IAQ AND HEALTH:
A Summary of Evidence

V.1. (14.03.16)

MY HEALTH MY HOME

Allergy UK. Work Fever: Report by Allergy UK into Allergies in the Workplace, November 2012.

Allergy UK surveyed over 1000 sufferers at their work place. They reported that “lack of ventilation is an office workers worst enemy” with headaches and lethargy the most commonly reported symptoms in last 12 months at work. But, 62% of respondents had experienced itchy or watery eyes, and 27% breathing difficulties over the last year in their office.

According to Allergy UK, headaches, lethargy and a dry throat can be caused by poor ventilation. In fact, only 9% of those who experienced breathing difficulties at work, worked in an office they considered well ventilated. The workplace was only classed as ‘well ventilated’ for just 10% of those who’d suffered a dry throat and 12% of those who experienced lethargy and/or tiredness, meaning that ventilation is a key area on which to focus.

American Society of Interior Designers (ASID) report. 2007. Indoor air quality–Interior design and global impacts. p6.

The University of Chicago stated “clear evidence” that poor air quality contributes to negative effects on those suffering with asthma with annual direct health costs of $9.4billion. In 2000, asthma cases were responsible for nearly 2 million emergency room visits at a cost of almost $2billion & nearly 13 million lost school days.

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

Professor Awbi found that building regulations have not taken into consideration the adverse impact of improved air tightness and increased energy efficiency on indoor air quality (IAQ) and the health of occupants.

He reported that the trend towards greater levels of air tightness will exacerbate pollutant levels in addition to elevated humidity levels during drying-out periods for new or refurbished dwellings. With the expected increase in air tightness for UK dwellings, it is anticipated that indoor air quality will generally become poorer, resulting in an increase in the number of cases of health symptoms related to poorer indoor environment quality. This is expected to mostly affect individuals prone to such health conditions and those who spend most time indoors, including young mothers, children and the elderly.

The report surveyed current knowledge on the effect of indoor air pollution on people’s health and projected how increased levels of energy efficiency and air-tightness of UK dwellings, to meet emissions targets, will impact on pollution levels and health up to 2050 if there is no additional IAQ intervention, over and above existing requirements.

Key projections include:

- an 80% increase in asthma sufferers from current levels
- TVOC concentrations up to 60% above WHO 24 hour limits
- NO2 concentrations up to 30% above WHO annual limits

The report recommended that:

- There should be a legal requirement for new homes, and guidance for retrofitted homes, to have an air exchange rate of at least 0.5/hour, to help protect human health.

- The standardised fitting of effective continuous mechanical ventilation, preferably with heat recovery (MVHR), is the most cost-effective solution for achieving this exchange rate whilst satisfying energy efficiency requirements

- Any future building regulations to reduce carbon emissions should be accompanied by government regulation to ensure effective and efficient design, installation, maintenance and operation of MVHR systems to reduce the impact upon human health.

Bakó-Biró, Zs, et al. "Ventilation rates in schools and pupils' performance."*Building and Environment* 48 (2012): 215-223.

Bakó-Biró et al. studied 8 schools and over 200 children, to reveal that poor ventilation rates in classrooms significantly impair children's attention and vigilance. The faster and more accurate responses in Choice RT and Colour Word Vigilance tasks reflect higher level of focused attention at higher ventilation rates compared to low rates with natural ventilation.

In poorly ventilated classrooms, students are likely to be less attentive and to concentrate less well on instructions given by teachers. The magnitude of the negative effects with inadequate ventilation was even higher for tasks that require more complex skills such as spatial working memory and verbal ability to recognize words and non-words.

Ventilation rates in the order of 8 l/s per person are recommended in all teaching facilities to prevent any impairment of pupils' performance due to inadequate ventilation. Additionally, it was demonstrated in one of the schools which had good ventilation background that pupils reacted significantly faster in a number of simple tasks when the classroom temperatures were reduced from existing slightly elevated levels to a more comfortable range.

The physical environment affects people's well-being in terms of mind and body. This work shows that elevated level of indoor air pollutants including CO2 due to inadequate ventilation encountered in classrooms can affect learning. We know that the air we breathe can affect the brain via the blood oxygenation in about 4 s. CO2 is seen as a harmless gas and so is often accorded little significance, other than as an indicator of ventilation, but if it contributes directly to increased tiredness and a loss of concentration then it might be regarded as a very significant air pollutant. Air quality is just as important as temperature so needs to be monitored so as to guide teachers when to open windows or switch on fans.

Coward et al. 2002 Indoor air quality in homes in England. Volatile Organic Compounds. BRE Report BR 446, CRC Ltd. London ISBN 1 86081 566 9.

Coward et al. found that levels of TVOC levels in the newer of the 876 homes that were studied were higher and significantly higher in the late 1990s. It is not known however, whether this was caused because of the stronger sources of compounds in newer homes or whether lower ventilation rates occurred resulting in less removal of the compounds (or a combination of both).

Davies, Ucci, McCarthy, Oreszczyn, Ridley, Mumovic, Singh and Pretlove. 2004. A review of evidence linking ventilation rates in dwellings and respiratory health – a focus on dust mites and mould. International Journal of Ventilation. 3 (2) p156-168.

Davies *et al.* reviewed the literature for evidence of links between ventilation rates in dwellings and moisture related respiratory health with a particular focus on house dust mites and fungal growth. The authors say that there is general consensus that a link exists between ventilation rates in dwellings and respiratory hazards. There is also general consensus of a link between these respiratory hazards and respiratory problems, but it is not clear to what extent hazards cause ill-health.

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

A BRE study of 37 homes in England, built since 1995, undertook simultaneous measurements of air quality and rates of ventilation. All homes in the study had central heating with radiators and were double glazed with trickle ventilators in the window units to provide background ventilation.

In winter, 68% of homes had a whole house ventilation rate below 0.5 ac/h, which is necessary to avoid condensation according to BRE research. In summer, 30% of homes had a whole house ventilation rate below 0.5 ac/h.

