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Chemicals of concern of household products

RESEARCH PAPER – LITERATURE REVIEW

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ABSTRACT

Exposure to volatile organic compounds (VOCs) from household products has raised increasing concerns regarding the potential health effects. In European residences, more than 65 VOCs have been identified, many of which are linked to respiratory, neurological and carcinogenic outcomes. In China, almost everyone in major cities face a lifetime cancer risk above acceptable threshold of 10^{-4} due to VOCs. This literature review examined the relationship between long-term VOC exposure and adverse health outcomes, especially depression and cancer risk. The study synthesizes data from peer-reviewed research, highlighting key VOCs such as formaldehyde, benzene, toluene, acetone, and limonene, which are commonly found in indoor environments. Inhalation was identified as the primary exposure route, with dermal absorption also contributing to systemic absorption.

Research papers were collected using systematic searches in PubMed and Elsevier, focused towards studies published between 2020-2025. Only peer-reviewed studies with household exposure and health effects were included, while occupational studies were excluded.

The aim of thesis was to assess the risk of depression and cancer risk related to exposure to specific VOCs present in household chemicals.

Findings indicated a significant correlation between VOC exposure and increased risk of depression, particularly through compounds like acrylonitrile and butadiene, with gender-specific differences in susceptibility. Furthermore, formaldehyde exposure was consistently associated with a higher risk of leukemia, as seen by epidemiological data from various regions. Global comparisons revealed disparities in VOC regulations, with exposure levels being substantially higher in China compared to the United States and Europe.

The study emphasized the need for stricter regulatory policies, public awareness initiatives, and technological advancements to reduce VOC exposure. Recommendations include improved ventilation, usage of low-VOC products, and targeted interventions to reduce exposure in vulnerable populations. By addressing these concerns through a multidisciplinary approach, the long-term health risks of VOCs can be significantly reduced.

Conclusion: The work hypothesis was partly proven, with evidence supporting associations between VOCs, depression and cancer risk. However, further longitudinal studies are necessary.

Keywords: Volatile organic compounds, household exposure, cancer risk, depression, public health, formaldehyde, environmental regulations

Kopsavilkums

Gaistošo organisko savienojumu (GOS) iedarbība no mājsaimniecības produktiem rada aizvien lielākas bažas par iespējamo ietekmi uz veselību. Eiropas mājokļos ir identificēti vairāk nekā 65 GOS, no kuriem daudzi ir saistīti ar ietekmi uz elpošanas un nervu sistēmu un kancerogēnitāti. Ķīnā gandrīz ikvienam lielo pilsētu iedzīvotājam mūža garumā ir palielināts vēža risks, kas pārsniedz pieņemamo slieksni 10^{-4}. GOS ekspozīcijas dēļ. Šajā literatūras apskatā tika pētīta saistība starp ilgstošu GOS iedarbību un nelabvēlīgu ietekmi uz veselību, īpaši depresijas un vēža risku. Pētījumā ir apkopoti dati no recenzētiem pētījumiem, izceļot galvenos GOS, piemēram, formaldehīdu, benzolu, toluolu, acetonu un limonēnu, kas bieži sastopami iekštelpās. Ieelpošana tika identificēta kā galvenais iedarbības ceļš, un dermālā absorbcija arī veicina sistēmisko absorbciju.

Pētījumu raksti tika apkopoti, izmantojot sistemātisku meklēšanu PubMed un Elsevier datubāzēs, koncentrējoties uz pētījumiem, kas publicēti laikā no 2020. līdz 2025. gadam. Tika iekļauti tikai recenzēti pētījumi par iedarbību mājsaimniecībās un ietekmi uz veselību, savukārt arodekspozīcijas pētījumi tika izslēgti. Pētnieciskā darba mērķis bija novērtēt depresijas un vēža risku, kas saistīts ar pakļaušanu specifiskiem gaistošajiem organiskajiem savienojumiem (GOS), kas atrodas sadzīves ķīmijas produktos.

Pētījumi liecināja par būtisku korelāciju starp GOS iedarbību un paaugstinātu depresijas risku, īpaši tādu savienojumu kā akrilnitrila un butadiēna gadījumā, ar dzimumam raksturīgām atšķirībām uzņēmībā. Turklāt formaldehīda iedarbība bija konsekventi saistīta ar lielāku leikēmijas risku, ko apliecina epidemioloģiskie dati no dažādiem reģioniem. Globālie salīdzinājumi atklāja atšķirības GOS noteikumos, un iedarbības līmenis Ķīnā ir ievērojami augstāks salīdzinājumā ar Amerikas Savienotajām Valstīm un Eiropu.

Pētījumā tika uzsvērta nepieciešamība pēc stingrākas regulējošās politikas, sabiedrības informēšanas iniciatīvām un tehnoloģiskiem sasniegumiem, lai samazinātu GOS iedarbību. Ieteikumi ietver uzlabotu ventilāciju, produktu ar zemu GOS saturu lietošanu un mērķtiecīgas intervences, lai samazinātu iedarbību neaizsargātās iedzīvotāju grupās. Risinot šīs problēmas, izmantojot daudznozaru pieeju, GOS ilgtermiņa veselības riskus var ievērojami samazināt.

Secinājumi: Darba hipotēze tika daļēji pierādīta, un pierādījumi apstiprina saistību starp gaistošajiem organiskajiem savienojumiem (GOS), depresiju un vēža risku. Tomēr ir nepieciešami turpmāki longitudinālie pētījumi.

Atslēgvārdi: gaistošie organiskie savienojumi, ekspozīcija mājsaimniecībās, vēža risks, depresija, sabiedrības veselība, formaldehīds, vides noteikumi

TABLE OF CONTENTS

INTRODUCTION

Exposure to household chemicals is an increasing concern to the public health, due to potential long-term effects. VOCs are a group of chemicals which are commonly found in many everyday products, such as personal care items, air fresheners, cleaning agents, furnishings and many others. Our lifestyle leads to greater time spent indoors compared to our ancestors, and this increases the exposure period to these compounds. Major concerning effects from VOCs, include the contribution to the depression (Ma, et al., 2024) and cancer development (Halios et al., 2022) which have become critical areas for investigation, due to recent studies showing correlation between these.

Despite increased awareness, most research today does not focus on any particular cancer types, as there is limited research available. Most of these studies are related to occupational chemicals (Lamplugh et al., 2018), leaving a gap in understanding between occupational and typical household chemicals. Given the extensive use of these products and their potential health risks associated with them, it is essential to evaluate their impact on human health and emphasize the need for healthier alternatives and interventions. Raising awareness within the population will also authorize individuals to make informed decision about potential hazardous chemicals in everyday household products.

Aim

The aim of this research paper was to assess the potential health effects related to exposure to specific VOCs present in household chemicals, focusing on both mental and physical complications such as depression and cancer risk.

Main objectives

- To identify the most common chemicals of concern present in household products used in daily routine.
- To examine potential exposure routes and levels needed for household chemicals to have statistically significant effect on mental health and increased cancer risk.
- To evaluate potential risks associated with chemicals of concern in household products and compare these between different continents, focusing on depression and cancer risk.
- To explore potential interventions needed to limit the exposure to VOC in household products.

