Research Summary

Timber and healthy buildings: indoor air quality

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Research indicates that the average person spends 92% of their time indoors[1], so it is important that our internal environments are comfortable and enjoyable to spend time in while also not impacting upon our health requirements. This review focuses upon healthy buildings, first defining what they are before examining aspects of both healthy and unhealthy buildings, then discussing the role that timber can play within an internal environment when considering air quality.

1: What is a healthy building?

In 1995 Hal Levin defined a healthy building as 'one that adversely affects neither the health of its occupants nor the larger environment'.[2] This extends beyond 'no adverse impacts' to 'more positive impacts' as the opportunity for buildings to enrich and contribute positively to our health and wellbeing is more widely understood.

Within any discussion of healthy buildings, comfort plays a key role. A healthy building provides comfort, shelter and security for an occupant, offering a sense of place, wellbeing and homeliness. Human comfort is a difficult concept to quantify, involving a complex range of factors, including temperature, humidity, acoustics, day lighting, layout, artificial lighting, location, external air quality, internal air quality, ventilation and views.

Figure 1 Camden Passivhaus
Photograph: © Bere Architects

As we look to build increasingly airtight buildings and refurbish existing ones, often with energy efficiency as the main driver, the subject of indoor air quality has become a growing concern. In total there are approximately 900–1,000 chemicals that evaporate and enter the surrounding air; these chemicals are often referred to as volatile organic compounds (VOCs). Indoor air can contain 5–10 times, and occasionally up to 100 times the amount of VOCs as air outdoors.[3]

There is of course a business case for healthy buildings. For the majority of businesses, the most significant outgoing is staff wages, so increases in productivity and wellbeing can have a significant effect on the bottom line. This is supported by research conducted at the Harvard T.H. Chan School of Public Health's Center for Health and the Global Environment (CHGE)[4], the first research to show that working in high-performing, healthy buildings can improve employee decision-making. Several studies on biophilic design – the concept of designing buildings that allow people to reconnect with nature – suggest that there is an increase in productivity where biophilic principles have been followed.[5]

Assessment and certification

Whole building assessment methodologies such as the Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) include credits for products that are low in VOCs. The WELL Building Standard[6], developed in the USA by Delos with a range of health practitioners, is a whole building assessment methodology for health and wellbeing. One feature of WELL certification requires that the VOC rating of all materials used must meet specific targets.[7] This ensures that office fixtures, fittings and fabrics do not expel harmful chemical or organic emissions.

One Carter Lane, leased by Cundall, achieved the first WELL Building certification in the UK in 2016. Alan Fogarty from Cundall considered satisfying the WELL Building criteria to be one of the most challenging elements of the project, stating that 'it immediately reduces your range of options in terms of what materials you can choose from. Even discovering the VOC content was a challenge because most manufacturers don't commonly list it.'[8]

Documents are now available that will map the WELL Building Standard to BREEAM[9] in order to allow easier alignment between certified BREEAM ratings and WELL certification.[10]

2: Benefits of healthy buildings

Increased productivity – the business case for healthy buildings

Economist Duncan Weldon has suggested that a 1% increase in UK productivity would add £20bn to the UK economy.[11] Companies have only recently started to research healthy buildings, in the belief that a healthier workforce is a happier workforce, which will therefore be more productive.

- Happy workers = reduced absenteeism and staff retention. Alan Fogarty from Cundall stated that 'the cost of achieving WELL Building certification was £150/per person; initial results indicate a significant reduction in absenteeism and saving from reduced staff churn, with a likely payback of one year'.[12] Elsewhere Skanska UK reported 3.5 times fewer building-related sick days alongside increased employee comfort and satisfaction.[13]
- Indoor air quality. A World Green Building Council report suggests that better indoor air quality (low concentrations of CO^2 and pollutants and high ventilation rates) can lead to productivity improvements of 8–11%.[14]
- Thermal comfort. Research on the Interserve offices suggests that thermal comfort has a significant impact on workplace satisfaction and modest degrees of personal control over thermal comfort can return single digit improvements in productivity.[15]
- Sleep. One study monitored the sleep quality of workers using watches with sensors that measured the length of sleep, tossing and turning and interruptions. The study suggests that those working in 'green offices' had higher sleep scores, with cognitive function scores being significantly better than those working in 'conventional building conditions'.[16]

Figure 2 Interserve's Passivhaus offices in Leicester
Photograph: © Interserve

Andrew Howard from Interserve reported on their offices constructed in 2012 to Passivhaus Standard in Leicestershire, stating that 'the new office is bright, efficient and provides a comfortable working environment. The additional unexpected benefit is that we have seen a 13% reduction in staff sickness compared to our old office.'[17]

Increasing asset value

Stadthaus at Murray Grove in Hackney was the tallest residential cross-laminated timber building in Europe when it was constructed back in 2009. Andrew Waugh, architect states: 'The residents in Murray Grove have stayed put – last time we checked only a couple had moved in the last six years... very unusual for such a transitory area.'

