



10 Questions

Ten questions concerning air fresheners and indoor built environments

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ABSTRACT

Air fresheners are pervasive within indoor built environments, such as workplaces, schools, housing, transportation, hotels, hospitals, care facilities, and a range of private and public buildings. Air fresheners are designed to impart an aroma to the air environment or to mask odors, with the intent of creating a pleasing indoor space. However, despite the intent, air fresheners can emit and generate a range of potentially hazardous air pollutants that can impair air quality. Even so-called green and organic air fresheners can emit hazardous air pollutants. Air freshener ingredients are largely unknown and undisclosed, owing to regulatory protections on consumer product ingredients and on fragrance formulations. In studies, fewer than ten percent of all volatile ingredients are typically disclosed on air freshener labels or material safety data sheets. From an indoor air quality perspective, air fresheners have been indicated as a primary source of volatile organic compounds within buildings. From a health perspective, air fresheners have been associated with adverse effects, such as migraine headaches, asthma attacks, mucosal symptoms, infant illness, and breathing difficulties. This article investigates the seeming paradox that products designed to improve the indoor environment can pose unintended and unknown risks. It examines the science, health, and policy perspectives, and provides recommendations and research directions.

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1. Ten questions

1.1. What are air fresheners?

Air fresheners are consumer products that emit a fragrance to provide an aroma to a space, to mask an odor, or both. Air fresheners come in numerous versions, including sprays, gels, oils, liquids, solids, plug-ins, hanging disks, beads, potpourri, wick diffusers, and scented candles; in active or passive forms; and with instant, intermittent, or continuous release. Air fresheners also include so-called air care, deodorizer, odor control and neutralizer products. In addition to site-specific units or portable products, air fresheners can include scented air systems, which deliver fragrance throughout a space, such as by connecting a fragrance diffuser to

the heating, ventilation, and air conditioning system. In this paper, air fresheners are considered as products designed to impart an aromatic fragrance or a masking fragrance into the air; they are not considered to include air cleaning devices designed to filter or purify the air.

1.2. Where are air fresheners used?

Air fresheners are used throughout society, by individuals, industries, and institutions. Typical indoor environments with air fresheners include the following: buildings and facilities such as offices, schools, hospitals, churches, theaters, stores, hotels, health clubs, restaurants, and restrooms; transportation such as airplanes, airports, cars, taxis, buses, trains, terminals, and boats; residences and care facilities, including homes, apartments, homeless shelters, detention centers, elder care and child care facilities; and others.

The global market for air fresheners exceeds US \$10 billion, and is increasing in most countries [17,19]. Europe is the largest market, and Asia is the fastest growing market. For instance, air freshener

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usage is increasing by as much as 8.8% every year in Korea [24].

Of the general population surveyed in the US, 72.8% use air fresheners and deodorizers at least once a week, and 57.9% are exposed to air fresheners and deodorizers from others' use at least once a week [39]. An earlier report indicated that air fresheners are used in nearly 75% of US households [31]. In a European population survey, air fresheners (spray, electric, and passive) are used by 39%, 40%, and 30% (respectively) of the surveyed population at least once a week in homes, and by 94%, 92%, 89% (respectively) at least once a month in homes [9].

1.3. What do air fresheners emit?

Air fresheners emit over 100 different chemicals, including volatile organic compounds (terpenes such as limonene, alpha-pinene, and beta-pinene; terpenoids such as linalool and alpha-terpineol; ethanol, formaldehyde, benzene, toluene, and xylene) and semi-volatile organic compounds (such as phthalates) [25,29,40,46].

Air freshener emissions can also react with indoor oxidants, such as ozone (O₃), hydroxyl radicals (OH), and nitrate radicals (NO₃), to generate a range of oxidation products [29,35]. For instance, primary emissions such as terpenes can readily react with ozone to generate secondary pollutants such as formaldehyde and acetaldehyde, glycol ethers, free radicals (such as hydroperoxy and alkyl peroxy radicals), and ultrafine particles. Factors that influence emissions of secondary pollutants include ingredient composition, ingredient concentrations, reactive chemistry, and product usage [29].