Hypotheses of the Research Paper:

1. Long term exposure to volatile organic compounds (VOCs) in household products increases the risk of depression.
2. Household exposure to VOCs containing formalaldehyde contributes to higher risk of leukemia.

Materials and methods

Methods conducted for this literature review included the search of peer-reviewed scientific studies. The primary database included PubMed and Elsevier with attention to recently published studies from last 5 years (2020-2025). Example of key words used included: “Volatile organic compounds”, and “Cancer”, “Cancer risk”, “Health effects”, “Exposure”. Only studies that contained common products seen in households were included, disregarding potential occupational exposure. The strategy for search included the division into sections to reflect separately on topics. Firstly, to identify VOC and exposure routes, then their potential effects, lastly focusing on comparison between countries and interventions on population and individual levels. Data for comparison used from given: European Chemicals Agency (ECHA), United States Environmental Protection Agency (EPA) and for China included household samples inside of 23 residences. Open AI was just to formulate the abbreviations, correct certain sentences to make them more formal and structure the sources.

ABBREVIATIONS

AAMA – Acrylamide metabolite, N-acetyl-S-(2-carbamoylethyl)-L-cysteine

ACET – Acetone

AMCC – N-acetyl-S-(N-methylcarbamoyl)-L-cysteine (metabolite of N,N-dimethylformamide)

ATCA - Cyanide

BD – 1,3-Butadiene

BMA - Toluene

BPMA – N-acetyl-S-(n-propyl)-L-cysteine (metabolite of 1-bromopropane)

CEMA – Acrolein, N-acetyl-S-(2-cyanoethyl)-L-cysteine (metabolite of acrylonitrile)

CYMA – Acrylonitrile metabolite, N-acetyl-S-(2-cyanomethyl)-L-cysteine

DHBMA – N-acetyl-S-(3,4-dihydroxybutyl)-L-cysteine (metabolite of 1,3-butadiene)

HPMMA – N-acetyl-S-(3-hydroxypropyl)-L-cysteine (metabolite of crotonaldehyde)

2-HPMA – N-acetyl-S-(2-hydroxypropyl)-L-cysteine (metabolite of propylene oxide)

3-HPMA – N-acetyl-S-(3-hydroxypropyl)-L-cysteine (metabolite of acrolein)

MA – Mandelic acid (metabolite of styrene)

MHBMA1/2/3 – N-acetyl-S-(4-hydroxy-2-buten-1-yl)-L-cysteine (isomeric metabolites of 1,3-butadiene)

2-MHA – 2-Methylhippuric acid (metabolite of o-xylene)

34-MHA – 3- and 4-Methylhippuric acids (metabolites of m- and p-xylene)

PGA – Phenylglyoxylic acid (metabolite of ethylbenzene and styrene)

XL – Xylene (m-, o-, and p-isomers)

Literature review

1. VOLATILE ORGANIC COMPOUNDS

Volatile organic compounds (VOCs) are chemicals which have been associated with negative health effects. Different definitions have been suggested. The World Health Organization (WHO) specify that VOCs are chemicals with a boiling point of $<250^{o}$C at standard pressure (1atm, 101.3 kPa) (Montero, López, Arellano, 2018). According to the European Union Council Directive it is “any organic compound having at 293,15K a vapour pressure of 0,01kPa or more, or having a corresponding volatility under the particular conditions of use” (OJ C, 1998). In China, it is mentioned that they have boiling point between 50-260^{o}C at normal temperature and pressure, and that they could originate from burning of all types of fuels, coating for furniture and machines and cooking oil fume (Zhang, et al., 2017). Lastly, the United States Environmental Protection Agency (EPA) states that VOCs are compounds where the composition makes it possible to evaporate under normal indoor atmospheric temperature and pressure (EPA, 2009).

The more general way to understand VOCs, is any organic chemical which have the ability to evaporate into the air when there is normal atmospheric temperature and pressure. Mostly they will be released into the air when we are utilizing the products responsible for them. Consequently, the breathing of polluted air could be harmful to our health.

These toxic carbon compounds could be found in multiple different environments that humans are surrounded by. Classical subdivisions include indoor/household, occupational and outdoors in nature. In this research the main focus is towards household chemicals containing VOCs. Typical sources include paint, cleaners with soaps and laundry detergents, air fresheners, furniture polish, wood finishing products, nail polish remover with acetone, paint thinner, smoke from candles and cigarettes.

Other examples that might be associated with household air pollution include hobby supplies, pesticides, building materials and especially in newer buildings, craft materials with glues and adhesives, photographic solutions, office equipment such as copiers and printer, and certain carbonless copy papers. Human activities with cooking could also be potential source, due to the release of long-chain aldehydes and alkanes which occur when oil is being heated, while terpenes could be released when spices are being prepared (David, et al., 2023).

A meta-analysis by Holøs and co-researchers from 2019 also found strong correlation of emission rates increasing during summer. This is largely due to diffusion of VOCs through materials which increases with temperature, and hence higher levels of VOCs indoors during summer.

A subsequent problem with household chemicals, is the limited air space which leads to consistently higher levels of VOCs, which have been described as up to ten times higher than outdoors (You, et al. 2022). Combined with our modern-day lifestyle in which most of us spent around 85% of our days indoors, especially industrialized countries, the exposure levels could be harmfully high.

1.1 Specific compounds

There is a wide range of VOCs mentioned in literature, but for the findings included in this research paper, only a few of them have been studied in detail. From a recent larger review in Europe, the most commonly identified VOCs was aromatics (14), alkanes (9), aldehydes (8), terpenes (6), chlorinated (4), aliphatic hydrocarbons (5), glycol and glycol esters (3) and esters (2) (Halios et al., 2022). Among them was 9 chemicals which is the most profound in European residences (ethanol, formaldehyde, toluene, limonene, hexaldehyde, α-pinene, butane, acetone and acetaldehyde) as shown in Table 1. They are mentioned to have more than 10 µg m^{-3} from calculated Weighted Average Geometric Mean (WAGM). Results show that ethanol, formaldehyde and toluene have highest concentration. A limitation of the study is that further research on health effects does not include ethanol. Concentration values were collected by using passive samplers with duration from 24h to several weeks. If shorter sampling times <24h, studies used active sampling where a pump draw air through the sampler (Halios et al., 2022).

Table 1
The summary of 9 VOCs found in household products with the concentration (weighted average geometric mean) above 10 µg m^{-3} (Halios et al., 2022)

VOC	WAGM (µg m^{-3})
Ethanol	92.00
Formalaldehyde	**18.04**
Toluene	**15.90**
Limonene	**13.65**
Hexaldehyde	13.30
α-pinene	12.10
Butane	12.00
Acetone	11.40
Acetaldehyde	10.14

VOCs identified as prevalent in household include formaldehyde (18.04 µg m^{-3}), toluene (15.90 µg m^{-3}), limonene (13.65 µg m^{-3}). Of these, formaldehyde, benzene and 1,3-butadiene are the most concerning due to established toxological effect, which include carcinogenicity and systemic toxicity (Feng et al.,2022; Ji et al., 2024; Halios et al., 2022). The exposure routes were through inhalation of contaminated indoor air and dermal absorption from personal care products (EPA, 2023).

