The inside story:
Health effects of indoor air quality on children and young people

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Royal College of Physicians

RCPCH
Royal College of Paediatrics and Child Health
Leading the way in Children's Health

Professor Alexander John Henderson
11th February 1958 – 24th July 2019

We dedicate our report to John Henderson who was a member of our Working Party. John went to Medical School in Manchester and qualified as a doctor in 1981. During his early clinical career, he developed his interests in Respiratory Medicine in children and was particularly focused on the physiology of breathing and lung function in tiny babies and children.

Within the Avon Longitudinal Study of Parents & Children (ALSPAC), he established a programme of respiratory follow up that included lung function measurements, assessment of allergies and longitudinal information on wheezing illnesses and asthma through childhood. He focused on identifying different phenotypes of asthma in early childhood and how genetics and environments influence their development. John died of cancer on the 24th of July 2019 in St Peter's Hospice, Bristol at the age of 61.

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Glossary

Some of the terms used in this report may be unfamiliar to readers. There are brief descriptions in the text; this glossary is intended as a helpful reference point and to provide some additional context.

Ammonia

At room temperature ammonia is a gas. It is found in many cleaning products and in tobacco smoke. Outdoor sources such as industry and agriculture can also contribute to exposure indoors.

Animal and biological pollutants

Indoor allergens include those from house dust mites (HDM), cat, dog, cockroach and mouse allergens. Mould and fungi are also found indoors and can reduce air quality. These pollutants are found in the air, dust and on furniture.

Carbon dioxide

Carbon dioxide (CO_2) concentrations are used to assess the adequacy of ventilation in rooms and buildings. High levels of CO_2 are a sign of inadequate ventilation and may have cognitive effects such as reduced ability to concentrate.

CO_2 in indoor air is also influenced by the levels outdoors. This atmospheric CO_2 has been increasing in recent decades, in part due to the use of fossil fuels, and is a significant factor in climate change.

Carbon monoxide

Carbon monoxide (CO) is a colourless and odourless highly poisonous gas, formed from the incomplete combustion of fuels. Common sources include cooking and heating appliances, vehicle emissions, and smoking.

Endocrine disrupting chemicals

Endocrine Disrupting Chemicals (EDCs) are generally synthetic compounds and interfere with human hormones. They are found in pesticides, personal care and cleaning products, household items and a range of materials including paints. Indoors these are often present in dust and in the air.

See also '*semi-volatile organic compounds*'.

Endotoxin

Endotoxin is shed from bacteria and can be found indoors in the dust or the air. Studies often look at endotoxin alongside β-d-glucan, a marker for bacteria or mould in the home.

Flame retardants

Flame retardants are substances added to combustible materials to stop or slow fire. The term is based on the function as the chemicals used are quite diverse. They are used to treat a variety of building materials and furnishings.

Some flame retardants are known to be Endocrine Disrupting Chemicals. One type, Polybrominated Diphenyl Ethers (PBDEs), is no longer produced in the EU.

Formaldehyde

Formaldehyde is a naturally occurring gas and produced synthetically for a wide range of uses. It is present in many building materials, furniture, coatings and finishes, and household products. It is also found in tobacco smoke, produced in chemical reactions, and can be emitted through cooking.

Nitrogen oxides

Nitric oxide (NO) and nitrogen dioxide (NO_2) are key components of outdoor air pollution. Together they are often referred to as NO_x and are a product of combustion. Sources include motor vehicles, energy production, and industry.

Indoor air quality is affected by outdoor NO_x coming inside. Indoor pollution (NO_2 in particular) can be caused by burning gas, oil, paraffin, coal or wood. Tobacco smoking and candles are also sources.

Ozone

Ozone (O_3) can be produced when sunlight reacts with pollutant mixtures in the atmosphere. At ground-level it is a significant air pollutant and, like other outdoor air pollutants, also enters buildings. Ozone can also be produced by some devices such as printers, photocopiers and some air cleaning appliances. Ozone reacts with other indoor air pollutants.

In contrast, ozone in the stratosphere protects against ultraviolet rays and became depleted through the use of Chlorinated Fluorocarbons (CFCs) which are now banned.

Particulate matter

Particulate matter (PM) is suspended droplets and inhalable solid particles found in the air, in dust, or on surfaces. PM is usually classified into three categories. These are grouped by the maximum diameter in micrometres: inhalable particles (PM_{10}), fine particles ($PM_{2.5}$), and ultrafine particles (UFP). UFP have a diameter of less than 0.1 micrometre.

The chemical composition of PM in the air changes depending on the source of the particles. Major indoor PM sources include outdoor air, smoking, cooking, burning (fires, stoves, candles, and incense), cleaning and people.

Per- and poly-fluorinated alkyl substances

Per- and poly-fluorinated alkyl substances (PFAS) are a group of manufactured chemicals. These chemicals do not break down, and they can stay in the human body for a long time. PFAS are used as stain or water repellents on a wide range of products, and in non-stick coatings. They have been found in air and dust samples indoors.

Pesticides or insecticides

Pesticides and insecticides are mainly used outdoors but can contribute to indoor air quality through air, soil or other particles entering the home. Indoor uses include to control pests in the home, on pets, and for houseplants. There are a range of diverse chemicals used, including organophosphates (halogenated and non-halogenated).

Phenols

Phenols are a type of synthetic, water-soluble chemical (organic phenol is commonly found in foods). Indoors, phenols are found in cleaning products, polishes, paints and adhesives. Phenols can also be released by burning wood, fuels or tobacco.

Polycyclic Aromatic Hydrocarbons

Polycyclic Aromatic Hydrocarbons (PAHs) are a sub-set of Volatile Organic Compounds. PAHs are formed from incomplete combustion of organic matter. Indoors this means key sources are outdoor air, cooking, and burning wood, coal or tobacco.

PAHs include benzene, benzo-a-pyrene, naphthalene, toluene, and xylenes.

See also '*Volatile Organic Compounds*'.

Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are emitted from a very wide range of indoor and outdoor sources. This happens through combustion and from the use of products such as paints, coatings or pesticides; VOCs can vaporise into the air from the source materials. Total VOCs (TVOCs) is used as a measure of the combined concentration of VOCs.

There are a very wide range of VOCs, with and without known health effects. This list draws from those mentioned in the report and from a list highlighted by Public Health England[69]:

Glycol ethers, 1-butanol, tridecane, and trichloroethylene are solvents. These are found in various paints, adhesives, waxes/finishes, and cleaning products.

Ethylbenzene is found naturally in coal and petroleum. It is also manufactured for products including paints, inks, and insecticide.

Octane is a component of petrol and used in paints, adhesives and building materials.

Acrolein is produced by cooking due to a chemical reaction from heating oil or fat. It is also a product of combustion of petroleum fuels, biodiesel or tobacco.

α-pinene and **d-limonene** are commonly used in fragranced products.

Acetaldehyde is found everywhere in both indoor and outdoor air. Sources include plant/animal respiration, combustion, vehicle exhaust, cooking, industry, some interior finishes and building materials.

Styrene is used in polystyrene, a very wide range of other plastics, and some resins.

Tetrachloroethylene is used in dry cleaning, certain fabric finishes, and as a de-greasing agent.

Radon

Radon is a radioactive gas and is found at varying levels across the UK. It enters a building through the ground, cracks in walls, and (generally in smaller amounts) can be released from some building materials. Radon can accumulate indoors if there is inadequate ventilation.

Semi-Volatile Organic Compounds

Semi-Volatile Organic Compounds (SVOCs) are like volatile organic compounds, although they have a higher boiling point. SVOCs can vaporise from products containing them and affect the indoor air quality. SVOCs are used in many indoor materials or products including plastic, pesticides, flame retardants and plasticisers. Phthalates are a group of SVOCs commonly used in plastic products for flexibility, many of which are examples of Endocrine Disrupting Chemicals.

1. Indoor air quality in homes and schools

The Royal College of Paediatrics and Child Health and the Royal College of Physicians wish to support clinicians by providing the tools to advocate for healthy air for their patients.

The United Nations Convention on the Rights of the Child sets out clear guidance to protecting the rights of children and young people, including a child's right to the best possible health (Article 24) and the right to a good standard of living. Government must support this where the family is unable (Article 27). Unicef also consider[1] that clean air is a right for all children. The Royal Colleges vigorously advocate for a healthy environment at the population level and in local communities, especially where socioeconomic circumstances limit the choice of where people can live, and which school children attend.

When there is mounting evidence to establish a potential cause of preventable ill health Royal Colleges can advocate for change, including regulatory change. This has happened before for tobacco smoking, asbestos, outdoor air pollution, and damp, mouldy homes. The focus of this report is about the emerging evidence on indoor air pollution, and sets out recommendations aimed at preventing poor indoor air quality affecting the health and well-being of children.

The importance of the indoors

The evidence[3] is such that *The Lancet* Commission on Pollution and Health declared pollution as the greatest environmental health risk to the world population, singling out the effects of air pollution in particular[4]. The World Health Organisation (WHO) reported[5] that, globally, 9 out of 10 people breathe air containing high levels of pollutants (that is, concentrations which exceed the WHO guidelines). *The Lancet* Commission stressed how outdoor air pollution is tied to human causes of climate change, which itself poses a serious threat to human health. The health effects from outdoor pollution mean that in developed countries there is increasing use of regulation to set legal limits on pollutants and acceptable emissions. Even though people spend the great majority of their time indoors, the potential risk to our health from poor indoor air quality has been over-looked.

Yet the indoor environment has never been more important. From 1975 to 2015 research tracked how and where children in the UK spent their days. The trend was clear that children are "leading less physically active, more home-based lives"[6]. During the week, the average person in the UK spends fewer than two hours a day outside[7].

Figure 1: Indoor air quality and children; statistics from the UK[2]

Source: Royal College of Paediatrics and Child Health

In 2016, the Royal College of Physicians (RCP) and the Royal College of Paediatrics and Child Health (RCPH) published *Every Breath We Take: The Lifelong Impact of Air Pollution*[8]. This reported that air pollution in the UK has a burden on mortality equivalent to 40,000 deaths per year. Further analysis placed the number between 36,000[9] and 65,000[10]. Lives are lost especially through increases in cardiovascular and respiratory conditions[8], but there are known health risks throughout the body.

These risks include:

- asthma and allergies
- impaired cognition
- impaired lung and cardiovascular development along with associated disease
- gene changes causing cancer
- many other diseases associated with ageing – chronic obstructive pulmonary disease, ischaemic heart disease and stroke, Type II diabetes, Parkinson's and Alzheimer's disease.

Sources of indoor pollution include smoking, damp, cooking, the burning of fossil fuels and wood, dust, chemicals from building materials and furnishings, aerosol sprays, cleaning and other household products. In the average house, concentrations of Volatile Organic Compounds (VOCs) released from these sources are up to seven times higher indoors than in the air outside[11]. The use of personal-care and household products indoors produces a significant portion of outdoor VOC pollution[11].

Little is known about how the different pollutants react with one another, once mixed together inside buildings[13]. However, it is now recognised that a range of chemical reactions can occur which produce a complex range of gases and particles. The products of these reactions are referred to as 'secondary pollutants', and they can be more harmful than the original pollutants. For example, nicotine and ozone can react to form carcinogenic compounds[14].

We are routinely exposed to outdoor pollution when we are indoors[15]. Nitrogen dioxide (NO_2), inhalable particles (PM_{10} and $PM_{2.5}$) and other pollutants in the surrounding outdoor air enters buildings and vehicles[16]. Higher outdoor pollution is found close to busy roads, and this disproportionately affects urban and low-income areas[17]. Outdoor air pollution has become a major challenge in urban classrooms, leading some schools to attempt to discourage parents idling car engines before and after school[18]. From conception through to early adulthood, organs such as the lung and brain continue to grow and develop. This makes children and young people particularly vulnerable to the effects of indoor and outdoor air pollution. It remains of utmost importance for children's health to reduce the exposure to and the adverse effects of outdoor air pollution[8], but little attention has been given to pollutant exposures indoors.

> **"We must further expand this focus to indoor air. Work to gather evidence of health impacts, raise awareness of any harm and highlight actions to address this is needed."[12]**
>
> Former Chief Medical Officer for England,
> **Professor Dame Sally Davies**

There are several well-established health risks from indoor pollution, which include:

- **Carbon monoxide**, which can be released by incorrectly installed, poorly maintained or poorly ventilated household appliances such as cookers, heaters and central heating boilers. It is a deadly indoor pollutant, for which there are tight regulations[19].
- **Tobacco smoke**, which is highly toxic and has health effects when directly inhaled as a smoker

or as a result of others smoking in the same environment. Less well-known is that tobacco smoke can be absorbed by surfaces in the home, and chemically react with other indoor pollutants. This is referred to as third-hand tobacco smoke[14].

- **Radon**, which is a radioactive gas found in parts of the UK. If a building is under-ventilated, dangerous levels of radon can build up indoors. It has been shown to greatly increase the risk of lung cancer, especially in tobacco smokers[20].
- **Asbestos**, which was widely used in building materials throughout the twentieth century. It was banned[21] after being found to cause serious health conditions. However, it can still be found in buildings built or refurbished before the year 2000 and its removal must follow strict safety procedures.

Beyond these well-established hazards and risks, the evidence base linking health effects specifically to indoor sources of pollution is still growing and developing. This emerging evidence base is the focus of this report. It was a key reason for undertaking this work: to bring the evidence relevant to children's health together, and advocate for the changes needed to protect them from polluted indoor air.

Changes in the indoor environment

There have been many relatively recent changes in our buildings and their contents which have had a major impact on the air we breathe[22]. Rather than solid wood, furniture and flooring are now more likely to be made with a veneer glued to composite wood. Cotton or woollen carpets have been replaced by synthetic fibres, which are treated with stain repellents and flame retardants. Feathers, wool and down once used as cushioning are routinely replaced by flame retardant treated, synthetic foams. Some of the replacements have known health effects, for example flame retardants have been associated with the most common type of thyroid cancer[23].

Over recent decades, cleaning products have changed from using fatty soaps and acids (such as carbolic acid) to non-ionic surfactants and terpenoid-based solvents. Frequent use of cleaning products at home or at work has been linked to lung function decline and the development of asthma[24].

Some changes have already been made to chemicals used in the home, driven by identified health risks. For instance, carbon tetrachloride, once used as a stain remover, was removed from domestic products in 2002 (although it continues to be used in professional dry-cleaning). Benzene was commonly used in cleaning products before it was confirmed as a carcinogen. Popular "air freshener" sprays were removed due to the huge environmental damage caused by CFC gases used in the aerosols. These were replaced with products such as scented candles, non-CFC sprays, and plug-in devices.

As well as being present in the air we breathe, chemicals from cleaning or other consumer products accumulate in indoor dust, becoming suspended in the air when the dust is disturbed[25].

Household dust has been found to contain:

- phthalates from shampoos and plastics
- phenols from paints and cleaning products
- flame retardants and pesticides
- fragrances and endocrine disrupting chemicals
- per- and poly-fluorinated alkyl substances (PFAS) used in some fabrics and non-stick coatings[26].

In the 1970's, the energy crisis changed the design and construction of houses and public buildings. There was rightly a new emphasis on insulation to save energy costs. Energy efficiency is both economically and environmentally important, and there are health benefits from warm, dry homes. Although energy efficient buildings have become increasingly air-tight, ventilation provision and advice has not followed suit. Without adequate ventilation, and with new sources of pollutants indoors, health issues have been associated with poor air quality[27]. Unfortunately, research has not kept pace with the changes to our indoor environments, and many products have been introduced with little known evidence on the effects for humans (especially when products are used in combination).

Indoor Air Quality Working Party

In 2015[8], the RCPCH and RCP highlighted indoor air quality as important to human health. As part of a larger piece of work it was difficult to do the subject justice without a thorough appraisal of the published literature. In April 2017, the RCPCH hosted a workshop, *Better homes, better air, better health*, that brought together professionals across research, industry and the third sector[29]. The workshop highlighted the need to understand how indoor air pollution exposure impacts on health; to identify ways to reduce indoor air pollution; and to communicate this information clearly to the public.

"Outdoor air has been regulated for decades, but emissions from daily domestic activities may be more dangerous than anyone imagined."[28]

The New Yorker, 2019

In 2018 the RCPCH led a systematic review of literature on the effects of indoor air pollution on children's health. This work has been supplemented by two additional reviews, and each of the three reviews have a different focus: the effects of exposure on child health[30], assessing air purification technologies[31], and factors influencing indoor exposure levels[32].

The RCPCH and RCP established an Indoor Air Quality Working Party (WP)[33] to use these reviews, to investigate the evidence around indoor air quality, and to propose steps to protect the health of children. The WP authored this report to:

- **communicate the evidence** on how indoor air pollution in homes and schools adversely affects the health of children and young people
- **make recommendations** for new and existing homes and schools to mitigate risk
- **highlight the potential impact** of cross-cutting social and environmental issues, such as climate change, on indoor air pollution.

The WP sought the views of stakeholders by issuing a call for evidence. Subject-specific experts also formed an advisory panel to review and guide the work. While the systematic reviews were a vital source of information, we are indebted to the evidence and experience from our advisors and stakeholders.

The WP focused on homes, schools and nurseries but excluded other buildings and transport. The range of pollutants included both chemical and biological substances as well as gases and particles. The WP decided not to focus on tobacco smoke, acute effects of carbon monoxide, radon or asbestos. Their health risks are well known and have been covered extensively elsewhere. There are existing strategies and regulations in place to prevent or limit indoor exposure to them, although these regulations are not always effective. In contrast to vehicles and public buildings, children's exposure to tobacco smoke in the home is not regulated.

To ensure the views and voices of children would shape the findings and recommendations, the RCPCH &Us network[34] engaged with over 200 children, young people and their parents, who took part in interviews, clinic discussions, art sessions, and workshops. The RCPCH &Us network is for children, young people, parents and carers. It was created to actively seek out and share their views to influence and shape policy and practice. An editorial committee of young people produced a key chapter of this report, drawing on the themes which emerged from the engagement work.

2. Recommendations

NHS England states that "Good health starts at home"[35], but the housing and homelessness charity Shelter found that in the UK more than 3.6 million children live in poor quality housing[36]. There is a lack of robust, longitudinal, consistent data on indoor air across the national housing stock[8]. For the sake of the next generations, we need action from across Government and society to prevent health being put at risk by the air inside our buildings.

Between February and August 2019, the RCPCH &Us team visited paediatric clinics in hospitals, youth centres and schools. They spoke with over 200 young people and their families about indoor air quality. Young volunteers, joined by some parents and carers, then came together as **#TeamCleanAir&Us** to identify common themes from the conversations. Based on these themes they developed their own recommendations, presented here in the yellow boxes. This unique contribution brings the views, ideas and experiences of children and young people together with the scientifically-based evidence from the Working Party.

The design of buildings and urban spaces frequently presents occupants with difficult choices to find a balance between affordable warmth and good indoor air quality. Poorly insulated homes often lead to damp; while subsequent advice to 'turn your heating up and open your windows' may improve ventilation, this comes with other consequences, including cold, heat loss, increased heating bills, and external problems with noise and concerns over security. Drying clothes is another example – where outdoor drying spaces are remote, or not useable in poor weather, occupants are caught between either drying clothes indoors, or (if available) using expensive tumble dryers. People living in existing buildings, particularly tenants, have no control of the wide range of materials that are used in their construction.

Advice to occupants has to be tailored for the nature of the building, its form, location, fabric, the heating and ventilation systems. Those responsible for the legislation, design and construction of buildings must ensure that these are fit for purpose. Improving indoor air quality is not the responsibility of individuals, one industry, one profession or one government department. We must work together to make safe air for children a reality.

To help everyone reading this report understand what action they can take, the recommendations are presented here by theme:

- Establish national strategy and regulations
- Advise the public and professionals
- Increase Local Authority oversight and powers
- Reduce the potential for inequality
- Performance-based building design, construction and management
- Protect school children
- Provide high-quality research and evidence.

Establish national strategy and regulations

1. **The Government should establish a cross-government committee to co-ordinate working in health, environment, education and homes for indoor air quality.**

   This committee should:

   (a) Develop a national strategy and policy for indoor air quality, including steps to raise public understanding of indoor air quality. The strategy should designate a ministerial lead to report on the work to the Cabinet.

   (b) Set emission standards and a labelling system for building materials, furniture, and home decorating, products, based on any health hazards.

   (c) Restrict the use of hazardous VOCs in personal care and cleaning products. Public Health England have produced a review of specific VOCs[69] which would help to inform this. People need clear information to support choice and enable substitution of less-polluting products.

   (d) Use regulations to take a precautionary approach to restrict the use of chemicals which have not been tested for their potential health effects.

   (e) Set quality standards for home air quality monitors, air filtration and air cleaning devices, to protect consumers from ineffective devices and ensure they do not re-introduce pollutants.

#TeamCleanAir&Us say:

Children and young people want Government to develop stricter regulations and guidance to control products and building materials that contribute to poor indoor air quality.

Many of the materials, products and designs that contribute to poor air quality are out of the control of children, young people and families. This is especially true if your family doesn't own their own house or can't make changes to their home. Government has an important role to play.

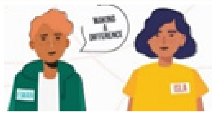
- Strict regulations about indoor air quality should be in place and should be monitored by Government.
- Social housing should have high standards for indoor air quality and this should be enforced.
- There should be clear information and warning systems developed for labelling products that can create poor air quality, so parents, carers and young people can make better purchasing choices.
- A 'clean air' house check-up system should be developed so that when families are thinking about buying a house it has a rating (like an energy certificate) to help them assess the air quality inside a building. There could also be an app for mobile phones that people could use to assess indoor air quality.

Advise the public and professionals

2. **The Government and Local Authorities should provide the public with advice and information about the risks of, and ways of preventing, poor indoor air quality.**

   This should include tailored messages for:

   - residents of social or rented housing
   - landlords and housing providers
   - home-owners
   - children with asthma and other relevant health conditions
   - schools and nurseries
   - architects, designers and the building professions.



#TeamCleanAir&Us say:

Children and young people want clear, factual and accessible information about what the potential harm is from poor indoor air quality and what we (children, young people, parents and carers) can do to avoid or reduce indoor air pollutants.