Figure 3 Stadthaus
Photograph: © Waugh Thistleton

A survey of over 3,000 homeowners and renters was commissioned by Saint-Gobain in 2016, which claimed that when buying or moving into a new home, 90% of consumers are concerned about the impact their homes would have on their health and wellbeing, with 29% being prepared to pay more for a home that doesn't compromise their health and wellbeing.[18]

Timber in healthcare and educational buildings

Biophilic design involves architects developing a connection to nature through the design and selection of materials, and has been given increasing emphasis in recent years. It proposes that a more human-centred approach to our built environment can improve many of the spaces in which we live and work, with numerous health benefits.[19]

There is increasing evidence of the physiological benefits of wood on humans, reviewed in a recent paper in the Journal of Wood Science.[20] It concludes: 'In the future, preventive medical effects by wood-derived stimulation, such as stress reduction and improvement in immune function, may potentially be explained through objective data obtained using a range of

physiological indicators, including brain activity, autonomic nervous activity, endocrine activity, and immune activity'.

The Dyson Centre for Neonatal Care in Bath, designed by Feilden Clegg Bradley Studios, was constructed using cross-laminated timber (CLT) in 2011. It was the first modern timber building with exposed internal timber surfaces in the UK to be utilised in clinical healthcare. Feilden Clegg Bradley Studios overcame the concerns of the infection control team by demonstrating the positive impact of exposed timber. Subsequent research suggested that the new unit enables babies to get 20% more sleep, giving them a greater chance of survival. 90% of babies in the new unit, compared to only 64% of babies in the old unit, go home breast feeding. Mother's anxiety scores dropped, visitors stayed longer and physical contact with the babies increased.[21]

Figure 4 The Dyson Centre for Neonatal Care
Photograph: © Fotohaus

Oak Meadow Primary School was designed by Architype to Passivhaus Standard, maximising natural daylight and ventilation. Headteacher Mrs S. Morris stated that 'the children absolutely love it and the teachers absolutely love it ... everyone is so enthusiastic with the whole building ... we find that the children are very attentive and they do appreciate the good air quality that we've got and I do believe they're far more alert in what they're doing each day.'

3: What are VOCs?

VOCs include both human-made and naturally occurring chemical compounds – most odours are made up of VOCs. They are organic chemicals that have a high vapour pressure

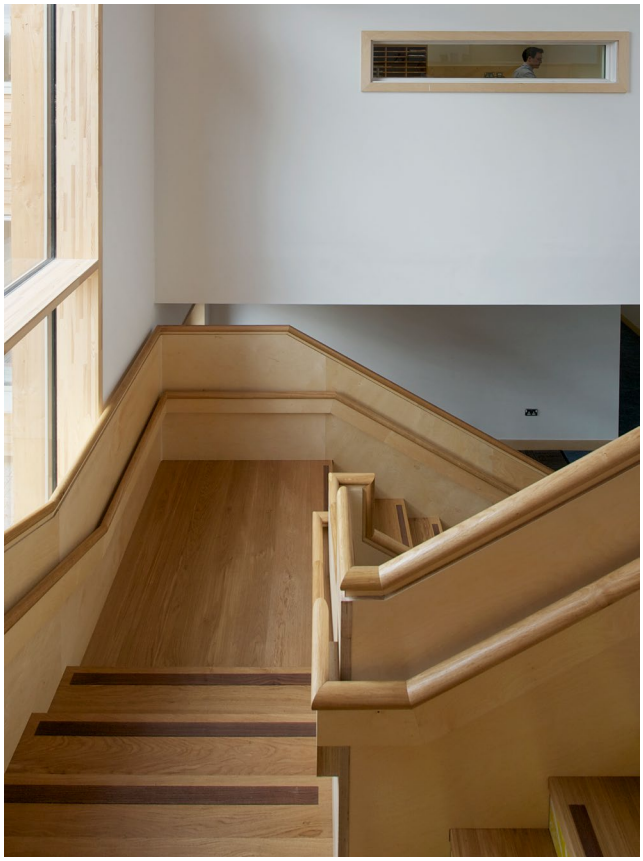

Figure 5 Interior of Oak Meadow Primary School
Photograph: © Architype

at ordinary room temperature. This high vapour pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the compound and enter the surrounding air. Less volatile chemicals are classified as semi-volatile organic compounds (SVOCs) and defined by a boiling point range of 240–260°C to 380–400°C.[22] These two types are commonly reported together and described together as a total – TVOCs (total volatile organic compounds). With VOCs and SVOCs mixing with NO_2, NOx, PM 2.5, 5, 10, moulds, pollen, and biological contaminants, the cocktail effect is a particular challenge.