In the study conducted in United States (Feng et al., 2024), they quantified urinary VOCs in order to examine their risk of mortality. A total of 10 urinary VOC was included in the study, as seen in Table 2. The study highlighted acrolein, acrylonitrile, 1.3-butadiene, ethylbenzene/styrene and styrene as strongest contributors to all-cause and cause-specific mortality, which included cancer, cardiovascular and respiratory death. After adjusting for all confounders, every 2-fold increase in some urinary VOCs was associated with an increase in all-cause mortality risk: the highest for 1.3-butadiene (35.2%), a moderate increase for acrolein (14.3%), styrene (12.3%), acrylamide (11.7%), and the lowest for ethylbenzene (7.7%) and acrylonitrile (6.1%).

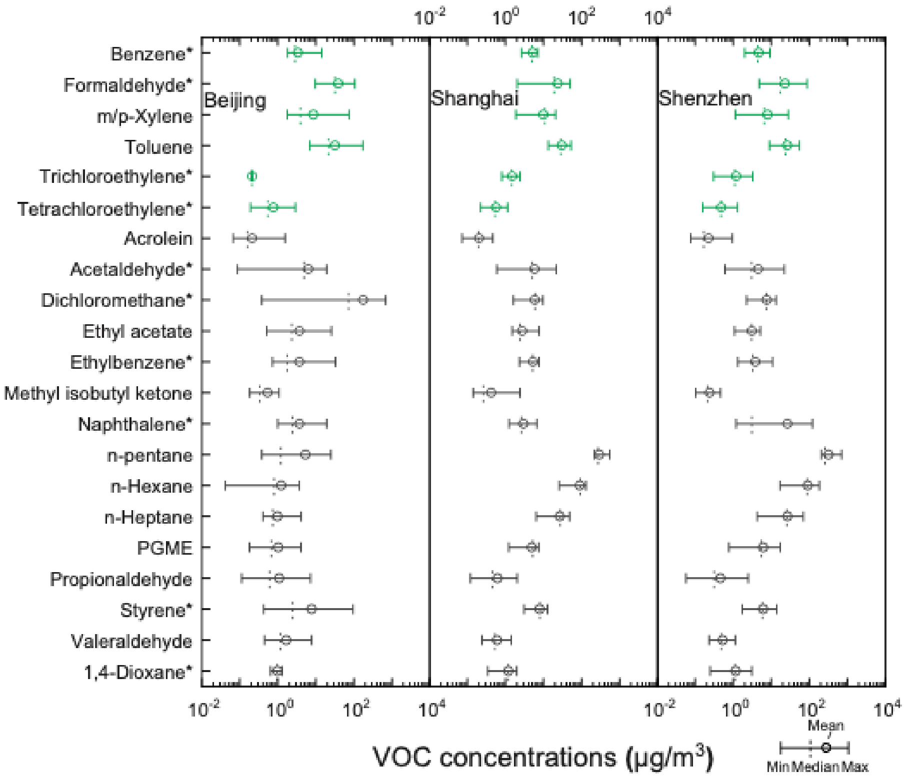
Table 2
Associations of urinary VOC metabolites with all-cause mortality and cancer mortality in US adults. (Feng et al., 2024)

Parent compound / urinary metabolites	Model	All-cause mortality	Cancer mortality
Acrolein	Model 1	**1.324 (1.246, 1.408)**	**1.407 (1.246, 1.588)**
CEMA	Model 2	**1.193 (1.119, 1.272)**	**1.266 (1.117, 1.435)**
	Model 3	**1.143 (1.070, 1.221)**	**1.160 (1.019, 1.319)**
Acrylamide	Model 1	0.982 (0.923, 1.046)	0.981 (0.866, 1.112)
AAMA	Model 2	1.158 (1.079, 1.243)	1.132 (0.984, 1.302)
	Model 3	1.117 (1.039, 1.200)	1.028 (0.892, 1.184)
Acrylonitrile	Model 1	**1.009** (0.984, **1.034)**	**1.057 (1.010, 1.107)**
CYMA	Model 2	**1.100 (1.073, 1.129)**	**1.138 (1.085, 1.194)**
	Model 3	**1.061 (1.032, 1.092)**	**1.081 (1.024, 1.141)**
1,3-Butadine	Model 1	**2.031 (1.831, 2.252)**	**2.169 (1.768, 2.660)**
DHBMA	Model 2	**1.464 (1.306, 1.640)**	**1.617 (1.289, 2.028)**
	Model 3	**1.352 (1.204, 1.517)**	**1.381 (1.095, 1.742)**
Crotonaldehyde	Model 1	1.160 (1.105, 1.217)	1.273 (1.161, 1.396)
HPMMA	Model 2	1.142 (1.083, 1.204)	1.260 (1.141, 1.392)
	Model 3	1.081 (1.023, 1.143)	1.154 (1.038, 1.283)
Cyanide	Model 1	0.922 (0.888, 0.957)	0.952 (0.882, 1.027)
ATCA	Model 2	0.943 (0.905, 0.984)	0.986 (0.905, 1.074)
	Model 3	0.942 (0.903, 0.984)	0.964 (0.882, 1.052)
Ethylbenzene/styrene	Model 1	**1.108 (1.052, 1.166)**	**1.202 (1.076, 1.342)**
PGA	Model 2	**1.127 (1.069, 1.188)**	**1.207 (1.081, 1.348)**
	Model 3	**1.077 (1.019, 1.140)**	**1.128 (1.004, 1.268)**
Propylene oxide	Model 1	1.019 (0.966, 1.074)	1.110 (1.004, 1.226)
2-HPMA	Model 2	1.045 (0.992, 1.101)	1.127 (1.022, 1.242)
	Model 3	1.031 (0.977, 1.088)	1.088 (0.983, 1.203)
Styrene	Model 1	**1.091 (1.015, 1.173)**	**1.286 (1.124, 1.471)**
MA	Model 2	**1.175 (1.095, 1.262)**	**1.345 (1.188, 1.523)**
	Model 3	**1.123 (1.046, 1.206)**	**1.251 (1.091, 1.436)**
Toluene	Model 1	1.044 (0.987, 1.105)	1.080 (0.966, 1.206)
BMA	Model 2	0.988 (0.934, 1.046)	1.026 (0.918, 1.147)
	Model 3	1.009 (0.953, 1.068)	1.032 (0.923, 1.154)

Model 1 were unadjusted for covariates, Model 2 adjusted for sex, age, and race/ethnicity (Mexican American, Non-Hispanic White, Non-Hispanic Black, Others), Model 3 was adjusted for BMI, educational level, married status, family-income poverty ratio, smoking, drinking status, physical activity, and cycles. (Feng, et al. 2024)

In the study of 3 big megacities in China (Beijing, Shanghai and Shenzhen), 21 VOCs were included, as presented in Figure 1 (Ji et al., 2024). Detailed concentrations are presented, with 6 aldehydes and ketones, 6 aromatics, 4 alkanes, and 5 other types of VOCs. Results showed that concentrations identified as highest in all cities was formalaldehyde and toluene, while acrolein was largest non-cancer risk. Formalaldehyde was also only VOCs mentioned to exceed the official limits set by the Republic of China "Indoor Air Quality Standards."

