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Indoor environmental quality in refurbishment

Richard Hobday

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Definitions

Indoor environmental quality (IEQ) and **indoor air quality (IAQ)** are terms referring to the environmental qualities within a building, used especially in relation to the health and comfort of building occupants.

Indoor environmental quality (IEQ) generally encompasses factors such as temperature, humidity, ventilation, indoor air quality, daylighting and lighting quality, thermal comfort and access to views.

Indoor air quality (**IAQ**) can be affected by microbial contaminants (including mould and bacteria), gases (including carbon monoxide [CO], carbon dioxide [CO_2], radon [Rn], volatile organic compounds [VOC]), and particulates [e.g. water]), or any mass or energy stressor than can induce adverse health conditions. Sometimes, IAQ also encompasses temperature, humidity and ventilation.

IEQ is one of five categories of the LEED (Leadership in Energy & Environmental Design) building assessment system, developed by the Green Building Council of the United States of America (USGBC). In the United Kingdom, assessments are often carried out under the BREEAM (BRE Environmental Assessment Method) building assessment system, developed by BRE (Building Research Establishment). In BREEAM, factors such as visual comfort, indoor air quality, thermal comfort and acoustic performance are included in the category 'Health and Wellbeing'.

Historic Scotland Technical Paper 12

Indoor environmental quality in refurbishment

Contents

Introduction

Historic Scotland Technical Paper 12 forms one of a series of three reports, Technical Papers 12 to 14, that look at some of the wider issues concerning the existing built environment and how it is altered to respond to current and emerging pressures regarding energy efficiency. These reports comment on topics that are often not fully investigated in the mainstream discussions on energy efficiency and the domestic housing stock. The topics are: embodied energy (How do we use carbon, and how is it accounted for in upgrade work?), considerations on how to heat traditional home (Are we doing it the right way?), and the topic of this paper that looks at what lessons can be learnt from the way we used to design and ventilate buildings for health.

Many factors in the built environment change and develop over time: the materials we use, the configuration and design of the structures that society creates, and the layout and design of settlements and communities. These are cultural and stylistic changes. However, a less noticed change is how current norms regarding building design and servicing have changed significantly from one where public health in buildings was the guiding principle to one where comfort, especially uniform comfort, has become dominant. That is not to say that being comfortable is somehow incorrect but that the guiding principle of health is now subordinate to other factors. The report considers some of these arguments, mainly by comparison with developments in the healthcare sector over the last few hundred years but the comments still hold for domestic structures. In improving energy efficiency, care must be taken not to substitute one set of problems with another which could be those reduced levels of public health. A delicate balance needs to be developed in retrofit and upgrade to ensure energy efficiencies are realised whilst the health and wellbeing of the occupants is maintained. This report asks questions in this area, on how we might achieve that balance, and also provides recommendations for further research.

Some of the themes in this series of three papers overlap, and this is deliberate, for in discussion of upgrade options many factors come into play, and in complex systems boundaries are sometimes fluid. The views expressed in these reports are those of the authors and not those of Historic Scotland or the Scottish Government.

Research report

Indoor environmental quality in refurbishment

Dr. Richard Hobday

July 2011

About the author

Dr. Richard Hobday MSc PhD CEng MEI

Richard Hobday is an engineering consultant who has been has been involved in a wide range of projects concerned with sustainability and health in the built environment. He received his MSc and PhD from Cranfield University, where he specialized in energy conservation.

An Energy Institute member and Chartered Engineer, Dr. Hobday teaches and lectures internationally, and has a number of design guides to his name, as well as two critically acclaimed books, *The Healing Sun: Sunlight and Health in the 21st Century* (1999), which has been translated into seven languages, and *The Light Revolution: Health Architecture and the Sun* (2006).

Contents

Abbreviations

BRE	Building Research Establishment	13
BREEAM	BRE Energy Assessment Method	13
CSH	Code For Sustainable Homes	13
IAQ	Indoor air quality	10
IEQ	Indoor environmental quality	6
LEED	Leadership In Energy and Environmental Design	12
MDR TB	Multi-drug-resistant tuberculosis	16
MRSA	Methicillin-resistant Staphylococcus aureus	16
MVHR	Mechanical ventilation with heat recovery	13
NHS	National Health Service	14
SAD	Seasonal affective disorder	6
SARS	Severe acute respiratory syndrome	11
SBS	Sick building syndrome	11
SHS	Sick house syndrome	12
TB	Tuberculosis	16
VOC	Volatile organic compounds	6

Executive summary

The Scottish Parliament has set ambitious targets for reducing carbon emissions – 42% by 2020, and 80% by 2050. If these are to be met, the building sector will have to be made sustainable and energy-efficient. This will require an extensive refurbishment programme. But it is not clear that all the measures proposed are appropriate for many older buildings, which were designed for natural ventilation and radiant heating. They were also meant to be permeable to air and moisture, having high air change rates and a thermally heavyweight envelope. If their refurbishment follows the airtightness and ventilation strategy required in all new buildings it might prove harmful to occupants – and to the buildings. They will not be sustainable if they are unhealthy.

Unfortunately, much that was once known about creating healthy indoor environments has been overlooked in recent years. There is also a notable lack of published data on indoor environmental quality in highly energy-efficient buildings (including both indoor air quality and other health factors, such as heating, lighting and ventilation). This report shows:

- The health effects of sealing buildings and of other measures now used to improve energy performance have not been properly assessed.
- Low-energy refurbishment could have unintended and adverse consequences. These include reduced indoor air quality and reduced natural lighting, together with overheating and other hazards.
- Rather than refurbish older building types to match the conditions now required in new-built ones, a combination of radiant heating and natural ventilation might create a healthier, more sustainable environment.
- With a combination of radiant heating and natural ventilation, air change rates could be higher than those currently specified. This would reduce the risk of health problems associated with poor indoor air quality.
- Another way to improve indoor air quality would be to avoid specifying materials and products that emit hazardous chemicals or prevent the movement of moisture.

Traditional structures often have innate health benefits. The best of them were carefully planned with high levels of natural light, space and other features conducive to well-being. The relatively new 'build tight, ventilate right' approach to refurbishment, while logical for energy efficiency, may nullify these benefits and compromise indoor environmental quality.

The findings of this report suggest that the refurbishment of older buildings requires a sympathetic approach. Ideally, refurbishment should improve any inherent environmental performance features. It might also help reduce the burden on NHS Scotland of respiratory disease, allergy and other health problems.

