BSRIA

TG 12/2021

Indoor Air Quality

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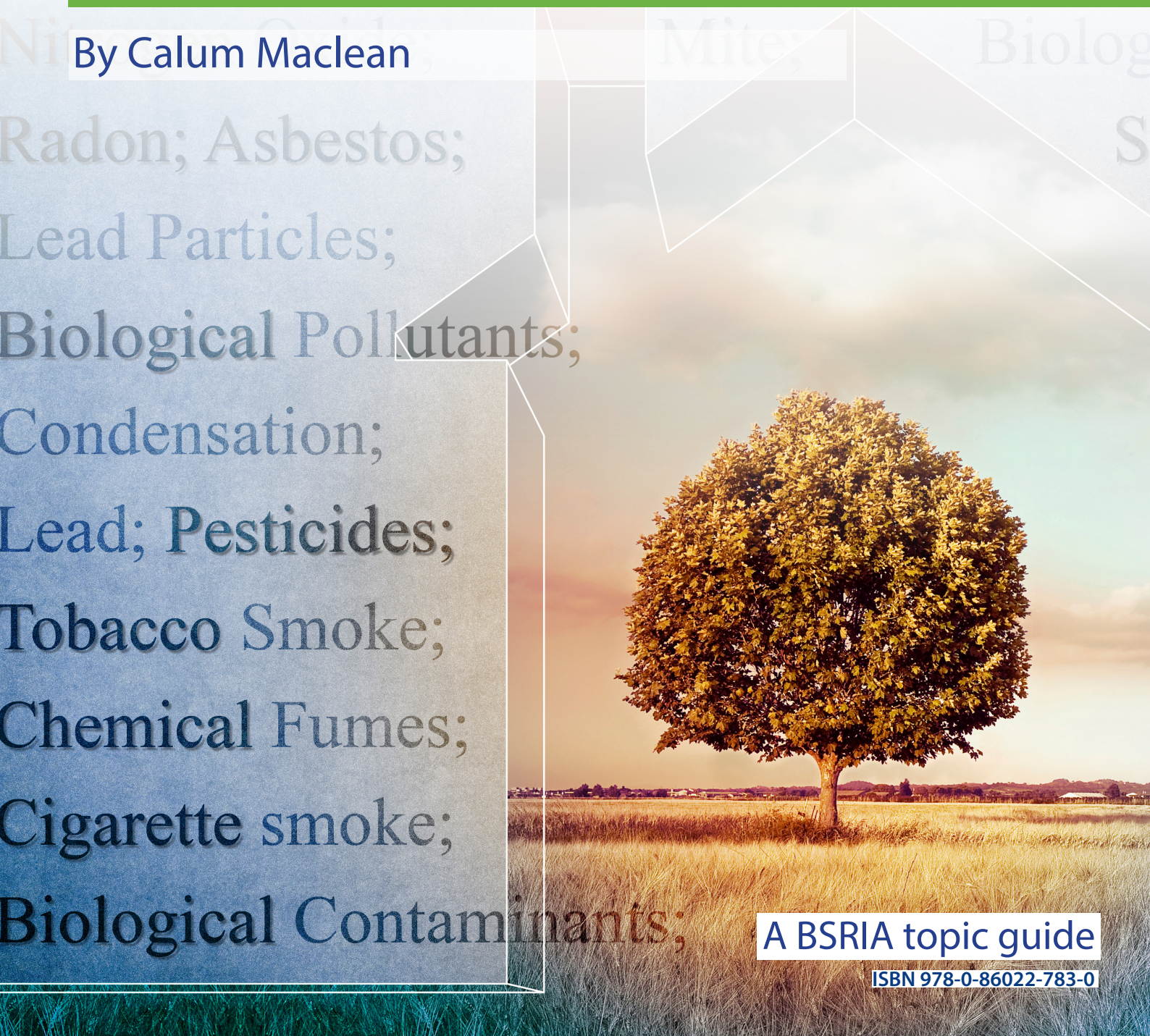


A BSRIA topic guide

ISBN 978-0-86022-783-0

INTRODUCTION

This guide gives a brief introduction to the topic of indoor air quality (IAQ). It describes the importance of indoor air quality, its effects on health, the most common contaminants and their exposure limits, how to measure them, the role of ventilation and the law.

Who is this guide for?

Facilities managers

Building owners

Building occupiers

Building services professionals

WHAT IS AIR QUALITY?

Air pollution can have a negative impact on our health; from short term effects such as eye irritation and coughs to long term effects such as respiratory infections and cancer. Air of good quality is air in which there are no known contaminants at harmful concentrations. The effect on health depends on the contaminant concentration and exposure time.

Outdoor Air Quality

Outdoor air pollution sources can be natural or human-made. Natural pollution is all around us all the time, from a variety of sources such as volcanic eruptions, biological decay and dust storms. These can dramatically increase the concentration of a contaminant in the atmosphere for a short period of time. Human-made air pollutants are of more concern since they can have a detrimental impact on public health. Most sources of outdoor air pollution are well beyond the control of individuals and demand action by local, national and international policymakers.

According to the World Health Organization (WHO), air pollution kills seven million people worldwide every year. WHO's urban air quality database covers 4300 cities across 108 countries, reflecting growing recognition of the health risks. Air quality in most cities worldwide that monitor outdoor air pollution fails to meet WHO guidelines for safe levels: 98% of cities in low and middle income countries and 56% in high income countries. This is putting more than 80% of people living in urban areas at additional risk of respiratory disease, cancer and acute respiratory infections.