Figure 1



Concentration of target VOCs in association of cancer risk in 3 Chinese cities. Green line represents compounds with concentration limits by the Chinese indoor air quality standards. Asterisk indicate that VOC have cancer risk. PGME - propylene glycol methyl ether) (Ji et al., 2024).

Lastly, in the cross-sectional study examining exposure to VOC and the risk of depression, were included 16 urinary VOC metabolism (mVOC) as shown in Table 3 (Ma et al., 2024). Top 3 mVOC in total population was DHBMA (302.717ng/mg creatinine), 3HPMA (239.084ng/mg creatinine) and HPMMA (213.836ng/mg creatinine). The smallest was CYMA (1.684ng/mg creatinine). The concentration of urinary mVOC in AAMA, AMCC, CEMA, CYMA, DHBMA, 3HPMA, 2HPMA, HPMMA, MA, 2MHA, 34MHA, MHBMA3 and PGA was all higher in people with depression. The only concentration that was statistically higher in non-depressed people was BPMA.

Table 3
Urine mVOCs (ng/mg creatinine) concentration of participants grouped by depression. Total values represent mean concentration of each VOC across the 3 big megacities (Ji et al., 2024).

mVOCs	Total	Depression	Non-depression	*p*-value
AAMA	51.119 (31.852, 90.556)	**62.766** (37.984, 111.035)	50.000 (31.560, 86.902)	<0.001
AMCC	146.552 (79.110, 264.026)	**198.898** (107.810, 416.268)	143.574 (77.977, 254.836)	<0.001
ATCA	122.272 (60.799, 227.033)	106.577 (56.841, 240.071)	123.515 (61.041, 226.502)	0.718
BMA	6.448 (4.045, 11.459)	6.244 (4.088, 11.968)	6.465 (4.035, 11.433)	0.853
BPMA	3.894 (1.667, 9.853)	2.851 (1.392, 6.691)	**4.021** (1.677, 10.137)	<0.001
CEMA	97.583 (62.091, 159.767)	**133.176** (70.594, 221.771)	95.900 (61.507, 155.870)	<0.001
CYMA	1.684 (0.956, 9.049)	**4.360** (1.194, 106.653)	1.613 (0.941, 6.151)	<0.001
DHBMA	**302.717** (232.216, 400.000)	**340.741** (249.789, 452.282)	299.677 (230.359, 392.980)	<0.001
3HPMA	**239.084** (146.541, 461.778)	**313.962** (164.737, 838.095)	235.985 (145.567, 444.803)	<0.001
2HPMA	27.898 (17.718, 51.524)	**32.864** (20.124, 68.771)	27.647 (17.381, 49.912)	0.001
HPMMA	**213.836** (149.029, 433.385)	**312.174** (187.623, 856.169)	208.211 (146.932, 402.472)	<0.001
MA	132.513 (93.079, 195.729)	**165.039** (110.049, 244.874)	130.452 (91.837, 191.813)	<0.001
2MHA	32.675 (15.000, 74.772)	**40.374** (19.661, 107.540)	31.830 (14.750, 72.385)	<0.001
34MHA	197.203 (95.000, 527.426)	**336.973** (118.301, 719.921)	189.091 (94.059, 495.000)	<0.001
MHBMA3	4.728 (2.921, 9.778)	**7.576** (3.648, 25.841)	4.615 (2.894, 9.164)	<0.001
PGA	201.664 (143.341, 291.264)	**240.909** (159.566, 346.233)	200.000 (142.172, 285.283)	<0.001

1.2 Exposure routes

There are 4 major routes of exposure to VOC: ingestion and inhalation, direct skin contacts and through the eyes. Inhalation is by far the most common route by breathing in these gases. Formaldehyde found in furniture could be emitted from paints, varnishes and adhesives which then are breathed in (Halios et al. 2022). Direct skin contact could be elicited by personal care products, cosmetics and not wearing gloves while handling cleaning products. Most commonly toluene from nail polish and hair dyes, formaldehyde from cosmetics and disinfectants and limonene from fragrances and detergents (Nnorom et al., 2020). Swallowing of contaminated food or water is another way for people to be exposed. This is particularly of concern in case of water supplied by domestic wells where trichlorethylene, vinyl chloride and benzene have been found (Rowe et al., 2007). Lastly, the VOC vapor could irritate the eyes, such as ammonia-based cleaners and disinfectants, or acetone from personal care items such as nail polish. (EPA, 2023)

1.3 Sampling methods

There are different methods in order to obtain VOC concentration levels. In the European study they were analysed by gas chromatography with flame ionization, electron capture or mass spectrometry detection (Halios et al., 2022). From Table 1 the presented compounds are seen, which included calculated WAGM.

The researchers from United States and in the cross-sectional study with focus on depression, used data from National Health and Nutrition Examination Survey (NHANES) in order to allocate the participants. This information was based on interviews, physical examinations and laboratory tests. From NHANES, urinary VOC metabolites were quantified by ultra-performance liquid chromatography coupled with electrospray ionization tandem mass spectrometry (Alwis, et al., 2012). After detection of the 15 metabolites, the concentration was calibrated against urinary creatinine and presented as μg/g Cr, which indicate amount of metabolite (in mcg) relative to 1 gram of creatinine.

In China, concentrations were collected inside of 23 residences across the 3 big megacities from June to August 2021. A total of 105 samples were collected, 40 samples from 6 households in Beijing, 32 samples from 9 households in Shanghai and 33 samples from 8 households in Shenzhen. Afterwards they estimated the health risk from measured VOC concentrations through Monte Carlo simulations, a technique that incorporate variability and uncertainty by running thousands of iterations. This will give a distribution of probable exposure outcomes, rather than single estimate.

2. HEALTH EFFECTS

From previously mentioned on exposure routes, we know that the respiratory system, eyes and skin are the most commonly affected organs, but others commonly manifesting with symptoms are central nervous system, cardiovascular system, and they have been associated with increased risk of cancer. If a person is exposed to sudden very high concentration and/or there are individual factors such as increased sensitivity or previous illnesses, then the symptoms might be rapid onset. For others, the symptoms and effects could be after prolonged exposure time.

According to EPA, typical immediate symptoms after exposure to VOC include eye and respiratory tract irritation, headache, visual disorders, memory impairment and dizziness. Other commonly seen are nose and throat discomfort, allergic skin reaction, dyspnea, epistaxis, fatigue, emesis, nausea, and on laboratory investigation, also declines in cholinesterase levels. Damages to the liver and kidney have also been described (EPA, 2024).