A balance needs to be struck between keeping building occupants healthy and reducing carbon emissions. Cold, damp housing poses a threat to health, but so does housing that overheats or concentrates pollutants. The challenge is to refurbish traditional buildings to an energy-efficient standard that maintains and promotes their health benefits.

1. Introduction

There are two ways of making buildings energy efficient – and they are fundamentally different. One goes back many centuries, the other is recent. The old way was to use local, natural materials and adapt a building to the local climate. In colder regions, this meant orienting buildings to benefit from winter sun and to exclude summer overheating. The fabric and internal spaces were often arranged to allow cool air to circulate in summer and warm air in winter. Such buildings had high levels of natural ventilation, plenty of natural light, and a radiant heat source. The traditional approach to energy efficiency produced structures with a low environmental impact – and healthy living conditions. In some cases the site was carefully chosen for its health-giving properties. The architecture of ancient China and Imperial Rome embodied these principles.[1] Some of the same features can be found in older British buildings.[2]

Two hundred years ago, Scotland was at the forefront of planning for health. At the beginning of the 19th century, the social reformer and philanthropist Robert Owen shaped a model community at New Lanark to improve the environment, education and well-being of millworkers and their families. Mr. Owen's pioneering social experiment at New Lanark attracted interest from around the world and inspired other enlightened industrialists to plan and build for health. Conditions in the workers' housing at New Lanark contrasted with the dark insanitary slums occupied by many working people at that time. Mr. Owen insisted on adequate ventilation.[3] He was not alone in this. Others, before and since, have stressed the importance of good ventilation in maintaining and improving health. In the past, ventilation rates in houses, schools and hospitals were kept high. Recent research supports the idea that high air change rates (via open windows) reduce the risk of respiratory infection.[4]

By contrast, current codes and regulations favour sealed, highly insulated buildings which exclude the external environment rather than adapt to it. With this strategy, ventilation rates are lower than in older designs, and heating is by convection rather than from a radiant source. As insulation levels rise, heat losses from ventilation assume greater importance. The maxim 'build tight, ventilate right' now holds sway. The aim is to make a highly insulated envelope airtight while, at the same time, upholding indoor air quality. But it is not clear what a 'right' ventilation is or how it is best achieved, as this report will show. Whether an airtight, highly insulated building provides a healthy living environment has yet to be determined. There is a notable lack of published research both on indoor air quality and other health factors in the latest generation of energy-efficient buildings.[5]

The same is true of refurbishment work. In order to achieve the targets, set by the Scottish Parliament, for reducing carbon emission of at least 42% by 2020, and 80% by 2050, the building sector will have to perform far better in energy terms than it does now.[6] It seems that refurbishment work will follow the same airtightness and ventilation strategy required in all new buildings.[7] Again, the health effects of this are not known. There is evidence that raising the thermal performance of some housing can improve health.[8] But making them highly energy-efficient may have negative impacts, and these have not been adequately assessed.[9] There has been little research into the way in which low-energy buildings perform and how people behave in them.[10]

Traditional structures often have innate health benefits, developed through many hundreds of years of trial, error and observation. The 'build tight, ventilate right' approach may nullify these benefits, or it could make conditions worse. For example, the fabric of older buildings is usually permeable to moisture and so can disperse moisture that has built up through occupation and topography. Ventilation rates have to be high enough to remove much of this moisture. Otherwise dampness in the building fabric will lead to the growth of toxic moulds and other microbial and biological agents that can cause health problems. The risk of timber decay can increase, too.[11] In recent years, the moisture burden in housing has increased as hygiene standards have improved. Ventilation rates have fallen. Also, many of the construction materials in use today are not hygroscopic and so are not able to buffer humidity. They can also act as a barrier to moisture movement. In addition, many building materials contain, and give off, potentially harmful chemicals, such as formaldehyde, a volatile organic compound (VOC) long associated with indoor air pollution. Common VOC emitters include particleboard, fibreboard, plywood, insulations, paints and adhesives.[12]

Saving energy by making buildings more airtight may concentrate moisture and any potentially toxic gases given off by building materials, and it may concentrate other pollutants. The average person now spends 22 out of every 24 hours indoors, which extends their exposure to what has been described as a 'chemical soup' of indoor pollutants. Certain contaminants can be many times higher indoors than in the air outside – occasionally 100 times higher.[13] This may be a factor in the dramatic increase in the prevalence of asthma, eczema, rhinitis and other allergic disorders. These are very common in Scotland, affecting over one in three of the population at some point in their lives.[14] Changes to the indoor environment are implicated. Warm, humid conditions and low ventilation rates are more common than they used to be. So the current drive to reduce carbon emissions from buildings comes with a health warning:

"Ambitious energy conservation programs should not lose sight of the lessons learned 40 years ago when sealing buildings with reduced ventilation led to sick building syndrome, combustion source problems and mould with associated health and productivity losses."[15]

Also, daylighting levels indoors are much lower than those outdoors. Prolonged exposure to low daylight levels can have adverse effects. Seasonal affective disorder (SAD) is a depressive illness that occurs in relation to daylight exposure.[16] Recent research supports the hypothesis that people in industrialised countries do not get enough daily light exposure for optimal health.[17] Reduced ventilation and reduced daylight could be two unintended consequences of imposing the 'build tight, ventilate right' approach to low-energy refurbishment.

This report outlines considerations – lessons from the past – to be kept in mind, when planning energy-efficiency refurbishments of older buildings, in order to achieve good standards of indoor environmental quality (IEQ) including heating, lighting and ventilation.

2. Healthy buildings

The idea that the built environment can influence public health, for good or ill, is not new. In the 4th century B.C., the Greek doctor Hippocrates wrote about the orientation of cities. He noted that cities with an easterly aspect "between the summer and winter risings of the sun" had healthiest residents.[18] Diseases were fewer and less severe in cities so situated. Later, during the 1st century B.C., Marcus Vitruvius Pollio, the Roman military engineer and architect, wrote his famous *Ten Books on Architecture.*[19] Vitruvius said that one of the skills architects needed was a working knowledge of medicine. They would then be able to select healthy sites both for cities and for the buildings within city walls. Vitruvius believed that careful design of buildings, such as theatres and temples, prevented illness and that street planning could help the cure of chronic sicknesses, such as tuberculosis.