Research has shown that once VOCs are introduced into the internal environment, products can continue to off-gas for up to two years[23], however, this can be reduced by careful selection of low VOC emission products.

The cumulative effect of emissions from all sources needs to be taken into account when considering indoor air quality. UK *Building Regulations Approved Document F: Ventilation* contains guidance relating to TVOC levels at post-construction, pre-occupation at 300µg/m^3, measured over 8 hours. The WELL Building Standard requirement is 500µg/m^3 or under, but results

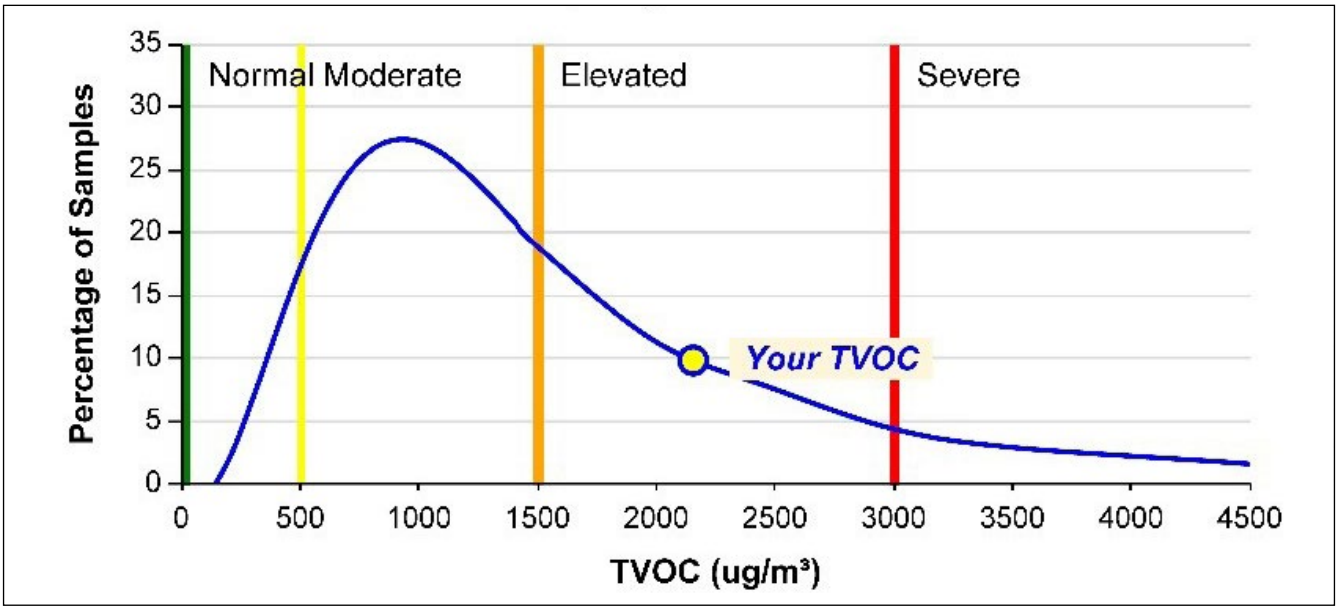

Figure 6 A summary of 8,000 internal snapshot air quality tests, including occupant behaviour (Waverton Analytics)

from 8,000 IAQ snapshot tests by Waverton Analytics show that the average home is 1,000µg/m^3, the mean is 1,900µg/m^3 and it is deemed critical at 3,000µg/m^3. However, it should be noted that snapshot tests will vary depending upon when they were taken, and may include occupant-related VOCs associated with indoor air fresheners, cooking, and smoking.

VOCs occur naturally in wood, and VOCs present in wood products such as wood binders, resins and engineered products (OSB, MDF, ply etc.), flooring products, coatings (paints, finishes, sealants, waxes), adhesives, mastics, cements, cleaning products, roofing materials and insulation can affect indoor air quality. However, many of the naturally occurring VOCs in wood are beneficial to health, as will be discussed later.