2.1 Potentially sensitive populations

According to the National Research Council (NRC) Committee´s book from 2009 (US) assessing contaminated water supplies and potential health effects, there are certain groups which are at higher risk of adverse effects from VOCs due to metabolic and physiologic differences. There is concern about infants and children being more vulnerable to chemicals compared to adults, especially premature and full-term newborns. Not only have they longer lifetime exposure, but they also have smaller body size and weight, which give higher dose of inhaled or ingested VOC per kilogram. They also have higher respiratory rates, ongoing development of the nervous and immune system and immature detoxification system (Montero-Montoya et al., 2018; Halios et al., 2022). Similarly, will be for geriatrics due to age-related pharmacodynamic changes such as neuronal loss and reduced hepatic and renal clearance, which leads to lesser ability to metabolize and eliminate VOCs (NRC, 2009).

No particular effect has been described between men and women, if any, could be related with higher quantity of body fat in females, hence the internal exposure could be longer. In pregnancy, there is limited evidence. Research on rats showed that fetal exposure to single bolus injection, which was equalized to drinking contaminated water, would be more than 60% of the maternal exposure and this could suggest that fetuses are at subsequent risk (NRC, 2009).

The lifestyle has also been mentioned as a risk factor for predisposition which is correlated to increasing CYP2E1, an enzyme considered to increase metabolism of VOCs

(Raucy, et al., 1991). Examples that enhance CYP2E1 include high-fat diet, carbohydrate deficiency, fasting for 1-3 days, flavonoids in grapefruit juice, certain components in cruciferous vegetables, medications (barbiturates, alcohols, acetone, salicylates, phenytoin, isoniazid, diazepam, acetaminophen, chlorpromazine), cigarette smoke, and ethanol especially from repeated exposure. Physical activity is also negatively related because it can double the pulmonary uptake of VOC from increasing respiratory and alveolar ventilation rate, and cardiac output and pulmonary blood flow (Raucy et al., 1991).

Individuals with underlying chronic illnesses may also have different response to VOC exposure. Cirrhotic patients are seen to have lower CYP2E1 activity and lower cytochrome P-450 mediated activation of VOC which would be beneficial, but at the same time they have lesser capacity to conjugate metabolites which give opposite effect (Murray, 1992). In chronic kidney disease, there is reduced renal clearance which delay excretion and raise systemic burden (Chang et al., 2010). In type 2 diabetes, there is altered lipid and glucose metabolism which could exacerbate oxidative stress response (Wang et al., 2023). Similar with obesity, which have been associates with increased VOC-related cardiovascular risk, possible from increased storage of lipophilic compounds in adipose tissue and enhanced CYP2E1 activity (Lei et al., 2023).

2.2 Depression

According to WHO, a depression will involve depressed mood or loss of pleasure or interests in activities for long periods of time (WHO, 2023). It will differ from regular mood changes and can affect everyone. They estimate that 3.8% of the world's population experience depression, which correlates to 280 million people.

The cross-sectional study from the Unites States, depression was examined in relation to urinary metabolites of mVOC among 3240 individuals (Ma et al. 2024). For assessment of depression, Patient Health Questionnaire (PHQ-9) was used. Largest concentrations found in total found was of DHBMA (1,3-butadiene (BD)), 3HPMA (acrolein) and HPMMA (crotonaldehyde). In individuals with depression, they found higher levels of AAMA (Acrylamide), AMCC (*N, N*-dimethylformamide), CEMA and CYMA (acrylonitrile), DHBMA (BD), 3HPMA (Acrolein), 2HPMA (Propylene oxide), HPMMA (Crotonaldehyde), MA (Styrene), 2MHA and 34MHA (Xylene), MHBMA3 (BD) and PGA (ethylbenzene/styrene). On the other hand, BPMA (1-Bromopropane) was seen higher in non-depressed people which is commonly found in medicine, pesticides, spices and dyes (Suo et al., 2019).

Linear and logistic regression analysis confirmed significant positive association with exposure to acrylamide, N,N-dimethylformamide, acrylonitrile, MHBMA3 (BD), acrolein, crotonaldehyde, styrene, xylene, MHBMA1 (BD) and depression. According to Bayesian kernel machine regression (BKMR) model, only 1.3-butadiene (DHBMA, MHBMA3) and styrene had positive exposure-response relationship. At high concentration, all 16 mVOCs with mixed exposure had positive relationship. If only demonstrating single mVOC and depression score, then acrylonitrile was only with positive association (Ma et al. 2024).

Gender-stratified analyses revealed significant differences. In men, depression was positively associated with xylene, 1,3-butadiene (DHBMA, MHBMA3) and crotonaldehyde, while in females strongest associations were observed with acrylonitrile (CEMA, CYMA), styrene and MHBMA3. BKMR analysis was further performed, showing correlation between depression and males with DHBMA, and in females with acrylonitrile and styrene. Table 4 summarizes these findings, by highlighting acrylonitrile (CYMA) as the main predictor in women and 1.3-butadiene (MHBMA3) in men.

CYMA is the urinary metabolite from acrylonitrile, which could be used for production of acrylic and modacrylic fibers in clothes and textiles, material for plastics production, rubber gloves and tobacco (GOV UK, 2024). MHBMA3 is a urinary metabolite of 1,3-butadiene, a carcinogen mostly used to make plastic and rubber products, other uses include paints, coatings, vehicle tire, tobacco smoke, and burning wood from fire place (EPA, 2024). Butadiene is considered one of the main components of tobacco, which could explain the positive association with depression, as smoking have been suggested to affect the mesolimbic dopamine system (Watkins et al., 2000). It could also explain the reason of gender differences as high proportion of smokers are males (Jamal et al., 2015).

Table 4
Association of mVOC and depression. Total score of 10 or more was defined as developing depression. Adjusted for age, gender, race, education, BMI, alcohol status, cotinine, survey cycle and 6-month period (Ma et al., 2024).

