentration. This statistic was not used when one of two situations applied: (1) when, owing to variations in reporting and in the values measured in different studies, the 95th percentile concentration was lower than one or more other summary statistics, or (2) none of the studies reporting data for a given compound included a 95th percentile value. Using the summary statistic with the highest concentration also leads to a more conservative selection of chemical contaminants of concern. We used the 95th percentile value as a representative upper bound for all the criteria pollutants, for 77 of the 79 VOCs with available 95th percentile values, and for both of the SVOCs with available 95th percentile values. For the remaining compounds we set the representative upper-bound value to the highest weighted statistic. For some of the SVOCs, only a TOR value is available, and in these cases we set the representative upper bound value to the TOR value and did not define a representative mid-range value.

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Hazard Assessment

We completed 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. Chronic health issues can take a lifetime to manifest and published health standards for chronic exposure are established to protect people exposed continuously for years to decades and up to a life-time. Health standards for acute exposures are typically specified for averaging times of 1 h to 1 day but can include levels above which even shorter exposure may be hazardous. Tables S8-S11 in the online supplemental list the health standards we used in the hazard assessment.

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. The standards are set to protect the most sensitive subset of the population. Several of these standards have been tightened since their inception in the 1970s. The USEPA has recently adopted a 1 hour NO_2 standard of 0.1 ppm (190 $\mu g\ m^{-3}$) (USEPA 2010). For some criteria pollutants, the California Environmental Protection Agency (CalEPA) has set standards that are more stringent than USEPA standards. Many governmental bodies outside of the U.S. promulgate standards for the same pollutants. The World Health Organization (WHO) tends to publish the most health-protective standards (WHO 2005), but unlike USEPA standards, these are recommendations or goals rather than legally mandated targets.

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 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 $\mu g\ m^{-3}$ 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.

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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.

In addition to the chemical pollutants that have available health-based concentration standards, there are several contaminants of emerging concern with comparably limited toxicity data. These include the following pollutants: SVOCs that are HAPs/TACs with no available health-based standards; SVOCs that are not HAPs/TACs including pesticides and brominated fire retardants; short-lived products of indoor secondary organic aerosol (SOA) chemistry; and ultra fine particles (UFPs). Since the toxicological and epidemiological data are as yet insufficient to set standards for these compounds, they are treated only qualitatively in this paper.

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). The health effects of exposure to radon have recently been reviewed by Al-Zoughool and Kreski (2009). Several major reviews have compiled data on measured concentrations and health effects of Secondhand Tobacco Smoke (Surgeon General 2006). For carbon monoxide (CO) there is evidence of acute hazard from hospital emergency room visits and deaths, along with growing concern about possible chronic health effects at levels not previously identified as harmful (Ashley et al. 2005).

Results and Discussion

Summary Statistics

Summary statistics compiled for chronic exposure-relevant concentrations are provided in Tables S2-S5 in the online supplemental information. Table S1 lists concentrations for the criteria pollutants, Table S2 lists the VOC concentrations, Table S3 lists the SVOC concentrations and Table S4 lists concentrations for metals that are components of airborne particulate matter. Of the pollutants measured, 192 have more than one type of summary statistic.

Large variations are seen in indoor concentrations for many of the chemical contaminants measured to date. Based on what has been reported by others (Hodgson and Levin 2003; Dawson and McAlary 2009), this was expected. Mean concentrations vary among chemicals by more almost nine orders of magnitude from ethanol ($9x10^2$ $\mu g\ m^{-3}$) to BDE85 ($1x10^{-6}$ $\mu g\ m^{-3}$).

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Differences between the highest and lowest summary statistic values vary widely by compound: 66 varied by more than a factor of ten and ten varied by more than a factor of 100. The largest variations are seen for cesium (Cs) and 1,1-dichloroethene, which each varied by more than a factor of 2000, followed by 1,4-dichlorobenzene and chlorobenzene, which varied by a factor of 500.

Potential Health Hazards from Chronic Exposures

In this section we compare our representative indoor air concentrations to the relevant standards for chronic health hazards. In all of the figures in this section, the bars indicate the representative mid-range concentration with a line that extends to the representative upper bound concentration. All the graphs are arranged, in decreasing order, by the ratio of the mid-range concentration to the lowest available health standard.

Criteria Pollutants

Figure 1 presents representative indoor concentrations of criteria pollutant along with standards developed by the USEPA (NAAQS), CalEPA, and WHO. The figure shows that the representative mid-range concentration for $PM_{2.5}$ is above the WHO annual standard and very close to the NAAQS annual standard. The representative upper bound concentration for $PM_{2.5}$ is above both the NAAQS and WHO 24-hour standards. Figure 1 shows that the representative upper bound for NO_2 is above the annual average values set by both WHO and EPA, and above the 1 hour WHO value. Thus, in some homes, NO_2 concentrations averaged over periods of days or longer can exceed both chronic and short-term acute health-based standards.

HAP/TACs

Figures 2 to 4 compare three subclasses of HAP/TACs concentrations to available chronic health standards. Of the compounds evaluated, 20 have representative mid-range or upper bound concentrations that exceed at least one 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. This is an important point since the chronic exposure concentration “standards” used to assess cancer hazards in this study are health protecive and inferred from *URE*s (not directly set) as described in the methods section.

Figure 2 illustrates how representative concentrations for HAP/TAC VOCs compare to standards developed directly by USEPA, CalEPA, ADSTR, and OSHA as well as the cancer exposure standards calculated from *URE*s. Of the 59 pollutants with applicable health *RfC*s, *REL*s, and *URE*s, eighteen pollutants have representative indoor concentrations higher than at least one health standard. Of those eighteen, fourteen have concentrations that exceed the cancer value only, two exceed non-cancer endpoints only, and two are potential hazards for both cancer and non-cancer effects. Eleven of the pollutants have representative mid-range concentrations above standards, indicating a potential hazard in a large percentage of homes. Two pollutants identified as hazards, acrolein and formaldehyde, have representative mid-range concentrations above the CalEPA acute standards. Figure 2 also shows that for ten additional pollutants, representative concentrations are within an order of magnitudeof at least one health-based standard.

Figure 3 compares the SVOC HAP/TAC concentrations to applicable standards. Of the 89 semi-volatile compounds for which residential indoor air measurements were reported, only 14 have

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relevant health standards. Of these 14, only napthalene is identified as a hazard using this methodology. Naphthalene concentrations exceed calculated limits for cancer in many homes and non-cancer chronic standards are exceeded in high concentration homes. Data were sparse for SVOCs other than naphthalene; most other compounds were reported in only one or two studies each.
Figure 4 compares particle-bound metals to relevant standards. Of the compounds for which measurements are available, only chromium and cadmium appear to pose a hazard. Nickel, chlorine, and arsenic were measured in some homes at concentrations within an order of magnitude of a health representative. There were only one or two studies available for each of these pollutants as well.

In total, we identified 14 chemical pollutants having representative concentrations that were below but within an order of magnitude of at least one health standard. For these pollutants we reviewed the studies that contributed data to their calculated representative concentration values. The intent was to assess whether the data were sufficient to reach a robust determination that the compound is not present at hazardous levels, or if the potential for hazard is uncertain due to data scarcity.

Five of these chemical pollutants are identified as potential hazards in a small percentage of homes. Sufficient data exist to determine that bromomethane, trichloroethane, chlorine, and 1,2-dichloroethane are present at levels exceeding at least one health standard in U.S. homes with the highest concentrations. Bromomethane exceeded the most health-protective standard in fewer than 5% of the 439 homes measured in one U.S. study (see Table 3). Chlorine, tricloroethene, and 1,2-dichloroethane were measured at concentrations above health standards in a limited number of Texas, New York City, and Saschwtchewan homes respectively. The potential for propanal to be present at hazardous levels is uncertain. Representative concentrations for propanal are within an order of magnitude of some standard primarily owing to high concentrations measured outside of the U.S. Propanal is identified for now as a potential hazards in a small percentage of homes; additional data are needed to clarify this assessment.

An additional five pollutants were identified as possible hazards in a small percentage of homes because available data were insufficient to reach a robust determination that levels are reliably below health-based standards. Nickel and arsenic representative values are all based on very limited data from one or two studies each. More data are needed to to reliably determine that these compounds are not substantial hazards in U.S. homes.

The remaining six pollutants with representative concentrations close to at least one heatlh standard do not appear to be substantial residential indoor-air hazards. Large studies have measured toluene, m/p-xylene, and MTBE and several of these have 95th percentile concentrations substantially below the most health-protective standard. Representative concentrations for 1,2-dibromomethane and 1,1,2-trichloroethane are biased by a single study with a very high minimum detection level (MDL) and a large number of non-detects that set the concentration to a level of half the MDL (NYDOSH 2006). There is no positive evidence that these compounds represent a hazard in U.S. homes.

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Health-based standards have been established for only a subset of the chemicals known to be present in indoor air. Over 40% of the pollutants with available concentration data do not have available health standards. Tables S6 and S7 in the online supplemental material list the compounds without standards. Table S6 lists the assessed carcinogenicity for chemicals included in the IRIS database and indicates that six are thought to be possible or probable carcinogens. The remaining 122 pollutants are listed in Table S7.

Potential Health Hazards from Chronic Exposures in New Homes

As new homes are added to the existing housing stock, there is concern that increasing home tightness may lead to reduced ventilation and hence higher pollutant concentrations indoors and hope that newer building materials will have reduced emission rates. We looked at new homes separately to investigate variations in hazard profiles. Of the 67 studies reviewed, only 3 focused on new homes. Offermann et al.(2009) measured pollutant concentrations in 108 detached single-family homes in California built between 2002 and 2004; measurements were conducted during 2006-2008 when homes were 1.7 to 5.5 years old. Park and Ikeda (2006) measured concentrations in 219 new homes (built in 2000) in Japan during the summers of 2000-2003. Hodgson et al. (2000) measured VOC concentrations in 11 new manufactured and site-built US homes within 10 months of construction. Summary statistics for new homes are included in Table S5 in the online supplemental. Similar to older homes, $PM_{2.5}$ concentrations are of concern in new homes. NO_2 mid-range and upper bound representative concentrations measured in new homes are below the standards, yet NO_2 is assumed to be a potential hazard in new homes with any unvented natural gas appliance(s). The rationale is that emission rates are of similar magnitude whereas dilution from whole house ventilation is reduced relative to older homes.

A limited number of VOCs and SVOCs have been measured in new homes. We plot representative concentrations and available standards for these in Figure 5. For comparison, the representative concentrations for all homes are also plotted. The hazards identified were a subset of the hazards identified for all homes and most appear as hazards for cancer only.

Potential Acute Exposures from Episodic Indoor Sources

Several studies have looked at specific events or activities in the home that give rise to high transient pollutant concentrations. Table 2 shows the sample durations (or integration times) and measured values of $PM_{2.5}$, CO, NO_2, chloroform, and formaldehyde associated with some episodic events and activities in the home. For studies that did not report sample duration, the reported peak concentration is included in Table 2. Peak concentrations were reported for studies that used highly time resolved instrumentation and refer to the single highest value measured. For these measurements sampling times were not reported, but are likely on the order of one minute based on the instrumentation used. Figure 6 compares the highest concentration for each pollutant to acute standards from WHO, USEPA, and CalEPA.

The review identified nine studies reporting PM mass concentrations. Fortmann et al. (2001) measured $PM_{2.5}$ during and after prescribed event in the kitchen of a house and showed that concentrations can be several orders of magnitude larger than acute health standards for several hours in homes. Singer et al. (2006) and Coleman et al. (2008) showed that use of terpene-containing products in the presence of ozone can cause particle generation events that lead to concentrations above acute standards for at least half a day.