We want to know what the risks are from poor indoor air quality and what we can do to reduce them. Information needs to be scary enough for us to take notice but with enough information about what we can do that we feel we have some control and clear actions we can take. We want to know:

- What products should we avoid? And what can we swap them with?
- What things should we try and avoid doing at home?
- What can we do to improve air quality in our homes and schools?

We want this information to be provided in lots of different ways to reach different people.

It is important that this message gets through and one approach will not work for everyone. Use social media, YouTube ads, billboard advertising, TV, radio as well as face to face outreach to get the information out to people.

To reach children and young people:

- Be creative, use stories, video, social media, work with celebrities and through school assemblies.
- Provide better environmental education in the school curriculum including indoor air quality.
- Provide clear messages of things that children and young people can do and information for us to take home and educate our parents, carers and families.

To reach parents and carers:

- Provide practical information and advice from when our children are born, through midwives, health visitors, parents groups and school newsletters.
- Have a clear website with information about what changes we can make at home and in schools.
- Information should include changes that people can make which are free or low cost.
- Work with us and our schools to get this information to parents and carers.

3. **The Royal College of Paediatrics and Child Health, Royal College of Physicians, Royal College of Nursing and Midwifery, and Royal College of General Practitioners should raise awareness among their members of the potential health effects of poor indoor air quality for children, and help to identify approaches for prevention.**

   This must include:

   (a) Support for smoking cessation services, including for parents to reduce tobacco smoke exposure in the home.

   (b) Guidance for health professionals to understand the health risks of poor indoor air and how to support their patients with indoor-air-related illnesses.

#TeamCleanAir&Us say:

Ensure General Practitioners (GPs) and other clinicians can talk and give advice about indoor air quality to children, young people and families.

When children and young people have symptoms that can be triggered or made worse by poor air quality we would like doctors and nurses to be able to advise on lifestyle or products changes we can make to improve indoor air quality.

- Training for paediatricians and GPs should include information about indoor air quality and the health impacts.
- GPs, paediatricians and other clinicians should discuss changes that families can make with them that might improve indoor air quality and help with related health problems.
- Equipment should be available to loan or buy through a grant scheme for young people whose health is most affected by poor indoor air quality.

Increase Local Authority oversight and powers

4. **Local Authorities should have the power to require improvements where the air quality fails to meet minimum standards in Local Authority-controlled schools and wherever children live. This should be extended beyond damp and mould (where powers already exist) to include other pollutants.**

5. **Revise the building regulations.**

   This should:

   (a) Set legally binding performance standards for indoor air quality that include ventilation rates, maximum concentration levels for specific pollutants, labelling materials and testing of appliances.

   (b) Conduct air quality tests when construction is complete and before the building is signed-off.

   (c) Check compliance after construction stages and assess buildings once they are occupied and in-use. This may require greater, ring-fenced resources for Local Authorities to take effective enforcement actions.

6. **Local Authorities should:**
   (a) **Follow the recommendations in the NICE guidelines** for '*Indoor air quality at home*'[37].
   (b) **Include indoor air in Air Quality Plans**. Ensure these specify how they meet the needs of low-income households and homes in areas of high outdoor pollution.
   (c) **Update existing instruments**, such as the Housing Health and Safety Rating System, to include more comprehensive and periodically updated evidence on a wider range of indoor pollutants.
   (d) **Provide greater support for environmental health officers** for the evaluation of indoor air quality risks in homes and schools.

Reduce the potential for inequality

7. **Local Authorities and housing providers should offer indoor air quality testing for their residents.**

8. **Local Authorities should establish a process or portal for residents to report potential problems with indoor air quality and access services.**

9. **The Government should provide a national fund for households with air quality issues caused by their housing but who are unable to make necessary improvements due to financial circumstances, or who are prevented from making necessary improvements by tenancy and leasehold conditions.**

Performance-based building design, construction and management

10. **Those responsible for construction, maintenance and repair of building must avoid the use of harmful chemicals and pollutants. This needs to be supported by clear labelling and a national system for control, in line with recommendation number 1. Attention should be paid when substituting materials or changing ventilation levels during construction and maintenance to ensure they meet the same, or higher, performance standards. Building managers must keep the air quality under review as they maintain and operate the property, providing residents with an effective channel to raise concerns.**

11. **With new or renovated buildings the ventilation, and heating or cooling should be designed to:**
    (a) Account for the location of nearby outdoor pollution sources, and any barriers to opening windows (noise, pollution, or security).
    (b) Take a performance-based approach which delivers effective ventilation while reducing energy demand and carbon emissions.
    (c) Avoid using gas heating and burning wood or coal for heating.
    (d) Correctly install and test systems after occupancy, providing clear instructions for use.

12. **Professional bodies for design and construction should provide or accredit training about indoor air quality.** This should provide high standards for ventilation, energy efficiency, and reduction in exposure to allergens and pollutants.
13. **Building professionals should ensure adequate ventilation is included in planning renovation and refurbishment works for existing properties while reducing energy demand and carbon emissions, in line with the newly released PAS2035 (Specification for the energy retrofit of domestic buildings).**

Protect school children

14. **Schools should:**
    (a) **Use adequate ventilation** to prevent the build-up of harmful indoor pollutants, ventilating between classes if outdoor noise causes a problem during lessons. If the school is located close to traffic, it may be best to do this during off-peak periods, or open windows and vents away from the road.
    (b) **Ensure classrooms are regularly cleaned** to reduce dust, and that damp or mould is removed. Repairs may be needed to prevent further damp and mould.
    (c) **Ensure that any air filtering or cleaning devices are regularly maintained.**
    (d) **Work with the Local Authority**, through the ambient air quality action plans, and with parents or carers to reduce traffic and idling vehicles close to the school.

Provide high-quality research and evidence

15. **UK Research Councils' should set the following priorities for indoor air quality research:**
    (a) **Establish large-scale research of UK homes and schools** on the indoor air quality, linking this with health and public health datasets. This should include provisions to monitor the impact of changes over time, to identify if improvements in indoor air are resulting in better health outcomes.
    (b) **Further research into the potential adverse health effects for children is needed**: to study a wider array of indoor pollutants; to increase the number of studies set in the UK; to study the effects from exposures in schools and nursery or day-care settings; for children with chronic respiratory conditions such as cystic fibrosis that may place them at greater risk.
    (c) **Gather evidence on emissions and ventilation rates in buildings of differing age and design**. This should identify the most cost-effective interventions and design choices for improving indoor air quality and lowering energy demand and carbon emissions.
    (d) **Measure emissions and exposure in a more realistic indoor environment** such as the House Observations of Microbial and Environmental Chemistry (HOMEChem)[38] experiments.
    (e) **Set a research design to test the safety of chemicals used in buildings and household products** under realistic indoor conditions. The test conditions should mimic an indoor environment, with mixtures of pollutants and the effects of humans included.

We welcome the NICE recommendations for research in the 2020 NICE guidelines for '*Indoor air quality at home*'[37]. In September 2019, the National Environment Research Council, UK Research and Innovation, and the Met Office have jointly announced new research funding. This provides a Strategic Priorities Fund for research which proactively addresses air quality challenges to protect human health. It is important that this research considers and includes the effect of indoor air pollution on children.

How to improve the air at home

Poor indoor air quality is not always easy to identify, so follow any guidance and advice for ventilation that was provided for your home. The actions below can help to improve the indoor air in your home. Every home is different; these are options to help guide the choices that are right for your home and family.

Cleaning and ventilation

- Regularly clean and vacuum to reduce dust. Ventilation is important during and after cooking, cleaning, and activities that create moisture or pollutants.
- Try to reduce moisture in the home to prevent damp, cleaning away condensation or mould. Ventilation (e.g. an extractor fan or temporarily opening windows) can remove moisture after bathing or drying clothes indoors. If you are a tenant with persistent damp or mould at home, contact your landlord or environmental health department.
- Many windows have small, built-in vents; keep these 'trickle vents' open if you have them. If your home has a mechanical ventilation system, make sure you regularly use and maintain it.
- Do not smoke, or allow others to smoke, in your home.

Cooking

- Use ventilation in the kitchen when you cook and try to avoid burning food. Closing internal doors when cooking reduces pollutants from entering other rooms. If you can, put hot pans outside to cool.
- If you have one, use the cooker hood or extractor fan while cooking with an oven, hob, or any other appliance. Try to use the back rings of the hob, as this can work best with a cooker hood. Use the highest fan setting and, if possible, continue to use it for around 10 minutes after cooking.
- If you are replacing appliances, it can reduce NO_2 to choose electricity rather than gas. Some newer ovens have 'self-cleaning' functions; try to stay out of the kitchen if you are using this function.

Furnishings and consumer products

Without clearer labels, it will be hard to know all the different properties of the products in our homes. If available, choose products labelled with clear information about their contents and instructions for use.

- Increase the ventilation after painting, decorating or having new furniture. Follow any manufacturer's guidance on products, for example to 'use in a well-ventilated room'.
- Reduce the number of cleaning or cosmetic products used to avoid them mixing in the air
- Increase the ventilation if you use cleaning or cosmetic products, air fresheners, candles or incense.

Children with respiratory allergies (such as asthma and rhinitis)

Taking steps to reduce exposure to allergens (from house dust mites, moulds and pets) is recommended to reduce symptoms and exacerbations.

Depending on the allergy, measures which can help include:

- reducing dust and dampness in the home
- reducing items which collect dust such as soft toys and, if possible, replacing carpets with hard flooring.
- washing bedding and covers (at 60ºC every two weeks), or using allergen-impermeable covers
- avoiding direct exposure to furry pets if the child is sensitised.

3. Children and young people: Clean air &Us

"Ask young people about their experience." – McKenzy (14)

In a meeting room in London, scientists, doctors, researchers, engineers and architects were talking about how to keep children and young people healthy, happy and well.

"*One of the issues is the air they breathe*" one of the scientists said. "*And it's not just the air outside we need to be thinking about, it's the air in their schools and where they live*" said one of the doctors.

"*What we should do is find out as much information as we can then tell people who build the houses, who run the schools and hospitals, how they can make the air inside as clean as possible*" said a researcher.

The Indoor Air Quality Project was created and Esta, one of the youth workers from RCPCH &Us was asked to speak to as many children, young people and families as possible around the UK to see what they think makes air clean or dirty when they are inside.

She needed some help – the UK is a big place! The other youth workers in the team packed their purple RCPCH &Us t-shirts and headed off on a road trip, going to Cambridge, London, Liverpool, Edinburgh, Dundee, Birmingham, Epsom and Enniskillen.

They talked to over 215 children, young people and family members. They saw them in hospitals while they were waiting for their clinic appointments, or in their schools, youth clubs and youth projects.

"We should write a story that makes it easy to understand about what we have found out, and then give people ideas of what they can do differently. Maybe we need to start with... what is indoor air pollution?"

#TeamCleanAir&Us

They also got a team of young people together who wanted to help read through all the ideas from children and young people across the UK and decide on what to tell the Indoor Air Quality group. More than 20 young people and their parents/carers got involved in looking at all the ideas. A team of young volunteers, called **#TeamCleanAir&Us**, came up with a plan to make a difference to the lives of children and young people across the UK.

"Is indoor air pollution farts?" – Maya (9)

"*People need to know what indoor air pollution means, what causes it or where it might be happening*" said one of the **#TeamCleanAir&Us** volunteers when they were going through all the information. They smiled when they read what Maya (9) had asked: "*Is indoor air pollution farts?*". They read that lots of people had said the same thing as one of the dads "*I know about air pollution from cars, but I haven't thought about indoors before*".

#TeamCleanAir&Us read what everyone had said and found out what children, young people and their families thought made the air dirty in their homes, schools or places like hospitals.

Things that make the air dirty

Mould	Dust
Gas	Carbon monoxide
People smoking	Cleaning products
People spraying	Nail varnish
Cooking smells	Body smells

Source: RCPCH &Us voice bank 2019

Sana (15) said "*I have done my own research because I have hay fever. We were also taught about pollution in school. I found out about smellies, cleaners and car pollution. I keep the windows shut, use a fan and my hay fever medicine*."

"We need to find out where children, young people and their families think has clean air. Let's get the youth workers to ask them."

#TeamCleanAir&Us

Many had heard about air pollution outside from cars from learning about it at school. For a lot of the children, young people and parents on the road trip it was the first time they had really sat and thought about how 'clean' the air was at home or in school.

The **#TeamCleanAir&Us** volunteers saw that young people were much less likely to think that cleaning products or 'smellies' could be linked with poor air quality. Although lots of people said they knew cleaning products had bad chemicals in them they didn't always realise this added to poor air quality.

"Dust mites make my eyes itch" – Cyra (5)

Lots of people on the road trip told the youth workers what happens when they breathed in dirty air in their home, school or hospital. Things happened to them like runny eyes, or having a scratchy feeling in their throat, feeling drowsy or not being able to breathe easily.

"*The science classroom air is really bad. I feel sleepy and drowsy in there*" Abi (16) told us and Grace (9) said "*I have drawn a picture of my classroom at school. I think the air is not so good here. I feel sleepy in the morning and after lunch, but I am not sure if this is because I am tired, bored or the air is stuffy*".

Source: "MRP - Hospital" by Strayfish (licensed under Creative Commons)

Some people said that if they already have asthma or an illness in their lungs, and they breathe in air when they are at home or school or inside somewhere that feels a bit dirty, then they can't breathe so well.

Sometimes this means that for children and young people who already have an illness like asthma, they have to go to hospital more often.

"*I really notice damp a lot too, especially when I was little. In the summer I had nose bleeds and the doctors said it might be the house. We washed the carpets and wiped down the ceiling*" Becky (17) told the team.

A mum said "*They [the doctors] don't want to talk about air pollution. They just want to talk about why he isn't taking his medication. The windows need replacing, the seals around the windows are broken. We live by a main road and there is a lot of building work going on*".

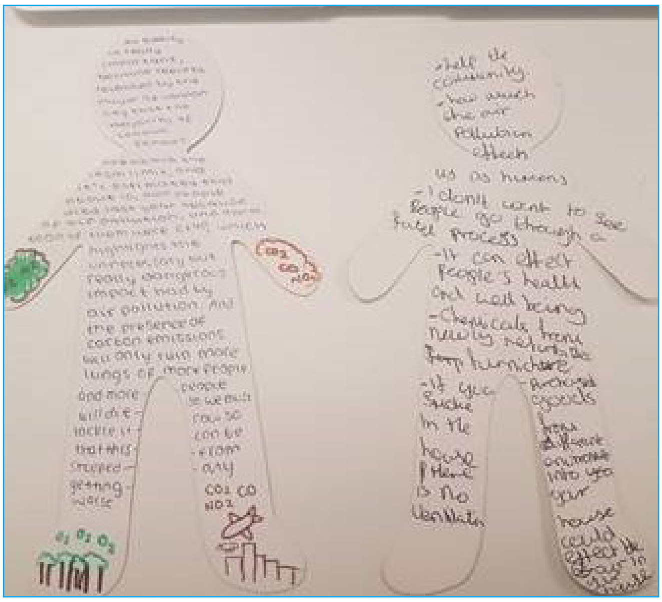


Figure 2: #TeamCleanAir&Us look at why people need to know about indoor air quality

As well as schools, **#TeamCleanAir&Us** also read about how sometimes different rooms in their homes made them feel drowsy and sleepy. They wondered if this was because of the air being dirty because of things like air fresheners and sprays. Cyra, who is five, told us that "*I have dust mite allergy, I can't have teddies in my bed with me. Dust mites make my eyes itch*".

Shaan and McKenzy, volunteers from **#TeamCleanAir&Us** started to have a think about why it was so important to get everyone talking about indoor air quality.

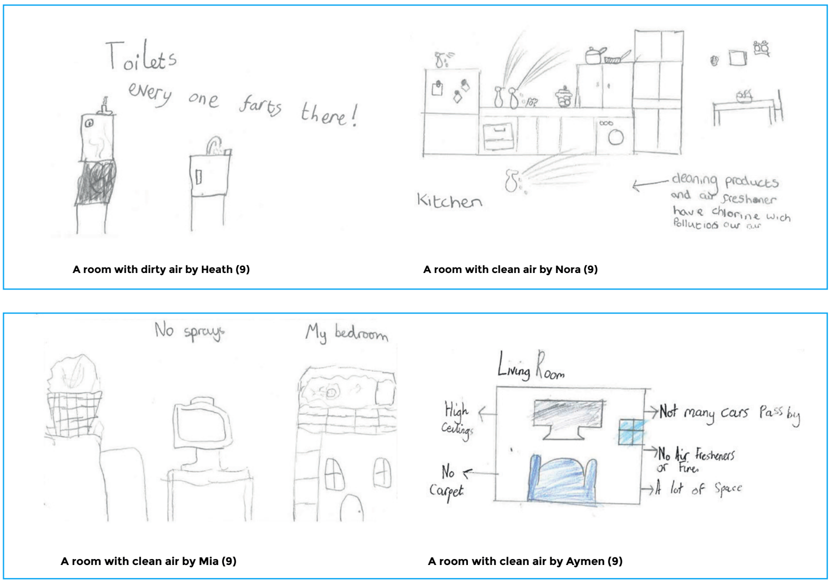
McKenzy (14) wanted to make sure that young people got involved and didn't get sick because of something they couldn't see or didn't know about: "*It can affect people's health and well-being... Ask young people about their experience*". Shaan (16) was focused on it being important for governments and decision makers to make a difference: "*More people will die so we must tackle it now so that this can be stopped from getting any worse*."

> **"Something has to be done to make all the air indoors clean and to keep all children and young people healthy."**
>
> **#TeamCleanAir&Us**

"We have black mould in the bedrooms." – Shazia (18)

#TeamCleanAir&Us heard what happened when 94 children were asked to pick and draw a room that they thought had clean air and one that had dirty air. Lots of the children talked about toilets being stinky and different places at school and home not having clean air. They all learnt through the sessions what helped rooms to have clean air like not using wood burning stoves or air fresheners.

Figure 3: Children's drawings of different indoor air quality.



A room with dirty air by Heath (9)

A room with clean air by Nora (9)

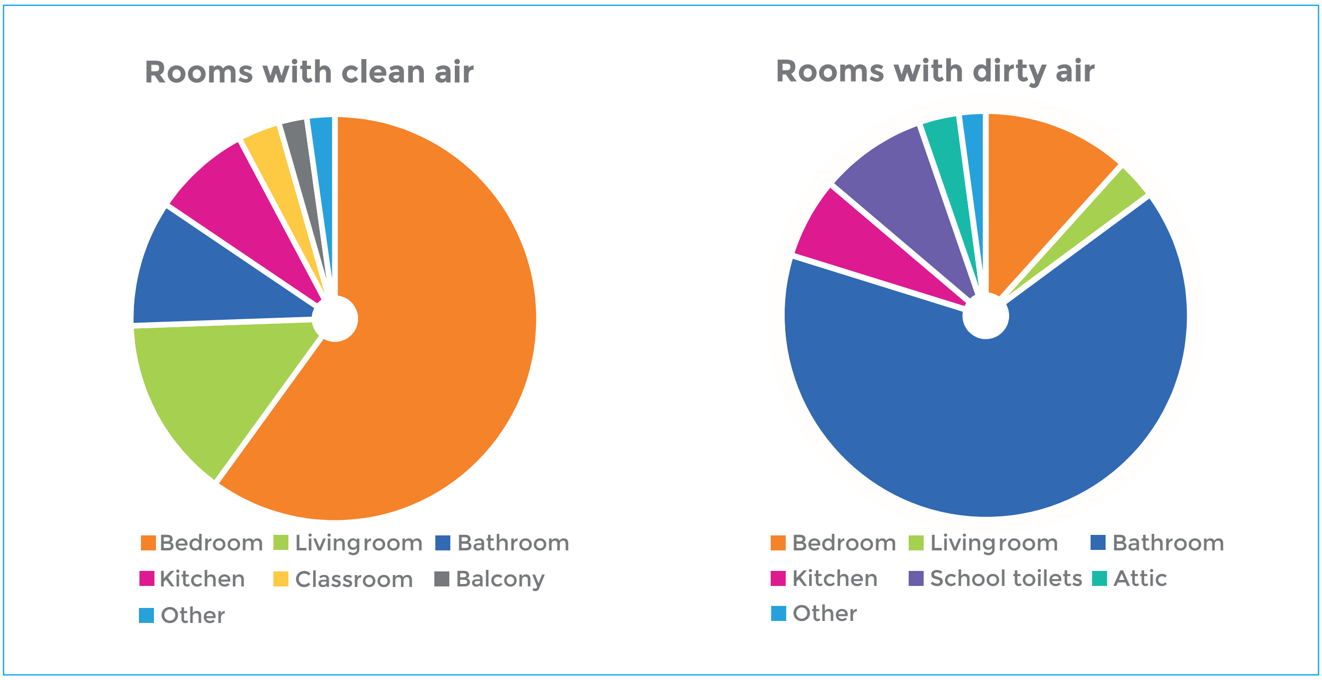
A room with clean air by Mia (9)

A room with clean air by Aymen (9)

Michael, Adam, Demi, Raheema and Afsana, young volunteers from **#TeamCleanAir&Us**, looked at all their pictures and worked out that most people said that their bedroom was the cleanest and that the worst place was the bathroom (that also included school toilets). Schools were talked about a lot in the workshops and hospital sessions too, Luke (15) said: "*Our toilets at school are really bad. There is no ventilation and it's hard to breathe in there*", and Yousef (8) said: "*My classroom is really smelly, it smells like burnt toast*".

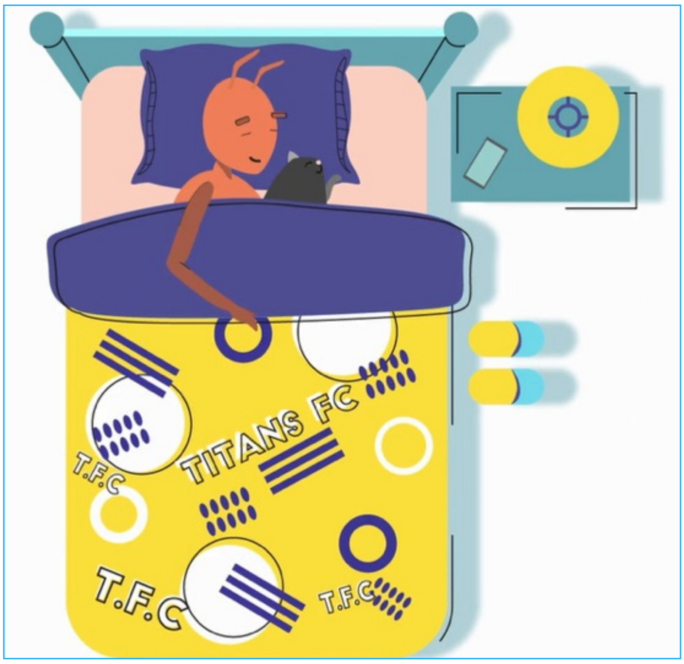
"*I wonder if people just talked about schools*" thought the **#TeamCleanAir&Us** volunteers. They looked at the results from the hospital visits and going to youth projects. They saw that people told the youth workers that they thought that home was a place with cleaner air quality.