mVOC	OR(95%CI)	P
2MHA		
Q1	Reference	
Q2	1.120(0.743, 1.693)	0.588
Q3	1.188(0.793, 1.789)	0.406
Q4	1.408(0.938, 2.129)	0.101
34MHA		
Q1	Reference	
Q2	0.874(0.572, 1.332)	0.53
Q3	1.213(0.820, 1.804)	0.337
Q4	1.626(1.101, 2.422)	0.015
AAMA		
Q1	Reference	
Q2	1.236(0.811, 1.894)	0.327
Q3	1.378(0.913, 2.097)	0.129
Q4	1.812(1.201, 2.762)	0.005
AMCC		
Q1	Reference	
Q2	1.130(0.748, 1.719)	0.563
Q3	1.042(0.684, 1.597)	0.848
Q4	1.582(1.041, 2.431)	0.034
ATCA		
Q1	Reference	
Q2	0.996(0.690, 1.437)	0.988
Q3	0.595(.391, 0.899)	0.014
Q4	0.682(0.453, 1.026)	0.066
BMA		
Q1	Reference	
Q2	1.154(0.806, 1.658)	0.435
Q3	0.799(0.540, 1.177)	0.257
Q4	1.027(0.708, 1.492)	0.887
BPMA		
Q1	Reference	
Q2	0.893(0.633, 1.258)	0.518
Q3	0.710(0.489, 1.023)	0.068
Q4	0.665(0.455, 0.964)	0.032
CEMA		
Q1	Reference	
Q2	0.797(0.526, 1.202)	0.28
Q3	0.981(0.665, 1.449)	0.922
Q4	1.408(0.969, 2.061)	0.075
CYMA		
Q1	Reference	
Q2	0.777(0.499, 1.203)	0.26
Q3	0.964(0.633, 1.468)	0.863
Q4	2.573(1.728, 3.879)	<0.001
DHBMA		
Q1	Reference	
Q2	1.232(0.801, 1.903)	0.344
Q3	1.507(0.992, 2.310)	0.056
Q4	1.969(1.298, 3.023)	0.002
2HPMA		
Q1	Reference	
Q2	1.491(1.009, 2.221)	0.047
Q3	1.106(0.734, 1.672)	0.63
Q4	1.580(1.067, 2.361)	0.024
3HPMA		
Q1	Reference	
Q2	1.079(0.712, 1.637)	0.719
Q3	1.184(0.790, 1.780)	0.414
Q4	1.680(1.130, 2.518)	0.011
MA		
Q1	Reference	
Q2	1.273(0.830, 1.965)	0.271
Q3	1.642(1.097, 2.485)	0.017
Q4	1.819(1.215, 2.761)	0.004
MHBMA3		
Q1	Reference	
Q2	1.145(0.775, 1.745)	0.528
Q3	1.047(0.683, 1.609)	0.833
Q4	2.080(1.396, 3.138)	<0.001
PGA		
Q1	Reference	
Q2	0.908(0.604, 1.362)	0.64
Q3	1.015(0.684, 1.512)	0.939
Q4	1.310(0.883, 1.953)	0.182
HPMMA		
Q1	Reference	
Q2	1.145(0.729, 1.806)	0.556
Q3	1.835(1.216, 2.807)	0.004
Q4	2.203(1.451, 3.395)	<0.001

Limitations of this study included the focus on general survey of all population, hence the exposure to VOCs would be relatively less and it could therefore be biased due to small concentrations. Also, it was not able to determine the sequence of mVOC exposure and depression, meaning that causal relationship was not proven and it will require further studies to demonstrate it.

2.3 Carcinogenicity

VOCs have for a long time been associated with carcinogenicity. A recent study published in the journal Nature, found that one third of the global population are at risk of cancer from VOCs (Xiong, Du, Huang, 2024). Researchers used a global chemistry-climate model to estimate risk from 2000 to 2019 and found that the global VOCs was raised with 10.2% in given period, mostly in Sub-Saharan Africa, Asia and China, and decreased in United States and Europe. The difference in exposures was tremendously high, with 82.8-84.3% in China, compared to 1.7-5.8% in Europe. Globally they estimated that between 36.4-39.7% of the global population was exposed to harmfully high levels and that cancer burden would affect 0.60 to 0.85 million individuals globally. This study however, focused on outdoor air pollution.

From European residences and the VOCs mentioned in Table 1, formalaldehyde, benzene and trichlorethylene are all classified as Group 1 human carcinogens by the International Agency for Research on Cancer (IARC). Other compounds such as styrene and tetrachlorethylene are listed as possible carcinogens (Group 2) (Halios et al., 2022; IARC, 2000).

Formaldehyde has been associated with nasopharyngeal cancer and leukemia. Benzene could affect blood and bone marrow causing acute myeloid leukemia (WHO, 2010). Tetrachlorethylene could cause liver tumor, kidney tumor and mono-nuclear cell leukemia. Trichlorethylene exposure has been associated with liver and kidney cancer, and non-Hodgkin lymphoma. Styrene gives increased risk of both leukemia and lymphoma. As for ethylbenzene, no human cancers were reported, but for mice, higher incidence of lung and liver adenomas are seen. (IARC IafroC, 2000).

As shown in Table 2 of VOC exposure on all cause and cancer specific mortality, 33.85% of cancer death was attributable to joint VOC exposure (Feng et al., 2024). In case of individual VOC, then 1,3-butadiene caused the highest all-cause mortality. Crotonaldehyde was the single VOC that ranked highest among cancer-specific mortality, followed by *N,N*-dimethylformamide. This confirms the high burden of multiple simultaneous exposures, in line with real world conditions where VOCs rarely occur in isolation. For CYMA, the point estimate for all-cause mortality was just above 1 (1.009), but the lower confidence interval was 0.984 and crossed 1, indicating no significant association at this level.

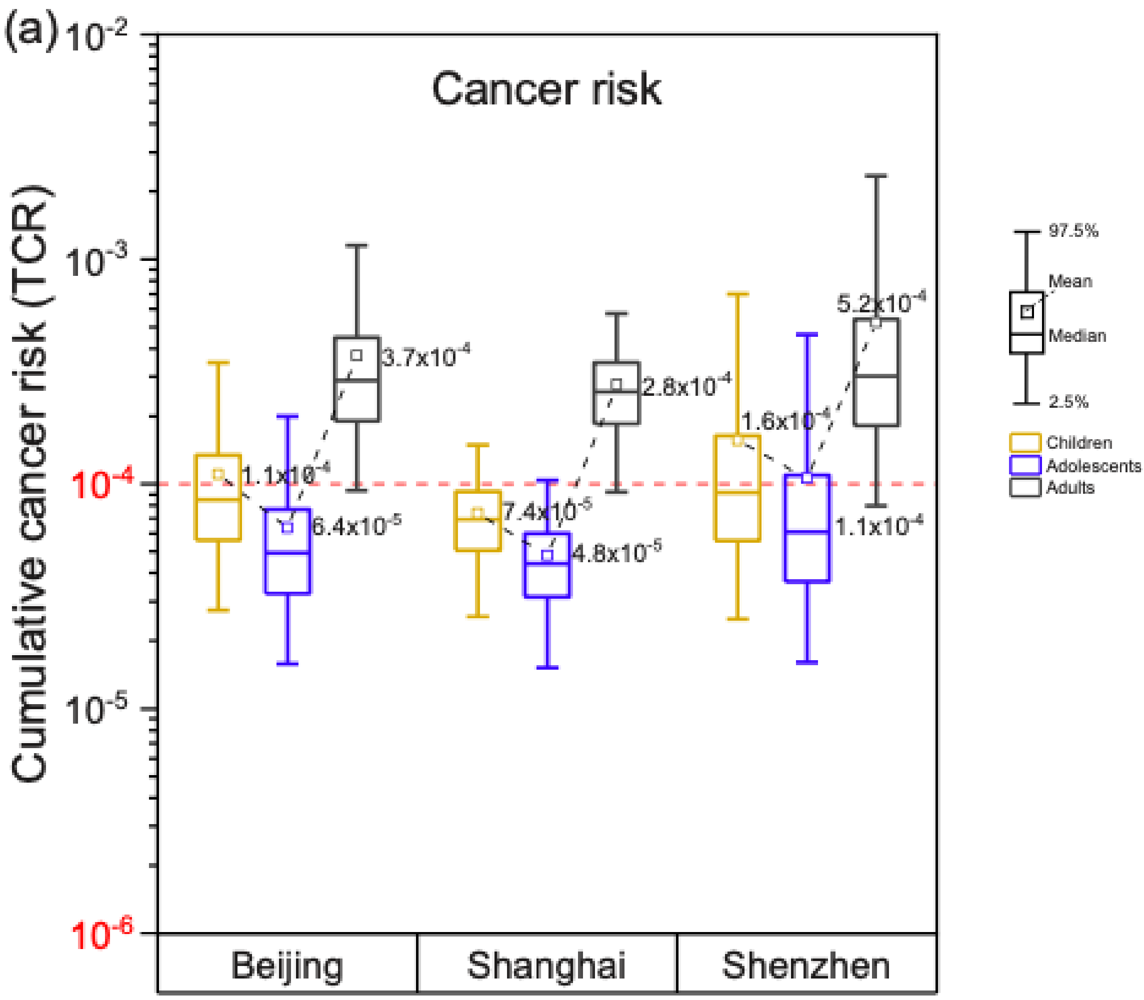
The mechanism of VOC carcinogenicity is multifactorial. Identified pathways include N-glycosylation abnormalities, unfold protein response, endoplasmic reticulum stress, impaired bile acid synthesis and FXR/RXR pathway, disruptions in lipid and pyruvate metabolism, mitochondrial dysfunction and subsequently cell apoptosis (Li and Wang, 2018). Additionally, they also increase the amount of oxidative stress, which further promote DNA damage and carcinogenesis (Hartman et al., 2017).