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The use of unvented gas cooking appliances and fireplaces can lead to CO and NO_2 concentrations above acute standards for several hours. Gordon et al. (2008) measured concentrations of CO and NO_2 in 30 homes with unvented natural gas fireplaces over periods of up to a few days in each home with occupants directed to not alter their appliance use patterns. During their period of measurement, NO_2 concentrations exceeded acute (1-h) standards in 80% of the homes and the 8-h CO standard was exceeded at least once in 20% of the homes. Dutton et al. (2001) operated an unvented fireplace in a single home through a series of scripted events and found that CO concentrations could exceed EPA standards.

Limited information is available in the literature for other pollutants and activities. Cooking was shown to elevate levels of formaldehyde above acute standards for several hours. Kerger et al. (2000) found that showering for 12 minutes elevated bathroom concentrations of chloroform above acute standards for half an hour. Although in this case, chloroform concentrations may be less than the standard over the course of an entire hour, shower durations longer than 12 min could easily lead to concentrations above acute standards for an hour.

Additional Contaminants of Concern

Whereas the analysis in preceding sections depend on the availability of health-based standards, this section explores the potential hazard associated with indoor air contaminants for which no specific concentration-based standards or guidelines have been established. Of the 267 compounds with available indoor concentrations measurements, 54% did not have available health standards to aid in the identification of indoor hazards. In this section a similar method will be used to identify indoor chemical hazards based on mechanistic, epidemiological and toxicological evidence.

It has been shown that SVOC concentrations can be an order of magnitude larger indoors than outdoors and moderately to highly sorbing compounds can persist indoors for weeks to several years (Weschler and Nazaroff 2008). Bio-monitoring studies have shown that SVOCs appear in human blood and urine samples (Wilford et al. 2005; Canosa et al. 2007; Mannino and Orecchio 2008) and there is significant epidemiological evidence that specific chemical classes may have harmful effects on the human body (Darnerud 2003; Legler and Brouwer 2003; Miyazaki et al. 2004; Ghisari and Bonefeld-Jorgensen 2009) including endocrine disruption that may affect the behavior of hormones in the human body. Increasing attention is being devoted to the potential hazards associated with indoor SVOCs. SVOCs indoors quickly absorb to available surfaces including human skin. Despite low concentrations indoors, indoor air is a medium for transporting SVOCs from surfaces to skin where they can potentially accumulate and be absorbed into the body (Weschler and Nazaroff 2008). Recently, the USEPA has designated phthalates and polybrominated diphenyl ethers (PBDEs) as chemicals of concern (USEPA 2010). Several phthalates and PBDEs were found to have measurable indoor concentrations in this study.

Ultra fine particles (UFP), <100 nm in diameter, make up more than 90% of the number count of $PM_{2.5}$, but only 10% of the mass (Buonanno et al. 2009). Health scientists have hypothesized that the small size and large surface area of UFP may lead to greater toxicity per unit mass then for the larger diameter particle fraction of $PM_{2.5}$ (Delfino et al. 2005; Gwinn and Vallyathan 2006;

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Peters et al. 2006). It has been suggested that the small size of these particles may make them more dangerous and potentially lead to translocation of particles to the blood stream and other organs or acting on the autonomic nervous system (Knol et al. 2009). UFP emissions are from both primary sources such as natural gas combustion and food preparation, as well as secondary sources such as ozone reactions with terpenes in cleaning materials (Singer et al. 2006). Bhanger et al. (2010) showed that in houses where people are at home and awake, and presumably undertaking everyday indoor activities, particle number (PN) concentrations are consistently higher than outdoors, by as much as a factor of 3. The same study showed that PN concentrations when people are home and asleep or when homes are unoccupied are consistently lower than concentrations outdoors, again underlining the importance of indoor sources. Recent expert review determined that there is sufficient evidence supporting the harmfulness of UFP (Knol et al. 2009), however no standard has been set.

Summary of Identified Hazards

Table 3 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), 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 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.

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 and McAlary (2009), Koistinen et al.(2008), and Loh et al.(2007) with some distinct differences. Loh et al.(2007) 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 and McAlary (2009) identified benzene as a having an elevated cancer risks in most homes by comparing concentrations of a subset of 10 VOCs to available standards. Koistinen et al.(2008) identified 5 priority pollutants in European homes, formaldehyde, CO, NO2, 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.

We also compared our results to an older review done by Brown et al.(1994) to look at changes in concentrations over time. The review only included two of our identified priority air toxics (benzene and 1,4-dichlorobenzene), but had data for several of the other VOCs that were included in the study. For the most part indoor representative and upper bound concentrations compiled here are lower by at least a factor of two from the geometric mean and 98th percentile values in the Brown et al.(1994) study. The exceptions were light solvents, (MEK, acetone, and ethanol) and products associated with deodorizers, insecticides, and cleaning (limonene and 1,4-dichlorobenzene). Brown et al.(1994) also saw a large increase in VOC concentrations in new homes, often an order of magnitude or more. We found however, that concentrations for most VOCs were reduced or only slightly increased in most new homes. This may reflect reductions in new materials emissions and improvements in home ventilation practices.

Summary and Conclusions

This analysis identified mid-range and upper bound chronic exposure relevant representative concentrations for over 260 chemical pollutants and acute exposure relevant concentrations for 5 indoor activity related chemical pollutants. The results are summarized in Table 3. Comparisons of pollutant concentrations to relevant health standards indicate 15 pollutants that are chronic hazards in most homes, 9 that are chronic hazards in some homes (on the order of 5-50%), and 6 that are chronic hazards in very few homes (fewer than 5%). Additionally, 6 pollutants were identified as potential acute health hazards indoors. Of those 32 chemical hazards, 9 were identified as priority chemical pollutants in U.S. homes:

- acetaldehyde,
- acrolein,
- benzene,
- 1,3-butadiene,
- 1,4-dichlorobenzene,
- formaldehyde,
- naphthalene,
- NO_2,
- $PM_{2.5}$.

Over 50% of the pollutants with available indoor concentration data did not have available health standards whether due to a lack of toxicity data or because the pollutant is non-hazardous. There are a vast number of pollutants in the indoor environment that cannot be said to be at safe or unsafe levels. Mechanistic and epidemiological evidence has suggested that certain pollutants, such as UFPs and select SVOCs including phthalates and brominated flame retardants, pose a potential hazard to human health. Further toxicological and epidemiological research is needed to quantify the risks posed by emerging pollutants of concern.

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It is important to note that, despite the large number of articles included in the study, that data included here is not fully representative of indoor exposures across the country due to biases in sampling locations, the large number of pollutants that were not measured by any study, and because the effect of residential concentrations on personal exposure is not perfectly understood.

There were several areas where data for particular sub-populations and pollutant groups were lacking. Relatively few concentration measurements were available for new homes, only three studies. Analysis of the two studies that focused on new homes indicated a similar hazard profile as seen in older homes. More data is needed for SVOCs. These pollutants have recently come to the attention of health professionals and, with the exception of naphthalene, have not been sampled as extensively as VOCs in the indoor environment. There is also insufficient data for the majority of US states. The measurement studies that have focused on the US have disproportionately focused on California and the east coast. Of the 40 studies in the US, 34 focused on only 7 states. The remaining states, representing diverse climates, have been largely underrepresented. The data compiled here is also largely for single-family homes. Despite the inclusion of six studies that surveyed lower socioeconomic status, more data is needed for multi-unit residential structures. More work is needed to determine the relative contributions of location and sub-standard housing to risks. Finally, the data have mostly been taken in developed areas, this may lead to slight overestimation of concentrations indoors due to the effects of infiltration from the outdoors.

This work successfully reduced a list of 267 indoor chemical pollutants to a set of 9 priority chemical hazards. The identification of a succinct group of chemical hazards in indoor air will allow for the design of mitigation strategies in the indoor residential environment that target these priority pollutants.

Tables

Table 1 Publications with chronic exposure relevant concentrations. (F=formaldehyde, NA=naphthalene, A=acrolein, P=$PM_{2.5}$, N=NO_2, O=ozone, C=CO). For some of the studies only one VOC or SVOC was included for these studies the individual pollutant is indicated instead of the pollutant class.

	Study	**Sample Period**	**Location: City, Country or US State**	**US homes**	**New homes**	**Criteria Pollutants**	**VOCs**	**Aldehyde**	**SVOCs**	**Metals**	**Number of samples**
1	(Topp et al. 2004)	2 weeks	Hamburg/Erfurt, Germany			N	X				2524
2	(Park and Ikeda 2006)	24 hrs	Japan		X		X	X			2151
3	(Geyh et al. 2000)	24 hrs	California, US	X		O					1980
4	(Rehwagen et al. 2003)	4 weeks	Leipzig, Germany				X		X		1499
5	(Garcia-Algar et al. 2003)	7-30 days	UK, Spain			N					1438
6	(Williams et al. 2009)	1 days	Detroit, Michigan, US	X		P					973
7	(Lee et al. 1998)	48 hrs	Boston, Massachusetts, US	X		N					942
8	(Raw et al. 2004)	2 weeks	England, UK			N,C	X	X			796-845
9	(Levy 1998)	48 hrs	Various Cities, North America, Europe, Asia	X		N					617
10	(Kirchner et al. 2009)	7 days	Nationwide, France			C,P	X				570
11	(Weisel et al. 2005)	48 hrs	Los Angeles; Houston; Elizabeth, NJ, US	X		P	X	X			121-554
12	(NYDOSH 2006)	2-12 hrs	Various Cities, NY, US	X			X		NA		4-546
13	(Saborit et al. 2009)	24 hrs	Wales/W. Midlands, England, UK				X		X		91-500
14	(Cyrys et al. 2000)	1 week	Hamburg/Erfurt, Germany			N					404
15	(Marchand et al. 2008)	30-95 mins	Strasbourg, France				X	X			244-286
16	(Turpin et al. 2007)	48 hrs	Los Angeles; Houston; Elizabeth, NJ,US	X		P			X	X	157-275
17	(Croxford et al. 2006)	1 week	London, UK			C					270
18	(Jia et al. 2008)	3-4 days	Michigan, US	X			X		X		251-257
19	(Jo and Lee 2006)	2 hrs	Daegu, South Korea			C					240
20	(Heroux et al. 2009)	24 hrs	Saskatchewan, Canada				X	X	NA		217
21	(Long et al. 2000)	12 hrs	Boston, Massachusetts, US	X		P					211
22	(Offermann 2009)	24 hrs	California, US	X	X	P,C, N	X	X	X		31-211
23	(Jarvis et al. 2005)	14 days	United Kingdom			N					203
24	(Edwards et al. 2001)	48 hrs	Helsinki, Finland				X	X	X		201
25	(Gordon et al. 1999)	6-7 days	Arizona, US	X			X				185
26	(Jia et al. 2008)	3-4 days	Southeast Michigan, US	X			X	X	NA		159
27	(Sexton et al. 2004)	2 days	Minneapolis/St. Paul, Minnesota, US	X			X				132
28	(Rudel et al. 2003)	24 hrs	Cape Cod, Massachusetts, US	X					X		30-120
29	(Fromme et al. 2004)	7-8 hrs	Berlin, Germany						X		115
30	(Simons et al. 2007)	3 days	Baltimore, Maryland, US	X		O, P, N					95-109
31	(Weisel 2006)	24 hrs	New Jersey, US	X			X				7-100
32	(Zota et al. 2005)	2 weeks	Boston, Massachusetts, US	X		N					100
33	(Guo et al. 2009)	24 hrs	Hong Kong				X	X			100
34	(Gilbert et al. 2006)	7 days	Quebec City, Canada			N		X			96
36	(Miller et al. 2009)	24 hrs	Commerce City, Colorado, US	X		C,P					92-97
37	(Phillips et al. 2005)	24 hrs	Oklahoma, US	X			X				90
38	(Kinney et al. 2002)	48 hrs	West central Harlem, New York, US	X		P	X	X		X	18-88
39	(Lee et al. 2002)	6 days	Southern California, US	X		N,O					92-106
40	(Sorensen et al. 2005)	48 hrs	Copenhagen, Denmark			P,N					73-87
41	(Dodson et al. 2008)	24 hrs	Boston, Massachusetts, US	X			X	X			83
42	(Janssen et al. 2005)	24 hrs	Amsterdam/Helsinki			P				X	82
43	(Garrett et al. 1999)	24 hrs	Latrobe Valley, Victoria, Australia			N					80
44	(Zhu et al. 2005)	24 hrs	Ottawa, Ontario, Canada				X		X		75
45	(Raymer et al. 2009)	24 hrs	Wisconsin, California, US	X			X	X			47-70
46	(Johnson et al. 2004)	3 days	Columbus, Ohio, US	X		C					32-67
47	(Sakai et al. 2004)	24 hrs	Nagoya, Japan and Uppsala, Sweden			N	X	X			64
48	(Baxter et al. 2007)	3-4 days	Boston, Massachusetts, US	X		N,P				X	54-64
49	(Kornartit et al. 2010)	1 week	United Kingdom			N					60
50	(Gilbert et al. 2005)	24 hrs	Prince Edward Island, Canada					X			59
51	(Leaderer et al. 1999)	24 hrs	Southwest and Central Virginia, US	X		P,SO2					58
52	(Piechocki-Minguy et al. 2006)	24 hrs	Lille, France			N					44
53	(Malkin-Weber et al. 2009)	7 days	Central North Carolina, US	X				X			36
54	(Harrad et al. 2006)	28 days	Birmingham, UK						X		31