Vitruvius also described how buildings should be arranged for the sun and oriented for comfort and energy-saving. The solar architecture of dwellings had to be adapted to suit the different climates of the Roman Empire:

"One type of house seems appropriate to build in Egypt, another in Spain, ... one still different in Rome, and so on with lands and countries of other characteristics. This is because one part of the earth is directly under the sun's course, another is far away from it, while another lies midway between these two. ... it is obvious that designs for homes ought ... to conform to the nature of the country and to diversities of climate."[20]

With the fall of Rome, the practice of laying out towns and buildings with due care for the health and comfort of inhabitants came to an end in Europe. So-called 'folk' architecture continued to demonstrate some of the principles described by Vitruvius. The aristocracy sometimes commissioned architects who had an understanding of them.[21] But planning for health in the manner of the Greeks and Romans had become "an art of intermittent activity."[22] During the Middle Ages, towns often consisted of one or two dominant buildings, such as a castle or church, one or two main avenues, and narrow lanes with squalid housing. Inhabited areas were not generally considered as one unit. During the 18th century, the art of planning streets enjoyed a revival thanks to the efforts of, among others, the architects John Wood, the Elder, at Bath and James Craig at Edinburgh.[23] Then came Owen's New Lanark. And in the 1860s, Florence Nightingale, a nurse, writer and statistician, set out how to create healthy healing indoor environments.

Like Vitruvius, Ms. Nightingale believed good design could shorten the course of diseases. She identified five essential features of a healthy dwelling: pure air, pure water, efficient drainage, cleanliness and light – especially sunlight.[24] Ms. Nightingale insisted that hospital wards, like houses, should provide patients with fresh air through open windows and with direct sunlight. Making conditions indoors as close as possible to those outside was thought to be both therapeutic and hygienic. Sunlight and fresh air prevented the spread of infections and speeded the recovery of the sick.[25] During the 1920s, Sir Leonard Erskine Hill, the director of the Department Of Applied Physiology at the National Institute For Medical Research, reached similar conclusions. Prof. Hill identified several factors that promote health in buildings. He concluded that the human body needs the stimulus of constantly changing conditions, and so a monotonous indoor environment was to be avoided. Like Ms. Nightingale, he favoured sunlight, fresh air and a radiant heat source.[26]

A century ago, town planning and good housing were seen as key to improving public health, but, with the passage of time, building design and even town planning stopped being seen as health interventions in themselves. The idea that a building could be therapeutic fell from favour. Creating comfortable conditions assumed greater importance than promoting health. The current move towards airtight building envelopes with sealed glazing, mechanical ventilation and convective heating continues this trend. It favours an environment which Prof. Hill and Ms. Nightingale warned against.

3. Health and refurbishment

At one time, typical Scottish houses were heated by solid fuel fires. These provided radiant heat and ventilation via chimneys. One of the biggest changes to occur in housing over the last 50 years is that radiant heating has been replaced by convection from 'radiators'. In 1970, some 31.1 percent of British homes had central heating. By 2006, this had increased to 90.1 percent. The average temperature in British housing was just 12.1°C in 1970. It had risen to 17.7°C by 2006.[27] So, indoor temperatures have increased, while ventilation rates have fallen due to, in part, the sealing of open fireplaces and the replacement of windows.

There may have been health benefits. A lack of central heating is associated with an increase risk of dying in winter.[28] Excess winter mortality is an important health issue in Scotland. So is fuel poverty. There is evidence that warmer, less humid housing improves health. Eliminating damp and mould and raising temperatures to comfortable levels can have a positive impact. For example, a study of residents in blocks of flats in the Easthall area of Glasgow showed that they experienced a significant fall in blood pressure when their accommodation was upgraded. They also gained an improvement in general health, as shown by a reduction both in medication use and in hospital admissions.[29]

The results of the Glasgow study suggest that there is much that could be done to the existing housing stock in Scotland to improve public health. But the potential for success of projects, such as this, may depend on the baseline condition of the housing. It seems that interventions of this kind require careful targeting if they are to be successful.[30]

The widespread adoption of central heating may have saved lives in the winter, but it may also have had a negative impact on health in the longer term. Increased average indoor temperatures, reduced background ventilation rates and other changes may have led to a significant increase in the concentration of house dust mite. This, in turn, could be the causal factor in the rising incidence of asthma in children.[31] The UK has amongst the highest prevalence of respiratory symptoms and asthma worldwide. Studies indicate that between the mid-1960s and mid-1990s, asthma prevalence in the UK increased by about 5 percent per year.[32] In addition to asthma, increased indoor temperatures have been linked to an increased incidence of obesity. The human body expends less energy in temperature ranges typical in modern buildings.[33] Ninety years ago, Prof. Hill, concluded that over-warm conditions were a factor in obesity, together with lack of exercise and too much food. But the link between indoor air temperatures and obesity does not appear to have been investigates since then.

Summer temperatures pose another potential risk to the health of building occupants. People in highly insulated buildings may be especially vulnerable. In August 2003, a heatwave caused more than 35,000 deaths in Western Europe, including 14,800 deaths in France. The burden for England and Wales, where temperatures were not as extreme, was some 2,000 deaths.[34] During heat waves, people in regions where very hot weather is relatively infrequent are at most risk. They have difficulty adapting, and their housing is not suited to the conditions. The elderly are particularly vulnerable.[35]

There have been few studies of overheating in highly insulated housing, but there is evidence that this can be a significant problem, particularly in summer. Only a small increase in heat gains over losses can lead to high temperatures. Significantly, overheating can even become a problem during the heating season if solar gains, resulting from lower sun angles, are not controlled. Heatwaves and high summer temperatures are less likely to trouble the central belt of Scotland than they are central London. However, overheating could still occur in refurbished properties that are highly insulated.

The literature suggests that dwellings with thermal mass are better able to cope with overheating than thermally lightweight ones. Also, mechanical ventilation systems may not be able to cope at high outdoor temperatures. Normally, they provide fresh air at a rate of about 1 to 1.5 air changes per hour. But this may not be enough to remove excess heat during warm weather. The results of thermal modelling suggest that night-time ventilation rates of 10 air changes per hour may be needed to remove unwanted heat from the thermal mass of a highly insulated house.[36] One alternative is to use air conditioning, and, indeed, it is already being used in some new dwellings. However, this runs counter to the principle of reducing carbon emissions:

“Overheating is not only a problem for future, low energy homes. It is a real risk for dwellings being built to today’s standards, and in today’s climate. Air conditioning already features in many of the higher quality new flats being built in London. But the risk will be exacerbated by climate change.”[37]

A traditional method of limiting overheating in buildings is to design for high levels of natural ventilation. Window detailing often played an important part in this, as it allowed controlled ventilation in summer. For example, one feature of sash windows is that they can promote the cooling of interiors during warm weather. With the top and bottom of a sash window opened by equal amounts, warm air at the top of a room can escape, and cooler air from outside is drawn into the space through the bottom opening. Other traditional features, such as shutters and blinds, can control direct sunlight in the summer and keep heat gains down as required. By contrast, there is a trend in modern developments to limit window sizes and exclude direct sunlight altogether. This could become more common in refurbishment projects as insulation levels approach those in new-build. Keeping the sun out does reduce the risk of overheating. But low light levels, like low ventilation rates, are linked to health problems in buildings.