Emissions from air freshener products have been studied around the world (e.g., [5,23,35,40,43,45,46]). Of the studies that examined multiple types of air fresheners (e.g., sprays, gels, solids, disks, oils, cartridges, diffusers, evaporators; both active and passive), results indicate that all types of air fresheners have the potential to emit high concentrations of volatile organic compounds. The composition of the fragrance mixture is likely more influential on emissions than the type of delivery mechanism [40,46].

Given the enumerable different air freshener types, brands, and ingredient compositions, as well as protections on ingredient disclosure, a complete taxonomy of emissions from air fresheners would be interesting although practically infeasible. Nonetheless, results from selected studies are provided to characterize typical product emissions and rates.

In chamber studies of air fresheners in Germany [46], found the highest emissions rates after 1 h ($\mu\text{g}/\text{unit h}$) of the following compounds: ethanol, 35,532; dipropylene glycol mono methyl ether acetate, 12,337; limonene, 9132; 2-propanol 5690; 3-methoxy-3-methyl-1-butanol, 4763; benzyl acetate, 3920; dihydromyrcenol, 3155; iso-alkanes, 3110; linalool, 2994; linalyl acetate, 2711; gamma-terpinene, 2688; dipropylene glycol isomers, 2529; myrcene 1679; and beta-pinene, 1391. Of these, limonene and linalool are listed as potential allergens under [16].

In this same study [46], the most common VOCs emitted (in at least half of the products) were the following: limonene, linalool, myrcene, beta-pinene, alpha-pinene, linalyl acetate, dihydromyrcenol, geranyl acetate, and 4-methoxy-benzaldehyde. Thus, the compounds with the highest emissions rates (over 1000 $\mu\text{g}/\text{unit h}$) and most common in the products were limonene, linalool, myrcene, beta-pinene, linalyl acetate, and dihydromyrcenol.

In a study of VOC emissions from air fresheners in the US, including sprays, gels, solids, disks, and oils [40], the most common VOCs (in at least half of the products) were the following: limonene; acetone; 2,4-dimethyl-3-cyclohexene-1-carboxaldehyde (Triplal 1); alpha-pinene; beta-pinene; 1-butanol, 3-methyl-, acetate; 2,4-dimethyl-3-cyclohexene-1-carboxaldehyde (Triplal

extra); beta-phellandrene; carene isomer; ethyl butanoate; o, m, or p-cymene; ethanol. Of all VOCs emitted, approximately one-fourth are classified as potentially toxic or hazardous under one or more federal laws in the US, and all air fresheners tested emitted one or more of these compounds.

In a study of air fresheners in Korea [23], found the most common VOCs (in at least half the products) were toluene, bis(trimethylsilyl) acetylene, benzene, hexamethylcyclotrisiloxane, pentadecane, ethanol, ethyl benzene, limonene, and m,p-xylene. The highest emission rate was limonene (1560 $\mu\text{g}/\text{h}$).

In a study of SVOC emissions from air fresheners in the US, including "all-natural" and "unscented" varieties, 12 of the 14 products tested emitted phthalates. Of these, 10 products emitted at least 1 ppm and up to 7307 ppm of phthalates [31].

1.4. How do air freshener emissions affect the indoor environment?

Air fresheners can contribute to indoor hazardous air pollutants, both through direct emissions and secondary reaction products (e.g., [4,20,22,25,27,28,32,46]). Within buildings and other indoor environments, the use of air fresheners has a strong association with high indoor levels of terpenes, benzene, toluene, ethylbenzene, m,p-xylene, and total volatile organic compounds (e.g., [23,27,30,33,44,45]).

In a notable study of the effects of different air fresheners on indoor air quality [46], found that air freshener use resulted in high concentrations (mg/m^3 levels) of solvents and fragrance compounds (e.g., limonene, 12 mg/m^3 after 0.5 h) in the room chamber environment (3 m^3). Emission rates exceeded 2 $\text{mg}/\text{unit hr}$ for six common solvents (e.g., 35.5 $\text{mg}/\text{unit hour}$ for ethanol) and for six common fragrance compounds (e.g., 9.1 $\text{mg}/\text{unit hour}$ for limonene). Thus, in addition to high concentrations of scent substances, air fresheners can emit even higher concentrations of odorless solvents, which may be difficult for people to detect [46].