4: Building comfort

Healthy buildings focus equally on the occupants' physical, mental and social health. The term 'sick building syndrome' was once used to include many health conditions linked to living indoors. Now it is understood that there is not one syndrome associated with buildings as such, but rather a wide variety of agents and individual sensitivities that create an array of possible symptoms.

For a person to be comfortable in a building, the whole matrix of human comfort must be addressed and catered for. As mentioned earlier, this includes temperature – not too hot, not too cold and easily controllable, with humidity levels ideally between 40–60% relative humidity. Research suggests that most people begin to feel 'warm' at 25°C and 'hot' at 28°C. 35°C has also been defined as the internal temperature above which there is a significant danger of heat stress.[24]

Human comfort also includes acoustics, day lighting, layout, artificial lighting, location, external air quality, internal air quality, ventilation and views. If any of these factors are compromised then the building can become uncomfortable.

Indoor air quality

The relationship between health and indoor air quality (IAQ) is complex. We are all individuals with different personal tolerances and within a building there are multiple products and multiple variables, with a likely cocktail effect.

The location of the building and the quality of the external air is also an important factor. Monitoring indoor air quality can be conducted easily, with several companies currently offering VOC testing. A key issue that must be considered when measuring indoor air quality is that most measurements of VOCs report a TVOC value and compare this to a specified threshold. However, not all VOCs are bad for your health – some can actually have a positive impact on people, producing a calming affect such as alpha-pinene. So the act of measuring indoor air quality becomes even more complex, because we should consider which VOCs make up our TVOC measure.

Snapshot tests for air quality

One-off test kits for air quality are available, which are plugged in for a period of time before being returned to the supplier, who will then send on a detailed report. Bespoke tests can also be developed depending on the individual concerns or circumstances.

While standalone tests can provide relatively accurate measurements, each one is an individual test that provides only a snapshot and doesn't take time variations such as temperature, humidity, season, and occupant activity into account.

Ongoing testing and feedback
For constant monitoring and feedback, a range of sensors and hand-held devices are now available. Humidity, CO, CO^2 sensors and temperature sensors can be reasonably cost-effective, with VOC measurement more costly. Sensors are unable to measure for all VOCs and often the information is presented as a range or a total: TVOCs. Sensors can be connected to portable devices, or even to a building management system that controls ventilation rates.

Support for monitoring studies
Conducting building performance evaluation studies of real operating conditions is crucial to understanding the impacts of our design decisions. In order to support this complex process and enable benchmarking, the Building Performance network might assist: http://building-performance.network/

Effective source control
Reducing the risk of exposure to VOCs from products is known as source control, and involves reducing the release of contaminants into the indoor atmosphere. Effective ventilation and source control are often described as two sides of the same coin, but experts such as Dr Ben Jones from Nottingham University, stress that a strategy for source control should be practised first.[25]

Effective source control is becoming increasingly important, and can reduce the risk of exposure to VOCs from construction products. To be effective this must work alongside good detailing, quality installation and an effective ventilation strategy.

Health benefits and VOCs
Importantly, research has shown that some VOCs are good for us; for instance the emission of terpenes from certain softwood species may confer health benefits.[26] Also, α–pinene and *d*–limonene that are emitted from some softwood species, play an important role in physiological relaxation.[27] Studies have reported that monoterpenes can have antimicrobial, anti-inflammatory, antipruritic, analgesic and stress reducing properties.[28] Rates of tumour growth in mice exposed to α–pinene were found to be reduced compared to a control group.[29] Komori et al. concluded that the citrus fragrance found in forests had a positive effect on the human endocrine and immune systems.[30]

VOCs and health effects
At present there is little published research into the health effects of long-term exposure to VOCs.[31] The health effects are usually referred to as:

Acute

- Irritation of eyes and respiratory tract.
- General headaches, dizziness, lack of coordination, nausea and visual disorders.
- Allergic reactions such as asthma and rhinitis.

Chronic

- Damage to liver, kidney, circulatory system and central nervous system, links to cancer.

