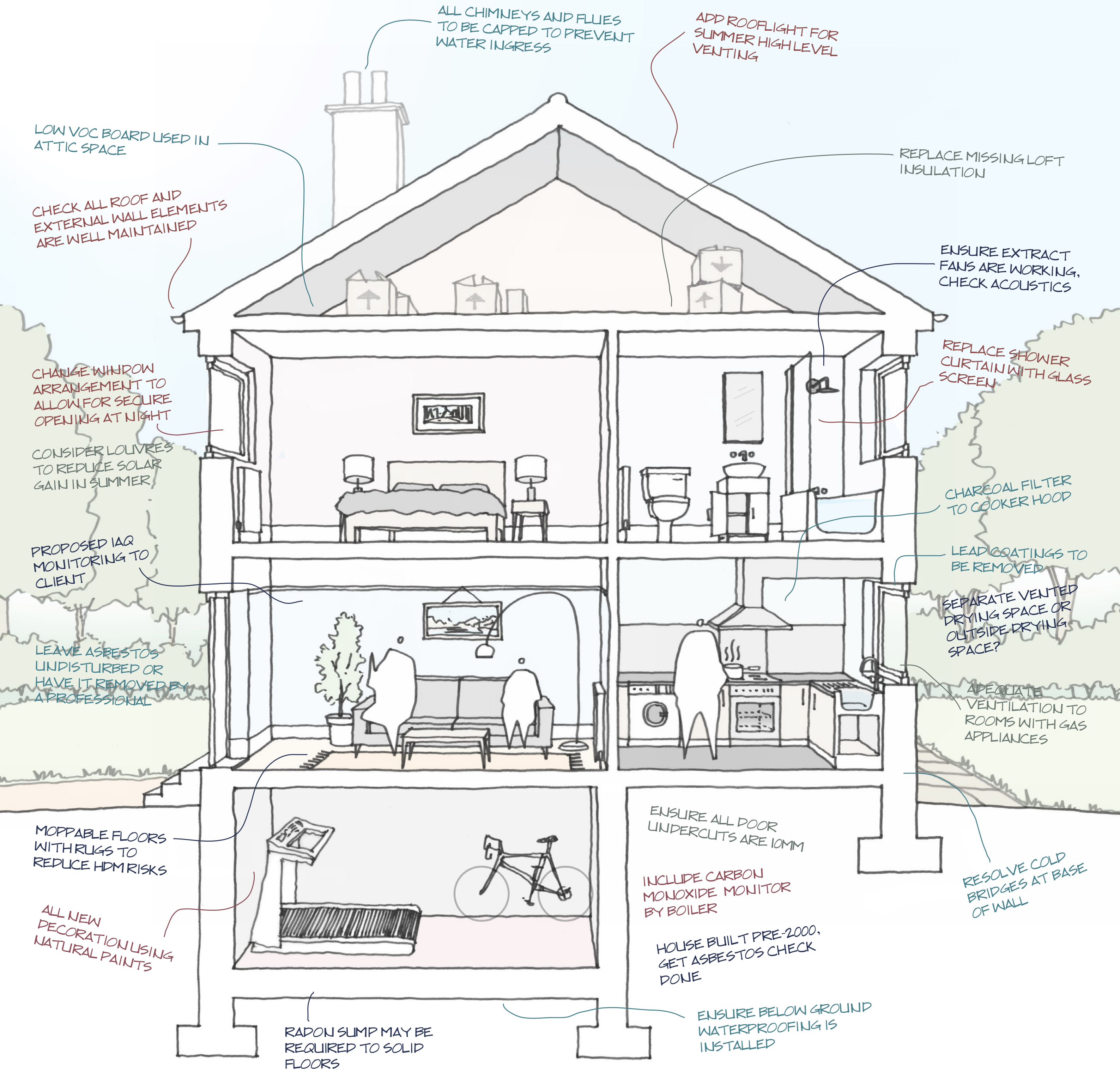
Indoor Air Quality *in Airtight Homes*: A Designer's Guide

Prepared for the HEMAC Network (Health Effects of Modern Airtight Construction) and supported by SEDA (Scottish Ecological Design Association). A SEDA Guide to Good Practice



HEMAC HEALTH EFFECTS OF MODERN AIRTIGHT CONSTRUCTION Multidisciplinary Network
UKRI Arts and Humanities Research Council
University of Strathclyde
John Gilbert ARCHITECTS
LSTM LIVERPOOL SCHOOL OF TROPICAL MEDICINE

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An initial series of events, including a symposium, a workshop and sandpit took place across 2016 and 2017 and summary report was published in July 2017 which is available on the main website at https://hemacnetwork.com. The follow-on study has supported the dissemination of knowledge through a policy workshop, patient focus groups, a user guide (for occupants of modern homes) and this guide for designers.

The guide was written by Architect Chris Morgan, director at John Gilbert Architects in Glasgow. Chris is a registered and chartered architect, a certified Passivhaus designer and additionally certified in Building Biology (Buildings and Health) and Permaculture. He was chair of the Scottish Ecological Design Association (SEDA) and is one of three architects in Scotland accredited to 'Advanced' level in Sustainable Design. Liaison with AHRC, the wider advisory group and editorial overview of this guide has been managed by Prof. Tim Sharpe, Dr. Grainne McGill, and Prof. Graham Devereux.

Drew Carr of John Gilbert Architects co-ordinated the layout and produced all drawings. Barbara Lantschner of John Gilbert Architects provided additional text and editorial guidance. All drawings and images are copyright John Gilbert Architects unless stated otherwise.

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Foreword

The way that buildings have been designed and constructed has changed rapidly in recent years, driven to a significant extent by the need to meet challenges of climate change and energy costs. Making buildings energy efficient is a must, but as the saying goes 'Build Tight, Ventilate Right'. We are clearly doing the former, but there is increasing evidence that we may not be doing the latter.

Links between health and ventilation are well established and so limited ventilation along with increasing sources of chemicals and moisture in buildings could be having a significant detrimental impact on indoor air quality (IAQ). The question arising from this is what the health impacts of this might be and this formed the basis of the establishment of Health Effects of Modern Airtight Construction (HEMAC) network. This brought together public health and building professionals with architects and their clients to identify shared research questions and develop ways of addressing these issues. The network gathered together a wide range of knowledge and expertise and has produced a number of research projects, but it became clear during the discussions that there is a significant gap in knowledge and awareness of the issues of ventilation, IAQ and health within the design communities, landlords, and building occupants. The aim of this guide is therefore to bridge this gap.

This work started well before the COVID-19 pandemic. The increasing evidence for airborne transmission has brought the performance of buildings, in particular ventilation provision, into sharp focus. They say timing is everything, and there has probably never been a more appropriate time to deliver this Guide. Raising awareness of the issues for both designers and occupants to ensure that we achieve energy efficient and healthy buildings has never been more important – we need to get this right and we need to get it right now.

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1.0 Introduction

The HEMAC network is made up of a steering committee of researchers and practitioners from medicine, indoor air science, microbiology, engineering, architecture and ventilation; including participants from the UK, Ireland, the Netherlands, Denmark, Belgium and China.

The HEMAC network (Health Effects of Modern Airtight Construction) was established to bring together researchers and practitioners from the fields of indoor air quality (IAQ), health and the built environment to identify shared research agendas and develop research questions and activity. The network has a particular focus on challenges concerning IAQ in new build and / or retrofitted airtight dwellings.

The premise is simple: we know that making buildings airtight is important for saving energy, but we also know that this is leading to unhealthy living conditions inside many homes. This is because closing up the draughts in a building can lead to a build-up of heat, moisture and pollutants which are commonly found inside buildings, if coupled with inadequate ventilation.

This guide has an equally simple premise: demonstrate how to reduce the heat, moisture and pollutants in the first instance – source control – and then demonstrate how to ventilate buildings properly, whilst retaining the airtightness we need for saving energy.

The premise may be simple but in practice this idea is complicated by a wide range of issues which require some unpicking.

Most people have experienced the effects of excess moisture, condensation and mould in homes and are familiar with the need to open a window to clear the air. In contrast, overheating is a relatively new phenomena in the UK, but a warming climate, improved insulation levels and airtightness have meant an increasing risk of overheating. When it is too warm however, most people will open a window.

Unlike both overheating and excess moisture, it has been shown that most people are not particularly sensitive to 'stuffy air' or other forms of indoor air with high level of pollutants, and so tend not to intuitively open windows when needed. In addition, the majority of people have little or no awareness of indoor air pollution as an issue, and little or no understanding of what they can do about it. This is as true for occupants of buildings as it is for designers and those that procure buildings. Unwittingly, clients of all sorts are asking for unhealthy homes, which designers are drawing, builders are building (or retrofitting), and we are all living in, developing a range of symptoms, sometimes severe, for which our health services are picking up the tab.

Overheating, excess moisture and indoor air pollution are all entirely avoidable and this guide is aimed therefore at those who procure buildings, those who design them, those charged with maintaining them and those who want to understand how to live healthily within them.

Another simpler guide has been produced by HEMAC especially for occupants of homes to show the ways in which they can reduce health risks to themselves and loved ones and create healthy homes. This guide can be downloaded from https://hemacnetwork.com. This guide also links to another report produced by SEDA which looks directly at the use of chemicals in buildings and how to avoid them. It is available from the SEDA website at https://www.seda.uk.net.

Most people are aware of external air pollution, but indoor air can be many times more polluted than outdoor air, contain up to 900 potentially dangerous chemicals, particles and biological materials... and it's where most people spend 90% of their time. (60% at home)

It is important to distinguish between external and internal air pollution. Most of us are familiar with images of industrial smog and traffic fumes and most people are aware that it is bad for them. Bad cases of external pollution have the 'benefit' of being visible, whereas most internal pollution is invisible, but internal air can be up to 50 times more polluted than external air and it is where most of us spend the majority of our lives and so, in terms of health impacts, it is much more important.

There is of course an overlap, because when we bring 'fresh' air into our homes, we usually bring any external pollution in with it, but this guide seeks to highlight only that pollution which is caused by materials or conditions within the home, or is largely a problem within homes.

Poor indoor air quality (IAQ) is not a small problem. Estimates vary but the World Health Organisation (WHO) has stated[1] that poor IAQ is responsible for almost 100,000 European deaths a year and the UK based Royal College of Physicians has warned that "Indoor air pollutants cause, at a minimum, thousands of deaths per year and are associated with healthcare costs in the order of tens of millions of pounds."[2]

The headlines of fatalities do not tell the full story of health problems. Poor IAQ is linked to problems ranging from relatively minor ailments like coughing, sneezing and watery eyes associated with hay fever to fatigue, dizziness, headaches, wheezing, allergic reactions and reduced cognitive function, through to long term problems such as lung cancer, chronic obstructive pulmonary disease (COPD), airborne respiratory infections and cardiovascular disease.

It has traditionally been difficult to establish clear cause and effect between a certain pollutant and a particular symptom, and little incentive from those in the construction industry to investigate too deeply into the potential health risks of their own products. The small but dedicated research community looking at IAQ has not been able to break through into the wider public consciousness despite the well known dangers of hitherto 'safe' materials such as asbestos and the rapid changes in public attitudes to tobacco smoking.

However the body of research has been building, and the weight of evidence is now bringing the subject to the fore. In 2019, two important studies were published. One was published by NICE (National Institute for Health and Care Excellence) and was a review of 'Indoor Air Quality at Home' which looked at how occupants can improve the health impacts of indoor air. The other was a joint publication by the Royal College of Paediatrics and Child Heath and the Royal College of Physicians entitled 'The inside story: health effects of indoor air quality on children and young people' and focussed on the particular damage IAQ does to children and young people.

The latter of these two is of particular interest because one important aspect of indoor air pollution is that certain people are much more vulnerable to its effects. Chief among these are the elderly, children and those with other health problems which render them more at risk, such as those with wider respiratory problems, and compromised immune systems.

Another important aspect, that very little is known about, is how different pollutants react with one another, or how these pollutants affect us over the long term. There is however enough evidence now to suggest that we should be much more careful about what we put in our homes and in the absence of proof that a certain material is safe, we should adopt the precautionary principle.

The precautionary principle suggests that something which could cause harm should not be used until it can be proven to be safe or used in a safe way.

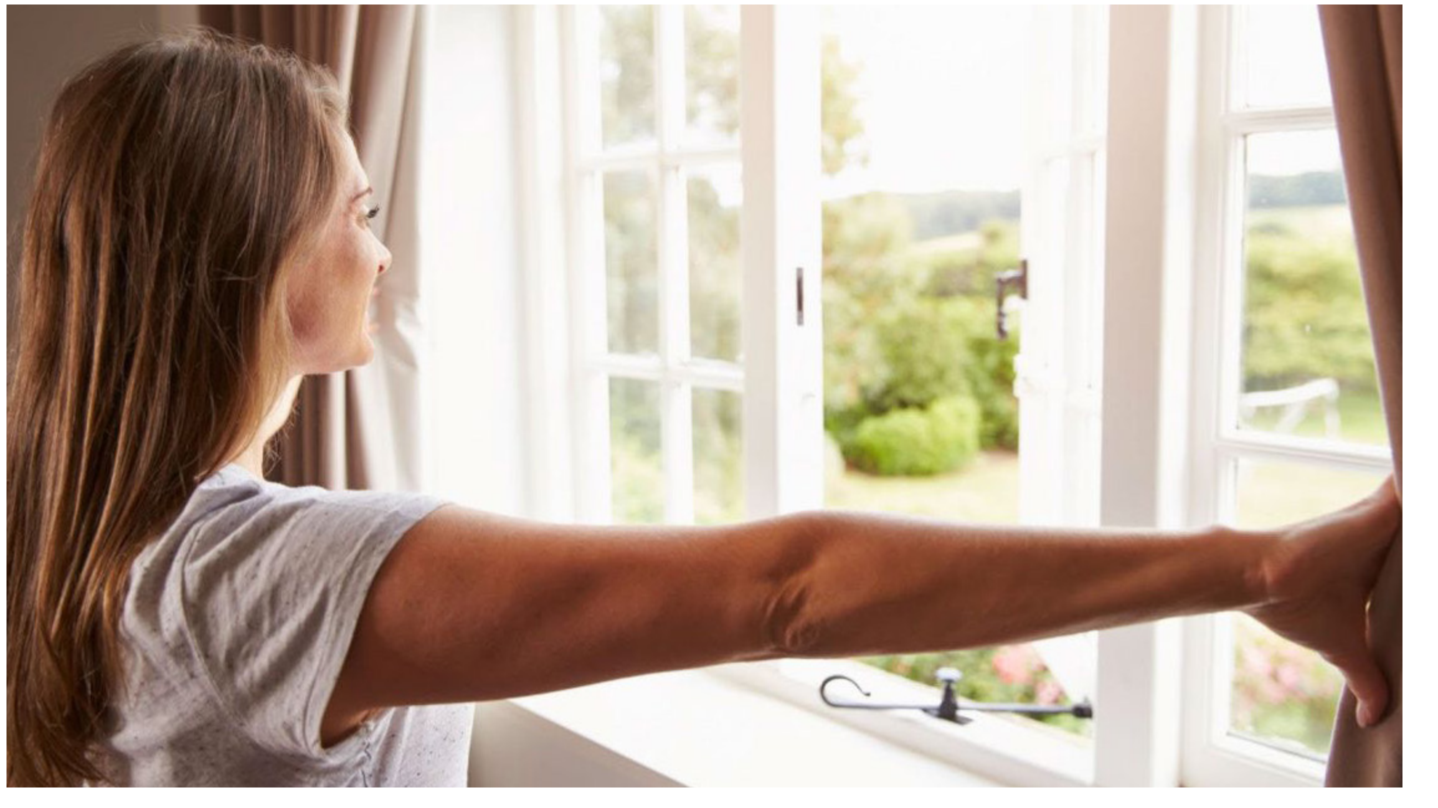
1 WHO 'Burden of disease from household air pollution for 2012', 2014
2 Royal College of Physicians. Every breath we take: the lifelong impact of air pollution. Report of a Working Party. 2016

For those in agreement, there are two items of good news. The first is that it is relatively easy to make homes much less hazardous to health and indeed supportive of health. The second is that there is a great deal of information out there for those interested.

In summary, we know that indoor air pollution is a huge problem and even though it is difficult to clarify the precise cause and effect of each pollutant in each person, adopting the precautionary principle, and undertaking relatively straightforward adjustments to building design means we can support, rather than undermine the health of all of those who inhabit the homes we own, design, build and maintain. This guide is here to help with exactly that effort.

The next section, Chapter 2 deals with reducing the pollution sources in the first place, while the third chapter looks at ventilation and how best to dissipate pollutants using a variety of common ventilation systems.

Chapter 4 considers the occupancy period, providing information for designers to support healthy living and guidance on ongoing building performance monitoring. The final chapter provides a range of resources for those who want to investigate further.



2.0 Source Control

Asbestos containing materials (ACMs) weren't fully phased out until the 1980s and so asbestos could still be present in many homes across Scotland. Asbestos is potentially very dangerous and all public buildings must have up to date registers. If in doubt, get a specialist company to survey your home. It should cost around £400. Asbestos can be removed or more often 'contained' so as not to cause a health risk.

If there are pollutants in our homes which can harm our health, the first thing we should do is try to reduce them appearing in the first place – source control. This chapter discusses this first step and the various pollutants of most interest.

Source control is important because reducing the scale of a problem is always more efficient than building systems to tackle the problem. It is also important because it shifts the focus of responsibility at those procuring, designing and specifying building fabric. This is where the bulk of the responsibility should lie, and where there is most potential for improvement. A better understanding of thermal comfort and moisture issues, as well as chemical loads and materials specification will also lead to better performing, more energy efficient, longer lasting and safer buildings generally.

There are many ways of identifying and grouping the many pollutants which can cause harm. Popular sources often classify pollutants by the room in which you might be most likely to encounter them, while academic journals might classify them by whether they are gaseous or particulate, or by particulate size. Pollutants are often categorised by their source; be it biological or synthetic in some way, or whether they are emitted directly (primary) or the products of secondary reactions. Many ignore the differences between pollutants which emanate from outdoors and those that are particular to indoors.

Ultimately, it probably doesn't matter exactly how we classify them so long as we cover the most important ones and ensure that those who wish to follow the precautionary principle in designing healthy buildings are sufficiently educated to be able to do so.

Another product which is dangerous but now longer made is lead paint. Older houses may well have old lead paint buried beneath subsequent layers of more modern paint, but the danger only comes if you seek to strip the paint, especially if you use heat to 'burn' it off. This is not advised and a range of safer and ecologically benign paint removal chemicals are available.

2.1 Overheating & Moisture

This section discusses two important aspects to the indoor air climate which set the context for the rest of the guide. Neither heat or moisture in the air are technically 'pollutants' but both, if not managed, can cause problems for occupants and can be resolved both by source control and by ventilation.

Overheating

Most people in the UK have at some point in their life experienced a cold house and there is no doubt that cold homes pose a very real threat to health across the UK. In modern, airtight homes which the HEMAC Network was set up to study, this is less of a problem however and the focus instead is on overheating. Overheating may sound like a distant and even desirable 'problem' to most people. Unfortunately however it is a real and occasionally serious health risk, and one which is increasing.

Climate change is one reason why we will encounter overheating more often in the coming years with the broad consensus that the UK will become warmer generally, especially in the summer. The other is that as we improve building design to retain heat, using more insulation and better airtightness, there is a risk that we increasingly trap heat when we don't want it. Insulation and airtightness can actually reduce overheating because both are as effective at keeping heat out of a building as they are as keeping it in. The solution is to design buildings to retain heat when we want it, and to repel it when we don't.

Health problems related to overheating are minor for most people but can become serious, and indeed fatal. 'Excess heat' in dwellings is a defined hazard in the UK Government's Housing Health and Safety Rating System (HHSRS). Some people are also more affected than others, with infants, the elderly, the obese, socially isolated, chronic disease sufferers and those living in urban areas most at risk. It is particularly important that bedrooms are protected from overheating because some of the most serious health risks are increased when people are unable to recover from heat stress during the day.

Mild heat-related health effects include dehydration, prickly heat, heat cramps, heat oedema (swelling), fainting and heat rash. More severe health effects include mental health consequences and heat exhaustion which can lead to heat stroke if not managed. Heat stroke can be fatal and is considered to be under-reported due to its similarity with strokes and heart attacks.

Overheating also has a secondary effect which is a risk to health. As is explained in more detail in section 2.4, there are many synthetic gases bound up in modern building materials and finishes, like paints, carpets, building boards and furniture. The 'off-gassing' of these chemicals can impact on occupant health and off-gassing is usually increased with increased temperatures.

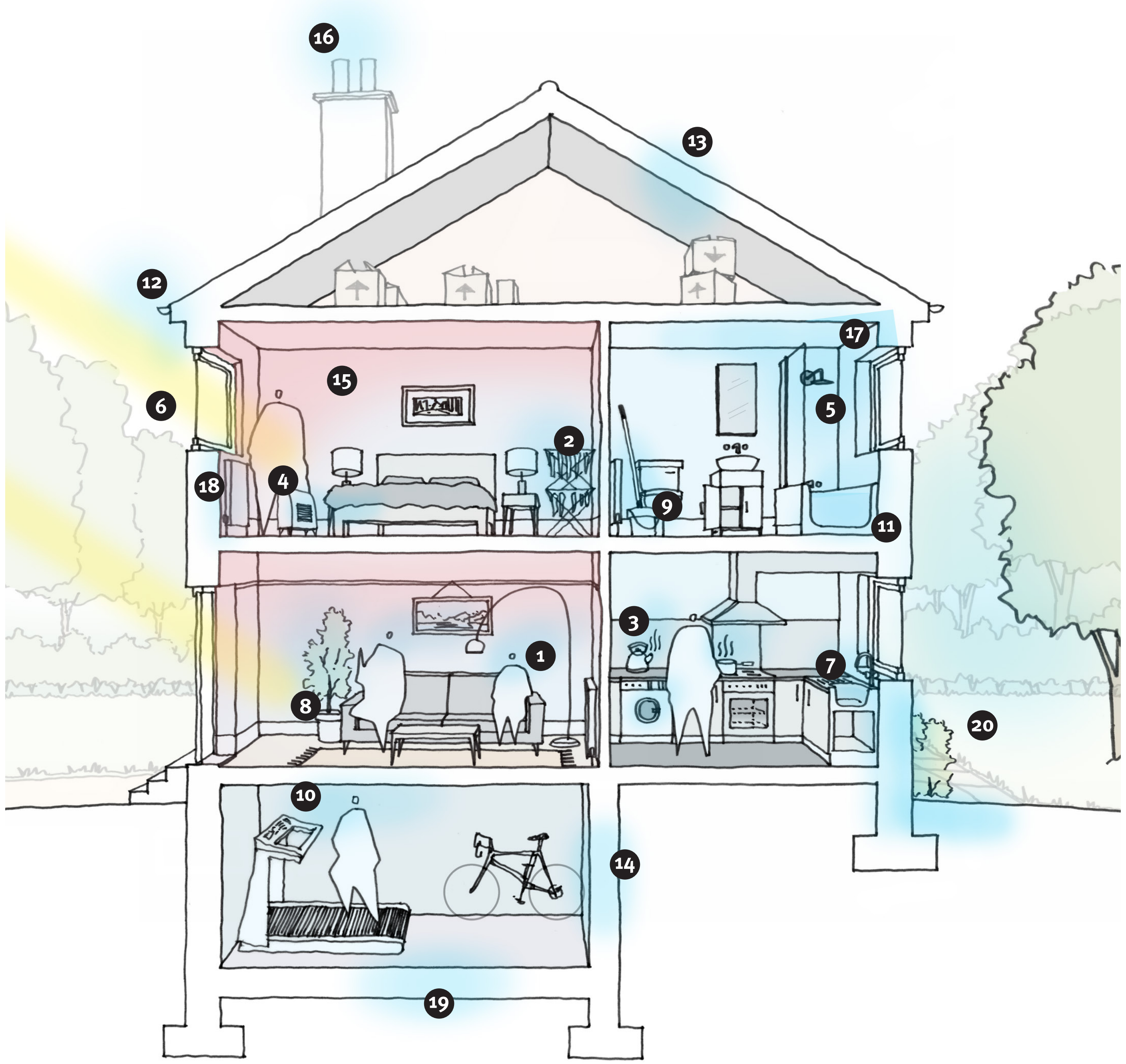
Defining overheating is not straightforward. People feel warm or cold differently and there are many reasons for this. Women, the elderly and those who do less exercise will tend to feel cold more. People acclimatise and so accept warmer temperatures in summer. Those who live in, or come from hotter countries will have entirely different thresholds of comfort, but in the UK the conventional threshold over which it is generally agreed overheating is taking place is 25°C. The temperature range which is generally considered healthy – not too warm or cold – is 1 or 2 degrees either side of 20°C.