In the extensive EPHECT project (Emissions, Exposure Patterns and Health Effects of Consumer Products) in the European Union [45], examined air freshener emissions of limonene, alpha-pinene, acrolein, and formaldehyde, and modeled resulting indoor air concentrations. For example, an electric air freshener generated indoor air concentrations of formaldehyde of up to 40 $\mu\text{g}/\text{m}^3$ (30-min rolling average, 24 m^3 , 0.1/hour ventilation rate), which represents 40% of the World Health Organisation recommended limit of exposure of 100 $\mu\text{g}/\text{m}^3$ [49].

In a chamber study, a plug-in air freshener emitted d-limonene, dihydromyrcenol, linalool, linalyl acetate, and b-citronellol at 34–180 mg/day over 3 days while air concentrations averaged 30–160 $\mu\text{g}/\text{m}^3$ [35]. In another chamber study with a plug-in air freshener, formaldehyde concentrations reached 28.2 $\mu\text{g}/\text{m}^3$, with total aldehydes approximately 50 $\mu\text{g}/\text{m}^3$ [51].

Emissions by air fresheners used indoors can also migrate outdoors, affect outdoor air quality, and contribute to photochemical smog. For instance, in California in 1997, air fresheners emitted an estimated 7.5 tonnes/day of VOCs, translating to 230 mg/day per person VOC emissions [29].

1.5. How do air freshener emissions affect human health?

Air fresheners can contribute to human exposure to primary and secondary air pollutants [29,45]. Air freshener exposures, even at low levels, have been associated with a range of adverse health effects, which include migraine headaches, asthma attacks, breathing difficulties, respiratory difficulties, mucosal symptoms, dermatitis, infant diarrhea and earache, neurological problems, and ventricular fibrillation (e.g., [6,18,25,27,30,34,38,39,45,50]).

Recent population studies have investigated the prevalence and

types of health effects associated with air fresheners. In a survey of the US population [39], in a nationally representative sample ($n = 1,136$, $CL = 95\%$, $CI = 3\%$), 20.4% of the population report health problems when exposed to air fresheners and deodorizers. Specific health effects include the following: 9.5% report respiratory problems, 7.6% mucosal symptoms, 7.2% migraine headaches, 5.7% skin problems, 4.7% asthma attacks, 3.2% neurological problems, 2.7% cognitive problems, 2.7% gastrointestinal problems, 2.6% cardiovascular problems, 2.4% musculoskeletal problems, 1.8% immune system problems, and 0.7% other health problems.

Similarly, in a survey of the Australian population [38], in a nationally representative sample ($n = 1,098$, $CL = 95\%$, $CI = 3\%$), 16.4% of the population experience health problems when exposed to air fresheners and deodorizers. Specific health effects include the following: 9.1%, respiratory problems, 6.2% mucosal symptoms, 4.2% migraine headaches, 4.8% skin problems, 4.5% asthma attacks, 2.2% neurological problems, 1.9% cognitive problems, 1.5% gastrointestinal problems, 1.9% cardiovascular problems, 1.6% musculoskeletal problems, 1.8% immune system problems, and 0.5% other.

Previous studies of the US population [6] found that 17.5% and 20.5% of the general US population (in 2002–2003 and 2005–2006, respectively), and 29.7% and 37.2% of asthmatics (respectively) reported headaches, breathing difficulties, or other health problems when exposed to air fresheners or deodorizers.

In addition to population based studies, specific air freshener chemicals (VOCs such as acetaldehyde, SVOCs such as phthalates, and ultrafine particles) emitted from air fresheners have been associated with adverse effects to the neurological, cardiovascular, respiratory, reproductive, immune, and endocrine systems, and with cancer [12,25,30,45,49]. For instance, acetaldehyde, which can be both a primary and secondary emission from air fresheners, is associated with both acute and chronic hazards to the respiratory system, and classified as a carcinogenic hazardous air pollutant in the US [12].

While epidemiological and toxicity studies reveal links between air freshener emissions and health effects, more research is needed to understand how and why individual ingredients, mixtures of ingredients, or secondary reaction products could be associated with the identified health effects. In addition, more research is needed to understand the implications of low-level exposures, particularly for vulnerable and sensitive populations [3].