The results from the measurements were statistically analysed, based on data from questionnaires, including house characteristics and occupant activity diaries.

The relationships between the ventilation rate for the dwellings and the concentration of some main indoor pollutants were found as well as correlations between certain sources and pollution concentrations, such as the presence of a gas cooker and the concentration of NO2. Among the statistically significant findings were that concentrations of formaldehyde and VOCs were highest in newer homes. It was not established whether these concentrations were higher because of stronger sources of these compounds in newer homes or whether lower ventilation rates occurred, resulting in less efficient removal of the compounds in the indoor air, or a combination of both of these factors.

Carrer, Fanetti, Forastiere, Holcatova, Molhave, Sundell, Viegi, Simoni. 2009. ENVIE Co-ordination action on indoor air quality and health effects. WP1 Final Report – Health effects. www.envie-iaq.eu

Carrer *et al.* reviewed the main studies of indoor air-related health effects and prioritised the following diseases as being caused or aggravated by poor indoor air quality:

- allergic and asthma symptoms
- lung cancer
- chronic obstructive pulmonary disease (COPD)
- airborne respiratory infections
- cardiovascular disease (CVD)
- odour and irritation (sick building syndrome symptoms).

They report that allergic and asthma symptoms are increasing throughout Europe affecting between 3 to 8% of the adult population with higher prevalence in infants (29–32% in Ireland

and UK in 1995/96). According to Asthma UK (10), there are now 5.4 million UK asthma sufferers, which is the highest in Europe as a percentage of the population. The cause of allergic diseases is considered to be a complex interaction between genetic and environmental factors and asthmatic patients are sensitive to allergens present in the indoor environment and are often hyperactive to a number of gases and particles.

The following may have a role in the development of allergy and asthma:

- Microbial agents (endotoxin of Gram-negative bacteria, fungal spores and fragments, bacterial cells, spores and fragments, microbial metabolites and allergens including house dust mites, pet allergens and fungal allergens).

- Chemicals (formaldehyde, aromatic and aliphatic chemicals, phthalates or plastic materials, products of indoor chemical reactions involving ozone and terpenes). Lung cancer is the most common cause of death from cancer in the EU (about 20% of all cases). Most are due to active smoking, but it is estimated that 9% are due to radon exposure in the home and 0.5% in males and 4.6% in females are due to exposure to environmental tobacco smoke. There is some evidence of risk due to combustion particles including PM2.5 (particulates with an aerodynamic diameter below 2.5 μm) in ambient air, and due to diesel exhaust and indoor cooking oil and coal burning.

Chronic obstructive pulmonary disease (COPD) is a chronic respiratory disorder that is usually progressive and associated with an inflammatory response of the lungs to noxious particles or gases. It is estimated that the prevalence of clinically relevant COPD in Europe is between 4 and 10% of the adult population. About 70% of COPD related mortality is attributed to cigarette smoking. Other risk factors identified are environmental tobacco smoke, biomass combustion fumes, and particulates in ambient air and long-term exposure to mould/dampness.

Airborne infectious diseases include Legionnaire's disease, tuberculosis, influenza and SARS (severe acute respiratory syndrome). Reservoirs in aquatic systems such as cooling towers, evaporative condensers and humidifiers have been the source of airborne agents in outbreaks of Legionella and pneumonia.

Symptoms of these diseases can be aggravated by exposure to ETS and combustion particles. Cardiovascular disease (CVD) is the leading cause of death in industrialised countries accounting for 42% of deaths in the EU. Causes include exposure to environmental tobacco smoke, particulates, CO and other gaseous pollutants (NO2 in particular).

Sick building syndrome (SBS) describes cases where building occupants experience acute symptoms and discomfort that are apparently linked to the time spent in the building, but for which no specific illness can be assigned. Symptoms include respiratory complaints, irritation and fatigue.

Crump, Derrick. "Climate change–health impacts due to changes in the indoor environment; research need." (2012).

Crump reported that one of a range of UK government actions to mitigate effects of climate change is to reduce carbon emissions to the atmosphere from the built environment. This has resulted in an on-going process of change in the way we construct and heat new buildings as well as renovation of existing buildings to improve their energy efficiency. Broadly these changes result in more air tight and highly insulated structures. These

changes can impact the quality of the indoor environment and there are concerns that some of these changes could have adverse consequences for occupant health.

The report details that indoor environment is a significant determinant of population health. The young and the elderly and people in poor health are likely to spend considerably more time at home, perhaps 100% on many days. Therefore all aspects of health that are related to environmental conditions can be impacted by the quality of the indoor environment. These are wide ranging and include safety in terms of prevention of accidents, the opportunity for exercise perhaps encouraged by safe access to an outside area, and well being arising from impact of the environment on mental health. A key function of the built environment is to provide shelter from the extremes of the outdoors and maintain a comfortable indoor climate; particularly thermal comfort. In so doing the building needs to provide appropriate protection against other environmental factors including pollutants, infectious agents and noise. Hence good building design supported by regulations and guidance established over many years seeks to optimise these features but this must be balanced against costs of provision.

Key housing related health risks include respiratory and cardiovascular disease from indoor pollution, illness and death from temperature extremes, communicable disease spread because of poor living conditions and risks of home injuries. Inadequate ventilation is associated with higher risk to health and poor housing quality and design can exacerbate health impacts of exposure to temperature extremes that are occurring more frequently due to climate change. One recommendation is that home occupants need to know how to use their homes in a healthier manner, particularly when homes are made more weather tight to save energy.

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

The COMEAP recommended maximum levels of indoor air pollution exposure for the home indoor environment. The committee reckoned that as people spend much of their lives indoors, it is plausible that the largest part of a person's exposure to pollutants actually occurs indoors. Levels of some air pollutants found in at least some homes in the UK exceed those demonstrated by epidemiological and other study methods, to be associated with adverse effects on health.