Indoor Air Quality (IAQ)

In the UK, people spend approximately 80% of their time indoors. The quality of indoor air is affected not only by outdoor pollution, but also by indoor sources and inadequate ventilation. Tobacco smoke, mould, and chemicals released from synthetic fabrics, paints, furnishings and household products are some of the sources of contaminants that make indoor air worse than outdoor air at times. Indoor air pollutants may be biological, such as dust mite faeces, mould spores, viruses and pollen, or chemical, such as carbon monoxide, ozone and volatile organic compounds.

Threshold Limit Values

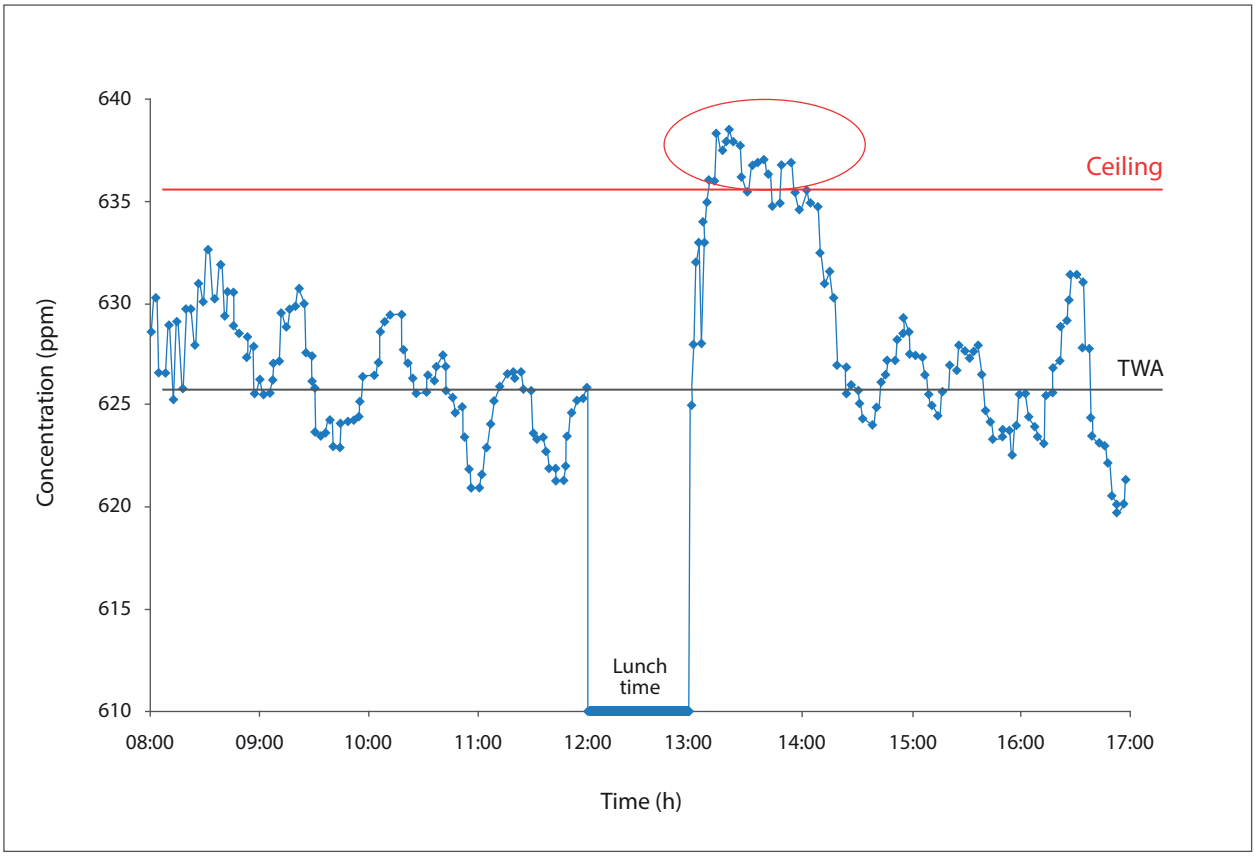
The threshold limit value (TLV) is a level to which it is believed a worker can be exposed day after day for a working lifetime without adverse effects to the health.

A TLV has three components:

- Time-weighted Average (TWA): The concentration of a contaminant averaged over a workday (usually 8 hours long)
- Ceiling value: A concentration of a toxic substance in air which should not be exceeded at any time during the workday.
- Short-term Exposure Limit (STEL) value: A TWA concentration over a shorter period of time, which should not be exceeded. TWAs and STELs are given for contaminants for which short-term hazards are known.

The figure below shows a potential contaminant, monitored during a day's work. Whilst the TWA is acceptable, the exposure to this contaminant exceeds the ceiling value.

Time weighted average and ceiling concentrations example



INDOOR AIR CONTAMINANTS

The table below shows the most common indoor air contaminants, their sources and their effects on health. More detailed information on some of these contaminants is provided further on in this guide. Where applicable, the table gives workplace exposure limits as stated in EH40/2005[1] and also the workplace exposure limit for Radon gas. More information about indoor air quality legislation is provided towards the end of this guide. Note that the table below is not an exhaustive list of all indoor air contaminants or of the EH40/2005 workplace exposure limits.