1.6. Do air fresheners disclose their ingredients?

Air fresheners are not required to disclose all ingredients [41], and typically do not. For example, in a comparison of declared and undeclared substances for six air freshener products [46], found high percentages of the number of undeclared substances (greater than 90%) and high percentages of the concentrations of undeclared substances (greater than 75%), relative to the total number and total concentration of declared and undeclared substances.

In an analysis of phthalate emissions from air fresheners, including those marketed as “all-natural” or “unscented,” none of the products listed phthalates on their labels. Primary phthalates detected but undisclosed were di-butyl phthalate, di-ethyl phthalate, di-isobutyl phthalate, and di-methyl phthalate [31].

An analysis of VOCs from common air fresheners, including ones called green and organic, found fewer than 10% of volatile ingredients disclosed on the product label, material safety data sheet, or elsewhere to the public [40]. Ingredients listed were typically general or neutral sounding ones, such as “fragrance,” “essential oils,” “water,” “organic perfume,” or “quality control ingredients.” All air fresheners tested (e.g., sprays, gels, solids, disks, oils) emitted chemicals classified as toxic or hazardous under US federal laws. However, fewer than 1% of these potentially hazardous chemicals

were listed on any product label or material safety data sheet.

The non-disclosure of air freshener chemicals is legal. According to a review of relevant federal legislation, no law in the US, the European Union, Australia, or any other country (to best knowledge) requires the disclosure of all ingredients in air fresheners [1,7,11,16,26,41]. Further, no law in any country (again, to best knowledge) requires the disclosure of all ingredients in a product’s “fragrance,” which is typically a mixture of several dozen to several hundred chemicals [41].

Striking differences exist between chemicals listed and chemicals emitted. For instance, an air freshener marketed as “organic” [41] listed the following ingredient information on the label: “fragrance, essential oils.” The product listed no ingredient information on the material safety data sheet. The air freshener emitted the following VOCs (above $300 \mu\text{g}/\text{m}^3$): d-limonene; 4-tert-butylcyclohexyl acetate; acetaldehyde; benzyl acetate; 2,7-dimethyl-2,7-octanediol; acetone; ethanol; carene isomer; citronellyl acetate; hexanal; 2,4-dimethyl-3-cyclohexene-1-carboxaldehyde (Triplal 1); allyl heptanoate; methyl-4-(1-methylethyl)-cyclohexane; ethyl butanoate; 3-hexen-1-ol; o, m, or p-cymene; alpha-pinene. Of these compounds, four (acetaldehyde, acetone, ethanol, alpha-pinene) are classified as toxic or hazardous under federal laws; further, acetaldehyde is classified as a carcinogenic hazardous air pollutant, with no safe threshold of exposure, according to the US Environmental Protection Agency [13–15].

Some air freshener companies have begun to voluntarily disclose ingredients, either in general (such as a consolidated list on a website) or in specific products. However, consumers may lack verification of the accuracy of the disclosed ingredients. For example, an air freshener product from one of these companies was analyzed using gas chromatography/mass spectrometry. The emitted ingredients were compared to listed ingredients, which were claimed to be fully disclosed. Of the emitted ingredients, only one of the fourteen VOCs detected was disclosed. Among the undisclosed chemicals was acetaldehyde (3300 ppbv), a hazardous air pollutant [36].

1.7. Do emissions from “green” air fresheners differ from regular air fresheners?

Claims of “green,” and related terms (such as organic and all-natural), have been sweeping society on consumer product labels. However, the term green lacks a regulatory or chemical definition when concerning air fresheners, and claims of green for consumer products often lack substantiation [47].

In tests comparing emissions among a range of air fresheners—including those with claims of being “green,” “organic,” “non-toxic,” “all-natural,” or with “essential oils”—all air fresheners, regardless of claims, emitted potentially hazardous compounds. Emissions of carcinogenic hazardous air pollutants from “green” air fresheners were not significantly different, in types or concentrations, from the regular brands [40].

The general public lacks awareness and assurance on the meaning of green. A survey of the US population found that 72.6% were not aware that fragranced products, even ones called green and organic, can emit hazardous air pollutants, and 60.1% would not continue to use a fragranced product if they knew it emitted such pollutants [39]. A similar survey of the Australian population found that 73.7% were not aware that fragranced products, even ones called green and organic, can emit hazardous air pollutants, and 56.3% would not continue to use a product if they knew it did [38].