The Committee's report issued guidance based on an understanding of sources of indoor air pollutants and on simple measures that people can take to ensure that concentrations of air pollutants are kept at a low level. The guidance developed was intended as an aid to manufacturers of materials or devices that release pollutants into the domestic environment; architects and building-engineers who are interested in designing buildings with adequate levels of ventilation; individuals who are concerned about concentrations of air pollutants in their homes, who are prepared to pay for monitoring to be done and who need a benchmark with which to compare the results obtained. Landlords, building owners and building managers concerned to provide a high standard of indoor air quality should also find the guidelines useful.

The guidelines for indoor air quality were established at levels of pollutants which the committee reasoned, if not exceeded, would offer a significant level of safety to those exposed to them. The committee accepted that complete safety cannot be guaranteed in the case of carcinogens such as benzene and PAH compounds.

COMEAP recommendations for guideline values for pollutants found in indoor air.

Pollutant	Concentration	Averaging time
Nitrogen dioxide	150 ppb (300 µg/m^3) 20 ppb (40 µg/m^3)	1 hour average Annual average*
Carbon monoxide	90 ppm (100 mg/m^3) 50 ppm (60 mg/m^3) 25 ppm (30 mg/m^3) 10 ppm (10 mg/m^3)	15 minutes 30 minutes 1 hour 8 hours
Formaldehyde	0.1 mg/m^3 (0.1 ppm)	30 minutes
Benzene	1.6 ppb (5.0 µg/m^3)	Annual average
Benzo[a]pyrene	0.25 ng/m^3	Annual average*

* Provisional Guidelines

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

The European Commission Scientific Committee on Health and Environmental Risks concluded that indoor air may contain over 900 chemicals, particles and biological materials with potential health effects. The EC SCHER note that concentrations of pollutants are usually higher indoors than outdoors and that people spend most of their time indoors. They recommend a focus on evaluating sources of pollutants and seeking to reduce exposures because of the difficulties of regulating the diverse range of indoor air scenarios. They identify a need for more research including work on exposure, reactions between pollutants, combined and mixture effects, causative factors to explain the link between dampness and health and development of health-based guideline values.

European Commission Joint Research Centre – Institute for Health and Consumer Protection. Report No 23: Ventilation, Good Indoor Air Quality And Rational Use of Energy (2003).

The IHCP reported that we spend 90% of our time indoors and indoor air can be up to 50% more polluted than outdoor air.

Fisk W, Lei-Gomez, Mendell M (2007), Meta-analyses of the associations of respiratory health effects with dampness and mould in homes. Indoor Air, V17, N4, pp284–296).

Fisk *et al*. undertook a meta-analysis of 33 studies investigating an association between occurrence of indoor dampness and mould with adverse health effects. This found building dampness and mould to be associated with an approximately 30 to 50% increase in a variety of respiratory and asthma-related health outcomes. The studies included those recording

visible dampness and or mould, or mould odour, by investigators or the occupants themselves.

Hänninen, Otto, and Arja Asikainen. "Efficient reduction of indoor exposures-Health benefits from optimizing ventilation, filtration and indoor source controls." *Raportti: 2013_002* (2013).

Air pollution is estimated to be the leading cause of environmental burden of disease in Europe. While more than half of this burden originates from outdoor air pollution, quite regularly many people including school children, adults and senior citizens are found living, studying and working in buildings seriously affected by moisture, dampness and mould and other problems generated by indoor sources of pollution.

The annual burden of disease caused by inadequate indoor air quality is estimated to correspond a loss of over 2 million healthy life years in the EU.

The results presented in the report show convincingly that the health risks caused by indoor exposures cannot be reduced to an acceptable level without accounting for all major factors modifying exposures: outdoor sources and infiltration, indoor sources, and ventilation. Acting efficiently on all is the only possible way forward in providing healthy indoor air to all.

Attributable burden in 2010

Exposures to indoor and outdoor originating pollutants were associated with a burden of disease corresponding to an annual loss of 2.1 million life-years in EU26.

These estimates are calculated as disability adjusted life-years (DALY) and account for loss of life years due to premature mortality and due to years lived with disabilities (i.e. morbidity). 0.74 million of these DALYs are associated with pollutants from various indoor sources.

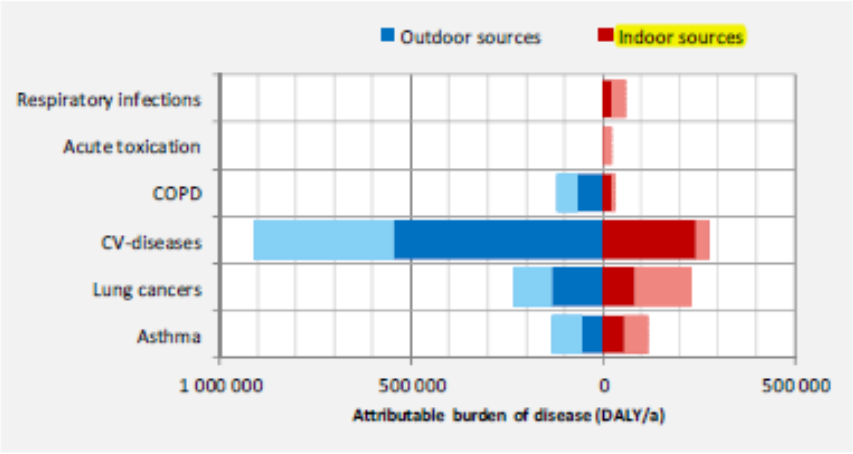

Figure 7. Attributable burden of diseases due to indoor exposures in 2010 in EU26. The lighter shade represents the maximum reducible fraction estimated in the following sub chapters.

The burden of disease caused by indoor exposures is dominated by cardiovascular (CV) diseases; 45% of the total burden comes from CV-diseases associated with

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The burden of disease caused by indoor exposures is dominated by cardiovascular (CV) diseases; 45% of the total burden comes from CV-diseases associated with outdoor particles, with an additional 12 % caused by indoor sources of exposures of particles and second hand smoke. Cardiovascular diseases are followed by asthma (total of 12%) and lung cancer (23%). The remaining 8% is divided between various respiratory symptoms and conditions.