The following terms are used in the table:

- STEL: 15-minute short-term exposure limit (see section on threshold limit values)
- TWA: 8-hour time-weighted average (see section on threshold limit values)
- ppm: parts per million
- Bq/m^3: Becquerels per cubic metre
- VOC: Volatile organic compound

Contaminant	Sources	Effects on health	Workplace exposure limits
Particulates	Volcanoes, desert dust, sea spray, vehicles, power plants, building materials, dust mite faeces, pollen	Respiratory diseases, allergies, lung cancer	Various limits for particulates commonly found in industrial environments
Ozone (O_3)	Photocopiers, electric motors, electrostatic air cleaners, outdoor sources	Irritation and lung damage	0.2 ppm STEL
Sulfur dioxide (SO_2)	Traffic, combustion	Irritation to the nose and throat High exposure can cause nausea and lung damage	0.5 ppm TWA 1.0 ppm STEL
Carbon dioxide (CO_2)	Combustion, breathing	Drowsiness at high concentrations. Used as a proxy for general indoor air quality at lower concentrations.	5000 ppm TWA 15,000 ppm STEL
Carbon monoxide (CO)	Incomplete combustion	Can cause death, even at low levels	20 ppm TWA 100 ppm STEL
Hydrogen sulfide (H_2S)	Organic waste	Nausea, headache	5 ppm TWA 10 ppm STEL
Nitrogen monoxide (NO) (also known as nitric oxide or nitrogen oxide)	Combustion	Lung irritant, heart conditions	2 ppm TWA

Contaminant	Sources	Effects on health	Workplace exposure limits
Nitrogen dioxide (NO_2)	Combustion	Lung irritant, heart conditions	0.5 ppm TWA 1 ppm STEL
Radon (Rn)	The ground beneath buildings	Increase risk of lung cancer	300 Bq/m^3 annual average
Tetraclhloroethylene (C_2Cl_4) (a VOC)	Dry cleaning	Carcinogen	20 ppm TWA 40 ppm STEL
Toluene (C_7H_8) (a VOC)	Paints	Tiredness, confusion	50 ppm TWA 100 ppm STEL
Formaldehyde (CH_2O) (a VOC)	Disinfectants	Carcinogen, strong irritant	2 ppm TWA 2 ppm STEL
Xylene ($C_6H_4(CH_3)_2$) (a VOC)	Nail polish, paints, adhesives and varnishes	Nose, throat and skin irritant, nausea, unconsciousness, embryo toxicity	50 ppm TWA 100 ppm STEL
1,3-Butadiene (C_4H_6) (a VOC)	Tobacco smoke, exhaust fumes	Irritant, carcinogen	N/A
Asbestos fibres	Older building materials and insulation	Asbestosis, lung cancer	0.1 fibres/cm^3
Mould spores	Mould growth on damp surfaces	Sneezing, red eyes, skin rashes, asthma attacks	N/A
Viruses	Infected people	Short to long term adverse effects from irritation through to death due to complications or susceptibility	N/A
Bacteria	Infected people, outdoor sources	Short to long term adverse effects from irritation through to death due to complications or susceptibility	N/A
Tobacco smoke	Outdoor smoking areas	Direct health concerns to smokers and secondary health impacts to others from respiratory irritation to lung cancer	N/A
Body odours	Building occupants	N/A	N/A

REQUIREMENTS FOR GOOD IAQ

In order to achieve good indoor air quality, three basic requirements must be met – these are discussed below:

Low concentrations of pollution in intake air

The level of outdoor air pollution depends on the location of the building. Design considerations can also affect quality of air used to ventilate a building, for example, the locations of fresh air intakes in relation to pollution sources such as roads and boiler flues, and the degree of filtration used in the building's ventilation system.

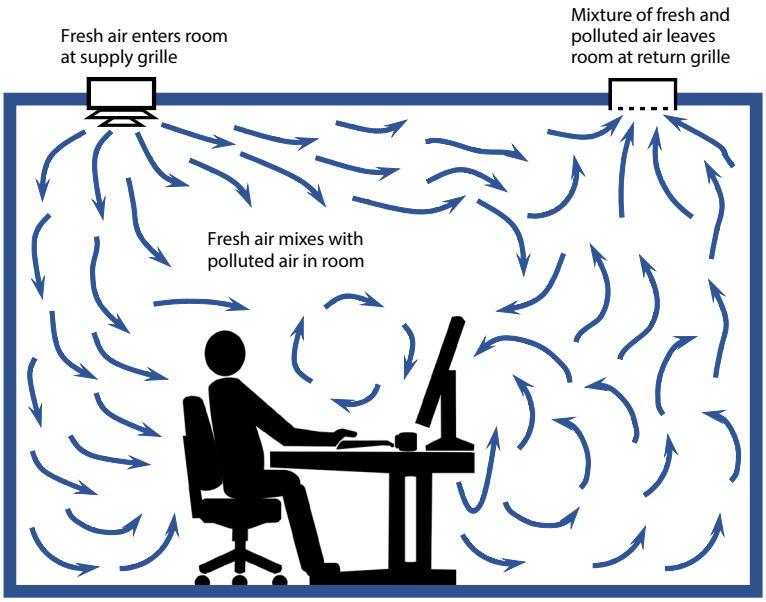
Low pollutant emission rates from internal sources

The emissions from internal sources can be limited in a number of ways, including the following:

- Selecting materials that have low VOC emissions
- Using cleaning products and processes that have low VOC emissions
- Regularly moving waste materials out of occupied areas
- Storing chemicals such as cleaning products in appropriate locations
- Locating equipment such as printers that emit ozone (O_3) in ventilated areas

Effective ventilation

Ventilation is required in all occupied buildings. It is particularly important in areas where moisture is produced, such as kitchens and bathrooms, as excess moisture can lead to mould growth. Natural or mechanical ventilation may be used, but in both cases the principle is the same – contaminants are diluted by the introduction of fresh air into the building. Some buildings make use of displacement, rather than dilution ventilation.