Unfortunately, it is not quite as simple as this[1], but in general, these are the temperatures for which we need to aim. The list on the following page provides a series of causes of overheating and can act as a checklist for those aiming to keep temperatures to within healthy limits.

1 Studies include the following, from which many others are referenced: Wouter van Marken Lichtenbelt, Mark Hanssen, Hannah Pallubinsky, Boris Kingma & Lisje Schellen (2017) Healthy excursions outside the thermal comfort zone, Building Research & Information, 45:7, 819-827

Overheating & Moisture Diagram – potential risks

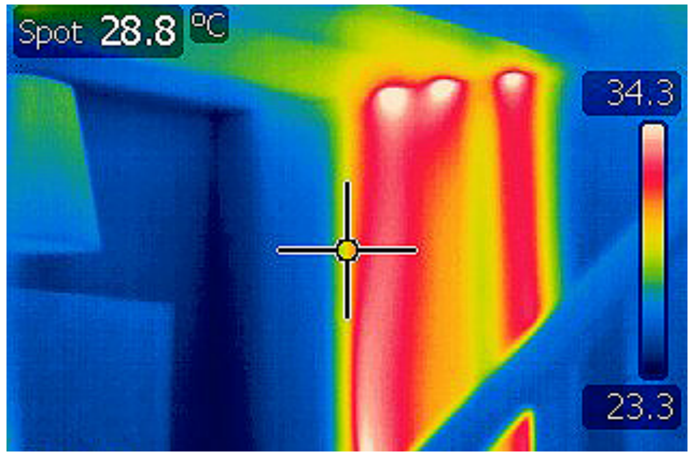
1. Humans and pets breathing
2. Clothes drying inside
3. Cooking and boiling kettles
4. Portable gas heating
5. Bathing and showering
6. Unshaded southerly windows leading to overheating
7. Dishwashing
8. Watering indoor plants
9. Floor and surface cleaning
10. Exercising indoors (breathing increased, sweating)
11. Damaged internal drainage or leaks
12. Damaged gutters overflowing
13. Damaged external envelope
14. Groundwater penetrating walls or floors
15. Upper rooms can overheat without high level ventilation
16. Uncapped chimneys or flues
17. Condensation in wet or cold rooms or at thermal bridges
18. Moisture in building fabric
19. Flooding or high water tables
20. Shaded or overgrown external areas



- Latitude (the further north the less risk in relation to average air temperatures, but conversely longer summer days, meaning possible increased risks)
- Altitude (the closer to sea level, the higher the risk)
- Distance from coast (proximity to the coast can have a moderating influence on temperatures reducing risk in summer)
- Urban context (urban areas experience the 'Urban Heat Island' effect which can increase temperatures in warm weather due to large areas of dark and thermal massive buildings, roads and infrastructure and restricted air movement. By contrast rural areas suffer less)
- Local micro-climate (local shading by buildings, trees or higher land can help reduce overheating and some moderation of this is possible, eg. by planting trees to the south of a building)
- Storey (upper storeys will tend to get warmer because warm air rises)
- Low ceilings (these trap warm air whereas higher ceilings allow warmer air to rise providing some respite and a reservoir to buffer warmer periods)
- Small rooms (these provide less volume and so exacerbate potential overheating)
- South-facing windows (contribute most of the heat gain, but are also valuable for heat gain in winter)
- West-facing windows (often contribute to overheating as they gain heat on long, warm evenings when the house may already be warm)
- Large windows (will obviously gain more heat, but also useful in winter)
- Window u-values (double or triple glazing will retain heat once in, but also reduce heat gain in the first place)
- Lack of shading (external fixed or adjustable shading most effective in reducing solar gain into the building)
- Thermally coupled, i.e. solid wall construction (can allow heat to permeate and contribute to overheating whereas de-coupled walls (eg. with a ventilated rainscreen) will prevent radiative heat gain)
- Thermal mass (can reduce peak temperatures by absorbing excess heat in summer, but it must then be able to be released effectively, eg. through ventilation. If not, it could exacerbate overheating)
- Thermostatic / programmatic control (some heating systems are difficult to control or understand so heating can be switched on when not needed, or set too high, unnecessarily heating the home)
- Occupancy levels (people give off heat, so more people in a house will increase the risks of overheating, especially if they are all in one room for a prolonged time)
- Cooking can add a good deal of heat (and moisture) to a home
- Hot water storage (even when well insulated, hot water tanks can contribute a fair bit of heat into a home which is welcome in winter, but can contribute to overheating in summer)
- Hot water pipework if not insulated can lead to uncontrolled heat gains in summer
- Incidental heat gains from electrical equipment (fridges, TVs etc.) although small, when combined with the growing number of electrical appliances and equipment in homes can become a significant contributor to overheating.

As discussed in more detail in Section 3, ventilation can reduce overheating effectively. There are two types of natural ventilation: cross ventilation and stack ventilation. Cross ventilation – where windows on opposite sides of the house let warm air through and out is effective, but the warmest days are often accompanied by a lack of wind, so stack ventilation – allowing warm air out at the top of the house and cooler air in at low level – is also valuable. Both tactics should be available for all building designs. Mechanical ventilation can also be effective in driving air movement but needs to be controllable to allow this. Heat recovery ventilation systems need to be fitted with 'summer bypass' modes which turn off heat recovery when temperatures rise to a set level. Some older systems don't have this, but can be set to 'extract only' thereby avoiding the heat recovery.

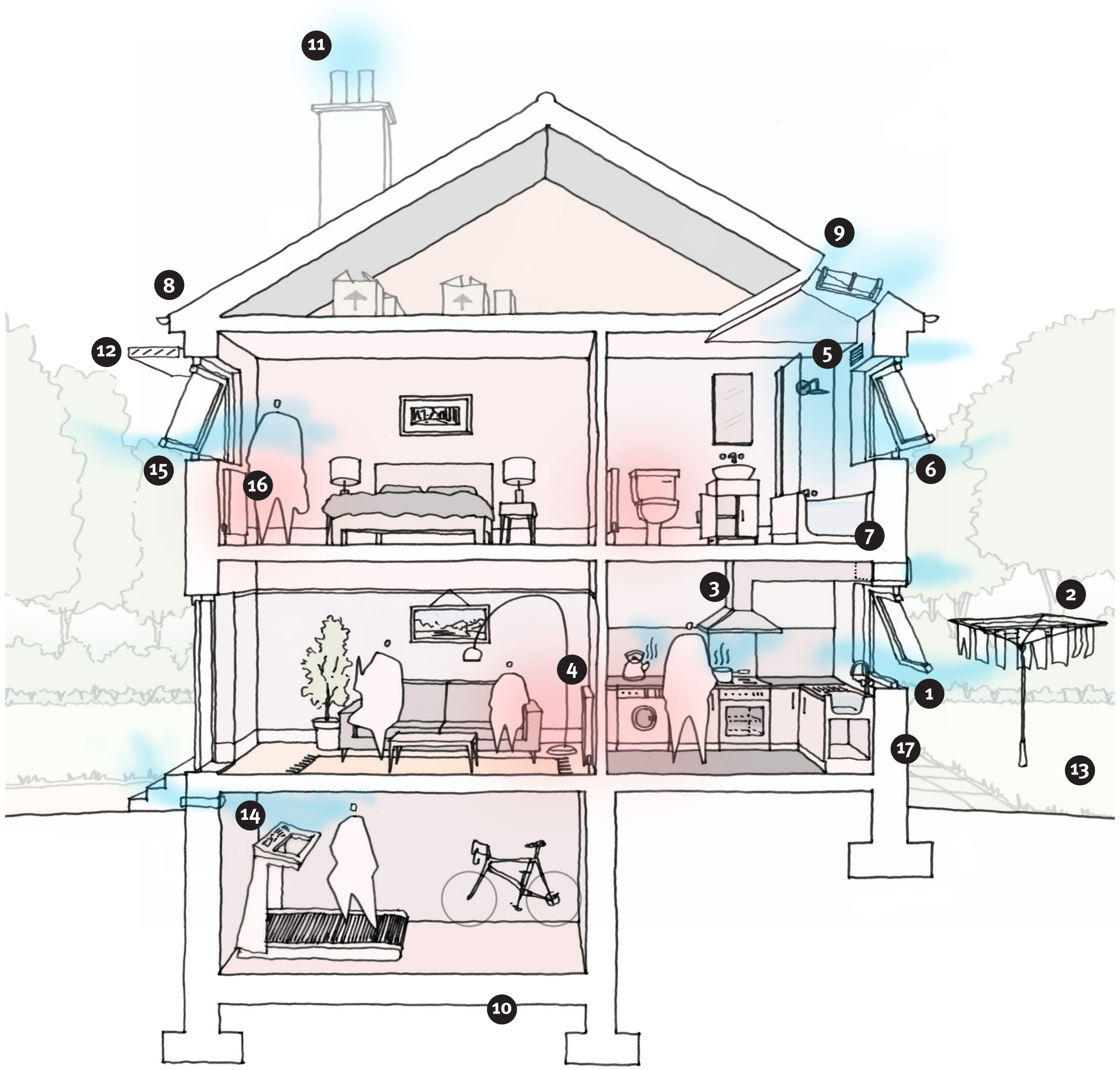
Preventing overheating in well insulated and airtight homes is not difficult but requires some attention during the design process. The most important aspects are the careful consideration of external shading and ventilation.



Uninsulated hot water pipes (in this case from solar thermal panels) can 'leak' heat into a building and exacerbate overheating in warm weather. Thermographic image copyright MEARU.

Overheating & Moisture Diagram – potential solutions

1. Adequate ventilation (natural and mechanical)
2. Clothes drying outside
3. Cooking with extract hood activated
4. Maintain internal temperature of 21°C
5. Bathing with extract fan activated
6. Adequately ventilate wet areas, especially after cleaning
7. Maintain internal drainage
8. Maintain external envelope and gutters
9. Openable rooflight to prevent overheating
10. Below ground waterproofing or land drainage
11. Capped chimneys and flues
12. Louvre shading device to south facing glazing
13. Maintain garden spaces
14. Ventilate internal spaces during exercise
15. Ventilate bedrooms while sleeping
16. Efficient heating system, no need for portable heaters
17. Well insulated envelope with no cold spot which could result in mould



Moisture

There is moisture all around us at all times. In buildings moisture is normally considered as being from three sources: the ground, the sky or from vapour in the air inside the building. Moisture from the ground is usually known as 'rising damp' and can push up within the base of walls and into the ends of ground floor joists. Despite the familiarity of the phrase, rising damp is not common and is often misdiagnosed. 'Penetrating damp' is the term given to rain (usually) which gets into buildings via gaps and cracks in the roof and walls, or via blockages or leaks in downpipes, gutters, pipes etc. When this occurs it is normally obvious and needs to be fixed. Because rising damp is not as common as often thought, and because penetrating damp normally gets fixed as a matter of urgency, on a day to day basis these two are the least common source of moisture in buildings.

The most common, especially nowadays, is water vapour generated in the house and which has cooled and condensed onto cool parts of the building like window frames, corners and low points on walls behind sofas or wardrobes. Moisture from water vapour is now more prevalent in houses for a number of reasons. Firstly, homes are now routinely kept a few degrees warmer than 50 years ago and this warmer air is able to contain more water vapour. More moisture is generated in homes because our modern lifestyles tend to generate more, through cooking, washing, drying clothes, bathing and so on, and ultimately, because our homes are more airtight, less of this moisture is lost in draughts. The diagram on page 13 shows some of the many and various sources of moisture in a typical modern home.

This moisture is not of itself particularly problematic but continuously high (or low) levels of relative humidity are associated with a number of increased health risks as shown in the diagram right[1]. For example, levels of relative humidity continuously over 70% will increase risks associated with bacteria, more dust mites, mould and fungi growth as well as increased chemical reactions. All of these health risks are discussed in later sections but the key aspect is that each of these risks is increased by longer periods of extremes of humidity. To minimise risks to health, the design aim is to achieve a reasonably constant relative humidity of between around 40 - 60%, thereby avoiding the extremes of both humid and overly dry air as shown in the diagram.

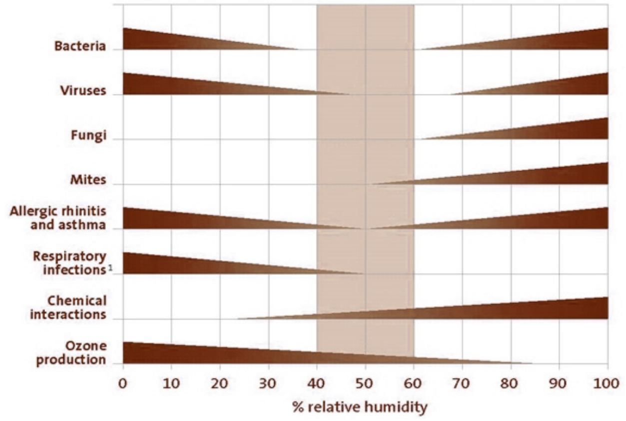
The first place to start is to 'design out' some of the potential sources of moisture in a building. Providing a place where clothes can be dried safely outdoors (eg. from a sheltered garden or balcony space, or bespoke drying cupboard) should ensure people do not dry clothes indoors, and ensuring wet rooms are well ventilated, using continuous ventilation if possible will ensure that humidity cannot be too high for too long. Adequate central heating will ensure no portable gas heaters need to be used. Good detailing, which takes account of the need for maintenance and access to specific areas will ensure that it is easy to keep the building in good condition in the long term.

A second technique to reduce moisture at source is to try and support occupants in finding ways to avoid excessive moisture generation. Quick start guides, for example could contain guidance on how to avoid excessive moisture generation. Simple humidity monitors, that indicate current levels of relative humidity can help warn occupants.

It is possible to use a technique known as 'passive humidity buffering' to reduce fluctuations in humidity. This technique relies on hygroscopic materials - which readily absorb and desorb (release) moisture from the air – as surface materials thereby acting as a buffer. Clay plasters are among the best products for this but other, largely natural materials will also work. A related way is to use 'breathing walls' which are not – as the name might suggest – allowing air in and out of the building, but moisture. More accurately termed 'moisture transfusive construction' these constructions allow vapour to pass safely through the building fabric.

However, the most common way to manage humidity is to ventilate, either mechanically or naturally. Mechanical systems can be controlled using humidistats which automatically boost the system when excess humidity levels are sensed. Since incoming external air is almost always drier and cooler than internal air, then ventilating a property will lower the aggregate temperature and humidity of the air in the building as long as it is adequately mixed. An integrated approach to managing moisture in buildings is available from the UK Centre for Moisture in Buildings.[2]

2 Available as a free download from: https://shop.bsigroup.com/Browse-by-Sector/Building--Construction/Whitepaper-Moisture-in-buildings/Thank-you/



Optimum Relative Humidity Ranges for Health

1 Based on the 'Sterling Bar Chart' introduced in "Indirect Health Effects of Relative Humidity in Indoor Environments" by Anthony V. Arundel, Elia M. Sterling, Judith H. Biggin and Theodor D. Sterling. Environmental Health Perspectives, Vol. 65, (Mar., 1986), pp. 351-361.

2.2 Biological & Natural

This section discusses a range of pollutants which are natural in origin. In most cases they cannot be avoided altogether, and indeed don't need to be except in cases of extreme allergy. For most people they may have always represented a very small risk, if at all, but in modern, airtight homes however, that small potential risk may be considerably increased and so – natural or not – we need to consider carefully how we can safeguard health by minimising excessive exposure to these materials.

We have divided the pollutants into three sections; the smallest micro-organisms or microbes, the larger particles which are often termed allergens, and radon, which is a naturally occurring gas.

Microbes

There are seven types of microbes which make up the microscopic spectrum of life forms. Being microscopic, they are readily dispersed by air movement. They exist at all times in outdoor air and thus in most indoor air and mostly pose no problem except when things get out of balance. Because microbes are so small, they can find their way into the deepest recesses of our lungs and so if they do pose a risk to health, they can be more effective and the illnesses more serious.

Four microbes play little or no role in indoor air quality and these are archaea, algae, protozoa and helminths. The three that are of interest are bacteria, fungal spores (particularly mould) and viruses. These are discussed below.

Bacteria

Bacteria can be found all over the planet and can be airborne, in soil or water as well on, and inside animals and humans. The vast majority are harmless or even helpful, for example the beneficial bacteria in our intestines which aid digestion and produce vitamins. Some bacteria do pose a risk to our health however and these are known as 'pathogens'.

Many bacterial infections can be similar to viral infections and are often discussed together when considering health risks generally. Bacterial infections can affect the skin (Cellulitis, Impetigo, boils), be caused by food (E. coli, Listeria and Salmonella) or sexually transmitted (Chlamydia, Gonorrhoea, Syphilis). However, the bacteria of most interest for building designers are those which are airborne, enter humans via breathing and affect the respiratory tract. Examples are bronchitis, sore throats, sinusitis, tuberculosis and pneumonia. These tend to enter the respiratory system, cause inflammation and can then be coughed or sneezed out again passing on the infection.

Avoiding risks from bacteria is essentially the basis of general hygiene – keeping surfaces clean, washing hands and preparing food carefully, for example. Avoiding risks from airborne pathogenic bacteria will be familiar to everyone: avoiding close contact with infected people, staying home when ill, wearing a face mask and covering your mouth when you cough or sneeze.

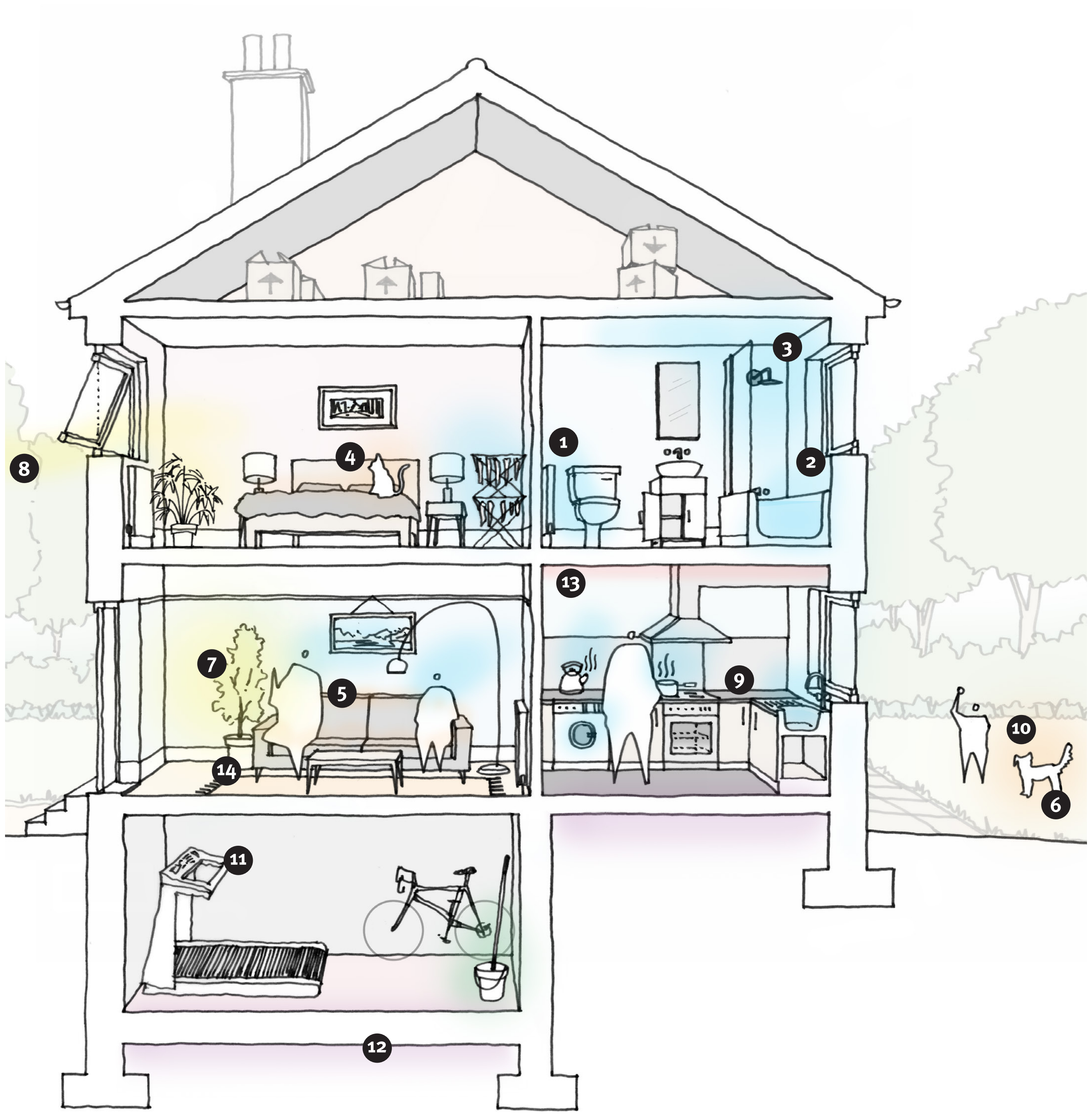
For designers there are two main areas to consider[1]. The first is good ventilation which is covered in Section 4. Note that ventilation is linked to thermal comfort and humidity and these in turn are important factors in the overall spread of all microbes. Thus low or high levels of humidity will increase the risk of bacterial spread, and so air-conditioning (which often uses a reservoir of water to humidify overly dry air) and humidifiers can both incubate pathogenic bacteria and thus increase the risk of infection.