The EU26 average burden corresponds to slightly over 4000 DALY in a year per one million population.

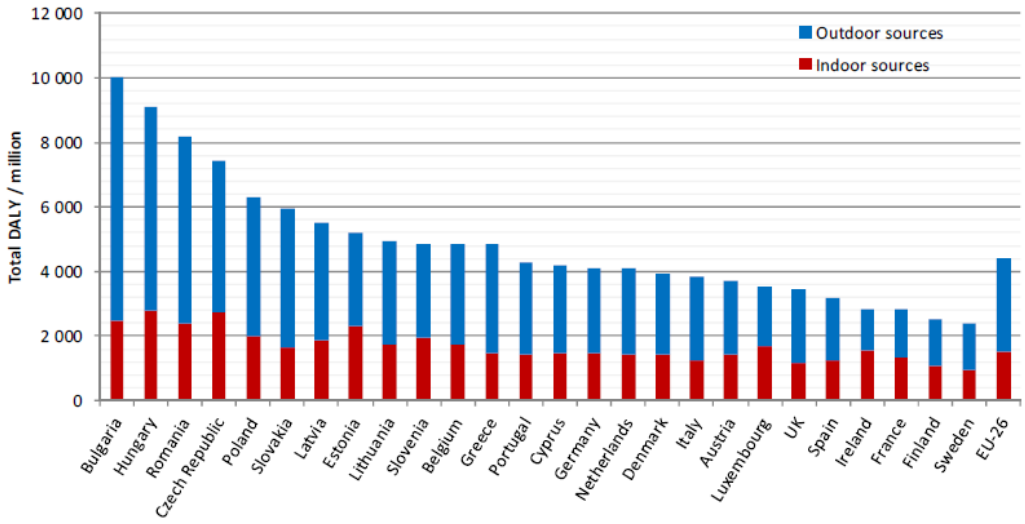


Figure 8. Total burden of disease as DALY/million population from indoor exposures in European countries with division to indoor and outdoor sources in the 2010 building stock

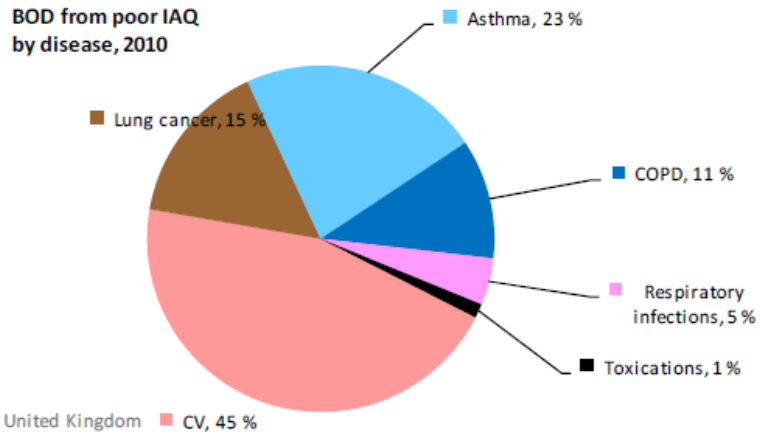
Over 2 million disability adjusted life years (DALY) are annually lost in the European Union due to compromised indoor air quality including morbidity and mortality due to cardiovascular diseases, lung cancer, asthma and allergies, acute toxication and respiratory diseases caused by particulate matter, pollen, radon, second hand smoke, dampness and mould, volatile organic compounds, and carbon monoxide exposures that take place in indoor environments.

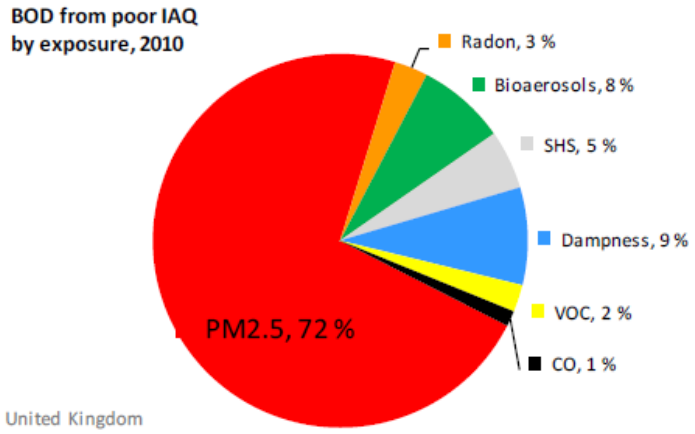
UK results on baseline burden

United Kingdom

Disease	Burden of disease in 2010		Source contributions		Percentage of
			Indoor	Outdoor	National BoD
United Kingdom	DALY/million	DALY	%	%	%
Cardiovascular (CV) diseases	1 563	92 335	7.8 %	34.9 %	45.2 %
Lung cancer	531	31 338	5.2 %	10.1 %	15.4 %
Asthma (& allergy)	780	46 072	9.8 %	12.8 %	22.6 %
COPD	386	22 793	2.0 %	9.1 %	11.2 %
U&L respiratory infections	151	8 908	4.4 %	0.0 %	4.4 %
Acute CO toxication	45	2 682	1.3 %	0.0 %	1.3 %
Total	**3 456**	**204 129**	**30 %**	**67 %**	**100.0 %**

Exposure	Burden of disease in 2010		Source contributions		Percentage of
			Indoor	Outdoor	National BoD
	DALY/million	DALY	%	%	%
PM2.5	2 476	146 273	13.2 %	59.1 %	72.2 %
Radon	99	5 868	2.9 %	-	2.9 %
Bioaerosols	263	15 522	-	7.7 %	7.7 %
Second hand smoke (SHS)	175	10 331	5.1 %	-	5.1 %
Dampness and mould	289	17 070	8.4 %	-	8.4 %
Volatile organic cmpounds (VOC)	80	4 737	2.3 %	-	2.3 %
Carbon monoxide (CO)	45	2 682	1.3 %	-	1.3 %
Total	**3 428**	**202 485**	**33.3 %**	**66.7 %**	**100.0 %**





Health Protection Agency (HPA) 2008. Health Protection Agency gives advice on radon measures for new homes. Press Release 21 May.