Figure 4: Rooms identified by children as having clean and unclean air.



Source: Analysis of 94 drawings by children aged 5-11 years

Parents and young people talked about how much effort they put into keeping their homes clean and that this felt like it would make the air clean too. Children did say that kitchens and bathrooms were sometimes smelly rooms because of cooking, toilets and condensation.



Also, when a parent or carer smoked in the home, children and young people said they really felt strongly that the air that they were breathing was not good.

One youth project talked about home being a safe space. When they thought about the rooms that had cleaner air, they chose bedrooms and living rooms. They felt safe and relaxed in them, so their breathing was relaxed, and they think about those rooms as having good air quality.

"*I think of my bedroom as having clean air. It's warm and cosy but it is a bit stuffy and I do get a runny or blocked nose. I often feel sleepy or drowsy, but maybe I am just tired. I think of this as a good space but is it a healthy space?*" said Adele (18).

Children, young people and families who had allergies, asthma or breathing problems were much more aware of indoor air pollutants, but just like other families they didn't know all the everyday things that caused indoor air pollution. They knew what would make their asthma or allergy bad and had learnt this through experience.

"OK, so when people have time to think about it, they know the kinds of things that can make the air we breathe indoors not as clean. Does anyone know what it does to children and young people if they breathe it in?"

#TeamCleanAir&Us

"I would suck the dirty air up with a hoover, go outside, hold my breath, empty it, come back inside and quickly close the windows." – Elenor (9)

The **#TeamCleanAir&Us** young people sat in a room looking at everything that people had said. One thing was clear... people didn't really know that some things made the air dirtier when you are inside than other things.

Most young people and parents did not know that the cleaning products they were using could affect the air quality, or things like air fresheners, gas cookers, open fires, burning candles or using incense could make the air quality worse. Cienna (9) said "*If the cooker is on it will make a smelly smell and you might have to put air freshener spray to make a nice smell*".

Ideas to make the air cleaner

- **Opening windows** (fresh air in)
- **Closing windows** (keep dirty air out)
- **Dehumidifiers**
- **Air purifiers**
- **Cleaning more**
- **Air flow in kitchens**
- **Plants in the house**
- **No carpets**
- **Cleaning products** (chemical free)

Source: RCPCH &Us voice bank 2019

The children, young people and families did have ideas about what people could do to make it better with a few saying they chose "greener" cleaning products as they thought they were less harmful, and one parent made cleaning products using vinegar, bicarbonate of soda and lemon juice as their child had severe allergies and asthma.

Many people opened the windows to freshen up their house, but just as many people closed the windows to keep pollution, bugs, or neighbours cigarette or marijuana smoke out. A mum said: "*Our house smells nice, I do open the windows to ventilate but sometimes you get the smell of people smoking drugs outside.*" Sara (14) said: "*I keep the windows closed to keep the car pollution and dirt out*".

#TeamCleanAir&Us realised that people were really, really trying to keep their homes clean, but without knowing it they might be creating a different problem. It didn't feel fair that people were trying their best but not having all the information or being helped with their choices. Some people said that they would not cook in the evening or try to cook less. Others thought that it would be better if they sprayed deodorant by the window, and thought about having the heating on to help dry out clothes.

The young volunteers could see that some parents were worried that they didn't know what to buy when they were in the shop to clean their homes that didn't then make the air dirty. One mum in Liverpool said: "*I have thought about how dust affects the air at home, so I ventilate and clean*

"OK, so now we know that people are confused. They just need clear information about what to do and what not to do – and everyone needs to know about it and be doing their bit. Hopefully the scientists will be able to help!"

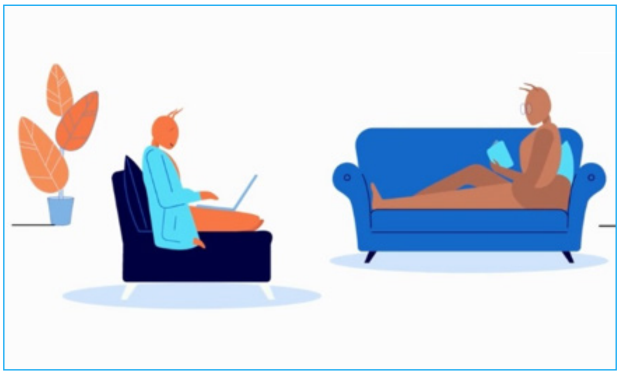
#TeamCleanAir&Us

more. I am surprised that some cleaning products are bad for air quality though. I use a lot of bleach, I thought that was clean and healthy but maybe it's not?"

Families were aware about dust and germs and talked a lot about how much they cleaned. One mum said: "*My son has a lung illness, I haven't really thought about indoor air quality before but I do know that the 'plug ins' (air fresheners) are bad, so I don't use them. I know some cleaning products are really strong. I either don't use them or I wait until he is out.*"

"There are some problems with water and damp in our block of flats" – Shazia (18)

"*What about for people who can't just put a fan in their kitchen or who live in a council house with mould or can't afford the expensive things that could really, really help them?*" asked **#TeamCleanAir&Us**. They realised from reading all the stories from the children, young people and families, that for some of them, there are other issues that people don't realise.



The poorer you are, the more likely you are to be living in a house with more people, or with no outdoor space to dry clothes. This would mean that there might be more damp. You might not get to change to an electric cooker instead of cooking with gas. You might also be living closer to a polluted road.

One dad said: "*We have thought about indoor air quality a bit before. Our old apartment had poor ventilation, and suffered from mould. The children were always passing germs around. It was very hard to keep ventilated. We have moved to a bigger house now and noticed we don't have these problems so much.*"

Some parents were worried about the things they couldn't change, like the materials that were used when their flat was put back together after a flood which might have made their child ill. One mum said: "*The front door is not sealed so the outdoor pollution comes in and we had leaks and damp problems – I have had to call the council.*"

"What if we started an equipment bank so that people could borrow the machines rather than raise money or worry about buying them".

#TeamCleanAir&Us

If you live in a council property, you can't always decide what you do to improve your building either. It can be stressful for families who know there is poor air quality where they live but who are unable to change things. "*We have black mould in bedrooms. My parents are really worried, they clean it off every couple of months but it comes back. It affects our skin and we breathe it in. It makes me feel drowsy. I just go to sleep to avoid the dust*," said Shazia (18).

Some families with young people who had severe allergies or respiratory issues were saving money or crowd-funding to try to afford air purifying and dehumidifying machines.

“It’s time for people power.” – Michael (18)

We have found out what lots of children, young people, parents and carers think makes the air quality indoors poor, that lots of people don’t really understand it, or are confused about what to do. We have read and listened to their experiences about how they have problems with their health and can’t always make the changes in their homes or schools that are needed. We have also looked at different ideas that could help to make a difference. So now: People Power!

We all must do something. Whether you are a government worker, or a doctor, or a builder, or a scientist, or a parent, or a young person reading this: there is something that everyone can do.

Read up about indoor air pollution and make some simple changes at home or school or your work, or make some new laws that help all children and young people to be able to breathe clean air indoors. There needs to be lots of things done – one thing on its own won’t improve the air we are breathing. Everyone needs to work together.

Our recommendations are:

1. Make sure there is clear, factual and accessible information about indoor air pollution.
2. Share this information in lots of different ways.
3. Ask GPs and clinicians to give us advice that helps us if we have health problems that are getting worse because of poor quality air indoors.
4. Get the Government to make rules that control products that contribute to poor air quality.

You can read our ideas in more detail in the yellow boxes on pages 13 to 20.

We think YOU can help too.

As children, young people, parents, carers and families, you can help make a difference to campaign for awareness of indoor air pollution.

- In **30 seconds**, you can sign a petition aimed at tackling indoor air pollution.
- In **1 minute**, you can tweet your support urging decision-makers to champion indoor pollution.
- In **5 minutes**, you can write a letter or email to your Member of Parliament, expressing what indoor air pollution is and why clean air is important to you.
- In **10 minutes**, you can make a video with your friends and family raising awareness about indoor air pollution, its consequences, and how we overcome it.

Thank you

Thank you to our youth authors #TeamCleanAir&Us

Adam Rujabally, Afsana Miah, Asha, Demi, Gabriel Philbin, Janani, Michael Bryan, McKenzy, Niamh, Raheema, Raphael Philbin, Shaan from RCPCH &Us with support from the Young People's Executive from the Oxford University Hospitals NHS Foundation Trust.

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- Addenbrooke's Hospital, Cambridge
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- Birmingham Children's Hospital, Birmingham
- Epsom Hospital, Surrey
- Fitzrovia Youth in Action, London
- Hyde Housing Association & Young People Matter, London
- Newham University Hospital, London
- Ninewells Hospital, Dundee
- North Haringey Primary School
- RCPCH &Us
- Royal Brompton Hospital, London
- Royal Free Hospital, London
- Royal Hospital for Sick Children, Edinburgh
- South West Acute Hospital, Enniskillen
- Waltham Forest Young Advisors, London
- Whipps Cross University Hospital, London.

By Maya, age 11

4. Factors affecting indoor air quality

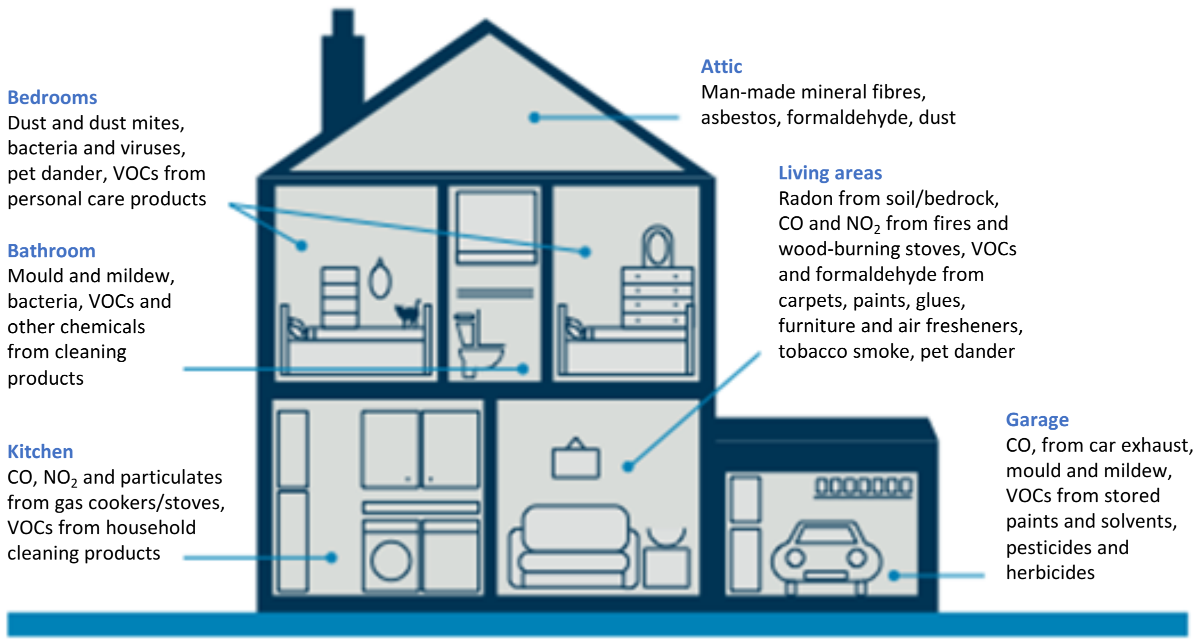
This chapter outlines the key factors affecting indoor air quality (IAQ) in the home and the school environment. We examine which sources, built environment characteristics and individual habits can give rise to these different patterns of exposure to indoor pollutants. We explore how, directly and indirectly, children are exposed to pollutants of indoor and outdoor origin.

Children and adults in the UK spend most of their time indoors. Poor air quality at home, in school, and in other enclosed environments can present a health risk, given the amount of time children spend in these spaces. Patterns of exposure to indoor pollutants, and related health effects, are the result of a complex range of factors and vary in terms of intensity and duration. Indoor air quality depends on the building's location and characteristics, pollution levels outside, indoor pollution sources, and lifestyle factors.

To some extent, everybody is exposed to indoor air pollution. Indoor exposure to pollutants comes from air, dust and surfaces. The main way people are exposed is by inhaling pollutants, but they can also be ingested or absorbed through the skin. In this regard, infants and young children may be at greater risk due to behaviours such as crawling and "mouthing" objects or surfaces.

People can be exposed to high levels of indoor air pollution over a short period of time – 'acute exposure'. They can also be exposed to relatively low pollution levels over prolonged periods – 'chronic exposure'. Both acute and chronic exposures need to be considered indoors. Pollutants from indoor sources can become trapped and reach high levels in under-ventilated rooms. Children spend many hours a day in their homes, and classrooms, so even low levels of pollution can contribute to accumulating exposure.

Figure 5: An overview of sources of indoor pollutants in a home.



Sources and types of indoor pollution encountered in homes. VOCs = volatile organic compounds. Please note that these lists are not exhaustive and that the actual pollutants present, and their amounts, will vary from household to household.

Source: Royal College of Physicians[8]

Measuring exposure to pollutants

Exposure to indoor air pollution has been linked to health effects in children using a variety of methods. A common approach is to use standardised questionnaires. These collect data on the home conditions, development of disease, variation in symptoms, and measures for quality of life. Studies often use questionnaires to assess damp and mould in the home. These 'self-reported' levels are used instead of directly measuring the humidity and levels of mould spores in the air or dust. Health assessments include physical examination, lung function testing, evidence of allergic sensitisation, and imaging.

Dust from rooms or mattresses is often collected to test for allergens, but levels in dust only approximate the allergens an individual is exposed to. Personal samplers, worn by an individual, can give a more accurate exposure assessment, but these can be a burden for research participants. Sensors in different rooms and time-activity diaries have also been used to model individual exposures to a variety of air pollutants[39].

To measure pollution accurately, capturing changes throughout the day and in response to different activities, requires sensitive and complex monitoring equipment. One less complex method is to use passive samplers. These are tubes with filters and materials to absorb pollutants. Once removed and analysed, passive samplers provide a total or average level of the pollutant. They cannot record how levels vary over time, and only provide a measure of average exposure over the entire period. Some studies rely on the use of proxy values to estimate exposure to pollution. For instance, CO_2 is often used as an indication of ventilation (instead of measuring ventilation air flow rates directly). Total Volatile Organic Compounds (TVOCs) are also used as a proxy for VOCs but do not distinguish between different VOCs.

The difficulty of measuring pollutants means that the number of individuals or homes in studies tends to be low. This reduces the power of the studies to detect health effects from observations made in real indoor environments[40], and our ability to draw firm conclusions from the results. Despite the challenges, several important and good quality indoor research projects have been undertaken in the UK and overseas.

Helpfully, technology to monitor indoor air quality is improving. This could make large-scale research easier. There is an increasing number of small domestic sensors becoming available. These are designed as much for individuals, interested in the quality of their air, as they are for scientists to conduct research. Typically, the sensors connect to a mobile app and show the air quality over time. These lower-cost sensors can be less accurate but may be more useful in detecting relative changes in concentration levels of pollutants rather than being used to detect whether a specific threshold is exceeded. While not aimed at children, such devices could help parents protect their child's health. One study found that when parents were given personalised information about their exposure, they were more likely to take steps to reduce allergens in the home[41].

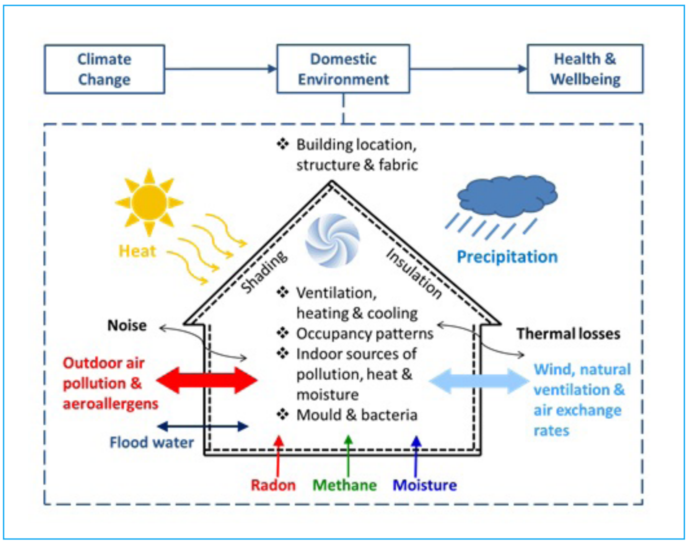
Most health studies have focused on outdoor air pollution. A comparatively small number of studies have been specifically designed to estimate air pollution exposure and associated health effects in the indoor environment. It is possible that indoor and outdoor pollution have different health effects. There is some emerging evidence, for example, that indoor particulate matter could be more harmful than equivalent levels outdoors. A study from Germany suggested that PM_{10} collected in classrooms induced more inflammatory and allergenic reactions, and accelerated blood coagulation, than outdoor PM_{10} on an equal weight basis[42]. This is an area that requires further study.

Factors affecting exposure to pollution

Air pollutant concentrations inside buildings are dependent on the presence, location and number of pollutant sources. Various indoor and outdoor factors change and evolve over time, often in ways which are outside the control of the building occupants[43, 44]. Indoor air pollution can be diluted by 'clean air' coming into the room, often from outside.

Simplistically, exposure to pollutants is determined by the presence of indoor and outdoor sources, and the air exchange between the indoor and outdoor environment. However, various interconnected factors directly or indirectly affect these exposures to pollutants. In this chapter they are discussed under three themes: outdoor factors, building characteristics, and activities.

Figure 6: Drivers of indoor air quality in homes and schools.



Source: Vardoulakis et al[58]

Outdoor factors

Due to legislation and advances in technology, outdoor air pollution caused by humans today is different from past decades. Higher reliance on coal burning in the past produced sulphur dioxide, black smoke, and acidification[45]. Over time the composition of our outdoor air has changed and the current concerns include particulate matter, nitrogen dioxide, and products from chemical reactions between pollutants in the atmosphere.

Human causes of air pollution include transport, industry, housing, and agriculture[46]. Construction sites and certain industries, such as quarrying, emit mineral dust that contributes to the coarse PM levels outdoors. Natural events can also reduce air quality; wildfires, volcanic activity, sea sprays, and wind can suspend particles and gases in the air.

In the right weather conditions, pollution can travel for days and cover long distances. This is most obviously demonstrated by episodes of Saharan dust pollution reaching the UK several times a year when desert storms coincide with the right wind direction. The same issue of long-range pollutant transport applies to industrial, traffic and other pollution. Air pollution is influenced by local pollution sources, but it cannot be fully addressed by one area or even one country acting alone. Reducing sources of pollution and minimising the harmful effects requires co-operation across local, national and international levels.

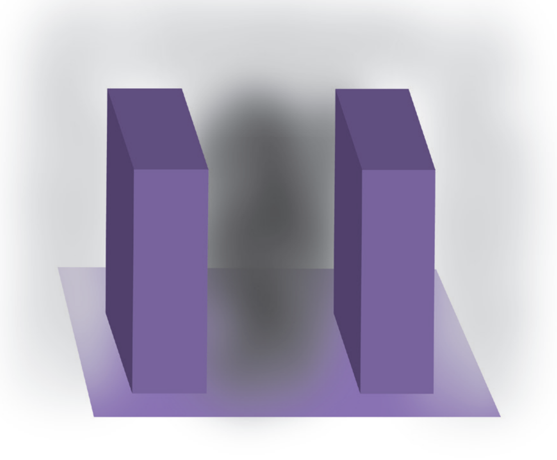
Urban planning

The interactions between outdoor emission sources and indoor air quality are complex. The location, type and number of pollution sources within an area have a great effect on the quality of the air.

Urban layout especially can impact air pollution levels. Buildings and industry change the ground-level emissions and how easily pollution can disperse. Designs such as 'street canyons', where a space is flanked by buildings, can trap air pollutants. Simple changes, and careful planning of new buildings, can be used to create openings and vary the heights of buildings. These features can help pollution to disperse more easily. The building shape, size and orientation in relation to other buildings will also affect the level of pollution. Tall buildings, courtyards and enclosed spaces can trap pollution[47].

The location of pollution sources, such as busy junctions or power-plants, can be designed and located in ways that improve the local environment. Public Health England (PHE) recently identified planning as one of 5 priority areas for action and interventions to reduce outdoor air pollution[48].

Figure 7: A 'street canyon' between buildings, which can result in a build-up of air pollution.



Source: RCPCH

Weather and season

Weather conditions can influence both outdoor and indoor levels of pollution. The wind speed and direction will change how pollution disperses or accumulates in an area. Wind also changes the rate of ventilation in buildings[49], even for buildings with mechanical ventilation systems.

The outdoor temperature can have a similar effect to wind because of the movement as hot air rises and cooler air falls. This effect is sometimes referred to as 'buoyancy-driven' motion. It can be especially influential in built-up areas, where urban 'heat islands' can be significantly warmer than surrounding areas[49, 50].

In countries like the UK, the seasons can influence levels of pollution. There are typically higher indoor NO_2 levels in winter, due to the increased use of gas appliances, solid fuel heating, candles, and reduced ventilation in houses[51]. Studies in London[52] and Yorkshire[53] both found higher indoor $PM_{2.5}$ levels in winter than in summer.

Schools

SINPHONIE was the first Europe-wide project that monitored the school environment and children's health in 23 European countries. This concluded that the major sources of air pollutants inside schools were infiltration of outdoor air pollution[54], school air intakes near sources of pollution and odour, and underground sources (e.g. radon, pesticides).