Claims of green, organic, or all-natural concerning air fresheners are essentially unregulated and unmonitored. Even if fragrance aromatics are considered in some way as natural, air fresheners

could nonetheless contain a range of other ingredients in their product base, such as petrochemical solvents, which may not be considered as natural. Further, seemingly natural aromatics such as essential oils can nonetheless emit and generate hazardous pollutants such as formaldehyde and nano-sized secondary organic aerosols, with potentially substantial health risks [21].

1.8. What about involuntary exposure to air fresheners within indoor environments?

People are exposed to air fresheners both through voluntary use (such as in private homes) and involuntarily (such as in public places). The latter is a particular concern because individuals may experience adverse effects without their awareness or agreement.

In addition to health risks, involuntary exposure to air fresheners can also prevent access for individuals in society and in the workplace. For example, the presence of an air freshener in a restroom can restrict an individual with asthma from accessing the restroom, if that individual experiences asthma attacks when exposed to air fresheners. Also, businesses that use air fresheners may lose customers, as recent studies indicate.

Of the general population surveyed in the US, 17.5% are unable or reluctant to use the restrooms in a public place, because of the presence of an air freshener, deodorizer, or scented product. Also, 20.2% of the population reported that if they enter a business, and smell air fresheners or some fragranced product, they want to leave as quickly as possible [39].

In a similar survey in Australia, 11.6% are unable or reluctant to use the toilets in a public place, because of the presence of an air freshener, deodorizer, or scented product. Also, 16.7% of the population reported that if they enter a business, and smell air fresheners or some fragranced product, they want to leave as quickly as possible [38].

Some businesses have been implementing scented air systems, which disperse fragranced air throughout indoor environments. However, based on survey results, customers may prefer fragrance-free rather than fragranced air.

Among the US population surveyed, if given a choice between flying on an airplane that pumped scented air throughout the passenger cabin, or did not pump scented air throughout the passenger cabin, 59.2% would choose an airplane without scented air (compared to 23.6% with scented air). Thus, over 2.5 times more passengers would prefer an airplane without scented air than with scented air. Similarly, if given a choice between staying in a hotel with fragranced air, or without fragranced air, 55.5% would choose a hotel without fragranced air (compared to 27.8% with fragranced air). Thus, about 2 times more hotel guests would choose a hotel without fragranced air than with fragranced air [39].

Among the Australian population surveyed, 57.7% would prefer flying on an airplane without scented air pumped through the passenger cabin (compared with 16.3% with scented air), and 55.6% would prefer staying in a hotel without fragranced air (compared with 22.7% with fragranced air) [38].

While legislation exists to protect people from secondhand smoke, the law is evolving to protect people from “secondhand scents,” or involuntary exposure to fragranced products. For instance, under the US Americans with Disabilities Act (ADA) [2], an individual who experiences disabling effects from exposure to air fresheners can request a reasonable accommodation for the air freshener to be removed or disconnected. Similar legislation and protection exists in other countries, such as in Australia under the Disability Discrimination Act (DDA) [8]. In the aforementioned surveys of the US and Australian populations, half of the health effects reported could be considered as potentially disabling under the language of the ADA and DDA.

1.9. What are possible solutions or alternatives?

A goal of air fresheners is to provide a more pleasant indoor environment: to impart a fragranced mixture into the air, or to mask an existing air quality problem. That a majority of the population, in many countries, use air fresheners is an indication of their popularity and their desired effects. However, the use of air fresheners can come with unintended effects and risks for the indoor environment and human health.

As solutions, source reduction or elimination is a relatively straightforward approach to lower indoor pollutant levels and exposure risks associated with air freshener compounds. If an indoor environment has undesired odors, then removing the source, remedying the cause, or increasing ventilation (such as opening a window or using an exhaust fan) may help to eliminate the source of the odors, but without using an air freshener to mask the odor. However, continuing to use air fresheners but increasing mechanical ventilation to reduce pollutant levels may not be optimal, as the air freshener emissions can be dispersed to other parts of the building or outdoors, along with potential higher energy use and costs [10,42].