While smoking is the greatest risk factor for lung cancer, causing more than 30,000 cases each year, radon is the second most common cause in the UK and it is estimated, by the Health Protection Agency, that it causes 2000 cases per year. To protect against this risk, the HPA has recommended that all new properties should incorporate methods to reduce internal levels of radon. They comment that the low ventilation rates common in modern buildings for energy conservation reasons can encourage the build-up of radon gas concentrations indoors.

IOM (Institute of Medicine). 2011. Climate change, the indoor environment and health. The National Academies Press. Washington DC.

The US Institute of Medicine identified extensive scientific literature on the effects of poor indoor air quality, damp conditions, and excessively high or low temperature on human health.

Epidemiologic literature reviewed by the committee indicates that pollution intrusion from the outdoors, emissions from building components, furnishings and appliances, and occupant behaviours introduce a number of potentially harmful contaminants into the indoor environment.

Dampness problems in buildings are pervasive, and excessive indoor dampness is a determinant of the presence or source strength of several potentially problematic exposures, notably exposures to mould and other microbial agents and to chemical emissions from damaged building materials and furnishings. Damp indoor environments are associated with a number of respiratory and other health problems in homes, schools, and workplaces.

The elderly, those in frail health, the poor, and those who live in cities are more vulnerable to exposure to temperature extremes and to the effects of exposure. Those population groups experience excessive temperatures predominantly in indoor environments.

Less information is available on the effects of adverse indoor environmental conditions on the productivity of workers and students. Available studies indicate that inadequate ventilation is responsible for higher absenteeism and lower productivity in offices and schools. Indoor comfort is also important: experiments suggest that work performance and school performance decrease when occupants perceive that a space is too warm or cool or the ventilation rate is too low.

Based on the research studies reviewed, there seems little doubt that poor IAQ is associated with a variety of undesirable health effects. Although it is suggested that further research would be needed in order to reach a full understanding of the direct links of specific pollutants, the precautionary principle should be adopted and measures taken to ensure good IAQ in new homes. The need to do so may be even greater in homes that are occupied by infant, elderly and/or frail people.

Jacobs, Kelly and Sobolewski. 2007. Linking public health, housing, and indoor environment policy: successes and challenges at local and federal agencies in the United States. Environmental Health Perspectives. 115 (6) p976-982.

Jacobs reviewed knowledge of the links between health and the quality of the indoor environment of homes, and policies in the USA, to address these risks to health. Indoor air pollution is one of the top four health risks identified by the US Environmental Protection Agency (EPA).

This pollution is estimated to cause thousands of cancer deaths and hundreds of thousands of cases of respiratory health problems each year. Millions of children have experienced elevated blood levels of contaminants from exposure to indoor pollutants. Other effects include irritation, and more subtle neurotoxicological, behavioural and other adverse effects. The associated economic costs are considerable; the EPA estimating that net avoidable costs in 2001 alone were likely to be between $150 billion and $200 billion.

Maio, G Sarno, S Baldacci, I Annesi-Maesano § & G Viegi § (2015): Air quality of nursing homes and its effect on the lung health of elderly residents, Expert Review of Respiratory Medicine, DOI: 10.1586/17476348.2015.1105742

Indoor air pollution may play a special role in the elderly, since they are likely to spend most of their time indoors due to reduced outdoor activities. Under the hypothesis that the severity of respiratory diseases may depend on intensity and duration of exposure to air pollution, the

elderly might be at higher risk of suffering from air pollution–related diseases than the rest of the population because of their longer exposure to air pollution.

The results of the GERIE study (study referenced in the article) clearly highlight that the elderly are at risk of respiratory health impairment, even at moderate air pollutant concentrations, particularly if over 80 years and living in poorly ventilated nursing homes.

Mendel. 2007. Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: a review. Indoor Air. 17 p259-277.

Mendel reviewed 21 research studies that have associated residential chemical emissions from indoor materials and activities with risk of asthma, allergies and pulmonary infections.

Risk factors identified most frequently included formaldehyde or particleboard, phthalates or plastic materials, and recent painting. Others such as aromatic and aliphatic chemical compounds were suggestive. Elevated risks were also reported for renovation and cleaning materials, new furniture and carpets or textile wallpaper. It is concluded that while these risk factors may only be indicators of truly causal factors, the overall evidence suggests a new class of residential risk factors for adverse respiratory effects that is ubiquitous in modern residences. If the associations are proved to be causal, Mendel considers it would mean that there is a large-scale occurrence of adverse respiratory and allergic effects in infants and children that is preventable and related to modern residential building materials and coatings, and possibly exacerbated by decreased ventilation.

Mitchell, Zhang, Sigsgaard, Jantunen, Lioy, Samson, Karol. 2007. Current state of the science: health effects and indoor environmental quality. Environmental Health Perspectives 115. p958-964.

Mitchell et al. reviewed current knowledge on health effects and indoor environmental quality and suggested:

- a particular need for research on interactions of multiple exposures
- risks to particular vulnerable groups (e.g. children)
- benefits of interventions and trade-offs for ventilation and energy efficiency
- better measurements of dose, particularly for biological agents.

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

NHBC warned that a lack of adequate ventilation in newly built homes could result in a build-up of pollutants released by furnishings and building insulation materials, alongside humidity and condensation. The possible health effects of poor indoor air quality could include asthma, severe respiratory conditions or even cancer. People spend the large majority of their time indoors and particularly in the home. Those most vulnerable to pollutants and other adverse environmental conditions such as the very young, the elderly and the sick may spend nearly all of their time indoor and also because they are more likely to spend more time at home and also try to reduce heating and ventilation costs.

NHBC Foundation and Zero Carbon Hub. Mechanical Ventilation with Heat recovery in new homes. Interim report. Ventilation and indoor air quality task group. January 2012.

