Public Health England

Indoor Air Quality Guidelines for selected VOCs in the UK

Sani Dimitroulopoulou and Clive Shrubsole
Air Quality & Public Health
Environmental Hazards and Emergencies Department,
Public Health England

HEMAC network, Glasgow, 3 December 2019

Public Health England

Background and Context

Until recently, in the UK, there were no IAQ guidelines for individual VOCs.

Exposure to total volatile organic compound (TVOC) levels should not exceed 300 $\mu g.m^{-3}$ averaged over 8 hours (ECA,1992).

TVOC as a measure reveals little regarding the nature of the individual compounds, their concentrations and possible toxicity to humans.

WHO (2010) IAQ guidelines provide limit values for a few VOCs (benzene, naphthalene, polycyclic aromatic hydrocarbons (PAHs), tetra- and tri-chloroethylene) including formaldehyde

Public Health England

Review Objectives

The overall objective of this work was to carry out a comprehensive literature review to propose health based IAQ guidelines for individual VOCs in the UK.

We investigated:

- ✓ The occurrence of VOCs in indoor residential and public buildings (offices), focussing in the UK and Europe.
- ✓ VOCs present, their sources, concentrations, toxicity and health impacts
- ✓ VOCs emitted from construction products and building materials (construction phase) but also from consumer products (post-occupancy)
- ✓ We reviewed existing assessment values proposed by other countries and organisations, and selected the most appropriate existing health-based guidance values for inhalation and propose these as **IAQ guidelines.**

Public Health England

Inclusion Criteria and Analysis

To be statistically relevant only large-scale monitoring studies were investigated - more than around 40 buildings.

Emphasis was given to research demonstrating robust, clear methodologies and analysis using established protocols (e.g. ISO-16000-6 quantitative analysis) and indicated measurement uncertainties.

The findings of included studies were grouped to characterise individual VOCs and permitted health-based guidance values seen in existing national and international standards and their measured concentrations in buildings, in relation to toxicological data and potential health impacts.

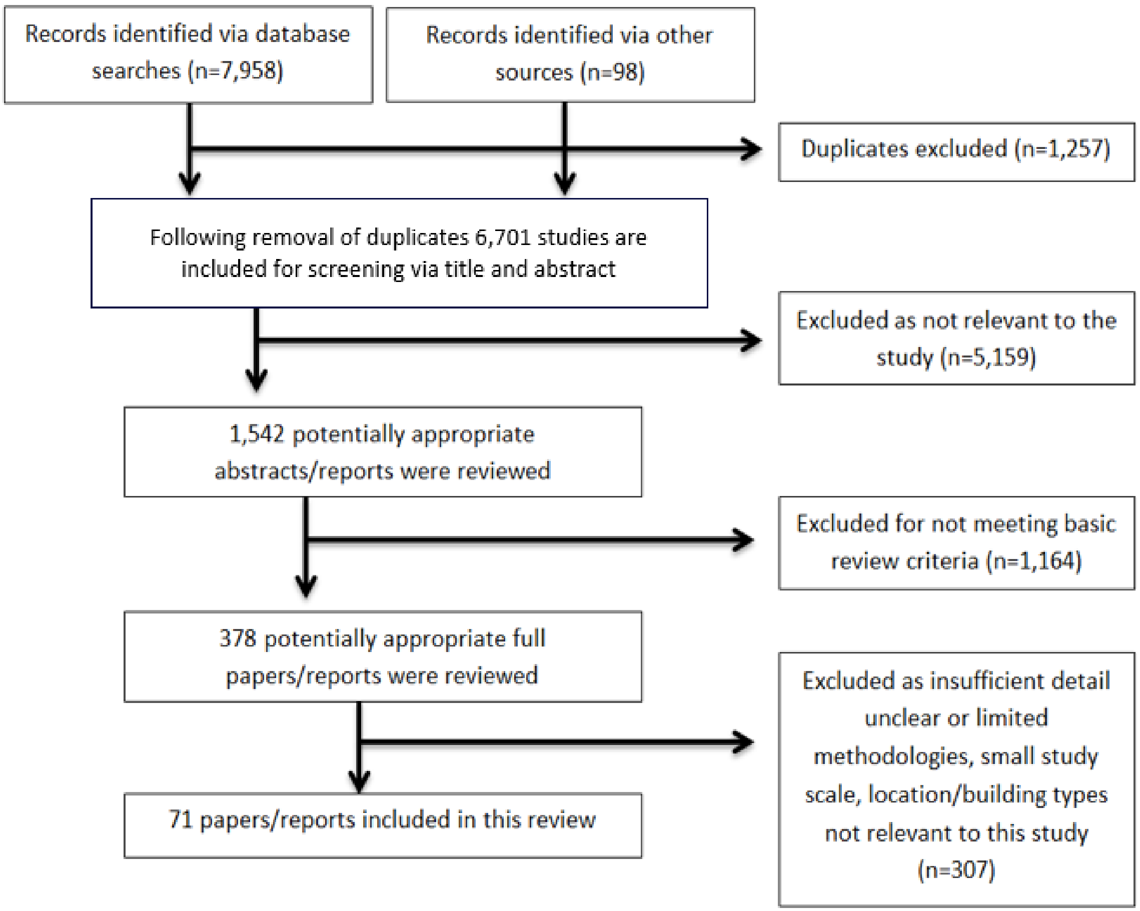
Building types 1) housing and 2) public buildings/offices