4. Indoor air quality and health

There is increasing concern within the scientific community about the effects of the indoor air quality (IAQ) on health. There is also a growing public awareness of the risks associated with poor indoor air quality in the workplace and the home.[38] The accumulation of chemical pollutants, such as VOCs, poses a significant hazard. This is a recent development. A century ago, the off-gassing of pollutants from synthetic building materials was not a problem. Rather, the overriding concern was to prevent the spread of infectious diseases. Codes and standards set high ventilation rates to dilute air to minimise the risk of airborne contagion. At the end of the 19th century, tuberculosis was endemic in Britain. According to one estimate of the period, it claimed more than 1 million lives in Europe each year, and figures for the UK show that tuberculosis caused the deaths of about 1 in every 8 of the population.[39] Other potentially lethal respiratory diseases have been linked to housing. They include diphtheria, scarlet fever, pneumonia, meningitis, whooping cough, measles, mumps and rubella.[40]

Ventilation rates in buildings have fallen markedly over the last hundred years. Research indicates that, in terms of volumetric air-flow, a late Victorian Scottish tenement had more than nine times the rate of a modern timber-frame house.[41] The presence and use of open chimney flues in tenements accounts for much of this difference. Figures published in 1905 suggest that a typical fireplace of the period would move 10,000 cubic feet (283 m^3) of air per hour; and an ordinarily fitting window, when shut, would allow 300 to 480 cubic feet (0.14 to 0.22 m^3) of air per hour to pass into a room. The minimum air exchange rate recommended for occupant health was thought to be 3,000 cubic feet (85 m^3) per person per hour.[42]

This is excessive by today's standards, but, at the time, fresh air in buildings was held to be hygienic and therapeutic. Ms. Nightingale was keen on high ventilation rates. Best remembered as 'The Lady of the Lamp' because of the way she cared for the sick and wounded during the Crimean War, she went on to become an international authority on the design of hospitals. Ms. Nightingale considered fresh air to be of the utmost importance providing a healthy healing environment for the sick. She stipulated that the first canon of nursing was that air indoors had to be as fresh as it was outside – without chilling the patient.[43] And it had to come into a building via the windows. In her opinion, no system of mechanical ventilation could supply air which was really fresh. There was no guarantee that the incoming air would not mix with contaminated air. Ms. Nightingale held that, if a hospital had to be ventilated mechanically, it was because the original construction was defective. Natural ventilation and open fireplaces were the only suitable means of renewing and warming the air in hospitals. An open fireplace supplied radiant heat, and its chimney was indispensable as a ventilating shaft. Radiant heat was considered natural, whereas air heated by metal surfaces was to be avoided, particularly if it was supplied by the ventilation system. Health was not to be sacrificed because of bad design or to save energy.[44] Two of the features which distinguished Ms. Nightingale wards were extensive glazing, with a minimum of one window to every two beds, and cross-ventilation. Also, wards had high ceilings, so that the cross-ventilation layout would provide a supply of gently moving air high up – without draughts.

With the passage of time, better public health provision and improved living standards led to a decrease in the incidence of tuberculosis and other airborne infections. As the need to control them became less urgent, the rationale for ventilation changed. Rather than prevent infection, the aim was to create comfortable conditions and remove odours produced by occupants.[45] Standards based on comfort remained in place until the Arab Oil Embargo in October 1973, when energy efficiency became a priority. Air change rates fell further to save fuel. The phenomenon that became known as sick building syndrome (SBS) soon appeared. It was characterised by an array of temporary symptoms and conditions, such as headache, dry eyes, nasal congestion, nausea and fatigue. The syndrome was linked to inadequate ventilation and was sometimes called 'tight building syndrome'.[46]

In 1976, an outbreak of respiratory illness at a hotel in Philadelphia, PA, USA, proved a turning point. Delegates at an American Legion convention suffered 182 cases of pneumonia and 29 deaths. The infection was caused by a previously unrecognised bacterium later named *Legionella pneumophilia*. The hotel's ventilation and humidification system was found to be the source of the bacterial exposure.[47] This outbreak revived interest in IAQ and health in buildings.[48]

Nevertheless, in the years that followed relatively little research work was done on airborne transmission of bacteria and viruses. It seems that the threat to health posed by airborne microbes has been underestimated.[49] They are still a cause for concern. Pandemic influenza has recently been at the top of the health agenda, while multi- and extensive drug-resistant tuberculosis is a threat to public health.[50] Ventilation and airflow in buildings may have played a significant role in some of the SARS (severe acute respiratory syndrome) outbreaks in 2003.[51] SARS could re-emerge, or another novel infectious agent could appear which prospers in the modern built environment.[52] There is strong evidence that ventilation and air movement in buildings is involved in the spread of other infectious diseases, such as measles, tuberculosis, chickenpox, influenza and smallpox.[53] New data suggest influenza can be transmitted via the airborne route.[54]

Modern buildings are not arranged to prevent the spreading of diseases. In recent years, the trend has been to design new buildings, and to retrofit old buildings, to reduce the contribution of fresh outdoor air to indoor ventilation. Significantly, the minimum amount of ventilation needed to prevent the spread of infectious diseases, such as SARS, influenza and tuberculosis, is unknown.[55] More fresh air may be needed than is currently specified for hospitals, schools, offices and homes.[56]

Indoor air contamination

The air inside a modern dwelling includes a mixture of particulates (such as dust and pollen), gases (such as nitrogen dioxide, ozone and carbon monoxide and VOCs) and biological agents (such as bacteria, fungi –e.g. moulds– and viruses). Contaminants come from outside and from various indoor sources. The latter include building materials, carpets, furnishings, the occupants, pets, household items and everyday practices, such as heating, cooking, cleaning and home repair.[57] Personal exposure to them has increased, because of reduced air exchange rates and increased time spent indoors.[58] Moulds can release microbial VOCs. These have been associated with eye, nose and throat irritation; wheezing and cough; headache and fatigue; and dizziness.[59] Chemical pollutants indoors can be persistent, presenting health risks for years beyond their use. Many of those now found in indoor environments (and in the urine and blood of building occupants) were not present 50 years ago.[60] And the air change rates typical of modern dwellings may be low enough for chemical reactions to occur.[61] Organic pollutants in indoor air can react with ozone, producing highly reactive compounds. These can, in turn, react with the skin or mucous membranes.[62]