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55	(Gustafson et al. 2007)	24 hrs	Hagfors, Sweden				X	X			21-23
56	(Na et al. 2004)	24 hrs	Riverside County, California, US	X		P				X	20
57	(Stranger et al. 2009)	24 hrs	Antwerp, Belgium			P				X	19
58	(Zipprich et al. 2002)	48 hrs	Richmond, Virginia, US	X		N					19
59	(Strandberg et al. 2006)	2 weeks	Hagfors, Sweden						X		15
60	(Batterman et al. 2009)	7 days	Southeastern Michigan, US	X					X		12
61	(Johnson-Restrepo and Kannan 2009)	8 hrs	Albany, New York, US	X					X		12
62	(Chao 2001)	48 hrs	Hong Kong			O,N,SO2					10
63	(Toms et al. 2009)	31 days	Brisbane, Queensland, Australia						X		10
64	(Seaman et al. 2007)	24 hrs	California, US	X				A			9
65	(Missia et al. 2008)	7 days	Europe				X	X			8
66	(Hodgson et al. 2000)	3 days	Southeastern United States	X	X		X	X			11
67	(Arhami et al. 2009)	5 days	San Gabriel Valley/Riverside, California, US	X		P, C,N					8

Table 2 Short-term concentrations during typical indoor residential activity

Pollutant	Activity	Conc. (µg/m3)	Measurment Duration	Source (Study #)
Chloroform	12min shower	157	32min	Kerger et al. 2000 (68)
Formaldehyde	oven cleaning	417	5.5hrs	Fortmann et al. 2001 (69)
	gas)	129	3hrs	Fortmann et al. 2001 (69)
NO2	unvented fireplace use	2422	1hr	Gordon et al. 2008 (70)
	oven cleaning	1435	5.5 hrs	Fortmann et al. 2001 (69)
	cooking french fries (gas)	772	2.5hrs	Fortmann et al. 2001 (69)
	unvented fireplace use	677	4 hrs	Dutton et al. 2001 (71)
	cooking	355	4 min	Park et al. 2008 (72)
	maxiumum in kitchen	243	3.7(2.6)hrs	Franklin et al. 2006 (73)
CO	unvented fireplace use	114000	2hr	Dutton et al. 2001 (71)
	unvented fireplace use	20486	1hr	Gordon et al. 2008 (70)
PM1.1	cleaning products	89	12hr	Singer et al. 2006 (74)
PM2.5	oven cleaning	6381	5.2hrs	Fortmann et al. 2001 (69)
	cooking fish (gas stove)	3146	3hrs	Fortmann et al. 2001 (69)
	maximum in house	2842	peak conc.	Morawska et al. 2003 (75)
	constantly sooting candle	1400	1hr	Pagels et al. 2009 (76)
	cooking	745	peak conc.	He et al. 2004 (77)
	grilling bacon	389	peak conc.	Buonanno et al. 2009 (78)
	expirement)	215	steady state	Coleman et al. 2008 (79)
	candle vapour eucalypt oil	132	24hrs	He et al. 2004 (77)
	maximum in house	105	peak conc.	Stranger et al. 2007 (80)
	hair dryer	45	peak conc.	He et al. 2004 (77)
	washing machine	43	peak conc.	He et al. 2004 (77)
	sweeping	35	peak conc.	He et al. 2004 (77)
	kerosene lamp	32	1min	He et al. 2004 (77)
	oil lamp	30	1min	He et al. 2004 (77)

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Table 3 Pollutants that potentially pose an adverse indoor health risk. Study numbers correspond to study lists in table1 and table 2.

Chronic Health Hazards

Hazards in most homes	Studies	Hazard*	Level of Certainty
acetaldehyde**	**10,11,15,20,22,38,41,45,50,55,65,66**	**C/NC**	**high**
acrolein**	**10,11,20,50,64**	**NC**	**high**
benzene**	**1,4,10,11,12,13,18,20,22,24,25-27,31,37,38,41,44,55,65**	**C**	**high**
butadiene, 1,3-**	**11,13,20,31,38,44,55**	**C**	**high**
carbon tetrachloride	11,12,18,27,31,38	C	high
dichlorobenzene, 1,4-**	**2,10,11,12,13,18,22,26,27,31,33,37,38,41,47**	**C**	**high**
formaldehyde**	**2,10,11,15,22,25,33,34,38,41,45,47,50,53,55,65**	**C/NC**	**high**
naphthalene**	**4,12,13,18,20,22,24,26,44,59**	**C/NC**	**high**
NO2**	**1,5,7,8,9,14,22,23,30,32,34,39,40,43,47,48,49,52,58,62,6**	**NC**	**high**
PM2.5**	**6,10,11,16,21,22,30,36,38,40,42,48,51,56,57,67**	**NC**	**high**
acrylonitrile	44	C	medium
chromium	16,38,56	C	medium
hexachlorobutadiene	12	C	low
benzyl chloride	12	C	low
vinyl chloride	12	C	low
Hazards in some homes			
chloroform	11,12,18,22,26,27,31,38,41,44,47	C	high
environmental tobacco smoke	not applicable	C/NC	high
ethylbenzene	1,2,4,10-13,18,24,26,27,31,33,37,38,41,44,47,65	C	high
methylene chloride	11,12,20,27,31,38,41,44	C	high
radon	not applicable	C	high
tetrachlorothene	4,10,11,12,18,22,26,27,31,37,38,41,44,47	C	high
cadmium	16,38,56	C	medium
dichloropropane,1,2-	12,44	NC	medium
tetrachloroethane, 1,1,2,2-	12,44	C	medium
Hazards in very few homes			
bromomethane	12	NC	high
chlorine	16,42,48,56	NC	high
CO	8,10,17,19,22,36,46,67	NC	high
dichloroethane, 1,2-	12,20,44	C	high
trichloroethene	2,4,10,11,12,18,27,38,41,44,47	C	high
propanal	2,11,45,65	C	low

Acute Health Hazards

acrolein	10,11,20	SI	high
formaldehyde	2,10,22,33,34,50	SI	high
CO	70,71	H	high
PM2.5	6,10,11,22,30,48,56,57,69,75-80	R/H	high
NO2	69-73	R	high
chloroform	68	RD	low

***NC=noncancer, C=cancer, SI=sensory irritation, H=cardiovascular, R=respiratory, RD=reproductive/developmental**

****priority hazards**

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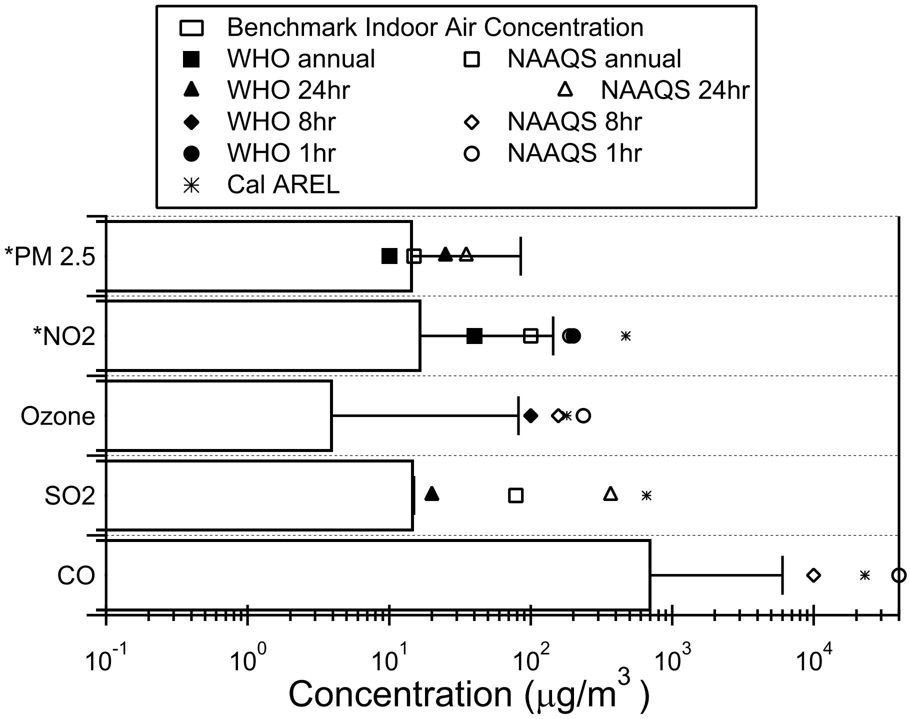

Figure 1 Representative indoor air concentrations compared to relevant national and international standards. Line extends to the upper bound indoor concentration. CAL AREL is the CalEPA acute reference exposure level (1hr).