Strategies for VOC reduction/removal from the indoor air were investigated as well as suggested methods of mitigation.

We started with the WHO guidelines for indoor air quality (2010)

Public Health England

Results of the literature search



Priority VOCs in homes and offices in UK and major international studies

Building types	Residential	Residential	Residential	Public buildings/ Residential (+Schools)	Residential	Public buildings/ Residential (+Schools)	Residential	Residential	Low-energy/non low-energy residential and public buildings
Project/case study	BRE study (1996)[a]	THADE -EFA (2002-2004)	Index Project (2005)[b]	BUMA Project (2008)	Lawrence Berkley (Logue et al 2010)	AIRMEX Study (2011)	EPHECT Project (2015)	MHCLG (2016)[c] unpublished small-scale UK study	IEA EBC Annex 68 (2016)[d]
TVOC	High	High			High			High	High
2-Butoxyethanol						Low			
Acetaldehyde			Low	High		High			High
Acrolein					Low		Low		Low
α-Pinene			Further research needed	High		High	High	High	High
Benzene	High		High	High	High	High		High	High
Chloroform					Low				
D-Limonene			Further research needed	High		High	High	High	
Ethylbenzene				Low	Low	Low			
Formaldehyde	High	High	High	High	High	High	High		High
Hexanal						Low			
Naphthalene			High		High		High		
n-Hexane						Low			
Propionaldehyde				Low					
Styrene			Low		High	Under evaluation			High
Tetrachloroethylene (T4CE)					High				
Toluene	High			High		Low		High	Low
Trichloroethylene					High				High
Xylenes	Low			High		Low			Low

'High' and 'Low' refer to the statements of priority for compounds seen in individual studies

*WHO proposed guidelines include benzo(a)pyrene. However, reviewed studies show no evidence of its occurrence in domestic or office environment

[a]BRE study large study, limited range of species measured, as seen in large TVOC concentration compared to relatively small measured species concentration

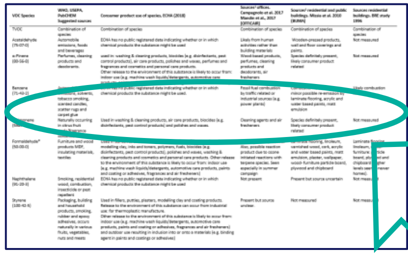
[b]Priorities in the INDEX project are stated as based on occurrence, dose-response relationship

[c]IEA study based on large scale measured values- occurrence only

[d]MHCLG unpublished study. Qualitative method used (toluene equivalent concentration according to ISO 16000-6), species present but quantity subject to large uncertainties.