The main purpose of ventilation is to remove such pollutants or dilute them to levels that are not harmful to health and do not cause discomfort. Until recently, houses in Britain relied for fresh air on a combination of air filtration through gaps in the building fabric and through window openings. This is set to change in response to the performance targets set in the building regulations and other codes and standards. Significantly, the amount of outdoor air needed to keep building occupants healthy has been debated for years and remains uncertain.[63] Little information exists on permissible exposure levels for known indoor air pollutants in the home or non-industrial workplace.[64]

When ventilation rates are measured in buildings, the results often reveal significant gaps between the design intent and performance. Studies from many countries show high levels of dissatisfaction in buildings in which ventilation standards are met.[65] There is a notable lack of data on the impact of ventilation rates below 0.5 air changes per hour on airborne contaminants, moisture extraction or respiratory health. However, there is strong evidence of an association between IAQ and lung cancer, allergies and other hypersensitivity reactions, such as multiple chemical sensitivity and SBS.[66] People with existing medical conditions, such as asthma, allergies and connective tissue disorders, are at even greater risk than the general population. So are those whose immune systems are suppressed by medications, such as steroids or chemotherapeutic agents.[67]

In Japan, where the inefficient ventilation of tightly sealed rooms has caused health problems, SBS is called sick house syndrome (SHS). This came about because symptoms of SBS were reported in people living in houses as well as schools and offices. Chemical emissions from building materials are now measured in Japan, and their use is controlled. The rate of SHS in newly-built residences has fallen since new regulations there came into force.[68]

Denmark uses a labelling system that rates VOC emission from building materials according to its impact on comfort and health.[69]

Other countries do not control building materials in this way. In the United States, the LEED (Leadership In Energy And Environmental Design) certification programme for sustainable new and renovated buildings has been criticised on these grounds. The recent report *The Green Building Debate: LEED Certification: Where Energy Efficiency Collides With Human Health*[70] notes that many of the building materials in use today contain chemicals considered to be hazardous by the World Health Organisation, the U.S. National Toxicology Program, and the U.S. Centre For Disease Control. Yet few of these chemicals have been regulated in building products:

"The overwhelming majority of chemicals in the built environment remain untested individually or as chemical mixtures that are routinely released to indoor environments. Thus new products may incorporate tens of thousands of untested chemicals with no government oversight."[71]

The report also argues that a building can gain the highest LEED certification rating even if it makes no improvements in IAQ and in spite of hazardous chemicals being present in the materials used in its construction. Programmes such as LEED, BREEAM (BRE Energy Assessment Method) and CSH (Code For Sustainable Homes) are weighted towards energy efficiency. They place less emphasis on health and, in particular, the impact of the off-gassing of chemicals from building materials.

The key aim of Part F of the English building regulations is to limit the accumulation of pollutants and moisture that would otherwise be harmful to occupants.[72] The document sets exposure limits for nitrogen dioxide, carbon monoxide and VOCs. Part F offers guidance on how these criteria can be met, but it does not set limits for chemical emissions from building materials, nor does it address the airborne spread of infection and how buildings should be designed to prevent it.

Natural or mechanical ventilation?

It seems likely that properties built to the CSH level 5 or 6 ratings, i.e. the best possible ratings, will need mechanical ventilation with heat recovery (MVHR) to achieve an acceptable indoor climate.[73] If existing buildings are refurbished to a similar standard, they may need MVHR, too. Mechanical ventilation was, at one time in the 19th century, thought to be healthier than natural ventilation. The thinking was that air breathed by the sick and infirm had to be filtered, warmed, moistened and delivered to them without draughts.[74] As noted earlier, Ms. Nightingale opposed mechanical ventilation in the 1860s. In the years that followed, the sanatorium regimen of treating diseases, such as tuberculosis, in the open air became popular.[75] Together with this and the work of scientists, such as Prof. Hill on the physiological action of moving air, opinion changed. Mechanical systems of ventilating hospitals and schools were scrapped in favour of natural cross-ventilation.[76]

Recent findings suggest that the risk of transmission of airborne diseases is lower in naturally ventilated spaces than in mechanically ventilated ones. Significantly, older buildings with large windows and high ceilings appear to be much safer than more recent designs in this respect. In a study published in 2007, researchers measured natural ventilation in 70 different rooms in hospitals where tuberculosis patients were being treated. These included respiratory wards, general medical wards, outpatient consulting rooms, waiting rooms and emergency departments. They compared air exchange rates in these rooms with those in mechanically ventilated, negative-pressure respiratory isolation rooms. An airborne infection model was then used to predict the effect of these ventilation rates on tuberculosis transmission. The highest risk of infection was in closed, unventilated spaces. By contrast, clinical rooms in hospitals built before the 1950s with high ceilings and large windows on more than one wall gave the greatest protection.[77]

Modern wards with low ceilings and small windows were associated with higher risk of airborne contagion. Mechanically ventilated rooms with sealed windows had even greater risk, despite being ventilated at the rates recommended by guidelines. The results suggested that, after 24 hours of exposure to untreated tuberculosis patients, some 39 percent of susceptible individuals in mechanically ventilated rooms would become infected. This compared with 33 percent in modern, naturally ventilated clinical rooms with windows and doors open; and just 11 percent in pre-1950 ones. Overall, natural ventilation, with windows and doors opened, was more than double that of mechanically ventilated, negative-pressure rooms. And even at the lowest wind speeds, natural ventilation performed better than mechanical ventilation. This research also showed that protective rates of ventilation are achievable with windows only partially open.