Recent proposals[55, 56], suggest that exposure to pollution at school should be reduced by:

- pedestrianizing streets and urban greening around school buildings within 150-250 metres of the major roads
- locating new schools away from heavily used streets and busy roads
- discouraging engine idling near school buildings
- locating drop-off areas away from school doors and windows
- opening windows furthest away from sources of pollution
- increasing ventilation at times which avoid the heaviest periods of traffic
- planning for the weather conditions (e.g. smog, pollen count), and seasonal energy-efficiency requirements.

Weekly measurements in urban parts of Hertfordshire and north London showed that outdoors NO_2 concentrations were significantly higher than indoor concentrations in winter. There were no significant differences in indoor and outdoor levels in summer[57].

People tend to open their windows more in warmer weather. There are situations where this is not possible – for example, due to external noise or security issues. In these cases homes can become polluted and also very hot.

Building characteristics

The design, ventilation and size of the building can have a large effect on the concentration of indoor air pollutants. Higher PM concentrations are typically found in houses with sources of smoke or burning, or with open-plan kitchens. There is an increasing trend towards smaller homes with open-plan designs. In the presence of indoor pollution sources, this may result in increased exposure to particulate matter[106].

Homes are also becoming more airtight, to reduce thermal losses and improve energy efficiency. Energy efficiency is important to reduce our use of fossil fuels and to prevent climate change, but without adequate ventilation it could inadvertently worsen indoor air quality and impact health[58]. There must be performance-based design of buildings that prioritises solutions which improve energy efficiency, protect the health and well-being of people inside, and reduce carbon emissions.

Construction materials

Different chemicals can be emitted from the materials used to construct buildings, and from their ensuing decay. These are materials such as insulation, natural wood and wooden composites, flooring, wall papers, solvent-based varnishes and adhesives. Some materials are known to be very harmful. For example, asbestos is still present in many older buildings and is a serious health risk if the fibres are inhaled. Radon is another carcinogen and construction materials can also be a source of indoor radon (though generally at a lower level than from the ground)[59]. These sources are both addressed in current regulations, but it is less clear how well these regulations are applied, particularly in building refurbishment.

The materials used to decorate, preserve, and seal, such as paints, caulks, adhesives, varnishes, waxes, and polishes, are all long-term sources of VOCs or formaldehyde. They are often highly reactive with other pollutants[60]. The emissions from building materials can reduce the indoor air quality of new homes and following renovations to older properties. Formaldehyde persists in new homes longer than VOCs[61]. Levels of formaldehyde were found to be higher in new homes[51, 62, 63] in apartments renovated in the past two years[64], and in homes constructed or furnished with wood products[65, 66]. Some building materials are treated with chemical flame retardants, which have been found in house dust and can have harmful effects.

Cables and pipes for electricity, water (drinking and waste), and heating are often contained within the building fabric. It is sometimes a design choice to expose them, in which case they should be considered as a source of indoor air pollution. Copper water and heating pipes have been replaced by PVC in many new and renovated buildings. PVC pipes release semi-volatile organic compounds (SVOCs) that could migrate into indoor environments over time[62, 67]. Electrical, audio-visual, and computing cables are often insulated with PVC. The covering contains plasticisers to make it flexible and releases SVOCs.

A common list of substances and their emission limits (EU-LCI values) is due to be published by the European Commission. This will allow comparison of the emissions from building products, helping to protect and inform people across Europe. It could be used to develop UK materials' labelling schemes, which currently only exist for paints.

Furnishings

Furnishings include all the furniture, fittings, floorings, curtains, and other accessories in the building. Many furnishing items and materials are a known source of chemicals and VOCs. The emission of pollutants can be increased by regular treatments such as polishing, or by the presence of ozone[68]. PHE carried out a systematic review of VOCs present in homes, focusing on those known to negatively affect health. This review was used to develop guideline limits for short and long-term exposures for selected VOCs[69].

Fabrics and some furnishings are treated with chemical flame retardants. These tend not to be emitted into the air but are long-lasting, inhaled, found in dust, and have been linked to long-term health effects[23]. In the UK, the Furniture and Furnishings (Fire Safety) Regulations govern the required fire resistance for upholstered furniture and furnishings for homes[70]. This includes the 'crib-5 test' of resistance to an open flame, which has been associated with a higher use of flame retardants than methods to test the product as a whole. Britain and Ireland are the only countries in the EU that require the 'crib-5 test'.

Figure 8: Table of indoor pollutants from building materials.

Sources	Emissions of pollutants and chemicals
Mineral wool insulation[71]	Particulate matter (PM)
Polyurethane spray-foam insulation[72]	Flame retardants (tris phosphate) as well as aldehydes, under specific conditions
Urea-formaldehyde insulation[67, 73]	Formaldehyde
Paints (water-type latex types[67, 74]	Texanol® and formaldehyde
Older paints[67]	Mercury and lead
Green or natural paints[75]	Linseed oil, limonene, and other terpenoids, which can react with ozone to produce inhalable aerosols and formaldehyde
Wallpapers[76, 77]	Phthalate plasticisers
Adhesives and preservatives[67, 73]	Formaldehyde throughout their life, along with benzene, aldehydes and terpenoids
Furniture, soft furnishings, and soft toys, mattresses, and curtains[73]	Natural fibres or synthetic foams containing bromine flame retardants, dust mites
Flame retardants[78]	Organophosphates, both halogenated and non-halogenated
Carpets[73, 79]	Dust mites, VOCs, flame retardants
Flexible smooth floors[67]	Phthalate plasticisers
Composite wooden floors[73]	Formaldehyde and VOCs

Ventilation

Ventilation is used to exchange air from inside and outside to stop pollutants accumulating. This can be achieved naturally with vents, doors and windows, by a mechanical ventilation system, or by hybrid systems which combine the two. Fully mechanical systems use fans to send air in and out of buildings, usually through a network of ducts between rooms. By bringing outdoor air inside, indoor air contains both particles that have infiltrated from outdoors and particles that have been generated indoors[80]. Mechanical systems often include filters, but these are generally intended to reduce the maintenance requirements for the equipment rather than protect against pollutants. Use of higher-grade filters in higher polluting areas may be beneficial.

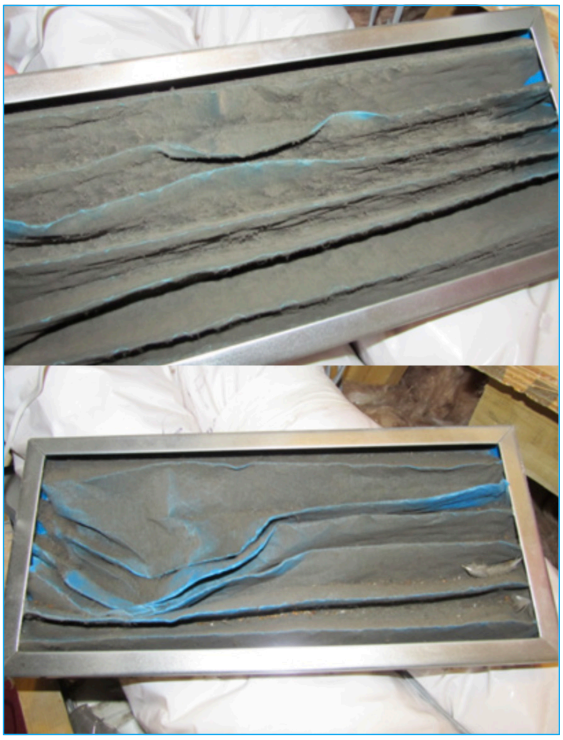
To meet the needs of modern building designers and specifiers there have been new technical standards developed by BSI, CEN, and ISO (the British, European, and world bodies responsible for standards development). These latest standards were developed to help address the needs of modern building design, including residential or commercial uses.

Figure 9: A dirty ventilation fan.

Source: Steven Lilley (licence: Creative Commons)

Ventilation ducts can be a source of particles, odours, bacteria, and viruses. Settled dust in ducts can be sent back into the air when fans are switched on[81]. Cleaning the ducts generally leads to a reduction in exposure risks to pollutants. However, it can also cause reduction in short-term air quality because the cleaning also raises settled dust. Biocides, sealants, and encapsulants are sometimes used to treat dirty ducts; the health risks from these are often unknown[81].

Figure 10. A dirty ventilation filter.



Source: Professor Tim Sharpe

Air cleaners and purifying devices

It is increasingly possible to use devices that filter or 'clean' the air, either with filters in a ventilation system or with a standalone air purifier[31].

Indoor air cleaning uses several different technologies including thermal or photocatalytic oxidation, adsorption, filtration (of particles), ultra-violet germicidal irradiation, ion generation, and electrostatic precipitation[82, 83]. The cleaners often target biological pathogens, with applications including hospital disinfection, odour removal and removal of air pollutants from residences.

There is some evidence that purification and filtration methods can create problems of their own. Systems have been found to re-emit filtered particles, harbouring microbial growth, and enhance the rates of chemical reactions which produce secondary pollutants. Many of these technologies are inefficient and some produce potentially harmful secondary products such as PM, ozone, formaldehyde and other VOCs[82, 83, 84].

Activities

Large, rapid changes to air quality can result from activities that generate indoor PM, NO_2, CO and VOCs. In school buildings, additional sources of pollutants include office equipment such as photocopiers, science laboratory activities, use of dry-erase markers and art supplies[54, 85]. Anything which disturbs the air and dust, such as cleaning or moving about the home, can re-suspend PM from cooking and burning into the air[86, 87, 88].

Cooking

PM concentrations in the home vary throughout the day and increase in response to activities such as cooking[89, 90, 91]. The decline in air quality is not limited to the kitchen. When cooking raises the particulate levels in the kitchen, measurements showed a similar pattern in the living room[89]. During cooking, $PM_{2.5}$ concentrations in kitchens are generally higher than those found outside, especially in winter, and can remain elevated long after cooking ends[91, 92]. What remains unknown is whether particles generated by cooking are of equivalent toxicity to other sources of particulate pollution from sources such as vehicles.

The design of the home and how we cook is also important. Ventilation is very important as indoor $PM_{2.5}$ and NO_2 concentrations are typically lower in kitchens with extractor fans[91, 92, 93]. The most effective kitchen ventilation system is an extractor fan. Ideally, it should be mounted in a cooker hood that extracts directly to the outside and is located over the hob to cover all burners or rings. The filters should be regularly cleaned. The fan should be switched on whenever cooking, even when using an oven, grill, or a toaster, used on its highest setting, and used for at least 10 minutes after cooking ends.

Modelling shows that open-plan kitchens, which combine a kitchen with a living room, generally have lower PM concentrations, decreasing the exposure of those cooking but increasing the exposure of other family members[94]. The browning of foods by frying, roasting, toasting, and grilling all increase PM emissions[92] so it is important to have adequate ventilation.

Cooking with gas is more polluting than cooking with electricity because gas stoves, grills, and ovens are a significant source of NO_2 and carbon monoxide (CO). NO_2 concentrations were higher in both the kitchen and living room in homes with gas cooking appliances[95]. Homes with gas appliances had higher concentrations of NO_2 than was found outdoors[96, 97].

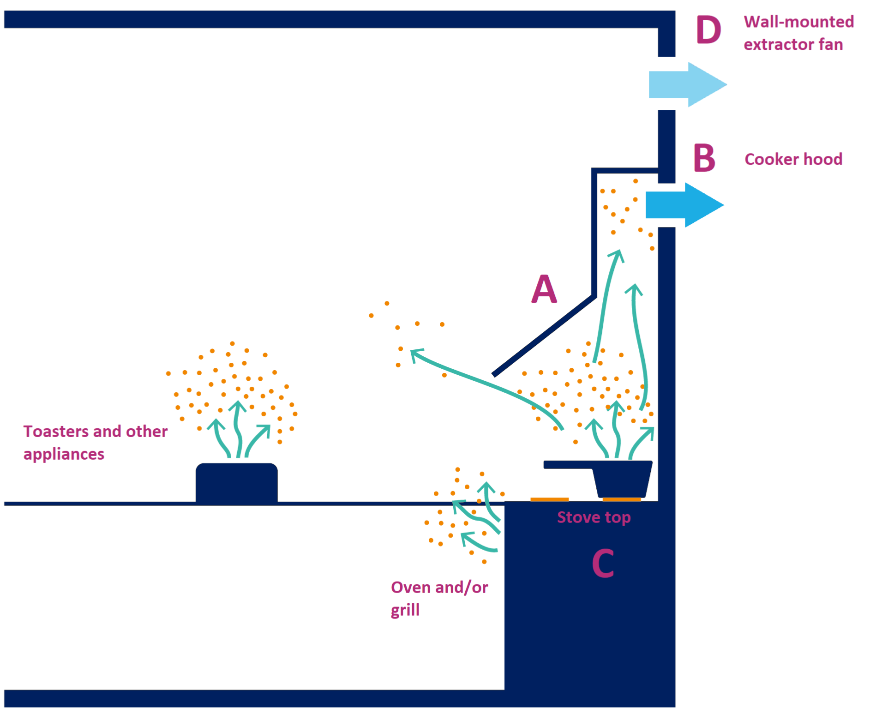
Figure 11: Recomendations when cooking.

A: The cooker hood should cover all rings or burners.

B: The cooker hood should extract the air outdoors.

C: Cook on the back rings or burners whenever possible, especially during frying, to help the cooker hood capture as many pollutants as possible. Consider using other cooking appliances under the hood.

D: If a cooker hood is not available: use a wall mounted extractor fan on its highest setting whenever cooking, and for 10 minutes afterwards. Otherwise, try to find another means to ventilate the room such as opening a window.



Source: Catherine O'Leary[91, 92, 94]

During the winter, kitchens with gas appliances are found on average to have NO_2 concentrations that are twice those found in kitchens with electric appliances, and to have elevated NO_2 concentrations throughout the rest of the home[97].

Carbon monoxide

Gas heating, stoves, pilot lights and other appliances can be a source of carbon monoxide (CO) if they are poorly maintained or defective. CO is fatal at high concentrations. Each year there are around 25 accidental deaths from acute CO poisoning in England and Wales[98].

Chronic, low-level exposure to CO is of increasing concern. It does not produce the same clinical symptoms of acute poisoning, but it may still damage the central nervous system[99]. The exact way this occurs is not fully understood. The concern is that low-level CO produces initially mild but escalating health effects[40]. With mild symptoms, and no colour or odour, low-levels of CO can go unnoticed and lead to long-term exposure.

A study in Hackney, London, looked at how widespread a problem low-level CO is. The study in Hackney estimated that for social housing almost five households out of 1000 have levels above 50 ppm[100].

A study in Oxford[101] showed that indoor exposure to $PM_{2.5}$ was higher than outdoor exposure. Measurements of PM_{10} in Birmingham, Wales, and Cornwall demonstrated higher concentrations indoors, although the composition of indoor PM_{10} was also influenced by outdoor sources[102, 103].

Without pollution generated indoors, indoor NO_2 and PM concentrations are typically lower than outdoors. The CO in buildings is mostly due to infiltration of outdoor air and, without indoor sources, CO indoors is very similar to that outdoors[96]. For NO_2 and $PM_{2.5}$ modelling suggests that, without indoor sources, NO_2 concentrations are 40% of those occurring outdoors, and 50–70% of the outdoor concentrations of $PM_{2.5}$[96, 104]. When cooking or smoking occurs indoors, the average NO_2, CO, and PM concentrations can be much higher than outdoor levels.

Burning

Open fires and older wood-burning stoves emit a mixture of gases (including CO, nitrogen oxides, VOCs) and PM (including inorganic material, organic carbon, PAHs and acids). Burning of wet or unseasoned wood is especially polluting. In the UK, Defra[46] recommends only burning approved solid fuels or wood with less than 20% moisture content. A Defra scheme identifies less-polluting stoves, which are referred to as 'Defra Smoke Exempt Appliances'.

Domestic burning can worsen outdoor air quality. It can also worsen air quality within the home[46, 105]. In the UK, living rooms with wood stoves had higher concentrations of PM than those with central heating[106], with this problem being worse in the colder winter months.

For urban areas, the sources of burning are closer together and buildings can prevent pollutants from easily dispersing. However, in the UK, wood or solid fuel burning is more common outside cities and rural households had higher PAH levels than urban or sub-urban homes[107, 108].

On a smaller scale, candle and incense burning can also impair the air quality. In Danish homes, candles were the dominant source of indoor PM[109]. Candles are less polluting than incense, and both generally have lower emissions than cooking[110].

Smoking

Smoking is a major source of pollutants indoors and will dominate exposure to air pollutants for smokers and their co-habitants[111].

Exposure to third-hand smoke (THS) is when chemicals emitted from smoking stick to and react with indoor surfaces. Nicotine can react in this way to form carcinogenic particulates[112]. Higher PAH (particulate matter produced by burning) concentrations occur in houses with smoking[113]. In non-smoking houses, emissions from cooking and fireplaces are the main sources of PAHs.

In Scotland, children's exposure to second-hand smoke was lower in households with smoking restrictions and where the mother felt confident enforcing the restrictions[114].

As e-cigarettes and vaping rise in popularity, there is little evidence about their impact on air quality. It is not known if there are adverse health effects for children exposed to the emissions. Until this evidence is available it would be sensible to take a precautionary approach and avoid exposing children to vaping and e-cigarettes indoors.

Consumer products

Consumer products for cleaning, polishing, indoor fragrances, or personal care and cosmetic products are a source of indoor air pollution. These products release a range of different VOCs which can be suspended in the air or settle in dust and on surfaces.

Levels of VOCs in the home are influenced by the products we use, the furnishings and building materials, and the rate of ventilation. Indoor VOCs do not appear to be significantly influenced by outdoor sources. Homes near high volumes of traffic had similar levels of VOCs indoors as homes away from busy roads[107]. The concentration of VOCs in the home is strongly correlated with the level of exposure for an individual[108]. This shows that the home is the key factor in how we are exposed to VOC pollution. In London, West Midlands and rural South Wales[108], home VOC concentrations were not significantly different between sites or according to the type of location (urban, suburban, or rural).

A European research project found that both acute (high-level, short-term) and chronic (low-level, long-term) exposure to certain VOCs were related to irritative and respiratory health effects[115, 116, 117]. This includes acrolein, formaldehyde, benzene, naphthalene, d-limonene and α-pinene. These were emitted during household use of 15 consumer products[118, 119]. The last two pollutants react with ozone indoors to produce PM and formaldehyde amongst other pollutants.

Naphthalene can be present at very high concentrations in houses where pest repellents or household products to remove odours (for example, certain types of deodorant blocks for toilets) are used[120, 121]. Exposure to high concentrations of naphthalene can irritate the eyes and respiratory system as well as having some concerning long-term toxicity including cancer. Insect repellents and mothballs should be used with caution, especially in any rooms where young children spend time.

Cleaning products

Cleaning products can add to VOCs and PM in the air. The cleaning itself can raise dust and release VOCs from the surfaces disturbed. Any health risk from cleaning must be weighed against the hygiene benefits, the possibility of choosing less-polluting products, and the potential to remove pollutants with ventilation.

Acute exposure to formaldehyde was identified in homes where cleaning products, candles and plug-in indoor fragrances were used most often. In York, the highest concentrations of limonene and formaldehyde were found for a house where nine different cleaning or fragrance products were used more than 10 times a week[122]. In a separate study, ventilation reduced formaldehyde; the sharp rises in concentrations were only found in low ventilation conditions[119].

In addition to using ventilation, there are other behaviours that may reduce exposure to pollutants from cleaning products:

- using fewer cleaning products or one 'multi-purpose' cleaner (to reduce different ingredients or VOCs)
- reducing the amount of product applied to clean a surface
- making sure you remove cleaning products off surfaces completely after cleaning.

Settled dust

Settled dust is a source of pollutants, including PM, biological pollutants (from house dust mites and other pests, pet allergens, mould and fungi), SVOCs, pesticides, flame retardants, phthalates, and even peanut or other food allergenic proteins[123].

Keeping a building clean is an obvious priority for many building owners and users. Vacuum cleaning is one of the simplest methods for clearing dust and is particularly important for those who suffer from asthma. However, vacuum cleaners can release and resuspend dust and allergens, presenting an additional source of exposure for susceptible populations[124]. This happens both through vacuuming disturbing the dust and through emissions from the vacuum cleaner. It is important that the dust collection chamber retains the dust efficiently and is emptied regularly. Bacteria can survive for up to two months within these spaces and then be released into the air when the vacuum cleaner is used again[124].

Pets and plants

Pets are a source of indoor allergens and for some sensitive members of the population, exposure to these allergens can exacerbate disease. Plants may also be a source of allergens in pollen, mould in the soil, or pesticides. The extent to which these pollutants will affect indoor air quality is highly variable. It depends on the plant species, the amount of pollutant released, and the differences in sensitivity to allergens between people. Except for tests in laboratory air-chambers, there is little evidence that specific plants can noticeably reduce indoor air pollutants in rooms of homes and schools[125].

Moisture and temperature indoors

Activities such as cooking, showering or drying clothes indoors introduce moisture into the home. Cold floors, walls and surfaces can lead to condensation. Water damage from leaks or flooding cause damage in themselves but also contribute to moisture loads in the building. The weather and season also affect indoor moisture, increasing when there are wet or high humidity conditions outdoors. Moisture is a problem indoors because it promotes mould growth and other biological contaminants, such as house dust mites.

Figure 12: Mould growth and dampness.

Source: MEARU

Humidifiers add moisture to the air to prevent dryness that can irritate some parts of the body, such as the skin and lips. Increasing the humidity can increase release of formaldehyde from the building materials and surfaces[126]. Humidifiers can also increase the likelihood of damp, condensation on cold surfaces, and mould or fungal growth[127]. Damp rooms can be controlled using a dehumidifier, but these can facilitate mould growth if stagnant water is left inside them[128].

Humidity above 65% in an indoor environment encourages chemical reactions that leave a thin 'film' that coats surfaces[129]. This can increase the concentration of potentially irritating chemicals indoors[130]. Microbes are often associated with damp surfaces in homes and these can also emit reactive chemicals[131].

Conditions leading to increased damp and mould

Moisture gets into the home from outdoors, normal household activities such as cooking and washing, or due to damage such as leaks. Cold surfaces due to lack of insulation and 'cold bridges' (gaps in the home insulation) can trigger condensation. Lack of effective and affordable heating exacerbates these conditions.