Chinese residential studies, as shown in Figure 1, highlight severe risks of indoor exposure. The top three VOCs with highest cancer risk in Beijing, Shanghai and Shenzhen was formaldehyde, naphthalene and benzene (Ji et al., 2024). Formaldehyde contributed to the cumulative cancer risk (TCR) of 77% in Beijing, 65% in Shanghai and only 29% in Shenzhen. Naphthalene however, posed the highest risk in Shenzhen which gave a TCR of 64%, but less than 20% in Beijing and Shanghai. The TCR for benzene did not pass 10% in any region. In the study, TCR was estimated separately for children 0-9 years, adolescents

9-18 years and adults 18-70 years, which was based on age-specific inhalation rates, body weights and exposure durations. The overall lifetime cancer risk (LCR) was estimated by summing up these subgroups, using a 70-year lifetime assumption. LCR means exposure exceed 10^{-4} for 100% of the population. Highest LCR was in Shenzhen where 19% of population had LCR more than 10^{-3}, compared to 7% in Beijing and 1% in Shanghai.

Overall, these observations support the hypothesis which states that long-term exposure to formaldehyde and other VOCs in household environments contribute to leukemia and other cancers. They have revealed substantial disparities in exposure between regions, where stricter directive is seen in Europe and United States corresponding to lower risks compared to China. This highlights the urgent need for harmonized international standards and improves strategies to reduce VOC emission.

Figure 2



Cancer risk from VOC exposure by age group and city

As seen in Figure 2, there are variations of cancer risks and VOC exposure across different cities and age groups. In Shenzhen we can see that mean TCR for children, adolescents and adults are above the tolerable limit of 10^{-4}. In Beijing the mean levels of adults and children are above, while adolescents are below. In Shanghai, only adults have TCR above tolerable limit. Even if above limit, the TCR in Beijing ($3.7x10^{-4}$) and Shanghai ($2.8x10^{-4}$), are much lower compared to Shenzhen ($5.2x10^{-4}$).

Across all cities, the TCR is consistently higher in adults compared to children and adolescents, which could be explained by higher exposure duration (ED). Children also demonstrated elevated risks due to higher inhalation rate relative to body weight ratio. In contrast, adolescents were observed to have the lowest TCR in all locations, which could reflect on a potential “protected group” status. Likely from shorter cumulative exposure compared to adults, while at the same time benefiting from more developed detoxification capacity then children. Nevertheless, given the global VOC rise in the last decades, we also know that the increase was 10.2%, meaning that the total exposure for today’s children is expected to be overall greater.

There are some limitations of these studies worth mentioning. In the study from US adults, the single-spot urinary VOC metabolites are not precise enough to estimate long-term VOC exposure, a better option would be 24-hour urine sample. There was also short time follow-up with at least 2 years, meaning that result could be unstable. Researchers also had problems with fully covering all potential pollution factors, such as ozone and PM2.5, and they ignored possible interference of other co-exposures.

There was also mentioned two primary limitations from China. Firstly, only a limited number of VOCs was investigated, with 9 in total: formaldehyde, benzene, toluene, xylene, acetaldehyde, dichlorobenzene, butadiene, trichlorethylene and tetrachlorethylene. Secondly, most of attention was made towards newly renovated residences. The main source of harmful VOCs is from newly renovated houses including renovation materials and furniture, which have high initial concentrations and rapid emission rate. In contrast, those established residences would have considerably more stable VOC profiles.

2.4 Benefits of VOCs

Although VOCs are often considered harmful, naturally emitted VOCs released by forests may exert beneficial effects on human health. In a comprehensive review by Antonelli et al. (2020) reported that inhalation of terpenes such as limonene and α-pinene can provide antioxidant and anti-inflammatory activity within the airways. Biogenic VOCs may also contribute to immune modulation, as studies on *shinrin-yoku* (forest bathing) have shown increased natural killer cell cytotoxicity, and up-regulation of anti-cancer proteins, with effect lasting several days after exposure. Some terpenes appear to support neurological health by reducing mental fatigue, promoting relaxation, and enhancing mood and cognitive performance when absorbed though inhalation. It should be emphasized that the outcomes cannot be attributed to VOCs alone, since the multisensory experience of natural environment likely plays a synergistic role. Furthermore, direct comparison between naturally occurring VOCs in outdoor environments and household chemicals is not straight forward, as their composition, concentrations and biological effects differ significantly.

3. INTERVENTIONS

Growing awareness of health effects which are associated with VOCs has led to increased focus on interventions aimed at decreasing the exposure in households. These interventions series from regulatory actions and product reformulations, to technological improvements and community-based strategies. The intricacy of VOC emissions, are influenced by various factors such as product composition, indoor ventilation, and pattern of usage, which demands a complex approach to effective mitigation.

One of the primary intervention strategies involves regulatory frameworks that set permissible limits of VOC emission, such as shown in Figure 1. In the 3 big megacities of China, only benzene, formaldehyde, m/p-xylene, toluene, trichlorethylene and tetrachlorethylene are included in the Chinese indoor air quality standards regarding concentration limits, even though many others show high levels such as naphthalene.

These policies made by governments and international organizations are meant to commence policies that restrict the use of high-emission chemicals in household products, leading to low- or free-VOC alternatives. Regulations should encourage manufacturers to reformulate products and provide the consumers with safer choices, hence reducing ED.

As we have seen from literature, more is yet to be done when there still are high concentrations levels detected and populations at subsequently increased health risks.