The large windows and high ceilings of many older buildings allowed 40 air changes per hour. The study assumed that the mechanical ventilation plant would deliver 12 air changes per hour. However, a subsequent inspection found poorly maintained electric motors, corroded fan blades clogged with deposits, and air extraction and supply fans unprotected by filters. In practice, the mechanically ventilated rooms in this study only achieved half the air changes they should have.[78] This is not unusual. As the authors of that paper noted, respiratory isolation rooms often do not deliver the recommended air exchange rates. Field studies have shown that ventilation systems in many hospitals fail to work properly because of poor design or construction, or because of poor maintenance. Such failings have been implicated in several outbreaks of tuberculosis.[79] As one expert, who reviewed this comparison of natural and mechanical ventilation, observed:

“The current practice of sealing in the local environment is probably the wrong route for hospital wards.”[80]

The same could be said of other building types. If airborne infections were to become more problematic, high levels of ventilation would be needed to disperse them. Newer, tighter buildings might not be safe, especially if they are mechanically ventilated. Pathogens (i.e. infectious agents, or germs) can be transported through ventilation systems, as has been documented for measles and tuberculosis.[81] Over time, dust can accumulate in duct-work. This can be a source for chemicals, allergens and microbes in the indoor air.[82] If mechanical ventilation systems are not designed, installed, commissioned, maintained and operated properly, the effects could be harmful. The experience of mechanical ventilation in hospitals is not encouraging.

Even if airborne infections do not become more severe, ventilation remains a major health concern. Respiratory disease kills one in four people in the UK, which is well above the European average. It is the most common long-term illness among children and costs the National Health Service (NHS) more than any other disease area.[83] Asthma care costs NHS Scotland over £130 million per year. It is likely to remain a burden for many years to come, because of the high proportion of children now affected.[84] However, research does show that improvements in IAQ, to levels above those typical of current practice and standards, decrease the risk of asthma and allergy in homes. They have also increased productivity in offices and improved learning in schools.[85]

5. Lighting and health

Illumination levels indoors are import to mental well-being.[86] Doctors in ancient Greece and Rome called the emotion associated with gloom and darkness 'melancholia'. During the 1980s, the link between daylight deprivation and depressive illness was scientifically proven.[87] In 2002, the discovery of 'non-visual' receptors in the eye provided an anatomical basis for the biological effects of light. Bright-light therapy is now established as an effective treatment for a range of psychiatric conditions, in particular sleep disorders and depression.[88] Both, seasonal and non-seasonal depression, are influenced by environmental illumination.[89] As noted earlier, daylighting levels indoors are far lower than those outside. Research shows that people in industrialised countries do not spend much time outdoors. So they do not get enough daily light exposure for optimal health.[90]

Surveys show that people prefer natural light. They believe that working by daylight results in less discomfort and less stress, and is better for their overall and visual health.[91] While daylight may not be inherently better than artificial lighting for most visual tasks, it is better for health. The human body has a biological clock in the centre of the brain. This internal clock controls a range of physiological functions, such as hormone production, core body temperature cycles, sleep-wake cycles and alertness patterns. Light entrains this circadian clock (*circa,* about; *diem*, a day) to the solar 24-hour day. Without light it 'runs free' at an average of about 24.25 hours. The light levels needed to regulate the body's circadian rhythms are higher than those needed for visual tasks.[92] Natural light is more effective for this than electric sources. First, it provides a higher light level at the eye. Second, it is more closely matched to the spectral sensitivity of the eye's non-visual receptors than most artificial light sources.[93] People prefer lighting levels which are significantly higher than current indoor lighting standards. These match levels where biological stimulation of the circadian system can occur. Building users prefer lighting that follows the daylight cycle instead of a constant level of illumination.[94]

In the past, architects designed hospitals, schools and other building types to admit the sun. As with fresh air, this was thought to be both hygienic and therapeutic. More than a century ago, Ms. Nightingale identified sunlight as key to promoting health in the sick:

"Direct sunlight, not only daylight, is necessary for speedy recovery, except, perhaps, in certain ophthalmic and a small number of other cases."[95]

She also insisted on sunlight, because she believed that it reduced the risks of cross- and re-infection. Ms. Nightingale's thinking was in advance of the available scientific evidence, but research soon began to support many of her assertions about the positive impact of sunlight. In 1877, two British scientists confirmed light, and especially sunlight, does have a bactericidal effect – even when it has passed through glass.[96] Their work prompted other scientists to study the effects of exposing bacteria to the sun's rays. Soon, sunlight was an important weapon in the fight against infectious disease. Before antibiotics became widely available, sunlit rooms and hospital wards were held to be hygienic, while those that did not admit the sun's rays were not. Architects began designing hospitals with large south-facing windows to prevent the spread of diseases. They built terraces and balconies where patients could be put in the sun under medical supervision. Homes were designed for the sun, too, with extensive glazing and solaria.

Today, in marked contrast, the germicidal properties of sunlight are rarely considered. However, there is a growing awareness of the presence of potentially harmful microbes in buildings. One of the pathogens that infect hospitals is becoming established in the wider community: The MRSA bacterium, or Methicillin-resistant *Staphylococcus aureus,* has long been a problem in wards and nursing homes where it infects patients weakened by disease or injury. But a strain has emerged that can infect healthy young people who have had no prior hospital exposure. Tuberculosis has re-emerged as a major health concern, mainly in the developing world, but also in the more developed countries of Europe.[97] In 2007, there were five cases of multi-drug resistant tuberculosis (MDR TB) in Scotland and 55 the UK as a whole. MDR TB is life threatening and is expensive both in terms of the types of drugs needed to treat it and the need for long periods in hospital. These are the highest numbers ever recorded across the United Kingdom.[98] There are also new pathogens, such as SARS and avian flu. With drug-resistant bacteria and novel viruses posing an increasing threat to public health, sunlight's germicidal properties merit more attention than they currently receive. So do the other health benefits of sunlit spaces.

Sunlight and indoor lighting

Opportunities to benefit from light of sufficient intensity to have a favourable impact on psychological and physiological well-being can be limited in buildings. This is especially the case if they are not arranged for the sun. Electric lighting provides a light level somewhere between 50 and 400 lux. Although this is usually adequate for vision, it is close to biological darkness for the body's circadian system. It needs to be over 1000 lux to have a positive impact on the human circadian system. This gives the same light intensity that someone experiences outdoors when the sun comes over the horizon. Outdoors at midday, sunshine can deliver a light level of 100,000 lux. And in a sunlit room there can be as many as 60,000 lux falling on a plane surface.[99] But without the time-cues given by the sun and, to a lesser extent, by the normal daily routines of breakfast, work, lunchtime, bedtime and so on, the underlying rhythm of the body can become disturbed. This can cause a range of health problems. Disruption of the body's circadian rhythms has been linked to depression, sleep problems, heart disease, diabetes, obesity, and breast and prostate cancer.[100]

During the first half of the last century, it was widely held that sunlit houses were healthier than those that excluded the sun's rays. In 1938, the American Public Health Association identified direct sunlight as a basic health requirement. Their Committee On The Hygiene Of Housing wrote:

"No definite quantitative limits can be set; but it is clearly desirable for all dwellings, and essential for those occupied by persons who are housebound, that direct sunlight should enter at some places and hours, even in winter. Sunlight, particularly through its ultraviolet components, provides valuable physiological stimulation."[101]

A growing body of evidence supports the principle that sunlit rooms can be healthier than those that are not. Research in hospitals shows that heart attack victims stand a better chance of recovery if they are in sunlit wards.[102] So do premature babies with jaundice.[103] In one study, patients in wards exposed to an increased intensity of sunlight suffered less stress and less pain, and needed 22 percent less analgesic medication per hour to cope with it.[104] Depressed psychiatric patients recover better if they get some sun while in hospital.[105] Researchers have also found that low levels of sunlight more than double the risk of cognitive impairment in people with a history of depression.[106]

Experiments with bright light – using light at levels above those normally found indoors – show that it has benefits beyond relieving the symptoms of depression. During the winter months it seems to be effective at improving vitality and reducing distress.[107] Continued, high intensity, daily, bright light can improve sleep patterns in the elderly and reduce the incidence of delirium in hospital patients.[108] Also, exposure to bright light may help with dementia. In one study, increasing light levels in the day-rooms of nursing homes to 1,000 lux slowed down the rate of cognitive decline in demented patients. It also improved their depressive symptoms and disturbed sleep patterns.[109] Findings such as these may explain why people who live and work in solar houses, offices and apartments have a high opinion of them.

The British standard on lighting, *BS 8206-2:2008 Lighting For Buildings: Code Of Practice For Daylighting*[110], discusses the importance of natural light in the well-being and satisfaction of building occupants. The recently revised version refers to seasonal depression and the entrainment of circadian rhythms. It points out that high levels of daylight are important to people of limited mobility, such as those in nursing homes and hospital wards. The standard also contains references to sunlight's germicidal properties, as well as the harmful effects of ultraviolet radiation. Unfortunately, the criteria set out in this standard are not compulsory. And as insulation levels increase in buildings and the risk of overheating goes up, there is less and less room for solar gains.

Orientation for health

The sun's rays are still let into some new buildings. At northerly latitudes this is for the purposes of heating rather than keeping the occupants well. The underlying principles of solar design for energy thrift differ from those for health promotion in a number of respects. For example, a south-facing orientation is widely recommended as being most suitable for saving energy. But this is not the best for health. There are two disadvantages with positioning a building in this way. The first is the area of complete shadow on the north side for one-half of the year, and the second is that there is more over-shading, or a longer shadow, than with any other position.

In the past, dwellings arranged for health often had a different orientation – away from due south. In part, this was for the purposes of sanitation. It can be much more difficult to clean and maintain an outdoor space which gets little or no sunlight than one which is sunlit. Wall surfaces, especially brick and stone walls, absorb a large amount of moisture when it rains. This moisture quickly dries when exposed to sunlight, but is retained for a long time in walls that do not get the sun. Dampness, with lack of sunlight, is a combination favourable to the growth of fungi –such as moulds– and other micro-organisms. This is why designers used to make sure that the exterior wall surfaces and the ground around hospitals and other buildings had the direct rays of the sun for as long a time as possible each day. It also meant that the occupants could get out in the sun for much of the year.

The best designs had their long axis placed as close to north-east and south-west as possible. This kept them free of shadow and allowed winter and early-morning sunlight in to disinfect the interior. Square buildings were also set on the diagonal, with the living room, or the rooms that are used most often during the day, placed at the southern apex. Many older buildings were arranged so that occupants could benefit from the therapeutic and germicidal properties of the sun. Such health advantages may be lost if buildings are refurbished. If they are insulated to a high standard, overheating may become a concern. In this case, keeping the sun out will be a priority. So, buildings designed for the sun may have to be reconfigured to keep direct sunlight out.

6. Heating and health

It is clear from the writings of Prof. Hill and Ms. Nightingale, amongst others, that the way in which a building is heated has health impacts. They both concluded that the environment within a building needs to be as close as possible to ideal outdoor conditions. Prof. Hill defined these as follows: cool breezes around the head; the radiant heat of the sun; and warm ground to stand on. Outdoors, the wind moves at a greater velocity at head than foot level, because of the friction of the moving air against the ground. Prof. Hill reasoned that if the head is cooled out of doors at a greater rate than the feet, then the same conditions should apply indoors:

"The ideal method of warming and ventilating rooms would give radiant heat, a warm floor, and agreeable movement of cool air – the conditions of a sunny spring day out of doors."[111]

His research showed that the warm, humid atmosphere typical of today's buildings reduces the body's capacity to produce heat. This, in turn, lessens the appetite, depth of breathing, muscular tone, vigour of circulation, and provoked relaxation and sleep. He concluded that the depression of the metabolism by too sedentary a life in too confined an atmosphere was a contributory cause of infection and other ailments.[112]

Prof. Hill made an important distinction between comfort and health. He argued that the aim should not be to pamper individuals by giving them comfortable indoor conditions, but to keep them strong and fit. Prof. Hill's premise was that humans have an inherent need to challenge and exercise their thermoregulatory system. There is some support for the view that designing for comfort may not be healthy in the longer term.

The human body's sympathetic autonomic nervous system controls both the cardiovascular and thermoregulatory systems. An increase in cardiovascular activity raises metabolic heat output which, in turn, must be balanced by the thermoregulatory system.[113] It is widely recognised that the cardiovascular system requires exercise for health. Prof. Hill's research suggests that the thermoregulatory system may need it, too. Current standards limit the thermal stimulation occupants may need for long-term health.[114] As noted earlier, the increased use of central heating may be contributing to rising obesity levels. Prof. Hill alluded to this in the 1920s. He argued that inadequate ventilation and stagnant heating, combined with overeating and taking too little exercise, posed a significant threat to health.