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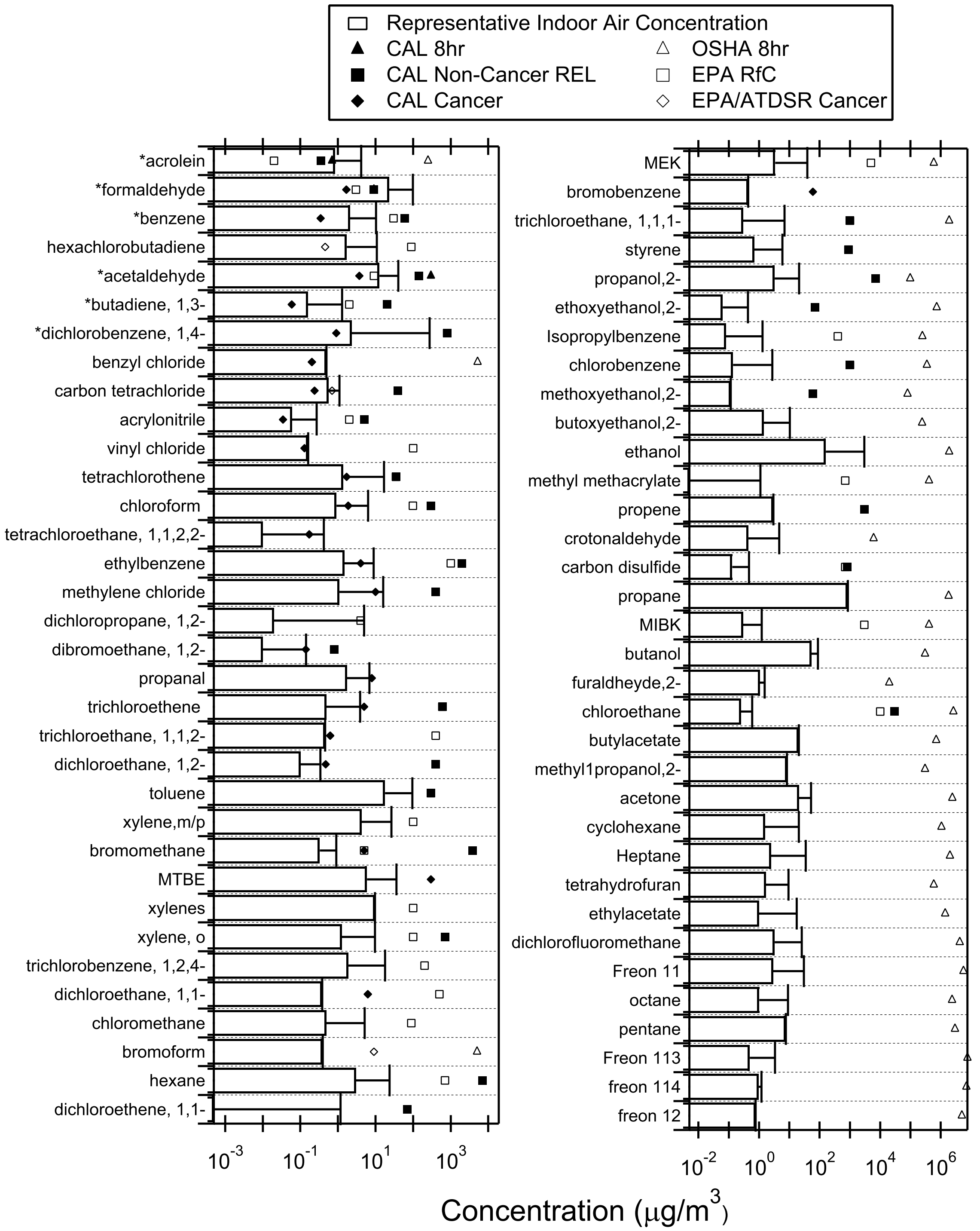

Figure 2 Our representative indoor air concentrations compared to volatile organic HAP/TAC health standards. The line extends to representative upper bound indoor concentration. Cancer, RfC, and REL standards are for chronic long term exposure (70 years). OSHA standards are for workday exposure for a significant portion of a lifetime. (CAL=CalEPA, EPA=USEPA). Priority pollutants are identified with an asterisk.

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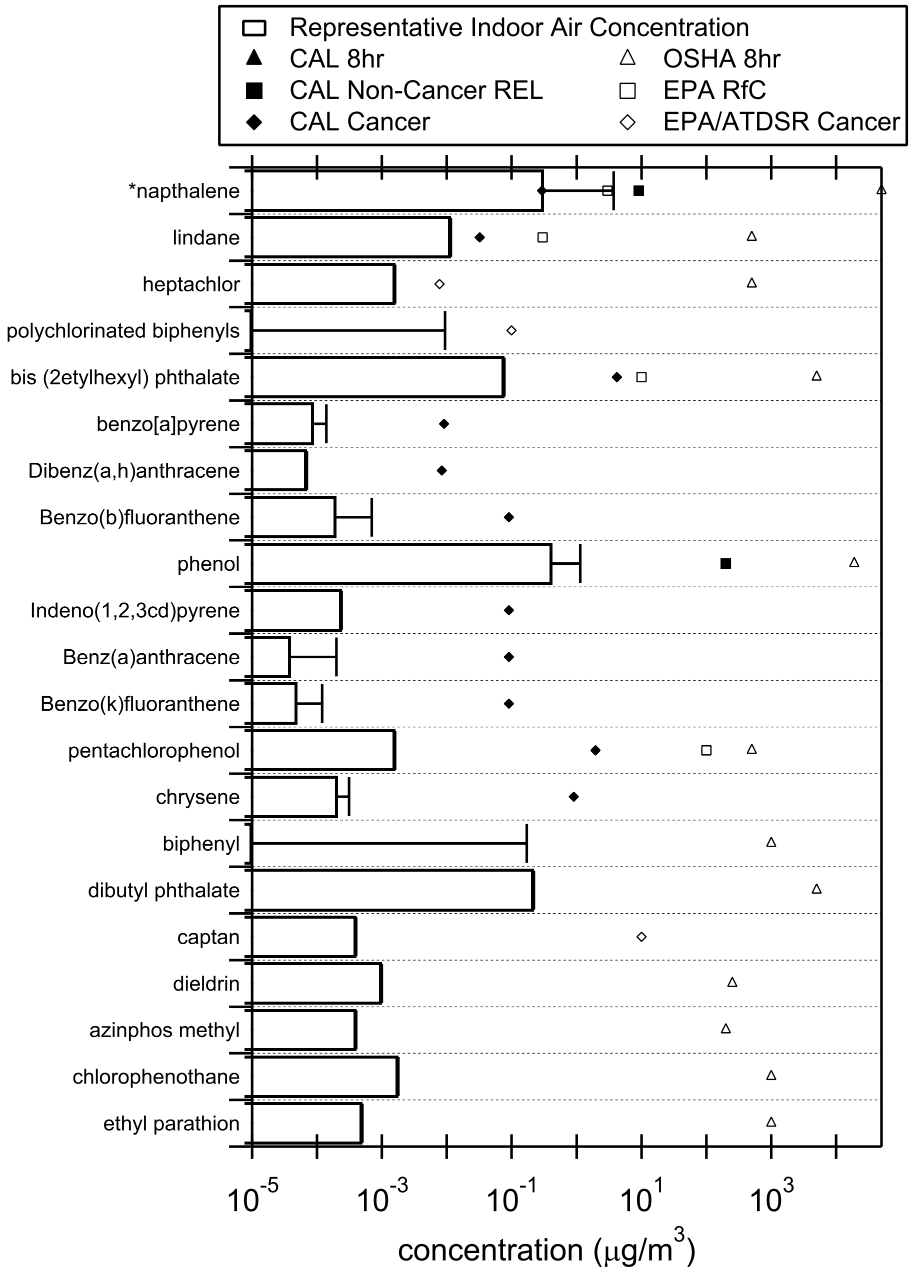

Figure 3 Representative indoor air concentrations compared to SVOC HAP/TAC health standards. The line extends to our upper bound representative indoor concentration. Cancer, RfC, and REL standards are for chronic long term exposure (70 years). OSHA standards are for workday exposure for a significant portion of a lifetime. (CAL=CalEPA, EPA=USEPA) . (CAL=CalEPA, EPA=USEPA). Priority pollutants are identified with an asterisk.

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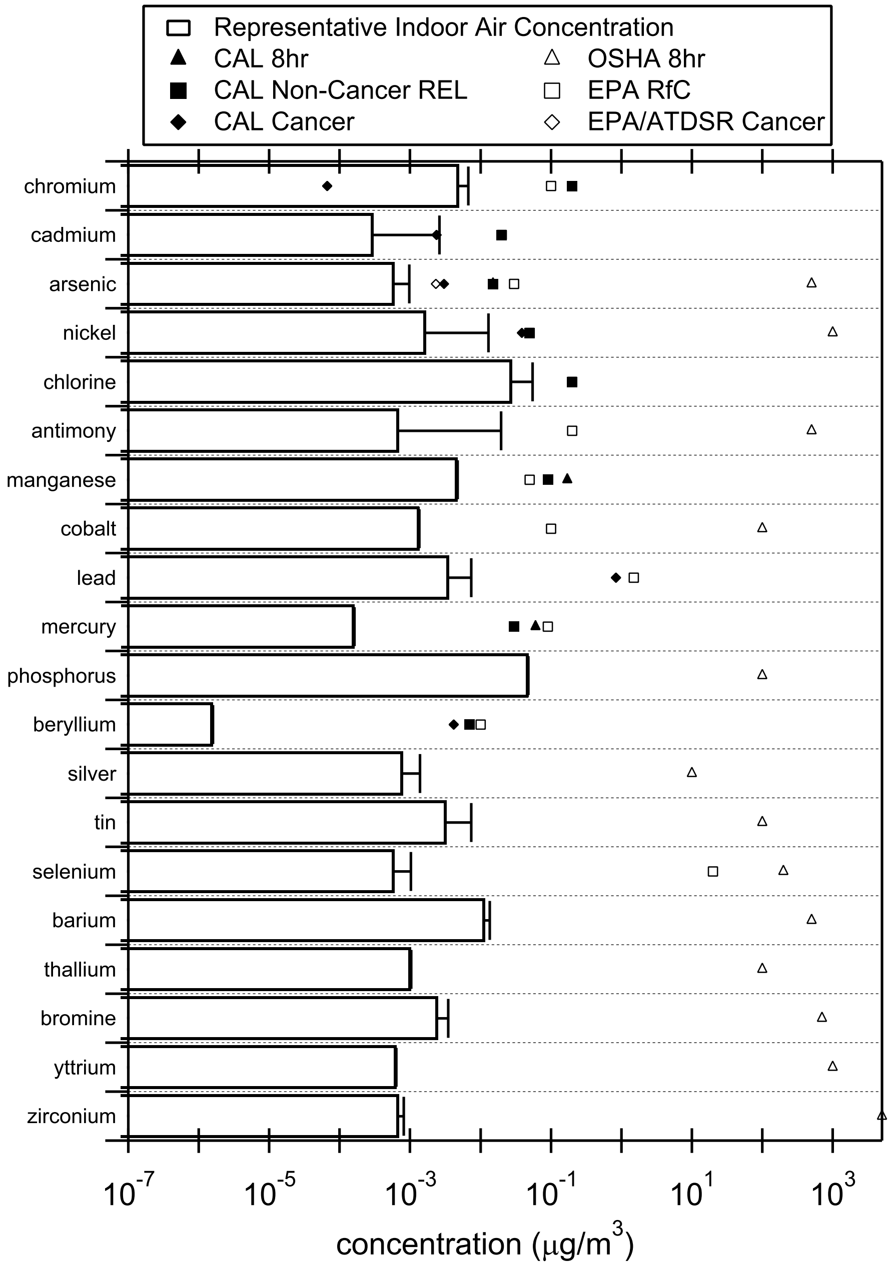

Figure 4 Representative indoor air concentrations compared to metal HAP/TAC health standards. The line extends to the upper bound representative indoor concentration. Cancer, RfC, and REL standards are for chronic long term exposure (70 years). OSHA standards are for workday exposure for a significant portion of a lifetime. (CAL=CalEPA, EPA=USEPA).