The second is to ensure all of the surfaces traditionally associated with hygiene – in kitchens and bathrooms / toilets are easily cleaned and wipeable. This means going beyond simple wipe-clean surfaces though and considering things like accessibility for cleaning at junctions and simplifying the cleaning process. Certain types of grout will support mould while others won't, for example, while the use of hidden items like toilet cisterns and other plumbing may help, whilst on the other hand exposed stainless steel plumbing is easy to keep clean.

1 Some interesting perspective on the microbiology of the built environment is given in: Gilbert, J.A., Stephens, B. Microbiology of the built environment. Nat Rev Microbiol 16, 661–670 (2018).

Biological & Natural Diagram – potential risks

1. Mould due to high levels of moisture
2. Mould due to poor ventilation
3. Mould due to cold surfaces internally
4. Hair and dander caused by pets inside and being on soft furnishings
5. Hair and dander lingering internally due to lack of regular cleaning, especially sofas, beds etc.
6. Pet faeces carry bacteria
7. Pollen from indoor plants
8. Pollen from external sources unfiltered
9. Bacteria on unclean surfaces, especially bathrooms and kitchens
10. Bacteria on animals generally
11. Bacteria on humans, especially in areas after exercise
12. Radon from the ground
13. Asbestos fibres in the air from building materials (pre 2000), ceiling tiles for example
14. House dust mites (HDM) on soft furnishings and carpets, especially in dusty and moist conditions



A third area worth mention is mitigating the risk from Legionella and Legionnaire's Disease. This is an issue for all homes, not just modern, airtight homes and is primarily a case of good maintenance. Ways to reduce risks are noted in Section 4.1.

Some perspective on hygiene may be useful. Some people feel that only by wiping every surface in their home with powerful detergent will they be safe from infection, while others may believe that their own immune system will take care of any invaders. Building up your immune system is important, so there is certainly some value in the latter approach, but there are two areas: the risk of infection from urine or faecal matter, and the preparation of uncooked meat, where hygiene really is important and so if nothing else, it is important to follow good hygienic practice in toilets and kitchens, especially around uncooked meat.

Fungal Spores (including mould)

Unlike plants which get part of their energy from light (photosynthesis) fungi derive their energy from absorbing the nutrients in other life forms. As such fungi such as moulds perform a critical role in decomposition of plants and animals.

At a certain point in their development, fungi will release spores which are dispersed by the wind and when they find a suitable substrate / organism to feed on, they can begin to form a colony.

There are over 100,000 forms of fungal spores and they float about in the air all of the time. Of these, some produce toxins, others are allergenic to humans and some can cause bronchitis and life-threatening fungal infections in residents who have weakened immune systems. Mould spores can cause eye and throat irritation, sneezing, nasal congestion and itchy skin or skin rash. More serious effects can include asthma attacks.

As a fungus, mould relies on a nutritious substrate (in buildings it is usually cellulose-based materials including wood and paper, for example), warmth and moisture. Mould and its spores represent a particular problem in modern airtight homes because there is usually an abundance of all three things. People used to cold houses do not want to go back to the cold winters of their childhoods and will tend to keep houses warm most of the time, too often poor ventilation and modern lifestyle lead to excess moisture as discussed in the last section and most modern houses in the UK have an abundance of materials suitable to support mould growth.

So the key to reducing the incidence of mould is to keep a house relatively cool – not too much above 20ºC, and relatively dry – no more than 60% relative humidity. If that can be achieved there is little chance of mould becoming established, even if there are suitable surfaces.

Beyond the wipeable surfaces noted elsewhere, there are two other design-related aspects of importance. One is to avoid 'thermal bridging' or 'cold spots'. Common examples of this are windows, window frames, areas of wall near vents or pipes, and corners, especially behind sofas or large furniture. These are areas which, due to poor insulation or air gaps have become colder than the surrounding areas and as such cool the air which creates condensation and prolonged moist conditions. If the temperature generally is warm enough, there will be enough overall warmth, and moisture to give mould a chance. Effective ventilation is also important because even if poor conditions prevail, the dilution effect and associated reduction in RH will help.

Example of serious mould growth to ground floor tenement bathroom

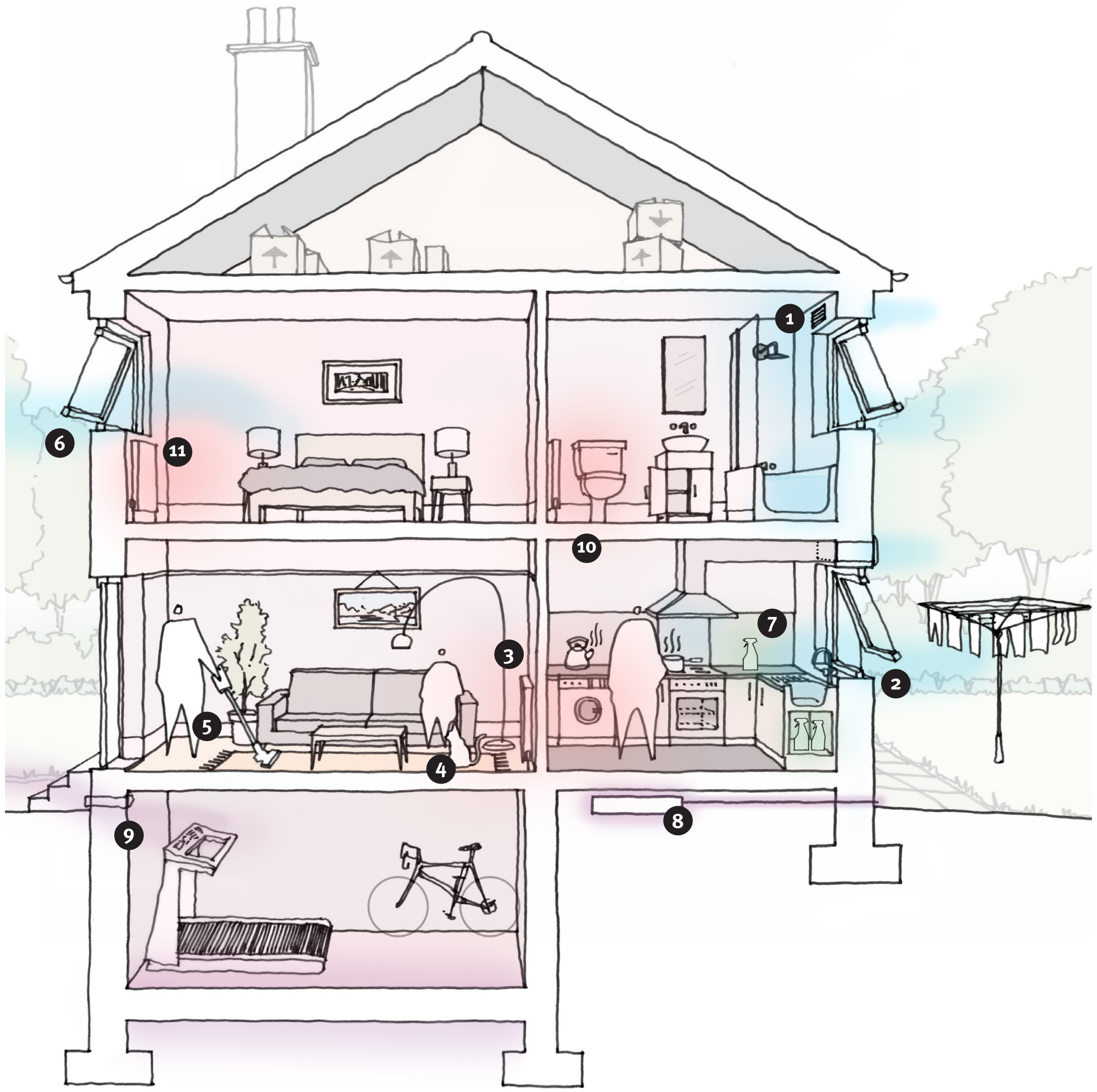
Viruses

Viruses are acellular, meaning they are not composed of cells like all other microbes. They are also not strictly considered life forms because they cannot multiply outside a host organism. Once they are attached to a host organism however, they can multiply and infect other hosts. Many viruses are harmless, but in humans viruses are responsible for many diseases, from the common cold and measles to Ebola and of course, COVID-19.

As noted, viruses are usually considered in the same way as bacteria, the ways of preventing spread of infection tend to be the same and from a designers' point of view, the two areas to consider are cleanable surfaces and ventilation as above.

Biological & Natural Diagram – potential solutions

1. Prevent mould growth with adequate mechanical ventilation, especially from wet areas
2. Prevent mould growth with adequate natural ventilation generally
3. Maintain 21°C internally to avoid cold surfaces where condensation and mould are a risk
4. Avoid letting pets on soft furnishings
5. Regular cleaning and vacuuming to reduce pet hair and dander and pollen internally
6. Close windows and doors if pollen count it high
7. Minimise bacteria with regular cleaning throughout, especially kitchens and bathrooms
8. Radon sump to solid floors
9. Minimise radon with ventilation to solums beneath suspended floors or basements
10. Leave asbestos undisturbed or have it professionally contained or removed
11. Regular cleaning, ventilation and heating to minimise house dust mites



To minimise the symptoms of pet allergies, brush them down regularly (ideally outside) and keep the pet out of the bedroom. Denaturing agents can be used on furniture and hoovering with a HEPA filter (+collection bag) will help (although steam cleaning is better). Don't over wash as this can dry out skin and exacerbate dander shedding.

Allergens

Allergens as a term has been used here to describe a range of natural pollutants which are larger in particle size than microbes but can still cause problems. Because they are larger, they tend not to be able to reach as far into the depths of lungs, and so will often cause irritation rather than serious illness. On the other hand, some allergens can trigger severe reactions, meaning the risk to people can be just as high, and can indeed be fatal.

There are a number of allergies and not all relate to airborne particles. For example, people can be allergic to certain drugs, foods (eg. nuts), and some materials like latex. And because things are never simple, some of the microbes mentioned above can trigger allergies, particularly mould spores. However the bulk of allergies relate to materials largely of animal, insect or plant origin, that is, small airborne particles derived from the natural world around us. The most commonly discussed are pet hair and dander, dusts mites and pollen.

Animals / Pets

Many people are allergic to animals and birds but as people only tend to come in close or prolonged contact with pets, it is usually dogs, cats and other common pets that get the blame. Allergies usually relate to the proteins found in fur, dander (skin that has been shed), saliva and urine or faeces and as anyone who has ever owned a pet will know, that fur and dander in particular can get everywhere. This is because they are usually small and light enough to become airborne and tend to have jagged edges which enable them to catch easily on surfaces. Animal allergies often accompany asthma or hayfever.

Symptoms of these allergies include itchy or watery eyes, coughing & sneezing, wheezing, eczema and stuffy or runny nose. Symptoms can be mild or severe. There are no guideline levels because people vary so much in their sensitivity. For those who are sensitive, even the tiniest amounts of the allergen may be problematic.

Potential solutions for those with pets and allergies are noted in the box-out. From a design point of view, the key is to provide surfaces – particularly floors – which are easily mopped or wiped, so materials like wood, tiles and linoleum[2] are fine whereas carpets are not. This is because carpets are perfectly designed to trap all manner of pet-related pollutants and make it difficult to remove them. Carpets can be steam cleaned which is helpful if you own them and suffer from allergies of any sort, but the simplest solution of course is not to have them.

Dust Mites

Dust is usually made up of about two-thirds airborne particles from outdoors such as soot and pollen as well as dirt tracked in on shoes, with the remaining third made up of carpet and clothes fibres, pet hair and human skin. Most skin is shed in baths and showers but some will end up in the dust that coats every home. Dust mites (shown below) feed on that human skin and it is dust mite faeces which triggers many allergies, being small and light enough to become airborne.

Like animal-related allergens, the most effective way for the building designer to counter dust mites is to avoid carpets by specifying floor finishes that can be easily cleaned. This may not be difficult for those who design bespoke homes, but it is problematic for those who work in social housing, where it is almost universally held that tenants will provide their own finishes (almost always carpets) and that all that is needed is a cheap chipboard or concrete floor. It is also worth noting that dust mites only thrive in temperatures over around 21°C and relative humidity of over 50% so cooler and drier conditions will control them. Occupational ways to reduce the risks from dust mites are regular hoovering, cleaning and airing of rooms, 60°C washes, freezing and then washing soft toys, using dust mite covers on mattresses and bedding, and air cleaners.

2 Note that both wood effect laminates and vinyl (PVC-based) are also cleanable but most will emit VOCs and other gases which make them much less desirable from an indoor air quality perspective, refer section on VOCs.

Pollen

Pollen grains are effectively the male sperm cells of plants issued to the wind or via the legs of bees and other insects to find and germinate corresponding female pistils or cones. The whole process is called pollination. Pollen allergies occur mostly in temperate climates where the process is more seasonal. In the UK, tree pollens tend to occur first, from February until June, while grass and some weed pollens occur generally in June and July. Most pollen which triggers allergic reactions is the type dispersed by the wind, because it is especially lightweight and generated in vast quantities.

Pollen allergies are technically known as seasonal allergic rhinitis and can be specific to a certain plant. Hay fever, for example is the common name for an allergy to grass pollen but is often used for all pollen allergies. Symptoms include a runny or blocked nose, sneezing and coughing and itchy or watery eyes. If a pollen allergy triggers existing asthma, this may be accompanied by shortness of breath, a tight chest and wheezing.

Beyond the use of inhalers, anti-histamines, decongestants and immunotherapy, there are a number of practical ways to combat pollen. Windows kept closed will reduce pollen entering the home, as will keeping pets away from bedrooms and living areas, avoiding drying clothes externally and washing hair before bed. Air purifiers may help and these are available from the many allergy, asthma and healthy-home websites.

There isn't a lot designers can do about pollen. It may possible to close all windows and only supply air to a building via a fine filter, but for most people this is impractical and is of no use when outside anyway.

Radon

Radon is an invisible, odourless and tasteless radioactive gas which comes from the natural radioactive decay of uranium in soil, rock and water. Radon is mostly associated with granite rock areas and the presence of radon varies widely across the UK. An indicative risk level can be found on the searchable map on www.ukradon.org.
Radon can seep into buildings and build up in the air. As it breaks down it can enter lungs and after lengthy exposure and high levels, can cause lung cancer. Radon is responsible for over 1,000 deaths a year in the UK.[3]
Tests are available to measure radon levels in a building but because levels fluctuate these take at least 3 months. Safe levels are considered anything below 100 Bq/m³, while action is usually recommended with measured levels of over 200 Bq/m³. Tests and much more guidance is available at the website noted above.

Good ventilation will of course reduce radon concentrations in the home but if there appears to be a risk, then the solution is to prevent radon entering the building. Radon barriers will work where they are installed without any gaps and are mandated in some areas of the country. Where an effective barrier exists (such as a concrete slab) a sump can be used to draw radon out and away. Sumps can be passive or actively driven with a fan. With suspended floors, the solum can be naturally or mechanically ventilated.

These solutions are not fool-proof however and need to be carefully undertaken. Tom Woolley discusses these potential shortcomings and notes that where buildings are made more airtight for energy efficiency reasons, these shortcoming can become more serious with much higher radon concentrations measured in several renovated buildings. Positive Input Ventilation (PIV) is sometimes recommended to 'push' radon out of homes but we do not recommend that for a variety of reasons related mainly to moisture risks in the building fabric.

Most guidance on radon pertains only to the risk from the ground. However, a number of building materials contain radon or similar radioactive materials. This radioactivity comes either from use of radioactive virgin mineral components or from the use of post-industrial components such as fly ash. Some of the worst affected materials include concrete, aerated concrete, red clay bricks and gypsum plasterboard. Woolley again discusses examples where worryingly high levels have been recorded (in the USA) in upper levels of a multi-storied building. Information on this is not too easy to find but those concerned should aim to avoid or reduce those materials and components most likely to contain high levels of radioactivity.

3 www.ukradon.org.

2.3 Combustion Products & Particulates

Ever since humans used fire to keep warm and cook food, they will have been aware of smoke and the need to let it escape. Once chimneys were introduced, this became a lot simpler but not without the occasional problem. The 20th century ushered in a range of new combustion appliances and fuels, often with less obvious, but sometimes more insidious risks. The industrial revolution brought an awareness of combustion in the wider atmosphere and large scale atmospheric pollution is still a major issue, especially near heavy industry and traffic. In this guide we are mostly concerned with domestic combustion, but since external pollution enters homes and workplaces as well, it needs to be considered too and several of the following pollutants emanate from both internal and external sources.

Carbon Dioxide

When we breathe in, the air is almost exclusively nitrogen (78%) and oxygen (21%) with trace amounts of other gases. When we breathe out, on average, the nitrogen drops to around 75%, the oxygen is around 15% and the other 10% is made up roughly of 5% each of water vapour and carbon dioxide (CO_2). In buildings it can come from fuel burning appliances like stoves and boilers. Carbon dioxide can be present in outdoor air where it comes from industrial burning, traffic, decomposition of organic material and of course respiration from other humans and animals.

Carbon dioxide is colourless and odourless but is heavier than air. It is not really considered a pollutant, although very high levels can be problematic. Levels of CO2 are measured in ppm (parts per million) and in the outside air, levels are normally close to 400. The acceptable limit for indoors is generally around 1,000 ppm and beyond this it can cause drowsiness at around 2,000 ppm and headaches, sleepiness, poor concentration and increased heart rate as it nears 5,000 ppm. This is considered the safe workspace exposure limit but research in schools shows that children's concentration levels drop well before this level.

Very high levels are rare however and tend to be associated with working in specialised, sealed environments (eg. submarines), unusual ground conditions such as volcanoes, and leaks from compressed CO_2 gas canisters, such as those found commonly in pubs.

So while carbon dioxide is very rarely a major health hazard of itself, it is important because it is relatively easily measured and has become the default gas to measure in lieu of all other air pollutants. If CO_2 levels are good (low), it's usually likely that other pollutants are low, and if it's high, then there might well be other potentially more troublesome pollutants around. Low CO_2 levels have become, in effect, a proxy for good indoor air quality (IAQ). For this reason, in Scotland the technical standards for new buildings have mandated the use of CO_2 monitors in the main bedroom of each property to raise awareness of the need for adequate ventilation and good air quality.

The key thing to reduce carbon dioxide exposure is not to have boilers, stoves and gas-burning cookers and hobs in the home. If they are to be installed, or retained, it is important that they are regularly and fully maintained along with their flues and air supply routes by suitably qualified persons. Thereafter it is mostly about good ventilation since there will always be some CO_2 in the air of an occupied home.

Carbon Monoxide

Like carbon dioxide, carbon monoxide (CO) is a colourless and odourless gas that is produced by the incomplete combustion of carbon-based fuels. This can occur if there is a reduction in the supply of supply air for combustion, or a blockage that prevents flue gases escaping.

Carbon monoxide however is more dangerous under normal circumstances. It restricts the transport of oxygen to the body and can cause headaches, dizziness, nausea, impairment of the eyes and brain functioning as well as irregular heart functioning. At high levels, it can be fatal and around 50 people a year die from carbon monoxide poisoning across the UK. Most carbon monoxide in the atmosphere comes from traffic but most deaths tend to be associated with malfunctioning cookers, heaters and central heating boilers.

Levels are measured in milligrams per cubic metre, or mg/m³. The lower the better of course but anything up to 7mg/m³ is considered acceptable by the WHO over long periods, while higher levels are acceptable for shorter periods under the building regulations.

The most important source control measure is to avoid all combustion appliances, or at least to ensure that all stoves, cookers and boilers are maintained. In addition, ensure that adequate sensors and alarms are located as necessary and also fully maintained. There should be a CO sensor around 2m from every boiler or stove and where a flue passes through a room. They should be installed about 2m from the floor and interlinked (so any sensor sets off all alarms) and its wise to include one in a garage or basement, especially if cars, mowers or other engines are stored / maintained there.

A wood stove can be delightful but there are risks to health from a range of potential gas leaks. This stove has a separate combustion air supply which connects in beneath direct from outside and is 'room sealed' which reduces the risks somewhat.

Nitrogen Dioxide & Nitric Oxide

There are actually seven oxides of nitrogen that can be found in ambient air (collectively known as NO_x) but the two of most interest are Nitrogen dioxide (NO_2) and Nitric oxide (NO). Both are associated with the high temperatures of air during combustion and are therefore found at higher levels near traffic, but more importantly for indoor air quality are associated with smoking, cookers, boilers and stoves. Depending on the temperature of the combustion, it is mainly nitric oxide that is produced but it tends to oxidise in air so that we end up with mainly nitrogen dioxide, which is why this is often the only one of the two discussed.

Nitrogen dioxide is most associated with gas burning and so is often largely associated with cooking and air quality in kitchens. It is heavier than air and is an irritant, affecting respiratory health, particularly in children. It can also act to reduce the body's own immune defence and therefore increases the risk of respiratory infections.

Recommended average indoor levels are 40 µg/m^3 with higher levels acceptable for short periods. Nitrogen dioxide is an important pollutant because numerous studies have shown that this safe level is often exceeded in homes, mainly in kitchens and during and after cooking.

As mentioned above, NO_x levels can be very high in urban areas, especially near traffic so this is worth bearing in mind when locating buildings on a plot near a busy road, for example, and when considering where intake points should be for mechanical ventilation systems. Obviously good maintenance of cookers, stove and boilers is the main defence against nitrogen dioxide, although the risks are entirely avoided if an electric (eg. an induction) hob and electric oven are used. Cooker hoods should be used where possible which exhaust to outside or re-circulate through charcoal filters. Nitrogen dioxide sensors and alarms are available but very much as industrial units which are quite expensive. Beyond this of course, good overall ventilation is critical.

Sulphur Dioxide

Sulphur dioxide (SO_2) is a colourless gas which has an unpleasant smell. It is created from the combustion of materials containing sulphur, of which coal has historically been the prime source. With the reduction in coal burning, SO_2 levels have dropped across the UK, but it is also associated with oil burning, many industrial processes and vehicle fumes. Almost all SO_2 in the air is anthropogenic – caused by human industrial processes, while the only natural source – volcanoes – contribute around 1% of the total.

Sulphur dioxide reacts easily with other materials including water vapour in the atmosphere causing 'acid rain' and was the main culprit in the 'Great Smog' of London in 1952 which resulted in approximately 4,000 premature deaths.