Today, heating to promote health is not considered in current standards and codes. There is little authoritative guidance on the subject. However, there are concerns about the health effects of the convected warm air that MVHR and other systems deliver. The World Health Organisation's guidance on healthy housing states that convective heating must be designed and maintained so as not to give rise to noise nuisance or distribute dust and bacteria around a building. Their guidance also states that:

"Radiant heating is preferred to heating by convected warm air wherever possible."[115]

Convective heat acts mainly on the skin. By contrast, radiant energy has a marked biochemical effect. As well as acting on the surface of the body, it stimulates deeper-lying tissues. This influence extends to the internal organs, the central nervous system and enzymatic processes.[116] Also, with a radiant heat source, air temperatures can be kept lower than with convective systems. A radiant source heats internal surfaces. Within limits, the warmer the internal surfaces, the cooler the air can be while still maintaining comfortable conditions. Studies show that people perceive IAQ to be better at lower air temperatures. There are health benefits and potential energy savings, as the book *The Physiological Basis Of Health Standards For Dwellings* outlines:

"comfortable conditions can exist with radiant heating at a lower air temperature, so that, with normal clothing, the tone of the muscular system is high, and there is a feeling of freshness and vigour."[117]

Two thousand years ago, the Romans made extensive use of radiant energy in buildings. They designed them to capture the heat of the sun. Solar energy was so important that they had right-to-sunlight legislation – which we do not.[118] They also combined solar design with their under-floor *hypocaust* radiant heating technology. Several centuries earlier, the Koreans developed under-floor heating and still prefer it to other forms of heating. Almost all buildings in Korea and northern China have radiant floor heating.[119] Also, in Germany, Austria and Denmark, some 30 to 50 percent of new residential buildings have under-floor heating systems.[120]

One advantage of a warm floor surface is that it can quicken blood flow in the feet through vasodilatation. This can improve some vascular-related disorders. In the 15th century, Korean under-floor heating systems were used to treat weak and elderly patients.[121] A further benefit of under-floor heating is that carpets are not needed. This removes a major source of house dust mite and other pollutants. In addition, there is less movement of dust; and the higher surface temperatures reduce condensation and mould growth. There are also potential energy savings: lower indoor air temperatures reduce ventilation heat losses.[122]

A further benefit of radiant under-floor heating is that it provides more uniform floor-to-ceiling temperature gradients than convective heating. A 3°C drop in vertical temperature can cause the lower limbs to feel cold and cause reflex changes in the temperature of the upper respiratory tract.[123] Radiant under-floor heating keeps the feet warm. One effect of this is the rise of the temperature of the nasal mucosa.[124] This, in turn, improves the ability of the nose to condition inspired air.[125] Conversely, if the feet become chilled, this causes a constriction of the blood-vessels in the nose. Recently, vasoconstriction of the upper airways has been proposed as a mechanism that reduces defence against infection. It cuts off the blood flow that supplies the white cells that fight respiratory illness.[126] This is not a new idea. Prof. Hill conducted experiments on this in the 1920s and reached similar conclusions. He was an advocate of under-floor heating and believed that the radiant energy of a fire was important for health, as it made up for the absence of sunlight. Prof. Hill concluded 90 years ago:

"There is no doubt that the radiant heat of an open fire and the ventilation maintained by it, and by an open window when necessary, is the most healthful in this climate of mist and cloud."[127]

In short, thermal comfort can be achieved by heating internal surfaces with a radiant source, rather than heating indoor air. There are potential health benefits to this approach. Also, as air temperatures can be kept lower, air tightness and, to some extent, insulation levels may not have to meet current standards to achieve a neutral carbon footprint. The potential of radiant heating to save energy via lower air temperatures, while improving health, has been overlooked. Modern radiant heat systems are available, but they are not at the forefront of heating codes and standards. They may have to be adapted for some older properties. One advantage of using them for refurbishment projects is that some elements of traditional buildings, notably high ceilings, are not then an impediment to good energy performance. With radiant heating, the volume of air in a space does not have to be warmed, but rather the objects and surfaces in it.

7. Conclusions

Many of the older buildings in this country, especially hospitals, were designed to secure the health of their occupants in ways that modern buildings are not. During the 19th and into the 20th century, the view gained ground that homes, hospitals and other types of property should promote well-being and not merely prevent disease. Energy efficiency was secondary to health. Improvements in ventilation, lighting and crowding are credited with helping to reduce the prevalence of tuberculosis. Today the position is reversed. The focus is now more on carbon emission savings and less on high standards of IEQ. The refurbishment of older properties seems set to follow the airtightness and ventilation strategy required for new buildings. This may improve thermal efficiency, but it ignores some of the lessons learned in the past about creating healthy indoor environments.

There is a dearth of published data both on IAQ and other health factors in highly energy-efficient buildings. The negative effects of sealing buildings and of other measures now used to improve their energy performance have not been properly assessed. What little evidence there is suggests that low-energy refurbishment could have unintended and adverse consequences. These include reduced IAQ and lighting, together with overheating and other hazards. Many of the construction materials now used in refurbishment act as a barrier to moisture flow. If damp accumulates, it can cause health problems and result in increased deterioration of building fabric. Also, construction materials now contain more potentially dangerous chemicals than they used to. Exposure to them has increased with reduced air exchange rates and increased time spent indoors.

A balance needs to be struck between keeping occupants healthy and reducing carbon emissions. Cold, damp housing poses a threat to health, but so does housing that overheats or concentrates pollutants. The ventilation rates specified in current codes and standards may not be high enough to avoid illness in healthy people or exacerbating illness in those already sensitised. If the impact on health proves to be as significant as the literature suggests, it might be that the costs to society could be large. A substantial portion of the British population already suffers from respiratory illnesses, allergy and depression. The incidence of these and other conditions could increase if the building stock is sealed and insulated to the levels required in new buildings.

Before gas-fired central heating became popular in this country, radiant heating and high ventilation rates were the norm. Historical and more recent evidence suggests that radiant heating is healthier than convected warm air. It provides comfortable conditions at lower indoor air temperatures with lower ventilation heat losses. Rather than refurbishing older building types to match the conditions now required in new ones, a more sympathetic approach might both save energy and provide a healthier indoor environment. Key to this are radiant heat sources that are clean and efficient, whilst also meeting occupants' health and comfort requirements. As ventilation heat losses are not such a concern with radiant heating, air change rates could then be higher than those currently specified. This would reduce the risk of health problems associated with poor IAQ.

Another way to improve IAQ would be to avoid specifying materials and products that emit hazardous chemicals or prevent the movement of moisture. Evidence from other countries suggests that a labelling system that rates building materials according to their potential impact on health could help reduce building-related sickness.

Illuminations levels indoors, and the forms of lights provided, are important to well-being. Daylight is better for health than artificial light. Exposure to sunlight can be beneficial for health. Although the recently revised British standard on *Lighting for Buildings* notes some of the benefits of daylight and sunlight, the criteria set in this standard are not compulsory. As insulation levels increase in buildings and the risk of overheating goes up, there is less and less room for solar gain.

Many traditional buildings were design well for health in terms of ventilation, heating and natural lighting. The challenge is refurbishing them to an energy-efficient standard that maintains and promotes their health benefits.

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