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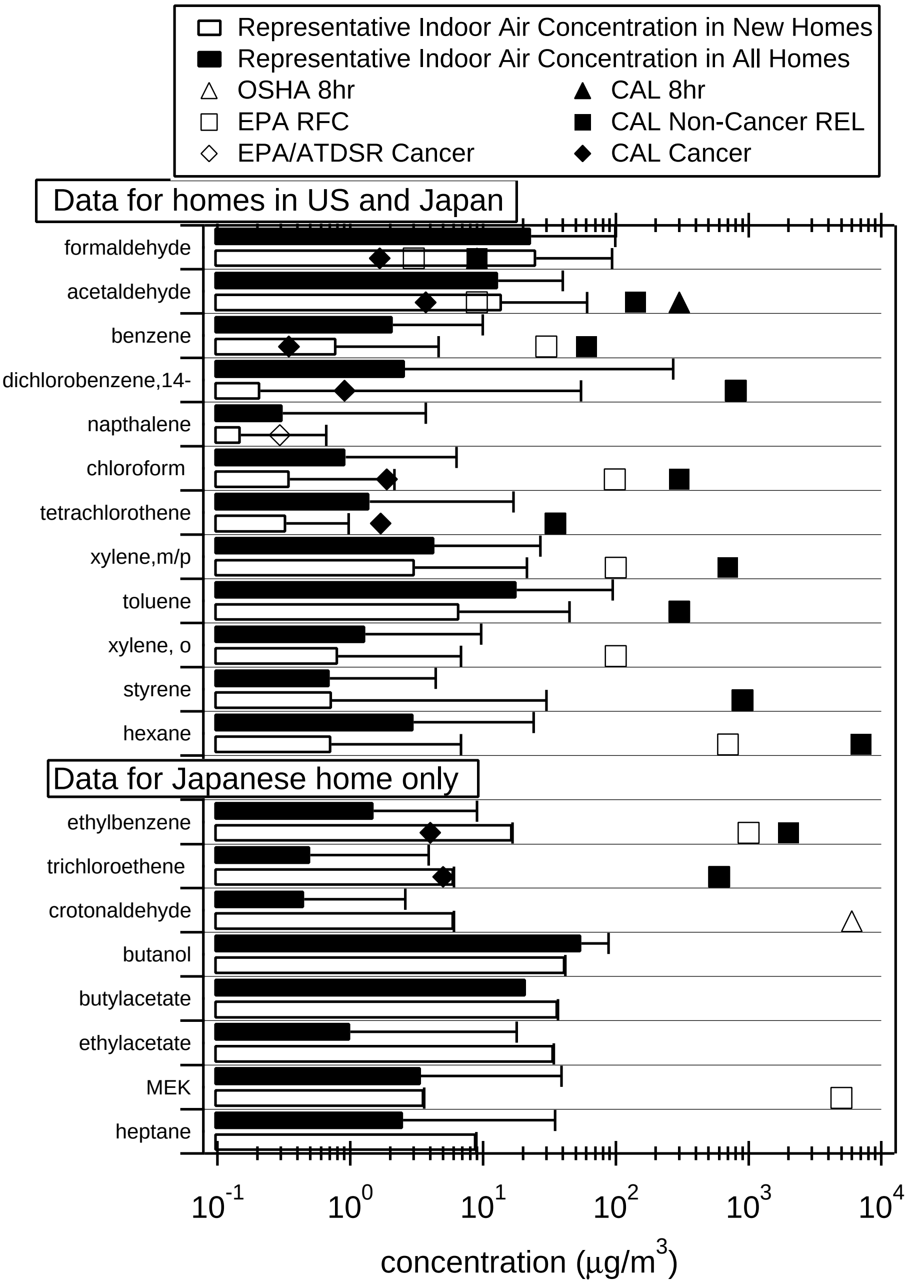

Figure 5 Representative indoor air concentrations in new homes compared to HAP/TAC standards. Error bar extends to the upper bound representative indoor concentration. Cancer, RfC, and REL standards are for chronic long term exposure (70 years). OSHA standards are for workday exposure for a significant portion of a lifetime. (CAL=CalEPA, EPA=USEPA). Representative indoor air concentrations in all homes are added for comparison.

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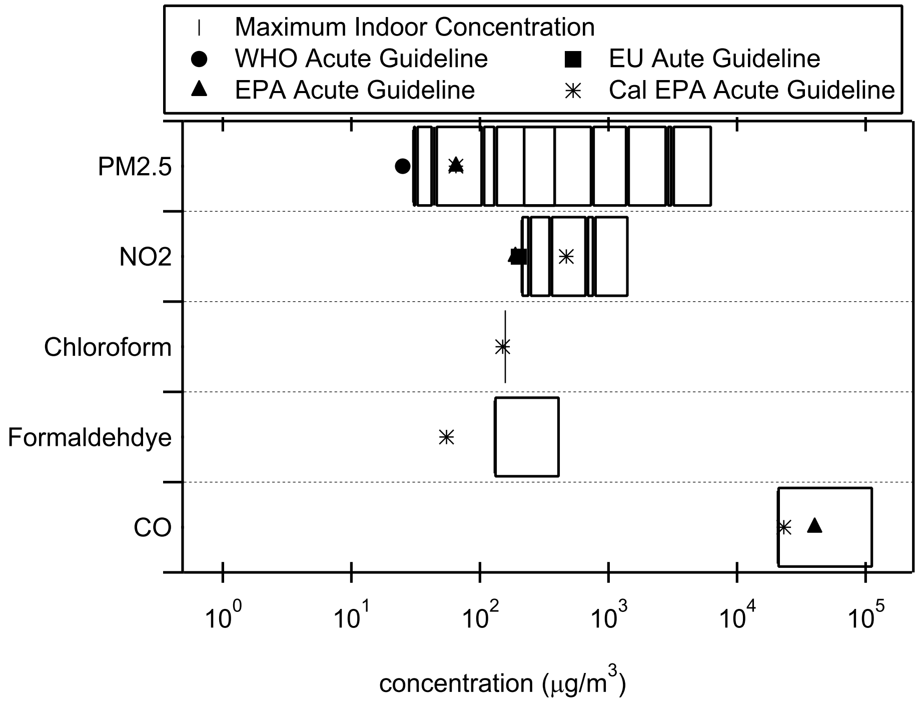

Figure 6 Range of acute concentration measurements compared to acute standards for WHO (1hr standard for NO_2, 24 hr for $PM_{2.5}$), EPA standards (1 hr for $PM_{2.5}$, NO_2, and CO), and CalEPA (1 hr for CO, chloroform, and formaldehyde). The bars repesent the range of measured acute concentrations and each vertical line in the bar repesents an individual measurement

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Supplemental

for

Hazard Assessment of Chemical Air Contaminants Measured in Residences

Jennifer M. Logue, Thomas E. McKone, Maxwell H. Sherman, Brett C. Singer

J.M. Logue, T.E. McKone, M. H. Sherman, B.C. Singer, *Hazard Assessment of Chemical Air Contaminants Measured in Residences, LBNL-3650E*
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Summary Statistics

Tables S1-S4 in the supplemental present the summary statistics from the chronic concentration database. Table S1 shows the criteria pollutants, Table S2 lists the VOCs, Table S3 lists the SVOCs and Table S4 lists the metals concentrations (metals are part of $PM_{2.5}$). The summary statistics include the number of studies/papers that had data on each pollutant and the number of measurements for the mean, 25^{th}, 50^{th}, 75^{th}, 95^{th} percentiles as well as top of the range values (TOR) for select SVOCs. The pollutants that are identified as hazards are in bold and indicated by asterisks after the name.

Table S1 Summary Statistics of Criteria Pollutants (concentration values in $\mu g/m^3$)

		Mean Values			25th percentile			50th percentile			75th percentile			95th percentile		
Compound	CAS #	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value
ozone	10028156	4	2114	17.2	1	88	3.9	3	2084	3.1	1	88	31.4	2	107	80.5
PM 2.5**		**13**	**2267**	**15.9**	**4**	**312**	**9.1**	**13**	**2804**	**15.7**	**4**	**312**	**20.2**	**4**	**1138**	**86.0**
CO**	**630080**	**6**	**1699**	**810**	**2**	**270**	**340**	**4**	**1077**	**710**	**1**	**203**	**1720**	**2**	**770**	**6030**
SO2	7446095	1	222	15												
NO2**	**10102440**	**16**	**3257**	**13.1**	**6**	**3036**	**11.2**	**12**	**2815**	**16.5**	**7**	**3440**	**19.7**	**6**	**1642**	**144.2**

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Table S2 Summary Statistics of Volatile Organic Compounds (concentration values in $\mu g/m^3$)

		Mean Values			25th percentile			50th percentile			75th percentile			95th percentile		
Compound	CAS #	Study #	Data #	Value	Study #	Data #	Value	Study #	Data #	Value	Study #	Data #	Value	Study #	Data #	Value
1,1,1-trichloroethane	71556	5	1143	2.4				3	973	0.3	1	533	1.1	1	533	6.9
1,1,2,2-tetrachloroethane	79345	1	483	0.42				1	75	0.01	1	75	0.01			
1,1,2-trichloroethane	79005	1	483	0.46												
1,1-dichloroethane	75343	1	465	0.38												
1,1-dichloroethene	75354	1	441	1.2				1	75	5.0E-04	1	75	0.37	1	400	0.7
1,1-dichloropropene	563586	1	22	4.8												
1,2,3-trimethylbenzene	526738	1	400	1.2				1	400	0.4	1	400	1.1	1	400	5
1,2,3-trichlorobenzene	87616	2	277	1.4				1	251	0.4						
1,2,4-trimethylbenzene	95636	8	860	4.2	3	460	0.73	7	1353	2.8	5	535	4.3	3	1024	20
1,2,4-trichlorobenzene	120821	1	465	1.4										1	400	6.3
1,2-dibromoethane	106934	2	514	0.14				1	75	0.01	1	75	0.01			
1,2-dichlorobenzene	95501	3	624	0.37				1	75	0.01	1	75	0.01	1	400	1
1,2-dichloroethane	107062	3	755	0.34				2	292	0.1	1	75	0.01			
1,2-dichloropropane	78875	2	538	0.55				1	75	0.02	2	138	0.02	1	63	5
1,3,5-trimethylbenzene	108678	2	652	1.6	1	400	0.3	2	652	0.6	1	400	1.7	1	400	6.5
1,3-butadiene**	**106990**	**7**	**879**	**0.46**				**3**	**313**	**0.16**	**1**	**75**	**0.47**	**1**	**7**	**1.3**
1,3-dichlorobenzene	541731	2	565	0.65				1	75	0.15	2	475	0.6	1	400	0.9
1,4-dichlorobenzene**	**106467**	**12**	**3985**	**50**	**2**	**22**	**2.0**	**7**	**1691**	**2.8**	**4**	**422**	**0.59**	**4**	**1626**	**270**
1-methoxy-2-propanol	107892							1	567	1.9				1	567	17.5
1-methoxy-2-propylacetate	108656													1	567	2.3
2,3-dimethylpentane	565593	1	129	3.4				2	144	0.7	1	129	2.2	1	129	16
2,4-dimethylpentane	108087	1	143	2.9				1	143	0.6	1	143	2	1	143	15
2-butoxyethanol	111762	2	276	2.6				2	642	1.42944	1	75	1.9	1	567	10
2-carene	554610	1	1499	0.29				1	1499	0.03				1	1499	1.5
2-ethoxyethanol	110805	1	75	0.43				1	75	0.064	1	75	0.064			
2-ethyltoluene	611143	2	1751	1.5				2	1751	0.5				1	1499	6.3
2-methoxyethanol	109864	1	75	0.12				1	75	0.12	1	75	0.12			
2-methyl1propanol	78831	1	201	8.2												
2-methylhexane	591764	1	1	0.13				1	15	1.8						
2-methylpentane	107835	1	1	0.37				1	15	1.6						
2-propanol	67630	1	75	18				1	75	3.3	1	75	21			
3-carene	13466789	2	1700	8.5				1	1499	3.7				1	1499	31
3-ethenylpyridine	1121557	1	500	0.28												
3-ethylhexane	619998	1	1	0.13												
3-ethyltoluene	620144	1	1499	2				1	1499	0.66				1	1499	5.4
4-ethyltoluene	622968	3	1807	2.6				2	1765	0.99	1	56	2.8	2	1555	6.3
acetaldehyde**	**75070**	**9**	**1181**	**22**	**1**	**70**	**13**	**7**	**1578**	**13**	**2**	**106**	**19**	**2**	**965**	**40**
acetic acid	64197	**1**	**4**	**15**	**1**	**4**	**7.1**	**1**	**4**	**9.4**	**1**	**4**	**17**			
acetone	67641	6	1016	40	2	321	9.9	5	1011	21	3	396	52	3	719	46
acrolein**	**107028**	**4**	**683**	**2.3**				**4**	**1241**	**0.84**				**2**	**965**	**4.18363**
acrylonitrile	107131	1	75	0.27				1	75	0.06	1	75	0.13			
ammonia (NH3)	7664417	1	222	28												
a-pinine	80568	10	5365	37	1	400	0.3	6	2922	12	2	400	4.4	3	2453	90
benzaldehyde	100527	4	2996	2.5				1	400	2.9				1	400	0.12
benzene**	**71432**	**16**	**4400**	**2.5**	**2**	**2924**	**1**	**14**	**6882**	**2.1**	**5**	**3219**	**3.5**	**5**	**3240**	**10**
benzyl chloride	100447	1	39	0.5												
beta pinene	127913	3	2159	3.3878648				3	2159	1.2				2	1897	13
bromobenzene	108861	2	78	0.44												
bromodichloromethane	75274	2	221	0.49				1	74	0.2						
bromoform	75252	2	72	0.39												
bromomethane	74839	1	439	0.33										1	400	0.9
butanal	123728	4	2394	7.1				2	196	1.2	3	158	2	1	121	3.2
butanol	71363	3	2363	35	1	11	14	1	11	55	1	11	88			
butylacetate	123864	1	2151	21												
butylbenzene	104518	2	678	0.62				1	252	0.08	1	400	0.5	1	400	2.1
carbon disulfide	75150	1	75	0.34				1	75	0.13	1	75	0.46			
carbon tetrachloride	56235	4	1111	0.68				2	846	0.57				1	554	1.1
chlorobenzene	108907	4	2114	0.68	1	400	0.1	2	1574	0.14	1	75	0.005	1	1499	2.8
chloroethane	75003	1	490	0.26										1	400	0.6
chloroform	67663	10	1949	1.5	1	29	0.98	6	1202	0.92	4	504	0.5	3	1107	6.3
chloromethane	74873	2	560	1.8	1	81	1.1	2	481	0.5	2	481	1.8	2	560	5.2
cis-1,2-dichloroethene	156592	1	463	0.54										1	400	1.2
cis-1,3-dichloropropene	10061015	1	484	0.55												