Sulphur dioxide irritates the nose, throat, and airways causing coughing, wheezing, shortness of breath and a tight feeling around the chest. The effects are felt quickly with most people experiencing symptoms within ten minutes. Those most at risk of developing problems are people with asthma or similar conditions. Normal background levels are generally around 5 µg/m^3 although levels in many cities lie around 15 - 20 µg/m^3. Levels over 100 µg/m^3 for long periods can lead to observable health effects and peaks of over 1,000 µg/m^3 should not be tolerated for more than ten minutes.

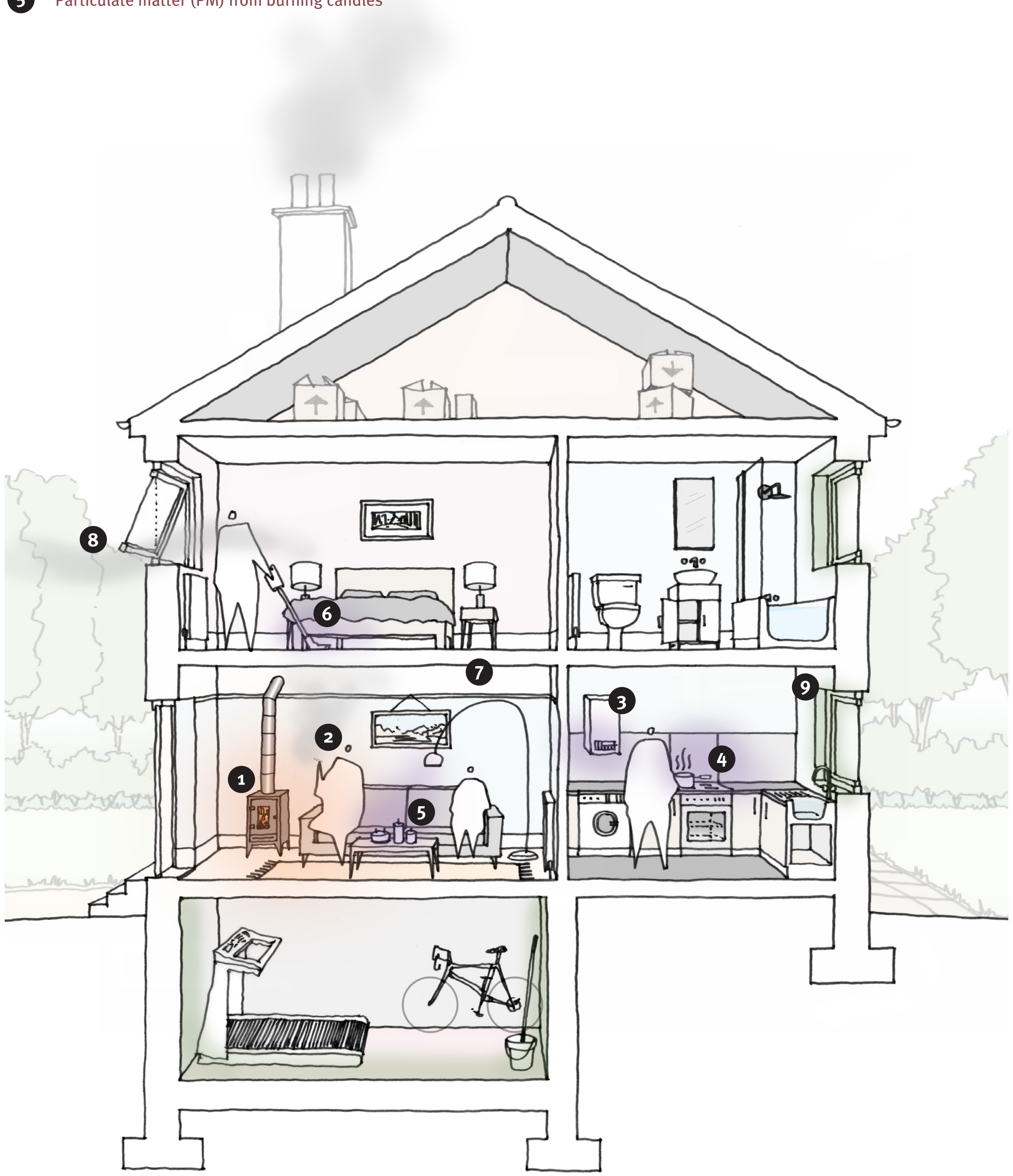
Sulphur dioxide is largely an external pollutant but of course may be a risk where coal, oil or gas burning appliances are used internally and the same comments about good maintenance of all appliances made above should be followed.

Environmental Tobacco Smoke

Environmental Tobacco Smoke (ETS) is the name given to the combination of smoke which comes from the

Combustion Products & Particulates Diagram – potential risks

1. Solid fuel stove a potential source of CO_2, CO, NO_x, SO_2 and PAHs
2. Many pollutants from smoking or second hand smoking
3. Boiler is a potential source of CO_2, CO, NO_x and SO_2
4. Gas hobs and ovens are a potential source of CO_2, CO, NO_x and SO_2
5. Particulate matter (PM) from burning candles
6. PM from vaccuming and disturbing dust
7. Asbestos in 'Artex' ceilings and many other possible locations, for homes built pre-2000
8. External air is a potential source of CO_2, CO, NO_x, SO_2, PM and PAHs, especially in urban areas, near traffic or industrial processes
9. Inadequate ventilation from kitchen



burning end of a cigarette, cigar or pipe along with the smoke exhaled by the smoker. ETS contains tar droplets and a variety of chemicals including carbon monoxide, nitric oxide, ammonia and hydrogen cyanide. It also contains trace amounts of a number of other substances (eg. benzene and polycyclic aromatic hydrocarbons (PAHs) known to be carcinogenic.

Smoking is known to cause lung cancer and a host of other problems while ‘passive smoking’ or second hand smoking is now established to be sufficiently hazardous to health that the Scottish Government banned smoking indoors in all public places from 2006 leading to a 15% reduction in the number of children with asthma being admitted to hospital in the three years after the ban came into force.

Needless to say, the solution is not to smoke at all, but certainly not indoors. Where appropriate (for example in public buildings) it makes sense to provide sheltered spaces to allow those who continue to smoke to do so out of the rain and in well ventilated spaces.

Particulate Matter

Particulate matter (PM) is the term used to describe a complex mix of solid and liquid particles suspended in the air, and which then settles as dust on surfaces within the home. Most particulate matter is the result of combustion (eg. soot from wood stoves) hence its inclusion in this section, but as ever, things aren’t that simple and the term is also used to describe particles from other human or natural sources such as mineral dust from quarrying, construction and demolition, as well as metals from various industrial processes or mixed into fuels. There are also many ‘secondary’ sources of PM created after reactions with moisture or other gases in the atmosphere.

PM is most commonly associated with outdoor air pollution but common indoor sources include all combustion processes (smoking, stoves, boilers and cooking in particular) along with items like candles, and incense producers, as well as via the disturbance of settled dust via vacuuming, dusting and cleaning generally.

PM is normally divided into three main types related to size. These are important because in general terms, the smaller the particle, the further into the body it can travel, increasing its ability to cause trouble if it inclined to do so. The three types are PM10, also known as inhalable particles of no more than 10 µm (micrometers), PM2.5 (fine particles < 2.5 µm) and PM0.1 (ultrafine particles < 0.1 µm).
Particles larger than around 15 µm tend to be filtered out by the nose while smaller particles will settle out in the respiratory tract. These will tend to be dislodged, exhaled or swallowed and excreted within day or two with no ill effect. However, particles of PM10 or less can get into the lungs which is more problematic and the smallest can be absorbed into the bloodstream. There are no safe thresholds for PM and all represent something of a risk. Because PM can get into the bloodstream, they can increase risks from cardiovascular diseases while they also irritate the respiratory system exacerbating established asthma and other respiratory problems, as well as skin conditions like dermatitis and eczema.
From the perspective of designing out risks, since much PM is from external sources, distance from urban, high industrial or traffic areas is key, while planting can help to filter out some of the particles. Filtration of air intake can be used where there is a suitable mechanical ventilation system. Hobs should be fitted with overhead hoods with filtration. Surfaces generally should be smooth, i.e. wipeable minimising the need for vacuuming and if possible the number of horizontal surfaces (where dust can settle) should be minimised.

Beyond this, the cleaning regime itself is important, with careful maintenance and servicing of combustion appliances, avoiding candles and incense burners and an emphasis on wiping surfaces to clean, rather than vacuuming, brushing and dusting (which disturbs dust).

PAHs

Polycyclic Aromatic Hydrocarbons (PAHs) are carbon based substances associated with incomplete combustion from organic material. In the developing world they are associated with crop, dung and wood burning, whereas in the developed world, they are more readily associated with traffic fumes, industrial processes and therefore outdoor air, as well as stoves, cookers and tobacco smoking. Grilling meat on barbecues can also be a source.

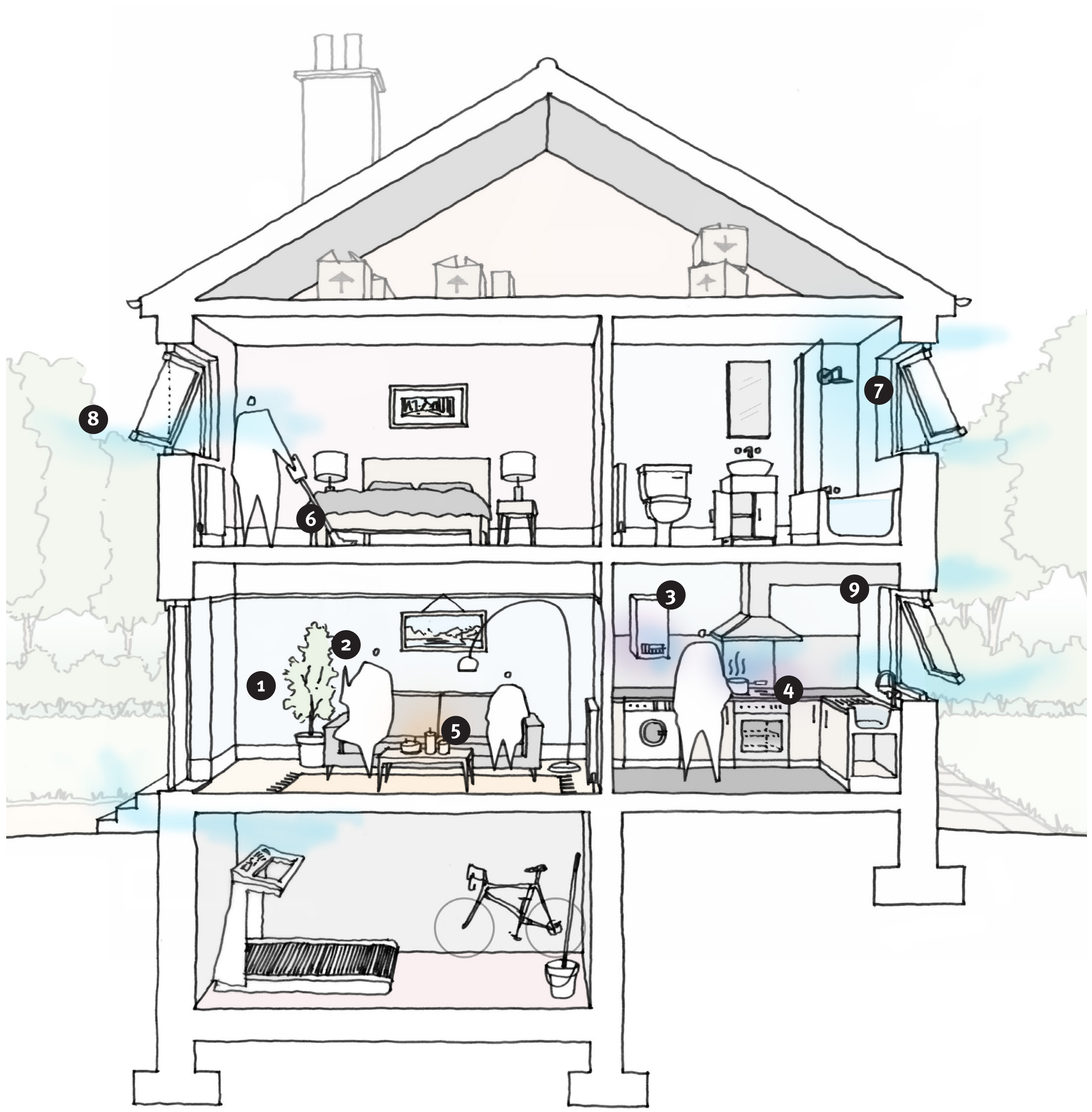
PAHs are considered to be particularly hazardous to human health. Historically linked to cancer in chimney sweeps, it is linked to several forms of cancer, cardiovascular problems and poor foetal development.

One of the most important PAHs is Benzo[a]pyrene (B[a]p), partly because it is usually the most commonly found, often makes up over half of the PAH measured and because it also one of the most hazardous.

To avoid risks from PAHs, the simplest solution is not to have any combustion appliances in the house and if you do, to ensure that they are well maintained and well and safely ventilated. For wood stoves, a separate combustion air supply (‘room sealed’) will achieve this, as will an operational extract hood over a hob. Distance from main traffic routes, centres of heavy industry and urban areas will also lower likely outdoor concentrations.

Combustion Products & Particulates Diagram – potential solutions

1. No solif fuel stoves, or if present, well maintained with separate combustion air supply and ‘room sealed’
2. Don’t smoke or allow others to smoke in your home
3. No gas boiler, or if present, well maintained with CO alarm
4. Electric oven and induction hob - no gas-related risks
5. Avoid using candles or use fake LED candles to minimise PM build up internally
6. Floors cleaned using damp mop, surfaces wiped with damp cloth
7. Ideally continuous extract ventilation from bathrooms and kitchens
8. Rural or cleaner external air. Windows opened when needed
9. Extract fan or recirculation fan with charcoal filter directly over hob



2.4 VOCs & other Chemicals

Until this point, it is likely that most people will have been familiar with some if not all of the pollutants discussed. In this section however, we introduce a number of relatively 'modern' chemicals and substances with which most people are not familiar. As a result the dangers posed by these chemicals are not widely appreciated or understood, despite the fact that these chemicals are ubiquitous within the construction industry and within homes across the country.

There are a number of problems hampering any attempt to establish the risks of these products. The first is that there are many thousands of such chemicals and the sheer scale and complexity of the problem is perhaps the biggest obstacle. The second is that there is a wide variation in the toxicity of the various chemicals out there. Some are entirely safe while others are known to be extremely hazardous.

A third problem is that insofar as these products - or their component parts - are tested, they tend (logically enough) to be tested on young and healthy participants. What is not always known, is how each and every chemical tested affects babies and children, the elderly and infirm, those who are immuno-compromised or in some way sensitised to certain products or substances.

The fourth problem is that each substance is tested in isolation in order to minimise variables and establish cause and effect, if any. What is not tested is how such chemicals will react with all of the other thousands of other chemicals in the air around us beyond the confines of the lab.

A fifth problem is that not all health effects are evident immediately. Many chemicals may appear to be safe initially, and it is only after many years, or even decades, that ill effects become clear.

A sixth problem, which to an extent is an amalgamation of the others, is that it is very difficult to establish a clear cause and effect. Even where a tentative correlation can be shown, it is difficult to nail down when there are so many variables at play. This conundrum becomes even harder when you bear in mind that to be considered statistically or clinically reliable, results need to be demonstrated over hundreds or thousands of cases. The complexity – and therefore cost – of such investigations can be very high.

As a result of all of the above it is not surprising that we know little about the long-term effects of many of the chemicals with which we surround ourselves. It is also testament to the enormous effort of those who have, despite the odds, begun to delineate the health risks posed.

What can be said unequivocally is that some of these chemicals are known to be dangerous, many more are likely to be hazardous to an extent, especially as we do not know how they affect people when mixing and reacting with other materials, how they affect people over the long term, or how they affect more vulnerable people. For this reason it makes sense to adopt the precautionary principle and look carefully at reducing the overall scale of this insidious chemical load on occupants until such time as we are sufficiently confident that there is no risk.

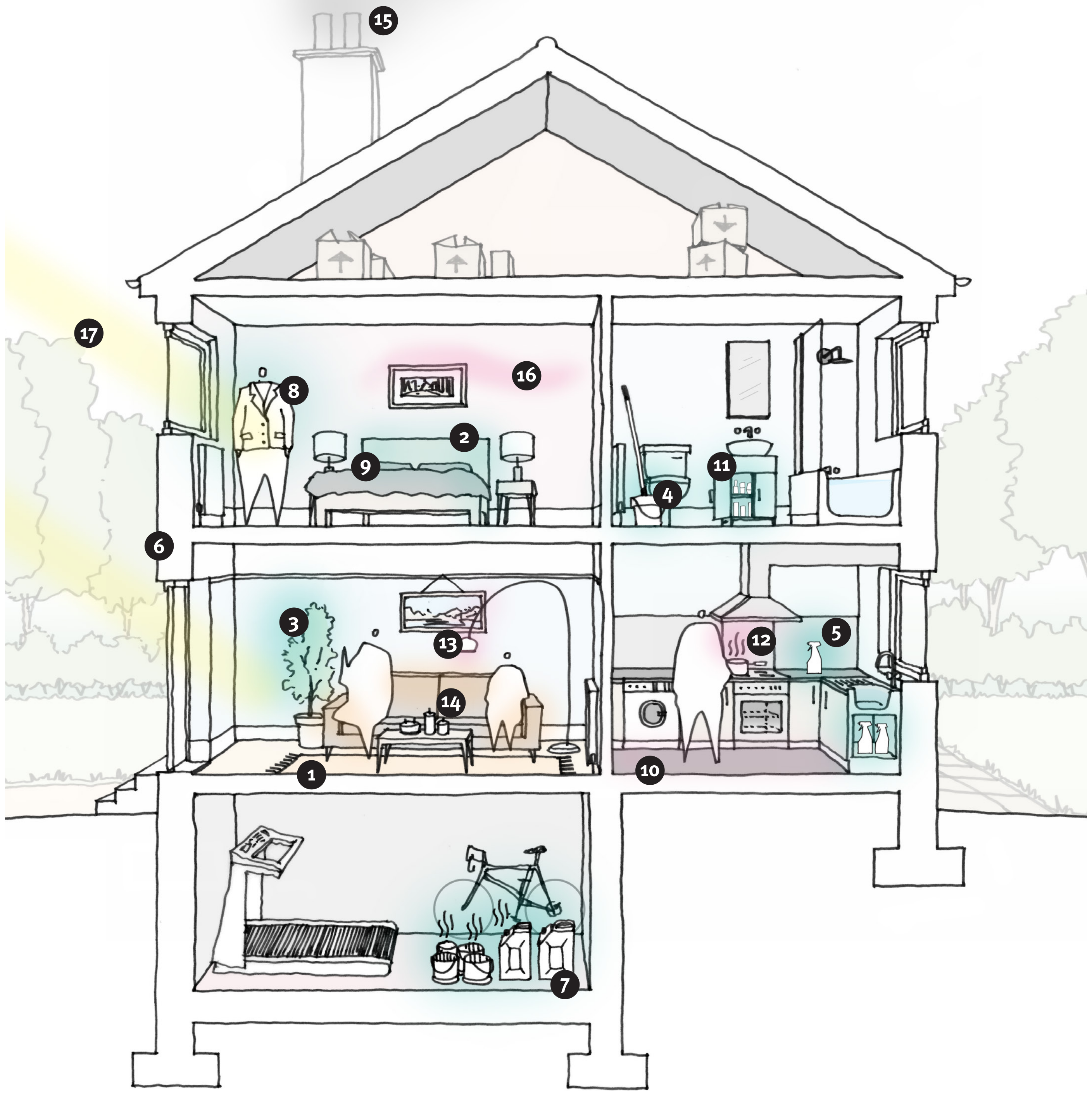
Because of the number of chemicals, it does not make sense to attempt to list and describe all of them. In the rest of this section we will highlight a few of the more common or important ones, and concentrate on the products and material substitutions which can be usefully made to reduce the chemical load overall.

VOCs

Volatile Organic Compounds (VOC)s are a loose group of thousands of different compounds all of which contain carbon (hence 'organic') and have relatively low boiling points (hence 'volatile') and are therefore readily emitted as a gas in most internal conditions. Some are safe, some are known carcinogens and many appear to have long-term effects on our health. They are usually grouped into three sub-types relating to boiling point, being 'Very volatile' (VVOC), (Normal) VOC and 'Semi-volatile' (SVOC). When monitoring properties, many sensors take an aggregate value for a range of VOCs and the phrase 'Total VOC' (TVOC) is often seen as a catchall figure for VOCs generally.

VOCs & other Chemicals Diagram – potential risks

1. VOCs from internal finishes such as carpets or wallpaper
2. VOCs from furniture
3. VOCs from pesticides
4. VOCs from cleaning products
5. VOCs from surface cleaners
6. Formaldehyde from building materials, paints, preservatives etc.
7. Benzene levels typically high in gargaes and basements due to solvents, paints, petrol storage
8. Naphthalene from mothballs or deodorants
9. Flame retardants applied to soft furnishings
10. Chemicals plasticisers from vinyl floors
11. Chemicals from personal care products
12. Chemicals from non-stick cookware
13. Chemicals from most plastic products
14. PAHs from burning candles or cooking
15. PAHs from solid fuel burning
16. PAHs attached to particles in the air
17. Ozone from when sunlight enters the building which can then react with other pollutants



VOCs have a bewildering range of useful properties and as a result have found their way into innumerable products, many of which are used in construction, particularly liquids such as adhesives and coatings, while they are also common components of pesticides, cleaning products and beauty products.

A list of some of the most common within construction is given below with a brief note on their effects and where they are most commonly found.

Many VOCs are very effective solvents because they 'dry off' quickly due to their volatility. Importantly, this volatility is increased as temperatures rise, so the warmer the house, the more VOCs will off-gas. They are found in many liquid components in building work, such as paints, adhesives, preservatives, sealants, varnishes, waxes, polishes as well as liquid cosmetics and cleaning products.