It is also common for specialised ventilation systems to be present, such as dedicated extract systems for toilets and kitchens, and local extract ventilation (LEV) systems for industrial activities which generate contaminants. Systems are generally designed to deliver a certain amount of fresh air per person, or per unit of floor area, but it is also important to ensure ventilation is effective. For example, the position of the internal supply and extract grilles should be considered to avoid short circuiting. Correct control is essential for all ventilation systems.

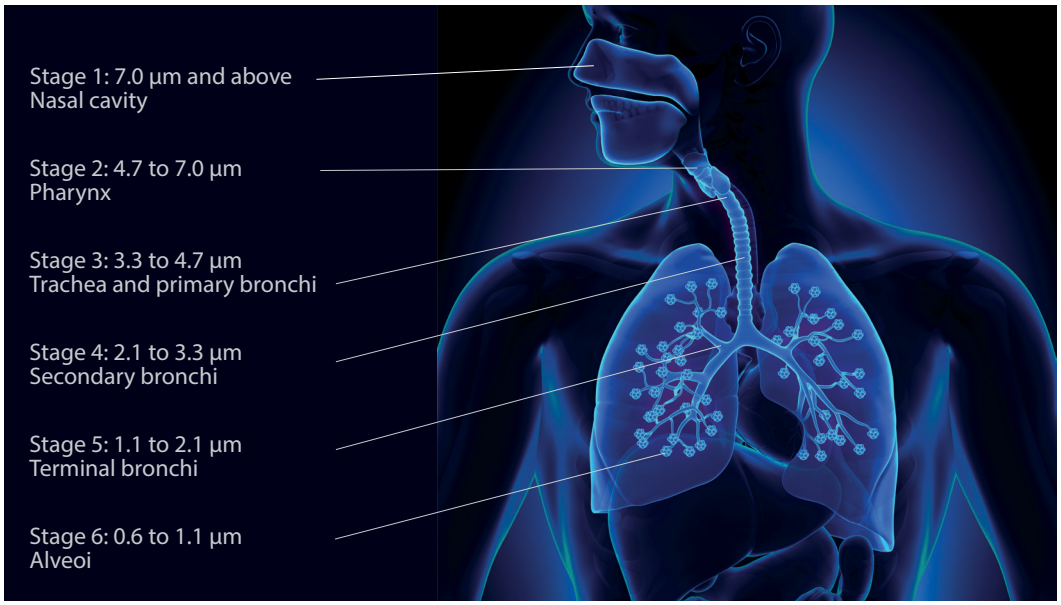
All ventilation systems need to be commissioned – a process of testing, adjusting and balancing – to ensure they are delivering the correct flow rates. They also need to be maintained throughout their lives, including changing filters, and internally cleaning ductwork and auxiliaries to keep them working efficiently and to reduce the risk of pathogenic infections. Further protection against bacteria can be achieved through the use of ultraviolet germicidal irradiation (UVGI) devices in the ventilation system. These devices can only work effectively if surfaces are free from deposits which could shield microbes from the UV radiation.

COMMON CONTAMINANTS

Particulates

Particulates (also known as aerosols) are small particles that are normally in air and can get into the respiratory tract (see diagram below). Particulates are often categorised according to the size of particles. Size categories which are commonly used in discussions of indoor air quality are PM_{10}, which refers to particulates of 10 µm (micrometres) or smaller and $PM_{2.5}$, which refers to particulates of 2.5 µm or smaller.

In general, the smaller the particle, the further it can reach into the human respiratory system. The diagram below illustrates this concept. Exposure to $PM_{2.5}$ can cause cardiovascular and respiratory diseases and cancers. Size is not the only determinant of the health effects of particulates – their shape and chemical composition also play a part, and the needle-like shape of asbestos fibres makes them particularly hazardous. Age and underlying health conditions such as asthma also have an effect.

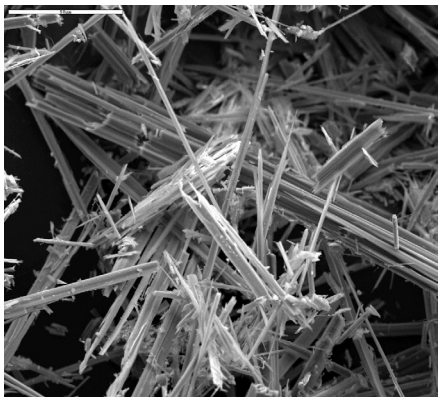


Much of the particulate pollution that damages health is the result of human activities, although some has natural sources. Particulates are released generally during combustion, thermal, mechanical and chemical processes – for example diesel vehicles are a major source of outdoor particulate pollution. Construction and demolition activities can also release large amounts of particulates.