A variety of pollutants arising from a number of sources exist in the indoor environment of homes. Levels of many of those pollutants are likely to be at their highest levels in newly-built homes and homes that have been recently refurbished due to emissions from building materials and furnishings.

The report concluded that:

- Based on a number of international studies reviewed, the consensus is that poor IAQ is connected with various undesirable health effects. This reinforces the need for the design, construction and commissioning of buildings to be undertaken with IAQ firmly in mind.

- An increasing trend towards more airtight homes could exacerbate pollutant levels particularly if the ventilation system does not operate as intended.

- To realise the benefits of MVHR, in terms of both energy/CO2 emissions and IAQ, and to avoid any adverse consequences, systems must be properly specified in airtight homes and close attention needs to be paid to system design, installation, commissioning and operation.

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

As stated in more detail in the Interim Report, the report found that a variety of airborne pollutants exist in homes, many of which are likely to be at their highest levels in newly built and newly-refurbished homes.

The group also reported that the trend towards greater levels of air tightness may well tend to exacerbate pollutant levels. Based on the review of a number of international studies, the report stated that there is little doubt that poor IAQ is connected with a range of undesirable health effects such as allergic and asthma symptoms, lung cancer, chronic obstructive pulmonary disease, airborne respiratory infections and cardiovascular disease.

The report reinforced the need for the design, construction and commissioning of buildings to be undertaken with IAQ firmly in mind so that adequate ventilation is provided.

Olesen, Bjarne W. "Indoor environment-health-comfort and productivity."*Procedings of Clima* (2005).

People in industrialised countries spend more than 90 % of their lives in an artificial indoor environment (home, transportation, work). This makes the indoor environment much more important for people's health and comfort than the outdoor environment. In a typical office environment the cost of staff is a factor 100 higher than energy costs, which make the performance of people at their work significantly more important than energy costs.

Recent studies under laboratory conditions and in the field have shown a significant influence of the indoor environment on people's productivity and studies on sick leave show

a very high loss of work time and performance, which have significant economical consequences for companies.

The report recommends that the required ventilation rate in buildings must take into account both comfort and health and claims that an increased ventilation rate will also increase the performance of the occupants. Limiting the pollution sources, improving air quality by air cleaning or increased ventilation rates may increase performance of the occupants by 5 to 10 %.

To reduce energy consumption by decreasing the quality of the indoor environment is therefore reported as a 'bad investment'.

Osman, Douglas, Garden, Reglitz and Lyon. 2007. Indoor air quality in homes of patients with chronic obstructive pulmonary disease. American Journal of Respiratory and Critical Care Medicine. 176 p465-472.

Osman *et al*. measured concentrations of particulates (PM2.5) and NOx in air and endotoxins in house dust in homes of 148 patients in Scotland suffering from severe COPD. PM2.5 was significantly higher in smoking households and these levels were associated with the poorer health status of the patients.

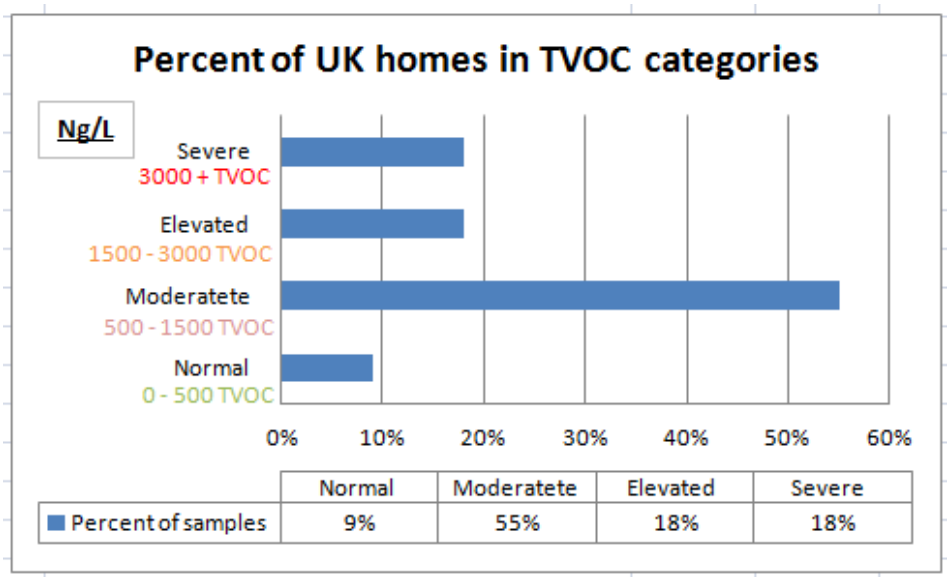
Prism Analytical Technologies & Waverton Analytics (2013) IAQ Home Study

Results from 122 IAQ home tests showed that UK households are at risk of experiencing aggravated health problems due to poor air quality inside the home.

The independent study tested the air quality in British homes; analysing the level of Volatile Organic Compounds (VOCs) present in the air. Out of the 122 homes tested in the UK, only 9% were considered in the normal category of recommended level of pollutant concentration, with the remaining 91% of homes above the recommended level.

The U.S. Green Building Council (USGBC) recommends 500 ng/L as the upper TVOC limit. TVOC levels below these limits indicate that the IAQ is acceptable for most individuals; however, chemically sensitive persons may require lower levels. TVOC levels between 500 and 1,500 ng/L indicate that air quality is marginal and some effect on the occupants is possible. Levels above 1,500 ng/L indicate that your IAQ should definitely be improved.

These levels are based on observed health effects and have been determined from a combination of published journal articles and the statistical distribution of TVOC concentrations from the IAQ Home Survey methodology. The presence of chemicals in the home can cause a wide range of problems, ranging from an unpleasant odour to physical symptoms (burning and irritation in the eyes, nose, and throat; headaches; nausea; nervous system effects; severe illness; etc.). In some cases, these conditions may make the home unliveable. Anyone with respiratory issues like asthma and allergies, as well as children, the elderly and pregnant women are more susceptible to poor indoor air quality than healthy individuals. However, at elevated TVOC levels even healthy individuals are likely to experience ill effects.