- **Benzene is a known carcinogen found in paints, adhesives, carpeting, general solvents and petrol, it is a component of cigarettes and a number of common building materials.**
- **Formaldehyde is found in many products such as plastics, insulation (in the binder), paints, preservatives, sealants, adhesives, (eg. in building boards) varnishes, waxes and polishes. It is also associated with smoking and combustion in homes. It is a known carcinogen and is implicated in a wide range of other health problems. It is one of the most common, well known and dangerous of the VOCs.**
- **Styrene is used as the base in polystyrene insulation and in various latex and rubber products, including within carpets. It is a likely carcinogen in relation to eye and skin contact, ingestion and inhalation, with additional effects on the nervous system and as a neurotoxin.**
- **Toluene is used in paints, paint thinners, lacquers, adhesives, silicone sealants and rubber. It is less toxic than benzene but at higher levels of exposure can cause nausea, intoxication, drowsiness, unconsciousness, brain damage and death.**
- **Trichloroethylene is used in metal cleaning and degreasing. It can cause dizziness, headaches, nausea and vomiting followed by drowsiness and coma. Severe exposure can cause heart problems and death.**
- **Xylene is used in paint thinner and varnishes. Long-term exposure may lead to headaches, irritability, depression, insomnia, agitation, extreme tiredness, tremors, hearing loss, impaired concentration and short-term memory loss. Xylene is also a skin irritant.**

Ozone

Ozone is not normally associated with homes, it is an irritant which can damage the lungs with a pungent odour making it easily sensed. Indoors, it is most commonly associated with photocopiers and laser printers which is why they should be placed in separate rooms where possible and well ventilated. Oxygen can be converted to ozone through ultraviolet light (photocopiers) or electric discharge.

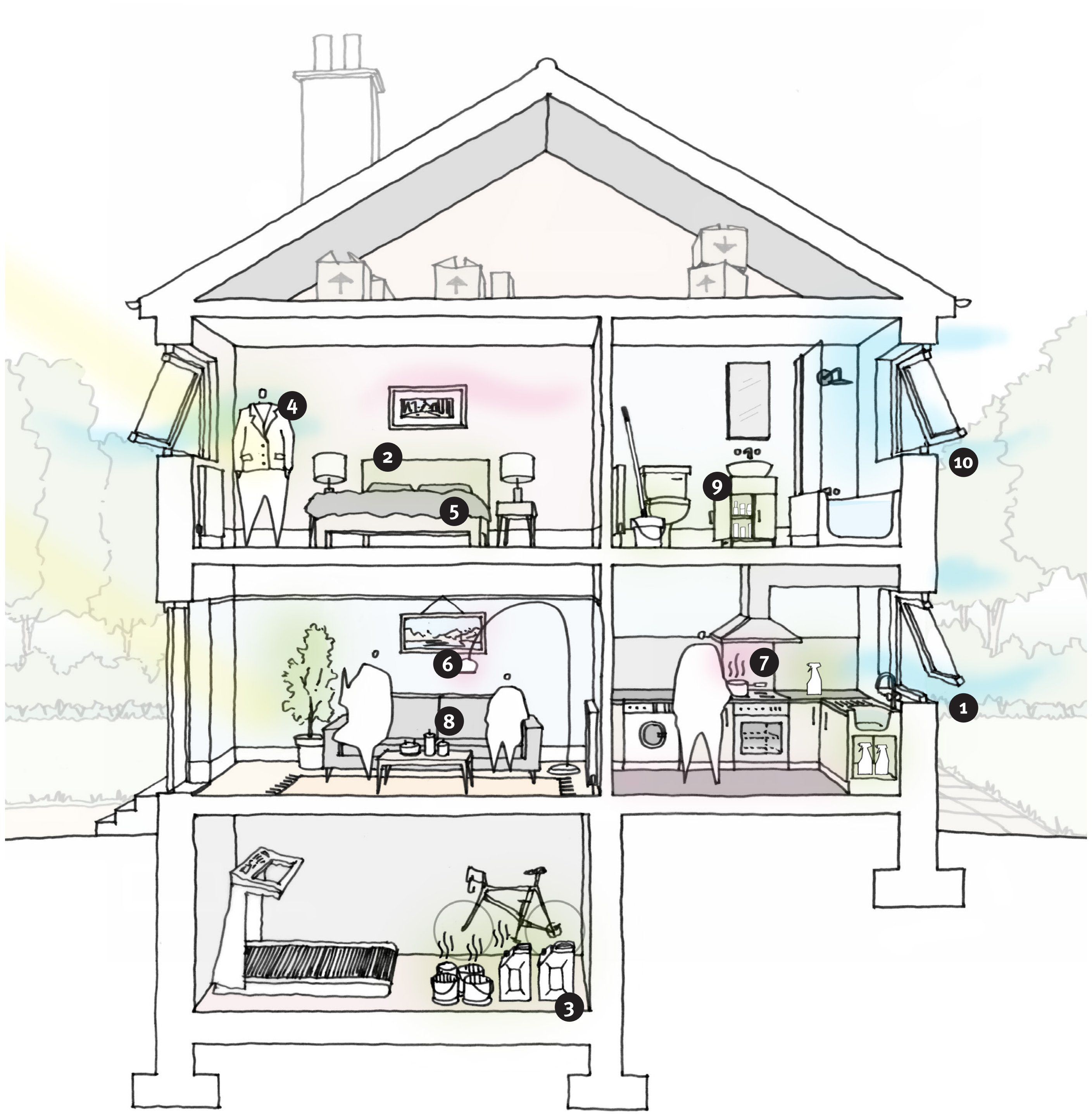
In countries and cities with photochemical smog, ozone can be prevalent in outdoor air and is then brought into homes through open windows and ventilation intakes. It can also be created when NO_x reacts with certain VOCs. Conversely it can be used to react with known air pollutants and in some cases neutralise them.

Potential Alternatives

The following tables identify some of the most common materials which represent some of the more pressing health and air quality concerns, with a very brief note on potential health risks and alternatives.

VOCs & other Chemicals Diagram – potential solutions

1. VOCs minimised via adequate ventilation throughout
2. Use low emitting materials to minimise Formaldehyde levels
3. Adequate ventilation throughout and VOC-free products to minimise Benzene levels
4. Avoid mothballs and deodorant containing Naphthalene
5. Ensure any flame retardants applied to soft furnishings are safe products
6. Minimise plasticisers by avoiding plastic products where possible
7. Reducing meat and dairy consumption can reduce exposure to chemicals
8. Avoid burning candles or fake LED candles to minimise exposure to chemicals
9. Use natural personal care products to minimise exposure to chemicals
10. Adequate ventilation will minimise PAH levels



Construction Materials

Material / Component	Examples / Health Risks	Potential Alternatives
Treated timber	Treatments are to protect timber from insect attack and decay mainly, sometimes fire. Different treatments offer different risks. Wide range of risks associated with different components and different treatments, refer to safety data sheets or equivalent. Some flame retardants are particularly toxic. Chromated copper arsenate (CCA) treatment now banned, remaining are less toxic but still present risks.	Untreated timber in all internal or non-decay risk situations, durable species for external (eg. oak, heartwood of European larch), thermally treated timber (eg. acetylated), improved detailing (keep dry). Some treatments are less toxic (eg. boric based solutions). Ensure treated timber, if used, is not exposed to internal spaces
Timber product building boards	Main risk to health here is from the adhesives used to glue the timber components together. For this reason, boards with less glue and more timber preferable.	Most boards have high levels of glues which are mostly high in VOC content. Plywood has less glue than OSB which has less than chipboard, less than MDF but different boards available.
Insulation	Synthetic plastic based insulations (EPS, XPS, PIR, PUR, phenolic foam, sprayed foams and others) will off-gas a range of VOCs and other chemicals, especially in fire. Most mineral wool products use binders which include formaldehyde and other pollutants. Formaldehyde-free options are available. Mineral wools tend to be irritants and a respiratory health risk as well.	In general, 'natural' insulations will not offgas due to their main materials nor their binders, but check in each case. Natural insulations include sheepswool, wood fibre, hemp, jute, sisal etc. Recycled cellulose can be categorised similarly and rigid insulants such as foamglas, cork and loose fill minerals like perlite.
Composite / bonded components	As the name implies all composite or bonded comments use adhesives to achieve their composition, and the majority of adhesives used contain VOCs and other pollutants which can offgas. Composite products can be more difficult to reuse / recycle at end of life as well.	Where possible try to use monomeric materials, that is individual components held together using friction or mechanical fixings. This also makes the task of reuse and recycling simpler and more economical.
Plastic pipes	By far the worst for health is PVC. Highly toxic in manufacture, can leach additives in particular during use and at disposal (into groundwater) but biggest risk is in fire – emits highly toxic fumes.	Other less toxic plastics, eg. HDPE (above ground waste), clay pipes (underground), steel, copper or PE (polyethylene) PTFE, cast iron or other metal rainwater goods. Refer 'Greenpeace plastics pyramid' for relative plastics risks
Plastic joinery	Main issue is PVCu windows, also doors, external joinery like eaves and verge boards, soffits and cladding panels.	Timber or metal for windows, doors and joinery generally.
Plastic cabling	Main material used is PVC, for risks see above, also Greenpeace research also by Healthy Buildings Network (US). Gives off halogen gases and toxic fumes when burnt. Note there are some 'bio-based' plastics (eg. starch) but tend not to be used in construction.	Low density or high density polyethylene (LDPE / HDPE), Rubber and synthetic rubber (Neoprene) which is cheaper, LSHF (Low Smoke Halogen Free) cables are far safer when burnt, PTFE (Teflon) and PUR. Note "LSF" ("Low smoke & fumes") material is still PVC with modified (28 to 22%) hydrogen chloride gas given off when burnt, i.e. not much better.
Adhesives	Many of the most toxic pollutants are associated with adhesives and other 'liquids' used in construction, like additives, thinners, foams, sealants. Wide range of pollutants as all 'wet' products need to 'dry out' and VOCs, being volatile, are ideal for this.	Where possible simply avoid 'wet' solutions, i.e. dry fix all components, use overlaps or rubber sealants in preference to applied sealants, dry fillers (eg. sheepswool between window frame and masonry in lieu of expanding foams)

Building Finishes

Material / Component	Examples / Health Risks	Potential Alternatives
Paints / Coatings	As with adhesives above, many and wide ranging health risks associated with paints, lacquers, stains, varnishes and thinners / removers etc.	Avoid where possible, i.e. use materials which are inherently durable or attractive and need no coating (also helps at disposal). There are several companies who use close to 100% natural and non-toxic materials for their paints. None are mainstream but far less health risk. Other conventional paints eg. 'Low emissions' etc. may be better than normal but for example water-based in lieu of solvent based was good in some ways but far more complex chemistry so overall hard to gauge if better. If unavoidable, ensure good ventilation and don't inhabit rooms for as long as possible with heating on and open windows etc. to minimise residual off-gassing.
Flooring Laminates	Risk associated with plastics and adhesives used.	Solid timber or engineered timber (glues used for lamination but preferable to 'laminates') Also rubber, tiles, timber etc.
Flooring Vinyl	Vinyl is PVC, it is highly toxic in manufacture, off gases in use and toxic again in disposal and especially in fire where it gives off dioxins. Particular risks associated with various additives used incl. plasticisers (for flexibility) and stabilisers (often heavy metals)	Linoleum. Largely natural materials and made in the UK.

Material / Component	Examples / Health Risks	Potential Alternatives
Flooring Carpets	Carpets present a health risk to IAQ on two fronts: by virtue of their nature, collecting and trapping particulate matter, pollen, dust, dust mites and their faeces, dirt etc. but also due to the materials used and treatments required, eg. fire retardents, anti-static, anti-mould, anti-stain coatings.	Any surface which is relatively easy to sweep / vacuum / mop and thereby remove all pollutants / dirt etc. 'Softness' of carpets can be partially re-introduced via (washable) rugs if necessary. In flats where increased percussive noise (from footfall) could be an issue, rugs, additional acoustic separation and no-shoes policies can help. Carpets are popular in UK as our homes tend to be colder than Scandinavia where carpets are rarely used, so if removing carpets, important to also address energy efficiency generally.
Composite / Bonded Components	Like carpets, furniture, especially soft furnishings, normally cannot be sold without a variety of treatments, usually fire retardents, anti-static, anti-mould and anti-stain treatments.	For new furniture and soft furnishings usually impossible to avoid. Use 'hard' furniture (timber / metal etc.) with cushions / throws etc., antique, or at least older options, built-in furniture etc.

3.0 Ventilation

The previous section looked at the range of pollutants in indoor air and ways we can reduce the incidence of these at source. In every situation however, we will still need to provide adequate levels of ventilation.

At the most basic level, all buildings need to:

- provide 'fresh' air for people to breathe
- get rid of 'stale' air which has been polluted with moisture, or any of the pollutants discussed in the previous section.

This can be more complicated when the outside air itself is polluted, but in general terms it means that homes and other buildings need to:

- remove polluted air from the building (ideally close to the pollution source)
- have a system that provides fresh air into the building
- ensure that the air is effectively transferred throughout the house.

It is important to stress this third item because in some modern ventilation arrangements it often gets forgotten. The above mechanisms can be natural or mechanical and can also be used to heat, cool or otherwise moderate the internal climate.

In traditional buildings, the three main elements used to achieve this were chimneys, windows and cracks and gaps in the building fabric. The first two of these could be considered as the 'designed' or 'intended' ventilation system, while gaps in the building fabric provide 'unintended' or 'uncontrolled' ventilation. When fires were lit chimneys acted almost exclusively to extract air (and smoke) from the building and when unlit, all three elements effectively allowed air in and out depending on controls used and the natural forces of wind and stack effect.

However, the drive to increase airtightness has changed things, and the draughts which have been an unintended but integral part of the effort to move air in, out and through buildings are no longer available to those designing 'airtight' buildings. It is these buildings with which the HEMAC Network is concerned because while the draughts have been removed, this has not been accompanied by a concomitant improvement in the designed ventilation system.

This is recognised to an extent in the various UK building regulations, with more mechanical systems which can guarantee more consistent air change rates identified as being more suitable for airtight buildings. Even where it is not required, for example in retrofit projects, it is worth commissioning an air pressure test to ensure that the strategy and system chosen is suitable.

Improving the building standards related to ventilation might help, but the most pressing issue is that quite often, when tested, ventilation systems don't reach the performance requirements of the standards as they stand. A number of recent UK studies have shown that the real performance of the various ventilation strategies employed is often inadequate. The reasons for the poor performance of ventilation systems are complex and interrelated, but some of the most common issues are noted below.

Extract routes / equipment are often inadequate:

- passive stack ductwork does not exert the requisite draw
- windows are not opened by occupants who are less sensitive to poor air quality than to overheating
- other natural stack or cross-ventilation routes are compromised by fluctuating weather conditions
- extract fans are incorrectly sized
- fans are connected to ductwork which increases resistance without adjustment made (a common example is the use of flexible ductwork which is

easier to use but increases resistance)
- noisy extract fans result in systems being turned off, disconnected or simply not used
- fans are broken and have not been replaced
- filters are clogged with dirt or grease (eg. in kitchens) and no longer extracting effectively.

Inlets are often inadequate:
- located too close to extract routes, creating short circuits which leave other areas under ventilated
- inlets are left closed (occupants either don't know about them, or have left them closed deliberately)
- inlets are under-sized
- inlets such as trickle vents are partially or fully blocked by dirt, and debris
- inlets are compromised by too many adjacent obstacles, such as curtains, blinds etc.

In many cases occupants find it hard to reach and control trickle vents, especially when they are obscured by net curtains and blinds etc. Photo by Tim Sharpe

Finally, anticipated transfer routes often become blocked:
- partition doors are kept closed, do not have the requisite undercut, or are blocked by carpets
- transfer grilles are blocked, sometimes intentionally, eg. where related to contradictory fire regulations

There is no doubt that some occupants do not appreciate the need for adequate ventilation and for whatever reason do not operate the ventilation systems in their homes optimally. There is considerable scope to help educate and motivate occupants, but in many cases, they are not helped by systems which do not work well and where controls are not clear (see below).

Ventilation needs to be taken seriously in order to ensure that air quality is not compromised. Everyone involved in building procurement, design, installation and maintenance needs to understand the importance of ventilation, how to design and install ventilation properly and how to commission and maintain it to ensure that it provides many years of trouble-free, healthy fresh air to those inside.

The following sections describe the various types of ventilation systems, offer some insights into their relative merits and provide some best practice guidance.

Controls

In any mechanical ventilation system, the controls are how people interact with the system and must be easy to understand. Too often this is not the case and sometimes it is not surprising that people don't know how to operate their system effectively. A helpful document called 'Controls for End Users' is available from the Building Controls Industry Association (BCIA) which discusses the need to make controls intuitive and clear. For those interested, more information is available from the Usable Buildings Trust (www.usablebuildings.co.uk)

3.1 Ventilation Systems

The following section discusses five basic types of ventilation commonly used in homes across the UK. Traditionally, all homes were ventilated entirely using natural ventilation, whereas in new homes, this is typically supplemented by mechanical extract in kitchens, bathrooms and utility rooms.

Natural Ventilation (with intermittent extract)

Fully natural ventilation as a whole-house approach has not been an acceptable option under the building regulations for several years and the majority of the homes with which this guide is concerned use a hybrid involving some mechanical input. It remains acceptable to use opening windows for supply air in living rooms, dining rooms and bedrooms, but this is only on the basis that there is mechanical (or passive stack) extract ventilation in other areas of the house.

Opening windows is effective at providing a good 'airing' and is an important part of removing unwanted heat in summer, but as a strategy natural ventilation is dependent on wind speed and also the upward movement of warm air. It is also dependent on the orientation and layout of the building and the local micro-climate, so tends to work better in some houses than others. Finally, it is dependent on occupants and while research has shown that people tend to open windows if it is warm, they are not as sensitive to poor indoor air. As no filtering occurs in natural ventilation, the indoor air quality can only ever be as good as the air outside which can be an issue near busy roads, industrial zones or in built-up urban areas.

Intermittent ventilation is the system with which most people in the UK are familiar. Extract fans in the kitchen and bathroom extract air when switched on, usually by turning the light on and run for around 5 minutes afterwards. Replacement air usually comes from trickle vents in the windows in other rooms.

The theory with intermittent extraction is that moisture is only produced when people are in the room, and so rooms like kitchens and bathrooms only have the fan on when people are in (the light is on) ensuring that moisture and other pollutants are effectively removed at source, while avoiding running the fan all the time and thus saving energy. An alternative is to control fans via a humidity or CO_2 sensor whereby the system becomes a simple form of demand control ventilation. When fans are not switched on, the home is only ventilated through infiltration (leaks) and any opened windows – natural ventilation.

This remains the default system for most house builders because it is cheap and simple to install on most projects, and if the system is designed, installed and operated correctly then it is usually effective at removing moisture from wet rooms as required. Where it may be less effective is in heavily occupied living rooms, especially if clothes are dried there, and in bedrooms overnight where people exhale a good deal of moisture and for which there is no specific ventilation strategy in place.

This strategy is only suitable for properties with an airtightness level higher than $5m^3/hr/m^2$ at 50Pa or leakier, and as such is not suitable for highly airtight and energy efficient projects.

Pros	Cons
• Low cost • Effective in wet rooms • Simple to install • Minimal energy consumed by fans	• Relies on occupants using effectively • No filtration of outside air • Potential noise issues • Less effective in living rooms and bedrooms

System Components
Air input: windows, trickle ventilators located in living rooms and bedrooms, wall vents
Air transfer: door undercut gaps, air transfer grilles
Air extract: extract fans located in wet rooms

Best Practice Guidance
The main problem with most systems is that they are installed without the necessary care, so it is important to follow the guidance of the manufacturers very carefully to ensure that the optimum conditions are created for the system to work well.

However, not all manufacturer's guidance takes account of the wider need for a holistic approach and so in addition, all three components of the system should be explicitly designed to achieve the requirements of the technical standards with a drawing and specification which covers all components and demonstrates how the regulations are met.

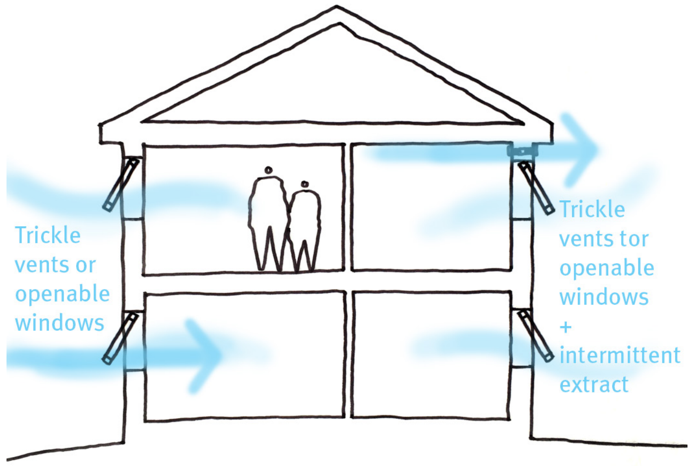
All parts of the systems should be carefully and independently inspected by a competent / certified professional on site and formal commissioning sheets should be completed and signed off for all properties. There is no current requirement for this in the UK and it is a contributory reason why so many problems arise.

Keep fans away from bedrooms where possible as it is noise overnight that is most irritating. Choose fans where possible according to their acoustic performance if this is likely to be an issue. Cored holes for fans should slope gently downwards towards the outside to prevent condensate or rain ingress. Ensure the installation of the fan through a wall is fully sealed on both sides of the wall, a common finding of Building Performance Evaluation (BPE) projects is cold air ingress around such penetrations.

Fans should not be located near flues or drainage vent pipes to avoid noxious or dangerous fumes getting into the house when they are not in operation. Care needs to be taken when there are combustion appliances in any ventilated space and the building regulations set out guidance for such spaces.

A manual override switch should be provided to allow for maintenance, but there is a risk that if these are too conveniently placed, they can be used as an 'on-off switch' which risks reduced use of the system. To limit the energy demand of the fans, they should have a specific fan power of less than 0.5 watts per litre per second.

Windows have to achieve a number of things in most buildings, not least in relation to providing views, natural light and fire escape as well as address security concerns. From a ventilation perspective however, it is



House Diagram – natural ventilation

important that openings are provided on both sides of a property to allow for cross ventilation, and also at both low and high levels (ideally rooflights) to allow for effective stack ventilation. This is particularly important to manage overheating since the warmest days are usually accompanied by a lack of wind.

For cross ventilation to work effectively, there needs to be a clear path through the property, so undercuts on partition doors are important while leaving internal doors open is best.

It is important to ensure that openings are not too close to any flue or drainage vent pipe and minimum areas for openings are given in the building regulations across the UK, although these can be relaxed if the air leakage rates exceed 10 $m^3/hr/m^2$ at 50Pa. Although trickle vents are usually inserted into window heads, these can be obstructed by blinds and curtains and it is worth remembering that other options for air intake are available.

Passive Stack Ventilation

Passive stack ventilation capitalises on the natural buoyancy of warm air and creates unobstructed paths for warm (and moist) air to escape vertically upwards from kitchens, bathrooms and other wet room areas as required. These paths consist of tubes which pass through upper floors or lofts to terminate usually on the roof of the building. They are most cost effectively used on single or two-storey properties. Replacement air is provided by windows or trickle vents in other rooms.