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Table S2 Cont. Summary Statistics of Volatile Organic Compounds (concentration values in μg/m^3)

Compound	CAS #	Mean Values Study #	Data #	Value	25th percentile Study #	Data #	Value	50th percentile Study #	Data #	Value	75th percentile Study #	Data #	Value	95th percentile Study #	Data #	Value
crotonaldehyde	123739	3	2612	4.7				1	398	0.45	1	63	0.57	1	398	2.6
cycloheptane	291645	1	400	1.2				1	400	0.5	1	400	1.3	1	400	5.1
cyclohexane	110827	5	2245	5.2				4	2022	1.6	3	523	2.6	3	1947	20
cyclopropylbenzene	873494	1	4	3.6												
decanal	112312	1	252	1.8				1	252	0.92						
decane	124185	7	4349	15	2	423	1.8	6	2564	3.8	4	498	7.4	3	2466	39
dibromochloromethane	124481	2	221	0.44				1	126	0.08						
dichlorofluoromethane	75434	2	488	7.8	1	88	2.8	1	88	3.3	2	488	4.1	2	488	26
d-limonine	5989275	9	1783	23	2	423	1.1	6	1491	9.5	3	423	9.1	2	954	100
dodecane	112403	4	4051	22	1	400	0.4	2	1899	2.5	1	400	3.9	2	1899	29
ethanol	64175	2	444	860	1	227	27	2	444	160	1	227	540	1	227	3000
ethylacetate	141786	2	2403	18				1	170	1						
ethylbenzene	100414	15	6296	3.9	3	2946	0.51	10	5674	1.5	6	3208	2.8	4	2640	9.0
ethylcyclohexane	1678917	1	400	1.1				2	967	1.5	1	400	1.2	2	967	11
ethylmethacrylate	97632	1	227	0.2										1	227	0.3
formaldehyde**	**50000**	**13**	**3370**	**69**	**3**	**212**	**29**	**9**	**1716**	**23**	**3**	**233**	**99**	**2**	**965**	**16**
freon 11	75694	2	533	6.5	2	476	1.1	2	476	2.9	2	533	5.4	2	533	30
freon 113	76131	1	446	0.82				1	400	0.5	1	400	1.1	1	400	3.4
freon 114	76142	1	439	0.98										1	400	1.2
freon 12	75718	1	45	0.77												
glyoxal	107222	2	468	2.4				2	434	2.6	1	70	0.92	1	398	4.4
heptane	142825	5	4122	11	2	404	1.07327	4	1971	2.51752	3	472	7.74661	3	1967	35
hexachlorobutadiene	87683	1	443	1.7										1	400	11
hexaldehyde,hexanal	66251	5	3023	5.9				3	1209	8.4				2	965	33
hexane	110543	3	2040	7.3	1	400	0.6	4	1989	3	2	555	5.9	3	2054	24
isobutane	75285	1	217	52				1	217	23						
isobutylketone	108838	1	2151	12												
isooctane	540841	1	400	5.5				1	400	0.6	1	400	2.1	1	400	14
isoprene	78795	1	400	4	1	400	0.8	1	391	2	1	400	4.3	1	400	15
Isopropylbenzene	98828	3	668	0.4				2	252	0.08	2	400	0.4	1	400	1.3
isovaleraldehyde	590863	1	142	1.2				1	121	0.97				1	121	2.9
limonine	138863	3	3867	34				2	1716	18				1	1499	120
mchlorotoluene	108418	1	4	3.6												
MEK	78933	5	2739	7.4	2	311	1.4	3	386	3.4	3	386	7.3	2	311	39
methyl methacrylate	80626	3	411	0.27				1	75	0.005	2	302	0.4	1	227	1.1
methylcyclohexane	108872	2	1899	5.2				2	1899	1.7	1	400	1.9	2	1899	20
methylcyclopentane	96377	2	1500	1.8				1	1499	0.8				1	1499	6
methylene chloride	75092	8	1873	8.2	1	400	0.3	5	1538	1.1	3	651	6.6	3	1130	16
methylglyoxal	78988	2	468	2.6	1	36	1.2	2	434	2.7	1	70	2.7	1	398	4.7
MIBK	108101	3	554	1.2				2	302	0.3	1	75	0.38			
MTBE	1634044	6	1080	12				4	921	6	3	368	5.6	3	846	36
nitrous acid	7782776	2	469	5.3	1	255	4.0	2	354	6.0	1	255	9.8	1	99	24
nonane	111842	4	2755	14	2	403	0.47	3	418	1.4	2	403	3.5	1	400	13
ochlorotoluene	95498	2	69	0.42												
octanal	124130	1	201	4.3												
octane	111659	2	1899	3.9	1	400	0.3	2	1899	1	1	400	2.3	2	1899	8.9
pchlorotoluene	106434	1	24	4.8												
pentanal	110623	2	2272	1.3				1	121	1.8				1	121	5.9
propanal	123386	4	2603	6.9	1	36	0.88	2	434	1.8	1	46	1.7	1	398	3.8
propylbenzene	103651	4	1123	1.1				2	496	0.5	1	400	0.7	1	400	2.8
secbutylbenzene	135988	2	553	0.52							1	400	0.6	1	400	1.7
styrene	100425	13	6149	5.9	1	4	0.2	9	3643	0.7	4	479	0.7	4	3020	4.4
tertbutylbenzene	98066	1	426	0.94							1	400	0.6	1	400	2.8
tetrachlorothene	127184	10	3429	2.9				9	3648	1.4	3	475	1.1	4	3158	17
tetrahydrofuran	109999	2	449	1.7							1	227	0.4	1	227	9.4
toluene	108883	17	6617	15	4	3235	9.7	14	6952	18	6	3310	39	5	3266	95
trans-1,2-dichloroethene	156605	1	26	4.5												
trans-1,3-dichloropropene	10061026	1	84	2.2												
trichloroethene	79016	10	5569	2.3				6	3118	0.5	1	75	0.08	4	3145	3.9
tridecane	629505	1	1499	3.3				1	1499	1.7				1	1499	11
undecane	1120214	3	2100	8.8	1	400	0.6	3	2466	4.0	1	400	5	3	2466	45
vinyl chloride	75014	1	447	0.16												
xylene, o	95476	11	3663	1.7	3	3007	0.6	10	6336	1.3	4	3226	2.1	5	3247	9.7
xylene,m/p	108383/ 106423	15	5956	8.2	4	2946	1.7	12	6621	4.3	5	3150	6.3	5	3150	27
xylenes	1330207	1	500	9.7												

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Table S3 Summary Statistics of Semi-Volatile Organic Compounds (concentration values in μg/m^3)

		Mean Values			50th percentile			75th percentile			95th percentile			Top of Range		
Compound	CAS #	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value
1-methylanthracene	610480	1	157	3.5E-03	1	157	3.1E-03									
1-methylnaphthalene	90120													1	15	7.5E-02
1-methylphenanthrene	832699	1	157	2.0E-03	1	157	2.0E-03							1	15	7.9E-03
2,3,5-trimethylnapthalene	2245387													1	15	1.0E-05
2,3-dimethylnapthalene	581408													1	15	2.3E-01
2-ehtylhexanol	104767	1	201	3.7E+00												
2-methylanthracene	613127	1	157	7.4E-04	1	157	4.9E-04									
2-methylnaphthalene	91576													1	15	8.4E-02
2-methylphenanthrene	2531842													1	15	1.7E-02
3,6-dimethylphenanthrene	1576676	1	157	9.5E-04	1	157	8.7E-04									
3-methylphenanthrene	832713													1	15	1.7E-02
4,5-methylenephenanthrene	203645	1	157	1.1E-03	1	157	1.0E-03									
4,9-methylphenanthrene	832644/ 883205													1	7	9.1E-03
4-nonylpehnol	104405				1	120	1.1E-01									
4-tert-butylphenol	98544				1	120	1.6E-02									
9,10-dimethylanthracene	781431	1	157	1.3E-04	1	157	4.4E-05									
9-methylanthracene	779022	1	157	1.7E-04	1	157	1.1E-04									
acenaphthene	82329													1	15	5.8E-02
acenaphthylene	208968													1	15	2.3E-02
anthracene	120127	1	157	1.0E-03	2	172	9.7E-04							1	15	6.3E-03
atrazine	1912249				1	14	3.2E-04									
azinphos methyl	86500				1	6	4.0E-04									
BDE 100		3	34	2.9E-05	3	34	1.1E-05									
BDE 153		1	12	3.2E-06	1	12	1.0E-06									
BDE 154		1	12	2.0E-06	1	12	6.0E-07									
BDE 17		1	12	2.4E-05	1	12	1.6E-05									
BDE 28		2	24	5.0E-05	2	24	3.2E-05									
BDE 47		3	34	3.7E-04	3	34	1.4E-04									
BDE 66		2	24	5.8E-05	2	24	4.5E-05									
BDE 71		1	12	1.9E-05	1	12	9.2E-06									
BDE 75		1	12	9.9E-06	1	12	1.2E-06									
BDE 85		1	12	1.0E-06	1	12	1.0E-07									
BDE 99		3	34	3.5E-04	3	34	4.1E-05									
benz(a)anthracene	56553	1	233	6.8E-05	3	284	4.0E-05							1	15	2.0E-04
benzo(b)fluoranthene	205992	1	91	1.4E-04	1	118	2.0E-04							1	15	7.0E-04
benzo(k)fluoranthene	207089	1	91	1.2E-04	1	118	5.0E-05							1	15	1.0E-04
benzo[a]fluorene	238846/ 30777185	1	157	1.3E-04	1	157	1.2E-04									
benzo[a]pyrene	50328	2	248	9.1E-05	2	275	9.0E-05							1	15	1.4E-04
benzo[b]fluorene	30777196	1	157	4.9E-05	1	157	3.3E-05									
benzo[b]naphtho[2,1d]thiophene	239350	1	157	2.4E-05	1	157	2.2E-05									
benzo[b+k]fluoranthene	205992/ 207089	1	157	2.4E-04	1	157	1.5E-04									
benzo[e]pyrene	192972	1	157	7.5E-05	2	218	1.2E-04							1	15	1.2E-04
benzo[g,h,i]perylene	191242	1	157	1.7E-04	2	275	1.9E-04							1	15	1.1E-04
biphenyl	92524													1	15	1.7E-01
bis (2etylhexyl) phthalate	117817				1	102	7.7E-02									
chrysene	218019	1	157	1.5E-04	2	269	2.1E-04							1	15	3.1E-04
cischlordane	5103719	1	157	2.1E-03	1	157	5.0E-04									
cisnonachlor	5103731	1	157	1.1E-04	1	157	4.1E-05									
coronene	191071	1	157	2.0E-04	2	275	1.5E-04									