Public Health England

Material and product emission sources for selected VOCs indoors



VOC Species	WHO, USEPA, PubCHEM Suggested sources	Consumer product use of species, ECHA (2018)	Sources[1] offices. Campagnolo et al. 2017 Mandin et al., 2017 (OFFICAIR)	Sources[2] residential and public buildings. Missia et al. 2010 (BUMA)	Sources residential buildings. BRE study 1996
Formaldehyde* (50-00-0)	Furniture and wood products MDF, insulating materials, textiles	Used in adhesives and sealants, coating products, fillers, putties, plasters, modelling clay, inks and toners, polymers, fuels, biocides (e.g. disinfectants, pest control products), polishes and waxes, washing & cleaning products and cosmetics and personal care products. Other release to the environment of this substance is likely to occur from: indoor use (e.g. machine wash liquids/detergents, automotive care products, paints and coating or adhesives, fragrances and air fresheners)	Flooring, wood products. Also, possible reaction product due to ozone initiated reactions with terpene species. Seen especially in summer campaign	Laminate flooring, linoleum, varnished wood, cork, acrylic and water based paints, matt emulsion, plaster, wallpaper, wood- furniture particle board, plywood and chipboard	Laminate flooring, linoleum, wood-furniture: particle board, plywood and chipboard (Higher levels seen in newer homes).

Formaldehyde concentrations in homes and public buildings/offices

Mean	Median	Max	Min	SD	95th percentile	Study Sample	Environment	Location	Source
23.4		135.2	2.6			182	Homes	UK	BRE (1996)
22.2		171.0	1.0		61.2	876	Homes	UK	Raw et al. (2004)
24.0		75.0	10.0	9.0		32	Homes Living room	UK	Dimitroulopoulou et al. (2015)
26.0		80.0	11.0	10.0		33	Homes Main bedroom	UK	Dimitroulopoulou et al. (2015)
34.7		86.0	14.4			3,601	Low energy homes	Worldwide (incl. UK and Europe)	Salis et al. (2017)
57.8		160.0	5.8			22,783	Non-low energy homes	Worldwide (incl. UK and Europe)	Salis et al. (2017)
23.5				1.8		61	Homes/Apartments	Paris	Clarisse et al. (2003)
	18.5				46.6	567	Homes/Apartments	Paris	Kirchner et al. (2006)
	19.4	86.3	1.3			490	Homes/Apartments	Paris	Billionnet et al. (2011)
17.6	16.6			6.9	29.9	82	Homes	Finland	Du et al. (2015)
23.2	[illegible]			10.5	44.2	95	Homes	Lithuania	Du et al. (2015)
16.7		[illegible]	[illegible]			112	Public buildings	Europe	Kotzias et al. (2009)
8.1		23.0	1.7			148	Offices (Summer)	Europe	Mandin et al. (2017)
16.0		49.0	4.7			140	Offices (Winter)	Europe	Mandin et al. (2017)
16.7		49.7	1.5			185	Public buildings	Europe	Geiss et al. (2011)
21.5		57.2	3.9			97	Homes	Europe	Geiss et al. (2011)
		62.2	5.8			60	Homes and Public Buildings	Europe	Missia et al. (2010)
69.0					99.0	3370	Homes	USA	Logue et al. (2010)
94.0					69.0	671	New Homes	USA	Logue et al. (2010)
26.1		134.0	<LOD*			4,292	Homes	Australia	Goodman et al. (2017)
31.0	25.4	110.0	8.8			50	Homes (Summer)	Alberta	Bari et al (2015)
23.7	21.3	65.0	1.7			50	Homes (Winter)	Alberta	Bari et al (2015)
86.0				58.0		1125	Homes	Japan	Park & Ikeda (2006)
134.0				93.0		292	New Homes	Japan	Park & Ikeda (2006)
160.0		450.0	20.0	70.0		471	Decorated Homes	Xi'an China	Chang et al. (2017)

*<LOD = Below limit of detection

Table 3f Formaldehyde (50-00-0) concentrations ($\mu g.m^{-3}$) observed in indoor environments

Mean	Median	Max	Min	SD	95th percentile	Study Sample	Monitoring Period	Environment	Location	Source
23.4		135.2	2.6			182	3 days	Homes	UK	BRE (1996)
22.2		171.0	1.0		61.2	876	3 days	Homes	UK	Raw et al. (2004)
24.0		75.0	10.0	9.0		32	2 weeks	Homes Living room	UK	Dimitroulopoulou et al. (2015)
26.0		80.0	11.0	10.0		33	2 weeks	Homes Main bedroom	UK	Dimitroulopoulou et al. (2015)
34.7		86.0	14.4			3,601	Variable	Low energy homes	Worldwide (incl. UK and Europe)	Salis et al. (2017)
57.8		160.0	5.8			22,783	Variable	Non-low energy homes	Worldwide (incl. UK and Europe)	Salis et al. (2017)

