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

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Background

With the UK population spending on average around 80-90% of their time inside buildings, and up to 60% of their time in their homes (Kornartit et al., 2010; Dimitroulopoulou et al., 2017), buildings are important modifiers of population health (Thompson et al., 2013). Poor indoor air quality may cause or aggravate odour and irritation, allergic and asthma symptoms, airborne respiratory infections, chronic obstructive pulmonary disease, cardiovascular disease and lung cancer (Carrer et al., 2009). In addition, the effects of indoor air pollution exposure on school performance, office productivity, comfort and well-being of occupants has become an emerging focus of research (eg Wargocki and Wyon, 2017; Eitland et al., 2018; Gupta et al., 2018) and statutory guidance has recently been published (eg DfE, 2018). Overall exposure levels inside buildings are likely due to pollutants from both indoor and outdoor sources, although some attenuation by buildings occurs. Although there is a plethora of pollutants found indoors, including gaseous pollutants (inorganic chemicals, radon, volatile organic compounds, VOCs), biological pollutants (allergens, viruses and bacteria, mould) and particulate matter, the current work focusses on indoor generated VOCs and the guideline values that would aim at their control in the indoor environment.

According to BS EN16516:2017, *very volatile organic compound* (VVOC) is the volatile organic compound eluting before n-hexane on the gas chromatographic column, as specified in the Standard. *Volatile organic compound* (VOC) is the organic compound eluting between and including n-hexane and n-hexadecane on the gas chromatographic column, as specified in the Standard. *Semi-volatile organic compound* (SVOC) is the organic compound which elute after n-hexadecane, on the gas chromatographic column, as specified in the Standard. *Total volatile organic compounds* (TVOC) is the sum of the concentrations of the identified and unidentified volatile organic compounds, as specified in the Standard. All compounds listed in Annex G of BS EN16516:2017 shall be regarded as VOC, even if they elude from the gas chromatographic system before n-hexane or after N-dexadecane. 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 (WHO, 2010).

The presence of volatile organic compounds (VOCs) and the associated health risks in residential and public buildings are well reported (eg Sarigiannis et al., 2011). Due to their properties, VOCs are widely used in construction and building products (eg paints, varnishes, waxes, solvents), in household consumer products (detergents, cleaning products, air fresheners and personal care products) and are also emitted while using electronic devices such as photocopiers or printers (eg Missia et al., 2010, Bartzis et al. 2015; Cacho et al., 2013; GEA, 2017). Secondary pollutants can be also formed by ozone-initiated chemistry of terpenes and degradation (eg Nazaroff and Weschler, 2004; Kephalopoulos et al., 2007; Nørgaard et al., 2014). Health Organisations (eg The World Health Organization, The US Environmental

Protection Agency, PHE) have assessed the evidence and listed the health impacts of VOCs, which include irritation of the eyes and respiratory tract, allergies and asthma, central nervous system symptoms, liver and kidney damage, as well as cancer risks.
Given the presence of VOCs in residential and public buildings and their health impacts, prioritisation of the air pollutants and individual VOCs that should be considered for monitoring campaigns and proposing guideline values has been carried out by various researchers (eg COMEAP, 2004; Kotzias et al., 2005 – INDEX project; SCHER, 2007; Carreer et al., 2009 – ENVIE project). These early European projects led to the development of the WHO indoor air quality guidelines for selected pollutants (WHO, 2010), which are intended for use in countries with no relevant regulations. However, there are countries that have made real advances in mitigating indoor air pollution and developed guidelines for the indoor air contaminants in recent years (eg Germany, Canada, Japan and the Flemish Government.).

In the UK, there are currently no indoor air quality guidelines for individual volatile organic compounds. In their absence, the recently revised Department for Education Guidance BB101: Ventilation, thermal comfort and indoor air quality (DfE, 2018) recommended the use of the WHO (2010) Indoor Air Quality (IAQ) guidelines. The current Building Regulations Part F (2010) gives guidance regarding the maximum concentrations of certain pollutants within the building envelope for ventilation purposes (HM Government, 2010). Apart from inorganic pollutants, these include TVOCs. TVOC is used as a measure giving a possible indication of poor/good indoor air quality; furthermore it is proposed as an indicator for the calculation of ventilation rate (eg Hormigos-Jimenez et al., 2017). However, TVOCs reveal little regarding the nature of the individual compounds, their concentrations and their possible toxicity to humans.