Moisture in the air, in the building fabric (e.g. walls) or furnishings (e.g. carpets/mattresses) also affect mould and dust mites. Energy efficiency measures such as airtightness and insulation could support house dust mites and mould growth, unless adequate ventilation is provided to extract moisture.

Ventilation can extract moisture, so long as the air entering the building is less humid than the air it is replacing. Dehumidifiers are a mechanical way of extracting moisture, but they consume energy which has financial and environmental costs.

Using extraction ventilation in bathrooms and kitchens, and drying clothes outside or in a well-ventilated space, can help reduce moisture levels.

Cleaning can help by removing mould spores and reducing food sources for house dust mites.

Swimming pools are relatively uncommon in UK homes and schools but are another source of moisture. Chlorine levels are relatively high in swimming pools and a range of by-products are formed when the chlorine interacts with organic matter. Some of these have carcinogenic properties[132]. The evidence around childhood swimming and new-onset asthma is emerging. There need to be larger health studies to look at the risk to swimmers. Currently, that potential harm must be weighed up against the known benefits of exercise.

Heating and ventilation

High ventilation rates dilute indoor generated air pollutants but allow higher ingress of outdoor air pollutants. For example, by bringing outdoor air in, ventilation may also lead to higher indoor ozone concentrations. Ozone is very reactive, and can produce secondary pollutants from chemical reactions, including with nicotine and d-limonene (used in air fresheners for example). With enough ventilation the conditions for chemical reactions are disrupted, and any secondary pollutants created would be quickly flushed out of the building. Other outdoor-generated pollutants entering the building via ventilation can include PM and NO_2. Higher temperature can also increase the emissions and chemical reactions between certain chemicals indoors. If they become warm some plastics emit higher rates of VOCs; for example children's toys left near radiators or in direct sunlight.

Buildings with identical indoor pollution sources could still have very different indoor air. This will depend on the ventilation rates, heating patterns, behaviour of the people using the building, and the outdoor climate. People will influence the ventilation and heating in homes and schools. This happens both intentionally, such as when altering thermostats or using windows and other means of ventilation, and unintentionally, such as when opening external doors to enter or leave the building.

People as sources of pollution

The presence of people indoors can significantly alter the air quality. This is because our skin oil contains compounds that can react with ozone to produce a range of VOCs. Humans breathe out CO_2 and VOCs. The exact contents of exhalation depend on the individual; age, gender, smoking habits and diet each have an impact[133]. Emissions from humans are called 'bio-effluents' and include the smells we associate with people. Smell can be an effective prompt to increase ventilation; it is a sign of insufficient ventilation. However, not all pollutants that cause poor indoor air quality are detectable by smell (including those such as CO and radon which can be deadly).

These emissions are more likely to have an impact in schools than homes. Classrooms hold a relatively high number of children for the space they occupy and, as a result, may be inadequately ventilated. CO_2 is currently used as an index of ventilation performance in the

Figure 13. Rooms with poor air quality.

By Adiel age 10 and Fatima age 9

Government Guidance for Schools[134]. Higher CO_2 concentrations have been correlated with a decline in cognitive performance, such as the ability to concentrate. There is uncertainty about whether these effects are caused by CO_2 itself, or related to other chemical and biological pollutants present that accumulate in parallel with CO_2[135].

5. Health effects for children

Children, and particularly children in the UK, spend almost all their time indoors, and this is a trend that is increasing. In infancy this is mostly in the home. As children grow up, this expands to nursery, school, and the homes of friends and relatives. This chapter summarises the potential health effects of indoor pollution during childhood. The studies were mostly identified through a systematic evidence review led by RCPCH.

The RCPCH &Us team spoke with children and families in hospitals, youth centres and schools. Quotes from these conversations are used alongside the evidence to help represent families' day-to-day experiences and views about indoor air quality. We have divided the evidence by age, discussing the exposures of infants, pre-school children and school-age children separately. This report is focused on the experience of children in the UK, and similar countries. The challenges faced by low- and middle-income countries need to be addressed separately, as both the causes and solutions are different.

A large majority of studies were concerned with exposures in the home, with a small number from the UK. Far fewer considered exposures in day-care or at school, and none of them were set in the UK. Few studies directly considered the issue of poverty and associated socioeconomic deprivation. Yet it is highly likely that through excess indoor pollution, poor housing conditions are in part responsible for the stark social gradient of childhood disease observed in the UK.

Over 80% of studies linking adverse health to air pollution indoors were concerned primarily with respiratory health. There is a small amount of literature on dermatitis and a range of other conditions. Almost all studies focussed on a specific pollutant or type of pollutant (such as mould or groups of chemicals). Damp and mouldy housing was the focus for a high proportion of studies. Studies looked at allergens in dust from house dust mites, pets, pests, and vermin. Others tested dust to estimate exposure to 'chemicals' including those of endocrine disrupting compounds (EDCs), pesticides, moulds, bacteria and endotoxins. A few studies tested the indoor air for VOCs, NO_2, CO_2 or PM.

Figure 14: Health effects from indoor air pollution in childhood.

	**Birth and infancy** • Respiratory problems – wheeze, rhinitis, atopic asthma, respiratory infections • Low birthweight and pre-term birth
	**Pre-school** • Respiratory problems – wheeze, allergies, asthma, risk of respiratory diseases and pneumonia • Eczema and atopic dermatitis • Greater hyperactivity, impulsivity and inattention
	**School age** • Respiratory problems – wheeze, rhinitis, asthma, throat irritation, nasal congestion, dry cough • Eczema, dermatitis, conjunctivitis, skin and eye irritation • Reduced cognitive performance, difficulty sleeping

Source: Royal College of Paediatrics and Child Health

Global perspective on indoor air: solid fuel in the home

Biomass is rarely used for cooking and heating in high-income countries but is used extensively in low-income and rural areas. It poses a serious risk to infant health.

Still-birth and premature birth

Studies across the developing world demonstrate that still birth, perinatal and infant mortality is increased by burning fuel in the home. It has been estimated that fine particulate matter (PM) was associated with 2.7 million preterm infants globally in 2013; 18% of all preterm births[136]. In a study of 188,917 women in India, biomass and kerosene cooking fuels were associated with an increased stillbirth occurrence[137]. This suggests around 12% of stillbirths in India could be prevented by providing access to cleaner cooking fuel[137]. Ten years of health data in Bangladesh showed cooking with polluting fuels increased the stillbirths and deaths in the first week after birth[138]. Likewise, in Nigeria, research found that in poor, rural households 43% of post-neonatal deaths could be attributed to solid fuels[139]. In India, amongst 1744 pregnant women, premature birth was more common for those cooking with wood[140].

A trial in Nigeria randomly allocated pregnant women to receive either an ethanol stove, or continue using kerosene and firewood. The average gestational age was one week longer for the women who received an ethanol stove (39 weeks). Stillbirths and deaths within the first week were twice as high for those using kerosene or firewood to cook (8%)[141].

Lower birth weight

The impact of burning biomass has been shown to increase the risk of a low birth weight (below 2500g). In Bangladesh, mothers who used high pollutant cooking fuels such as coal or wood had an increased risk of a low birth weight, compared to those who used electricity or gas[142]. One systematic review, of five studies, found indoor pollution from solid fuel increased the risk of low birth weight[143]. Other studies of babies in households cooking with biomass fuels – including wood, dung, straw, charcoal, and garbage – also found a reduction in birth weight: babies in Zimbabwe were 175g lighter[144] compared to households using other fuels; in Malawi they were 92g lighter[145]; in Ghana, a small study found an average 429g reduction[146]; a review of 19 studies estimated that use of solid fuels is associated with an 86g reduction in birth weight[147]. In Ghana indoor air pollution was found to account for between 31-52% of the difference in birth weight between socioeconomic groups[148].

A trial in Mongolia found use of a portable air cleaner at home reduced particulate matter by 29%. Use of an air filter was associated with an 85g increase in birth weight for a sub-group of the births but did not have a significant effect overall[149].

Respiratory disease

In Santa Domingo, children under 18 months in homes cooking with charcoal were more likely to develop acute lower respiratory infections[150] compared to those in households using propane gas. In Chile, amongst 504 four-month-old infants, an increase in $PM_{2.5}$ was related to wheezing; the association was stronger in infants without a family history of asthma[151].

Birth and infancy

The literature search revealed only a few studies from the UK and similar countries regarding the effects of indoor pollution on outcomes in birth and infancy.

Moisture and mould

Evidence regarding the association of exposure to moisture and mould with respiratory problems in infancy strongly suggests an adverse effect.

In a European birth cohort[152], the severity of moisture damage in the kitchen and visible mould in the main living area were associated with an increased risk for wheezing in the first 18 months of life. These results were not replicated in a birth cohort in the USA[153, 154].

Figure 15: Mould in a child's bedroom

Source: Professor Tim Sharpe

In the USA, some species of fungi, found in domestic dust samples, were correlated with rhinitis and wheezing during infancy. Similarly, in a birth cohort of Italian children[155], visible mould in the home significantly increased the risk of hospitalization for a respiratory infection (bronchiolitis) during infancy. In Finland, a study of 398 children (aged up to 18 months) found those diagnosed with wheezing were more likely to live in damp homes. This was assessed by the severity of moisture damage in the kitchen and visible mould in the living area[156]. Amongst 103 infants at risk for asthma in the USA, high levels of *Penicillium* mould were a significant risk factor for wheeze in the first year. The analysis was adjusted to remove the influence of factors such as the season in which damp was assessed, endotoxin levels (a marker for bacteria levels), and whether the child attended a day-care or nursery[156].

Chemicals

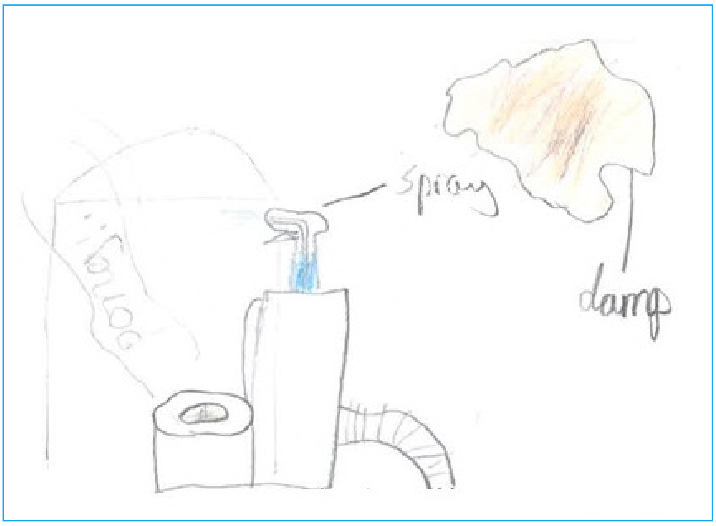
Redecoration

Redecorating or refurnishing the home can release VOCs and cause a higher than usual exposure. In the LINA birth study, home decorating increased the risk of infants under one year old being diagnosed with wheeze. The health effects were attributed to styrene, ethylbenzene, octane, 1-butanol, tridecane and o-xylene[157]. It appears that exposure during infancy was less detrimental than during pregnancy and changing the flooring material was highlighted as a concern. The Leipzig Allergy Risk Children Study found redecoration of an apartment increased the risk of infants having acute inflammation of their airways[158]. When 25 VOCs were measured in the bedrooms of 475 infants with allergic risk factors, those exposed to higher concentrations of styrene and benzene had more respiratory infections (OR 5.6, 95% CI 1.3-24.0)[159].

Similarly, in the Pollution and Asthma Risk Infant Study (PARIS), indoor renovation was reported to be a risk factor for respiratory symptoms or allergies[160]. Evidence from that cohort suggests that the risk may be attributable to formaldehyde[161, 162].

In the Avon Longitudinal Study of Parents and Children, a high maternal composite household chemical exposure score was associated with an increased risk of wheeze in the first 18 months after birth[163]. Amongst 257 children in Krakow with pre- and postnatal exposure to PAHs, there was an increased risk of wheezing[164].

Figure 16: Damp and cleaning products indoors.



By Stanley, age 9

Household products

Ventilation could mitigate the effects of indoor air pollution during pregnancy. A study looked at the outcomes of births in women who were regular or frequent users of household cleaning products. Those who kept the windows open for at least half the day had no increased risk of having a pre-term or low birthweight child[165]. There was an increased risk of preterm birth for regular users of nail polish or hairspray for at-home mothers, but not for mothers working out of the home.

Endocrine disrupting chemicals (EDCs)

This heterogeneous group includes synthetic chemicals used as industrial solvents and lubricants and their by-products (such as polychlorinated biphenyls, dioxins), plastics (bisphenol A), plasticisers (phthalates) and some pesticides (such as methoxychlor or chlorpyrifos) which tend to accumulate in household dust. They are often designed to be long-lasting, and so they can remain in the home for very long periods. Exposure to EDCs has been linked to a variety of adverse reproductive, malignant and metabolic outcomes including childhood obesity. There is also growing concern over the possible long-term effects, such as infertility, due to exposures in very early life[166].

Congenital abnormalities

The evidence that exposure to air pollutant chemicals may increase congenital abnormalities is relatively weak. In a Chinese study, women's exposure to indoor air pollution during pregnancy increased the risk of neural tube defects in their babies[167]. The study was of mothers with a specific genetic variant and it may not apply to other women. A small study in France found a strong association between pregnant women's exposure to endocrine disrupting chemicals at work and a birth defect where the urethra's opening develops on the underside of the penis (hypospadias)[168].

"I have the heating on, because I don't like to be cold. I don't like to open the windows, because the bugs come in, but sometimes my son opens them.

I want the council to put ventilation in the kitchen, so I don't have to open the window."

A parent

Particulate air pollution

A systematic review of 84 studies reported that many types of particulates were associated with low birth weight and decreases in birth weight. The review also highlighted that there were some inconsistencies in the included studies[169].

The Taiwan Birth Cohort Study, involving 15,773 births, found incense burning was associated with lower birth weight in boys (18g) but not girls. Smaller head circumferences were found in both genders[170].

Cooking fumes

In Rome, seed oil for cooking was associated with an increased risk for a type of respiratory infection (bronchiolitis) in infancy[171].

Pre-school children

Figure 17: Mould in a child's bedroom.

Source: Professor Tim Sharpe

Moisture and mould

The evidence for an association of dampness or mould on adverse respiratory outcomes in pre-school children is conflicting, but overall it appears to exacerbate the symptoms of allergies and respiratory conditions. In a Polish birth cohort, a damp or mouldy home was associated with persistent wheeziness up to the age of two years[172].

In a large case-control study from New Zealand, the adjusted risk of pneumonia in pre-school children was doubled among children who slept in a bedroom where mould was visible[173]. Similarly, in a study from the UK, a damp home was independently associated with a higher risk of asthma and associated allergies[174].

In contrast, several studies have failed to find a link between mould and childhood respiratory diseases. A study in Sweden found no link between children's asthma and the levels of mould in dust collected from their bedrooms[175]. In the USA, there was no association between mould in the home and recurrent night cough in children aged three years or younger[176].

"I have nowhere else to dry the washing, it's muggy and you can smell it.

My daughter coughs and it affects her eczema – the dehumidifier was £200! But I bought it and I have it on every night."

A parent

In an Italian study of under-fives, there was no significant difference in damp or mould in the child's bedroom when comparing those who had had bronchiolitis with a group who did not[171]. In a study of 408 children (aged two to three months) with a family history of allergic disease or asthma, bedroom dust samples were collected and tested for fungi. Children whose bedroom floor had high levels of yeasts were at a reduced risk of wheeze at any age and a reduced risk of asthma by age 13[154].

In studies of day-care facilities, measures of moisture and mould did not have a clear effect on respiratory health among children attending day-care in Portugal[177] or in Oslo[178].

Chemicals

> **"I have to be aware of it because of his allergies.**
>
> **I don't use cleaning products, I just use vinegar to clean and baking soda. I don't use perfume."**
>
> **A parent**

In preschool children, exposure to certain air pollutant chemicals increases respiratory problems and may increase dermatitis. The findings of a systematic review of ten studies[179] suggest that high exposures to NO_2 and VOCs in the home increase the risk of developing wheezing respiratory diseases before the age of five. Amongst 150 children between two and six years of age with a physician diagnosis of asthma in Baltimore, higher NO_2 concentrations were associated with increased cough and nocturnal symptoms. After adjustments for confounders were made there was no increase in use of healthcare. The presence of a gas stove or the use of a space heater were independently associated with higher NO_2 concentrations[180]. In Polish children the frequency of wheezing was significantly associated with increased postnatal indoor exposure to PAHs[164]. In South Korean children there was a significant association between VOC exposure in the bedroom and atopic dermatitis at the age of three[181].

In one disastrous use of chemicals in the home, disinfectants used for domestic humidifiers in South Korea caused serious lung injuries. There were deaths, including both young children and their parents. The problem promptly disappeared when the sale of these disinfectants was prohibited in 2011[182].

In a case-control study of 500 Danish children aged three to five years, the dust from both home and day-care environments was tested to measure phthalates. One phthalate (diethyl phthalate) was found in higher proportions for children with asthma and allergies, compared to children without pre-existing health conditions[183]. A different phthalate (Di2ethylhexlyphthalate) was associated with current wheeze. There was no significant difference found for two other phthalate derivatives (di(isobutyl) phthalate [DiBP] butyl benzyl phthalate [BBzP]).

In a Swedish study, 198 children with asthma and allergy were compared to 202 healthy controls. Their bedroom air samples were tested for eight types of VOCs. Propylene glycol and glycol ethers were associated with a greater likelihood of asthma, rhinitis and eczema. The analysis was adjusted to control for the effects of the child's gender, exposure to secondary smoking, parental allergies, construction period of the building, and for the presence of d-limonene (a terpene used in cleaning fluids and air fresheners), cat and dog allergens, or selected phthalates[184].

A small case-control study from the USA suggested that developmental delay before the age of five years may be associated with levels of phthalates in the dust at home[185]. Although the levels were not significantly associated with autism spectrum disorder, higher indoor dust concentrations of diethyl phthalate were associated with greater hyperactivity, impulsivity and inattention.

Carbon dioxide exposure

In a study in Denmark, despite only one day-care centre having CO_2 concentrations above 1000 ppm, children missed fewer days due to illness when the CO_2 levels were reduced[186]. In Portugal, higher CO_2 levels in day-care centres were associated with wheeze. The CO_2 concentrations were reduced by opening windows or internal doors, and by higher wind speeds[187]. These studies use CO_2 levels as a proxy for the ventilation and poor indoor air quality. The CO_2 concentration is reduced by increasing the intake of air; this change in the air may be responsible for the health outcomes rather than the reduction in CO_2 alone.

Allergens and endotoxin

The evidence on the impact of allergens and endotoxin is variable. Two studies of young children in the USA[188, 189] did not find a relationship between the levels of pet allergen in the home and rates of wheeze or eczema. Furthermore, a longitudinal study of children in the Netherlands followed to the age of five years failed to find any relationship between cat and house dust mite allergen exposures and development of respiratory symptoms[190]. In a community study with a low prevalence of pet-keeping and low mite allergen levels, exposure to cat allergens in early life increased the risk of late childhood asthma and bronchial hyper-responsiveness (BHR). There was no effect on the risk found for dog allergens, endotoxin and β (1,3)-glucans[191].

A meta-analysis of observational studies demonstrated that endotoxin was positively associated with wheeze in infants and toddlers, but not with asthma in school-aged children[192].

Figure 17. A house dust mite

By Cyra, 5

Particulate matter

Exposure to particulate matter (PM) has been shown to increase the risk of asthma, dermatitis and eczema. In a survey of children in the US[193] eczema, but not wheeze, was associated with high exposures (mean 85 μg/m^3) to PM. In one study, PM was measured using an innovative mobile sampler (the Pre-Toddler Inhalable Particulate Environment Robotic [PIPER]). In 75 households with children under five years of age, the risk of asthma was increased in those with the highest concentrations of larger PM_{10}. This was discovered when using the mobile PIPER device, but not by the stationary samplers[194].

Amongst children aged two to six years in Baltimore, increases in home PM concentrations were associated with increased respiratory symptoms and use of asthma rescue medication. Increases in $PM_{2.5}$ were also associated with respiratory and asthma symptoms during exercise[195].

There is some evidence on PM having an adverse effect on children's skin. In a study of 425 children in a Korean kindergarten, atopic dermatitis and eczema were reduced when an enhanced cleaning programme was used by the kindergartens to reduce PM concentrations[196].

School-aged children

Moisture and mould

The review identified many studies examining the effects of indoor damp or mould in school-aged children, although just one was of children in the UK[174]. Most were concerned with damp in the home, in most cases described by parents. Two studies were of damp in schools. The studies of domestic damp suggest modest associations with asthma-like symptoms, rhinitis and eczema.

Several studies were reviewed by Castro-Rodriguez[197] who reported a summary odds ratio of around 1.5 for the presence of mould or dampness at home and asthma or wheeze. Studies of consecutive cohorts of children in Sweden suggest that the risks probably diminish as children get older[198, 199]. In the UK study, a damp home in infancy was independently related to atopic asthma over the subsequent seven years. Findings from studies in Italy[200], Australia[201] and Sweden[198] suggest that between 7% and 14% of childhood asthma can be attributed to damp housing.

Two studies compared the school environment and the health of pupils in Spain, the Netherlands and Finland[202]. In the Finnish group – but not the others – there was an association between a damp school and wheeze, rhinitis, and school absence from respiratory illnesses. In a survey of 1,000 children in Denmark[203] there were no significant associations between symptoms and mould levels in naturally ventilated classrooms. Importantly, this was not the case for classrooms with exhaust or mechanical ventilation systems. In these classrooms, higher mould levels were related to the children experiencing increased eye and throat irritation, nasal congestion, and itchy skin.

"The council gave us a dehumidifier but it is still a big problem. We have black mould in the bedrooms. My parents are really worried, they clean it off every couple of months but it comes back.

It affects our skin and we breathe it in… My dad went to the doctors about it – the whole family has eczema now. The doctor gave some advice about the cleaning."

Shazia, 18

Similar findings were reported in schoolchildren from 21 schools in five European countries[204]. In a Polish secondary school, breathlessness and cough after physical exercise were related to the humidity level in the gymnasium[205]. In a high-risk birth cohort in the US, in which one parent was atopic, exposure to moulds was assessed by the Environmental Relative Moldiness Index (ERMI)[206]. Mould exposure at one, but not at seven years, was associated with a significant increase in the risk for asthma at seven years of age. In a Colombian survey of children (from birth to 17 years), mould exposure was noted to be a risk factor for asthma-related absences from school[207].