Public Health England

Indoor air guidelines for VOCs proposed by various organisations and research projects

Standard	IEA-EBC Annex 68 2016	Europe Index project 2005	Europe EPHECT Project 2015	WELLv2*	LEEDv4	ASHRAE 189.1
Applicable to	Low energy homes and public buildings	Homes	Critical Exposure Limit (CEL) Homes	Ventilation /material emission-based Offices and public buildings	Ventilation /material emission based All building types	Ventilation only Green buildings non-residential
TVOC	600 ST4	-	-	500 LT3	500 ST4	-
Acetaldehyde	48 LT3 4600 ST3	200 LT3	-	-	140 ST4	140 ST4
Acrolein	0.35 LT3 6.9 ST4	-	10 LT2 21 ST3	-	-	-
α-Pinene	200 LT2	-	4,500 LT2 45,000 ST3	-	-	-
Benzaldehyde	-	-	-	-	-	-
Benzene	0.2 LT2	0	-	30 LT3	3 ST4	60 ST4
Benzo(a)pyrene	-	-	-	-	-	-
Chloroform	150 LT1 300 ST3		-	1000 LT3	2000 ST4	2000 ST4
D-Limonene	-	-	9,000 LT2 90,000 ST3	-	-	-
Ethylbenzene	0 LT 3800 ST		-	3500	7000 ST4	7000 ST4
Formaldehyde	9 LT2 123 ST3	1 LT3	100 ST2, LT2	33 LT3	9 ST4, LT3 55 ST4	100 ST4
Naphthalene	2 LT3	10 LT3	10 LT2	-	9 ST4	9 ST4
n-Hexane	-	-	-	3500 LT3	7000 ST4	7000 ST4
Propionaldehyde	-	-	-	-	-	-
Tetrachloroethylene	100 LT2 1380 ST3	-	-	17.5 LT3	600 ST4	600 ST4
Toluene	250 LT2-3	300 LT3	-	150 LT3	300 ST4	300 ST4

Standard	IEA-EBC Annex 68 2016	Europe Index project 2005	Europe EPHECT Project 2015	WELLv2*	LEEDv4	ASHRAE 189.1
Applicable to	Low energy homes and public buildings	Homes	Critical Exposure Limit (CEL) Homes	Ventilation /material emission-based Offices and public buildings	Ventilation /material emission based All building types	Ventilation only Green buildings non-residential
Formaldehyde	9 LT2 123 ST3	1 LT3	100 ST2, LT2	33 LT3	9 ST4, LT3 55 ST4	100 ST4

Health-based indoor air quality guidelines for selected VOCs

VOCs	Limit Values in µg.m[-3] Short Term	Limit Values in µg.m[-3] Long Term	Source Document	Reasoning for choice	Potential Health impacts
Acetaldehyde (75-07-0)	1,420 (1h)	280 (1day)	Health Canada (2018)[a]	Most recent appraisal of evidence	Irritation of the eyes, skin, and respiratory tract following acute exposure.[3] Long-term animal studies have reported carcinogenicity and inflammation and injury to tissues of the upper respiratory tract (Health Canada, 2018)
α-Pinene (80-56-8)	45,000 (30min)	4500 (1 day)	EPHECT (Trantallidi et al., 2015)	Critical Exposure limit (CEL) inhalation exposure to key and emerging indoor air pollutants emitted during household use of selected consumer products	With the exception of its irritative (skin, eyes) and sensitizing properties, it is a chemical with fairly low acute toxicity.[4] Ozone initiated reactions with terpenes produce gaseous and aerosol phase products, causing sensory irritation of upper airways and airflow limitation.
Benzene (71-43-2)	No safe level of exposure can be recommended. The unit risk of leukaemia per 1µg.m[-3] air concentration is 6×10^{-6}. The concentrations of airborne benzene associated with an excess lifetime cancer risk of 1/10 000, 1/100 000 and 1/1 000 000 are 17, 1.7 and 0.17µg.m[-3], respectively.		World Health Organisation (2010)	The risk estimates are based on human health risk. However, it is noted that the current Defra national air quality objectives for benzene for England and Wales is an annual mean of 5µg.m[-3], based on the European (EU) ambient air quality directive 2008/50/EC (EU, 2008), (Defra, 2010).	The International Agency for Research on Cancer has classified benzene as carcinogenic to humans (Group 1). Benzene causes acute myeloid leukaemia in adults. Positive associations have been observed for non-Hodgkin lymphoma, chronic lymphoid leukaemia, multiple myeloma, chronic myeloid leukaemia, acute myeloid leukaemia in children and cancer of the lung. (IARC, 2018a).
D-Limonene (5989-27-5)	90,000 (30min)	9000 (1 day)	EPHECT (Trantallidi et al., 2015)	Critical Exposure limit (CEL) inhalation exposure to key and emerging indoor air pollutants emitted during household use of selected consumer products	As for α-Pinene above
Formaldehyde (50-00-0)	100 (30min)	10 (1yr)	World Health Organisation (2010). ATSDR MRL (1999)	World Health Organisation guidelines valid for short term exposure. ATSDR value of 10 µg/m[3] suggested as the long-term health-based guideline value which accounts for the potential for child susceptibility.	Sensory irritation of the eyes, nose and throat, together with exposure-dependent discomfort, lachrymation, sneezing, coughing, nausea and dyspnoea. Human carcinogen -long-term exposure linked to nasal cancer.[1]
Naphthalene (91-20-3)	-	3.0[+] (1yr)	Agency for Toxic Substances & disease Registry (2005), USA	Value also selected by the Flemish Government (2018) There is no proposed guideline for short term exposure due to the lack of scientific evidence.	Haemolytic anaemia in humans at high doses. Respiratory tract lesions including carcinogenicity reported in long-term animal studies. [1,3]