Therefore, the overall objective of this work is to carry out a comprehensive literature review to propose indoor air quality guidelines for individual VOCs in the UK. The starting point was the 2010 WHO IAQ guidelines and our objective was to investigate if the proposed individual VOCs and their limit values are still appropriate for use and if new compounds should be considered based on the recent scientific evidence about their toxicity and presence in buildings. A short description of the methodology is given below together with the proposed VOC guidelines, whereas the full details of the work and analysis are presented and discussed in Shrubsole et al. (2019).

Methodology

To target the individual VOCs for which indoor air quality guidelines should be proposed in the UK, we carried out a systematic literature review of the current research evidence on the occurrence of VOCs in the indoor residential and public buildings (offices), mainly in the UK and Europe. The compounds present, their sources and concentrations, their toxicity and health impacts were investigated. The individual VOCs that were identified were further investigated to assess their relevance according to the limits of exposure and their prevalence in residential and office buildings. The VOCs, for which we propose IAQ guidelines, are emitted from construction products and building materials; however, most monitoring studies are carried out post occupancy, and the contribution of VOCs from consumer products represents a large component of individual indoor exposure and are also considered here.

We reviewed existing the evidence base of health-based guidelines proposed by other countries and organisations, to identify which existing guidelines could be adopted for individual VOCs. We did not aim to carry out a full review of the toxicological evidence, to produce new guidelines. For this project, we selected the most appropriate existing health-based guideline values (HBGVs) for inhalation and propose these as UK IAQ guidelines. In the case of naphthalene there is emerging toxicological data that may change proposed guideline values. However, it has yet to be reviewed by an authoritative body (eg PHE, US EPA) and it was outside the scope of this project to derive new HBGVs.

Search

The comprehensive literature search was limited to studies in English published from 2000 to 2018 and included the following aspects and disciplines: building physics, indoor air quality and ventilation, VOC emissions from construction and consumer products, case studies of concentrations for individual VOCs - with a focus on statistically significant/large scale studies, health effects, international guidance on health based domestic concentrations and suggested mitigation strategies. The following electronic databases were investigated: Scopus, including citation reports, Elsevier, Google Scholar, PubMed, Ovid Embase, EBSCO Global Health, TRIP and NICE Evidence. Furthermore, we investigated the grey literature, including European Union, UK and other Government legislative and policy documents, national and international VOC guidelines for indoor air, technical data sheets and specifications, published textbooks, reports from organisations involved in the investigation of VOC emissions from construction products, the refurbishment process, recognised websites (for example from construction organisations).

The comprehensive review is presented and discussed by Shrubsole et al. (2019). The PHE indoor air quality guidelines for selected VOCs in the UK are presented in Table 1.

Table 1 Indoor air quality guidelines for selected VOCs in the UK ($\mu g.m^{-3}$)

VOCs	Limit Values in $\mu g.m^{-3}$		Source Document	Reasoning for choice	Potential Health impacts
	Short Term	Long Term			
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 $1\mu g.m^{-3}$ 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 $0.17\mu g.m^{-3}$, 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 $5\mu g.m^{-3}$, 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 $\mu g/m^3$ 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]

Table 1 contd. Indoor air quality guidelines for selected VOCs in the UK (µg.m^{-3})

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)	No safe level of exposure can be recommended. Based on continuous exposure to 1 µg.m-3 from birth to age 70 the estimated lifetime unit risk of kidney cancer (adjusted for other cancers) is 4.8 x 10-6. The concentrations of airborne trichloroethylene associated with an excess lifetime cancer risk of 1/10 000, 1/100 000 and 1/1 000 000 are 21, 2.1 and 0.21 µg.m-3, respectively. respectively.		World Health Organisation (2010)	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.

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[2]Public Health England. Chemical hazards compendium.
[3]United States Environment Protection Agency. Iris Assessments.
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