While the evidence about damp or mould is mostly about respiratory and skin conditions, a study of German children[208] suggested that those in damp homes have more trouble sleeping through the night. In addition, in upstate New York, school absenteeism was significantly associated with poor school building conditions (visible mould, high humidity and poor ventilation)[209].

Chemicals

Several studies have shown an association between various chemicals and adverse respiratory and skin problems. Five studies examined the effects of VOCs in the homes of school-aged children and highlighted an association with respiratory problems. In France[210], levels of benzene in the home were related to non-atopic asthma. In Portuguese homes, similar findings were found for toluene and acetaldehyde[211]. In homes in the USA, this was for four different VOCs[212]. Amongst Alaskan native children, VOCs, use of wood as a primary heat source, and a $PM_{2.5}$ level above 25 ug/m^3 were associated with a higher risk of cough between colds and an asthma diagnosis[212]. In Canadian homes, where 47 VOCs were measured, significant associations with deficits in lung function were observed for all, apart from naphthalene[213].

In a comparison of French urban and rural homes, urban homes had more indoor pollutants. In both urban and rural homes, acetaldehyde and toluene were significantly associated with a higher risk of asthma[214]. In a survey of over 6,500 French schoolchildren, rhino-conjunctivitis and asthma were significantly associated with high levels of formaldehyde or acrolein in classrooms[215]. In Japan, where it is common for children to sit on the floor, levels of phthalates in dust were associated with higher prevalence of rhinitis, conjunctivitis and dermatitis[216].

The systematic review identified three studies of oxides of nitrogen (NOx) in the home. In the strongest of these, a longitudinal study of 1300 children with asthma in the USA, levels of NO_2 greater than

14.3ppb were associated with increased asthma severity[217]. In the French school study[215] the prevalence of asthma was higher in classrooms with higher levels of NO_2.

A study of nine-year-olds in Spain[218], used MRI scanning to study the impact of indoor pollution on the brain. This found a potential link between higher levels of PAHs (specifically, benzo-[a]-pyrene) at school and a reduced size of caudate nucleus (basal nuclei toward the front of the brain essential for controlling motor functions, as well as learning and memory).

"I think of my bedroom as having clean air. It's warm and cosy but it is a bit stuffy, and I do get a runny or blocked nose.

...I think of this as a good space, but is it a healthy space?"

Adele, 18

Seven studies, all but two undertaken in the USA, were concerned with pesticides. In a study of over 14,000 American children, pesticide use in the kitchen or dining room significantly increased the odds of childhood wheeze and dry cough[219]. In Austria, phthalates and compounds, used in pesticides and found in the indoor PM, were associated with reduced cognitive performance in six- to eight-year-olds. Increased CO_2 levels were also associated with reduced performance[220]. There are case-control studies which suggest a risk of childhood cancers or multiple sclerosis from pesticide use at home, but the collective evidence is weak.

Allergens and endotoxin

Several birth cohort studies have attempted to relate the onset of school-aged asthma to measurements of domestic allergens made early in life. With respect to allergens from pets and from house dust mites, the evidence is very largely negative. Cross-sectional evidence suggests a role for cockroach and mouse allergens in US homes. For example, in children with asthma, the concentration of cockroach (but not dust mite) allergen in household dust was significantly related to the risk of hospitalisation. This was true even after adjustments were made to account for different asthma severity and socioeconomic status[221].

Among children living in US inner cities, where socioeconomic deprivation is common, mouse allergen levels in bedroom dust were associated with greater asthma morbidity[222]. Similarly, a USA study focused on children whose parents had a history of asthma or allergy. In this group, current mouse exposure in each of the first seven years of life increased the risk of wheeze[223]. In contrast, in another USA study, among 442 inner city children, higher levels of pet or pest allergens in infancy were associated with a lower risk of asthma[224]. Furthermore, Mendy and colleagues[192] systematically reviewed the evidence on endotoxin and, based on 19 studies, reported that higher levels were associated with a lower risk of asthma and related symptoms.

Particulate matter

A small number of studies concerned particulate matter measured in the home and the health of school-aged children. In three small studies of American children, levels of $PM_{2.5}$ were associated with a variety of respiratory symptoms[195, 212, 225]. In one, the increased risk of respiratory disease was only found for overweight children. Exposure to fine particulate matter ($PM_{2.5}$) during pregnancy was associated with increased susceptibility to respiratory infections by seven years old[226]. In the USA, for 44 asthmatic children aged between 1 and 16 years, indoor but not outdoor $PM_{2.5}$ was associated with reductions in lung function[227].

Carbon dioxide exposure

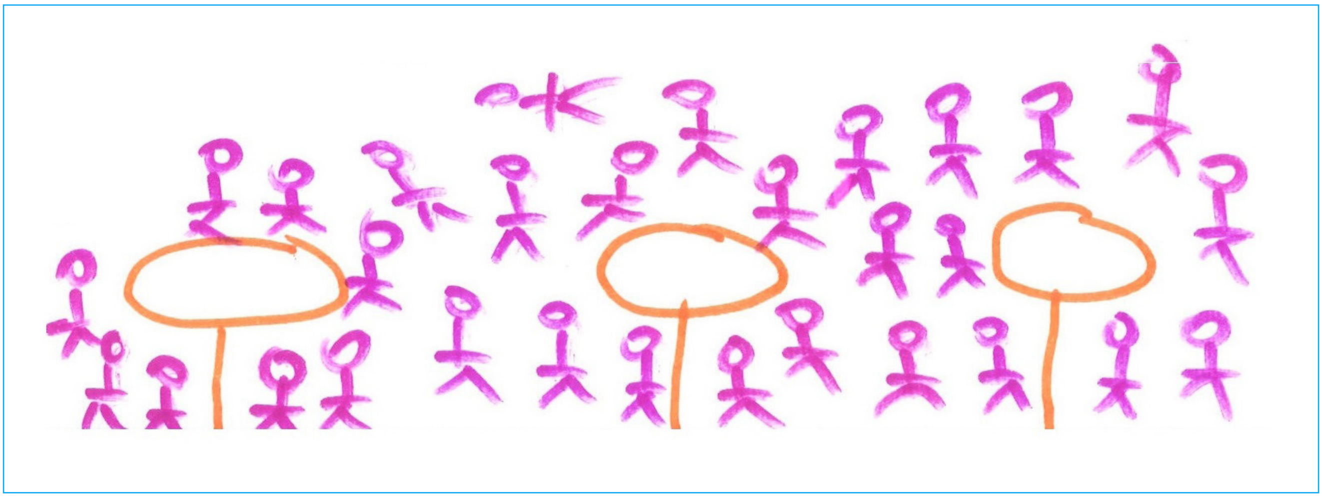
A European-Union-funded study demonstrated that 66% of school children in Norway, Sweden, Denmark, France and Italy were exposed to CO_2 concentrations above 1,000ppm. Children exposed to the higher levels were at higher risk for developing a dry cough or rhinitis[228]. Similarly, in China the mean CO_2 concentration exceeded 1,000ppm in 45% of the classrooms and was associated with an increased risk of asthma and requirement for asthma medication[229].

> **"I notice the dirty air in school. In class the air is not fresh.**
>
> **There are bad smells and it's hard to breathe. They have damp and mould."**
>
> **Daniel, 9**

Furthermore, in a study in Washington and Idaho, 45% of classrooms had a CO_2 concentration greater than 1,000ppm. Pupils in these classrooms with high CO_2 concentration had reduced attendance at school. Over a year these high CO_2 concentrations were associated with a 0.5% decrease in average daily attendance, which for each classroom was an increase in absences of between 10 and 20%[230]. In Scotland, higher than average CO_2 concentrations were also linked to lower attendance. Using a time-weighted average, for each 100ppm increase in CO_2 concentrations there was a 0.2% reduction in the annual school attendance. This is roughly equivalent to half a day of school missed per annum[231]. In Californian elementary schools, increasing the ventilation rates for classrooms reduced the level of absences[232].

Elevated CO_2 concentrations have been shown to also reduce the power of attention by 5%[233, 234]. Increasing ventilation rates in schools with mechanical systems has installation and running costs. Whether by natural or mechanical means, increased ventilation could raise the overall heating or air-conditioning bills. However, the likely net annual costs were calculated as less than 0.1% of typical public spending on elementary and secondary education in the USA[235]. In all these studies CO_2 concentrations have been used as a proxy for overall ventilation.

Figure 18. A crowded classroom



By Shaan, age 16

6. Improving indoor air quality

Urgent action is needed to address the problems of poor indoor air quality. Children are potentially being exposed to harmful levels of pollutants throughout their daily lives in the buildings where they live, play and learn. It is to be welcomed that there has been a greater focus on the harmful impacts of outdoor air pollution. Indoor exposures can also be harmful and less apparent to occupants. We need to do more to prevent these from occurring in the first place and to understand better how they impact on children.

This chapter outlines actions to prevent indoor pollution problems from occurring, and interventions that may mitigate unavoidable pollutants. In general, there are two strategies:

a) **source control** – measures to avoid the presence of pollutants in buildings

b) **mitigating actions** – measure to remove and dilute pollutants from buildings.

Strategies for source control

Strategies for source control will depend significantly on what the sources are and how they get into homes. These were identified in the '*Factors affecting air quality*' section of this report and include both external and internal sources.

Internal pollutants can come from building materials, furnishings, household products, and human activities (such as cooking). Indoor source control examines how polluting materials can be avoided, replaced with a lower or no emission alternative, or used in a way to minimise the risk.

External pollutants come in from the outside and include traffic fumes, emission from industry, and airborne pesticides. Reducing outdoor pollutants relies on wider actions, such as using less-polluting modes of transport or changing the nature or location of industrial processes.

Mitigating actions

Mitigating actions attempt to remove or at least dilute indoor pollutants from buildings. All buildings have some form of ventilation – this is the exchange of polluted air with 'fresh' air. Ventilation is needed to ensure that occupants can breathe and have a comfortable indoor environment. Ventilation ranges from the very simple, such as opening windows, to complex mechanical systems. It remains the main way of diluting or removing pollutants from buildings. There are other ways to reduce pollution: air filtration, dehumidifiers, air cleaning devices, or materials designed to absorb pollutants, but use of these is not widespread. The efficacy of many of these devices and materials is not yet established[31], and was discussed in the section 'Factors affecting indoor air quality'.

To provide good indoor air, a combination of source control and mitigating actions will be needed. Even with rigorous source control, some internal pollution will always occur and need to be removed. Design strategies to reduce and control indoor sources of pollution can help improve future buildings. Better standards for new-build homes are important but not a solution on their own; new buildings make up only a small proportion of homes. There is a need to improve existing buildings, which be in a poor condition or contain pre-existing sources of pollution.

Legislation

Legislation to control exposure to indoor air pollution is not unified to the extent currently applied to outdoor air. Even with current legislation there continue to be problems relating to both outdoor and indoor air pollution. Legislation relevant to indoor air quality is currently spread across several areas:

- building standards specifying minimum ventilation requirements, and specific measures such as preventing radon from accumulating
- workplace standards, banning or limiting the exposure of workers to hazardous substances
- chemicals legislation, banning or restricting the use of some hazardous substances for workers and/or members of the public
- product legislation which controls the use of hazardous substances
- smoking legislation, which has banned smoking in enclosed public places, levied taxes on tobacco, and required services to help those wishing to quit.

Legislation that is not specific to the indoor environment, but which has an impact upon it includes:

- controls on outdoor air pollution and use of pesticides
- climate policies for reduced energy consumption
- environmental health protection
- legislation for landlords
- town planning.

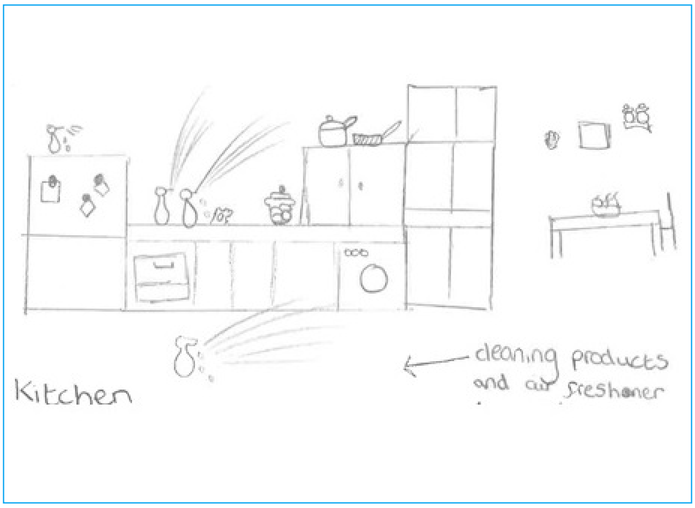
Prevention

One of the challenges in making recommendations is the strength of the evidence that can be used to drive change. Where clear health effects of individual pollutants have been identified, legislation has been enacted that affects how buildings are designed. An example of an external pollutant is radon, a radioactive, odourless, naturally-occurring gas in the ground that is a known carcinogen. In areas where this is prevalent, specific building fabric measures are required to prevent its ingress into buildings, such as radon barriers and sub-floor ventilation. An example of an indoor pollutant is asbestos. It was widely used in building materials but was later found to cause serious health conditions, such as asbestosis and mesothelioma. Asbestos was banned in the UK and over 50 other countries[236] but it is still present in many older buildings.

These examples show that legislation can be enacted to protect human health. However, the reactive nature of the response, and the slow pace of change, meant that many people became ill or died before action was taken. Radon and asbestos are also relatively localised, which is not the case for all the pollutants described in this report, and many are more commonly occurring. One barrier to change was the need to demonstrate a clear health effect. In both the above cases, causal links were established between the pollutant and health outcomes which gave a clear evidence base for legislation. But this took time and, despite the evidence of harm, these pollutants continue to be found in our buildings. This reinforces the need to take a precautionary approach to the use of materials that contain harmful chemicals.

There is good evidence of adverse health effects on children for some contaminants, for example mould growth, formaldehyde and particulates. This provides the grounds to adopt measures for prevention and intervention to reduce exposures to poor indoor air quality. Such measures will often reduce other pollutants; a warm, dry, and well-ventilated building mitigates against a wide range of pollutants. The alternative to how asbestos was handled would be to take a precautionary approach. That would mean restricting the use of compounds until they are tested and rated for safety.

Figure 20. Cleaning products in the kitchen.



By Nora, age 9

A precautionary approach is advisable where either the chemical content, or the health effects, are unknown. The European Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation[237] places responsibility on industry to manage the risks from chemicals. Industry must provide safety information on substances and avoid their use where safety cannot be demonstrated. The approach is summarised as "*no data, no market*".

In 2019 the UK Government pledged[238] to develop a voluntary labelling scheme for non-methane VOC-containing products. The range of products identified includes carpets, upholstery, paint, cleaning, fragrance, and personal care products.

Using evidence in prevention

At present there is little data is gathered on indoor air quality in buildings. Studies have tended to be small-scale and focussed on specific issues. Unlike for outdoor air pollution, it is difficult to map indoor air evidence onto population-level health data. The direct health effects of many pollutants in buildings remain relatively unknown. Nor is it fully understood how other building factors affect the production of pollutants, for example temperature and moisture levels. Without detailed data, the extent to which pollutants react together in ways important to health is not known.

There is an urgent need for research that investigates this problem. There are a range of harmful pollutants that may be found in homes and schools. Comprehensive investigations are needed to establish what the actual health impacts might be and to inform policy. It would help to have routine gathering of data on air quality in buildings to make comparisons to population health.

Such evidence would enable improved labelling of consumer products and guidance on the use of products indoors. Proactive engagement with stakeholders, for example through Defra's UK Chemicals Stakeholder Forum and the Hazardous Substances Advisory Committee, would bring together the expertise needed to translate the evidence into policy. It could rapidly transform the indoor environment and reduce toxic exposure of children.

Indoor air quality policy-makers for the UK

Currently national and local air quality strategies do not need to include indoor air. While reducing outdoor pollution can help indoor air quality, measures are also needed to address the pollution generated indoors. This will require improved co-ordination across Government agencies with clearly defined areas of responsibility and action.

The regulation of indoor and outdoor air quality is a relatively complex environment, with several UK bodies taking different responsibilities, including devolved Government and assemblies. These include:

- Ministry for Housing Communities and Local Government (MHCLG), which takes the lead on Building Regulations through its Housing Health and Safety Rating System.
- Department of the Environment, Food and Rural Affairs (Defra) and the devolved assemblies which fund the national UK monitoring network for air pollution outdoors.
- Department of Health and Social Care (DHSC), including PHE, which lead on the health impacts of air pollution.
- Department for Business, Energy & Industrial Strategy, which has responsibility for certain areas including carbon monoxide safety.
- Health and Safety Executive (HSE), which leads on limiting exposure to harmful levels of air pollutants at work. Together with the Environment Agency, HSE provides the UK's Competent Authority under the EU's Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) Regulation.
- The Northern Ireland Building Regulations are legal requirements made by the Department of Finance and Personnel and administered by 26 District Councils.
- The Welsh Assembly, which had responsibility for setting building regulations in Wales. Now, many of the same building regulations that apply in England also apply in Wales and Northern Ireland.
- The Scottish Government, which is responsible for making building standards (equivalent to the building regulations in England) and the associated technical guidance documents. Ventilation is addressed in Section 3 (which also includes Radon protection), and energy in Section 6.
- Local Government and city-region policies or strategies.
- Standards agencies such as British Standards Institute (BSI), the International Organisation for Standardization (ISO), and the British Board of Agrément (BBA, the UK's leading construction certification body).

Energy Efficiency in Scottish Social Housing (EESSH)

The Energy Efficiency in Scottish Social Housing (EESSH) bill introduced new energy efficiency standards for existing social housing in Scotland. A review in 2017 proposed to adapt EESSH to include air quality. Landlords collect data on air quality by measuring CO2, temperature and humidity. This will set air quality and environmental impact requirements (from 2025).

Specification for the energy retrofit of domestic buildings (PAS 2035)

This Publicly Available Specification (PAS) is a key document in a framework of new and existing standards on how to conduct effective energy retrofits of existing buildings and has been updated in June 2019. PAS 2035 covers how to assess dwellings for retrofit, identify improvement options, design and specify Energy Efficiency Measures (EEM) and monitor retrofit projects, and includes specific guidance on the need for effective ventilation in retrofit projects.

PAS 2035:2019 specifies the requirement for a holistic approach to the retrofitting of dwellings. The document also gives better clarification regarding the qualifications and responsibilities of individual retrofit roles and respective activities required prior to the commencement of the physical installation.

Building regulations

Building regulations are the main regulatory requirement for buildings, with devolved responsibilities for the different nations. UK guidelines for energy efficiency and ventilation are set down in the Approved Documents of the Building Regulations and Standards in devolved Governments and assemblies. These include protection from moisture and radon, and energy efficiency, which includes air-tightness. Ventilation requirements are primarily based on control of moisture and only specify indoor air standards for a few substances. The concentrations are rarely checked post-construction.

Substantial risks occur in existing buildings, such as damp and mould, and potential pollutants in paints and finishes. Policy and legislation have been enacted for other areas that impact on public health, such as chemical and food labelling, and public health advice. Unfortunately, there is little public awareness of the potential risks and causes of poor indoor air quality, and action is needed to change this.

Example of international practices: Indoor Air Quality in Finland

Finnish building regulations[239] include a section on air quality which requires that:

Buildings are designed and constructed in such a way that the indoor air does not contain any gases, particles or microbes in quantities that will be harmful to human health, or any odours that would reduce comfort.

The regulations specify limits for acceptable levels of specific pollutants including formaldehyde, particulates and styrene. Air quality is measured after the building has been occupied for six months.

In general, current regulations place more emphasis on energy efficiency than on air quality. Though there are recommended minimum levels of air flow through a building, regulations assume that outdoor air is 'fresh'. The regulations apply both to new buildings and changes to existing buildings, but in practice they are mostly enforced in new developments, and do not vary for different locations or building types. The regulations do not mandate compulsory air quality checks indoors.

Building regulations should specifically address indoor air quality and health in buildings. This would be either through improvement of existing building standards (for example ventilation and safety) or developing new standards (such as for buildings materials). Regulations need to minimise sources and require effective removal of pollutants through ventilation. There also need to be clear criteria and performance standards, setting concentration levels of chemicals and particulates that can be measured and verified. There is a need to ensure a more 'joined-up' approach – for example, the sections for energy efficiency and ventilation are separate and this can work against holistic approaches.

These criteria could be applied as an incentive for high standards by making compliance a condition of any grants, loans or subsidies. For example, a demonstration home was created by the Prince's Foundation for Building Community which used natural materials and traditional methods of energy efficiency to create a home that both protected health and lowered carbon emissions[240]. It performed well on both energy and ventilation testing.

Building regulations do not address existing buildings in detail. Opportunities may exist in retrofit projects to undertake mitigating actions. For example, the newly released PAS2035 (Specification for the energy retrofit of domestic buildings)[241] includes specific requirements for improvement of ventilation in retrofit projects.

Regulatory authority is required to ensure uptake of these standards setting specific measures for:

- acceptable levels for formaldehyde and $PM_{2.5}$
- mandatory labelling of construction products and materials to identify the pollutant content, emission rates, and restrictions on the materials' use
- restrictions or improved standards for services and appliances that emit pollutants (for example gas cookers, solid fuel heating systems)
- improved guidance and regulation for removal of specific pollutants
- explicit links between different parts of standards that may affect indoor air quality, for example energy and ventilation sections
- specific standards for indoor air in building modelling and benchmarking tools
- designers and builders to provide clear information on the operation of ventilation systems and related services (for example heating and cooking appliances).

Environmental assessment tools for building

There are existing tools for modelling the environment of buildings. The tools are designed primarily to help improve energy efficiency and, unless stated, do not include measures for human health impacts. These are widely used tools and could be adapted to create standards and measures for protecting occupant health.

BREEAM is a sustainability assessment method for buildings and infrastructure. The building's sustainability is measured across different categories including energy, health, materials and pollution. A building performance rating is calculated from weighted scores across the different categories.