Formaldehyde
Formaldehyde occurs naturally and is considered toxic in high quantities, but it is ever-present. Within the indoor environment (homes, offices, schools, hospitals etc.) formaldehyde emissions may arise from a variety of products and activities such as
the following:

Building-related materials

✓ Paints and varnishes

✓ Adhesives

✓ Carpet and vinyl flooring

✓ Composite wood products

Home-based products

✓ Air fresheners

✓ Cleaning products

✓ Cosmetics

✓ Upholstery and foams

Activities

✓ Smoking

✓ Dry cleaning

✓ Photocopiers

✓ Cooking

✓ Burning fuels

Scavenger materials

Research has been carried out which suggests that scavenger materials within insulation and building materials could effectively be used to help remove extant formaldehyde/ VOCs from buildings.[32] The BioComposites Centre at Bangor University have been researching the feasibility of incorporating natural scavengers within MDF boards.

Regulatory background

EU regulation has driven significant reductions in toxins within construction products and DIY products, and emission rates from wood-based panels have been dramatically reduced over the last 20 years. In Europe, CE marking is used to comply with both the Construction Products Regulation and the Building Regulations. Products achieving a CE mark will have met rigorous standards, which includes testing for VOCs.

It is important to be aware that countries follow different standards for indoor air quality, and care should be taken when comparing products. For example, the voluntary German Blue Angel label require levels of below 0.05ppm, while the ecolabel natureplus would be 0.036ppm.

CEN TC 351 *Construction products – assessment of release of dangerous substances* has a remit for the development of horizontal standardized assessment methods for harmonized approaches relating to the release of regulated dangerous substances under the Construction Products Regulation, taking into account the intended conditions of use of the product.

VOCs from stains, paints and finishes

Low VOC wood paints and finishes are now widely available. However, it should be noted that there is an ongoing tension between levels of VOCs and relative performance. In one study scientists measured the compounds – propylene glycol and glycol ethers, known as PGEs – in the bedroom air of 400 toddlers and pre-schoolers.[33] Although water-based paints are generally recommended as the healthy option, they found that children who slept in bedrooms containing fumes from water-based paints and solvents were two to four times more likely to suffer allergies or asthma.

VOCs from flooring – the consequences of getting it wrong

At the new German Federal Environment Agency HQ in 2004, 18,600m^2 of rubber flooring had to be replaced after elevated levels of napthalene x 3 and organochlorine x 22 were found.[34] The principal source of emissions from hardwood parquet floors are the ureaformaldehyde (UF) or polyurethane coating applied to the surface. Exposed timber floors are generally seen to be a healthier option than carpets, but if carpets are to be used foam underlays should be avoided and woodfibre or wool used instead.

Humidity

Humidity, or the amount of water vapour in the air, is an important influence on health that is easy to overlook, yet often easy to remedy. Ideal humidity indoors is generally described as between 40% and 60%. When humidity is higher, it can contribute to the growth of mould, dust mites, and fungus, making it particularly dangerous for people with asthma and allergies. Low humidity can also cause health risks, however, and may lead to issues such as dry eyes and cracked skin.

As a hygroscopic material wood has the capacity to absorb moisture and thus moderate the indoor relative humidity, resulting in lower ventilation demand. This variation in moisture content in wood means that it could hold a potential for contributing in the buildings energy balance.[35]

Moisture and mould

There is a significant amount of research demonstrating that moisture and mould in buildings correlate with sickness. Many studies have associated them with asthma, and there are now 5.4 million people with asthma, including on average three children with asthma in every classroom in the UK. The UK has among the highest prevalence rates of asthma symptoms in children worldwide.

In the UK, approximately 33% of adults and 50% of children are affected by one or more allergic disorders. Nearly £1 billion a year is spent on prescriptions by the NHS to treat allergy symptoms, and there has been a substantial 615% increase in hospital admissions related to allergic diseases during the last 20 years.[36]

Mould and moisture hot-spots within buildings can contain a few types of filamentous fungi, yeasts and bacteria that proliferate in moisture. A build up in moisture within the building fabric is a major risk for all timber products, as well as being a risk for occupant health.

Within an analysis of 1,500 properties Colin King at BRE reported[37] that the sources of mould growth were as follows:

35% – Insufficient or defective insulation

33% – Poor ventilation

22% – Defective damp proof courses/trapped moisture

10% – Sealing and internal leaks.

Poor ventilation

Ventilation limits exposure to indoor pollutants, but is not always well implemented. National building regulations specify minimum ventilation rates for background ventilation. These can be achieved with the use of trickle ventilators over windows, extract fans, passive state ventilation or continuous mechanical extract systems.

Radon

Radon, an odourless radioactive gas found in soil and rocks, is the leading cause of lung cancer in non-smokers with approximately 1,100 lung cancer deaths attributed to it each year in the UK.[38] Radon mitigation measures are fairly simple to apply to new builds but retrofitting is likely to be more complex. Refer to www.ukradon.org/information/ukmaps for further information on hotspots.