Passive stack ventilation is the only truly 'natural' ventilation allowable in modern homes and because it relies on natural processes it is subject to the same variabilities as other natural ventilation techniques. Although the systems are designed to optimise performance, it cannot be guaranteed and there are a number of examples of relatively poorly performing systems. The open ducts mean that it is impossible to achieve a high level of airtightness. Passive stack systems are not suitable for properties with an airtightness less than 5m3/hr/m2 @ 50Pa so cannot be used as part of a highly energy efficient design such as Passivhaus.

<u>Pros</u>

- Silent operation
- Continuous operation
- Low cost (unless installation is tricky)
- No energy consumed by fans

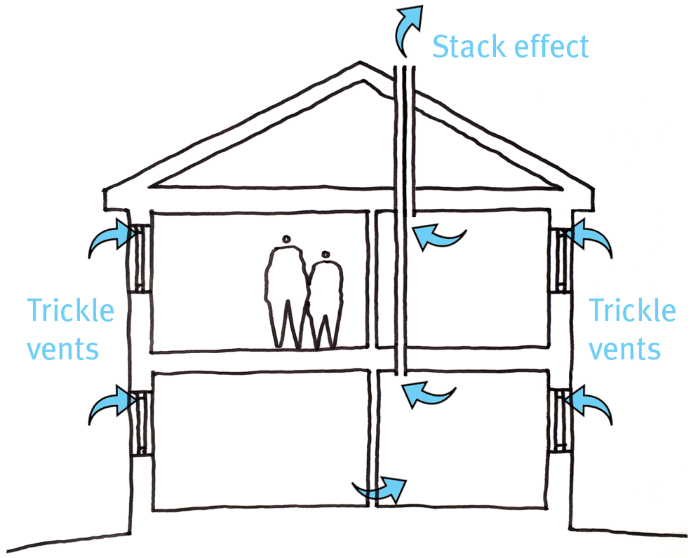
<u>Cons</u>

- Variable performance
- No filtration of outside air
- Not used on buildings above three storeys

System Components
Air input: windows, trickle ventilators located in living rooms and bedrooms, wall vents
Air transfer: door undercut gaps, air transfer grilles
Air extract: passive stack tubes with grilles located in wet rooms

Best Practice Guidance
It is important to follow the guidance of the manufacturers very carefully to ensure that the optimum conditions are created for the system to work well. There are additional contextual limitations if there are much higher nearby buildings or other objects.

As with all systems, all three components of the system should be explicitly designed to achieve the requirements of the technical standards with a drawing and specification which covers all components and demonstrates how the regulations are met. All parts of



House Diagram – stack ventilation (natural)

the system should be carefully inspected on site and formal commissioning sheets should be completed and signed off for all properties.

Stack ventilation tubes work best when they are kept vertical and straight and long / tall tubes tend to work better than short ones. If bends are unavoidable, they should not be greater than 45 degrees. Ducts need to be well insulated if they pass through an unheated space to avoid maintain the stack effects and avoid condensation forming inside the duct and there are additional requirements where ducts penetrate a floor or wall that has a specific fire resistance. Terminals should be placed at or near the ridge of the property to maximise the 'draw' on the system and need to be designed to inhibit ingress from rain, insects and birds.

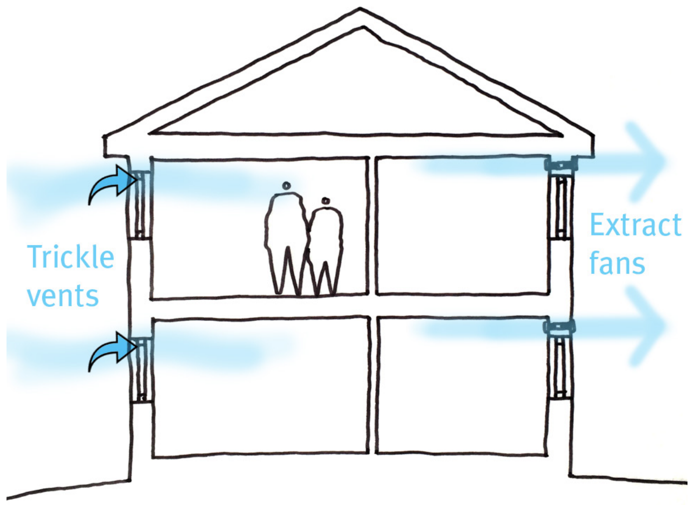
Like all ventilation systems it is important there is a free flow of air from intake points, through the house to the exhaust grilles. If there is likely to be noise from outside, an attenuator may be helpful. Each space to be ventilated needs to be served by an individual duct and there are minimum diameters for ducts according to the room being served.

The same comments as above apply to the placement and arrangement of windows.

Decentralised Mechanical Extract Ventilation (dMEV)

Like intermittent ventilation, dMEV features extract fans in wet rooms with input air coming from trickle vents and windows. However, in dMEV systems, the fans run continuously. This means that they are always slightly de-pressurising the whole house and this generally leads to better overall air quality across the whole property than intermittent extraction. It also means that they are suitable for properties with lower airtightness levels.

In order to avoid excessive energy consumption, the fans tend to run at lower rates (trickle mode) and rather than switching them 'on' when you visit the kitchen or bathroom, you get the option of pressing a 'boost' (boost mode) to ensure that, as before, they extract air and moisture at a higher rate once the room is occupied. Minimum rates are set within the building regulations for each room type.



House Diagram – dMEV

dMEV systems are suitable for use in more air-tight building, that is, those constructed to an infiltration rate of between 3 and 5 $m^3/hr/m^2$ at 50 Pa in Scotland. The guidance is less specific in England and Wales where infiltration rates are linked to trickle vent provision.

Pros

- Relatively low capital cost
- Simple to install
- More reliable performance than intermittent

Cons

- Fan noise (dependent on installation)
- Electrical consumption (very small)
- No filtration of outside air

System Components
Air input: windows, trickle ventilators located in living rooms and bedrooms, wall vents
Air transfer: door undercut gaps, air transfer grilles
Air extract: extract fans located in wet rooms

Best Practice Guidance
Like intermittent systems, the main problem with most systems is that they are designed and installed without the necessary care. It is important to follow the guidance of the manufacturers very carefully. Not all manufacturer's guidance takes account of the wider need for a holistic approach however, and so in addition, all three components of the system should be explicitly designed with a discrete drawing and specification which covers all components and demonstrates how the regulations are met.

All parts of the systems should be carefully and independently inspected by a competent/ certified professional on site and formal commissioning sheets should be completed and signed off for all properties.

As with intermittent systems, it is best to keep fans away from bedrooms where possible as it is noise overnight that can be most irritating. Choose fans where possible according to their acoustic performance, note that the maximum noise generated on continuous rate should be 30 dB.

Keep fans away from bedrooms where possible as it is noise overnight that is most irritating. Choose fans where possible according to their acoustic performance. Cored holes for fans should slope gently downwards towards the outside to prevent condensate or rain ingress. Ensure the installation of the fan through a wall is fully sealed on both sides of the wall, a common finding of BPE projects is cold air ingress around such penetrations.

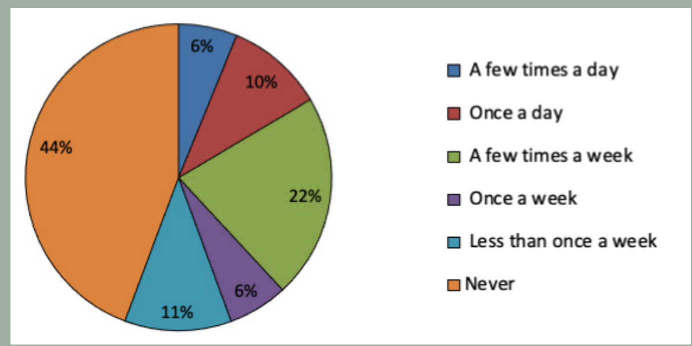
Care needs to be taken when there are combustion appliances in any ventilated space and the building regulations set out guidance for such spaces.

A manual override switch should be provided to allow for maintenance, but there is a risk that if these are too conveniently placed, they can be used as an 'on-off switch' which risks reduced use of the system. To limit the energy demand of the fans, they should have a specific fan power of less than 0.5 Watts per litre per second.

Ability of dMEV to act as 'whole-house' ventilation system

The Scottish Government Building Standards Division (BSD) commissioned a study to examine the real-world performance of modern homes with dMEV systems. The study undertook a survey of 231 homes to ask occupants about their knowledge and operation of their ventilation system, and a subset of these homes were monitored to examine the actual ventilation performance and determine the factors that affect this. A further study was undertaken in a selected dwelling to experiment with different ventilation strategies using dMEV to identify key factors.

The survey found that although there was good awareness of the presence of ventilation provisions, there was also a lack of knowledge regarding how these systems were controlled. Many households did not know how to boost the ventilation rate in the dMEV system (or didn't feel the need to do so), and a lack of engagement with trickle vents was clear.



Reported frequency of using boost switches

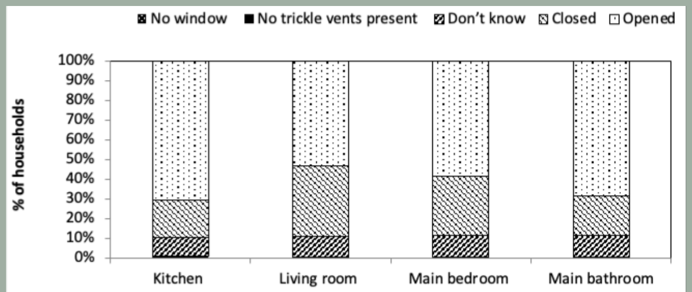
The monitoring found that over 50% of homes appeared to have poor ventilation overnight (where carbon dioxide levels exceeded 1,000ppm for the majority of the time), and that bedrooms were a particular cause for concern. There were a number of variables that affected this. These included the nature of the trickle vents, the window coverings, the path between the room and the dMEV (including the door opening or undercut, and the arrangement of the home) and the installation and performance of the system. Essentially homes with shorter, more open paths for air movement performed better, but rooms which relied on more remote dMEV systems frequently had poor ventilation.

Inspection of the monitored homes found a high number of installed dMEV systems (42-52% – depending on location) were sub-optimal (exceeding recommended airflow rates by >15%), or non-compliant with the guidance (17-48%). Flow rates were highly variable, sometimes this was due to the system setup and commissioning, but some systems had provision for occupant control. Given that bedroom doors were often closed (41%) due to occupant preference or fire requirements, the strategy relies on door undercuts but these were undersized in 20% of properties.

There were a number of homes (51%) where trickle vents were installed in wet rooms with dMEV systems. Whilst this may improve the efficacy of extract and moisture control in these rooms, this undermines the ability of the system to assist with ventilation in more remote rooms. Whilst dMEV systems in ensuite bathrooms provided the best outcomes for adjacent bedrooms, problems with systems being disabled were encountered in 56% of homes and the predominate problem was one of noise. The physical monitoring found a much higher incidence of this than the overall survey.

In the test house a number of different ventilation scenarios were tested over a week. The bedroom with an ensuite performed reasonably well, but the bedroom which relied on a remote dMEV only achieved good ventilation when the windows were open at night. The next best scenario was when the occupants left the bedroom door open overnight. Subsequent modelling suggests that air flows from door undercuts are less effective.

The findings would suggest that whilst there are some situations where a dMEV system can assist with the ventilation provision of modern airtight homes, the ability to act as a whole house system is limited, particularly in larger more complex layouts, and where ventilation loads are high.



Reported position of trickle vents (open / closed)

Although trickle ventilation provision in habitable rooms did not appear to be a major determinant of carbon dioxide concentrations in the monitored dwellings, these results should be interpreted with caution, given the small sample size and large number of confounding variables identified. It is likely therefore, that the impact of reduced area of trickle ventilation was overshadowed by other key components such as air flow pathways, pressure differentials, dMEV extract rates etc. As such, the system as a whole requires careful design, taking into account the house layout, paths for air movement (including undercuts and pass vents), the nature of the mechanical system, and consideration of remote rooms. The system will only be effective when these are optimised.

Issues to consider therefore include:

- better design of ventilation strategies using dMEV as a component of the system and accounting for other key components
- a need for pass vents between rooms, fire protected where required, ideally at higher levels
- better standards for commissioning and testing in use
- improved standards for noise for as-installed systems
- better design of occupant interfaces of mechanical system, in particular boost modes and occupant control elements
- better advice and information for occupants about the ventilation system, its optimal use, and requirements for maintenance
- fall-back strategies for ventilation, where mechanical systems may fail or become sup-optimal over time
- direct extract ventilation for non-flued gas appliances
- the development of performance standards for ventilation rates that can be compared with in-use data, and that provide an alternative means of compliance.

Centralised Mechanical Extract Ventilation

Centralised mechanical extract ventilation is sometimes shortened to MEV. Centralised mechanical extract ventilation is extract only, always operates continuously, and can also include demand control.

As its name suggests, a centralised system does away with separate fans and uses just one central unit - located in any accessible location - while air from the bathrooms and kitchen is ducted to it. These systems have a continuous 'trickle' rate and at least one 'boost' rate which is either locally controlled (eg. by buttons by the bathroom door) or via humidistat or other automated control.

Because it means replacing two or three fans with one, these central fans tend to be bigger, of higher quality and more expensive. The significant disadvantage of all centralised systems is that they need ducting to work, and ducting not only costs more (especially if it has to be boxed in) but can be problematic in retrofitted properties. Another disadvantage is that if the fan fails, then there is no designed ventilation for the whole house.

The main advantage is that, if designed and installed correctly, you tend to get better results from centralised systems in terms of air quality, the fan unit can be positioned to be acoustically separate meaning less noise, and one fan means only one power supply.

Extract-only systems continue to get the supply air from windows and trickle vents and this means you only have to include for the extract ducts.

Another option is to use demand control. Demand control ventilation can involve a variety of intake sources and works on the principle of sensing the air, usually centrally, and then deciding how much ventilation to provide, and from where. These systems rely on sensor technology which is not failsafe, but the savings in energy consumption can be impressive.

MEV systems are suitable for properties with an airtightness level down to 3 m³/hr/m² at 50 Pa.

<u>Pros</u>

- Operate continuously
- Simple to operate
- Reliable performance
- Flexibility in location of fan unit

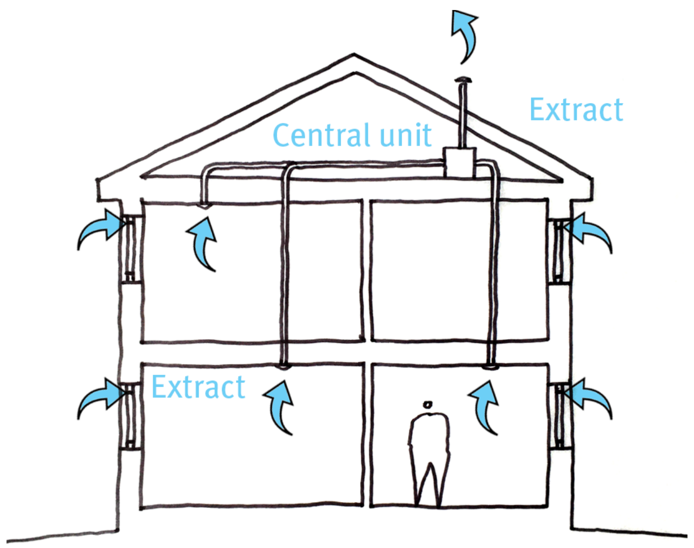
<u>Cons</u>

- Ducting adds cost and can be difficult to install
- Fan noise (dependent on installation)
- No filtration of supply air
- Energy consumption (reduced with demand control)

System Components
Air input: windows, trickle ventilators located in living rooms and bedrooms, wall vents
Air transfer: door undercut gaps, air transfer grilles
Air extract: MEV unit and associated ducting from wet rooms and out to a terminal

Best Practice Guidance
Although centralised systems do tend to perform better, there are many examples of poor performance, and so it is every bit as important that the manufacturer's written instructions and guidelines are fully followed during both design, installation and commissioning, taking into account all three components as noted above including internal door undercuts.

Central units must be located somewhere accessible so that maintenance (and replacement) is easily and safely carried out. Remember the need for condensate drains and an array of requirements related to these. If possible, keep the units away from bedrooms and



House Diagram – CEV

within acoustically separated spaces to reduce noise spillage. It is important to fit the unit exactly according to the written guidance and include any anti-vibration isolation that is available.

Extract grilles should be located to optimise the removal of air, away from doors and in wet rooms ideally directly above the bath and /or shower. Where terminals are fixed, there should be a means of achieving effective balancing of the system using dampers or within the fan unit. Some terminals are adjustable and in these cases, once balancing is achieved, these should be lockable to ensure the system remains in balance.

Duct runs (both to the unit from wet rooms, and from the unit to the terminal) should be kept as short and straight as possible. It is best if the duct design is cleanable and for that reason robust and rigid ducting is to be preferred. External terminals should be located so as to minimise the potential for recirculation of air back into the air inlets. Terminals should prevent ingress of rain, birds and insects while cored holes and ducts through walls should always slope slightly downwards to outside.

Continuous ventilation systems of any sort should not allow the occupier to turn off the fan easily so ensure that the isolator switch is visible but not readily accessible. Boost controls should be provided locally, clearly labelled and simple to use. Any sensors chosen to add demand control should only be those specified by the system manufacturer.

The installation, adjustment and commissioning should be conducted by a competent professional, using suitable and calibrated equipment. Measurements should be taken at both maximum rate and minimum rate fan speeds and should be recorded onto the commissioning sheet. To limit the energy demand of the fans, they should have a specific fan power of less than 0.7 Watts per litre per second.

Simple and clear instructions and maintenance requirements should be made available to the occupier as part of the handover process.

MVHR (Mechanical Ventilation with Heat Recovery)

MVHR is usually a centralised ventilation system with ducts leading from bathrooms and kitchens to a central unit like MEV. In addition however, there are ducts from outside to the unit bringing in outdoor air which then picks up heat in a heat exchange unit and is ducted to the living spaces and bedrooms.

MVHR is always continuous and is normally controlled to operate at a range of air flow rates to suit circumstances in the home. The two primary disadvantages of MVHR are the cost relative to simpler forms of ventilation, and the need for ductwork for both extract and intake.

The main advantage is that you can recover over 90% of the heat being removed from the house if well designed, and the high efficiency of MVHR systems is one of the main reasons why Passivhaus projects can reduce energy consumption overall to such low levels.

Like other centralised systems, if designed and installed correctly, you tend to get better air quality, the fan unit can be positioned to be acoustically separate meaning less noise and the better quality systems are very quiet.

There are a few variations on MVHR designs. It is possible to get decentralized MVHR units which are stand-alone fans which extract and supply air into a room, and there are systems without heat recovery in which case these are usually described as continuous balanced whole house ventilation. It is also possible to add demand control to an MVHR system which adds some flexibility because sensors can be added to any part of the system.

Supply air is filtered and different grades of filter can be used depending on requirements, trickle vents are not required. MVHR systems work most efficiently and are therefore more suitable for properties with an airtightness level below 3 $m^3/hr/m^2$ at 50 Pa.

Pros

- Work continuously and provide better air quality in general
- Recover most of the outgoing heat, so reducing pressure on heating systems

Cons

- Ducting increases installation costs and can be problematic in retrofit situations
- Higher performance options are much more costly
- Electricity costs to run fans continuously
- Acoustic issues if not designed well
- Filters are normally required and need cleaning and regular replacement, adding to running costs

System Components
Air input: intake ducting to central unit
Air transfer: door undercut gaps, air transfer grilles
Air extract: MVHR unit and associated ducting

Best Practice Guidance
The best MVHR systems perform extremely well, but there many examples of poor performance, and so it is every bit as important that the manufacturer's written instructions and guidelines are fully followed during both design, installation and commissioning, taking into account all three components as noted above including internal door undercuts.

Central units must be located within the thermal envelope and ideally adjacent to an external wall so that intake and exhaust ducts are as short as possible. However, they also need to be somewhere accessible so that filters can be readily changed and maintenance easily carried out. If possible, keep the units away from bedrooms and within acoustically separated cupboards to reduce noise spillage. If installing MVHR systems in social housing, it is worth considering placing the units in the common close or shared areas, to simplify access for maintenance and replacement of filters. Note that units will need to be connected to a condensate drain for which there are various requirements.

Duct runs should be kept as short and straight as possible. Longer ductwork with many turns will increase noise and reduce the efficiency of the system, increasing energy consumption. Rigid ductwork is far preferable to flexible ductwork with circular cross section being the most efficient. Ducts within building elements such as floors which need to last a specified time in a fire may need additional protection and metal ducts are preferable here. Ensure systems are linked to fire alarms to ensure flames are not drawn into these areas in the event of fire, as well as being easily reset afterwards.

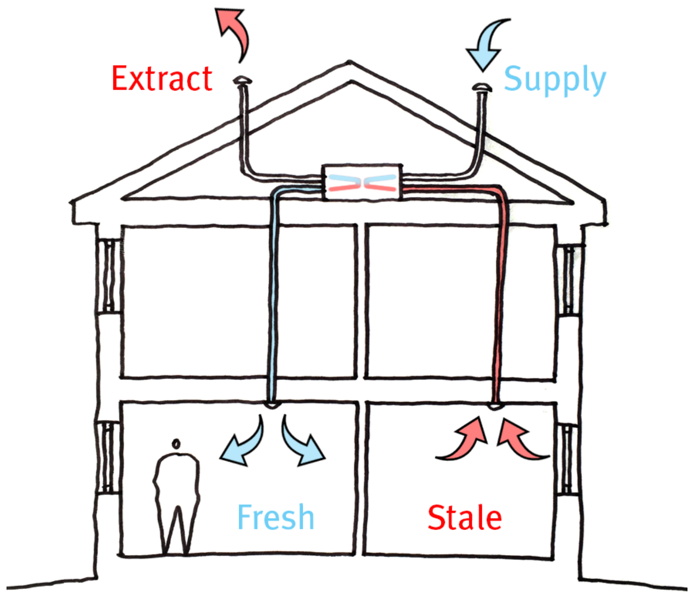
To avoid any pollutants from entering the dwelling the external grilles should be located remote from any flue or drainage vent, and where possible away from busy roads. Internally, air supply terminals should be at high level, away from internal doors and directed across an area of unobstructed ceiling to provide good mixing without causing draughts, while extract ducts should again be away from doors, and ideally above baths and showers.

Continuous ventilation systems of any sort should not allow the occupier to turn off the fan easily so ensure that the isolator (on / off) switch is visible but not readily accessible. Controls should be labelled, simple to use and accessible. The method of operating the fan in boost mode should be made obvious and should be accessible. Switching should be provided locally to the spaces being served.

The installation and commissioning should be conducted by a competent professional, using suitable and calibrated equipment. Measurements should be taken at both maximum rate and minimum rate fan speeds and should be recorded onto the commissioning sheet. Systems should be balanced to ensure that the designed airflow rates are achieved at each room. This should be set and adjusted during the commissioning process, where the total supply and extract air volume rates should be balanced to within +/- 15%.