House dust mites are microscopic arachnids which are present wherever humans live. Their faeces are a constituent of dust in buildings and are an allergen, causing itching, eczema and asthma.

Natural sources of particulates include pollen, windblown desert dust, volcanoes and sea spray aerosols.

More information on particulates can be found in the BSRIA webinar *An introduction to aerosol particles, common sources, measurement methods, guidance and regulations* (**www.bsria.com/uk/information-training/events/webinars/**)



Asbestos

Asbestos was formerly used as a building material, noted for its excellent insulation, fireproofing and acoustic properties. Its use has been banned in the UK, and buildings constructed after 1999 should not have any asbestos-containing materials (ACMs) in them. However, many older buildings do contain ACMs. These can present a serious health hazard if disturbed, as fibres can be breathed in and become lodged in the lungs. Undisturbed asbestos does not present a health hazard; however, building owners should maintain a register of ACMs present, and take steps to manage the risk.

Odours

One of the roles of ventilation in buildings is to control odours. Odours are closely linked to IAQ. Although some harmful contaminants do not smell (for example carbon monoxide), odours can be unpleasant and can sometimes give occupants an indication that there are harmful substances in the air that need to be addressed, or that ventilation is needed. The main sources of odours in a building are the occupants themselves; however, odours can also be produced from other sources such as food.

Nitrogen Oxides

Nitrogen oxides, including NO and NO_2 (often referred to collectively as NO_x) are formed during the combustion of fossil fuels. Their impact on health includes respiratory problems, heart conditions and lung damage. These gases not only have a strong impact on health, but also contribute to climate change, as chemical reactions involving nitrous oxides contribute to the creation of tropospheric ozone, smog and indirectly, climate change.

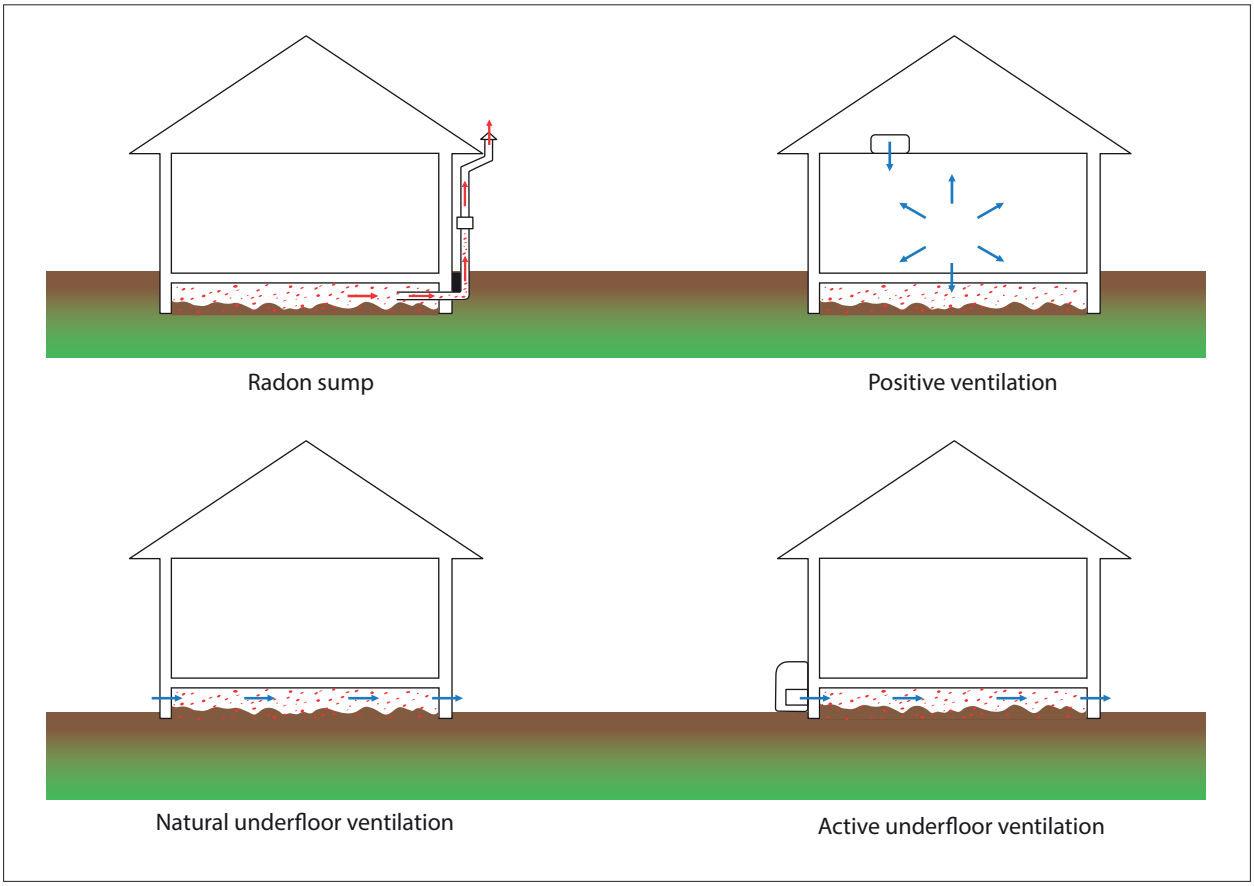
Carbon Monoxide

Carbon monoxide (CO) is an odourless, colourless gas produced by the incomplete combustion of fuels such as oil, wood or gas. CO binds with haemoglobin and hinders the ability of the body to deliver oxygen to cells. Therefore, CO acts by rendering a person gradually unconscious and it is lethal at low concentrations.