5: Timber and wood products within healthy buildings

With the emerging focus on the indoor environment and air quality, the timber industry is presented with many opportunities. Wood is an attractive and renewable building material, and is capturing more of the housing market. Initiatives such as the wood encouragement policy in Powys and policies in Hackney, for example, have resulted in a significant increase in timber being used in construction.

Hackney's councillor Vincent Stops has become a keen advocate of the use of timber and has witnessed a big shift towards the use of structural timber within modern construction:
'I have visited many of the timber buildings in Hackney and spoken to both builders and residents. All say they like working with timber and living in timber buildings.'[39]

Alongside the many opportunities for the healthy building agenda, the timber industry does have specific challenges. Some aspects of timber products; from resins and binders, preservative remedial timber treatment, paints, finishes, adhesives and varnishes should be specified carefully with reference to guidelines such as BREEAM (Indoor environment – health and wellbeing section) and timber dust controlled according to COSHH requirements.

6: Specifying timber and wood products for healthy buildings

Tools for the specifier

A key challenge for the construction industry is the complex chemistry and uncertain clinical evidence relating to this subject. In the absence of strong policy drivers, indoor air quality is an area where voluntary standards and procurement tools can play a helpful role. The Ecolabel Index indicates that there are 120 ecolabels relating to construction products, and the Eurofins website makes some useful comparisons.

In the USA Google have developed Portico, a building materials evaluation web application service managed by The Healthy Building Network, which integrates project management functions and a growing database of over 2,500 building materials and products evaluated by material health and transparency criteria. To learn more visit www.healthybuilding.net/portico

7: Post-build issues

The task of retrofitting our entire building stock to enable zero carbon buildings by 2050 is a daunting one, which requires an estimated 781,250 homes to be refurbished every year – or 1.5 homes per minute. Most pre-1950 buildings are vapour-open and inappropriate materials applied in a retrofit may prevent the passage of moisture through the building. However, the concept of breathability is poorly understood. This lack of understanding is making communication difficult and allowing misinformation to spread. For example, vapour-open is not the same as breathable. Airtightness and breathability are not mutually exclusive, and should be thought of as complementary strategies.

Research into the passage of moisture through solid walls by SPAB suggests that woodfibre board assists with moisture buffering and allows buildings to breathe.[40]

The importance of building maintenance and monitoring cannot be stressed highly enough. A bit like people, buildings need to be nurtured, with gutters cleaned, leaks fixed, vegetation removed etc. in order to keep them performing as they were intended to.

8: Summary

Each year in the UK, some 40,000 deaths are linked to air pollution. *Every Breath We Take* by the Royal College of Physicians et al[41], published in February 2016, for the first time combined the PM2.5 and NO_2 figures to create a total figure of 9,500 annual deaths in London, with nearly half of the health effects caused by air pollution produced outside of London. This report acknowledges a lack of focus on the indoor air environment and states that:

'The construction, occupancy, and exposure profiles of newer workplaces will lead to the potential for novel inhaled hazards and risks, and vigilance will be required in order to identify the occupational lung problems attributed to the workplace of tomorrow'.

This group have now turned their attention to the indoor air environment with their latest report in April 2017; *Better Homes, Better Air, Better Health*[42] and it is suggested that it will likewise catapult this area into the mainstream. This is evidenced by a related article in Which[43] on IAQ. The Energy Performance of Buildings Directive currently includes a section around the indoor environment for consideration.[44]

The National Institute for Health and Care Excellence (NICE) are commencing a two-year programme to develop standards for the internal environment and a revised Building Bulletin 101 on ventilation and IAQ for schools from the Education Funding Agency is due imminently. UKIEG launched their report *Healthy Indoor Environments: Challenges for Policy Makers*[45] on 4th July 2017.

The health and wellbeing movement has brought about a big shift in focus within the built environment. Businesses are refocusing their sustainability agenda around healthy buildings, both for people and for the planet. There is a lot of ongoing research in this area, with buildings and their internal environment increasingly being monitored in their thousands.

The advent of smart buildings should allow all of us to monitor and control our internal environments better, and it won't be long before we all have an app on our phone that displays the indoor quality of our workplaces and homes. The key takeaway from work in this area is that VOC monitoring is becoming relatively affordable. Monitors are now available that measure the indoor environment through the day. The adage 'build tight, ventilate right' should now be extended to 'build healthy, build tight, ventilate right'.

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