Units should include for a summer bypass or extract-only function so that in warm weather the unit is able to 'turn off' heat recovery. It is important that the house still has opening windows so that in summer these can be opened to reduce overheating. In cold weather, some form of frost protection should also be in place to protect the heat exchanger.

Simple and clear instructions and maintenance requirements should be made available to the occupier as part of the handover process.



House Diagram – MVHR

4.0 Occupancy & Monitoring

The first section of this guide described the range of indoor pollutants and how best to minimise these at source. The second described how best to ventilate a building to ensure that whatever residual pollutants are left can be safely ventilated away.

But what about when the building is occupied? HEMAC has produced a complementary guide which provides information for occupants or users to help keep their homes clean and healthy. In the first part of this chapter we make a note of the many decisions designers can make to ensure that occupants have the best chance of maintaining a clean home. The second part provides guidance on how to monitor the indoor air quality and conditions of a home to ensure that it not only starts out as healthy, but can be kept healthy throughout its occupation.

Building Performance Evaluation (BPE)

The 'Performance Gap' is a phrase used to describe the fact that buildings often do not perform as they were intended. The first investigations began in the UK in 1995 (the 'Probe Studies') and several studies have been carried out since then, all of which confirm that the gap between predicted performance and 'real' performance can be significant.

To begin with, the work focussed on establishing that the energy consumption levels predicted were often not being met and this remains a key component, but it quickly became clear that there were other unforeseen consequences. In particular, it was shown that air quality in many buildings was far from adequate, whilst there were other problems being caused by a lack of understanding or awareness of moisture that was causing durability / maintenance issues.

The study of this performance gap has become known as Building Performance Evaluation (BPE) and sometimes post-occupancy evaluation (POE). The RIBA Plan of Work now includes a Stage 7 – 'Use' in which BPE is a major component and most industry organisations now recommend that BPE is carried out on projects.

Nobody wants to imagine that they are involved in buildings which fall short of their predicted energy efficiency, increasing carbon emissions and fuel bills for occupants, while also creating health risks due to poor air quality, and in some cases risks to the fabric of the building itself. So the value of BPE is that it allows everyone involved to understand, learn and ensure that buildings are fully as energy efficient, comfortable, healthy and durable as intended.

An interesting and important component of BPE is the recognition that building performance is intimately related to how people behave in the building. Certainly there are those who do not use a building as intended (for example, keeping the heating on, while leaving windows open) but the overall impression from BPE is that those that procure, design and build buildings do not make it easy for people to understand or interface with the building and its systems. Some of the most important lessons from BPE detail how designers in particular can address this, and Section 4.1 is an example of ensuring that we support occupants in achieving a healthy internal space if they are motivated to do so, while Section 4.2 provides support for those considering monitoring the internal air quality.

4.1 Occupant Support Checklist

A number of guides on indoor air quality in homes provide a list of measures that occupants can take to keep their home clean and healthy. However, they can only do this if the design of the house allows it. In this next section, we pick up on the most common guidance given to occupants, and add tabulated notes for designers to ensure that all such good advice is at least possible.

Ventilation Generally	
Advice for Occupants	**Guidance for Designers**
Private and social tenants should contact their landlords if any aspect of their installed ventilation system in inadequate (and contact their local authority if no action is taken)	Add to 'Quick Start Guides' (QSGs)
In general, provide extra ventilation (turning on fans, boosting fans or opening windows) when generating more moisture than normal (showering / clothes drying) or more fumes (painting, stoves or gas hobs, cleaning products and sprays)	Add to QSGs
Keep ventilation systems well maintained. This includes keeping filters clean where they are part of the system	Add to QSGs
Make sure air inlets on any mechanical system are not close to any potential pollution sources	This should be designed at the outset, but bear in mind external arrangements (for example in relation to bin storage or BBQs) may change over time
Although while cooking or bathing, it is worth keeping doors closed, most of the time, it is better to keep doors within the home open to let air flow freely	Add to QSGs
A number of air quality monitors are available. Many are inexpensive but be aware that they are also not necessarily that accurate. However, they can be invaluable in helping occupants understand the state of the air quality in their homes	Ideally, indoor air quality (IAQ) information can be added to properties but if not, it is worth letting people know that this is possible. Add to QSGs

Kitchens and Cooking	
Advice for Occupants	**Guidance for Designers**
There are risks associated with gas hobs and cookers generally, keep maintained if you have one, but preferably use an electric oven and hob	Best to install electric oven and induction hobs in all properties (reference Section 2.3 for details). Use QSGs and include the need to keep gas appliances maintained
Do not use your gas oven or hob for heating the space – it costs more and creates higher levels of moisture	Add to QSGs
Use a cooker fan or hood when cooking. If no fan, use the extractor fan in the kitchen. Keep fans running at least 10 minutes after cooking	As an absolute minimum, ensure every kitchen has an extractor fan linked to outside (or to central unit). They should have grille with grease filter, especially if linked to a central unit (apart from smell and mess, grease in ducts increases fire spread risk). Ideally install close to hob (more effective and lower extract rate required under regulations). Ideally, in addition to a kitchen extract fan, ensure all kitchens also have an overhead hood. Can be direct extract or recirculation. This should have washable grease filters and charcoal filter. If so, grease filter less critical on main extract.
Use rear rings on hob as these work better with overhead hood fans	Add to QSGs
Some ovens have 'self cleaning' functions. Stay out of kitchen and ventilate while these are operational	Add to QSGs
Keep food preparation areas and worktops generally clean and wiped down	Ensure kitchen design includes hygienic wipe-able surfaces with no crevices
When cooking or using the kettle, only use as much water as you need, keep pan lids on	Add to QSGs
To minimise spread of moisture from cooking to other rooms, keep the kitchen door closed	Add to QSGs. Not possible in open plan space

Bathrooms and Washing	
Advice for Occupants	**Guidance for Designers**
Ensure that whatever ventilation system you have, that it is on during any bath or shower and / or for a period afterwards to clear away excess moisture in the air. This is especially important if your home already suffers from damp, condensation or mould	Add to QSGs
Whatever ventilation system you have, ensure it is clean and maintained so that it is always working to its full potential. Blocked vents or grilles and fans which are not working properly will not extract moisture as effectively and may be noisier	Add to QSGs. If you are a landlord, it is important that all parts of the ventilation system are maintained and fully functional. Agree an annual maintenance check with tenants and include in tenancy agreements
To minimise spread of moisture to other rooms, keep the bathroom door closed during and for a period after washing	Add to QSGs
Shower curtains can become a source of mould. Ensure they can dry freely after a shower and/or use washable options. Avoid PVC curtains (refer Section 2.4). Rigid, usually glass options are available	If specifying a shower-over-bath, it is best to specify a glass screen which is easier to keep clean wherever possible
Showerheads (and plumbing with warm water generally) can be a source of a bacteria called Legionella and Legionnaire's disease which is a serious form of pneumonia. A build-up of the bacteria relates to warm water standing for long periods, so if you haven't used your shower for a while, run it for 5 minutes or so to clear the pipework and ensure taps and shower heads are cleaned carefully every three months or so.	Add to QSGs

Bedrooms and Bedclothes	
Advice for Occupants	**Guidance for Designers**
If you have a CO_2 monitor in your bedroom it is worth taking steps to keep levels below around 1000ppm if possible by optimising any existing ventilation options. The simplest is often to keep bedroom doors open at night but if levels are consistently higher than 1500ppm it may be worth adding ventilation or opening a window ajar at night if this is safe to do	Under Technical Standards 3.14.2 all new homes require a mains operate Carbon Dioxide monitor in main bedrooms to help support awareness of ventilation efficacy generally. This is worth considering for all properties
Be aware that people breathing emit a lot of moisture so, for example, two people sleeping in a room for 8 hours will generate a good deal of moisture. If this is not effectively ventilated, it can condense on cold areas and create a mould risk	Where possible ensure that all bedrooms have an effective method of ventilation. People are often unlikely to leave windows open at night meaning that if bedroom doors are closed and there is no other ventilation operational, there is a high chance of air quality dropping considerably overnight
Because we spend so much time in close contact to them, ensure pillowcases and bedsheets are regularly washed on hot washes ideally.	Add to QSGs

Clothes Drying	
Advice for Occupants	**Guidance for Designers**
Where possible, always dry clothes outdoors. This avoids excess moisture being generated in the home	All new build homes should have designated places for clothes drying but in all properties and projects, designers should ensure that a suitable outdoor clothes drying option is included
If drying clothes indoors is unavoidable, the best solution is some kind of rack over the bath, close to the extract fan in the bathroom. Keep the bathroom door closed. This way moisture is removed at source and cannot spread into the rest of the house. The worst solution is to dry clothes on radiators	If outdoor drying isn't possible, it would be good to ensure each property has a clothes drying option as close to the ideal noted left. Drying racks come in various types and can be fixed or portable. Add the guidance left to any QSGs
If you have a tumble drier, make sure that it vents to outside. Be aware that this can be an expensive way of drying clothes because it uses a lot of electricity	If tumble driers are to be part of the design or wider installation, ensure outdoor vents are provided, otherwise add to QSGs

Furniture and Finishes (ref 2.4)	
Advice for Occupants	**Guidance for Designers**
Position furniture a little way 'in' from the walls so that there is space for air to circulate around. This is particularly useful for larger, solid items like wardrobes and where there is evidence of condensation and mould risk	Add to QSGs
Where possible, avoid having carpets in your home. Carpets are coated in an array of chemicals to achieve resistance to stains, fire, mould and electro-static charge, they also harbour dirt, dust mites, pet hair and all manner of other possible allergens. If it is possible to remove them, bear in mind the need for a replacement finish and the possible risk of causing more noise (from footfall) if you are in a upper floor property. (but see 'cleaning' below)	Avoid specifying carpets wherever possible. Where the standard specification is a plywood deck - onto which it is presumed a tenant will provide their own carpet finish, we strongly recommend designers and landlords consider upgrading the floor finish to a timber or similar finish which doesn't need additional carpet or other tenant-provided finishes
While carpets are to be avoided wherever possible, it is still possible to have rugs which can be washed to recreate some of the 'softness' of a carpet finish. The best alternatives to carpet include solid timber flooring or linoleum because these are wipeable but also natural products themselves. Other common wipeable finishes include timber laminates and 'Vinyl' flooring, both of which however will off-gas volatile emissions. Stone, slate and tile floor are also beneficial where practical	Add to QSGs
Avoid most commonly used paints when decorating as these off-gas high levels of unwelcome chemicals. Using 'low VOC' paints is a an improvement, but there are many paints which have significantly lower emissions of VOCs and other chemicals. These are normally termed 'natural paints' and are widely available	Natural paints should be used on all projects to minimise health impacts on painters and occupants
Always ensure good ventilation while decorating and allow paint plenty of time to dry before inhabiting rooms	Add to QSGs

Cleaning	
Advice for Occupants	**Guidance for Designers**
Regularly clean and vacuum your home to minimise the risks to health from allergens, bacteria and other pollutants	Add to QSGs
A simple way to reduce dirt and outdoor pollutants is not to wear outdoor shoes indoors. Leave shoes at the entrance and use either socks or 'indoor shoes' / slippers indoors.	Ensure that there is adequate space for storage of coats / shoes etc. by the entrance door. Add to QSGs
Consider 'wet cleaning' rather than dry dusting to capture dust and avoid it being raised into the air (which can exacerbate health problems)	As far as possible ensure surfaces, especially floors, are wipeable or moppable, in preference to carpets which need to be vacuumed
If using a vacuum, ensure the filter is kept clean and consider a HEPA filter (which removes more of the fine particles)	Add to QSGs
Avoid air fresheners, deodorisers, perfumes and other chemicals. Even 'natural' ones can emit potentially hazardous chemicals	Add to QSGs

When cleaning the house, increase ventilation levels locally as far as is practical	Add to QSGs
Use cleaning products which are as 'eco-friendly' as possible. Use fragrance-free and / or milder options. Avoid aerosol products and store these products carefully with tops tightly on.	Add to QSGs

DIY and Household Products	
Advice for Occupants	**Guidance for Designers**
Choose products which are as 'eco-friendly' as possible because these will usually offer the least risk to human health	Add to QSGs
Store household or DIY chemicals in a safe place, either outside the home (in a shed or garage) or if indoors, ideally ventilated directly out of the home	If an external space is not available, consider adding an extract fan or duct to a suitably sized cupboard to ensure dangerous fumes are removed at source
In all cases, read and follow instructions on common products, store carefully with tops securely fastened, never mix products and only buy what you need, avoid keeping unused or little used containers	Add to QSGs

4.2 Monitoring

Being presented with a home which is 'healthy' is one thing, keeping it 'healthy' is another! For those who are keen to ensure that homes remain healthy, this section provides a brief introduction to the subject of ongoing indoor environment monitoring.

Before opting for a system to monitor a home, it is worth going through a few initial questions.

Regulatory Minimum

In any new build home, in accordance with the latest (2017) Technical Standards, the following sensors are required and linked to suitable alarms.

2017 Technical Standards – Detectors in Dwellings						
	Room	**Kitchen**	**Living Room**	**Main Bedroom**	**Circulation**	**Inner Room**
	Clause					
Smoke	2.11.1		1		min. 1	1
Heat	2.11.1	1				
Carbon Dioxide (CO_2)	3.14.2			1		
Carbon Monoxide (CO)	3.20.20	1	(or room containing boiler and any room with flue running through)			

In a retrofit, there are no specific requirements but if the project is a conversion, or is being significantly upgraded, then depending on the building control officer, some or all of these may be required.

In any event, our recommendation would be to upgrade these items to new build standard on all projects, whether they are required by regulation or not, because of the relatively small cost of doing so against the significant potential to save lives.

Who wants to know?

Broadly, there are three types of person who might want to know about the conditions inside a home. Understanding this helps clarify what sort of system should be chosen

The first is the owner or landlord, where that person is separate from the occupant. This may be because the landlord wants to understand the trends related to energy consumption and internal conditions within their buildings, to be able to pinpoint households who do not appear to be keeping their homes adequately warm (and may therefore need additional support) and to provide background evidence when in dispute with a tenants about conditions. The information may or may not be being shared with the tenants / occupants and is likely to be at a fairly basic level of detail since it is usually associated with high numbers of households.

The second type would be a researcher or practitioner seeking to better understand their own work, or the work of others, usually as part of wider research into housing conditions, fuel poverty, occupant behaviour etc. Typically, this would involve a smaller number of properties and much greater detail, but in many cases, this could be a version of the landlord type above spread over a large number of properties. The point being that the information is for a third party who wants to understand one or more particular aspects of housing occupation from a relatively objective standpoint.

The third type is the owner or occupier who wants to understand better their own energy consumption or air quality in order to learn and develop more efficient or healthy ways of living in their own home. This could range from a desire to cut energy bills or improve air quality because of an asthmatic child, to gathering evidence of inadequacy of the home to use in a dispute against a landlord.

It is worth noting that any combination of these three types may wish to have the information and establishing this from the outset is useful in deciding which sort of system will best meet everyone's needs.

How accurate?

In broad terms there are two types of sensors. The first are what might be called 'scientific equipment' and tend to be expensive and accurate. They often only measure one type of pollutant and almost always require to be re-calibrated and re-registered annually to allow the information gathered to be used in any form of academic paper or professional consultancy. This type will almost certainly be used in the first and second type of investigation described above.

Professional monitoring equipment is expensive and not always convenient to have around the home

The second type is more affordable but tends to be less accurate. Often, this type is aimed directly at the householder market and the more useful ones measure a range of different things to give a broader picture of the indoor environment. The fact that they are less accurate is unlikely to be a problem unless the user has particular sensitivities for which the sensors need to give a warning. Otherwise, getting a fairly accurate picture – and the trends over time – is adequate for most people.

What sort of feedback is required?

Feedback differs widely and its worth being clear about what you need. A carbon monoxide alarm, for example just needs to monitor for that gas and if it senses a dangerous level, it needs to sound an alarm. That's all it needs to do. Academic building performance evaluation monitoring may require dozens of sensors and co-ordinating loggers, taking 5 minute readings over a period of 2 years or more, all sending data to a remote portal where it can be stored and studied by researchers. Household monitors may be quietly taking readings and sending it to a 'real time' interface which allows householders to see the air quality or temperature at any given time and adjust accordingly. Some of the questions to ask include:

Intermittency
Most sensors operate by taking a reading of whatever it is they're monitoring at regular intervals. Usually these intervals can be adjusted and the more often you take a reading, the more accurate the graph you can draw, but also the more quickly the memory can get used up. It all depends what you want to find out and why.

Data Storage
Do you need to chart the history of whatever you're monitoring over time? If you're a researcher or landlord, then the answer is probably yes, but if you're a householder who only needs feedback in real time, maybe not? If you do need to store data, the next question is where?

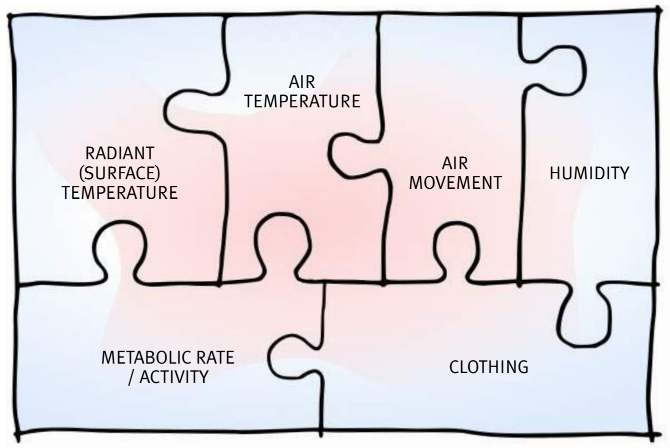
Remote Storage
Most sensors have a chip that will store the data they generate. In some cases, if you want the data, you need to take the sensor away and download the data onto your computer. In order to avoid only getting a few weeks data and going back to pick up the sensor too often, some sensors are set to take a reading only every 10 minutes or longer. Others have the capacity to send their data to a data-logger which sits in the building and collects the data coming in from all of the sensors. In most cases, this data-logger then uses the house Wifi, or some other network to send this data to a remote site for storage and interpretation.

Battery Operated or Mains Supplied
It can often be much simpler to leave a few sensors in a house, set the readings for a suitably long interval and come back and get them 2 years later when the battery runs out. However, it may be beneficial to have them running on mains because you can use them indefinitely. For householders looking to measure their own conditions, a mains operated system is usually going to make most sense.

Interface
For researchers and those undertaking work for landlords, the chances are that they will have the system set up so that they can access a remote interface where all data readings are uploaded automatically and they can interpret the data and make graphs etc. back at their desk via some form of online portal. There may or may not be anything in the house to tell the occupant what is going on.

For anyone wanting to understand their own home, there needs to be some form of interface in the home which allows you to see what is happening. Some form of screen will need to be mounted somewhere easy to see displaying all of the feedback you need, both in real time, and potentially historically. This allows you, for example, to compare this week's usage against last week, or to track trends over the year etc.

Alarm
Some pollutants are extremely dangerous, for example carbon monoxide, so all CO sensors will come with an alarm which sounds when the gas is found. In most cases however, there is no need for an alarm although this can be usefully employed to warn people who my be particularly sensitive to something to boost ventilation or make other changes.



Six components of thermal comfort

Rather than using an alarm, it is however useful to provide some sort of intuitive feedback about the various pollutants. For example, a simple 'green / amber / red' graphic feedback of some sort is useful to warn people when levels of any pollutant are rising too far.

What is to be monitored?

There are three things that are almost always monitored in any project. In part they are useful to know themselves, but they also set the context for other pollutants and as such are always worth knowing.

Temperature (Air Temperature)
The first and foremost aspect of comfort and well-being is temperature. In airtight, well insulated homes it is unlikely that occupants will still be too cold for long, but there is a very real risk of overheating so it is important to have a handle on this in any household. Unfortunately air temperature is only one determinant of true thermal comfort [box-out] but it is the most easily measured and unless a specialist understanding of thermal comfort is required, will suffice.

In addition, temperature sets the context for relative humidity, higher air temperatures mean that more moisture can be contained safely in the air, and temperature also affects the rate of off-gassing of many chemicals.

Relative Humidity
Absolute humidity is the amount of moisture in the air at any given time. If you take a fixed amount of air and raise its temperature, without any other change, the absolute humidity in the air would remain the same, the but relative humidity would go down. Although it is combination of two other metrics, in practice, relative humidity is the most useful to measure because the warmer the temperature, the more moisture air can contain. Relative humidity is a better indication of whether you are likely to get condensation and mould formation, it also affects comfort levels and in some cases the way other pollutants act.

There are six components that make up thermal comfort, as shown in the diagram. Air temperature is only one of these, and in fact less important than the surrounding surface temperatures. There is an international standard, ISO 7730 which describes the six components and their interrelationships in more detail.

Carbon Dioxide (CO_2)

As mentioned in Section 2, carbon dioxide (CO_2) is not considered a serious pollutant, although high levels can be unwelcome. It is however easy to measure and tends to be a good indicator of other, possibly more serious pollutants. If the CO_2 levels are low, it is likely that any other pollutant levels are also low because it usually indicates good ventilation. Conversely, if CO_2 levels are high, that in itself isn't necessarily a problem, but it can be a sign that ventilation levels are inadequate and there's a chance that other pollutants are also prevalent.

Example of an IAQ monitor. Monitoring in real time is useful but monitoring over a period of time is more beneficial so trends can be found

Beyond these three, it is very much depends on circumstances. For example, if you are in a known area of radon, a radon monitor would be sensible, whilst if you have particular sensitivities to certain pollutants, like pollen, these are the ones to check. Sensors are available for all of the pollutants discussed in Section 2, but some are more commonly monitored than others and while some sensors will only measure one thing at a time, overs can cover a range of pollutants.

It is always important as noted above to monitor for carbon monoxide if there is a combustion appliance in the property because it is so dangerous.