Richardson, Eick and Jones. 2005. How is the indoor environment related to asthma? Literature review. Journal of Advanced Nursing. 52 (3) p328-339.

Richardson *et al.* reviewed existing literature, finding evidence of a link between asthma and a small number of indoor environmental factors. Although there is a lack of medical evidence for reducing the high number of known sensitisers, such as mould, this is because of a dearth of research rather than evidence of no association.

As well as changes to the air tightness of homes, the paper stresses that activities within the home have changed. Housecleaning routines predominantly use vacuum cleaners and a variety of chemical-based cleaning agents, adding to the environmental burden indoors. A good quality indoor environment is important because most people spend more than 90% of their time indoors, and more than half of this time at home.

Royal College of Physicians. Every breath we take: the lifelong impact of air pollution. Report of a working party. London: RCP, 2016.

The RCP report conducted a limited review of the health effects of indoor pollutants, and showed that they cause, at a minimum, several thousands of deaths per year in the UK, and are associated with healthcare costs in the order of tens of millions of pounds. The report stated that a more systematic approach to the quantification of the effects of indoor air pollution would be beneficial, not least as this is where people in the UK spend most of their time.

The report also called for strengthened understanding of the relationship between indoor air pollution and health, including the key risk factors and effects of poor air quality in homes, schools and workplaces. The report argued that a coordinated effort among policymaking bodies will be required to develop and apply any necessary policy changes.

SCHER (2007) Opinion on risk assessment on indoor air quality, Scientific Committee on Health and Environmental Risk, European Commission, May 2007

SCHER concluded that indoor air may contain over 900 chemicals, particles and biological materials with potential health effects. It also noted that concentrations of pollutants are usually higher indoors than outdoors and that people spend around 90% of their time inside.

Sharpe, *et al.* (2015), Higher energy efficient homes are associated with increased risk of doctor-diagnosed asthma in a UK subpopulation, Environment International, V 75, pp 234-244.

The study of 944 social houses in Cornwall found that a unit increase in household Standard Assessment Procedure (SAP) ((which is the UK Government's standard measure of household energy efficiency) rating was associated with a 2% increased risk of current asthma, with the greatest risk in homes with SAP N71. The research also assessed exposure to mould and found that the presence of a mouldy/musty odour was associated with a two-fold increased risk of asthma.

The research therefore concluded that residing in energy efficient homes may increase the risk of adult asthma. Mould contamination also increased the risk of asthma, which is in agreement with existing knowledge. Exposure to mould contamination could not fully explain the association between increased energy efficiency and asthma. The findings may be explained by increased energy efficiency combined with the provision of inadequate heating, ventilation, and increased concentrations of other biological, chemical and physical contaminants.

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

Ucci et al. reviewed the literature on the links between ventilation rates in dwellings and moisture related respiratory hazards and revealed a general consensus on the link between ventilation rates in dwellings and respiratory hazards as well as a general consensus of a link between these respiratory hazards and respiratory problems.

A number of studies appear to indicate that a link exists between ventilation in housing and moisture-related pollutants. Analysis of the EHCS database suggests that mould growth is related to occupancy levels, energy efficiency and age of the property. The analysis also revealed a trend for higher asthma prevalence in dwellings built after 1980. Further studies are required in order to confirm and interpret these findings.

Most current guidance on domestic ventilation is based on the assumption that if ventilation levels are sufficient to avoid mould growth, then other IAQ problems will be contained as well. However, the modelling work outlined in their paper suggests that this may not be the case.

U.S. Environmental Protection Agency, (2015). Air and Radiation, Basic Information. Available at http://www3.epa.gov/air/basic.html Accessed 14/12/2015.

The US EPA claims that indoor air levels of many pollutants may be 2-5 times, and occasionally, more than 100 times higher than outdoor levels. Indoor air pollutants are of particular concern because most people spend as much as 90% of their time indoors.

Common sources can include burning kerosene, wood or oil, smoking tobacco products, releases from household cleaners, pesticides, building materials, and radon.

Venn et al. 2003 Effects of volatile organic damp and other environmental exposure in home on wheezing illness in children, Thorax, V 58-pp 955-960.

Venn *et al*. investigated the relationship between exposure to some indoor air pollutants and the occurrence of childhood wheezing illness in a study of 410 homes in Nottingham. They reported indoor concentrations of total volatile organic compounds (TVOCs), some individual VOCs, formaldehyde, and NO2, took measurements of surface dampness and recorded presence of mould. Visible mould was only identified in 11 homes but was significantly associated with an increased risk of wheezing illness. The risk of wheezing was significantly increased by dampness. Among the 193 cases with persistent wheezing, formaldehyde and damp were associated with more frequent nocturnal symptoms.

Wargockj, Sundell, Bischof, Brundrett, Fanger, Gyntelberg, Hanssen, Harrison, Pickering, Seppanen, Wouters. 2002. Ventilation and health in non-industrial indoor environments: report from a European multidisciplinary scientific consensus meeting (EUROVEN). Indoor Air. 12 p113-128.

The following consensus was reached by the EUROVENgroup:

- The literature shows a strong association between ventilation and comfort (as indicated by perceived air quality) and health (as indicated by SBS symptoms, inflammation, infections, asthma, allergy, short-term sick leave). It also indicates that there is an association between ventilation rate and productivity (as indicated by performance of office work).

- The literature indicates that outdoor air rates below 25 l/s per person in offices increase the risk of SBS symptoms, increase short-term sick leave, and decrease productivity. They also suggest that the same may apply for schools but little information on this aspect is available at present.

- The literature indicates that air change rates above 0.5 h)1 in homes reduce the degree of infestation of house dust mites in Nordic countries. Taking into account the causal link between house dust mites infestation and asthma and allergies, these data suggest that decreased ventilation may exacerbate allergies.