Standard Assessment Procedure (SAP) is the tool used to calculate the energy performance of UK homes. It does not currently include wider environmental performance measures like indoor air quality.

Simplified Building Energy Model (SBEM) is a computer modelling tool to evaluate the energy use (and carbon footprint) of a building's heating, cooling, ventilation and lighting over a normal year. The amount of CO_2 emitted by the building is calculated, but it does not currently model the building's air quality when looking at the ventilation.

The **WELL standard** is a labelling system underpinned by a standardised methodology for the design, measurement and certification of health and well-being properties in buildings. Originally developed for commercial buildings, it is also applicable to other building types including some housing types.

Passive House Planning Package (PHPP) is a series of tools for architects and designers. These use standardised methods to calculate the building's energy balance, and to meet the Passive House requirements for building performance.

Chemicals regulation

Up to the present, UK chemicals policy has been driven by EU legislation, in large part through the Classification, Labelling and Packaging (CLP) and REACH Regulations. The CLP Regulation aligns European legislation with the UN's Globally Harmonised System of the Classification and Labelling of Chemicals. REACH requires companies producing, using or marketing chemicals to evaluate the risks of their substances and communicate them to downstream users.

Under REACH, 'Substances of Very High Concern' (SVHCs) are further controlled and companies must apply if they wish to continue to use a SVHC. Authorisation is only granted if a company can demonstrate that measures are in place to avoid risk. Where risk persists, the company must demonstrate why continued use of the substance is in the broader interests of society and explain the steps taken to minimise the risk. SVHCs can also be controlled through restriction, which means the substance is either banned outright or subject to specific conditions for use. These conditions can set limits for workplaces, presence in household goods, the rate of release permitted, and any other factor that influences exposure.

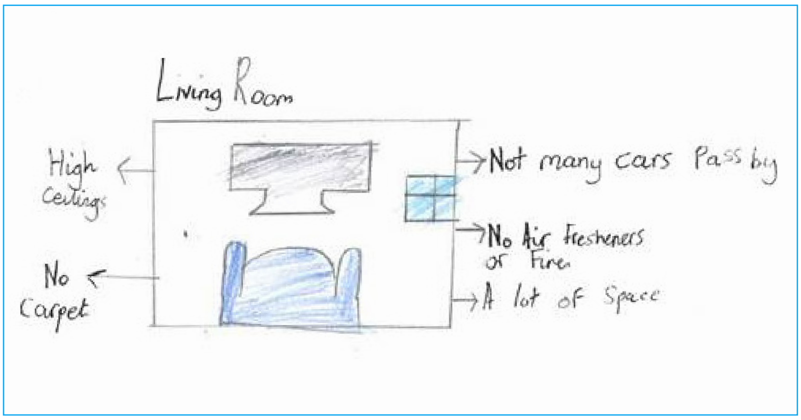
It is not clear what will happen to chemical regulation in the UK in the future. The CLP Regulation implements a UN initiative, so the UK is unlikely to change the CLP significantly, if at all. REACH is an EU initiative. It is likely that the existing controls under REACH would be carried over to UK chemicals regulations. As new standards are added or conditions for SVHC use change, the UK may begin to diverge from REACH (with either higher or lower standards possible in that case).

Alternatively, the UK may adopt future developments in REACH as they are agreed at an EU level, but with no input to the debate.

Further EU initiatives on endocrine disruption and toxicity of chemical mixtures must be monitored closely.

Enforcement and compliance

Figure 21. A living room with good indoor air quality.



By Aymen, age 10

Although Government agencies may be responsible for the development of standards and regulations, it often falls to other agencies and professionals to ensure that they are applied. As the tragic fire in Grenfell Tower has so clearly shown, it is becoming clear that there are problems with the application of the building and refurbishment standards. A standard is only effective if it is rigorously applied. It is an unfortunate fact that it took a disaster like Grenfell to stimulate action: fire regulations are now being radically overhauled. The evidence is that health impacts of poor indoor air quality may be far more widespread, but these illnesses and deaths are far less visible.

An initial challenge is that a large amount of compliance checking occurs during building design stages. Some aspects are subject to inspection during and post construction (examples are air tightness testing and commissioning tests), but these are not applied to every building. Post-completion airtightness testing has led to significantly improved levels of airtightness, but the lack of a similar rigorous evaluation of ventilation provision has led to many poorly ventilated buildings.

In addition, the tests are for minimum standards, so a compliance route does not necessarily produce enhanced or optimum solutions. There may also be confusing situations where the guidance is followed but the aim of the regulation is not achieved. There can also be conflicts between the different aims of regulations. For example, regulations aimed at preventing fire can reduce indoor air quality by restricting internal door openings or requiring use of fire retardant chemicals. Finally, the practice of following guidance can become a piecemeal checklist, rather than a holistic approach.

There are other mechanisms for policy and regulatory enforcement. Local Authorities have regulatory powers, for example landlord regulations, public health and environmental control. Mandated standards can be supported with incentives such as grants for retrofit measures that improve air quality, similar to the approach used to improve energy efficiency of older properties.

Action is needed to ensure that existing standards and regulations are met. This includes more rigorous enforcement of regulations to ensure that standards are being achieved in completed buildings. This should include increased use of punitive measures for lack of compliance and greater use of post completion and post occupancy testing and compliance. As well as building regulation this includes compliance with landlord regulation, health and safety regulations.

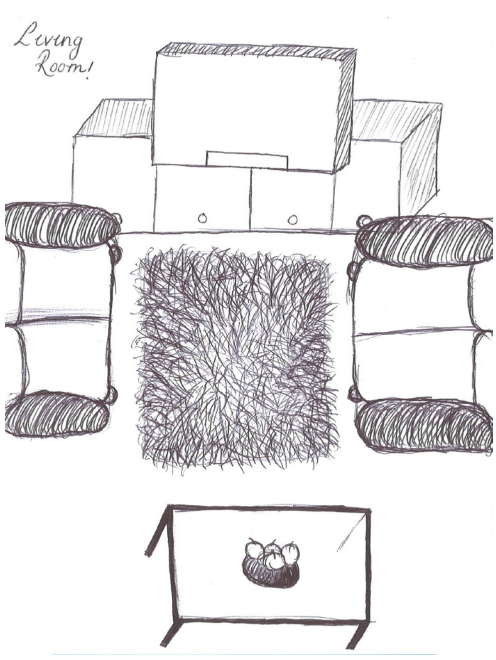
It should be acknowledged that a potential barrier to enforcement is the nature of indoor air quality, which is the result of many factors interacting (building characteristics, furniture and finishes, location, and human activities). If indoor concentrations of pollutants are found to exceed safe values, it is not always straight-forward to establish the root cause of the problem and apportion fault if applicable. Therefore, it is important that building regulations are devised to consider indoor air quality as a system. It will need the building regulations to work in conjunction with other regulatory tools such as product labelling schemes.

Procuring, designing and constructing buildings

Building regulations set down the minimum standards for compliance, and those who are responsible for designing and constructing buildings are responsible for ensuring that the design and construction meets these standards. These are minimum standards and there should be professional and ethical obligations to go beyond these to ensure the health and well-being of building occupants. This would require consideration of the building design in order to identify possible sources and interventions for pollutant reduction.

Action is needed by architects and other construction professional bodies who should be empowered to develop and maintain ethical standards and requirements that protect the health and well-being of the building's occupants. There must be increased use of evaluation of completed buildings to develop a more evidence-based design ethos.

Figure 22. A living room with good indoor air quality.



By Tori, age 15

Organisations that construct buildings must also act to ensure that the standards and specifications for indoor air quality are maintained. Where products and materials are substituted during construction, only use products meeting the same or better specifications should be used. Contractors must ensure that all installed products and materials comply with building regulations, design specifications and manufacturers' guidance on installation and commissioning.

For professionals responsible for the development of local plans and planning enforcement, the impacts on indoor air quality should be included in the evaluation of planning regulations, local plans, and assessment of applications. For example, there should be consideration of the location of buildings in relation to pollution sources, roads, and the need for protective elements such as physical and green barriers or landscaping. These responsibilities also apply to the clients and agents of buildings – architects and contractors are employed by client organisations who define the brief and the performance standards expected. Client bodies are ultimately responsible for their buildings and there is an onus on client groups to set standards and expectations of indoor air quality.

Client bodies must include required standards for good indoor air quality within their briefing documents and client requirements. These responsibilities should be passed down to those who manage and maintain the building. The responsibilities should be balanced with reward for those who do well, such as certification schemes that recognise buildings with high standards for health.

Building owners, landlords and employers

There are different groups and individuals who own and maintain buildings. These include:

- social housing landlords such as Local Authorities and housing associations,
- private home-owners,
- private landlords and private rented sector organisations,
- education departments and organisations who own or manage schools and nurseries,
- other related roles such as building facilities managers.

In England, around 170,000 new homes were built in 2018-19[242]. These are the minority; most buildings already exist and will do so for many years to come. Older buildings can contain materials that are highly polluting, and in the UK many buildings are thermally poor, resulting in damp and mould. They are also more likely to contain older furnishings and appliances.

Opportunities for source control may therefore be more limited because it is not always practical or affordable to replace building materials and the fabric of a home. For existing buildings, greater emphasis may be needed on strategies to mitigate and remove pollutants. This is particularly important during retrofit, which is an opportunity to act to improve indoor air quality. The earlier health evidence and exposure chapters showed that home renovations without ventilation can be detrimental to health.

In some cases, such as rented housing and leasehold apartment buildings, building owners have a duty of care toward their occupants. This should include standards for maintaining air quality. Standards could also include restrictions on the use of materials; ensuring proper provision of ventilation; and information for people to use the ventilation effectively.

Converting buildings into homes

A change in planning rules in 2015 has enabled new homes to be created in buildings converted from previous non-domestic uses such as offices. These can be submitted under 'permitted development' rules which mean they do not have to go through the planning system. This has increased the supply of housing but has also created some new problems. Housing developments that go through the planning system are subject to Local Authority oversight, enabling the authority to respond to their population needs by influencing where housing is created, the quality of applications, and the proportion of affordable homes developments provide.

There have been reports of some of these homes being extremely small; square footage proposed in one development was for family homes smaller than a hotel room[243]. Dense, over-crowded housing risks poor indoor air quality (among other negatives) if pollutants from people and their activities accumulate faster than they can be diluted by ventilation.

Building occupants and users

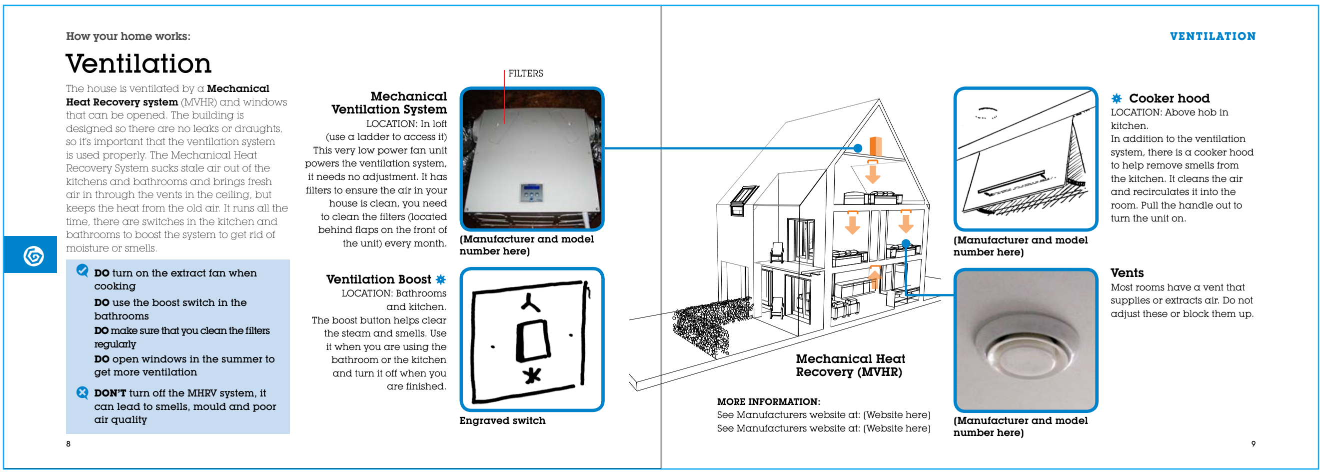
People who occupy and use buildings have a large degree of influence over the causes of poor indoor air quality. These include bringing in and using sources of pollutants, for example furniture, cleaning materials, personal care products, etc. It also includes how the building is used, particularly the ventilation provision.

There are steps people can take to help reduce the pollutants they, and their children, are exposed to. But there are significant barriers, and many people will struggle with this. As stated in this report and shown in the engagement work with young people, there is little public awareness of indoor pollution and products lack clear labelling and guidance. Without this information, the public and professionals are prevented from making informed decisions about steps that can benefit both their own and their children's health.

Use of ventilation can reduce pollutants indoors. Homes and schools need either adequate natural ventilation or an effective mechanical ventilation system. Ideally classrooms should be aired between lessons. Several factors can make people hesitant to open windows or use a ventilation system. People can have concerns about energy consumption, noise, external pollution, or security. These should be addressed in the design process, making it attractive and intuitive for people to use enough ventilation.

Provision of clear advice and guidance for building occupants about the causes and risks of poor indoor air quality is urgently required. One example is the ventilation guide for occupants illustrated below. This may be from public health bodies, designers and engineers, landlords, or owners and facilities managers. There needs to be information provided about how the building should be used and ventilated to maintain good air quality.

Figure 23. An example of an occupant's guide to using the ventilation in their home.



Source: Mackintosh Environmental Architecture Research Unit (MEARU)

Well-being, social care and health professionals

There are several professionals who have contact with children and their environments; for example, via visits to homes by housing officers, environmental health practitioners, midwives, social workers, care workers, and school inspections.

Professionals working with children could provide advice about clean air and how to address indoor air problems. This can be particularly important for vulnerable groups such as women during pregnancy and children with asthma, or allergies. Professionals will need training and support about the effects of indoor air quality and what questions to ask about the conditions at home. There is more familiarity with visible problems, such as damp and mould, than with other risks from chemicals and particulates.

Health professionals can use their expertise to call for improvements and influence strategies for prevention. Their connection to local families gives them an insight into issues such as disrepair, dampness or pollutant exposure.

However, air pollution cannot be solved or addressed by the health professions alone. There should be consideration of indoor air quality in a range of local plans and strategies, including but not limited to health and well-being, planning, or air quality strategies. Health and public health teams should be aware of the local risks in a child's home and school environments, in order to manage treatment and interventions accordingly.

Making Every Contact Count

Making Every Contact Count (MECC)[244] is an NHS initiative for any staff responsible for the health, well-being or safety of people.

It is a framework to guide discussions about long-term behaviour change to improve health and well-being. The current focus of MECC is on mental health, diet, exercise, and smoking. There is a significant behavioural component to improving indoor air quality, and so there could be scope for a similar approach to discussions with patients or individuals at risk.

7. Clean air for children: a call to action

This report has presented the current evidence about the factors determining indoor air quality, the known health effects for children, and recommendations about the actions which several stakeholders should promptly initiate to ensure we protect child health in homes and schools.

The current body of evidence has focused on how health effects of air pollution relate to outdoor sources and exposures, yet children spend most of their time indoors. We know comparatively little about the specific effects of indoor air pollution exposure, yet it is unlikely that the adverse health effects associated with air pollution all result from the relatively small amount of time children are exposed outdoors. Furthermore, children are also exposed to indoor sources of air pollution when at home or school. This report highlights that the cumulative health effects of children's indoor exposures to all these sources can be wide-ranging, a considerable source of inequality, and in many cases such effects could be reduced with coordinated actions by key stakeholders.

Modern homes, especially the move toward more air-tight housing for energy efficiency and changes in the materials we use, risk increasing emissions and concentrations of pollutants. Evidence is emerging of UK homes without adequate ventilation[91, 245]. The health effects of many of the products and materials used in buildings have not been comprehensively studied, yet there are indications that they could result in harmful health effects. There is also a lack of clear information to help guide consumers who wish to make healthier choices.

Several studies worldwide across low, middle and high-income countries have found evidence of environmental inequality related to outdoor air pollution, with the most disadvantaged communities living in areas with the poorest air quality. In developed countries like the UK the picture is more mixed. Some of the most affluent areas are dense, city-centre locations where air pollution levels may be higher due to higher traffic, proximity to industry, and human activity. However, the most disadvantaged in society have limited choice in selecting where their children live or go to school, as well as limited influence in pressing for improvements within their local environment.

While studies show that poor housing conditions and social inequalities are interlinked, there is limited evidence specifically on indoor air quality and inequalities. One exception, a study of the English housing stock, evaluated the potential impact of energy efficiency retrofitting interventions on indoor $PM_{2.5}$ concentrations. The study estimated that low-income households could have significantly higher $PM_{2.5}$ concentrations than others, a gap which *increased* after the energy efficiency improvements were made[246]. Regarding dampness, which could be a precursor or a proxy of mould and dust mites, data from the 2014 English Housing Survey indicates a greater prevalence of dampness in lower socio-economic groups[247]. Generally, the most socially disadvantaged are more likely to be most exposed to poor indoor air quality; although, for some products associated with an affluent lifestyle the reverse might be true.

This creates an unequal and unfair situation where the families with least means, and least choice over their housing, potentially face a greater burden from pollution exposure. There are actions individuals can take to improve the air at home, but the responsibility for clean air cannot solely rest with individuals.

Children and families told RCPCH &Us that they worry about the impact that the environment at home or school has on their health. They do not feel able to address this. Sometimes this is because, as tenants, they are prevented from making home improvements, or because the solution is out-of-reach financially with so many other pressures on families. It is also due to a lack of clear, easily-available information; for example, being aware of the impact of pollutants from cleaning products for children with respiratory conditions, and there being no labelling system to identify lower-emission products.

As the fifth-largest economy in the world[248], we should be capable of supporting families with this. We have enough knowledge and evidence to put in place the regulations and interventions needed. Children have a right to health and to be safeguarded when it comes to the air they breathe indoors. If we continue to be constrained by current structures and ways of working, we are in danger of exacerbating inequalities and of further commodifying childhood[249], by placing the means to have clean indoor air out of reach for many.

As seen in this report, there is a complex system of factors that determine indoor air quality. The buildings, the locations, the people and their activities – even the weather outside – all play their part in shaping the air we breathe. Instigating change across, and accounting for, such complexity will not be achieved through piecemeal and uncoordinated individual action. As called for in the recommendations, this requires new ways of decision-making, well-coordinated legislation and policy, new standards and financial resources, and concerted effort to transform the knowledge and skills of multiple sectors. The global challenges we face in air quality and climate change are highly complex and intrinsically linked with human activity, crossing political and cultural boundaries. They present complicated threats to health and well-being; to tackle them will require people to change what they do at home, school, and in the workplace.

Together with increased national leadership and individual action, there must be substantial changes in working practices across multiple sectors and trades to support it. Those involved in the design, construction and management of buildings, and the health professionals and others working with children, need a robust knowledge base so they can provide advice about harmful indoor environments and address indoor air quality problems.

Areas of the evidence remain under-developed and we have called for these to be made a priority. Opportunities to protect children – based on the knowledge we already have – are being missed. Every sector and organisation responsible for the legislation, design, construction, and operation of buildings must ensure that homes and schools are fit for purpose. Families need support and to be empowered to take actions which protect their children from the harmful effects of air quality in homes and schools.

Everyone – from children and their carers, researchers, politicians, health professionals, landlords, teachers and school governors, through to all the trades, suppliers and professions involved in valuing, letting, constructing, maintaining and renovating buildings – can make a start today. Use this report and the evidence referenced throughout, to be proactive in identifying indoor environments of concern and take action:

- **AVOID** pollutants being generated or brought indoors
- **REMOVE** sources of pollutants with known health effects
- **REDUCE** exposure to pollutants with ventilation and, where possible, reduce pollutants at their source.

It is right for children and young people to have the last word:

"We must tackle it now so that this can be stopped from getting any worse."

"Something has to be done to make all the air indoors clean and to keep all children and young people healthy."

"OK, so now we know that people are confused. They just need clear information about what to do and what not to do – and everyone needs to know about it and be doing their bit. Hopefully the scientists will be able to help!"

#TeamCleanAir&Us

Figure 24. Indoor Air Quality.

By Maya age 11

8. Annex: Common sources of indoor air pollutants

Category	Pollutant	What is it?	Common sources
Particulate Matter	Particulate matter (PM) of different sizes $PM_{0.1}$ (ultrafine particles); $PM_{2.5}$ (fine particles); PM_{10} (inhalable particles) *Refer to WHO 2010 guidelines for recommended limit values	Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets, usually classified into categories depending on their size. 'PM_{10}' are particles with a diameter less than 10 micrometres; fine particles '$PM_{2.5}$' with a diameter less than 2.5 micrometres; and ultrafine particles (UFP) with a diameter of less than 0.1 micrometres. All PM fractions can pass through the throat and nose and enter the lungs, but fine ($PM_{2.5}$) and ultrafine particles ($PM_{0.1}$) can go deeper into the respiratory system and cause inflammation.	• Indoor combustion activities: e.g. heating, cooking, burning of candles, wood and other domestic fuel burning, smoking. • Indoor vacuuming and cleaning activities during which settled dust becomes airborne. • PM concentrations in the indoor environment vary by season, location and emission sources (Ryan et al., 2015). Like other outdoor air pollutants, PM can enter into buildings. • Outdoor, human activities: e.g. air and road transport, combustion activities for industrial purposes; construction sites. • Outdoor, natural sources: e.g. volcanic eruption and cross-country transport of desert dust storms.
	Environmental Tobacco Smoke (ETS) The health risks of ETS are well established. Legislation and regulation is in place in the UK to prevent or limit indoor exposure. *WHO 2010 cited that air quality guidelines for Europe (2000) are clear and still valid - there is no evidence for a safe exposure level to ETS.	Environmental Tobacco Smoke (ETS) consists of particulate matter, carbon monoxide and more than 7,000 other chemicals. These chemicals include formaldehyde, acrolein, ammonia, nitrogen oxides, pyridine, hydrogen cyanide, vinyl chloride, N-nitrosodimethylamine, nicotine and acrylonitrile.	• Smoking indoors: the pollutants can persist in the indoor environment long after smoking –'second-hand smoke'. • Some components are absorbed by indoor surfaces and later released – 'third-hand smoke'.