Technology has also played a crucial role in mitigating VOC emission. Development of air purification system have enhanced the ability to remove VOC from indoor air. Additionally, improvements in building materials, such as substitution of harmful substances with safer alternatives, have contributed to reduction of the long-term release of VOCs. Today there are also smart home monitoring systems which can detect air pollutants and alert individuals of sources and enable preventative measures.

Educational campaigns are another effective intervention tool. Public health organizations and environmental advocacy groups have launched several programs to increase the awareness in the society about VOC sources and health effects. Their aim is guidance on safer product selections and behavioral modifications to furthermore decrease VOC concentration in residences. This however, could be organized in collaboration with researchers, policymakers and the industrial stakeholders. In addition, the American Lung Association´s guidance on VOCs and mobile applications like *IQAir Visual,* provide the public with practical tools to identify and limit VOC exposure indoors.

3.1 Recommendations

Recommendations to limit household VOC exposure are relevant at both individual and community levels, because actions could be taken by consumers, manufacturers and policymakers. At household level, the first thing would be to identify potential sources of VOC, and then minimize their use. Home furnishings such as carpets and draperies typically emit VOC, and especially with new products, therefore an option could be avoidance or second hands. Composite wood often contains formaldehyde-based adhesives, which make solid wood or pre-off-gassed furniture safer alternatives (ALA, 2023). Similar, the floor models in store will emit lesser VOCs, since the initial off-gassing occur before purchase.

For arts and crafts, choosing washable markers instead of permanent and dry erase markers, use tape and white wood glue instead of rubber cement and spray glues. If painting, use water-based as they are safer option, and generally only buy what you need, as storing could cause leakage of VOC into the air. If there are unused containers, throw them and dispose safely by checking the specific county regulations for hazardous waste (EPA, 2023).

Dry-cleaning cloths will also emit VOCs for a long time and generally do not bring indoors before properly dried, if so, make sure of proper ventilation, or have them outdoors for a few hours before they are taken inside.

The indoor air management is also important. Regular ventilation is central by regularly opening windows and doors, or using fans or other VOC-emitting products. Try to keep the temperature and relative humidity as low as possible, but still in optimal range, because chemicals will tend to evaporate more easily in higher temperatures and humidity. Also, in low humidity the skin and mucous membranes become dry and more receptive to various pollutants. When allowing outdoor air inside the home, the VOCs are diluted. Today you can also purchase activated carbon filters to neutralize indoor air.

When you are buying cleaning products or personal care items containing VOC, make sure you are correctly using them. Examples include not to touch directly, use personal protection equipment when advised such as mask and gloves, store them in well-ventilated areas and as far as possible away from the main living spaces. Do not perform mixing of these products if not mentioned by the packaging.

If planning renovations or moving into a new house, try to do it while the house is still unoccupied so that gas-off phase happens when no one is around. Remember also that new buildings typically have higher emission rates, compared to previously owned houses.

Cigarette smoking is a known toxic chemical which releases VOCs. If smoking indoors, even if opening windows or doors, the smoke will seep into the surroundings such as walls, flooring and furniture’s. By such means, the VOCs will be emitted continuously as long as person smokes. If moving into a house where the previous owner smoked indoors, then should properly wash every surface, preferably replace all carpeting, furniture’s and linens. Therefore, the best way of elimination is complete avoidance of indoor smoking, or total absence.

In case of personal care items, the best would be complete avoidance of products as this is typically not needed for most people. Avoid or limit fragrances. Avoid cosmetics containing VOCs. Do not use nail polish or nail polish removers. In general, all treatment or care for the nails containing acetone, b-butyl acetate and ethyl acetate are toxic (Lamplugh et al., 2019). Search for organic brands or products merchandised as VOC low/free. Typically, products for children or those with sensitive skin are the best.

CONCLUSIONS

This literature review has provided compelling evidence linking VOC exposure from household products to substantial health risks, particularly depression and cancer. The findings strongly support the research hypotheses. Long-term exposure to specific compounds such as formaldehyde, benzene, acrylonitrile and 1,3-butadiene was associated with a higher risk of depression and hematologic malignancy, most notably leukemia. Depression risk was strongly related to metabolites of acrylonitrile and 1,3-butadiene, in which gender-stratified analyses indicated increased susceptibility in men for butadiene metabolites and in women for acrylonitrile. Formaldehyde exposure was consistently a key contributor to leukemia risk across different regions.

In household prevalence, the most common VOCs identified were formaldehyde, benzene, toluene, acetone and limonene. Reported indoor concentration often exceed safe limits. In some situations, 2-10 times higher depending on compound and location. In European residences, formaldehyde concentrations above 10 $\mu g\ m^{-3}$ have been reported as typical (Halios et al., 2022). Higher levels usually found in newly renovated homes, while toluene and acetone were frequently measured at exceeding levels in Chinese households (Ji et al., 2024).

The exposure routes were mainly inhalation of indoor air and dermal absorption through personal care products. The most vulnerable populations include children and adolescents, due to longer total exposure time and higher respiration rates, pregnant women and fetuses from underdeveloped detoxification systems, and individuals with pre-existing conditions, such as chronic liver disease, kidney disease, diabetes or obesity, which can alter metabolism and clearance of VOCs.

A global comparison highlighted marked differences. In the European Union and United States, there are relatively strict VOC regulations, while studies from China and other rapidly developing regions indicate very high exposure levels. The lifetime risk of cancer in Chinese megacities such as Shenzhen have shown to exceed acceptable limits for the entire population, emphasizing urgent need for international guidelines.

The intervention strategies need to prioritize regulatory frameworks, consumer education and technological enhancements. Governments should strengthen VOC directives and instruct manufacturers to produce low-emission products. There should be public health campaigns to improve awareness and encourage safe choices for consumers. On individual level, measures such as improved ventilation, use of low-VOC materials and air purification systems are practical steps to mitigate exposure. To further reduce individual risk, indoor air monitoring systems may be used.

Nonetheless, interpretation of current evidence must be lightened by limitations in the reviewed studies. Cross-sectional designs, singe-spot monitoring or short follow-up duration limit causal interference. The restricted chemical panels in the studies and lack of control for co-exposures such as ozone, further weaken conclusions. Future research should therefore have longitudinal designs, broader VOC coverage and improved confounder adjustment.

In conclusion, reduction of household VOC exposure, will require multidisciplinary approach by involving policymakers, scientists, healthcare professionals and industry stakeholders. When implementing aimed interventions, support of future research and strengthening regulations, substantial improvement could be achieved toward reduction of long-term health burden from VOC, protection of public health and creating safe indoor atmosphere.

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DECLARATION

I, Victoria Pettersen Tviberg, certify that this Research Paper on the topic

” Bīstamās ķīmiskās vielas mājsaimniecības precēs"

(Title of the Research Paper in Latvian)

” Chemicals of concern of household products”

(Title of the Research Paper in English)

is my own independent research. All other sources of data, definitions and quotations in my Research Paper are referenced accordingly. The text of this Research Paper has never been submitted in any way to any other National Examination Commission for evaluation in its entirety or parts, and has never been published in its entirety.

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06.10.2025.