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Table S3 (Cont.) Summary Statistics of Semi-Volatile Organic Compounds (concentration values in $\mu g/m^3$)

Compound	CAS #	Mean Values # of Studies	Mean Values Data #	Mean Values Value	50th percentile # of Studies	50th percentile Data #	50th percentile Value	75th percentile # of Studies	75th percentile Data #	75th percentile Value	95th percentile # of Studies	95th percentile Data #	95th percentile Value	Top of Range # of Studies	Top of Range Data #	Top of Range Value
cyclopenta[c,d]pyrene	27208373	1	157	7.3E-05	1	157	4.0E-05									
DBP	84742				1	120	2.2E-01									
DEHA	103231				1	120	9.0E-03									
dibenz(a,h)anthracene	53703	1	91	1.9E-05	1	118	7.0E-05							1	15	2.9E-05
dibenzo[a,c+a,h]anthracene	215587/53703	1	157	1.4E-05	1	157	8.8E-06									
dibenzothiophene	132650	1	157	3.6E-03	1	157	3.0E-03									
diethyl phthalate	84662				1	120	5.9E-01									
diisobutylphthalate	84695				1	120	1.1E-02									
fluoranthene	206440	1	157	1.4E-03	2	275	4.5E-04							1	15	6.0E-03
fluorene	86737													1	15	1.2E-01
Indeno(1,2,3cd)pyrene	193395	2	248	1.6E-04	2	275	2.4E-04							1	15	5.3E-05
methyl paraben	99763				1	120	2.9E-03									
methylbenzoate	93583	1	1499	6.4E-01	1	1499	5.0E-02				1	1499	3.3			
napthalene**	**91203**	**9**	**2790**	**1.2**	**5**	**2043**	**0.31**	**2**	**75**	**1.1**	**2**	**1544**	**3.7**	**1**	**15**	**0.05**
nonylphenol monoethyoxylate	none				1	120	1.7E-02									
octylphenol monoethoxylate	none				1	120	8.6E-03									
o-phenylphenol	90437				1	120	7.1E-02									
oxychlordane	27304138	1	157	3.9E-05	1	157	1.8E-05									
PCB 101	37680732													1	15	9.6E-04
PCB 105	32598144													1	8	4.5E-04
PCB 110	38380039													1	15	1.1E-03
PCB 118	31508006													1	8	1.0E-03
PCB 141	52712046													1	8	7.0E-05
PCB 28	7012375													1	15	2.1E-03
PCB 37	38444905													1	15	1.4E-03
PCB 4	13029088													1	15	6.8E-04
PCB 47	2437798													1	15	2.6E-04
PCB 52	35693993													1	15	6.2E-04
PCB 80	33284525													1	15	1.4E-04
PCB138	35065282													1	15	8.2E-05
PCB153	35065271													1	15	5.4E-04
PCP	87865				1	120	1.6E-03									
perylene	198550	1	157	2.1E-05	1	157	1.1E-05							1	15	2.2E-05
phenanthrene	85018	1	106	1.8E-02	1	106	1.3E-02							1	15	1.9E-01
Phenol	108952	1	178	3.6E-01	1	75	4.2E-01	1	75	1.1						
pyrene	129000	1	157	1.3E-03	2	275	1.5E-03							1	15	5.8E-03
retene	483658	1	157	7.2E-04	1	157	7.1E-04							1	15	1.4E-03
transchlordane	5103742	1	157	3.5E-03	2	171	8.2E-04									
transnonachlor	39765805	1	157	1.4E-03	1	157	3.8E-04									
transpermethrin	51877748				1	14	9.0E-04									

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Table S4 Summary Statistics of metals (concentration values in μg/m^3)

		Mean Values			50th percentile		
Compound	CAS #	Study #	Data #	Value	Study #	Data #	Value
aluminum	7429905	2	345	1.7E-02	2	290	1.6E-02
antimony	7440360	3	372	5.8E-03	1	169	7.0E-04
arsenic	7440382	3	334	9.8E-04	1	275	6.0E-04
barium	7440393	1	275	1.3E-02	1	275	1.2E-02
beryllium	7440417	1	18	1.6E-06			
bromine	7726956	1	280	2.7E-03	2	290	2.5E-03
cadmium	7440439	3	372	2.6E-03	1	275	3.0E-04
calcium	7440702	3	419	5.7E-02	4	585	6.2E-02
cesium	7440462	1	77	5.8E-06	1	9	3.4E-02
germanium	7440564	1	275	1.6E-04	1	169	1.0E-04
chlorine	7782505	2	342	4.9E-02	4	499	2.8E-02
chromium**	**18540299**	**3**	**334**	**2.2E-03**	**2**	**284**	**5.0E-04**
cobalt	7440484	3	266	1.3E-03			
copper	7440508	2	352	7.2E-03	3	517	4.8E-03
gallium	7440553	2	295	4.1E-03	1	83	5.0E-04
indium	7440746	2	295	1.2E-03	1	83	4.9E-02
iron	7439896	3	419	6.4E-02	4	585	5.0E-02
lanthanum	7439910	2	352	2.1E-03	1	169	4.0E-04
lead	7439921	3	372	7.4E-03	2	284	3.6E-03
magnesium	7439954	3	365	7.1E-03	2	508	2.4E-03
manganese	7439965	1	82	3.3E-03	1	15	4.8E-03
mercury	7439976	1	275	1.6E-04			
molybdenum	7439987	2	295	5.4E-03	1	275	2.0E-04
nickel	7440020	2	352	1.3E-02	2	508	1.7E-03
nitrate		1	223	3.9E-06			
palladium	2023568	2	295	1.6E-03	1	106	1.0E-04
platinum	7440064	1	77	1.2E-06			
phosphorus	7723140	2	295	7.5E-03	1	9	4.8E-02
potassium	7440097	3	412	6.7E-02	4	585	8.5E-02
rubidium	7440177	2	295	2.2E-03	1	86	1.0E-04
scandium	7440202	1	68	3.1E-06			
selenium	7782492	3	334	1.0E-03	1	189	6.0E-04
silicon	7440213	2	342	6.3E-02	4	489	8.9E-02
silver	7440224	3	372	1.4E-03	1	275	8.0E-04
sodium	7440235	2	131	1.6E-01			
strontium	7440246	1	280	1.2E-03	2	290	5.0E-04
sulfate	14808798	1	223	4.0E-05			
sulfur	7704349	3	419	7.6E-01	4	585	7.1E-01
thallium	7440280	2	97	1.0E-03			
tin	7440315	3	372	7.4E-03	1	275	3.3E-03
titanium	7440326	2	357	9.8E-03	2	290	4.5E-03
vanadium	7440622	3	428	4.0E-03	4	576	3.5E-03
yttrium	7440655	2	212	6.3E-04			
zinc	7440666	3	419	5.5E-02	4	585	1.2E-02
zirconium	7440677	1	275	8.1E-04	1	275	7.0E-04

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Data for New Homes

Table S5 Summary Statistics for new homes (concentration values in μg/m^3)

		Arithmatic Mean			Geometric Mean			25th percentile			50th percentile			75th percentile			95th percentile		
Compound	CAS #	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value	# of Studies	Data #	Value
PM2.5**	**10028156**	**1**	**31**	**13**				**1**	**31**	**7.3**	**1**	**31**	**10**	**1**	**31**	**14.7**	**1**	**31**	**33**
CO	630080	1	203	1170				1	203	330	1	203	1100	1	203	1760	1	203	2740
NO2	10102440	1	31	11				1	31	5.6	1	31	6.1	1	31	12	1	31	25
caprolactam	872504	1	206	0.24				1	206	0.23	1	206	0.24	1	206	0.25	1	206	0.27
napthalene**	**91203**	**1**	**206**	**0.29**				**1**	**206**	**0.14**	**1**	**206**	**0.15**	**1**	**206**	**0.27**	**1**	**206**	**0.66**
phenol	108952	1	206	1.7				1	206	0.61	1	206	1.3	1	206	2.3	1	206	4.6
1-methyl-2-pyrrolidinone	872504	1	206	0.49				1	206	0.42	1	206	0.43	1	206	0.45	1	206	0.63
1,2,4-trimethylbenzene	95636	1	206	1.6				1	206	0.3	1	206	0.82	1	206	2.0	1	206	5.3
1,4-dichlorobenzene**	**106467**	**2**	**666**	**55**				**1**	**206**	**0.2**	**1**	**206**	**0.21**	**1**	**206**	**0.23**	**1**	**206**	**2.4**
2-butoxyethanol	111762	1	206	5.8	1	11	14.1	1	206	0.14	1	206	1.5	1	206	4.7	1	206	23
3-carene	13466789				1	11	23												
acetaldehyde**	**75070**	**1**	**211**	**20**	1	11	**29**	**1**	**211**	**3.9**	**1**	**211**	**14**	**1**	**211**	**26**	**1**	**211**	**61**
acetic acid	64197				1	11	190												
a-pinene	80568	2	666	140	1	11	130	1	206	0.23	1	206	7.7	1	206	16	1	206	40
benzaldehyde	100527	1	460	2.6															
benzene**	**71432**	**1**	**206**	**1.4**				**1**	**206**	**0.26**	**1**	**206**	**0.79**	**1**	**206**	**1.7**	**1**	**206**	**4.6**
butanal	123728	1	460	7.0															
butanol	71363	1	460	42	1	11	28												
butylacetate	123864	1	460	37	1	11	10												
b-pinene	127913				1	11	49												
chloroform **	**67663**	**1**	**206**	**0.69**				**1**	**206**	**0.34**	**1**	**206**	**0.35**	**1**	**206**	**0.43**	**1**	**206**	**2.2**
crotonaldehyde	123739	1	460	6.0															
d-limonine	5989275	1	206	13	1	11	25	1	206	0.32	1	206	6.3	1	206	17	1	206	41
dodecane	112403	1	460	38	1	11	25												
ethylacetate	141786	1	460	34															
ethylbenzene**	**100414**	**1**	**460**	**17**															
ethylene glycol	107211	1	206	8.9	1	11	150	1	206	1.2	1	206	1.2	1	206	9.7	1	206	42
formaldehyde**	**50000**	**2**	**671**	**94**	1	11	**43**	**1**	**211**	**4.0**	**1**	**211**	**25**	**1**	**211**	**46**	**1**	**211**	**59**
heptanal	111717				1	11	8.8												
heptane	142825	1	460	8.9															
hexaldehyde	66251	2	666	5.6	1	11	93	1	206	0.49	1	206	4.8	1	206	13	1	206	27
hexane	110543	1	206	1.8				1	206	0.31	1	206	0.72	1	206	1.8	1	206	6.8
hexanoic acid	142621				1	11	5.6												
isobutylketone	108838	1	460	27															
limonine	138863	1	460	33															
MEK	78933	1	460	3.6	1	11	24												
decane	124185	1	460	34	1	11	24												
nonane	111842	1	460	15															
nonanal	124196				1	11	18												
octanal	124130				1	11	13												
pentanal	110623	1	460	1.0															
phenol	108952				1	11	7.1												
propanal	123386	1	460	8.4															
propylene glycol	57556				1	11	18												
styrene	100425	2	666	30	1	11	8.4	1	206	0.23	1	206	0.73	1	206	1.5	1	206	3.6
tetrachlorothene	127184	1	206	0.7				1	206	0.32	1	206	0.33	1	206	0.36	1	206	0.97
toluene	108883	2	666	20	1	11	28	1	206	2.3	1	206	6.6	1	206	14	1	206	45
trichloroethene **	**79016**	**1**	**460**	**6.0**															
tridecane	629505				1	11	40												
viny acetate	108054	1	206	0.4				1	206	0.38	1	206	0.4	1	206	0.41	1	206	0.44
xylene, o	95476	1	206	1.8				1	206	0.27	1	206	0.81	1	206	1.9	1	206	6.8
xylene,m/p	108383/ 106423	2	666	19	1	11	12	1	206	1.4	1	206	3.1	1	206	6.3	1	206	21