- The literature indicates that occupants of many buildings with air-conditioning systems may have an increased risk of SBS symptoms compared with occupants in naturally or technically ventilated buildings, implying thus that new ways of conditioning the air may be required. These results could be confounded by a number of factors such as improper maintenance of HVAC systems (the more complex the system the more liable it is to fail), building age (new types of building material are likely to be found in air-conditioned buildings erected in the past 30 years), and unknown factors such as window opening. The studies were furthermore carried out mainly in transient and cold seasons, without taking into account the thermal benefits of air-conditioning in hot seasons.

- The literature shows that improper maintenance, design, and functioning of HVAC systems contributes to an increased prevalence of SBS symptoms.

- This indicates a need for safety factors and proper maintenance of ventilation systems, including such aspects as appropriate distance separating the inlet and exhaust, replacing dirty filters, cleaning ducts, and the prevention of water reservoirs and water in the systems.

- Pollution sources other than the pollutants emitted by humans (bioeffluents) are important indoors. Consequently, proper source control is required in the first place, and secondly the design of ventilation rates based on all pollution loads present indoors.

World Health Organization. 2009. WHO guidelines for indoor air quality–dampness and mould. WHO Regional Office for Europe. ISBN 9789289041683.

Problems of indoor air quality are recognised as important risk factors for human health in low- middle- and high income countries. Indoor air is also important because populations spend a substantial fraction of time within buildings. In residences, day-care centres, retirement homes and other special environments, indoor air pollution affects population groups that are particularly vulnerable due to their health status or age. Microbial pollution involves hundreds of species of bacteria and fungi that grow indoors when sufficient moisture is available. Exposure to microbial contaminants is clinically associated with respiratory symptoms, allergies, asthma and immunological reactions.

The presence of many biological agents in the indoor environment is due to dampness and inadequate ventilation. Excess moisture on almost all indoor materials leads to growth of microbes, such as mould, fungi and bacteria, which subsequently emit spores, cells, fragments and volatile organic compounds into indoor air. Moreover, dampness initiates chemical or biological degradation of materials, which also pollutes indoor air. Dampness has therefore been suggested to be a strong, consistent indicator of risk of asthma and respiratory symptoms (e.g. cough and wheeze). The health risks of biological contaminants of indoor air could thus be addressed by considering dampness as the risk indicator.

The report’s conclusions include:

- Sufficient epidemiological evidence is available from studies conducted in different countries and under different climatic conditions to show that the occupants of damp or mouldy buildings, both houses and public buildings, are at increased risk of respiratory symptoms, respiratory infections and exacerbation of asthma. Some evidence suggests increased risks of allergic rhinitis and asthma. Although few intervention studies were available, their results show that remediation of dampness can reduce adverse health outcomes

- There is clinical evidence that exposure to mould and other dampness related microbial agents increases the risks of rare conditions, such as hypersensitivity pneumonitis, allergic alveolitis, chronic rhinosinusitis and allergic fungal sinusitis

- Toxicological evidence obtained in vivo and in vitro supports these findings, showing the occurrence of diverse inflammatory and toxic responses after exposure to microorganisms isolated from damp buildings, including their spores, metabolites and fragments

- While groups such as atopic and allergic people are particularly susceptible to biological and chemical agents in damp indoor environments, adverse health effects have also been found in nonatopic populations

- The increasing prevalence of asthma and allergies in many countries increase the number of people susceptible to the effects of dampness and mould in buildings.

Wright, Gillian R. The effect of domestic mechanical heat recovery ventilation on asthma control of patients allergic to the house dust mite. Diss. University of Glasgow, 2008.

The prevalence of asthma has increased over the last generation, in parallel with a warm indoor microclimate. Central heating, fitted carpets and tight building construction have improved standards of heating and energy efficiency in homes, at the expense of ventilation.

Large studies of conventional measures to eradicate dust mites, such as mattress covers, have not shown a benefit for symptoms of asthma. As house dust mites are sensitive to humidity, an additional strategy would be to reduce indoor air humidity by improving ventilation. A randomised, double-blind placebo-controlled study examined the effect of the installation of domestic mechanical heat recovery ventilation on asthma control in the homes of 119 adults sensitive to house dust mite allergen.

The study involved collaboration between the University Departments of Architecture, Respiratory Medicine and Immunology, local General Practices, the district general hospital, the local councils and industry. 100 participants completed follow-up. At twelve months, there was a clinically significant improvement in evening peak expiratory flow in the mechanical ventilation group and fewer admissions to hospital with asthma.

Rhinitis visual analogue scores for sneezing, nasal discharge and nasal blockage significantly improved in the group with mechanical ventilation compared to the control group at 6 months.

In the mechanical ventilation group there was a modest individual gain of 0.02 Quality-adjusted life years over 12 months. However, it may still prove a cost-effective intervention if the clinical effects are sustained. Further research is required to establish if the clinical effects are sustained for greater than one year and to investigate the mechanism of the effect of improved home ventilation on respiratory health.

Yegambaram Manivannan,et al. Role of Environmental Contaminants in the Etiology of Alzheimer's Disease: A Review. Curr Alzheimer Res. 2015 Feb; 12(2): 116–146.

The link between air pollution and dementia is currently under investigation, as studies suggest exposure to environmental factors, including indoor air pollution, could contribute to an increased risk of developing dementia.

Alzheimer's disease (AD) is a leading cause of mortality in the developed world with 70% risk attributable to genetics. The remaining 30% of AD risk is hypothesized to include environmental factors and human lifestyle patterns. Environmental factors possibly include inorganic and organic hazards, exposure to toxic metals, pesticides, industrial chemicals and air pollutants.

Recent studies have implicated particulate matter (PM) in the causation of AD and other neurodegenerative disorders.

The authors suggest that particle exposure activates the pathogen sensors and reactive oxygen species, thereby generating brain inflammation. Importantly, human and animal

studies suggest that air pollution (PM, gases, organic compounds, and metals) may cause an increased expression of markers associated with neurodegenerative disease pathologies and also may cause developmental neurotoxicity contributing to the etiology of neurodevelopmental disorders. Epidemiological, observational, clinical, and experimental studies have reported that air pollution causes diseases of the central nervous system including AD.