Category	Pollutant	What is it?	Common sources
	Asbestos The health risks of asbestos are well established. Legislation and regulation is in place in the UK to prevent exposure.	Asbestos is the term given to a group of six naturally occurring minerals, made of thin, needle-like fibres. These microscopic fibres can easily become airborne and this 'asbestos dust' can be inhaled or ingested. Microscopic asbestos fibres cannot be seen, smelled or tasted.	• Natural deposits of asbestos minerals and are found all over the world. • Although now heavily regulated, asbestos was used widely in the building industry in a range of materials: e.g. floor tiles, ceiling tiles, roof shingles and flashing, insulation (around boilers, ducts, pipes, sheeting, fireplaces). • Asbestos may still be found in any industrial or residential building built or refurbished before the year 2000.
Inorganic air pollutants	Nitrogen Dioxide (NO_2) *Refer to WHO 2010 guidelines for recommended limit values	Nitrogen dioxide (NO_2) is a by-product of combustion produced by motor vehicles, energy generation and other outdoor sources involving combustion, as well as indoor sources such as wood burners or gas appliances (Hansel et al., 2013; Jones, 1999).	• Indoor combustion activities: e.g. burning gas, oil, paraffin, wood or coal in appliances such as stoves, ovens, space and water heaters and fireplaces, particularly if unflued or poorly maintained. Tobacco smoking and candles are also sources. • Gas stoves and cookers are significant sources of NO_2 for homes in the UK. • Outdoor burning of fossil fuels: e.g. vehicular traffic, factories. • The distance of buildings from roadways has an impact on indoor NO2 levels (Kodama et al, 2002, Nakaiet al, 1995). • Indoor levels of NO_2 in classrooms are significantly correlated with traffic density and distance of school from roadways (Janssen, 2001).
	Nitrogen Oxides (NO_x)	Nitric oxide (NO) and nitrogen dioxide (NO_2) are key components of outdoor air pollution. Together they are often referred to as NO_x – a product of combustion. Indoor air quality is affected by outdoor NO_x coming inside.	• Outdoor, human activities: e.g. motor vehicles, energy production, and industry. • NOx like other outdoor air pollutants, can enter into buildings.

Category	Pollutant	What is it?	Common sources
Inorganic air pollutants	Carbon Monoxide (CO) *Refer to WHO 2010 guidelines for recommended limit values	Carbon monoxide (CO) is a colourless and odourless poisonous gas, formed from the incomplete combustion of fuels. CO has no taste, smell or colour, and is not detectable to humans.	• Indoor (incomplete) combustion of fossil fuels: e.g. cooking and heating appliances, poorly maintained unflued boilers, unvented gas appliances, central heating systems, water heaters, open fire with solid fuels, coal burning, incense burning, smoking in the home. • Outdoor (incomplete) combustion of fossil fuels: e.g. vehicle emissions, vehicular traffic. • The lowest concentrations of CO are found in homes and schools further away (> 500 metres) from busy traffic and with no indoor sources (WHO 2010). • CO is not easily absorbed by building materials or ventilation system filters (WHO 2010).
	Carbon Dioxide (CO_2)	Carbon dioxide (CO_2) is a natural constituent of the air we breathe and at low concentrations is not harmful to health. At room temperature and atmospheric pressure CO_2 is a colourless and odourless gas. CO_2 has no taste, smell or colour and is not detectable to humans, even at elevated concentrations.	• Indoor, human activities: e.g. exhaled during human respiration, burning wood, coal or gas. • Outdoor, human activities: e.g. burning of fossil fuels, industrial processes such as cement production, deforestation and other land use changes. • Outdoor, natural sources: e.g. decomposition and respiration • CO2 is used as a proxy to assess the adequacy of ventilation in rooms and buildings. High levels of CO2 are a sign of inadequate ventilation. • CO2 in indoor air is influenced by the levels outdoors. Atmospheric CO2 has been increasing in recent decades, in part due to the use of fossil fuels, and is a significant factor in climate change.

Category	Pollutant	What is it?	Common sources
	Ozone (O_3)	At ground-level, ozone is a significant air pollutant and can enter into buildings. There is a substantial difference between the roles and harms of ground level ozone versus stratospheric ozone, the latter serving to benefit the Earth by shielding it from most of the sun's ultraviolet radiation. High concentrations of ozone near ground level can be harmful to people, animals, crops, and other materials.	• Indoor: O3 is generated through sunlight reacting with pollutants in the air – via photochemical reactions between NOx and VOCs. • Outdoor: O3 is produced in the same way as indoors however this occurs at higher rates given greater levels of sunlight outdoors. • Ozone can also be produced by some devices such as laser printers, photocopiers and some air cleaning appliances. • Ozone reacts with other indoor air pollutants and initiates many of the key indoor air chemical reactions.

Category	Pollutant	What is it?	Common sources
Chemicals **(Organic air pollutants)**	Volatile Organic Compounds (VOCs) *Refer to PHE UK guidelines (2019) for recommended limit values for all VOCs	Volatile Organic Compounds (VOCs) are a group of chemicals which are emitted from a range of indoor and outdoor sources through combustion and evaporation. Typical VOCs found in the indoor environment include: • benzene, toluene, ethylbenzene and xylenes (from fuel combustion and evaporation, and house renovations), • octane (a component of petrol and used in paints, adhesives and building materials), • glycol ethers, 1-butanol, tridecane, tetrachloroethylene and trichloroethylene (solvents found in various paints, adhesives, waxes/finishes, and cleaning products), • acrolein (produced during cooking through a chemical reaction from heating oil or fat), • acetaldehyde (found in both indoor and outdoor air from a wide range of sources including plant/animal respiration, combustion, vehicle exhaust, cooking, and produced in chemical reactions), • styrene (used in polystyrene and other plastics), • alkanes (in natural gas), • 1,4-dichlorobenzene (moth repellent), • terpenoids such as α-pinene, from wood-based building materials and furnishings, and d-limonene, from fragranced household cleaning and laundry products. (Vardoulakis et al., 2019, PHE, 2019).	Individual VOCs have different sources – the list below covers general sources: • Construction and building products: e.g. insulation, varnishes, paints, solvents, flooring. • DIY and office materials: e.g. glues, adhesives, emitted from photocopiers and printers. • Furniture: e.g. wood preservatives. • Household consumer products: e.g. detergents, cleaning products, personal care products, air fresheners, moth repellents, dry-cleaned clothes. • Once in the home, the chemicals in these products can be released or “off-gassed” into the indoor air. • Outdoor sources, human activities: e.g. combustion activities such as vehicular traffic,. plants, volcanoes and forest fires. • The variability in indoor VOC concentrations appeared to be strongly influenced by occupant activities, such as use of cleaning and fragranced products, indicating that activities in the home are a driving factor determining personal exposures to VOCs (Delgado-Saborit et al., 2011). • Both α-pinene and d-limonene are generally considered to have low toxicity, however they can form secondary pollutants through chemical reaction. • Toluene levels were higher in carpeted homes. • Elevated levels of benzene and toluene are found in basements, most likely due to things commonly stored there: solvents, paints, petrol and petrol-powered equipment (Du et al., 2015).

Category	Pollutant	What is it?	Common sources
Chemicals **(Organic air pollutants)**	Semi-Volatile Organic Compounds (SVOC): • Pesticides • Plasticisers • Flame retardants	Pesticides and insecticides are chemicals used to kill fungus, bacteria, insects, plant diseases, snails, slugs, or weeds. Plasticisers (phthalates) are typically solvents that are added to a synthetic material to alter its physical properties, by increasing its plasticity and flexibility, reducing brittleness. Flame retardants are compounds added to combustible materials to stop or slow fire. The chemicals in flame retardants are quite diverse. Some flame retardants are known to be endocrine disrupting chemicals.	• Pesticides: e.g. insecticides and termiticides, are mainly used outdoors but can contribute to indoor air quality through air, soil or other particles entering the home. Indoor uses include to control pests in the home, on pets, and for houseplants. • Plasticisers (phthalates): e.g. vinyl flooring, adhesives, personal-care products (soaps, shampoos, hair sprays, and nail polishes), some plastic-based products, which could also be found for outdoor use. • Flame retardants (PCBs, PBB) are found in building materials, building fabric, furniture, flooring, and household goods
	Formaldehyde *Refer to WHO 2010 guidelines and PHE UK guidelines (2019) for recommended limit values	Formaldehyde is a colourless gas which is highly reactive at room temperature. It is a naturally occurring gas but can also be produced synthetically through a wide range of uses.	• Mainly emitted from building materials (e.g. insulating materials and pressed-wood products), household products (e.g. paints, cleaning products, pesticides, adhesives), furniture, parquet flooring and carpets, smoking, and unvented fuel burning appliances (Marchand et al., 2006; Sarigiannis et al., 2011). • It can be emitted through cooking and made through chemical reactions indoors. • Formaldehyde levels are generally higher in newer houses (Uchiyama et al., 2015; Guo et al., 2009; Lee et al., 2014), particularly in those with wooden frames or furniture bought new or recently restored (Lovreglio et al., 2009; Villanueva et al., 2015). • Formaldehyde levels can vary widely in UK homes due to differences in building ages and methods of construction (Raw et al., 2004). A simple linear relationship was found between formaldehyde concentration and time since renovation (Maruo et al. 2010) with the highest concentrations found immediately after renovation. • Formaldehyde and α-pinene related to wooden materials need a longer 'flushing period' than other VOCs in new homes (Park and Ikeda, 2006).

Category	Pollutant	What is it?	Common sources
Chemicals **(Organic air pollutants)**	Polycyclic Aromatic Hydrocarbons (PAHs) *Refer to WHO 2010 guidelines for recommended limit values	Polycyclic Aromatic Hydrocarbons (PAHs) are formed from incomplete combustion of organic matter. PAHs are a sub-set of volatile organic compounds (VOCs). PAHs include benzo-a-pyrene and naphthalene.	• Indoor, human activities: e.g. smoking, heating and cooking, burning of coal, oil, gas, rubbish, wood and other organic substances. • Higher PAH concentrations occur in houses with smokers (Harrison et al., 2009). In non-smoking houses, emissions from cooking (frying and oil combustion), fireplaces and insect repellents (e.g. mothballs) are the main sources of PAHs. • Outdoor, human activities: e.g. PAHs are generated through incomplete combustion of wood, coal, oil, and gas burning, waste incineration, industrial power generation, and vehicular and air traffic (Kliucininkas et al., 2011). • Outdoor, natural sources: e.g. volcanoes and forest fires.
Airborne Radiation	Radon The health risks of radon are well known. Legislation and regulation is in place in the UK to prevent or limit indoor exposure. *Refer to Health Protection Agency (2010) 'Limitation of Human Exposure to Radon'.	Radon is a radioactive gas found at varying levels across the UK. Radon can accumulate indoors if there is inadequate ventilation.	• Outdoor: naturally occurring in certain regions of the UK in soil, rocks and water. • Indoor: enters a building through the ground, and through cracks and fractures in the foundations and walls. It can also enter, generally in smaller amounts, from some building materials. • Water supplies can contribute to indoor radon levels. Groundwater may contain high concentrations, depending on the uranium/radium content of the underlying rocks. Radon is out-gassed from the water to the indoor air when the water is used for washing, cooking etc. • Energy efficiency interventions in housing could increase radon concentrations through reduced ventilation (Symonds et al., 2019).

Category	Pollutant	What is it?	Common sources
Biological pollutants	House dust mites	House dust mites are microscopic arachnids which thrive in humid and warm environments, such as buildings with reduced ventilation and high levels of moisture in the air (e.g. due to occupant activities). They live off dead human skin cells and are invisible to the naked eye. Dust mite allergy in people is often from the proteins in the dust mite faeces and body parts. These particles continue to cause allergic symptoms even after the mite has died. Dust mites and their faeces are the major constituents of house dust.	• House dust mites are found in bedding, carpets, mattresses, clothing, and soft furnishings (e.g. pillows, soft toys, sofas). • The often humid and warm conditions found within a home support the growth of house dust mites. Some species are more resilient than others to dry periods.
	Moulds/fungi	Mould in the home is a common problem often caused by poor ventilation and high levels of moisture in the air, which causes condensation on cold surfaces including walls. Mould can also form within buildings as a result of water damage. There are many different varieties of mould that grow in the home, which may have different health effects. It can be difficult to identify by eye exactly which strain of mould is growing. Common moulds found in the home are Penicillium, Aspergillus, Cladosporium, and Alternaria.	• Ubiquitous in the environment if moisture is present, growing on food, plants and soil. Some species live on humans or animals. • Mould is most commonly found in damp areas of the home such as bathrooms and basements, but mould can grow anywhere in the home. • Mould spores and fragments from different species can form spores that travel through the air, enabling mould to spread. • Indoor moulds can be visible on damp/moist surfaces including walls, ceilings or furniture. • Indoor airborne mould can be found even when mould or dampness is not visible on surfaces.
	Endotoxin	Endotoxin is a toxic substance present inside a bacterial cell. It is released when the bacterium ruptures or disintegrates.	• The bacteria which produce bacterial endotoxins are very commonly found in the natural environment, on land and in the sea, as well as in the animals which humans eat, and in these animals' faeces. • Endotoxins are found indoors in the dust or the air after it has been shed from these bacteria. • Studies often look at endotoxin alongside β - d-glucan, a marker for bacteria or mould in the home.

Category	Pollutant	What is it?	Common sources
Biological pollutants	Pollen	Pollen is the minute grains or spores which are released from plants during their reproductive cycle. Pollen grains can vary in size from fine to coarse dust depending on the plant species.	• Outdoor or indoor plants • Recent studies have shown an interaction between airborne particulates and pollen whereby pollen from polluted areas is covered with pollutant particles. (Sedghy, 2018)
	Pet hair and dander	Pet dander is the small, sometimes microscopic, particles of skin shed by animals, such as cats, dogs, rodents and birds. The particles produced from dead skin or fur/feathers can cause reactions in people who are specifically allergic to them. Other sources of animal allergens include proteins in the saliva, urine and faeces, as well as dried saliva flaking from the animal's fur and become airborne.	• These allergens are found wherever the animal (household pets or pests) may have been, such as on carpets, on furniture, in dust as well as in the air.

Note: Some other pollutants are not listed above, including lead (e.g. used widely in paints, now banned); a wide range of bacteria and viruses (from multiple outdoor and indoor sources, including people, pets, plants, decaying materials); and methane.

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9. Declaration of interests from working group members

Professor Stephen Holgate

Appointments: UKRI Air Quality Champion. NC3Rs Board Chair, CRUK Trustee, Kennedy Trust for Rheumatology Research Trustee and Chairman, Great Ormond Street Hospital Children's Charity (GOSHCC) Trustee, DSRU Trustee, AAIR Charity Trustee, Governing Board of Nuffield Council of Bioethics Member, RCP Special Advisor on Air Pollution, adviser to PHE and DEFRA on air pollution.

Professional memberships: Academy of Medical Sciences (AMS), RCP, Academia Europaea, Royal Society of Biology (RSB), European Respiratory Society, British Thoracic Society, British Society for Allergy and Clinical Immunology (BSACI), American Association of Physicians.

Companies and businesses: Synairgen (cofounder, NEB Director, shareholder).

Conflicts: Consultant to Novartis, AZ, Sanofi and TEVA. Member of a scientific advisory board for Dyson.

Professor Jonathan Grigg

Appointments: Member of Committee on the Medical Effects of Air Pollutants (COMEAP)

Professional memberships: RCPCH

Conflicts: Gifts accepted from GSK, Flights and accommodation (Asthma). Novartis, Honorarium (Asthma, advisory board). BV Pharma Honorarium (Asthma, Advisory Board). MedImmune, Honorarium (Asthma/research)

Professor Hasan Arshad

Appointments: Director, The David Hide Asthma & Allergy Centre, Isle of Wight (Reg. Charity). Trustee, Allergy UK.Trustee, Asthma, Allergy and Inflammation Research Charity. Hon. Consultant, Isle of Wight Health Trust.

Professional memberships: Royal college of Physicians. British society of allergy & Clinical Immunology. American Academy of Asthma, Allergy and Immunology. European Academy of Allergy and Clinical Immunology. American thoracic Society. National, CRG, Allergy & Immunology

Companies and businesses: Director, Allergy Care Limited

Conflicts: A funder of this work, Dyson Technologies Ltd, is interested in funding a separate project (research into asthma control and removal of indoor allergens/pollutants).

Professor Nicola Carslaw

Appointments: Member of COMEAP. Spouse of a member of AQEG.

Professional memberships: ISIAQ

Conflicts: None

Professor Paul Cullinan

Appointments: Scientific Adviser: Colt Foundation. Committee on the Medical Effects of Air Pollutants (DEFRA) – co-opted member (2017-18). Healthy Lung Partnership (HSE) – member. HSE Workplace Health Expert Committee (WHEC). EU ad hoc Experts Group on Diagnostic Criteria of Occupational Diseases. Industrial Injuries Advisory Council (DWP) – member. Industrial Injuries Advisory Council: research working group – chair. CAA (Civil Aviation Authority) Specialist Appeal Panel – member. RAF Civilian Adviser in Asthma and Allergies. James Trust (Research Committee) – member. Group of Occupational Respiratory Disease Specialists (GORDS) – member. Faculty of Occupational Medicine; Academic Forum – member.

Professional memberships: Royal College of Physicians (Fellow). Faculty of Occupational Medicine (Fellow). European Respiratory Society (Member). British Thoracic Society (Member). Society of Occupational Medicine (member).

Conflicts: None

Dr Sani Dimitroulopoulou

Appointments: Honorary Affiliation with UCL (Honorary Senior Lecturer). PHE Topic Advisor and Committee Member, National Institute for Health and Care Excellence on Indoor Air Quality at home. Member of the Cross-Government Group on Gas Safety and Carbon Monoxide Awareness. Member of the British Standards Institute (BSi) on Emissions to internal environments. Temporary Advisor to WHO for the development of a tool for risk assessment from combined exposure of children to multiple air pollutants in indoor air in schools.

Professional memberships: Vice Chair of the UK Indoor Environments Group (UKIEG). Member of the MESAEP Executive Committee (Mediterranean Scientific Association of Environmental Protection).

Conflicts: Has published unpaid papers and reports in this field over the last 20 years. Has led the development of the PHE IAQ guidelines for selected VOCs in the UK. Invited speaker at various events organised by the Government, academia and industry on indoor air quality and health.

Professor Anne Greenough

Appointments: Previous Vice-President of Science and Research at RCPCH

Professional memberships: RCPCH, BTS, ERS

Conflicts: None

Dr Mike Holland

Appointments: Self-employed with contracts with central and local government, international organisations, NGOs and industry.

Professional memberships: Member of the European Association of Environmental and Resource Economists.

Conflicts: None

Dr Benjamin Jones

Appointments: Board member of the Air Infiltration and Ventilation Centre, an Annex of the International Energy Agency.

Professional memberships: Affiliate of the Chartered Institution of Building Services Engineers

(CIBSE). Member of the CIBSE Natural Ventilation Group.

Conflicts: None

Professor Paul Linden

Appointments: Fellow of the Royal Society, Fellow of American Physical Society, Member of Academia Europaea

Conflicts: None

Professor Tim Sharpe

Appointments: Member of the British Standards Institute (BSi) retrofit working group, Air Tightness and Ventilation. Topic Expert, National Institute for Health and Are Excellence Public Health Advisory Committee on Indoor Air Quality. Member UK Centre for Moisture in Buildings, Chair Ventilation sub-group. Chair NHBC Scotland Technical Committee. NHBC Construction Quality Expert Panel.

Professional role: Professor of Environmental Architecture, Mackintosh School of Architecture, Glasgow School of Art which includes undertaking funder research for a wide range of organisations, primarily RCUK, but including Innovate UK and organisations such as housing associations, government and local councils.

Companies and businesses: Director, Environmental Research Ltd.

Conflicts: Frequent talks about our research into issues of ventilation and IAQ on a number of public platforms for the public and industry. Partner is a landlord for one privately rented flat.

Professor Alan Short

Appointments: Vice-President Clare Hall Cambridge, Trustee

Professional memberships: RIBA

Conflicts: None

Briony Turner

Appointments: Trustee and Council Member, Scientific Exploration Society, Steering group member: London Climate Change Partnership, Heat Risk in London Group, CIBSE Resilient Cities, CIBSE Intelligent Buildings Group, SmartWork contractor.

Professional memberships: Fellowship of the Royal Society for the Encouragement of Arts, Manufactures and Commerce, Postgraduate Fellowship of the Royal Geographical Society, Associate member of the Institute of Environmental Management and Assessment. Co-founder MESH Network for UK Climate Services Professionals. Supporter of the Urbanistas network.

Finance: Shares in KEFI Minerals, Shares in Bird & Blend Tea Co.

Conflicts: Researching a PHD about climate change and the social housing sector in the UK.

Dr Marcella Ucci

Professional memberships: Secretary, UKIEG

Conflicts: Involved in indoor air quality research, with publication on the subject. Co-investigator on a Network funding bid on indoor environments and non-communicable diseases, to UKPRP. Shortlisted in 2018.

Professor Sotiris Vardoulakis

Appointments: Previously at the Institute of Occupational Medicine. Honorary Professor, European Centre for Environment and Human Health, University of Exeter Medical School. Honorary Assoc. Professor, London School of Hygiene and Tropical Medicine. Honorary Senior Lecturer, Division of Environmental Health & Risk Management, School of Geography, Earth and Environmental Sciences, University of Birmingham

Professional memberships: Fellow of the Institution of Environmental Sciences. Fellow of the Institute of Air Quality Management. Fellow of the Higher Education Academy. Topic Expert Member of NICE Public Health Advisory Committee on Outdoor Air Quality (2016-17). Co-Chair of Healthy-Polis: International Consortium for Urban Environmental Health and Sustainability Scientific Committee Member, Int. Net. Public Health & Environmental Tracking. Member of the International Society of Urban Health. Scientific Advisory Committee member, Urban Health 2018 conference. Member of the International Association for Urban Climate. Member of the UK Indoor Environments Group. Advisory Board Member, EPSRC/UCL Complex Built Environment Systems CBES programme

Conflicts: Scientific Advisory Board Member, Dyson Environmental Control.

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The inside story:
Health effects of indoor air quality on children and young people

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