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Table S6 Carcinogenicity classification of pollutants in IRIS database without available health benchmarks

Compound	CAS	Carcinogenicity	Compound	CAS	Carcinogenicity
1,2,4-trichlorobenzene	120821	D	copper	7440508	D
1,2-dichlorobenzene	95501	D	DEHA	103231	C
1,3-dichlorobenzene	541731	D	dibenz(a,h)anthracene	53703	B2
2-methylnaphthalene	91576	IAC	dibromochloromethane	124481	C
acenaphthylene	208968	D	diethyl phthalate	84662	D
anthracene	120127	D	fluoranthene	206440	D
BDE 153	68631492	IAC	fluorene	86737	D
BDE 47	5436431	IAC	isooctane	540841	IAC
BDE 99	60348609	IAC	phenanthrene	85018	D
benzo[g,h,i]perylene	191242	D	phosphorus	7723140	D
bromodichloromethane	75274	B2	pyrene	129000	D
cis-1,2-dichloroethene	156592	D	zinc	7440666	D

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Table S7 Compounds with no available health benchmark data

Compound	CAS	Compound	CAS	Compound	CAS
1,1-dichloropropene	563586	benzo[b]fluorene	30777196	methylcyclohexane	108872
1,2,3-trichlorobenzene	87616	benzo[b]naphtho[2,1d]thiophene	239350	methylcyclopentane	96377
1,2,3-trimethylbenzene	526738	benzo[b+k]fluoranthene	205992/	methylglyoxal	78988
1,2,4-trimethylbenzene	95636	benzo[e]pyrene	192972	molybdenum	7439987
1,3,5-trimethylbenzene	108678	beta pinene	127913	nonane	111842
1-methoxy-2-propanol	107892	butanal	123728	nonylphenol monoethyoxylate	none
1-methoxy-2-propylacetate	108656	butylbenzene	104518	ochlorotoluene	95498
1-methylanthracene	610480	calcium	7440702	octanal	124130
1-methylnaphthalene	90120	cesium	7440462	octylphenol monoethoxylate	none
1-methylphenanthrene	832699	cis-1,3-dichloropropene	10061015	o-phenylphenol	90437
2,3,5-trimethylnapthalene	2245387	cischlordane	5103719	oxychlordane	27304138
2,3-dimethylnapthalene	581408	cisnonachlor	5103731	palladium	2023568
2,3-dimethylpentane	565593	coronene	191071	pchlorotoluene	106434
2,4-dimethylpentane	108087	cycloheptane	291645	PCP	87865
2-carene	554610	cyclopenta[c,d]pyrene	27208373	pentanal	110623
2-ehtylhexanol	104767	cyclopropylbenzene	873494	perylene	198550
2-ethyltoluene	611143	DBP	84742	platinum	7440064
2-methylanthracene	613127	decanal	112312	potassium	7440097
2-methylhexane	591764	decane	124185	propylbenzene	103651
2-methylpentane	107835	dibenzothiophene	132650	retene	483658
2-methylphenanthrene	2531842	diisobutylphthalate	84695	rubidium	7440177
3,6-dimethylphenanthrene	1576676	d-limonine	5989275	scandium	7440202
3-carene	13466789	dodecane	112403	secbutylbenzene	135988
3-ethenylpyridine	1121557	ethylcyclohexane	1678917	silicon	7440213
3-ethylhexane	619998	ethylmethacrylate	97632	sodium	7440235
3-ethyltoluene	620144	gallium	7440553	strontium	7440246
3-methylphenanthrene	832713	germanium	7440564	sulfate	14808798
4,5-methylenephenanthrene	203645	glyoxal	107222	sulfur	7704349
4,9-methylphenanthrene	883205	hexaldehyde,hexanal	66251	tertbutylbenzene	98066
4-ethyltoluene	622968	hydrochloric acid	7647010	titanium	7440326
4-nonylpehnol	104405	indium	7440746	trans-1,2-dichloroethene	156605
4-tert-butylphenol	98544	iron	7439896	trans-1,3-dichloropropene	10061026
9,10-dimethylanthracene	781431	isobutane	75285	transchlordane	5103742
9-methylanthracene	779022	isobutylketone	108838	transnonachlor	39765805
acenaphthene	82329	isoprene	78795	transpermethrin	51877748
acetic acid	64197	isovaleraldehyde	590863	tridecane	629505
aluminum	7429905	lanthanum	7439910	undecane	1120214
ammonia (NH3)	7664417	limonine	138863	vanadium	7440622
a-pinine	80568	magnesium	7439954		
atrazine	1912249	mchlorotoluene	108418		
benzaldehyde	100527	methyl paraben	99763		
benzo[a]fluorene	238846	methylbenzoate	93583		

Table S8 Health standards and guidelines for criteria pollutants (μg/m^3)

	Cal EPA	World Health Organization				USEPA National Air Quality Standards			
	acute (1hr)	Annual	24hr	8hr	1hr	annual	24hr	8hr	1hr
PM 2.5		10	25			15	35		
NO2	470	40			200	100			189
Ozone	180			100				157	235.43
SO2	660		20			78.5	366.24		
CO	23000							10000	40000

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Table S9 Health standards and guidelines for VOC HAP/TACs (μg/m^3)

	California EPA				OSHA	USEPA	
	acute (1hr)	8hr	Non-cancer	Cancer	8hr	Non-cancer	Cancer
acetaldehyde	470	300	140	3.70	360000	9	
acetone					2.40E+06		
acrolein	2.5	0.7	0.35		250	0.02	
acrylonitrile			5	0.03		2	
benzene	1300		60	0.34		30	
benzyl chloride	240			0.20	5174		0.20
bromobenzene				60.00			
bromoform					5000		9.09
bromomethane			3900	5.00		5	
butadiene, 1,3-			20	0.06		2	
butanol					300000		
butoxyethanol,2-	1400				240000		
butylacetate					710000		
carbon disulfide	6200		800			700	
carbon tetrachloride	1900		40	0.24			0.70
chlorobenzene			1000		350000	1000	
chloroethane			30000		2.60E+06	10000	
chloroform	150		300	1.89		98	1.89
chloromethane						90	
crotonaldehyde					6000		
cyclohexane					1.05E+06		
dibromoethane, 1,2-			0.8	0.14		0.8	
dichlorobenzene, 1,4-			800	0.91	45000	800	
dichloroethane, 1,1-				6.25	400000	500	6.25
dichloroethane, 1,2-			400	0.48		400	
dichloroethene, 1,1-			70			70	
dichlorofluoromethane					4.20E+06		
dichloropropane, 1,2-					350000	4	
ethanol					1.90E+06		
ethoxyethanol,2-	370		70		740000		
ethylacetate					1.40E+06		
ethylbenzene			2000	4.00	435000	1000	
formaldehyde	55	9	9	1.67		3	1.67
Freon 11					5.60E+06		
Freon 113					7.60E+06		
freon 114					7.00E+06		
freon 12					4.95E+06		
furaldheyde,2-					20000		
Heptane					2.00E+06		
hexachlorobutadiene						90	0.45
hexane			7000		1.80E+06	700	
Isopropylbenzene					245000	400	
MEK	13000				590000	5000	
methoxyethanol,2-	93		60		80000		
methyl methacrylate					410000	700	
methyl1propanol,2-					300000		
methylene chloride	14000		400	10.00		400	
MIBK					410000	3000	
MTBE				300.00			
octane					2.35E+06		
pentane					2.95E+06		
propanal				8.00			
propane					1.80E+06		
propanol,2-	3200		7000		98000		
propene			3000				
styrene	21000		900			900	
tetrachloroethane, 1,1,2,2-				0.17	35000		0.17
tetrachlorothene	20000		35	1.69		35	
tetrahydrofuran					590000		
toluene	37000		300			300	
trichlorobenzene, 1,2,4-						200	
trichloroethane, 1,1,1-	68000		1000		1.90E+06	1000	
trichloroethane, 1,1,2-				0.63	45000	400	0.63
trichloroethene			600	5.00		600	
vinyl chloride	180000			0.13		100	
xylene, o			700			100	
xylene,m/p	22000					100	
xylenes						100	

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Table S10 Health standards and guidelines for SVOC HAP/TACs (μg/m^3)

	California EPA				OSHA	USEPA	
	acute (1hr)	8hr	Non-cancer	Cancer	8hr	Non-cancer	Cancer
azinphos methyl					200		
Benz(a)anthracene				0.09			
Benzo(b)fluoranthene				0.09			
Benzo(k)fluoranthene				0.09			
benzo[a]pyrene				0.01			
biphenyl					1000		
bis (2etylhexyl) phthalate				4.17	5000	10	4.17
captan							10.00
chlorophenothane					1000		
chrysene				0.91			
Dibenz(a,h)anthracene				0.01			
dibutyl phthalate					5000		
dieldrin					250		
ethyl parathion					1000		
heptachlor					500		0.01
Indeno(1,2,3cd)pyrene				0.09			
lindane				0.03	500	0.3	0.03
napthalene			9	0.29	50000	3	
pentachlorophenol				1.96	500	100	1.96
phenol	5800		200		19000	200	
polychlorinated biphenyls							0.10

Table S11 Health standards and guidelines for metal HAP/TACs (μg/m^3)

	California EPA				OSHA	USEPA	
	acute (1hr)	8hr	Non-cancer	Cancer	8hr	Non-cancer	Cancer
antimony					500	0.2	
arsenic	0.2	0.015	0.015	3.03E-03	500	0.03	2.33E-03
barium					500		
beryllium			0.007	4.17E-03		0.01	4.17E-03
bromine					700		
cadmium			0.02	2.38E-03		0.02	2.38E-03
chlorine	210		0.2			0.2	
chromium			0.2	6.67E-05		0.1	6.67E-05
cobalt					100	0.1	
lead				8.33E-01		1.5	8.33E-01
manganese		0.17	0.09			0.05	
mercury	0.6	0.06	0.03			0.09	
nickel	6		0.05	3.85E-02	1000	0.05	
phosphorus					100		
selenium					200	20	
silver					10		
thallium					100		
tin					100		
yttrium					1000		
zirconium					5000		

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