The use of an air freshener can create or exacerbate an indoor air quality problem by adding a chemical mixture to the air. A fragrance in a product is not intended to clean the air or reduce air pollutants. Although some air fresheners make claims of being able to remove odors, disinfect the air, or reduce allergens, these claims may not be possible to verify. When manufacturers of these products were contacted, none were able to provide any data, studies, or other information to substantiate their air freshener claims. A response from the companies was that the information requested was either confidential or proprietary [37].

Fragrance-free policies have been implemented in workplaces, schools, hospitals, and other indoor environments, around the world, to restrict the use of fragranced products such as air fresheners. An example is the [48]; which states that “Scented or fragranced products are prohibited at all times in all interior space owned, rented, or leased by CDC. This includes the use of: Incense, candles, or reed diffusers; Fragrance-emitting devices of any kind; Wall-mounted devices, similar to fragrance-emitting devices, that operate automatically or by pushing a button to dispense deodorizers or disinfectants; Potpourri; Plug-in or spray air fresheners; Urinal or toilet blocks; Other fragranced deodorizer/reodorizer products.”

Fragrance-free policies receive strong support [39]. Of the US population surveyed, 53.2% would support a fragrance-free policy in the workplace (compared to 19.7% that would not). Thus, 2.7 times more people would vote yes for a fragrance-free workplace than no. Also, 54.8% would prefer that health care facilities and health care professionals be fragrance-free (compared to 22.4% that would not). Thus, nearly 2.5 times more people would vote yes for fragrance-free health care facilities and professionals than no. In the Australian population [38], 42.8% would support a fragrance-free policy in the workplace (compared with 22.2% that would not), and 43.2% would prefer that health care facilities and health care professionals be fragrance-free (compared with 25.2% that would not).

As a consideration, after air fresheners are disconnected or removed from a location, the air pollutants may not immediately go away. Air freshener compounds can be adsorbed on walls, furnishings, and surfaces, and be reemitted into the indoor air environment. Research is needed to understand the factors that influence the attenuation of air freshener chemicals from an indoor environment, after the air freshener is no longer in use. This has relevance for the implementation of fragrance-free policies, as the indoor air environment may still contain fragrance compounds

even after the fragrance products are removed or discontinued.

A question with air freshener use is whether the perceived benefits are outweighed by the potential costs to personal and public health, and profits. As studies indicate, customers prefer fragrance-free to fragranced environments, so the use of air fresheners and scented air systems may deter rather than attract some customers. Also, the use of an air freshener can pose potential liability, if it triggers adverse or potentially disabling health effects in individuals. Finally, from a societal perspective, “secondhand scents,” or indirect exposure to air fresheners, raises concerns parallel to secondhand tobacco smoke.

1.10. What are research directions needed for science, health, and policy?

The topic of air fresheners within indoor environments is a rich area for research. Specific questions include the following:

- (1) What are the drivers behind the increased use of air fresheners?
- (2) What is the public awareness of air freshener emissions? Do people believe that so-called green and organic air fresheners have different types of emissions?
- (3) How would labeling of air freshener ingredients influence people's use of products?
- (4) If an air freshener does not contain a pollutant (such as formaldehyde), but it generates it during typical use (through terpene-ozone interactions), should the label indicate the potential to generate secondary pollutants?
- (5) Do reported health problems result from primary emissions, secondary pollutants, individual ingredients, mixtures of ingredients, or some or all of the aforementioned?
- (6) What is the relative effectiveness of different strategies (e.g., fragrance-free policies, increased ventilation) for reducing indoor pollutants, including those associated with air fresheners?
- (7) What are the differences in aroma compounds (e.g., limonene) emitted from air fresheners versus truly natural sources such as oranges?
- (8) Should the terms “green,” “organic,” or “natural” for air fresheners have chemical and regulatory definitions?
- (9) How can individuals be protected from involuntary exposure to air fresheners?
- (10) How can we improve indoor air quality and control odors within the indoor built environment, but without the potential risks to air quality and health?

In conclusion, air fresheners are used throughout society, often with the intent to create a favorable indoor air environment. However, air fresheners may come with unintended and perhaps invisible risks. This article looked at the science, health, and policy dimensions of air fresheners, and offered research findings and directions on ways to improve the air quality indoors and reduce potential exposures to pollutants.

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