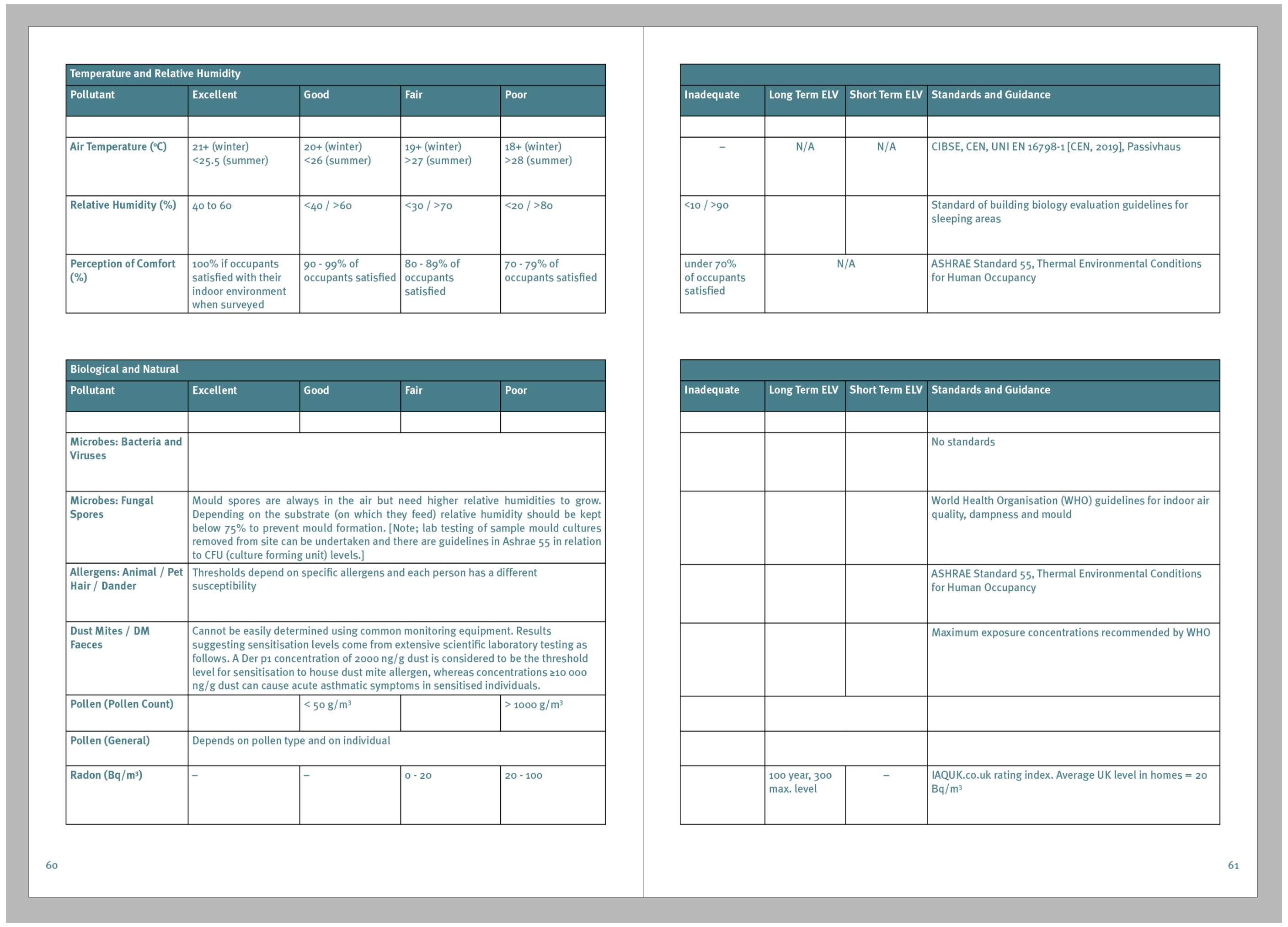
Common Pollutants and Thresholds

The following section provides some guidance on what constitutes 'good' or 'bad' air quality in relation to a range of pollutants, ordered per the preceding sections.

The first table takes figures agreed internationally and note that overheating is generally considered to be taking place at temperatures over 25ºC in the summer in the UK. Figures for relative humidity tally with the diagram shown in Section 2.1. ELV = exposure limit values. These correspond to the concentration thresholds and timescale, above which exposure potentially presents a risk to health.

A note of the International System of Units (SI) multiples of grams. Most people are familiar with a kilogram which is 1,000 grams or 10^3g. Units noted below are however sub-multiples, i.e. a lot smaller and it can be confusing. The largest are milligrams, a thousandth of a gram and measured in mg, or 10^{-3}g. Smaller still are micrograms, each being a thousandth of a milligram, µg or 10^{-6}g. Smallest are nanograms, ng or 10^{-9}g.

Note: the following tables are double page spreads. If you are viewing this report electronically you will need to switch to 'Two Page' view.



Temperature and Relative Humidity

Pollutant	Excellent	Good	Fair	Poor	Inadequate	Long Term ELV	Short Term ELV	Standards and Guidance
Air Temperature (ºC)	21+ (winter) <25.5 (summer)	20+ (winter) <26 (summer)	19+ (winter) >27 (summer)	18+ (winter) >28 (summer)	–	N/A	N/A	CIBSE, CEN, UNI EN 16798-1 [CEN, 2019], Passivhaus
Relative Humidity (%)	40 to 60	<40 / >60	<30 / >70	<20 / >80	<10 / >90			Standard of building biology evaluation guidelines for sleeping areas
Perception of Comfort (%)	100% if occupants satisfied with their indoor environment when surveyed	90 - 99% of occupants satisfied	80 - 89% of occupants satisfied	70 - 79% of occupants satisfied	under 70% of occupants satisfied	N/A		ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy

Biological and Natural

Pollutant	Excellent	Good	Fair	Poor	Inadequate	Long Term ELV	Short Term ELV	Standards and Guidance
Microbes: Bacteria and Viruses								No standards
Microbes: Fungal Spores	Mould spores are always in the air but need higher relative humidities to grow. Depending on the substrate (on which they feed) relative humidity should be kept below 75% to prevent mould formation. [Note; lab testing of sample mould cultures removed from site can be undertaken and there are guidelines in Ashrae 55 in relation to CFU (culture forming unit) levels.]							World Health Organisation (WHO) guidelines for indoor air quality, dampness and mould
Allergens: Animal / Pet Hair / Dander	Thresholds depend on specific allergens and each person has a different susceptibility							ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy
Dust Mites / DM Faeces	Cannot be easily determined using common monitoring equipment. Results suggesting sensitisation levels come from extensive scientific laboratory testing as follows. A Der p1 concentration of 2000 ng/g dust is considered to be the threshold level for sensitisation to house dust mite allergen, whereas concentrations ≥10 000 ng/g dust can cause acute asthmatic symptoms in sensitised individuals.							Maximum exposure concentrations recommended by WHO
Pollen (Pollen Count)		< 50 g/m³		> 1000 g/m³				
Pollen (General)	Depends on pollen type and on individual							
Radon (Bq/m³)	–	–	0 - 20	20 - 100		100 year, 300 max. level	–	IAQUK.co.uk rating index. Average UK level in homes = 20 Bq/m³

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Temperature and Relative Humidity								
Pollutant	**Excellent**	**Good**	**Fair**	**Poor**	**Inadequate**	**Long Term ELV**	**Short Term ELV**	**Standards and Guidance**
Air Temperature (°C)	21+ (winter) <25.5 (summer)	20+ (winter) <26 (summer)	19+ (winter) >27 (summer)	18+ (winter) >28 (summer)	–	N/A	N/A	CIBSE, CEN, UNI EN 16798-1 [CEN, 2019], Passivhaus
Relative Humidity (%)	40 to 60	<40 / >60	<30 / >70	<20 / >80	<10 / >90			Standard of building biology evaluation guidelines for sleeping areas
Perception of Comfort (%)	100% if occupants satisfied with their indoor environment when surveyed	90 - 99% of occupants satisfied	80 - 89% of occupants satisfied	70 - 79% of occupants satisfied	under 70% of occupants satisfied	N/A		ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy

Biological and Natural								
Pollutant	**Excellent**	**Good**	**Fair**	**Poor**	**Inadequate**	**Long Term ELV**	**Short Term ELV**	**Standards and Guidance**
Microbes: Bacteria and Viruses								No standards
Microbes: Fungal Spores	Mould spores are always in the air but need higher relative humidities to grow. Depending on the substrate (on which they feed) relative humidity should be kept below 75% to prevent mould formation. [Note; lab testing of sample mould cultures removed from site can be undertaken and there are guidelines in Ashrae 55 in relation to CFU (culture forming unit) levels.]							World Health Organisation (WHO) guidelines for indoor air quality, dampness and mould
Allergens: Animal / Pet Hair / Dander	Thresholds depend on specific allergens and each person has a different susceptibility							ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy
Dust Mites / DM Faeces	Cannot be easily determined using common monitoring equipment. Results suggesting sensitisation levels come from extensive scientific laboratory testing as follows. A Der p1 concentration of 2000 ng/g dust is considered to be the threshold level for sensitisation to house dust mite allergen, whereas concentrations ≥10 000 ng/g dust can cause acute asthmatic symptoms in sensitised individuals.							Maximum exposure concentrations recommended by WHO
Pollen (Pollen Count)		< 50 g/m^3		> 1000 g/m^3				
Pollen (General)	Depends on pollen type and on individual							
Radon (Bq/m^3)	–	–	0 - 20	20 - 100		100 year, 300 max. level	–	IAQUK.co.uk rating index. Average UK level in homes = 20 Bq/m^3

Combustion Products and Particulates								
Pollutant	**Excellent**	**Good**	**Fair**	**Poor**	**Inadequate**	**Long Term ELV**	**Short Term ELV**	**Standards and Guidance**
Carbon Dioxide (CO_2) (ppm)	< 600	601 - 1,000	1,001 - 1,500	1501 - 1,800	> 1,800	N/A	N/A	CEN, UNI EN 16798-1
Carbon Monoxide (CO) (mg/m³)	0	–	1 - 7	–	> 7	7 mg/m³ over 24 hours	100 mg/m³ over 24 hours	WHO European guidelines
Nitrogen Dioxide (NO_2) (µg/m³)	> 20	–	200 - 400	–	> 400	40 (1 year)	200 (1 hour)	WHO air quality guidelines 2005
Sulphur Dioxide (SO_2) (µg/m³)	5 (natural backgound level)	> 20	50		> 125	20 (24 hours)	500 (10 mins)	WHO air quality guidelines 2005
Environmental Tobacco Smoke (ETS) (µg/m³)	Acute and chronic respiratory health effects on children have been demonstrated in homes with smokers (nicotine 1–10 µg/m3) and even in homes with occasional smoking (0.1–1 µg/m3). There is no evidence for a safe exposure level							WHO, various publications
Particulate Matter: PM2.5 (µg/m³)		< 10		> 25		10 (1 year)	25 (24 hours)	WHO air quality guidelines 2005
Particulate Matter: PM10 (µg/m³)		< 20		> 50		20 (1 year)	50 (24 hours)	WHO air quality guidelines 2005
Polycyclic Aromatic Hydrocarbons (PAHs)	No safe level. Unit risk for lung cancer for PAH mixtures is estimated to be 8.7 x 10 - 5 per ng/m³ of B[a]P (Benzo[a]pyrene)							WHO guidelines

It is unlikely that under normal domestic circumstances, any further information would be needed other than total volaitile organic compound load (TVOC) so we have listed that here.

Volatile Organic Compounds (VOCs) and other Chemicals								
Pollutant	**Excellent**	**Good**	**Fair**	**Poor**	**Inadequate**	**Long Term ELV**	**Short Term ELV**	**Standards and Guidance**
All VOCs (TVOC) (µg/m³)		< 300	300 - 500	> 500	–		300	CEN, UNI EN 16798-1
Ozone (µg/m³)						100 (8 hours or daily max.)		WHO air quality guidelines 2005

5.0 Resources

Organisations

Many of the organisations listed below have a huge range of advice and downloadable guidance for those who wish to investigate further.

Alliance for Sustainable Building Products (ASBP)
https://asbp.org.uk
Independent association championing sustainable building products for a healthy, low carbon environment

Association for Environment Conscious Building (AECB).
https://www.aecb.net
Network promoting sustainable building.

Breathing City
http://breathingcity.org
Future Urban Ventilation Network

British Lung Foundation
https://www.blf.org.uk
UK charity concerned with ing health and clean air

Building Research Establishment (BRE).
https://bregroup.com
Huge range of research, reports, the developers of SAP and EPCs, BREEAM and much more.

Building Services Research and Information Association (BSRIA)
https://www.bsria.com/uk/
Trade and Professional Association promoting knowledge and providing services for construction and building services stakeholders

Construction Industry Research and Information Association (CIRIA).
https://www.ciria.org
Supports collaborative work, innovation and research across the construction industry.

Energy Saving Trust (EST).
http://www.energysavingtrust.org.uk
Domestic energy advice agency, lots of information

Good Homes Alliance (GHA).
http://goodhomes.org.uk
An organisation dedicated to high quality and sustainable housing, new and refurbished.

Health and Safety Executive (HSE)
https://www.hse.gov.uk
The HSEb is an independent regulator on all aspects of health and safety in the UK

HEMAC Network
https://hemacnetwork.com
Multi-disciplinary network bringing together medical and building experts to promote healthier modern homes

Indoor Air Quality UK
http://www.iaquk.org.uk/index.html
Independent organisation aiming to raise the agenda of indoor air quality within homes and workplaces

Institute for Building Biology (IBN)
https://buildingbiology.com
European Institute mainly involved in training in Building Biology (buildings and health). There is also a separate US institute. Provide a useful ' 25 principles of building biology'

International Society of Indoor Air Quality and Climate (ISIAQ)
https://www.isiaq.org
International independent association of scientists and practitioners supporting healthy internal spaces

My Health My Homes
www.indoorairpollution.co.uk
Website and campaign to raise awareness of poor indoor air quality supported by a range of ventilation equipment manufacturers

Scottish Ecological Design Association (SEDA).
https://www.seda.uk.net
A members' organisation with good events across Scotland and a number of downloadable documents, all with sustainability at their core.

United Kingdom Centre for Moisture in Buildings (UKCMB).
http://www.ukcmb.org
A collaborative group dedicated to moisture issues, including decay and health in buildings.

UK Indoor Environment Group (UKIEG).
http://www.ukieg.org
An independent network of professionals and academics in the field of health, wellbeing and indoor environments

UK Radon
https://www.ukradon.org
A branch of Public Health England dealing with all aspects of radon in the UK

World Health Organisation (WHO)
http://www.who.int/hia/housing/en
Worldwide organisation supporting all forms of health and wellbeing.

Books, Papers, Reports

Awbi, H. B. 'The Future of Indoor Air Quality In UK Homes and its Impact on Health' BEAMA (2015)

Balvers et al. 'Mechanical ventilation in recently built Dutch homes: technical shortcomings, possibilities for improvement, perceived indoor environment and health effects' Architectural Science Review (2012)

BCIA 'Controls for End Users: a guide for good design and implementation' BSRIA / Usable Buildings Trust (2007)

Borsboom et al 'TN 68: Residential Ventilation and Health' AIVC (2016)

BRE Report BR 446 'Indoor air quality in homes in England'. Volatile Organic Compounds (2002)

BRE Report BR 466 'Understanding dampness: Effects, causes, diagnosis and remedies' (2004)

BRE Report BR 477 'Ventilation, air tightness and indoor air quality in new homes', (Dimitroulopoulou S, D Crump, S K D Coward, V Brown, R Squire, H Mann, M White, B Pierce, D Ross) (2005)

BRE Report BR 262 'Thermal insulation: avoiding risks' (2002)

BRE IP 1/00 'Air tightness in UK dwellings' (2000)

BSRIA 'Building Performance Evaluation in domestic buildings (2016)

CIBSE 'Design methodology fo the assessment of overheating risk in homes' TM59: (2017)

CIBSE 'CIBSE Guide B2: Ventilation and Air Conditioning' (2001)

Davies, Ucci, McCarthy, Oreszczyn, Ridley, Mumovic, Singh and Pretlove. 'A review of evidence linking ventilation rates in dwellings and respiratory health – a focus on dust mites and mould'. International Journal of Ventilation. (2004)

Department of Health. Committee on the Medical Effects of Air Pollutants (COMEAP) 'Guidance on the Effects on Health of Indoor Air Pollutants' (2004)

Dimitroulopoulou et al. EPHECT I 'European household survey on domestic use of consumer products and development of worst-case scenarios for daily use' Science of the Total Environment (2015)

European Commission, Health and Consumer Protection Directorate, Scientific Committee on Health and Environmental Risks (SCHER) 'Opinion on risk assessment on indoor air quality' (2007)

Greenpeace UK 'What's wrong with PVC: The Science behind a phase-out of polyvinyl chloride plastics' (1997)

HEMAC Multi-disciplinary Network: 'Health Effects of Modern Airtight Construction' (Summary Report) (2017)

International Energy Agency 'Indoor Air Quality Design and Control in Low-energy Residential Buildings- Annex 68 | Subtask 1: Defining the metrics' (2017)

ISO 16814:2008 'Building environment design- Indoor air quality – Methods of expressing the quality of indoor air for human occupancy'

Mazzeo. N. A (ed) 'Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality' Intact (2011)

McGill G. Et al 'Meta-analysis of indoor temperatures in new-build housing' Building Research & Information (2016)

Morgan C. et al 'Overheating in Scotland: contributing factors in occupied homes' Building Research & Information (2016)

Medical Research Council / Institute for Environment and Health: 'IEH Assessment on Indoor Air Quality in the Home' (1996)

Medical Research Council / Institute for Environment and Health: 'IEH Report on Health Effects of Waste Combustion Products' (1997)

Mendel. 'Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: a review' Indoor Air. 17 (2007)

My Health My Homes 'IAQ and Health: A Summary of Evidence' v1 (2016)

NHBC Report NF18 'Indoor air quality in high energy efficient homes - A review' (2009)

NHBC Foundation 'Assessment of MVHR systems and air quality in zero carbon homes' (2013)

NHBC Foundation and Zero Carbon Hub. 'Mechanical Ventilation with Heat recovery in new homes. Final report' Ventilation and indoor air quality task group (2013)

NICE ‘Indoor air quality at home’ NICE Guideline NG149 (2020) (free download available at https://www.nice.org.uk/guidance/ng149)

RIBA ‘Post occupancy evaluation and building performance evaluation primer’ (2016)

Roaf and McGill ‘Indoor air quality and ventilation in modern airtight homes’ RIAS Practice Note (2016)

Royal College of Paediatrics and Child Health ‘The inside story: health effects of indoor air quality on children and young people’ RCPCH & Royal College of physicians (2020)

Royal College of Physicians ‘Every breath we take: the lifelong impact of air pollution’ Report of a working party (2016)

Royal Commission on Environmental Pollution ‘Chemicals in products: Safeguarding the environment and human health’ (2003)

SCHER ‘Opinion on risk assessment on indoor air quality’ European Commission, Health and Consumer Protection Directorate, Scientific Committee on Health and Environmental Risks (2007)

Scottish Government ‘Building Standards Supporting Guidance Domestic Ventilation’ (2017) (version 2.1)

Sharpe R. et al. ‘Higher energy efficient homes are associated with increased risk of doctor-diagnosed asthma in a UK subpopulation’ Environment International, V 75 (2015)

Sharpe T. et al. ‘Characteristics and performance of MVHR systems: A meta study of MVHR systems used in the Innovate UK Building Performance Evaluation Programme’ (2016)

Sundell et al. ‘Ventilation rates and health: multidisciplinary review of the scientific literature’ (2011)

Toledo L et al ‘Unintended consequences of sustainable architecture: Evaluating overheating risks in new dwellings’ PLEA Conference 2016

Turiel I. ‘Indoor Air Quality and Human Health’ STandford University press (1985)

Ucci, M., et al. ‘Ventilation rates and moisture-related allergens in UK dwellings’ Proceedings of the 2nd WHO International Housing and Health Symposium (2004)

Wargocki P. ‘The Effects of Ventilation in Homes on Health’ International Journal of Ventilation (2013)

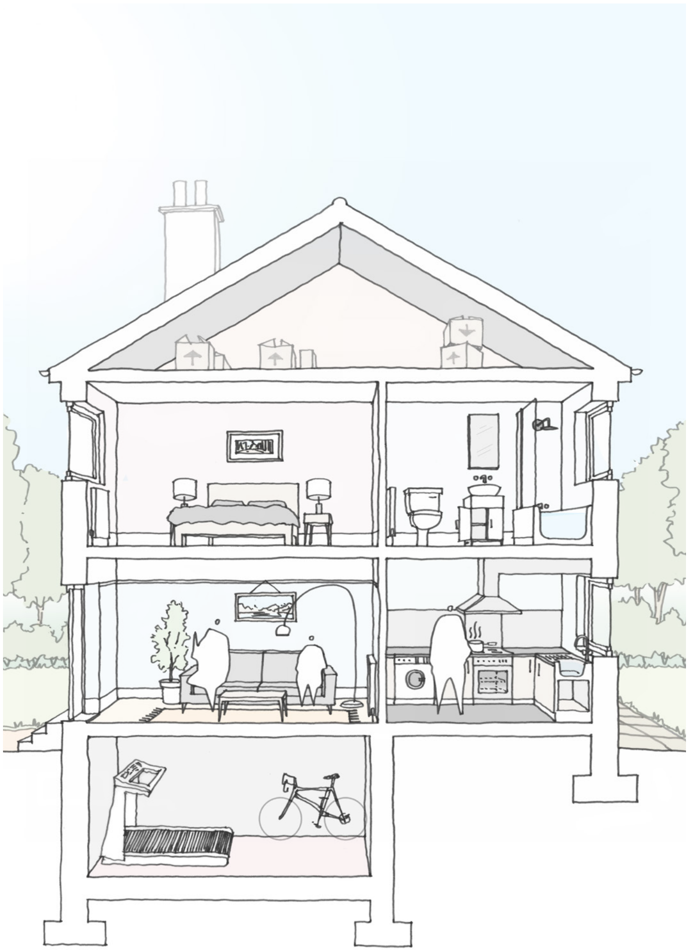
Woolley T. ‘Building Materials, Health and Indoor Air Quality’ Routledge (2017)

World Health Organisation ‘Housing and Health Guidelines’ (2018)

World Health Organisation ‘WHO guidelines for indoor air quality–dampness and mould (2009)

Indoor Air Quality *in Airtight Homes*: A Designer's Guide

Prepared for the HEMAC Network (Health Effects of Modern Airtight Construction) and supported by SEDA (Scottish Ecological Design Association). A SEDA Guide to Good Practice



Making buildings airtight is good for comfort and energy efficiency, but it comes with risks to our health if not properly managed. Airtight homes can overheat, become too humid and suffer from mould and a number of indoor air pollutants which harm human health, especially in those more vulnerable such as children, the elderly and those with respiratory or immunity problems.

Avoiding these problems is relatively simple however, and this guide describes how to minimise the creation of indoor air pollutants, and effectively ventilate them away, to create fresh and healthy buildings which are also warm and comfortable!

The guide also provides an introduction to monitoring the air quality of a building for those who want to understand better how to maintain these good conditions, along with sources of further information.

The guide should be of interest to anyone interested in improving health within the home, but is particularly aimed at Architects and other designers, as well as homeowners and those responsible for providing and maintaining homes for others, such as private landlords, factors, council housing officers and those who work in social housing provision and broader healthcare.

HEMAC Health Effects of Modern Airtight Construction Multidisciplinary Network
UKRI Arts and Humanities Research Council
University of Strathclyde
John Gilbert Architects
LSTM Liverpool School of Tropical Medicine

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