Radon

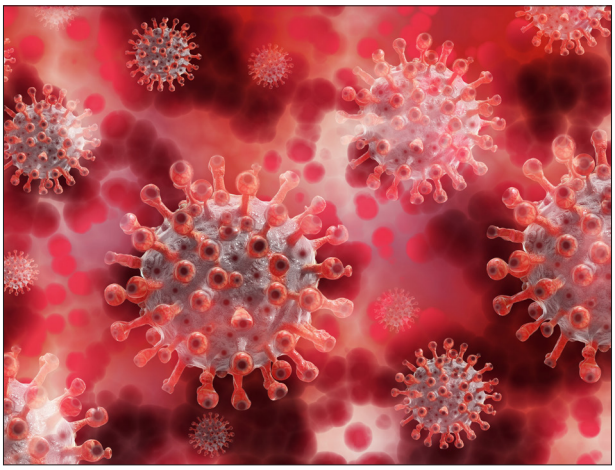
Radon is a gas that is formed by the natural decay of uranium that exists naturally in rocks. It is responsible for over 1100 deaths from lung cancer every year in the UK. For buildings in high radon areas, there are steps that can be taken to reduce the concentration of radon, such as a radon sump or underfloor ventilation.

Radon ventilation solutions



COVID-19

At the time of publication, a global pandemic is affecting the way buildings are occupied and operated. The COVID-19 virus is an indoor air pollutant, and as with others, its effects can be reduced through dilution. In addition to practices such as social distancing and mask-wearing, the risk of airborne transmission in the indoor environment can be reduced by increasing the amount of fresh air ventilation. The methods of achieving this are dependent on the type of ventilation system present in the building, but may include:



- Opening windows
- Increasing rates of mechanical ventilation
- Switching recirculation systems to deliver 100% fresh air
- Utilising room cleaners with HEPA filters
- Ultraviolet germicidal irradiation (UVGI), also called germicidal ultraviolet (GUV)

Further information can be found in the REHVA COVID-19 guidance[2].

Volatile Organic Compounds

Volatile organic compounds (VOCs) are carbon-based chemicals that easily evaporate at room temperature. There are many different VOCs and their effects on health can vary from causing respiratory system irritation to cancer. Health effects depend on the toxicity of the VOC, the exposure and a person's health, for example if they have asthma.

The most common sources of VOCs in indoor environments are:

- Carpets and furnishings
- Building materials
- Paints*, adhesives and varnishes
- Cosmetics
- Perfumes
- Cleaning products
- Cooking
- Dry cleaning
- Tobacco smoke

*While solvent-based paints can be major sources of VOCs, water-based paints can also produce small amounts of VOCs.

Short-term and long-term effects of exposure to VOCs

Short-term (acute) effects of high levels of VOCs	Long-term (chronic) effects of high levels of VOCs
– Eye, nose and throat irritation – Headaches – Nausea / Vomiting – Dizziness – Worsening of asthma symptoms	Increased risk of: – Cancer – Liver damage – Kidney damage – Central nervous system damage

Mould

Moulds are fungi that produce spores that float in the air, land on damp surfaces, and grow. They can cause sneezing, red eyes and skin rashes and can aggravate respiratory problems. The key to mould control is moisture control - water vapour is not a pollutant per se; however, high moisture content in the air contributes to creating an ideal environment for mould growth.