Health-based indoor air quality guidelines for selected VOCs

Public Health England

VOCs	Limit Values in µg.m-3 Short Term	Long Term	Source Document	Reasoning for choice	Potential Health impacts
Styrene (100-42-5)	-	850 (1y)^	Health Canada (2018)	Most recent appraisal of evidence	Sensory irritation of the eyes, nose and throat. High concentrations- headache, nausea, vomiting, weakness, tiredness, dizziness, mild irritation to skin. Long-term exposure has been reported to cause neurological effects in humans including changes in hearing, balance, colour vision and psychological performance.
Tetrachloroethylene (127-18-4)	-	40 (1day)	US EPA (2012) and Health Canada (2018)	Most recent appraisals of evidence	Effects in the kidney indicative of early renal disease and neurotoxicity (visual and autonomic disturbances)[1,3] Evidence of carcinogenicity in animals. Limited evidence for carcinogenicity in humans (positive associations have been observed for bladder cancer)
Toluene (108-88-3)	15,000 (8h)	2,300 (1 day average)	Health Canada (2018)	Most recent appraisal of evidence, specifically the dose response relationship.	Eye, nose and throat irritation, headaches, dizziness and feelings of intoxication following short-term exposure. Neurological effects including reduced scores in tests of short-term memory, attention and concentration following long-term exposure[2]
Trichloroethylene (71-01-06)	-	0.2* (1yr)	US EPA (2011)	This value is based on human data for kidney cancer, which has also been adjusted for other cancers.	The International Agency for Research on Cancer has classified trichloroethylene as carcinogenic to humans (Group 1). Trichloroethylene causes cancer of the kidney. A positive association observed for non-Hodgkin lymphoma and liver cancer. It is assumed that trichloroethylene is genotoxic (IARC, 2018b)
Xylenes-mixture (1330-20-7)	-	100 (1y)^	Health Canada (2018)	Most recently derived and most precautionary value.	Irritation to the nose, throat and lungs. Severe inhalation exposure can cause dizziness, headache, confusion, heart problems, liver and kidney damage and coma[2]

*No safe level of exposure can be recommended. The concentrations shown are associated with an excess lifetime risk of 1/1,000,000 and are applicable to both long and short-term exposures.

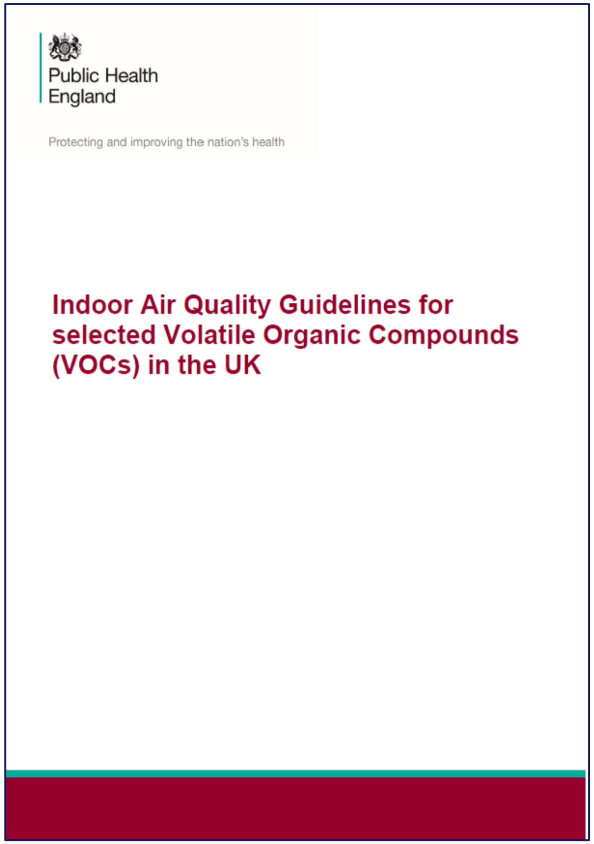
+We are aware of new data that indicates that effects may occur at lower doses; however, this new data has not yet been evaluated by an authoritative body.

^ Health Canada uses screening values for some species - Indoor Air Reference Levels (IARL). These are used to assess possible risk. They are associated with acceptable levels of risk after long-term exposure (over several months or years) for each specific VOC. Due to uncertainties in derivation; these have simply been labelled as annual. In these cases, no separate short-term exposure limit has been stated.

Main References

[1]World Health Organisation. WHO Guidelines for selected pollutants.
[2]Public Health England. Chemical hazards compendium.
[3]United States Environment Protection Agency. Iris Assessments.
[4]Sarigiaannis et al., 2011

Public Health England



Public Health England

Protecting and improving the nation's health

Indoor Air Quality Guidelines for selected Volatile Organic Compounds (VOCs) in the UK

Building and Environment 165 (2019) 106382

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

IAQ guidelines for selected volatile organic compounds (VOCs) in the UK

C. Shrubsole[a], S. Dimitroulopoulou[a,*], K. Foxall[b], B. Gadeberg[b], A. Doutsi[a]

[a] *Air Quality & Public Health Group, Environmental Hazards and Emergencies Department, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Harwell Science and Innovation Campus, Chilton, Oxon, OX11 0RQ, UK*

[b] *General Toxicology Group, Toxicology Department, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Harwell Science and Innovation Campus, Chilton, Oxon, OX11 0RQ, UK*

A R T I C L E I N F O

Keywords:
Volatile organic compounds
VOC
Indoor air quality
TVOC
Building regulations
Guidelines

A B S T R A C T

Poor indoor air quality, can cause a variety of adverse health effects. Pollutant exposure levels inside buildings are likely due to pollutants from both indoor and outdoor sources. Although there are many indoor airborne pollutants, the current review focusses on Volatile Organic Compounds (VOCs), and considers the current Total Volatile Organic Compounds (TVOC) standards alongside other guideline values, to control levels within the indoor environment. We reviewed the current scientific data showing the occurrence of various VOCs in buildings internationally, and the available toxicological reviews for the individual VOCs with potential for adverse health effects that require attention. We considered available health-based general population indoor guidelines for long and short-term exposure in respect of individual compounds, including acetaldehyde, α-pinene, D-limonene, formaldehyde, naphthalene, styrene, tetrachloroethylene, toluene and xylenes (mixture).

We conclude individual VOC guidelines are the most appropriate way forward and that TVOC can be used as an indicator for indoor air quality. This study highlights which compounds should be prioritised for monitoring purposes. Our findings inform discussions around the improvement of general population health, source control and the need to raise awareness of the potential impacts of pollutants in the home.

1. Introduction

Given that the UK population spend around 80–90% of their time in buildings and around 60% in their homes [1,2], buildings are important modifiers of population health [3]. Overall exposure levels inside buildings are due to pollutants from both indoor and outdoor sources, although some attenuation by buildings occurs.