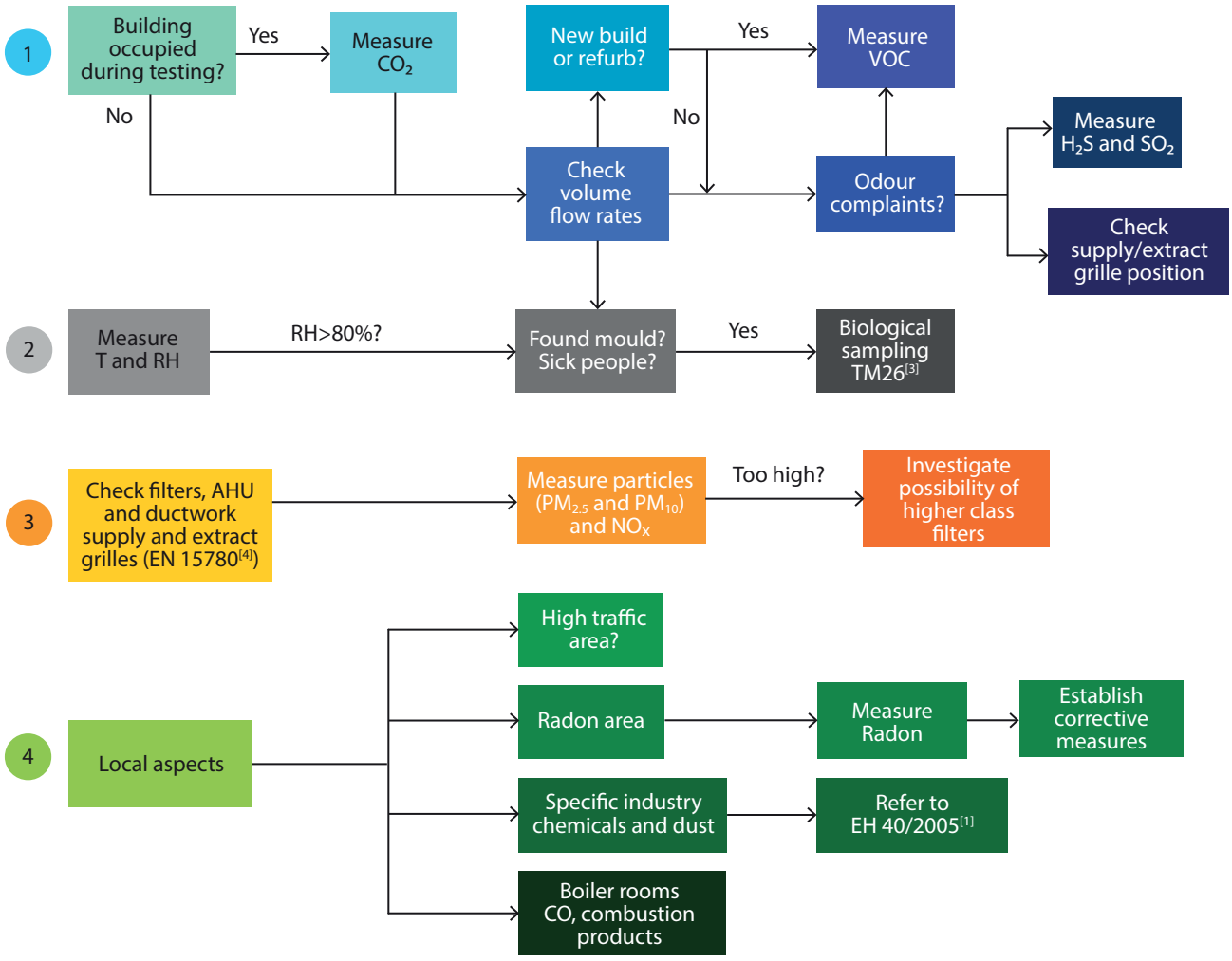
MONITORING OF INDOOR AIR QUALITY

Monitoring IAQ in a building can help with identifying sources of indoor air pollution and improving the health and wellbeing of occupants. Measuring for a long list of contaminants can be expensive, so an informed approach must be found. The flow chart below suggests a structured approach to deciding which contaminants to measure.

The level of CO_2 in an occupied space is a good indicator of the general IAQ. Measurements taken in a space that has been fully occupied for some time can be compared with benchmark measurements from the same space after a period of being unoccupied.

Measuring for total VOCs (TVOC) as a whole and identifying the VOCs with the largest concentrations can give an indication of any problematic pollution sources and it is not an expensive test.

The location of the building can indicate what contaminants to look for. For example, if the building is next to a busy road, measuring for NO_x (NO and NO_2) and particulates ($PM_{2.5}$ and PM_{10}) should be considered. If the building is in a radon risk area, checking radon levels in the building and investigating ventilation solutions should be a priority.



LEGISLATION

Building Regulations include requirements for ventilation. In England, Wales and Northern Ireland, the requirement is "There shall be adequate means of ventilation provided for people in the building." In Scotland, the requirement is "Every building must be designed and constructed in such a way that ventilation is provided so that the air quality inside the building is not a threat to the building or the health of the occupants." Guidance is provided in the following documents:

- England: Approved Document F[5]
- Wales: Approved Document F[6]
- Scotland: Technical Handbook Section 3.14 (domestic and non-domestic)[7]
- Northern Ireland: Technical Booklet K[8]

It should be noted that Building Regulations and associated guidance apply to carrying out building work – for example new buildings, extensions, material changes of use and fitting of new ventilation systems.

Building Regulations do not apply to ongoing management and maintenance of buildings. However, if the building is a workplace, then the **Workplace (Health, Safety and Welfare) Regulations 1992** apply. These are UK-wide and require that "Effective and suitable provision shall be made to ensure that every enclosed workplace is ventilated by a sufficient quantity of fresh or purified air." Guidance is provided in L24[9]. This doesn't give specific contaminant levels or ventilation rates, but does include guidance such as "Mechanical ventilation systems (including air-conditioning systems) should be regularly and adequately cleaned. They should also be properly tested and maintained to ensure that they are kept clean and free from anything which may contaminate the air."

The Control of Substances Hazardous to Health Regulations 2002 (better known as COSHH) require employers who carry out work which may expose employees and others to hazardous substances to undertake a suitable and sufficient assessment of the risks created by that work and the provisions required to prevent exposure. In support of COSHH, the Health and Safety Executive (HSE) provides workplace exposure limits in their publication EH40/2005[1]. General guidance on COSHH can be found at **www.hse.gov.uk/coshh**.

The **Ionising Radiations Regulations 2017** (sometimes referred to as IRR17) come into effect in workplaces where radon is present above the defined level of 300 Bq/m^3 (as an annual average). Employers are then required to take action to restrict exposure to their employees. Guidance can be found at **www.hse.gov.uk/radiation/ionising** and in HSE publication L121[10].