There are a variety of pollutants in the indoor environment, including gaseous pollutants (inorganic chemicals, radon and volatile organic compounds (VOCs)), biological pollutants (allergens, viruses and bacteria, mould) and particulate matter (PM). The current work focusses on VOCs in the indoor environment from both indoor and outdoor sources. The presence of VOCs in residential and public buildings are well reported (e.g. [4]. Health organisations (e.g. The World Health Organisation, The US Environmental Protection Agency and Public Health England) have assessed the evidence and listed the potential health effects of VOCs, including irritation of the eyes and respiratory tract, allergies and asthma, central nervous system symptoms, liver and kidney damage, as well as cancer risks. The health risks from VOCs are determined by the level of exposure experienced as well as the time spent within indoor environments (the focus of this study). Thus, there is a need for health-based guidance values.

As defined in the building standard [5], VOCs are the organic compounds eluting between and including n-hexane and n-hexadecane on the gas chromatographic column. *Very volatile organic compounds* (VVOCs) are the volatile organic compounds eluting before n-hexane on the gas chromatographic column. *Semi-volatile organic compounds* (SVOCs) are the organic compounds which elute after n-hexadecane, on the gas chromatographic column. *Total volatile organic compounds* (TVOCs) are the sum of the concentrations of the identified and unidentified VOCs. All compounds listed in Annex G of BS EN16516:2017 are to be regarded as VOC, even if they elute from the gas chromatographic system before n-hexane or after n-hexadecane. These include aromatic hydrocarbons, saturated aliphatic hydrocarbons (n, -iso, cyclo-), terpenes, aliphatic alcohols, aromatic alcohols, glycols, glycolethers and aldehydes. Formaldehyde (HCHO) is of greatest importance, due to its prevalence in the indoor environment and its known health impacts [6].

In *outdoor air*, the primary VOC sources include those from incomplete combustion e.g. road traffic exhaust gases and volatile by-products of various industrial and commercial operations, as well as biological metabolism, decay and degradation processes [7]. In *indoor*

* Corresponding author.
E-mail address: Sani.Dimitroulopoulou@phe.gov.uk (S. Dimitroulopoulou).

https://doi.org/10.1016/j.buildenv.2019.106382
Received 6 June 2019; Received in revised form 27 August 2019; Accepted 28 August 2019
Available online 11 September 2019

https://www.gov.uk/government/publications/air-quality-uk-guidelines-for-volatile-organic-compounds-in-indoor-spaces

Building and Environment, 2019, https://doi.org/10.1016/j.buildenv.2019.106382

Public Health England

IAQ work at PHE - 1

Cross-government / Organisations / Stakeholders

- Cross Government Group On Gas Safety And Carbon Monoxide Awareness / All Fuels Action Forum
- CIBSE TM40: Health Issues in Building Services
- NICE guidance on indoor air quality at home - PHETA
- RCP and RCPCH Systematic Review: “Effects of Indoor Air Quality on Children and Young People’s Health”.
- Government Review into CO Alarm Requirements (England)
- WHO project on “assessment of cumulative risk to children of indoor air pollution”
- Input to MHCLG for the revision of Building Regs (Part L, Part F)

Public Health England

IAQ at PHE - 2

➢ QUASIMODO project

"Quality of Indoor Air on Sites Matched with Outdoor Datasets to improve Outcomes"

Real-time monitoring of indoor air quality data combined with outdoor air quality information. Indoor air quality will be measured and allergens may be removed, using home air purifiers (HAP), in homes of both vulnerable population and general public.

- Comprehensive literature review on the impact of home air purifiers on domestic indoor air quality and human adult health.

➢ CO_2 project

Review of the health impacts of exposure to indoor CO_2, looking at toxicological evidence

Public Health England

IAQ at PHE - 3

- PhD projects (co-funded PHE and UCL LoLo CDT)

PhD project 1 (2017-2021) - Lauren Ferguson

"Quantifying the benefits of measures to reduce exposure of deprived communities to indoor and outdoor sources of air pollutants".

PhD project 2 (2018-2022) – Cairan Van Rooyen

"Ventilation practices in new homes in relation to air quality, noise and overheating risk, and their impact on health"

Public Health England

Let's work together

To reduce our personal exposure to indoor and outdoor air pollution

Thank you!

www.gov.uk/phe

Sani.Dimitroulopoulou@phe.gov.uk