The **Control of Asbestos Regulations 2012** require dutyholders to manage asbestos in premises over which they have control. This includes finding out whether asbestos is present, assessing the risk, making a plan to manage that risk and providing information to contractors who are likely to disturb any asbestos. Guidance can be found at **www.hse.gov.uk/asbestos** and in HSE publication L143[11].

REFERENCES

1 HSE EH40/2005 *Workplace Exposure Limits*
Free download from **https://www.hse.gov.uk/pubns/books/eh40.htm**

2 REHVA *COVID-19 guidance*
Available from **https://www.rehva.eu/activities/covid-19-guidance**

3 CIBSE TM 26 *Hygienic maintenance of office ventilation ductwork*
Available from **https://www.cibse.org/knowledge**

4 BS EN 15780:2011 *Ventilation for buildings. Ductwork. Cleanliness of ventilation systems*
Available from **https://shop.bsigroup.com**

5 Approved Document F: *Ventilation*
Free download from **https://www.gov.uk/government/collections/approved-documents**

6 Approved Document F: *Ventilation*
Free download from **https://gov.wales/building-regulations-approved-documents**

7 Technical handbooks, domestic and non-domestic
Free download from **https://www.gov.scot/policies/building-standards/monitoring-improving-building-regulations/**

8 Technical Booklet K: *Ventilation*
Free download from **https://www.finance-ni.gov.uk/publications/technical-booklet-k**

9 HSE L24 *Workplace health, safety and welfare. Workplace (Health, Safety and Welfare) Regulations 1992. Approved Code of Practice and guidance*
Free download from **https://www.hse.gov.uk/pubns/books/l24.htm**

10 HSE L121 *Work with ionising radiation. Ionising Radiations Regulations 2017. Approved Code of Practice and guidance*
Free download from **https://www.hse.gov.uk/pubns/priced/l121.pdf**

11 HSE L143 *Managing and working with asbestos – Control of Asbestos Regulations 2012 – Approved Code of Practice and guidance*
Free download from **https://www.hse.gov.uk/pubns/books/l143.htm**

FURTHER READING

- BSRIA BG 49/2015 *Commissioning Air Systems*
  Available from **https://www.bsria.com** (free download for BSRIA members)
- CIBSE *KS17 Indoor Air Quality and Ventilation*
  Available from **https://www.cibse.org/knowledge**
- WHO *Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide*
  Available from **https://www.euro.who.int**
- Air Quality Expert Group *Fine Particulate Matter ($PM_{2.5}$) in the United Kingdom*
  Available from **https://uk-air.defra.gov.uk**
- ASHRAE I*ndoor Air Quality Guide: Best Practices for Design, Construction and Commissioning*
  Available from **https://www.ashrae.org**

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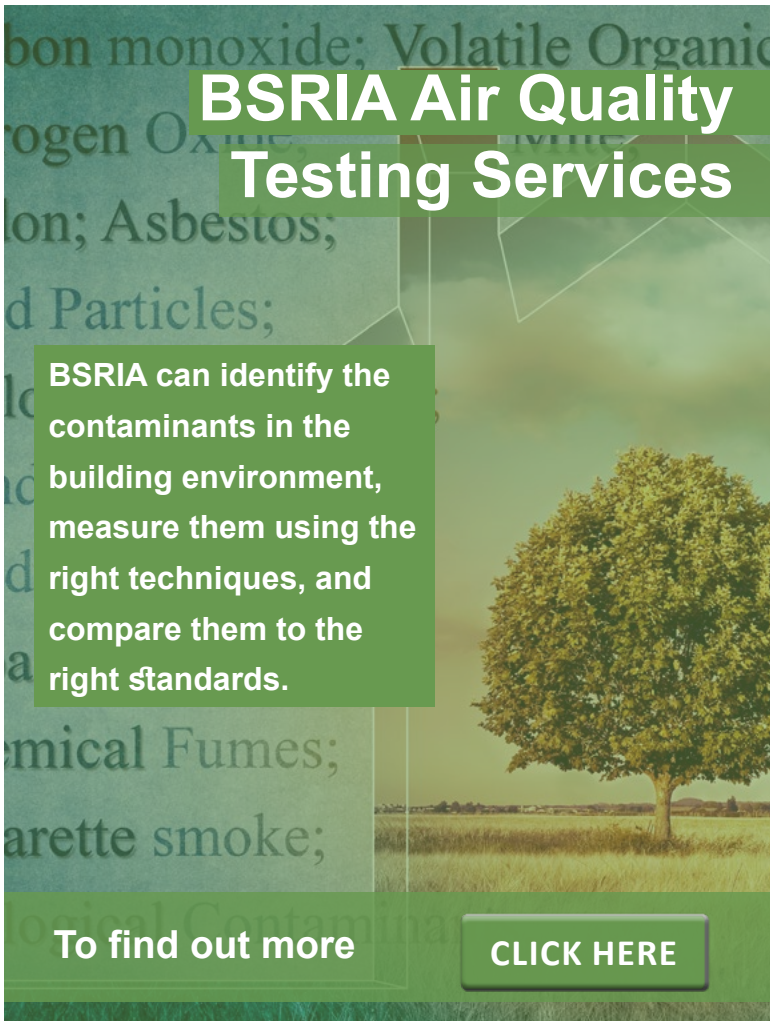

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